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FINAL REPORT

Sunrise

SOLAR ENERGY FOR A CIRCULAR ECONOMY

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[1] The term 'project' used in this template equates to an 'action' in certain other Horizon 2020 documentation

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1. Explanation of the work carried out by the beneficiaries and Overview of the progress

The overall objective of SUNRISE coordination and support action (CSA) is to provide the comprehensive design and description of the SUNERGY European large-scale research initiative (LSERI) to secure the supply side of the circular economy with a pipeline of disruptive technologies for manufacturing renewable fuel, chemicals, fertilizer and hydrogen from atmospheric H_2O, N_2 and CO_2 at high yield with up to 2500 ton/ha.yr CO_2 sequestration (Figure 1). The demonstration of the value chain from source to final product is the single prioritizing criterion to deliver plug-in technologies for supplying fuel and chemicals manufactured from renewables at an affordable cost along three global priority research directions:

- Can we combine water electrolysis with CO_2 capture for realizing fully integrated value chains?
- Does integration of steps (photovoltaic (PV) + electrolysis vs photoelectrochemical (PEC) vs molecular vs biological) lead to superior processes in terms of efficiency, selectivity/purity, and concentration over the value chain?
- How do we get access to all the hydrogen we need to defossilize our economies?

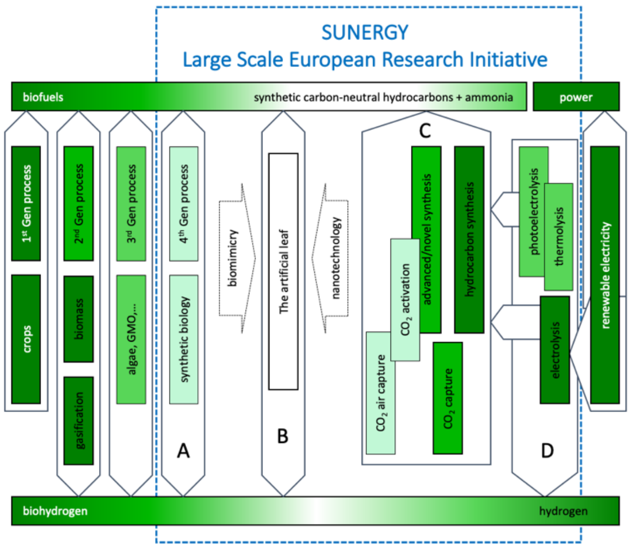

Figure 1. The Large-Scale European Research Initiative positioned in the renewables to fuel and chemicals landscape

The exploitable result of the SUNRISE CSA is the complete design and description of the SUNERGY LSERI in six Chapters, which is delivered in the form of this Final Report D5.3 (Figure 2). Each Chapter encompasses one or more of the reports that are delivered in the CSA and are publicly available. The Chapters are a **consolidated vision** (D1.1), a strategic long-term **research roadmap** (D1.2), a **blueprint** for the large scale research initiative's implementation (D1.3), an effective scientific leadership and **governance structure** (D4.1 and D4.2), an **innovation and exploitation plan** (D2.3), and **community building** (D3.1 and D3.3). These Chapters cover the work plan of the SUNRISE CSA (Fig. 1) and are further explained under 1.1 Objectives. The latest updated versions of the reports are included as annexes to this document. For the innovation and exploitation plan the process and structure were defined in discussions between stakeholders for which study documents are also publicly available (D2.1 and D2.2 "other" deliverables). The community building is supported by the public website that is available online (D3.2 “other” deliverable) and in addition an open research data pilot data management plan is provided (D3.4, ORDP).

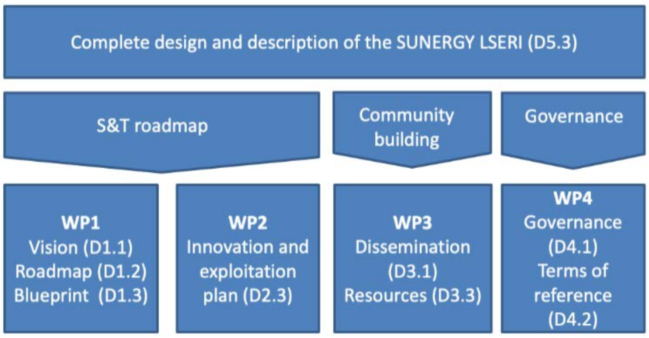

Figure 2. Work plan for the complete design and description of the SUNERGY LSERI according to SUNRISE-CSA

1.1 Objectives

The objective of SUNRISE-CSA is to perform the necessary preparatory actions to prepare for a LSERI (Figure 3). The first stages (vision, global context and goal setting and involvement of stakeholders) were well seeded while preparing the proposal. During the action the community building, S&T Roadmap development, planning for exploitation, and development of governance were performed. The CSA has now delivered the LSERI's unifying goal, its underlying S&T roadmap to encourage greater participation from industry, strengthened the consortium and its governance structure, and has attracted large public support through education, dissemination, and outreach.

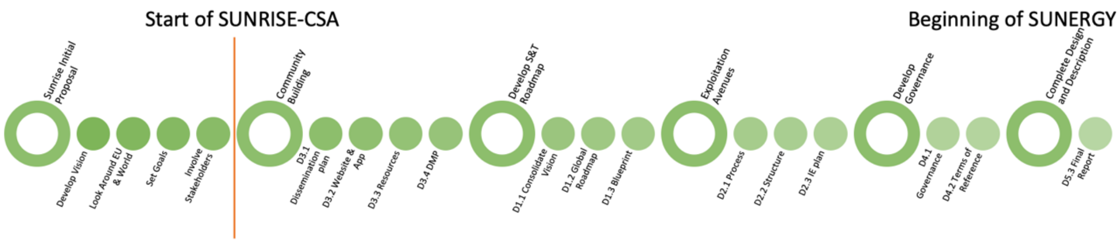

Figure 3. Preparatory actions for the SUNERGY LSERI performed in SUNRISE.

The complete design and description of the LSERI includes:

- **A consolidated vision** (D1.1 described under Task 1.1, section 1.2.1). The three global research directions listed above bridge the gap between the current state of the art and a unifying visionary goal of a CO_2-neutral economy with affordable negative emissions technologies on a significant scale, which is articulated in this report as the manufacturing of fuel and chemicals to phase out fossil resources. Terms of reference are five S&T objectives that form a ten-year timeline towards targeted impact on economy and society (2020 to 2030), and on a longer timescale (2030 to 2050):
    - 2023: Seasonal storage demonstrated with solar to chemical energy conversion better than 15%
    - 2025: Demonstrator at a scale of > 1 MW that will provide an urban environment with 10% of its energy in sustainable form, with CO_2 neutrality.
    - 2027: Demonstration of 80% circularity at the regional level with artificial photosynthetic technologies for industrial feedstock, products and processes

- 2029: Negative emission carbon capture and utilization (CCU) and sustainable ethanol production on the industrial scale (*i.e.*, with concentration to the MW level)
- 2030: 1000 ha (>150 MW) scale of SUNRISE/SUNERGY technologies for liquid fuels production for, *e.g.*, air transportation; Decentralized and CO_2-neutral ammonia fertilizer production for precision farming

- **A strategic long-term research roadmap** (D1.2 described under Task 1.2, section 1.2.1), showing how the unifying goal of net zero carbon emission in 2050 can be realised with cost-competitive decentralized production of fuel and chemicals, EU-wide massive deployment of sustainable hydrogen, and cost-competitive decentralized production of ammonia. The roadmap has two major milestones:
    i. *seasonal storage in 2025* with direct air capture and conversion for sustainable production of fuel and chemicals, and cost-competitive production of ammonia and hydrogen in 2025; and
    ii. *demonstration of negative emission in 2030* with decentralized carbon free production of ammonia; cost-competitive decentralized production of hydrogen, and cost-competitive mid-scale jet fuel production.

  The roadmap addresses a carbon-neutral European society by 2050, in accordance with the EU policy goals, a socially fair and economically viable transition to a carbon-neutral society, import-independent production for EU autonomy and sovereignty, energy security, and, ultimately, reductions of the atmospheric CO_2 concentration. The technologies take inspiration from nature, mimicking the natural photosynthesis processes in part or as a whole. Energy from sunlight or wind and raw materials abundantly available in the atmosphere (water, carbon dioxide, nitrogen) are transformed into green fuels and chemicals. This enables a progressive de-fossilization of the energy and transport sector, as well as the chemical industry (including agrochemistry). SUNRISE and SUNERGY technologies provide sustainable fuels with high energy content to the transport and heating sector, using existing infrastructure, while chemical industry profits from fossil-free raw materials and energy. Converting sunlight and electricity into chemical energy represents a safe and easy way of long-term storage for intermittent renewable energy sources. In the longer term, CO_2 is taken directly from the atmosphere and becomes a valuable raw material. When transformed into fuels and burnt afterwards, a net zero-carbon emissions cycle is established, while when transformed into long-lasting chemical products, such as polymers, net CO_2 reductions (negative emissions) are achieved.

- **A blueprint for the LSERI's implementation** (D1.3 described under Task 1.3, section 1.2.1) that sets out the collaboration and S&T framework for the large-scale research initiative. It maps the necessary competencies and resources, including infrastructure aspects, that are needed for an implementation with openness. It provides a mapping of competencies and resources within Europe. The blueprint also considers the parameters for openness in the process of exploitation of results, and develops a possible call scheme for the first billion Euro of investments over the course of 10 years through a portfolio of RIA and IA calls that serve to implement the roadmap for reaching the SUNRISE, and subsequently SUNERGY goals.

- **An effective scientific leadership and governance structure.** This Chapter was split into deliverables D4.1 Governance Plan and D4.2 Terms of Reference, described in section 1.2.4. These elements were jointly developed between the ENERGY-X and SUNRISE consortia based on the analysis of the governance structure of running

European large-scale initiatives. It contains a tentative scenario for launching a SUNERGY LSERI in the context of Horizon Europe (HE) with a short-to-mid-term transition and “ramp-up” phase (2020-2024) and a long-term LSERI phase (after 2024). A co-programmed European partnership (cPPP) appears as the most suitable option, with both bottom-up Research and Innovation Action (RIA) and programmatic Innovation Action (IA) components and the necessary flexibility in terms of composition of partners, objectives and activities. Besides having both public and private partners, the cPPP instrument also allows to have member states (MS) and associated member states involved to align with national priorities in a tripartite research initiative at the required scale, which is much larger than current practice with cPPPs.

- **Innovation and exploitation** describing the Intellectual Property (IP) structures and Science-to-Science (S2S) and Science-to-Business (S2B) exploitation methods within the large-scale partnership. This Chapter was split into deliverables D2.1, Innovation Process; D2.2, S2S & S2B Exploitation plans and IPR consortium guidelines structured; and D2.3, Innovation and Exploitation plan fully developed and IPR consortium guidelines updated, described in section 1.2.2. The proposed IP system on the individual project level will follow the established framework for EU funding programs with project partners sharing background IP as needed, while newly generated IP is owned by the inventing parties with conditional access and licensing rights for others. Since the possibility to transfer IP across the partnership is considered as beneficial in order to achieve the overall targets, and a coercive mechanism would highly discourage private parties from participating, it is proposed to create an environment which facilitates the transfer of IP on voluntary basis and that the partnership coordination actively encourages IP sharing by its community members. Different approaches for S2S and S2B exploitation will be used – also depending on the maturity of the development activity. Key for both S2S and S2B is making information timely and consistently available – either regarding interim or final development results or regarding market or business needs and requirements. Failure to commercialize technology is often largely related to a poor understanding of the market. It is hence proposed that project teams are actively coached in order to build their business case, and that the progress of the projects is continuously monitored in order to ensure their quality and impact, and hence their subsequent exploitability.
- **Community building**. This Chapter is split into deliverables D3.1, Dissemination, Communication and Education Plan; D3.2, Project website, App and social media tools; D3.3, Dissemination and communication resources; and D3.4, Data Management Plan, all described in section 1.2.3. The documents describe how a growing community has been built during the preparatory action and identifies the main dissemination and communication objectives of the upcoming **SUNERGY** large-scale research initiative and the activities and tools that will be defined and implemented. We define the backbone of the future plans for dissemination, communication and education for responsible research and innovation (RRI) based on the evaluation of the activities carried out during the coordination and support action that comply with three conditions: (1) Continuous operation of communication tools; (2) Up to date and adapted content to address the different target audiences; and (3) Active engagement at the European and member states level. The plan includes an evaluation of the initial KPIs (Key Performance Indicators) to be considered in the short-term concerning the ramp-up phase and long-term, the large initiative phase. As the funding resources for the ramp-up phase are not yet ensured, keeping the current momentum achieved by the SUNRISE and ENERGY-X communities will be the main challenge. Reaching further

the general public and policy makers will also be one of the main objectives, which will be crucial in order to reach the second phase of the SUNERGY project: becoming a large-scale research and innovation initiative.

1.2 Explanation of the work carried per WP

1.2.1 Work Package 1: Strategy and Structuring

Beneficiaries involved: CNR, ULEI, CEA, EMPA, UU, IMDEA Energia, Fraunhofer, FZJ, Imperial, EMIRI AISBL, UTU, UNIWARSAW, HIPC, JM, ICIQ, EERA AISBL, NTNU, UCL, ENGIE

Objectives:

- Establishing the vision and mission of SUNRISE through S&T objectives, with quantitative targets and impacts (Task1.1).
- Structuring the long-term scientific and industrial roadmap of the large-scale research initiative (Task 1.2).
- Providing the blueprint for the implementation of SUNRISE (Task 1.3).

Summary of progress and significant results for each task:

Task 1.1 (months 1-12): S&T objectives and assessment of their impact on a broader scale (task leader- CEA)

In the first months of the project, the strategic directions of the SUNRISE community were determined, in particular by establishing the S&T objectives of the three designated approaches, *i.e.* electrochemical conversion, photoelectrochemical direct conversion and biological/bio-hybrid direct conversion. The concepts emerged from the discussion within the consortium partners and endorsing stakeholders. This active participation was summarized and rationalised in the first major deliverable, the SUNRISE consolidated vision (D1.1), which was the first significant output of the CSA. The document is an extension of the vision reported in the proposal and it defines the targets and innovative pathways of the project. Its focus is on the chemicals enabling the SUNRISE vision, namely hydrogen (H_2), ammonia (NH_3) and carbon-based molecules produced using CO_2. In this context, it identifies performance targets and innovation needed. Most importantly, it clearly defines the objectives of the SUNRISE technologies for solar fuels and chemicals by 2030, including the initial demonstrators targeted by 2025 at > 1 MW scale and larger-scale plants to be deployed by 2030 (1000 ha, >150 MW). The feasibility of the most ambitious objective, *i.e.* carbon negative emissions, was set for the period 2030-2050. Impacts at the economic and social level (*e.g.* social acceptance of technologies to be deployed on a large-scale) were also examined.

The strategy for the elaboration of this deliverable was established at the post-award meeting in January 2019 (Leiden) and consolidated at the project meeting in mid-May 2019 (Bologna) in order to be submitted by the end of May 2019. A preliminary draft of D1.1 was made by CNR, which was then consolidated by CEA, UCL, Fraunhofer, ULEI and UU. The final version of the deliverable was elaborated by the Task Leader CEA, with the contribution and final revision of all partners.

Task 1.2 (months 1-12): Roadmap of the SUNRISE large-scale research initiative (task leader: UCL)

The main goal of this task was the preparation of the global roadmap of SUNRISE, defining activities across mainly the decade from 2020-2030, up to 2050 for less mature technologies, which will open the route to a pipeline of new materials for the transition from a linear to a circular European economy. The preparation of the roadmap document (D1.2) ran through several steps, also with the active involvement of stakeholders and supporters. The basis of the document – which is a pillar of the legacy of the CSA SUNRISE – was laid down at the post-award meeting in January 2019 (Leiden). On this occasion, nine dedicated task forces were established across the three approaches, each of which working on a specific topic (*e.g.* hydrogen, CO_2-to-chemicals, ammonia, jet fuel for Approach 1). A priority research direction (PRD) template was elaborated, in order to address the work of each task force to a homogeneous input for the final document. This complex work also benefited from the input of external stakeholders, which was collected during dedicated open events. The top event (Stakeholders Meeting) took place in Brussels in June 2019, but other events at the national level were also organized in several countries by individual SUNRISE partners (*e.g.* Italy, France, Sweden, Finland, Poland, just to mention a few). The roadmapping required an impressive amount of work, tackled by a dedicated team coordinated by Dr. Carina Faber (UCL) who also attended a roadmapping course in England. A roadmapping meeting was held in Brussels in July 2019, whereas further work and refinement was made at the consortium meeting in October 2019, in which the roadmap was assessed also by the external advisors of the mid-term review panel. The SUNRISE roadmap was published in November 2019. It consists of a main document and four technical appendices where the technical requirements for the development of the different technologies envisaged by the SUNRISE initiative are analytically reported and summarized. The writing team of the roadmap, led by the Task Leader UCL, included CEA, CNR, UU, UTU, ENGIE, Siemens, UNIWARSAW, ICIQ, Fraunhofer. Throughout the process, it received relevant contributions from all the other partners and from the supporters.
The SUNRISE roadmap complements the ENERGY-X research agenda. These reports provide the technical underpinning of the SUNERGY initiative. This undertaking has been recently established with the joint contribution of both the energy-related CSAs, *i.e.*, SUNRISE and ENERGY-X.

Task 1.3 (months 1-12): Blueprint of the large-scale research initiative
The activities of Task 1.3 were devoted to merging the S&T approaches and objectives determined in Task 1.1 and 1.2 into a coherent framework, with a focus on impact on EU industries and the economy. One of the final steps of the project – and the main goal of Task 1.3 – was to deliver the blueprint for the European large-scale research initiative (aka SUNERGY). In the blueprint (D1.3) the overall collaboration along with the Science & Technology framework have been presented, also with the identification of necessary competencies, resources and infrastructures. A key step in the preparation of the blueprint was the last project meeting in Brussels (February 2020), where the consortium focused on the drafting of proposals for future EU calls (particularly IA, RIA and CSA) open for all organizations that are active in the field of solar fuels and chemicals, with the aim of promoting a future large-scale research initiative possibly in the context of a large partnership to be launched within 2024 and in the framework of the European Green Deal.
The blueprint includes an overview of organizations that are active in the area of our objectives, including SUNRISE and ENERGY-X supporters as well as organizations from EERA joint programs. It also highlights the involvement of relevant stakeholders, with SUNRISE having gathered more than 200 supporters, from academia (ca.100), industry (55), local research networks and funding agencies. This shows that SUNRISE has been

successful in gathering a critical mass of research excellence and industrial capabilities, which will be crucial for addressing the challenge of reaching a carbon neutral energy system and chemical industry by 2050, in line with European long-term strategies.
Upon finalization of the blueprint, SUNRISE industrial partners Siemens, Engie and Johnson Matthey provided letters of intent for participation in future SUNERGY proposals to be submitted in the research calls outlined in the SUNRISE blueprint deliverable. These letters are found in annex 5 of this document. D1.3 was written by Task Leaders UU and ULEI, in close collaboration with M2i, with input from all other partners during project meetings and dedicated discussions.

The following **Deliverables** were due within the reporting period:

D1.1 Vision due Month 2 (04/2019)
submitted in 06/2019

D1.2 Roadmap due Month 6 (08/2019)
submitted in 11/2019

D1.3 Blueprint Month 12 (02/2020)
submitted in 04/2020

1.2.2 Work package 2: Innovation and Exploitation

Beneficiaries involved: Fraunhofer, CEA, EMPA, IMDEA Energia, FZJ, EMIRI AISBL, SIEMENS, UTU, UNIWARSAW, JM, UCL

Objectives:
- Development of an agile innovation process for SUNRISE
- Development of exploitation plans for scientific as well as commercial activities

Summary of progress and significant results for each task:

Task 2.1 (months 1-14): Innovation

The work in Task 2.1 was carried out in the following four sub-tasks.

Subtask 2.1.1 Innovation Strategy:
A high-level innovation strategy for technologies and processes pertinent to the scope of SUNRISE, *i.e.* the transformation from a linear to a circular economy based on utilization of solar energy, has been developed. In this context, *innovation* is the sum of invention/fundamental research and commercialization, so innovation relates to the process of bringing ideas, concepts and knowledge from basic science to commercial application.
There is a broad consensus of distinct stages in any innovation process and what constitutes best practice for a particular business. However, SUNRISE recognises that for the transition to a circular economy we are dealing with something beyond the normal commercial context. The problem to be solved is global in magnitude, albeit with a European epicentre.

Consequently, we will need from the outset to build collaborative forums for all partners and stakeholders to meet and set priorities for addressing short, medium and long-term

challenges for transitioning to a circular economy. The SUNRISE innovation strategy aims for bringing fundamental research to the market through the fastest possible route.
For that purpose, it is necessary to create an environment, where new start-ups are founded in addition to the present industrial companies and SMEs to cover TRL 4/5 to 7/8. These TRLs often suffer from an absence of industrial partners, especially when inventing disruptive new technologies. Additionally, innovation cycles in the field of chemical feedstocks are quite large in the range of >10 years, as often high investments have to be made to introduce new processes or plants. Existing companies often cannot afford high risk investments in addition to their existing business commitments.
To let technologies evolve in a free environment, the concept of *SUNRISE valleys* is introduced in the style of the Silicon Valley. To further realize this concept and to reduce the innovation cycle time demand, the combination of public funding as well as private investments and a long-term commitment (minimum of a 10 years period) from the EU is crucial to engage private investments.
SUNRISE valleys are local or regional innovation clusters, providing comparable infrastructure and supporting with *e.g.* bookkeeping, business angels, VC companies, IP support, lawyers, marketing experts etc. Contributors are purposefully exposed to the views and opinions of all stakeholders so that new concepts and approaches to converting sunlight into fuels and chemicals are in sync with the drivers that are shaping our societies of the future. This will enable the fast and focused development of technologies of the before mentioned fields of actions in a business-friendly environment. In cooperation with large industry, these technologies can be distributed on a global scale to ensure the fast acceleration in technology distribution.

The outcomes of sub-task 2.1.1 (Innovation Strategy) have been reported as part of D2.1 (Innovation process) and form the basis for Task 2.2 (Exploitation).

Subtask 2.1.2 Innovation Process:

An innovation process for a large-scale research initiative was outlined in Task 2.1.2. SUNRISE has three principal approaches to develop solutions to the chemical and fuel-based needs of Europe's circular economy *i.e.* electrochemical, biological/biohybrid and photoelectrochemical processes. Five distinct stages of innovation are considered for the SUNRISE Innovation Process, that are generally applicable across the relevant S&T landscape:

1. Idea generation
2. Evaluation & selection
3. Experimentation
4. Commercialization
5. Implementation

The process must be operated with enough flexibility to account for the different technology scenarios. For example, stages 4 (commercialization) and 5 (implementation) will have more immediate relevance to the electrochemical production of hydrogen as this has already reached demonstrator stage, but lessons learnt here will have real value for passing onto the bio- and photo-electrochemical operations.
The five stages of innovation are described and summarized in the following table.

	Idea generation	Evaluation, Selection	Experi-mentation	Commer-cialization	Imple-mentation
Objectives and Characteristics	• Networking, forums for discussion & exchange on topics related to circular economy • Provide participants with holistic view of the challenge and what their technical projects should encompass to be relevant to progressing the roadmap	Selection of projects for funding based on typical 'call gates': ▪ Being within scope of a particular call ▪ Well-defined techn. challenge ▪ Clarity of desired output & impact ▪ Risk mgmt. strategy ▪ Appropriate team with well-matched resources and tasks ▪ Logical cost basis and budget management plan ▪ Clear objectives and targets	• Trial, error, success, failure • SIP team will give support by providing contact point at local nodes for advice and guidance w.r.t. technical and administrative issues, arising IP, partner changes, accessing national S&T infrastructure (*e.g.* advanced analytical techniques)	• Involving end-users, analyzing costs and benefits • Involving new partners and partnerships, decoupling from academic input, moving towards commercialization • Further progress depending on nature of business endeavors such as spin-offs vs. large industrial company, state and EU-level financial incentives or subsidies, fossil-fuel prices, possible market shifts	• Most challenging stage as the required investment levels and risks rapidly increase • Commercialization and implementation of chemical processes take time ➔ evolutionary roll-out, first focus on local customer bases where conditions are most conducive to mitigate costs and maximize benefits • Use lessons learnt from rapid growth of renewable energy generation and electrification of drive trains
Deliverables (exemplary)	• Requirement specifications for technology (and future products) • List of stakeholders and cooperation partners • Market potentials • Technology ideas & concepts	Proposals including: • Technology design specification • Milestone & Review Plan • References to SUNRISE roadmap • Metrics for progress eval. • Risk assessment • Resource plan	• Technology specifications and test results • Technology capability evaluation (incl. benchmarking vs. established solutions) • Review documentation • (Scaled) Prototypes • IP	• List of potential markets and customers • Commercialization and financing plan • Market strategy and market entry documents • Implementation preparations (*e.g.* sourcing, manufacturing, validation)	• Full-scale prototypes • Qualified systems • Requirement definitions for S&T based on operational experience • Evaluation of product operation • Identification of basic S&T

Table 1. Overview of stages of innovation for the SUNRISE Innovation Process

The outcomes of sub-task 2.1.2 (Innovation process) have been reported as part of D2.1 (Innovation process) and form the basis for Task 2.2 (Exploitation).

Subtask 2.1.3 Innovation Management:

A system enabling the innovation management in a large-scale research initiative was outlined in Task 2.1.3. A central issue of innovation management is concerned with the management of knowledge and IP. This is particularly relevant for an initiative following the approach of open innovation. There must be clarity in respect of the rules of engagement that partners will be expected to abide by. This will facilitate both scientific information flow and the translation of acquired knowledge into practical, commercially viable technology.

All projects require an over-arching governance structure and any Legal Agreement in a partnership will need to reflect this. We recommend a similar governance structure for IP whereby all partners have a representative on an 'IP Management Committee' (IPMC) that should oversee the processes of publishing, patenting, managing the flow of technical and scientific information into and out of the partnership, reviewing the IP landscape relevant to the project objectives and dealing with any disputes (see sub-task 2.1.4). The basic structure and content of a typical IP agreement is laid out in D2.2 and D2.3.

A scheme for the connection and (inter)relation of individual projects to the overarching LSERI and its bodies, roadmap and R&D agenda, to the SUNRISE valleys as innovation nodes as well as for the entire flow of information has been developed and described in D2.3 (Innovation and Exploitation plan fully developed and IPR consortium guidelines updated).

Subtask 2.1.4 Innovation Conflict management:
Wherever there is new IP generated in collaborative projects, *i.e.* involving more than one partner, there are potential conflicts of interests. For that purpose, clear IPR guidelines are needed as part of the innovation management (see sub-task 2.1.3). A common understanding of and commitment to IPR guidelines from all partners is a prerequisite for the large-scale research initiative. In particular, where there are potential conflicts of interest, such as the academic imperative to publish against the need to protect know-how that might lead to commercial exploitation, ground-rules must be in place to help resolve potential issues at an early stage. Good note taking at meetings is a 'must' so that correct attribution in respect of inventorship of an idea, problem-solving etc, is recorded and made transparent. Finally, a word of caution in that trust between partners, critical to a successful project, can be quickly eroded unless potential disputes are dealt with in a timely and effective manner. Being alert to signs of discontent as well as potentially patentable results will be amongst the key functions of the IPMC (see sub-task 2.1.3). The IPMC should also actively promote, support and mediate the sharing of IP within the partnership when this is seen as beneficial from the partnership's point of view.

Task 2.2 (months 1-14): Exploitation

The work in Task 2.2 was carried out in the following two sub-tasks.

Subtask 2.2.1 "Science-to-Science" Exploitation plan (S2S)
The purpose of this sub-task was to increase the capacity of the scientific community to provide new ideas and technological bricks towards SUNRISE/SUNERGY objectives. The reflexion was devoted to making Science-to-Science communication easier and to ensuring that basic scientists would be properly aware of the roadmap targets, bottlenecks, obstacles, as detailed in the D2.3 deliverable. Using standard scientific communication tools and structures (publications, conferences, seminars, organized physically or on the Internet) and

the decentralized SUNRISE/SUNERGY "valley nodes", the community shall be made quickly aware of new results or new problems relevant to the roadmap. That for, a continuous scientific management of the roadmap, a kind of "scientific control room", shall be put in action. It will scatter information towards the community, especially to orient new calls and new projects. We built the SUNRISE roadmap with this requirement in mind, paying a lot of attention to bridging the gap between scientific bottlenecks and societal goals.

Subtask 2.2.2 "Science-to-business" Exploitation plan (S2B):

For ensuring the short-, mid- and long-term S2B exploitability of the outputs of SUNERGY, the following approach has been developed during the 14 months of project duration:

- On the one hand, a continuous coaching/outreach approach to the SUNERGY projects will be applied in combination with a stage-gate process to review the project progress. By doing so, compliance of the specific project objectives with the overall roadmap targets will be achieved and maintained, and hence the uptake and commercialization of the results by industry will be enabled.
- On the other hand, a short-, mid- and long-term commercialization strategy of SUNRISE's developments was defined by taking account of the fact that the creation of any new business inherently requires the availability of a complete and functional technology stack.
- Furthermore, to inform and upskill end users in industry regarding the technological results of SUNERGY, corresponding elements have been incorporated into the SUNRISE Innovation process and the SUNRISE Valley concept. The feedback loop from the definition of roadmap targets over their implementation in corresponding projects to the information and interaction with the stakeholders is schematically shown in Figure 4.
- As far as the contractual basis for IPR and knowledge management is concerned, the DESCA template was defined as a suitable baseline for low- to mid-TRL projects, while for mid- to high-TRL activities also other templates (like MCARD) can be used to address the specific needs of projects that are close to commercialization. That means that project partners share background IP as needed, and that newly generated IP is owned by the inventing party (or parties) with conditional access and licensing rights for other parties.

Further details regarding the S2B exploitation are described in deliverable D2.3.

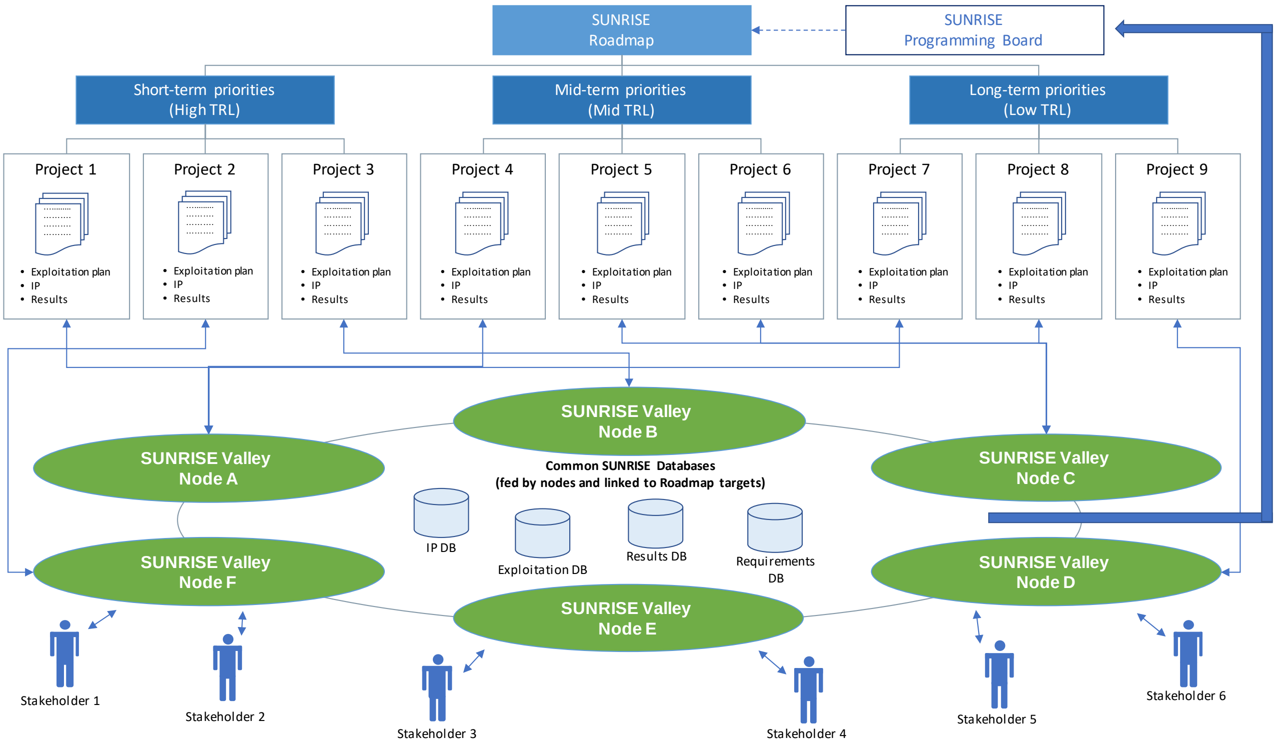

Figure 4. Relationship between the SUNRISE roadmap, SUNRISE projects, SUNRISE Valley nodes and the SUNRISE stakeholders to enable exploitation across the partnership

The following **Deliverables** were due within the reporting period:

D2.1 Innovation process defined for SUNRISE due Month 6 (08/2019)
submitted in 07/2019

D2.2 S2S & S2B Exploitation plans and IPR consortium guidelines structured due Month 6 (08/2019)
submitted in 12/2019

D2.3 Innovation and Exploitation plan fully developed and IPR consortium guidelines updated due Month 14 (04/2020)
submitted in 04/2020

1.2.3 Work Package 3: Dissemination, communication and education

Beneficiaries involved: ICIQ, ULEI, CEA, CNR, EMPA, UU, IMDEA Energia, Fraunhofer, FZJ, Imperial, UTU, UNIWARSAW, HIPC, JM, EERA AISBL, NTNU, UCL, ENGIE

Objectives:

The overall objective of WP3 is to build the SUNRISE community, denoted "SUNRISE ecosystem" consisting of (A) the research community, (B) the industry sector, (C) policy makers and (D) multiple advocacy groups including citizens, students and NGOs. The activities of WP3 build on the “SOLAR RESOURCES” database that was elaborated by CNR and refined with the contribution of other SUNRISE partners, prior to the submission of the SUNRISE CSA proposal, and the innovation network from WP2 in order to identify the research community and the industry sector, respectively. In addition, WP3 will add the

policy makers and advocacy groups and merge (A) - (D) to ensure the best impact of the planned activities in a Responsible Research and Innovation (RRI) framework.
There are three specific objectives:
1. Implementation of the Dissemination and Communication Plan.
2. Apply a Responsible Research and Innovation approach.
3. Build a strong and actively growing "Solar conversion" ecosystem community.

Summary of progress and significant results for each task:

Task 3.1 (months 1-12): Implementation of the Dissemination and Communication Plan. (Task Leader: ICIQ)

As part of the Dissemination, Communication and Education Plan, one of the main goals of the SUNRISE CSA has been to create a growing SUNRISE community that can contribute to work towards the large-scale research initiative's goals. The dissemination and communication actions were proposed to attract new interested stakeholders and keep a fluid communication and interaction with supporters and followers, contributing to create a growing ecosystem around the initiative. The actions have been addressed to four main target groups: (A) research community, (B) industry sector, (C) policymakers, and (D) advocacy groups including citizens and students as well as NGOs and associations dedicated to sustainable and renewable technologies and solar conversion applications. Several strategies and tools have been put in place to effectively disseminate and communicate the progression and outcomes throughout the action. A description and evaluation of these activities was done for the first 6 months of the action and again at the end of the 12 months. The final updated D3.1 deliverable is described in section 2 of this report and the entire document has been added as an annex.

Continuous activities monitoring has been used to adapt the SUNRISE Dissemination, Communication and Education Plan throughout the action, being a live document, starting with the first plan in the proposal that has been followed, updated and adapted to the action needs in the mid-term plan and at the end of the project. The final plan includes the common communication and dissemination actions agreed with the ENERGY-X CSA consortium as the two CSA projects, SUNRISE and ENERGY-X have merged in the broader SUNERGY initiative at their end.

3.1.1 SUNRISE Website and related tools.

The SUNRISE project website provides the basis for dissemination and communication actions. The current website will be expanded and updated regularly, and will be further developed to include an intranet. It will gather and promote relevant information related to solar-to-chemical technologies, and will include: (i) a news and events section to spread all the activities developed under the CSA umbrella; (ii) an open access portal with publications relevant to the SUNRISE mission with access to open data; (iii) a link to the solar resources database on research projects and initiatives on solar energy conversion and the circular economy; (iv) a link to the database on key research infrastructures to be networked during the early stage of the large-scale research initiative; (v) educational and training content, including e-learning material; (vi) a discussion forum including a blog and a questions corner where international experts can be contacted; (vii) promotional materials like posters, flyers, videos and newsletters; (viii) a contact section where followers and supporters can reach the management team and leave support statements and letters of support; (ix) a list of entities supporting the SUNRISE initiative and how they will contribute. The website will have an associated SUNRISE App and it will offer direct access to social media and professional networks that will be used to introduce the project to a broad audience. The development of the website, App and virtual networks will ensure an easy and cost-effective regular flux of information, and will be used as key elements beyond the CSA and form part of the large-scale research initiative blueprint.

The development of the website and social media profiles was one of the first goals within the WP, the main points related with this work and the strategy behind are summarised in the Deliverable D3.2 “Project website, App and social media tools”. This public deliverable describes the key points of design, execution, content, usage, and communication strategy behind the internet platform of the SUNRISE initiative.

The URL of the website is www.sunriseaction.eu or www.sunriseaction.com and it has been online since September 20th, 2018 (already before the CSA started). With the start of the CSA the website was reworked, and a new version has been available since May 2019. The online platform has been created to serve as a project content management system on two levels: (1) External Communication and Dissemination of the project objectives and results, and (2) Internal Communication Platform within the consortium. The SUNRISE public website was developed to act as an information hub about the project’s aims, goals, activities and results, working as a first public dissemination tool. The public section provides the following content: a) general information about the project, including initiative description and vision and FAQs; b) recent news about the project; c) description of events organized within the framework of the project and related events of interest; d) description of consortium members taking part in the project; e) support and training materials, deliverables and presentations; f) press releases and media clippings; g) contact information and e-mail address (contact@sunriseaction.eu); h) supporters logos and community contributions; i) blog; j) links to social media; k) appropriate acknowledgment and reference to the European Union’s Horizon 2020 Framework Programme.

The website also includes a direct link (with restricted access to validated users) to an intranet page used to share relevant information among all partners. The intranet used, called ‘Plaza’, has been made available by M2i (Materials Innovation Institute), the organization involved in the SUNRISE project management.

Profiles in social media networks have also been developed throughout the action to promote the content of the project’s webpage, related projects and relevant news concerning artificial photosynthesis and related topics:

- Facebook: https://www.facebook.com/sunriseaction/
- Twitter: https://twitter.com/sunriseaction
- LinkedIn: https://www.linkedin.com/company/sunriseaction
- YouTube: https://www.youtube.com/channel/UCWBoKlQrVNn_cJsTSwGz0pA
- ResearchGate: https://www.researchgate.net/project/SUNRISE-Solar-Energy-for-a-Circular-Economy-EU-H2020-CSA-Ref-816336.

Both the website and social media networks have been carefully designed to address the identified target groups in an effective manner, being the easiest way to ensure the visibility of the project for the EU as well as target audiences, consortium, stakeholders and general public. These communication tools have been continuously monitored during the action (See Deliverable 3.1 and its annex 1), including not only the number of followers and interactions, but also qualitative aspects like the most engaging posts content, etc.

Regarding the SUNRISE App, a demo version has been developed (http://events.tickaroo.com/projectsunrise/) and presented to visitors at the European Sustainable Energy Week (EUSEW), where SUNRISE had a stand. An internal survey within the consortium was also done, these feedbacks are the basis for its future development.

3.1.2 SUNRISE Symposium and other dissemination and communication actions.

SUNRISE partners have been very engaged and active introducing the initiative in the numerous conferences, workshops and meetings where they have participated, more than 50 (see Table 3 in annex 1 from D3.1). Most of the events, being scientific conferences, were targeting academic and industrial researchers, although it is worth highlighting that policy actors have also been present in some of the events. For instance, SUNRISE had a dedicated session in the 9th EuroNanoforum (Bucharest, June 2019). The initiative actively participated in EUSEW 2019, while the SUNRISE Stakeholder Workshop (17-18 June 2019) was organised in connection with the event, being one of the actions within the Energy Days and including a governance session with European Member States and European associations and foundations representatives. In addition, SUNRISE participated in the EUSEW conference, with a stand at the Networking Village and co-organizing the panel session ‘Energy storage to boost EU decarbonisation and competitiveness’. Together with ENERGY-X, the project also participated in a lunchtime conference organized by the Directorate General for Energy (DG Energy) on October 24, 2019.

The action has been successful in the organisation of its own events:

- “SUNRISE Community Building Event”: organized before the launch of the CSA to present the initiative to the supporting entities, already counted with around 90 participants (Brussels, 15 November 2018).

- “SUNRISE Stakeholders Workshop” (ramp-up meeting): it took place at month 4 of the CSA joining a big representation of supporters and followers with around 170 participants (Brussels, 17 and 18 June 2019).

- “SUNERGY Kick-off Event”: this has been combined with the final closing symposium for SUNRISE and was organized jointly with ENERGY-X . It has served as well to present the new joint initiative: SUNERGY. The event gathered about 120 participants and it was divided in a Lunch discussion in the European Parliament “Decarbonising Europe: how large-scale R&I initiatives on fossil-free fuels and chemicals can contribute to the European Green Deal” and a public event with both SUNRISE and ENERGY-X communities (Brussels 5 and 6 February 2020).

In addition, the action has organized 4 additional consortium meetings, with participation of different stakeholders, whenever possible: i) Kick-off meeting, March 2019, Brussels (EERA, included a streamline session for supporters); ii) Consortium meeting, May 2019, Bologna (University of Bologna, included an open session to Italian supporters, with a presentation by Prof. John Mathews); iii) Mid-term consortium meeting, October 2019, Brussels (EERA, included a session with feedback from the external advisory board and a coordinated session with the Mission Innovation initiative); iv) Final consortium meeting, February 2020, Brussels (EERA, included a blueprint session with participation of invited stakeholders).

Moreover, several national stakeholder meetings have been organized through the action to introduce the initiative and organize national support and actions, including participation of local industry and policy representatives.

To further promote the action, a young researchers' travel grant contest was organized to facilitate the participation of young researchers, from partner or support organisations, in dissemination events, contributing to their formation. In collaboration with E-MRS the CSA also sponsored a poster prize in the E-MRS Spring Meeting 2019, to highlight research advances in the area.

Regarding publications, all deliverables of the action will be publicly released after EC approval. Ahead of the other deliverables, the roadmap (D1.2) was approved and made public in November 2019. Importantly, an open and participatory approach has been followed for the most relevant technical documents: roadmap and blueprint, where consultation processes among supporters have helped to their preparation and consolidation. In addition, during the first months of the action, supporters contributed to set priority research directions through a password-protected site in SUNRISE's website, these have later become the basis for the roadmap annexes.

On the communication side, the plan has included actions to raise awareness of the project, project knowledge, actions to announce new updates, events, etc. and actions for stakeholder's involvement like activities online and offline to boost the followers and supporters' active participation and engagement in the project.

Besides the website and social media channels, other relevant tools have been: i) Newsletters: 4 public newsletters have been released to all contacts and published in the website as wrap-ups of the main highlights of the action. In addition, continuous information and participation opportunities have been sent to supporters; ii) Videos & podcasts: the official video has been translated to 5 languages, 5 video-interviews have been released with consortium partners, as well as a video for the final event and a new video presenting the continuation action SUNERGY. In addition, podcasts of radio interviews and live interview videos are also available; iii) Press releases and media clippings: four press releases have been prepared and distributed for mainstream media, appearing in publications throughout Europe in 10 different languages. In addition, consortium partners have also participated in media interviews in newspapers and magazines, radio and TV; iv) Interactive actions: the action has launched online events like interviews, twitter chats, contests and polls. For instance, for choosing the SUNRISE logo or the new name of the continuation action; and v) Outreach activities: project's partners have participated in several science and policy fairs, as well as other divulgation events, using the different dissemination and communication resources available. These actions have allowed a direct interaction with a big audience and are part of the basis for a future education plan, as further described below.

The Deliverable 3.3. Dissemination and Communication Resources, describes the promotional and training resources and materials generated during the action. A list and description of the promotional materials, including: mugs, slides templates, posters, roll-ups, factsheets, leaflets, infographics, different types of videos, podcasts, and newsletters; released throughout the past months is included, as well as the different press releases, and the agenda and list of attendees of the two main SUNRISE events.

3.1.3 Development of a Data Management Plan.

The purpose of the Data Management Plan (DMP) is to provide an overview of the main elements of the data management policy that is used by the consortium concerning the project data. The plan has evolved during the lifespan of the project to include additional datasets, and to adapt to changes. The plan covers the complete research data life cycle. It describes the types of data, its collection, storage, security and documentation, how they will be accessed and preserved and if they are shared or confidential.

The data produced by the consortium has been made available through the SUNRISE website and on the M2i intranet plaza. In addition, a new community space has been created within ZENODO (https://zenodo.org/communities/sunrise/?page=1&size=20), a public repository hosted at the Conseil Européen pour la Recherche Nucléaire (CERN).

Section 3 describes how the initial data management plan evolved into the final version that is also available as an annex to this report.

Roles of participants:

ICIQ has led this task with the preparation and update of the different plans, in continuous communication and coordination with the management board and the rest of the consortium. ICIQ appointed a Dissemination and Communication officer (part-time), this has been key to develop the planned actions (running the project website, prepare and select content for social media, managing the preparation of supporting materials, running interactive actions and contests, writing press releases, contacting media, helping in the preparation and edition of videos, monitoring tools, helping in deliverables preparation, etc.). ICIQ has prepared different dissemination and communication materials, with involvement of the management board and most of the partners, especially ULEI, FZJ, CEA, EERA, UW and EMPA have got a relevant role in the validation process.
Fraunhofer has taken the lead in the development of the smartphone App, ICIQ helped in the following surveys and evaluation.
EERA and UCL, helped by ICIQ, ULEI (and M2i) and the management board, led the organisation of the SUNRISE Stakeholder Workshop. EERA, ICIQ, ULEI (and M2i) together with ENERGY-X representatives led the organisation of the final symposium, the SUNERGY kick-off, helped by the management board. Different partners were in charge of organising national Stakeholder Workshops and other national events, with regional and national funding bodies. All partners have contributed to dissemination actions introducing SUNRISE in different events.
UW, NTNU, Imperial, IMDEA and ICIQ have led the outreach programme, with contributions also from other partners, *i.e.* EERA and EMIRI.
ULEI and ICIQ had been in charge of the Data Management Plan preparation and monitoring.
The full consortium also contributed with news and updates to be used for the website, social media tools and newsletters, press releases distribution, media interviews, etc.

Task 3.2 (months 1-12): Responsible Research and Innovation (RRI). Task leader: UW
3.2.1 Education.

Responsible research and innovation principles have been especially considered for the design of the WP3 actions. In the CSA period, the project has already included and analyzed activities with an educational character as a basis for a future education plan to be fully developed within a large-scale initiative.

The outreach activities developed during the action have been key to introduce this educational character, the project has applied and has been selected to participate at five different science fairs: the Big Challenge Science Festival (Trondheim, Norway), the EU Sustainable Energy Week (EUSEW, Brussels, Belgium), the Maker Faire (Barcelona, Spain), the 13th SET-Plan Conference (Helsinki, Finland) and the United Nations Climate Change Conference, COP 25 (Madrid, Spain). A description of these events can be found in Deliverable 3.1 Dissemination, Communication and Education Plan. The stands at EUSEW and the SET-Plan were more targeted to a general audience including policy makers, the other three ones included a general and familiar public, with young students that had access to interactive activities like a game App and live experiments showing how solar cells, electrolyzers, fuel cells and photo-electrochemical cells work.

The audiovisual materials prepared during the action, including video-interviews, have been very useful for outreach activities. In addition, various infographic materials have also been developed. A specific 3-pieces infographic about the circular economy has been used to introduce this concept, and its relationship with the action, at different stands. Another infographic showed facts and figures to illustrate how the SUNRISE's roadmap contributes to current challenges towards a fossil-free economy by 2050. All these materials are described in the Deliverable 3.3 Dissemination and Communication resources and available at SUNRISE's website.

Special activities have been developed during the action to involve and give visibility to the new generation of scientists, as these will be the ones applying and benefiting from SUNRISE's long-term development. As mentioned above, a travel grant contest was organized for young students to participate in a dissemination event within the area and a photo contest was organised for the final conference event. Young researchers were invited to send pictures related with their research and an abstract, a poll followed in a new Instagram account, specially created. The winner was invited to give a presentation at the final conference.

Finally, the consortium has kept close contact with universities. Academic partners have participated in their local events and outreach activities to introduce SUNRISE to undergraduate and graduate students. In addition, special sessions have also been organized at external universities and partners have also welcomed visits from groups of students at their facilities.

Based on the analyses of the actions developed within WP3, more focused to training and educational goals, a basic skeleton for a future education plan has been provided in D3.1. The major goal of this plan will be to identify the training needs for the new technologies to be developed within a big research and innovation project and develop a myriad of actions to cover them. This identification will need to be run together with specialized academic institutions (*i.e.* LERU – League European Research Universities and EUA – European Universities Association are SUNRISE supporters) and industrial associations (EMIRI is a partner). Therefore, complementary actions, like organization and participation in Erasmus+ programs and other related ones, should also be explored.

3.2.2 Gender equality.

Gender aspects have also been considered during the CSA action. The consortium has tried to maintain gender balance in the decision-making bodies, and this is also true for the design and preparation of dissemination, communication and education activities. For instance, audiovisual materials show images of both female and male researchers and experts, video interviews have also been done to both, contests and interactive actions have been open and inclusive to encourage participation of women and men. Gender balance has also been considered in outreach activities, SUNRISE stands have aimed for having a broad representation of researchers and experts, including both sexes, as well as PhD and master students when possible, to attract and interact with the youngest visitors.

Gender balance has been taken into account in consortium meetings, where contributions of women experts have been very relevant as they have led important tasks. This has also been considered for organized events, trying to have a broad representation of profiles within the invited speakers and moderators, as well as in the round tables.

Finally, a virtual campaign giving visibility to women in the consortium was done by UN International Day of Women and Girls in Science, 11 February 2020.

3.2.3 Societal, ethical and legal implications.

Societal, ethical and legal implications have also been very present throughout the preparation of the project's main deliverables. As explained above, the project has sought the involvement and interaction with the numerous supporters, coming from different areas, aiming for a multidisciplinary approach. Internally, also the appointment of a Quality and Impact Assurance (QIA) Team including different backgrounds has provided an important internal mechanism for keeping a broad vision and for maintaining high standards in all deliverables.

As explained above, numerous activities have been promoted for public engagement. In addition, the different events organised by the action, also at the national level, have taken care of inviting representatives coming from various areas, including from social sciences, funding agencies, governmental representatives, education associations, etc. and introduce discussions about how to integrate different aspects like societal impact, societal acceptance, legal and regulatory frameworks, funding schemes and other sensitive aspects within the initiative. For instance, Swiss supporters organised an interactive workshop about SUNRISE's impacts on society at the Switzerland Stakeholder Workshop, a Governance round table session with policy makers was included on the SUNRISE Stakeholder Workshop and several projects were invited to introduce their research approaches, including one project on social sciences, and participate in a round table discussion at the final conference, the SUNERGY kick-off.

3.2.4 Evaluation of the WP3 actions and stakeholder analysis.

The continuous evaluation and analysis of actions has been key to increase support for the project by involving more stakeholders and consolidate the final dissemination and communication plan. KPIs were set as measurement tools in the proposal stage and, during the first half of the project, website and social media data have been collected in order to know whether the target audiences are being reached or not, according to the different KPIs, *e.g.* number of website visits, number of newsletter subscriptions, number of social media followers, etc. The main tools utilised to collect these metrics are Google analytics for the SUNRISE website, and the different free-of-charge available tools of each social network: Twitter analytics, Facebook insights, YouTube analytics, LinkedIn analytics, and ResearchGate stats (see annex 1 to D3.1 for the metrics).

During the mid-term update of the Dissemination, Communication and Education plan and KPIs analysis, the different indicators were compared with the initial figures set in the proposal stage. This comparison and the trends identified in the analysis, allowed for a modification of the different indicators to better adapt them to the updated dissemination and communication actions. A comparison among the updated target indicators at the end of the CSA was also done and the results taken into account to propose future actions. In addition, qualitative values (such as the visited pages per session to the website, most viewed posts, etc.) and other values such as the number of interviews with consortium members in radio/TV, etc. have also been monitored through the action. The main results and conclusions of the evaluation are included all along the Dissemination, Communication and Education plan and the final update, and specifically detailed in annex 1 to D3.1.

Role of participants: UW and NTNU had a leading role in the definition of outreach actions and the young researcher's actions, together with ICIQ. They established contacts within their universities and other associations to plan the actions and prepare educational materials and experiments. ULEI and EMPA headed the introduction of SUNRISE at internal and external sessions and talks with university students, together with UW. ICIQ collected the KPIs, their analysis and adaptation were done at the mid-term of the action and at the end and presented at consortium meetings. The evaluation of the plan and the other WP3 deliverables by the management board, the QIA Team and the full consortium, to a lesser extent, have been key to ensure inclusion of responsible research and innovation principles within the project's activities and beyond plans.

The following **Deliverables** were due within the reporting period:

D3.1 Dissemination Plan due Month 6 (08/2019)
submitted in 10/2019 (updated version in section 2 of this report)

D3.2 Website & App due Month 2 (04/2019)
submitted in 06/2019

D3.3 Resources due Month 8 (10/2019)
Updated version submitted in 04/2020 (first version submitted in 12/2019).

D3.4 Data Management Plan due Month 6 (08/2019)
submitted in 11/2019 (updated version in section 3 of this report)

1.2.4 Work Package 4: Governance and processes

Beneficiaries involved: CEA, ULEI, Fraunhofer, FZJ, EMIRI AISBL, SIEMENS, JM, EERA AISBL, UCL
Objectives:

Developing and setting up an organisational structure and the operating and decision processes in order to ensure an effective scientific leadership and governance structure for the future large-scale research initiative.

Summary of progress and significant results for each task:

Task T4.1 (months 1-2): Analyze the governance structure of running large-scale research initiatives

At first, the governance structures of the current FET flagships, which will continue as co-funded European Partnerships in HE, were analysed and compared: *i.e.* the Graphene, Human Brain and Quantum Flagships. Next, we extended our analysis to existing European large-scale R&I initiatives with a private component, including the recently launched Battery 2030+ initiative as well as two different types of public-private partnership (PPP), namely the SPIRE co-programmed public private partnership (cPPP) and the FCH joint undertaking (JU).

In a second step, interviews with different members of the three running flagship initiatives were performed to get insights in learnings, findings, dos and don'ts regarding the various governance and organisational structures. The interviewed persons were:

- Prof. Katrin Amunts - Scientific Research Director of the Human Brain Flagship and sub-program leader (SP 2 "Human Brain Data"),
- Prof. Tommaso Calarco – Coordinator of the Quantum Support Action of the Quantum Flagship.
- Prof. Max Lemme – Scientific secretary of the Strategic Advisory Council and former leader of the Partnering Division of the Graphene Flagship.

The main findings from the interviews and the analysis were presented during a governance session at the SUNRISE stakeholder workshop (17-18 June 2019, milestone M1). They were also used as input to design specific SUNRISE governance structure, which was delivered in D4.2. The main results of Task 4.1 were detailed in Deliverable D4.2.

In practice, to run this task, besides the above-mentioned interviews, there were 4 remote Telco meetings.

Task T4.2 (months 3-8): Developing the organisational structure and processes of the large-scale research initiative

Due to the termination of the Flagship instrument which will no longer exist in Horizon Europe, a significant effort in this task was dedicated in exploring various possibilities and scenarios in Horizon Europe to launch a Large-Scale European Research Initiative (LSERI). In addition, during the course of this task, SUNRISE and ENERGY-X, agreed in August 2019 to merge at the end of the two CSAs and to launch a new initiative, SUNERGY and to join efforts to pave the way towards a SUNERGY LSERI. Thus, the governance teams of both CSAs joined efforts on the governance side after the merging and had common meetings to explore and build scenarios and relevant governance schemes. Two possibilities appeared relevant for a SUNERGY (LSERI), namely **partnerships** and **missions**.

Regarding **partnerships**, while current prospective HE public-private partnerships (PPP's) focus on improvements on the demand side with limited impact, SUNERGY proposes a pipeline of high impact technologies that boost efficiency on the supply side with light-to-products and fuel conversion from atmospheric CO_2 at high yields up to 2500 ton/ha.yr. To achieve this, a programmatic effort is highly recommended and a proposal entitled "3FCM: Fossil-free fuels, chemicals and materials for a circular economy" was put forward. The SUNERGY initiative thus urges to complement the scope of existing European partnerships and enable the full decoupling of economic growth from the utilization of resources at the local, regional, national and European levels with supply of renewables for a sustainable resilient growing economy. The possibility for SUNERGY to join other existing communities in the frame of new partnerships to be launched in 2021 was also considered, including "Carbon neutral and circular industry" (follow-up of SPIRE) or "Clean hydrogen". Because of the tilt towards the demand side and to narrow focus this did not appear a feasible scenario. Since these communities are already well established this would lead to a fragmentation and marginalization with lack of focus on the supply side. Additionally, splitting into different communities and candidate partnerships would not allow for a programmatic effort addressing all aspects of the SUNERGY. This would inevitably lead to a loss of the global disruptive vision and approach of SUNERGY and thus a loss of impact. Nevertheless, there are ongoing discussions with the candidate partnerships that could have links with SUNERGY.

The other option considered are the **missions** of HE, where there is a strong bottom-up approach to engage citizens and the society. Based on the five missions to be launched in 2021 and their associated keywords, it appears that SUNERGY could have links with at least 3 of these missions: "Adaptation to climate change, including societal transformation", "Climate neutral and smart cities" and "Soil health and food". As discussed above for partnerships, this appeared not to be a long-term scenario for SUNERGY due to the risk of fragmentation.

The main conclusion is that it is recommended for a SUNERGY LSERI to use the co-programmed public private partnership (cPPP) instrument in Horizon Europe. Due to the flexibility of the cPPP, it can include both the programmatic and the bottom-up components under a single governance terms of reference framework with a program board of mandated experts that are personally responsible for assuring quality and impact facilitating rapid progress, without transfer of authority from the member states (MS) and EC, rather than a new mission built on the SUNERGY vision be launched that is disconnected from the programmatic efforts. Besides having both public and private partners, the prospective cPPP instrument will have to allow for a tripartite approach to have MS involved via the signature of memoranda of understanding for aligning national priorities with the SUNERGY roadmap.

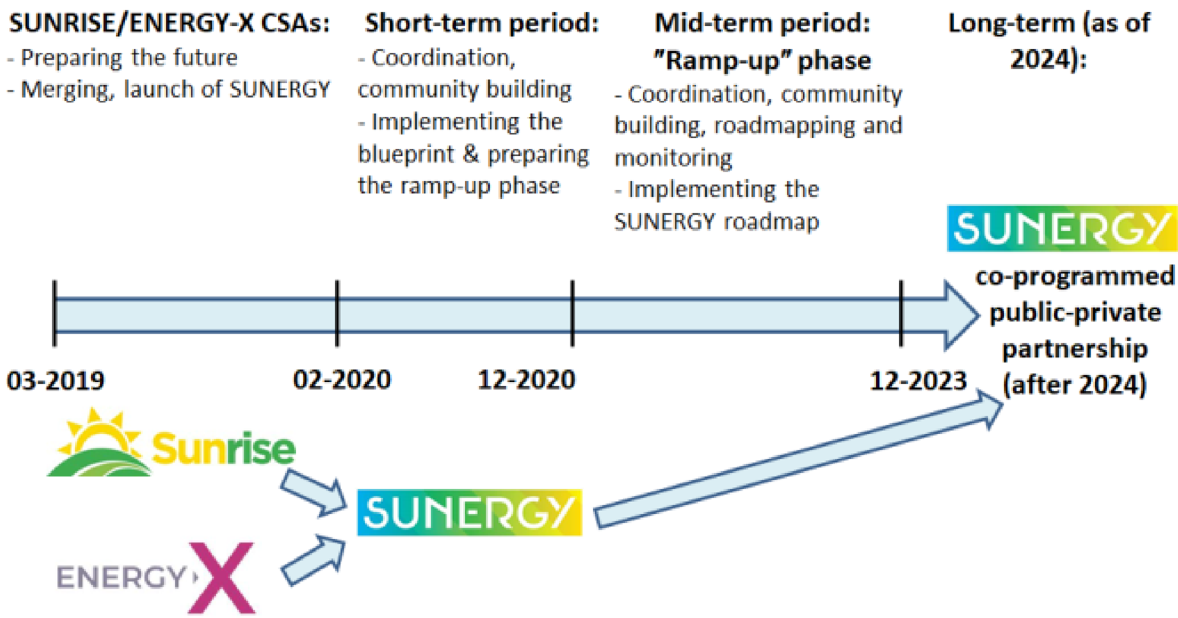

Figure 5: Tentative scenario and timeline for the SUNERGY large-scale European research and innovation initiative (LSERI).

A tentative scenario and timeline are displayed in Figure 5 with the following steps:
- **Short term (2020)**: it starts at the end of the two CSAs until a new SUNERGY project is launched. This period will be used to implement the blueprint and prepare the next "ramp-up" phase (*e.g.* strengthening the community, writing proposals, proposing topics for the work programmes of HE based on the SUNERGY design and description);
- **Mid-term (2021-2023)**: "ramp-up phase" towards a SUNERGY LSERI partnership with common coordination activities done in the frame of a common CSA (Coordination and Support Action) backed by several RIA (Research and Innovation Actions) and IA (Innovation Actions) open calls based on the roadmaps of SUNRISE and ENERGY-X. All the granted RIA and IA projects would conclude a collaboration agreement with SUNERGY and the CSA to contribute to the activities of the whole initiative and would be subject to mid-term review and evaluation at the end by a program board of experts with mandates from the MS and the EC to assure quality and impact without transfer of authority away from the MS and EU. This period would also be dedicated to develop and strengthen the SUNERGY community (academia, industry and society) and to pave the way towards the SUNERGY partnership with the contribution of the different stakeholders.
- **Long-term (after 2024)**: this corresponds to the start of a SUNERGY partnership "Fossil-free fuels, chemicals and materials for a circular economy (3FCM)". Regarding the type of partnership, with bottom-up (RIA) and programmatic (IA) components, a co-programmed European partnership (cPPP) appears as the most adapted.

All this was detailed in Deliverable D4.2 which also integrated the main outcomes of Task 4.1.

For the practical organization and running of this task, there were in total 5 remote Telco meetings, one governance session during a SUNRISE consortium meeting in Bologna and a joint ENERGY-X and SUNRISE governance meeting in Roissy (October 2019) to build scenarios and timeline towards a SUNERGY LSERI.

Task T4.3 (months 9-12): Set-up the organisational structure and processes of the large-scale research initiative

All activities in this task were jointly performed between the ENERGY-X and SUNRISE consortia which merged to launch the SUNERGY initiative. Four remote Telco meetings (followed by subsequent elaboration phases) and one physical meeting (19 February 2020, at DECHEMA, Frankfurt) were held between the teams dealing with governance definition to develop and align the joint proposal for the future organization of the SUNERGY initiative and to assemble the different bodies identified in the proposed governance structure. The latter comprised amongst others the identification and nomination of various members of the decision making, advisory and operational bodies for SUNERGY in due consideration of balance and diversity, as well as setting up suitable communication schemes and frameworks. At the SUNRISE symposium (M3 at month 12), the key elements of the future governance structure were presented to all stakeholders, and the governance setup was subsequently further refined in close cooperation with the ENERGY-X consortium until month 14. Accordingly, the final Terms of Reference (ToR, Deliverable D4.2) were jointly developed between ENERGY-X and SUNRISE and shared with all involved stakeholders at the end of the task.

The following **Deliverables** were due within the reporting period:
- **D4.1 Governance Plan** due Month 8 (10/2019): submitted in 04/2020;
- **D4.2 Terms of Reference** due Month 14 (04/2020)**:** submitted in 04/2020.

1.2.5 Work Package 5: Management (CSA)

Beneficiaries involved: ULEI, CEA

Objectives:

1. To ensure that the project runs efficiently and delivers objectives fully and on time
2. To facilitate communication between partners
3. To deliver reports to the European Commission
4. To oversee expenditure and provide financial management
5. To track progress and changes in the state of the art, and where appropriate update objectives
6. To identify and correctly manage IP
7. To manage the SUNRISE website
8. To organise international meetings

Summary of progress and significant results for each task:

Tasks (months 1-14):

Subtask 5.1 (months 1-14): Establishment of the project management structure. ULEI (lead partner), CEA

During the duration of the project, the coordinator (ULEI) has been supported by the Materials Innovation institute (M2i) as a third linked party, to set up the project management structure. This included organisation and maintenance of the project intranet workspace (Plaza), exclusively accessible for project partners, containing all relevant project documents, administrative information and overview of supporters. The period of active maintenance extended until six months after the original end date of the CSA.

M2i was also responsible for setting up and maintaining the structure of biweekly management meetings and the preparation and organisation of consortium meetings, as described under Subtask 5.3.

Subtask 5.2 (months 1-14): Website. CEA (lead partner), ULEI

The SUNRISE project website was set up by project partner ICIQ and provided the basis for dissemination and communication actions. During the duration of the project, the website was actively and continuously updated and expanded by ICIQ as described in this report, section 3.1.1. Four web domains, sunriseaction.eu, sunriseaction.com, sunriseflagship.eu and sunriseflagship.com, their dns settings and forwarding were maintained by ULEI using Europe Registry and Wix webhosting for community building purposes.

Subtask 5.3 (months 1-14): Day-to-Day and General Management. ULEI (lead partner), CEA

The communication between the partners took place on a continuous basis via email, the project website, distribution of documents via the intranet workspace, and in various project meetings. The overall supervision of project management, as well as the reporting to the European Commission, was in the hand of the coordinator. Apart from that, M2i was responsible for the organisation of online Management Board (MB) meetings every two weeks, including drafting of the agenda, minutes and follow-up of action points. In addition, biweekly Management Team (MT) meetings, *i.e.* meetings between the coordinator, the

deputy coordinator and M2i staff, were organized to ensure a continuous follow up of urgent actions.
The status of the deliverables, milestones and overall project objectives was closely monitored by the coordinator supported by M2i. The weekly management meetings served as a tool to track any delays and potential bottlenecks.
For specific activities, *e.g.* the contacting of Dutch National Contact Points for matters related to the project, or the formal invitation of various stakeholders, such as politicians, for project meetings, the coordinator was actively supported by M2i.
M2i had a coordinating role in preparing the consortium meetings, in close collaboration with the members of the Management Board. The activities included the drafting of agenda's, the selection of meeting locations, the follow up on participants, and the preparation of meeting minutes.

Subtask 5.4 (months 1-14): Monitoring and Evaluation. ULEI (lead partner), CEA, others
WP Leaders were responsible for gathering final progress reports from the partners in their WP. Deliverables were collected by the WP leaders and upon their approval reviewed for academic quality and societal impact assurance by the QIA Team prior to their release.

In October 2019, when the SUNRISE CSA was midway, the draft roadmap, the consolidated vision and the innovation framework were assessed within the consortium with a panel of external advisors. This resulted in a set of clear recommendations (Mid-term Review D5.1) that were taken into account for the remainder of the project. See D5.1 for further details.
The biweekly MB and MT meetings, described under subtask 5.3, were organized for weekly monitoring and evaluation purposes and ensured a continuous follow up of project activities.

Subtask 5.5 (months 1-14): Coordination of financial and administrative aspects. ULEI (lead partner), info all partners
The coordinator ULEI managed the administrative activities, including calculation of pre-financing distribution, collection of relevant information from the Partners for the preparation of deliverables, reports, cost statements, organization of the project meetings. In addition, the project coordinator managed the first Amendment to the Grant Agreement with regard to the change of the project's duration involving a two months extension as well as the inclusion of M2i, ULEI´s third party providing in-kind contribution against payment.

Subtask 5.6 (months 1-14): EU Final Reporting. ULEI (lead), CEA
This document including the annexes represent the technical report that has been created at the end of the SUNRISE project.
According to the timetable for reporting of the Amendment 1 of the Grant Agreement the final technical and financial reports were due at month 14, the end of the project. The project coordinator supported by the project manager prepared the technical report while all Partners prepared their financial statement individually. Results and information for each work package have been collected from the work package leaders and information on objectives, deliverables and milestones and meetings have been presented. All achievements have been highlighted and all deviations have been clearly described. The report has been checked by all Partners and the Project Coordinator before submission to the EC.

Subtask 5.7 (months 1-14): Liaison with other CSA candidates Energy and Climate (ULEI, CEA) Health (ULEI), ICT (CEA)

As described in, among others, sections 1.2.3 and 1.2.4 of this report, SUNRISE and its sister CSA ENERGY-X agreed in August 2019 to merge at the end of the two CSAs and to launch a new initiative, SUNERGY. The governance teams of both CSAs were combined after the merging and a series of common meetings were organized. Refer to 1.2.3 and 1.2.4 for further details.

Task 5.8 (months 1-14): Organisation of final international meeting. ULEI (lead partner), CEA

On February 5th and 6th 2020 the final international meetings were organized in Brussels, when over 100 stakeholders gathered for a series of events including a high-level lunch at the European Parliament. During the meetings both CSAs SUNRISE and ENERGY-X presented their achievements throughout the past year, proposed a joint vision, and presented recently awarded projects relevant for both CSAs as well as upcoming funding opportunities. The organization of meetings was a coherent team effort, not only within the SUNRISE consortium but also in collaboration with the organizational committee of Energy-X and the Representation of the State of Hessen to the EU.

Apart from the project partners and supporters of both CSAs, a number of politicians and public officials were invited. Despite the fact that the Executive Vice-President for the European Green Deal, dr. Frans Timmermans, was unable to attend, other prominent EC officials were present including Dr. Peter Dröll (Director Prosperity, Directorate General Research & Innovation) who held a Key Note speech on the strong support of the European institutions towards R&I to achieve the ambitions of the European Green Deal.

The following **Deliverables** were due within the reporting period:

D5.1 Mid-term Review due Month 6 (8/2019)
Performed in month 9, report submitted in 12/2019

D5.2 Symposium due Month 11 (01/2020)
Performed beginning of month 12, report submitted in 04/2020

D5.3 Final Report due Month 14 (04/2020)
The present report represents this deliverable

All **Milestones** were reached within the reporting period:
MS1 Ramp-up conference. Reached in 06/2019
MS2 Mid-term review Reached in 10/2019
MS3 SUNRISE Symposium Reached in 02/2020

1.3 Impact

SUNRISE has created a comprehensive design and description of the SUNERGY LSERI for a pipeline of technologies that allow for the transformation of the energy and chemical industry sectors into a circular and sustainable resource economy. This LSERI is necessary to forge the tools for offering a portfolio of manufacturing solutions to the long-term and large-scale storage of renewable energy from fluctuating primary sources. To meet the goals of the Paris Agreement (COP21), net negative CO_2 emissions must be reached. The LSERI provides the impetus to achieve this objective. It will foster the next generation of researchers, innovators, and companies, and bring the European industry to a competitive forefront. SUNERGY will make Europe the global leader of a future clean-energy technology with major societal impact and ensure Europe's energy independence.

SUNRISE CSA prepares the required groundwork to establish a fully developed LSERI, *i.e.* SUNERGY, that will deliver the unifying goal of turning sunlight and molecules from our atmosphere into valuable fuels and base chemicals, using technologies that are scalable on the gigawatt and terawatt scales. The close collaboration and consultation with key stakeholders has been essential to ensuring that SUNERGY is organized in the best possible way, learning from previous Flagship programmes in order to establish SUNERGY as a European hub for excellence in solar energy conversion.

The fuel market is the world's largest market by far. EU countries pay around €200 billion per year for imports of crude oil.[2] Strategic pillars of European industry (steel, cement, chemicals) and agribusinesses are highly energy-intensive and rely significantly on the import of crude oil and gas. SUNERGY will drastically reduce their reliance on fossil fuels, and shift the international upstream oil and gas market towards renewably produced fuels and chemical feedstocks. This will also create a large downstream market for new solar-fuel refineries. When successfully developed, SUNERGY technologies have global reach and allow Europe to export innovative technology for industrial symbiosis to a wide range of countries. Just targeting only 10% of global crude oil and gas production in the first stage would still represent a value of €250 billion per annum in the upstream sector, even at the current low-price level.

SUNERGY will also have a strong economic impact on the modernization of production processes: the investment costs for traditional refineries worldwide amount to €1700 billion, typically with a 10% reinvestment rate per year. The SUNERGY approach will create huge potential for upgrading existing plants and building new ones that transform SUNERGY products into certified fuels. To gain crucial understanding about what happens to the existing economic eco-system and the current flow of energy and materials if we replace one or more existing bricks by SUNERGY manufacturing of energy carriers and chemicals, the incorporation of new technologies and how these will impact the economics of the existing bricks will be modelled in a systems approach. This will help in providing resilience towards impact by identifying potential conflicts between environmental benefits and economic sustainability.

SUNERGY technologies will not compete with agriculture and have a high solar energy conversion efficiency, potentially reaching close to 30%, which is much higher than biomass production (typically less than 1%). Since fulfilling societal energy and commodities needs will be no longer a distant, out-of-sight activity but an activity close to one's household, distinguished by a highly decentralized character and spanning across densely populated urban areas, societal acceptance will dominate environmental benefits. Existing paradigms of nature as a resource to be exploited or of humans as passive consumers of natural resources are inadequate. **A full appreciation of the capacities and complexities of incorporating SUNERGY technologies in an existing ecosystem, requires evaluation of their impact on human dignity from the start for making strategic choices**. During the preparatory action, the input of **key stakeholders from society** in the definition of the large-scale research initiative scientific and industrial

[2] https://ec.europa.eu/energy/en/data-analysis/eu-crude-oil-imports

roadmap has optimized the overall societal and environmental impact by increasing the connection to the general public interests.

1.4. Access provisions to Research Infrastructures

In accordance with Section 4.1 of the DoA, in SUNRISE CSA we used the databases on research infrastructures provided by EERA. The blueprint document gives a comprehensive overview of the necessary European R&D collaborations, competencies and resources, including infrastructure aspects, that are needed for an efficient implementation of the large-scale research initiative. For this part ULEI, UU and M2i made use of databases from three relevant EERA joint programs, *i.e.* Advanced Materials and Processes for Energy Applications (AMPEA), Carbon Capture and Storage (CCS) and Fuel Cells and Hydrogen (FCH). In addition, we used the EMIRI industrial database and the ENERGY-X database of catalysis-oriented stakeholders to deliver a complete overview of organizations and infrastructure that are active in the area of the SUNRISE objectives.

2. Update of the plan for exploitation and dissemination of result (if applicable)

As described in section 1.2.3 of this report, deliverable D3.1 consists of the Dissemination, Communication and Education Plan which was split up in a plan delivered mid-term of the CSA and a final one at the end. The final updated D3.1 has been added as an annex to this report.

The main purpose of the plan has been to provide a formal strategic document for the actions to be done during the CSA and beyond, to ensure effective dissemination and communication. Looking for simplicity, the plan has been divided in short-term and long-term objectives and actions. In the mid-term review the short-term plan provided objectives and a more detailed description of actions until the end of the CSA project, indicating also the responsibilities of the partners and the key messages to be communicated. While the short-term actions in the plan provided at the end of the action, refer to the ramp-up phase once the two CSA projects have merged and prepare for a large-scale initiative. In both cases, the long-term plan gives a basis of the main dissemination, communication and education goals of a European large-scale research and innovation initiative.

3. Update of the data management plan (if applicable)

As described in section 1.2.3, the data produced by the consortium are available through the SUNRISE website, the M2i intranet plaza as well as at a new community space within ZENODO (https://zenodo.org/communities/sunrise/?page=1&size=20), a public repository hosted by CERN.

An initial plan was submitted after the mid-term revision and an updated version can be found in annex D3.4 of this report, with the latest updates. The last version of this plan is intended to be the basis to support future actions.

4. Follow-up of recommendations and comments from previous review(s) (if applicable)

A mid-term review was organized by the SUNRISE consortium, *i.e.* not by the EC, in October 2019. Several members of the SUNRISE Scientific Advisory Board were contacted to perform a mid-term review of the SUNRISE deliverables, with emphasis on the roadmap. The feedback received and how the conclusions were followed up are described in the mid-term evaluation report, added as annex to this report.

5. Deviations from Annex 1 and Annex 2 (if applicable)

5.1 Tasks

WP 1 – deviations:
No substantial deviations from planned tasks.

WP 2 – deviations:
No substantial deviations from planned tasks.

WP 3 – deviations:
Overall, most of the actions envisaged within WP3 were successfully accomplished and the main objectives fulfilled. The initial targeted KPIs have been continuously monitored and adapted to the action needs and performance, formulating new ones when needed. The tasks and expected deliverables have been correctly executed, with only minor deviations from the initial description:

<u>Task 3.1</u>
Continuous evaluation and adaptation led to some deviations from the initial plan. For instance, although a blog section was created in the web and visitors have access to a contact e-mail address and can leave messages in the ‘support us’ section, not many interactions were received through these channels in the first months of the project. Instead, social media networks and newsletters have become the real interaction points with the SUNRISE community, therefore the previous idea of a discussion forum was not further promoted. On the other hand, audiovisual materials had acquired a relevant role in the communication strategy, including a series of video interviews and a SUNRISE YouTube channel that has been used as an audiovisual repository, and was not previously planned.

Regarding the App, based on the primary feedback by visitors at the EUSEW stand, it was decided that a previous step for its development was needed with the collection of feedback and experience of a first group of users within the consortium partners. After presentation of the demo, a survey was done to consortium partners. Most of the participants expressed their interest in developing an App, however, most of them would not like to receive the latest research articles in their phones, other appropriate contents suggested are: open calls and events in the field and training and outreach/informative materials. Participants found interesting to keep working in the concept and development of an App as soon as possible, if funds are available, within the continuation action SUNERGY.

Since the announcement of the SUNRISE and ENERGY-X merging at the end of the CSA periods, several joint dissemination and communication actions have been developed, some were not previously planned or have caused some adjustments to the planned ones. For instance, the SUNERGY photo contest was initially thought as a slam video contest, but the idea evolved during the preparation and organisation of the final event, as many videos were already in place, but keeping the same spirit to be an interactive action, and adding a new social media profile. Altogether, the joint actions (described in D3.1) have complemented the initial plan, being positive for the task and objectives accomplishments, helping to reach an even bigger community.

Task 3.2
SUNRISE's actions having an educational and training nature have been focused on three main audiences: young researchers, primary and secondary students and general public. Although concrete actions were also initially thought for industry actors, a more general outlook has been prioritized as a first approach during the CSA, in an effort to broadly introduce some of the concepts to a larger audience, like artificial photosynthesis and chemical storage, before going for a major stratification and technical specification at a later stage.

WP 4 – deviations:
Task 4.2 was extended until February 2020 and the related Deliverable D4.1 was ready by the end of February 2020 and submitted in April 2020. There were two main reasons for this extension. The first one is that contrary to initial plans based on the Flagship instrument, as this did not exist in Horizon Europe, Task 4.2 was largely devoted to finding suitable instruments and building scenarios in the new framework programme, Horizon Europe. knowing that its strategic plan was under discussion during all the course of the CSA and of the task T4.2. The second reason was due to the agreement end of August 2019 to merge the two communities, SUNRISE and ENERGY-X, beyond the current CSAs and to share efforts on tasks of common interest including governance, which in the ENERGY-X CSA had a different timeline with deliverables on governance proposals at the end of the CSA (February 2020). Thus, a common workshop and meetings were organized until beginning of 2020 to share and align views on governance plans and schemes and the related deliverables.

WP 5 – deviations:

- The mid-term review was extended with a session with Mission Innovation IC5. The goal was to collect their suggestions for improvement of the SUNRISE roadmap, with the underlying idea that SUNRISE would benefit from the interaction with MI by increasing its impact and visibility on a global scale.
- The CEA mid-term meeting moved to Brussels and was extended with the above mentioned participation from Mission Innovation.
- Besides the mid-term meeting, several other consortium meetings were upgraded as well to reach a larger audience.
- The consortium meeting in Bologna evolved in a national Italian meeting for supporters.
- Inclusion of M2i as 3rd linked party for support on project management and drafting of deliverable D1.3
- The SUNRISE final symposium was extended with the SUNERGY starting event, which led to larger audiences. Further details can be found under, *e.g.* 3.1.2 SUNRISE Symposium and other dissemination and communication actions, section 1.2.3.
- We brought the SUNRISE App to the demo stage, but then it was overtaken by more successful social media activities. For further details, see 3.1.1 SUNRISE Website and related tools, section 1.2.3. In addition, it turned out that the scientists were not contributing enough to the App, they chose other means for contributing to SUNRISE.

- An amendment for a two months extension of the project was requested to postpone the due date of deliverables D2.3, the fully developed innovation and exploitation plan; D4.2, terms of reference; and D5.3 the final report, as this would allow to deliver a comprehensive design and description of the large-scale research initiative of the highest quality.

5.2.1 Unforeseen subcontracting (if applicable)

Not applicable.

5.2.2 Unforeseen use of in kind contribution from third party against payment or free of charges (if applicable)

In the Amendment 1 to the Grant Agreement the coordinator ULEI added M2i as third party under article 11 of the GA (third party providing in-kind contribution against payment) with the following justification:
During the grant agreement preparation of SUNRISE the intended project manager was no longer available for the appointment at ULEI. From a selection and screening procedure, M2i has emerged as the only party with the right expertise. They have a network that is both national and European international, focused on research and innovation. M2i is a professional project management organization for European projects and can also carry out project development at the interface of university and private research. M2i also has specific expertise that bridges biological and material research, which is the third leg of the SUNRISE approach.

Within the reporting period of the SUNRISE project M2i provided support in the project management of the project coordinator ULEI and therefore was mainly involved in WP 5. In addition, M2i drafted the deliverable D1.3 (“blueprint”) in WP1. The activities performed by M2i are described under WP1 Task 1.3 (blueprint) and WP5 (management).

List of Annexes: SUNRISE DELIVERABLES

Solar Energy for a Circular Economy

Deliverable D1.1

CONSOLIDATED VISION

Lead Beneficiary CEA
Delivery date 31/05/2019
Dissemination level Public
Version 0.1

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v1.0	13/05/2019	V. Artero, H. Bercegol	Revision
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EXECUTIVE SUMMARY

The vision of SUNRISE is to enable the production of renewable fuels, chemicals and materials on a global scale using abundant molecules as feedstocks (*e.g.*, H_2O, CO_2, N_2) and sunlight as the primary energy source. SUNRISE will develop artificial photosynthesis in a broad sense, aiming at solar to products yields tenfold to hundredfold higher than current biomass practice. SUNRISE will allow net-zero emission mobility and expedite the transition from a linear to a circular economy, with immense benefits for the society, the environment, the economy, and the ongoing efforts to mitigate climate change. The development of large-scale industrial processes employed in decentralized plants converting CO_2 into environmentally friendly long lasting (*e.g.* building) materials will lead to an important negative emission technology. SUNRISE will foster and rely on the development of energy-efficient disruptive manufacturing processes, sober in critical materials. The transition to a circular solar-powered society is a key step to preserve the biosphere and allow modern civilization to prosper. The key targets of SUNRISE on a 10-year timescale are:

2023: Seasonal storage demonstrated with solar to chemical energy conversion better than 15%

2025: Demonstrator at a scale of > 1 MW that will provide an urban environment with 10% of its energy in sustainable form, with CO_2 neutrality.

2027: Demonstration of 80% circularity at the regional level with artificial photosynthetic technologies for industrial feedstock, products and processes

2029: Negative emission carbon capture and utilization (CCU) and sustainable ethanol production on the industrial scale (*i.e.*, with concentration to the MW level)

2030: 1000 ha (>150 MW) scale of SUNRISE technologies for liquid fuels production for, *e.g.*, air transportation
Decentralized and CO_2-neutral ammonia fertilizer production for precision farming

On a longer timescale, 2030 to 2050, SUNRISE aims at a CO_2-neutral economy with affordable negative emissions technologies on a significant scale.

LIST OF ACRONYMS AND ABBREVIATIONS

CCU: Carbon Capture and Utilization

DAC: Direct Air Capture

EROI: Energy Return On energy Invested

FT: Fischer-Tropsch

ICE: Internal Combustion Engine

ICT: Information and Communication Technology

PEC: PhotoElectrochemical Cell

PEM: Proton Exchange Membrane

SOE: Solid Oxide Electrolysis

STC: Solar to Chemical energy conversion efficiency

STH: Solar to Hydrogen energy conversion efficiency

TRL: Technology Readiness Level

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1. SUNRISE concept

1.1 From The Fossil Linear Economy to The Solar Circular Economy

Fossil fuels have had a tremendous impact on improving the quality of life globally during the last century. However, current production of fuels, plastics, agrochemicals, and pharmaceuticals based on fossil resources results in a linear economic model that is unsustainable, affects the stability of the biosphere, and causes anthropogenic climate change, thus threatening the future of modern civilization.[1] The phasing-out of this linear model in favour of circular economic innovations, which focus on the renewable use of resources, is no longer an abstract scientific ambition but a key objective of global political action under the leadership of the European Union (EU).

The only energy source that, in principle, can completely replace fossil fuels is sunlight. Even the most conservative estimates conclude that the flux of photons hitting the Earth is far in excess of modern civilization's energy requirements. However, the energy of incoming solar radiation must be harnessed and converted into a storable, transportable and recyclable form. The most effective strategy for doing so is the direct conversion of solar energy into fuels and chemicals (**solar fuels** and **solar chemicals**), *i.e.* storing energy in chemical bonds. A viable alternative to fossil carbon sources in the manufacturing of fuels and chemicals is currently the atmosphere itself, where anthropogenic carbon dioxide (CO_2) has accumulated, leading to global warming and the acidification of surface waters. Besides carbon, the atmosphere and hydrosphere are vast reservoirs of the other three main elements that feed the chemical industry: hydrogen, nitrogen, and oxygen. **The production of alternative fuels, commodity chemicals and materials from renewable energy, water, and atmospheric sources is a real game changer and one of today's greatest challenges.** While electricity is currently the main renewable energy carrier, it represents less than 20% of end-use energy consumption, with the rest being used in the form of fuels. In addition, the intermittency of renewable energy sources requires efficient and sustainable storage technologies in order to be competitive and attractive to energy companies. **SUNRISE is the large-scale initiative that will address these scientific, technological, and societal challenges through the photorecycling of atmospheric CO_2 into a variety of products and the photofixation of nitrogen to produce ammonia for fertilizers. More generally, closing loops at all levels, SUNRISE will make possible the direct solar-driven production of fuels, commodity chemicals or building materials.** The concept of SUNRISE is schematized in Fig. 1.

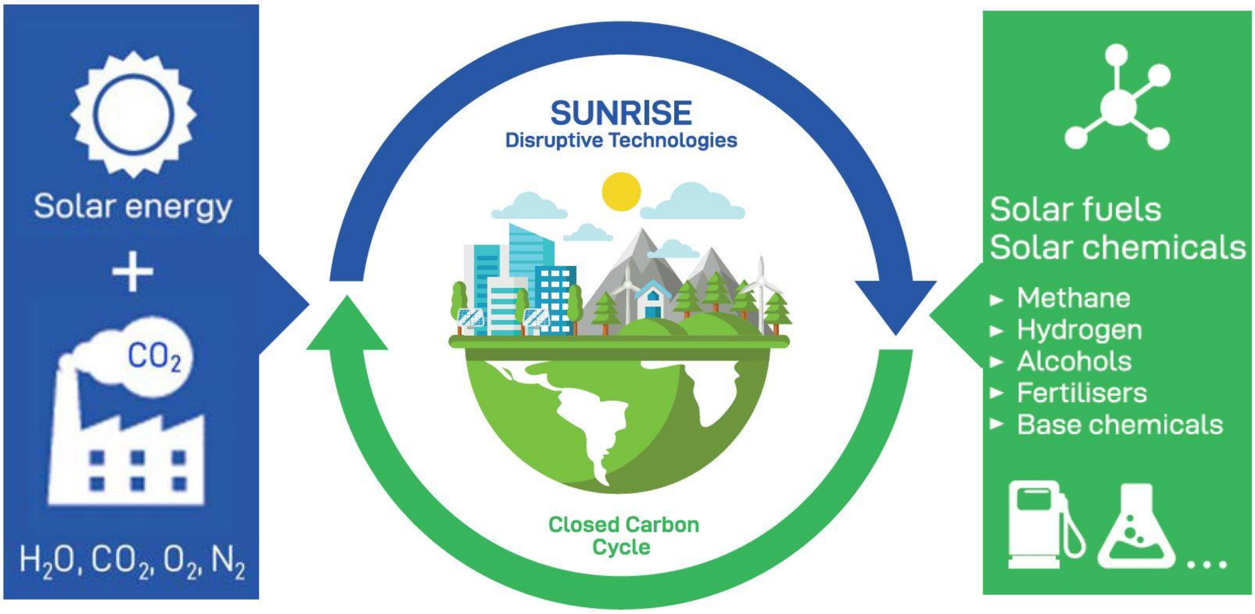

Fig 1. SUNRISE concept of a circular economy of carbon using solar energy input and atmospheric gases as feedstocks

[1] W. Steffen *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **2018**, *115*, 8252; W. Steffen *et al.*, *Science* **2015**, *247*, 736.

SUNRISE is a game changer that will have an impact in many areas. These include:

- Establishing sustainable and efficient ways of storing intermittent energy fluxes
- Supporting a fully sustainable hydrogen and e-mobility for zero net emission transportation in urban environments
- Producing sustainable fuels, commodity chemicals and materials using the most abundant energy source, the sun
- Developing a sustainable CO_2-neutral air transportation system
- Restoring balance in the nitrogen cycle through precision farming via in-field and CO_2-neutral production of fertilizers
- Transforming the chemical industry with innovative strength for the manufacturing of sustainable new materials including biodegradable plastic substitutes and CO_2-storing building materials which we could call "artificial wood"
- Developing region-specific solutions to sustainable chemical production and energy storage
- Delivering less harmful fuels and chemicals for health and the environment
- Enabling a radical change in the energy system, *i.e.* from centralized to decentralized
- Transforming anthropogenic CO_2 into a valuable resource
- Accelerating the transition from a linear to a circular economy
- Reducing Europe's dependence on imported fossil resources and improving its energy security
- Developing the energy awareness of citizens in an industrial society

2. SUNRISE as a grand S&T challenge and game changer

2.1 S&T CHALLENGE

The unifying goal of SUNRISE **is to provide the key enabling technologies to make sunlight and ubiquitous molecules the prime sources of energy and materials for modern society, and displace fossil fuels by renewables on the terawatt scale.** This objective has far-reaching consequences with global significance, such as (i) mitigating global warming, (ii) promoting the transition to a sustainable circular economy, (iii) reducing the European economy's dependence on energy and feedstock imports. SUNRISE thus addresses all three highly relevant issues simultaneously. Closing production cycles increases energy return on energy invested (EROI), is the optimal path for stabilizing and eventually reducing CO_2 concentration in the atmosphere and for decoupling the economic activity from depletion of natural resources. Furthermore it enables value creation from manufacturing renewables at a local level in a transaction economy that feeds into the economic system, thereby securing local energy supply, independent of imports.

The scale-up of current laboratory-scale solar energy conversion devices into widespread, efficient industry-grade systems and installations is a grand S&T challenge that requires both scientific and technological breakthroughs. **The added value SUNRISE creates for European countries will be essential, since it will provide tailored solutions for each European region to achieve the optimal manufacturing strength from utilization of solar irradiance and site-specific resources.**

2.2 SUNRISE GOALS AND APPROACHES (IN SHORT)

[*see §5 for a more detailed presentation of SUNRISE approaches*]

There are many different artificial approaches to producing chemicals from sunlight, ranging from electrochemical conversion to integrated photoelectrochemical cells and enhanced direct photobiological and biohybrid conversion systems (Fig. 2). SUNRISE will thus develop artificial photosynthesis in a broad sense, aiming at solar to products yields tenfold to hundredfold higher than today's usage of biomass. To optimize yield, SUNRISE will promote knowledge exchange, interdisciplinarity and cooperation among relevant scientific and industrial communities, and foster hybridized solutions.

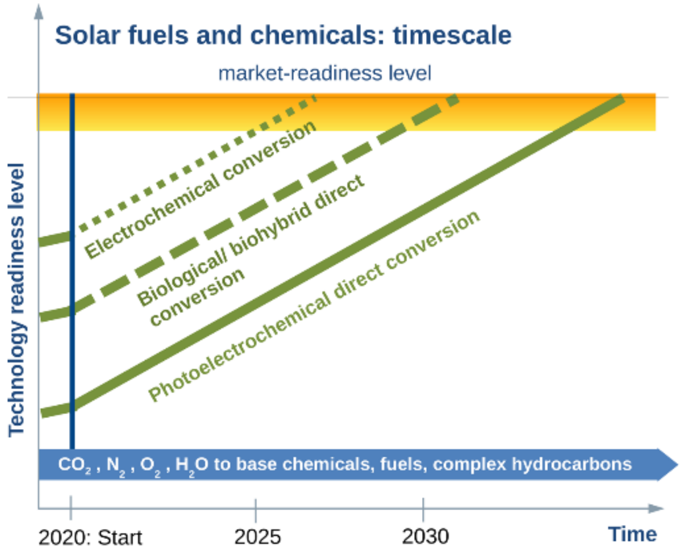

Fig. 2: Within SUNRISE, electrochemical conversion using renewable power in combination with electrolysers will be complemented with photoelectrochemical and biological/biohybrid approaches for the direct conversion of sunlight into fuels, chemical compounds, and building blocks (www.sunriseaction.eu).

The transition from a civilization that is fossil-fuel-dependent to one that is solar-powered, and which uses ubiquitous and abundant molecules as feedstocks in a circular manner, is the grandest scientific and technological challenge of our times. Addressing such an enormous feat requires a multidisciplinary, intersectoral, and strongly coordinated effort. Urgent action is required: the latest IPCC reports[2] underline the need to reduce anthropogenic CO_2 emissions to below zero within 50 years in order to reach the ambitious goals of the 2015 Paris agreement. Technologies enabling such a transition are still in their infancy. Large-scale research and development efforts (from the megawatt scale onward) and massive investment are crucial. The enormous increase of wind and photovoltaic capacity in the EU and worldwide shows that a consolidated alternative to the use of fossil fuels on the terawatt scale already exists for electricity production.[3] The situation is much less advanced for the conversion of solar energy into fuels and chemicals. Fossil fuels dominate transport and heating, with extensive existing infrastructure. The chemical industry, which supplies a variety of indispensable bulk chemicals, is dependent on fossil-based feedstocks. **Genuine manufacturing of concentrated energy carriers and sustainable feedstocks instead of extracting them from natural resources is a real game changer for today's energy system and the chemical industry.**

Table 1. Overview of SUNRISE Approaches and Goals. Present TRL levels are indicated. SUNRISE's ambition is to achieve TRL 9 for fuels and chemicals and at least 7 for CO_2 removal.

Approach	Present TRLs		
	Goal 1 Fuels	**Goal 2 Chemicals**	**Goal 3 CO_2 extraction and storage**
1. **Electrochemical conversion with renewable power** fuels and commodity chemicals from CO_2, H_2O, O_2, and N_2	**3-8**	**2-4**	**0-3**
2. **Direct conversion *via* photoelectrochemical systems** fuels and chemicals from CO_2, … N_2 and direct solar energy	**2-4**	**0-3**	**0-3**
3. **Direct conversion *via* biological and biohybrid systems** unconventional methodology for photochemical conversion of atmospheric CO_2 with high yields	**2-4**	**3-5**	**0-3**

SUNRISE will undertake three approaches (see Table 1 and Figure 2) to delivering solutions on different timescales for the replacement of fossil resources. In the short term (2020–2025), we will focus on efficient

2 *Intergovernmental Panel on Climate Change*, "Global Warming of 1.5 °C, an IPCC special report", 6 October **2018**

3 World Energy Outlook, *International Energy Agency*, **2017**.

and sustainable processes for the conversion and storage of renewable power into liquid or gaseous fuels, taking advantage of the continued growth of wind and solar electricity production. In the **medium term (2025–2030)**, we will forge tools to replace fossil feedstocks with key molecules and fertilizers produced with renewable energy. SUNRISE Goals (Table 1) will finally enable the Great Transition to take place on a longer timescale, deliberately reducing the level of greenhouse gases in the atmosphere **(2030–2050)**. The ultimate long-term goal of SUNRISE is to outsmart nature in the use of direct sunlight (see Fig. 7, p. 17), capturing CO_2 directly from the atmosphere and replacing fossil fuels as carbon sources. SUNRISE will systematically identify and address bottlenecks that could prevent a meaningful implementation of its goals, such as the need to develop technologies with a high EROI (> 10) and to sustainably use critical mineral resources in the manufacture of conversion and storage devices.[4]

The above challenges require scientific and technological activities that are intrinsically multidisciplinary. Most notably, **the kind of revolution envisioned by SUNRISE in the field of energy conversion/distribution and industrial production will go hand in hand with profound changes in society, the environment, and employment**. More generally, the energy and industrial revolution enabled by SUNRISE will also result in a paradigm shift in the way we understand and organize the global economic system, demonstrating circular economy practices on a large scale, requiring active contributions from social, economic, and environmental sciences as well as the humanities.

Fig. 3 outlines the pathway of the great energy and industrial transition, which aims at securing climate stability over the course of the 21st Century. The pivotal role played by SUNRISE in this epochal process is evident.

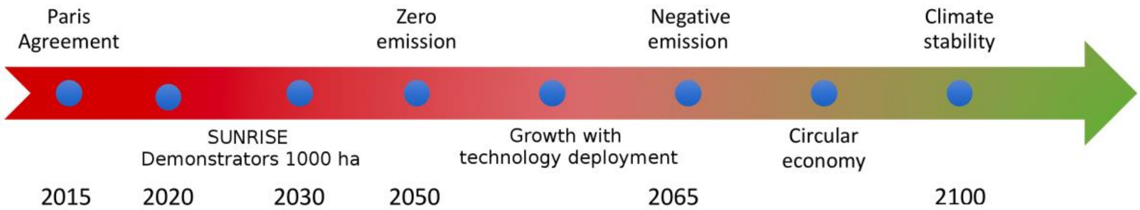

Fig. 3 SUNRISE will provide the technological capability, with high energy efficiency, chemical yield, and materials efficiency, to displace fossil resources over time at an affordable cost and with acceptable land use.

2.3 Energy

SUNRISE aims to provide energy conversion technologies that comprise stable, long-term storage of intermittent, solar renewable energy in the form of chemicals. SUNRISE not only provides a sustainable alternative to fossil-based energy carriers, including energy storage for e-mobility, fuels for transportation (*e.g.* hydrogen, gasoline, diesel and jetfuel) and heat generation, but will also replace the energy-intensive fossil-fuel-based production of commodity chemicals. The long term target is making sunlight the sole primary energy source. In the shorter term, SUNRISE will increase the potential of e-mobility and hydrogen mobility, by providing higher efficiency and CO_2-neutral chemical storage solutions; SUNRISE will use renewable power, sunlight or electricity as an intermediate stage, to drive the production of fuels and chemicals from CO_2 point sources, and atmospheric water and N_2 by upscaling and innovating electrolysis (including the production of H_2 as an intermediate) and by implementing new catalytic reactions and processes. The production of CO_2 neutral jet fuels will be pursued by advanced biosynthetic or biohybrid processes as well as by integrating photo-electrochemical conversion and CO_2 Direct Air Capture (DAC) technologies.

4 N. Armaroli, V. Balzani *Chem. Eur. J.*, **2016**, *22*, 32.

Europe beyond 2050:
700 million people - 2 TW SUNRISE Power

Efficiency of solar conversion	Surface per capita	Total area needed	
100 %	30 m²	0.3 %	
10 %	300 m²	3 %	Artificial Photosynthesis
1 %	3000 m²	30 %	
0.1 %	30000 m²	300 %	Biomass

Fig. 4 Primary average power consumption per capita is remarkably constant at ~6kW for European citizens. The table shows the land area required for solar fuel production at different energy conversion efficiency levels. It is assumed that 50% of the ~6kW/capita must come from solar fuel, which is lower than the current level of 75% of primary energy for a European population of 700 million and average insolation of ~ 100 W/m^2. SUNRISE aims for 30% efficiency with an external quantum yield of 70%. This translates into ~100 m^2 per capita of surface required, which corresponds to ~1% of the European surface. This represents a massive leap forward compared to current biomass practice, which operates with less than 0.5% energy efficiency. This would require 10,000 m^2 per capita for the same amount of fuel and might well require more than the entire European surface to fulfil the needs of the population.

With technologies converting 10-30% of solar energy into energy carriers (see Fig. 4 and §3 and 4 for performance targets), SUNRISE is in a very good position to turn metropolises, towns and suburbs into massive environmental improvement machines on the surface they already cover, based on the excellent economic efficiency that can be obtained in densely populated areas and establish a new conditional growth mechanism as a driver for eco-modernisation.

2.4 Reducing Europe's dependence on fossil fuels

Europe depends significantly on imported fossil fuels, with more than 85% of crude oil and 70% of natural gas currently being imported from foreign countries.[5,6] SUNRISE provides an alternative by replacing crude oil, natural gas, and other concentrated fossil-based energy carriers with sustainable fuels (including jet fuels) and commodity chemicals. The latter are produced using sunlight or renewable electricity and resources, which are abundant and ubiquitous. SUNRISE benefits from Europe's diversity and proposes a portfolio of solutions for each region, depending on the renewable energy sources available and on the economic environment. In regions with abundant renewable electricity (hydro, wind, solar,) and available concentrated CO_2 sources, electrolysis could provide a sustainable source of chemicals and fuels. In other regions with high solar irradiation, direct conversion approaches represent an ambitious, long-term option. With almost 75% of the European population living in urban areas, the importance of artificial photosynthesis for decoupling the economy from the consumption of natural resources cannot be overestimated.

2.5 New industrial opportunities for exploitation and sustainable development

In the short-to-medium term, electrolysis processes using renewable electricity and concentrated CO_2 sources will result in exploitation opportunities based on the replacement of fossil-based feedstocks with renewable commodity chemicals and the modernization of production processes. The newly developed technologies will allow industries emitting large amounts of CO_2 (*e.g.* cement manufacturing, iron- and steel-making) to reuse this greenhouse gas as a feedstock and remain competitive. The value for EU industry is evident also considering that Europe will become the leader for the global export of key industrial equipment in the energy and chemical sectors.

SUNRISE will propel Europe to a leading position in renewable energy and sustainable production. EU industry will depend less on imported fuels and will increase its competitiveness in a circular economic model. This, in turn, will facilitate industrial symbiosis, the development of smart cities and communities, and the deployment of innovative industry concepts. **New exploitation opportunities will emerge, especially for the materials and chemical sectors, leading to a complete modernization of industry, including new**

5 EU Crude Oil Imports and Supply Cost, *Eurostat*, **2018**.
6 Natural Gas Supply Statistics, *Eurostat*, **2018**.

catalysts, reactors, and processes. The sustainable and cost-effective electrochemical production of nitrogen-based molecules (fertilizers) and carbon-based fuels, and commodity chemicals will have a great impact on the chemical and transport sectors, respectively. The selection of novel commodity chemicals enabling the production of biodegradable and recyclable materials, including biodegradable plastic substitutes, with these new processes will also provide the European chemical industry with a tremendous innovative advantage in the pathway towards full sustainability. In addition, the advanced energy materials developed within the framework of the project will be of interest for other low-carbon energy technologies and will thus generate industrial opportunities in these areas. These include, for example, photosensitizers and light-harvesting materials for third-generation photovoltaics, new membranes for fuel cells, new catalysts and robust enzymes or strains for the chemical and biotech industry. SUNRISE technologies will also address the production of novel CO_2-storing building materials with the potential to revolutionize the construction sector.

3. SUNRISE Targets and Innovative pathways

3.1 Performance Targets

In order to make disruptive energy conversion technologies environmentally sustainable, it is crucially important that energy return on energy invested (EROI) indices[7] above 10 be achieved. Photovoltaic and wind technologies already achieve EROIs of about 15 and 20, respectively, whereas those of conventional oil and gas lie between 30 and 70, depending on various factors such as the geographical location of the extraction sites or the technologies employed.[8] The EROI index of solar fuels is currently very low. To improve it, the energy conversion efficiencies of solar fuel devices must be significantly increased. With today's commercial technologies, overall sunlight-to-fuel energy conversion efficiency is only around 10% when using average commercial wafer-based silicon modules with a 17% solar-to-power efficiency, combined with electrolysers and chemical reactors with a 50% power-to-hydrogen-to-hydrocarbons yield. Although this value is already significantly above that of natural photosynthesis (on average, < 1% of incident light converted into biomass), **SUNRISE aims for sunlight-to-fuel conversion efficiencies of at least 20% by 2025, aiming at 30% in 2030**. The short term goal could be achieved, for example, by 1) increasing the efficiency of photovoltaic systems to around 30% through the development of more efficient materials and device architectures (*e.g.* perovskites and highly ordered tandem solar cells), and 2) by raising the electricity-to-fuel efficiency to 80% using more efficient electrocatalytic hydrogen production coupled with downstream processes.

In the long term, SUNRISE will deliver technological approaches that convert solar energy and ambient CO_2 directly into chemicals. **Such a solar-driven chemistry represents a radical new form of energy and material conversion and storage**. SUNRISE aims to directly convert sunlight and small molecules into hydrogen, organic molecules (alcohols, hydrocarbons including aromatics), biodegradable plastic substitutes, fertilizers and CO_2-storing building materials. These radically new approaches include a range of new technologies from photo(electro)chemical processes to synthetic biology and biohybrid solutions. After 10 years, SUNRISE targets the ambitious goal of a 30% sunlight-to-fuel energy efficiency through direct photoconversion. The ultimate goal is the large-scale deployment of these technologies within a circular economic model, which will be implemented at all levels, all the way from decentralized devices to large integrated manufacturing plants and systems. SUNRISE aims for a sustainable CO_2 cycle, allowing for an initial decrease of CO_2 concentration in the atmosphere before maintaining it at a level compatible with climate stability. In line with a circular economy model, targeted products will include monomers for the synthesis of biodegradable plastic substitutes. The solar driven production of chemicals, including ammonia, must be associated with a smart (*i.e.* ICT-based) transport and concentration grid, for instance to deliver agricultural inputs in a precision farming approach. **SUNRISE will thus play a key role in enabling the shift to a carbon-neutral society, counteracting the effects of anthropogenic climate change.** For an effective impact on

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[7] Energy conversion efficiency is the ratio of the useful output of an energy conversion device (*e.g.* electricity) and the input (*e.g.* sunlight), in energy terms.

[8] Photovoltaics Report 2019, *Fraunhofer ISE*, downloadable at www.ise.fraunhofer.de

negative emissions, bulk materials shall realise carbon storage for the very long run, either in the form of carbonates with a mineral base, or CO_2-storing building materials which we could call “artificial wood”.

3.2 Quantitative Sustainability Assessment of SUNRISE technologies

SUNRISE will enable the deployment of radically new energy and chemical production as well as manufacturing technologies, which comprise light-harvesting and integrated conversion systems on a large scale. This rapid pace of technology development requires the development of new analytical methods and computational methods (software) for the rapid assessment of the environmental, economic, and social impacts of these emerging technologies. New methods shall provide integration of these different points of views, with a particular focus on the impact on climate, which is the main incentive of SUNRISE. The climate benefit induced by the avoided CO_2 will be calculated, but also possible leaks of chemical compounds produced or used in the catalytic chains will be studied in terms of risk for climate, health and environment. For this assessment, as well as for integrated techno-economic and social studies, SUNRISE aims at cooperating with European centres focused on advanced methodologies. This effort will be essential to provide recommendations for SUNRISE technologies during development beyond the 1000 ha scale.

3.3 ICT-based Materials Science

Novel materials will be crucial for achieving SUNRISE’s goals, because advanced materials are ubiquitous in the processes for the direct conversion of solar energy into fuels, chemicals and building materials. These include, for example, semiconductors, photosensitizers, catalysts, membranes and high-surface-area conductors, novel robust enzymes and microbial strains. Materials design and discovery is thus a cross-cutting key enabler for the entire SUNRISE technologies. However, translating new materials from the laboratory to the market can take 10 to 20 years and is very expensive, as highlighted by the Mission Innovation initiative.[9] According to the Energy Materials Industrial Research Initiative (EMIRI), advanced materials denote 50% of the manufacturing costs of clean energy technologies today and are expected to increase up to 80% in the near future. Materials discovery crucially needs scientific breakthroughs to optimally design the matter from the atomic scale up to the device scale.

Catalyst materials, crucial in photo- and electrochemical approaches, also play a major role in the production of modern materials and components, reducing significantly the amount of energy needed to manufacture devices. Today’s catalysts have to be significantly improved and optimized in terms of efficiency and durability; they need to be earth-abundant and non-toxic in order to allow for a sustainable and affordable upscaling of the proposed technologies.

European solar fuel materials hubs – where equipment and knowledge at the forefront are concentrated – could provide an automation of experimental synthesis characterization techniques based on modelling, big data analytics and artificial intelligence, and relying on expanding European **high-performance computing (HPC) facilities**. Advanced computer simulation techniques additionally guide experimental developments. Millions of hypothetical materials can be explored through high-throughput calculations and the most promising candidates are selected using artificial intelligence. Computational studies provide fundamental understanding enabling rational design and accelerating the exploration, discovery and use of new high-performance, low-cost and non-toxic solar fuel materials.

Once efficient materials are found, they have to be integrated and tested under real device conditions and the nanoscopic scale has to be bridged to the macroscopic world, for example with new bio-inspired engineering theories mimicking biological design principles. New components, catalytic electrodes, reactors, as well as innovative designs, shall also be investigated, *in situ* and *operando*, with the most advanced analytical techniques available to find functional relationship of the structure, reactivity and transport properties. In SUNRISE, the integration of the most promising materials into devices and systems will be addressed, while considering all relevant scales and aspects, from the molecular level up to the device integrated within the entire system environment. **The final objectives are to optimize materials, device and systems architectures to achieve the highest possible solar conversion yield, and to scale up procedures for their**

[9] Clean Energy Materials Innovation Challenge, Mission Innovation, 2018.

cost-effective production. Furthermore, eco-design principles and chemical processes for recycling materials and devices will be introduced without compromising the life cycle.

3.4 Innovation Process

A critical step for disruptive technologies and the SUNRISE vision is to bring fundamental research to the market through the fastest possible route across "the valley of death" for commercialization. In part 4 (see below), the TRL outline for the production of target molecules is given in view of different possible technologies. As innovation is the sum of invention/fundamental research and commercialization, SUNRISE will also put emphasis on commercialization to push innovation forward. It is necessary to create an open innovation network of incubators, where new start-ups, spin-outs and spin-offs are embedded in the SUNRISE research infrastructure to accelerate raising the TRL levels from TRL 4/5 to 7/8.

To let the SUNRISE technologies evolve in a free environment, the concept of SUNRISE valleys (see Fig. 5) is introduced in the style of the recently launched Hydrogen Valleys[10]. To further realize this concept and to reduce the innovation cycle time demand, the combination of public funding drawn in from the green bond market as well as private investments and a long term commitment (10 years period) from the European Commission is crucial to engage private investments.

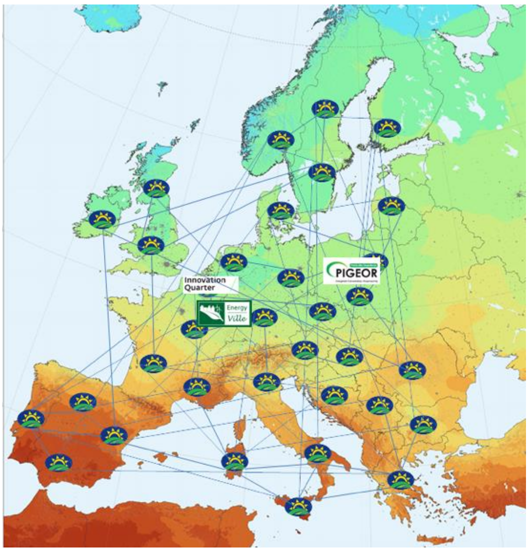

Fig. 5: Network of SUNRISE valleys in Europe. Geographical nodes shown are suggestions only.

A comparable infrastructure of each valley concerning support with *e.g.*, bookkeeping, business angels, VC companies, IP support, lawyers, marketing experts etc. will enable the fast and focused development of technologies of the before mentioned fields of actions in a business-friendly environment. In cooperation with large industry, technologies can be distributed on a global scale.

SUNRISE will adopt best practices from other sectors/ economic regions for structuring the innovation process and for handling attendant information flow including intellectual property. We will leverage the existing Member State ‘innovation infrastructure’ to provide local nodes for assisting the overall Sunrise Innovation Process (SIP). Our SIP will be built up using well-recognised stages (outlined below). From the outset, it will be vital to create an innovation environment where contributors are purposefully exposed to the views and opinions of all stakeholders so that new concepts and approaches to converting sunlight into fuels and chemicals are in sync with the drivers that are shaping our societies of the future.

SUNRISE will bring together an Innovation team as part of, and reporting to, the governance structure. The Innovation Team will be specifically responsible for organising and running the SIP. The team will be expected to evolve with time to reflect new developments in the political and social European landscape as they happen. The team will be tasked with leveraging relevant resource, assistance and advice from local, national and European organisations and institutions in building the SUNRISE innovation nodes.

4. The chemicals enabling the SUNRISE vision

The SUNRISE vision is enabled by the sustainable production of key molecules: hydrogen (H_2), ammonia (NH_3) and carbon-based platform chemicals. The latter are made from both point sources and distributed sources of CO_2, the ultimate goal being CO_2 extraction from the atmosphere with subsequent storage. Fig. 6 schematically illustrates the production and final utilization of the SUNRISE enabling chemicals, which are manufactured thanks to solar energy

[10] Launched in March 2019 by EC Fuel-Cell & Hydrogen Joint Undertaking, in the frame of the Mission Innovation Challenge 8: Renewable and Clean Hydrogen. https://www.fch.europa.eu/page/mission-innovation-antwerp-2019

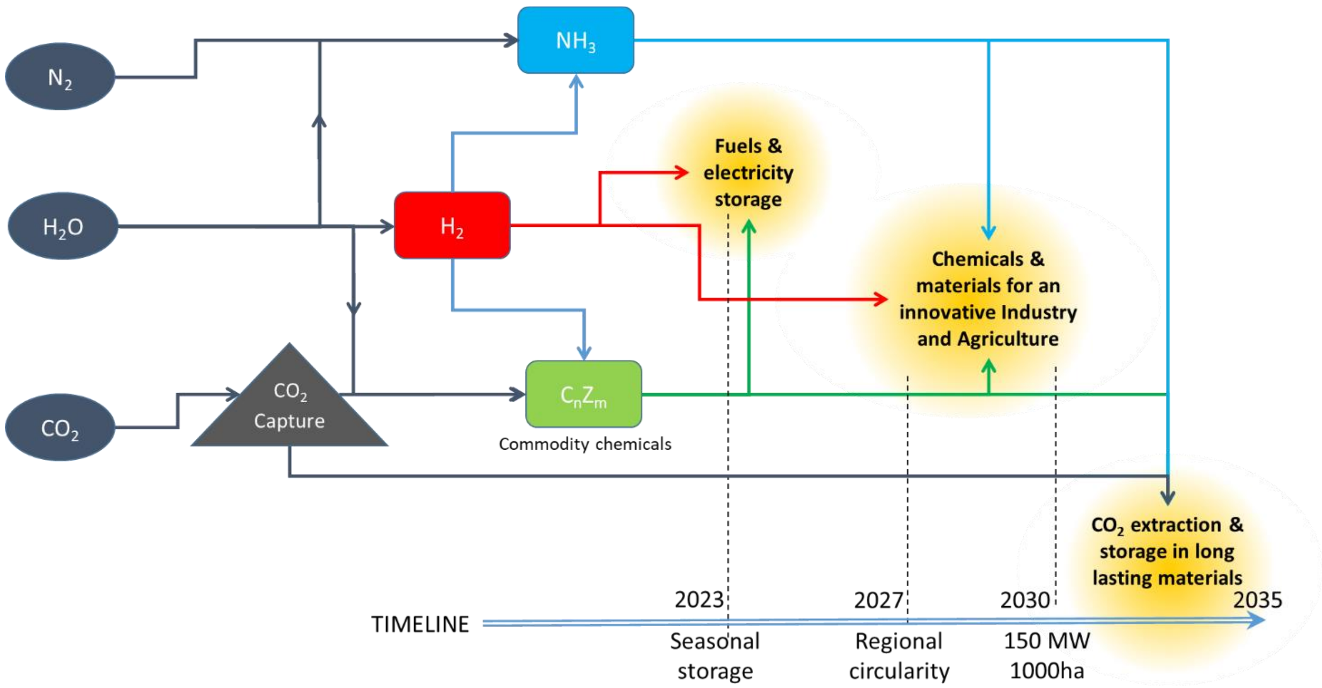

Fig. 6 SUNRISE simplified scheme of enabling chemicals production and usage

4.1 Hydrogen (H_2)

Hydrogen today

The lightest chemical element is largely abundant on Earth, but mainly covalently bound to other elements. Molecular hydrogen (H_2) is scarce and is currently produced from hydrogen-rich molecules, primarily hydrocarbons (*e.g.* by steam reforming) and partly H_2O (by electrolysis). At present, major uses of H_2 include fuel refining, steel production, and ammonia production via the Haber-Bosch process.

Impact

H_2 is the most appealing and sustainable carbon-free transportation fuel solution for heavy-duty vehicles and personal long-range vehicles, equipped with fuel cells. H_2 is also a key process gas in chemical and heavy industry (*e.g.*, synthesis of ammonia and methanol, hydrogenation reactions, steel industry). Large-scale implementation of SUNRISE technologies with high STH yield will provide both short-term and seasonal storage of fluctuating renewable energy fluxes in urban zones. Moreover, a renewable H_2 economy can operate in both large-scale centralized factories and in small-scale distributed installations. As the latter will allow on-site production and deployment without the need for a complex distribution infrastructure, SUNRISE will provide decoupling of the economic activity from fossil resources in smart cities.

The targets for hydrogen production

H_2 production by electrolysis of water (“water splitting”) is already available today, but at high economic and material costs. Developing electrolysis routes to sustainably produce H_2 is high on the agenda of European and global stakeholders, federated in the Hydrogen Council and Hydrogen Europe associations. With the overarching SUNRISE goal of optimizing land use and maximizing material efficiency, and increasing the Energy Return On Invested energy (EROI), we target the large-scale production of H_2 by light-driven water splitting using novel photo-electrochemical cell technology, as well as innovations in materials to sustainably combine solar cells and electrolyzers. Solar H_2 can be used directly as fuel, as energy carrier to produce electricity via fuel cells, as an intermediary, often necessary step towards other molecules and as feedstock for industrial processes affording ammonia and carbon-based molecules such as ethanol.
SUNRISE will set up operational systems in rural areas at the area scale of hectares, producing H_2 (> 90 ton/ha·y) across Europe and further allowing the production of 300 ton/ha.y of ethanol (or equivalent carbon based fuels), or 500 ton/ha·y of ammonia at competitive cost levels starting from 0.4 €/l and down to 0.2 €/l for liquid fuel. To accelerate development of large scale systems, we will create local testbeds based on end-user volunteers. In addition to stimulating social acceptance, these small scale test-beds will provide data for

scale-up refinements. In 2030, SUNRISE H_2 production technology will represent a giant leap forward on the way to zero-emission mobility for people and transport, and net climate neutral feedstocks and material production in urban zones through processes that are at least 80% decoupled from consumption of natural resources.

TIMELINE

2021: Engaging the public in outreach activities, such as take-home experiments and demonstration of existing H_2 technologies, to increase awareness of the benefits of, and social acceptance for, solar-to-H_2 as a viable carbon-free energy option.

2025: Development of new materials for incorporation into electrolyzers (TRL3), for connection to commercial PV modules that employ abundantly available, non-toxic, and environmentally safe elements. Development of production-near manufacturing technologies for cost-efficient and robust processing of new materials.

Development of a scalable PEC device for direct light driven water splitting at readiness level 5, for H_2 production above 15% STH efficiency. The device will utilize abundant elements and provide >1 year stability. Benchmarking will be made against PV+ electrolysis systems.

Implementation of a steam generator with heat utilization in a first demo plant for a PV-SOE system with 20% STH.

2030: Reaching 30% efficiency in solar H_2 production, in devices employing scalable and environmentally benign materials, as well as cost effective and scalable manufacturing technologies

Infrastructural and technological development for conditioning, storage and distribution or direct reuse of H_2. Integration of H_2 production plants in the landscape, community and economy, via local testbeds. Implementation of solar H_2 production at the 150 MW range (500 resp. 1000 ha range at 30 resp. 15% STH). Coupling Solar H_2 production with NH_3, ethanol and jet-fuel production at the 150 MW range (TRL 9).

4.2 AMMONIA (NH_3)

AMMONIA TODAY

Worldwide food production nowadays critically depends on the use of industrial fertilizers. Ammonia is by far the most used one,[11] almost 90% of ammonia synthesized is applied in farmland, the rest is used for the production of chemicals (organic molecules such as amines). Ammonia is produced with the Haber-Bosch process using atmospheric N_2 and H_2 produced from fossil fuels and resulting in huge CO_2 emissions. The annual global production of NH_3 is > 150 Mton, along with >220 Mtons of CO_2 waste. In addition, the supply of fertilizers is currently inefficient with less than 40% of the nitrogen supplied as fertilizer being actually taken by cultivated crops. This results in large nitrogen-based pollution, with severe negative impacts on the environment and biodiversity. The nitrogen cycle is the most unbalanced cycle in the planetary boundaries analysis.

IMPACT

The industrial ammonia production, mainly *via* the Haber-Bosch process, consumes 3-5% of the world's natural gas supply, contributing to *ca.* 3% of the global CO_2 release into the atmosphere. Photo- and/or electro-catalytic reduction of atmospheric N_2 under mild process conditions, using H_2 from water splitting, will save a substantial amount of energy and will avoid CO_2 release. The switch from centralized to distributed on-site and on-demand NH_3 production from sunlight, air and water in rural areas will also result in savings of transport and storage related costs. Through limiting the amount of unused nitrogen fertilizer, we can further reduce the impact on the environment and biodiversity, and rebalance the nitrogen cycle. Beside its major use as a fertilizer, NH_3 can play a role as hydrogen storage material[12] and fuel. Indeed, conversion of air-abundant

[11]World fertilizer trends and outlook to 2018, Food and Agriculture Organization of the United Nations, 2015

[12] Lamb, K. E., et al. (2019). "Ammonia for hydrogen storage; A review of catalytic ammonia decomposition and hydrogen separation and purification." International Journal of Hydrogen Energy 44(7): 3580-3593.

N_2 into nontoxic, safe nitrogen-based fuels such as aqueous urea ammonium nitrate, could provide comparable energy-returns to existing carbon-based fuels, but requiring lower energy for feedstock separation.[13]

THE TARGETS FOR AMMONIA PRODUCTION

Although the Haber-Bosch process now operates close to the thermodynamic limit in terms of efficiency, there is a need to develop efficient, sustainable and scalable processes that can operate at low temperature and pressure, to increase conversion. To achieve these goals, electrochemical and photo(electro)chemical catalysis are promising. A first objective will be the production of CO_2-neutral ammonia from atmospheric N_2 and solar H_2, using existing Haber-Bosch technology. On the longer run, we need to advance our understanding of biological N_2 reduction mechanism so as to first develop new homo- and heterogeneous electrocatalysts, photocatalysts and photoelectrocatalysts and then to integrate them into functional N_2 reducing systems driven by light or other renewable power. Direct and indirect (through intermediate production of solar H_2) co-(photo)electrolysis of N_2 and water should be considered.

These will allow for distributed ammonia production by converting atmospheric N_2 into NH_3 at ambient pressure and temperature. Within 10 years, SUNRISE will set up a pilot plant for decentralized solar ammonia production of 2 metric tons per day. In parallel, smaller systems will be developed, able to produce N-based fertilizers and to distribute them directly in the base of the plants in phase with culture needs.

TIMELINE

2021: production of CO_2-neutral ammonia from atmospheric N_2 and solar H_2 using existing Haber-Bosch technology.

2025: Developing electro- and photo-electrocatalysts able to convert N_2 to NH_3 (using electrochemical gas-phase conversion, photocatalytic N_2 triple bond cleavage, or any combination); Achieving selectivity between N_2 and proton reduction, using excited state properties and responsive matrixes; Ammonia synthesis prototype built for ambient condition operation (TRL 4).
Ready for operation plasma conversion prototype on a laboratory scale for the demonstration in a realistic environment.

2030: TRL6 electrochemical reactor for decentralized solar NH_3 production. The area claimed by the plant is smaller than 1 ha. The plant will produce 2 metric tons of fertilizer per day so that an agricultural area of 100 km^2 can be supplied with fertilizer with a density of 25 pound fertilizer per acre per year.
Autonomous solar-driven devices for decentralized (at the plant foot, in fields) NH_3 production for precision agriculture (TRL 5).

4.3 CARBON-BASED MOLECULES (CN) PRODUCED FROM CO_2

ARTIFICIAL CO_2 FIXATION TODAY

Low TRL technologies exist to turn CO_2 into carbon monoxide (CO) or formic acid with solar to chemical energy efficiency (STC) over 10%. Some catalysts are efficient and durable, but show a poor selectivity of products, except for CO and formic acid. Combining CO with H_2, or high-temperature co-electrolysis of CO_2 and water in SOE, produces syngas from which Fischer-Tropsch synthesis can be performed. Meanwhile electrolytic H_2 is being reacted with captured CO_2 in the thermo-catalyzed Sabatier process to yield methane. Molecules with two or more carbon atoms remain a challenge in (photo)-electrochemistry, as for Faradaic efficiency, selectivity and stability, although recent breakthroughs have been achieved for direct ethanol and ethylene electrocatalytic production from CO_2.[14] Very few complete laboratory demonstrators have been reported. Reliable technologies have been developed to capture CO_2 from industrial flue gas, or directly from the air (DAC), but have so far not been combined with (photo)-electrochemical processes. By contrast, photosynthetic organisms can directly extract CO_2 from their environment, and photobiological processes exist for the production of alcohols, terpenes, jet fuels and high-value organic molecules that can be used as precursors for the synthesis of polymers and fine chemicals, including aromatics that can hardly be produced

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[13] Grinberg Dana, A.; Elishav, O.; Bardow, A.; Shter, G. E.; Grader, G. S., Nitrogen-Based Fuels: A Power-to-Fuel-to-Power Analysis. *Angew. Chem. Int. Ed.* **2016,** *55,* 8798-805.
[14] De Luna et al, *Science*, **2019**, *364*, 350

by heterogeneous catalysis. Hypotheses exist to enhance CO_2 conversion into molecules of interest in phototrophs exploiting microbial CCM (carbon concentrating mechanisms), increasing at the same time photobiological-driven CO_2 sequestering.

IMPACT

SUNRISE will provide carbon-based liquid fuels for jets and internal combustion engines (ICE) as the sole solution for a CO_2-neutral development of long distance air and sea transportation. 72% of the European population lives in urban areas that cover 17% of the surface, 4% cities and 13% towns and suburbs.[15] The high yield solar-driven chemistry provided by SUNRISE will facilitate the full decoupling of the economic activity from natural resource consumption in smart cities. This will be a game changer in the decarbonization of Europe and its industry. New chemical synthesis routes will permit the transition towards CO_2-neutral biodegradable or environment-friendly materials, namely plastic substitutes and reinforcement fibers. Incorporation of carbon / CO_2 in building materials (artificial wood) able to store it for decades or even centuries, is indeed a main industrial concern, *e.g.* in the Cement industry. These are high on today's European agenda, with key European initiatives on the industrial side: Phoenix and the low carbon industry Strategic Value Chain worked out under European Commission leadership.

TARGETS FOR ARTIFICIAL CO_2 FIXATION

Carbon capture

SUNRISE will bring the energy efficiency to 70% of the thermodynamic limit at an affordable cost, by coupling DAC technologies with (photo)electrochemical conversion. By merging functions of electrodes or membranes with adsorbent materials needed to concentrate CO_2, we will cut losses for achieving a better economical and energetic yield.

Fuels, chemicals and materials

Although e-mobility and H_2-mobility are anticipated to take a large share of transport decarbonization, the availability of sustainable carbon-based fuels is considered indispensable for a CO_2 neutral long distance and aviation-based transportation system. ICE and jet fuels are priorities. Fuels for aviation will be obtained from biotechnological processes in the short to mid-term range, and later from a combination of solar-driven syngas production and Fisher-Tropsch processes. ICE fuels (*e.g.* ethanol) will be obtained either from (photo)electrochemical processes or via intermediate solar H_2.
Regarding commodity chemicals, ethylene should be obtained (photo)electrochemically, while synthetic biology is better fit to yield larger alkene derivatives, aromatics and synthons for *e.g.* biodegradable plastic substitutes and CO_2-storing building materials.

TIMELINE

In 2021, the result of "Fuel from the Sun" Horizon Prize will be known and used to refine the CO_2 to chemicals strategy.
2021: analysis of DAC technologies integration with SUNRISE electro- and photoelectrochemical approaches.

2025: Enhanced jet fuel production by biotechnological processes assisted by synthetic biology approaches, on the ha range with 40 tons/ha/y production target.
All-integrated PV+electrolyser for co-electrolysis of CO_2 and water, delivering liquid fuels/chemicals with a 15% STC efficiency.
The devices shall use flue gas from the industry, potentially the cement industry.

2030: deployment of 2025 device on the 150 MW scale (1000 ha at 15% STC), including DAC. This kind of devices will reach TRL 5-7 by 2030.
Reliable perspectives of large scale deployment shall be obtained, with anticipated price of this liquid commodities under 500 €/ ton. (about 0.4 €/l).

[15] https://www.pbl.nl/sites/default/files/cms/publicaties/PBL-2016-Cities-in-Europe-2469.pdf

A SUMMARY OF SUNRISE GOALS BY 2030

The complete replacement of fossil fuels as the main energy and chemistry feedstock represents a paradigm shift that will require decades to be fully accomplished. In the next 25 to 50 years, mankind can make the transition to a system of technologies that will transform CO_2, H_2O, N_2, and O_2 into fuels and commodity chemicals, using sunlight as the only energy source. This process will radically alter the existing paradigms of industrial production and energy transformation and usage.

In order to kick-start this epochal transition of the industrial society and the global economy, the first ten years (2020–2030) are crucial, due to the need for a substantial acceleration in technological development[2]. In terms of science and technology, SUNRISE will make Europe the global leader of this decade-long process by coordinating human resources, research infrastructure, and industrial know-how across the continent to accomplish the following goals by 2030:

- The use of CO_2, H_2O, N_2 and O_2, as feedstock to deploy solar energy converters that produce fuels (*e.g.* methane, ethanol, jet-fuels), synthesis gas (CO and H_2), commodity chemicals (*e.g.* ethylene, ammonia and biodegradable synthons for the plastic industry) and high-value chemicals at a groundbreaking level of over 100 ton/ha per year.
- The conversion of up to 2500 ton/ha per year of CO_2, depending on the molecular species and latitude, into the cyclic economic system.
- The enabling CO_2 mitigation strategies beyond 2050, when direct solar energy converters with a tenfold to hundredfold energy gain over the current biomass practice will be deployed worldwide on the TW scale for a negative-emission Earth system. This will allow for the production of long-lasting carbon based materials (*e.g.* ‘artificial wood’) for long-term carbon storage.

The key targets of SUNRISE on a 10-year timescale (and beyond) are:

2023: Seasonal storage demonstrated (*e.g.* a PV field >15 kW with e-fuel conversion) with solar to chemical energy conversion better than 15%

2025: Demonstrator at a scale of > 1 MW to provide an urban environment with 10% of its energy in sustainable form, with CO_2 neutrality.

2027: Demonstration of 80% circularity at the regional level with artificial photosynthetic technologies for industrial feedstock, products and processes

2029: Negative emission technologies for carbon capture and utilization (CCU) and sustainable ethanol production on the industrial scale (i.e., with concentration to the MW level)

2030: 1000 ha (>150 MW) scale of SUNRISE technologies for liquid fuels production for, e.g., air transportation.
Decentralized and CO_2-neutral ammonia fertilizer production for precision farming.

On a longer timescale, from 2030 to 2050, SUNRISE aims at a CO_2-neutral economy with affordable negative emissions technologies on a significant scale.

5. SUNRISE Goals and approaches

[*This section contains a detailed presentation of SUNRISE approaches, already introduced in §2.2*]

A realistic approach to SUNRISE's ambitious goals requires a thorough examination of the flux of solar photons that reach the Earth's surface and of the potential chemical conversion yields of these photons. Global irradiance on the ground varies continuously around an average value of 150 W/m^2 (mid-latitude average value: 180 W/m^2 see Fig. 7) depending on time, meteorological conditions, geographical location, and seasons. **The limits for candidate energy carriers are shown in Table 2, listing common half reactions starting from H_2, CO_2, and N_2.** Estimates for CO_2 conversion and fuel production are obtained under the following assumptions: (a) systems absorbing 90% of the photons and converting 80% into products (SUNRISE target); (b) two photons per electron transfer; and (c) maxima and minima based on average annual solar irradiation in Malaga (Spain) and Stockholm (Sweden), respectively. The realization of such targets on the hectare scale in rural areas or on a smaller scale in urban zones requires radical new concepts and tandem devices that operate on a laboratory scale with a photochemical current of 16 mA/cm^2 under AM 1.5 irradiation. The half reaction n · (CO_2 + $4H^+$ + $4e^-$) → carbohydrates + n · H_2O also includes natural photosynthesis, with the additional restriction that it only uses half of the photons over the photosynthetically active region (PAR). Optimized biomass practice with *Beta vulgaris* L. (sugar beet)

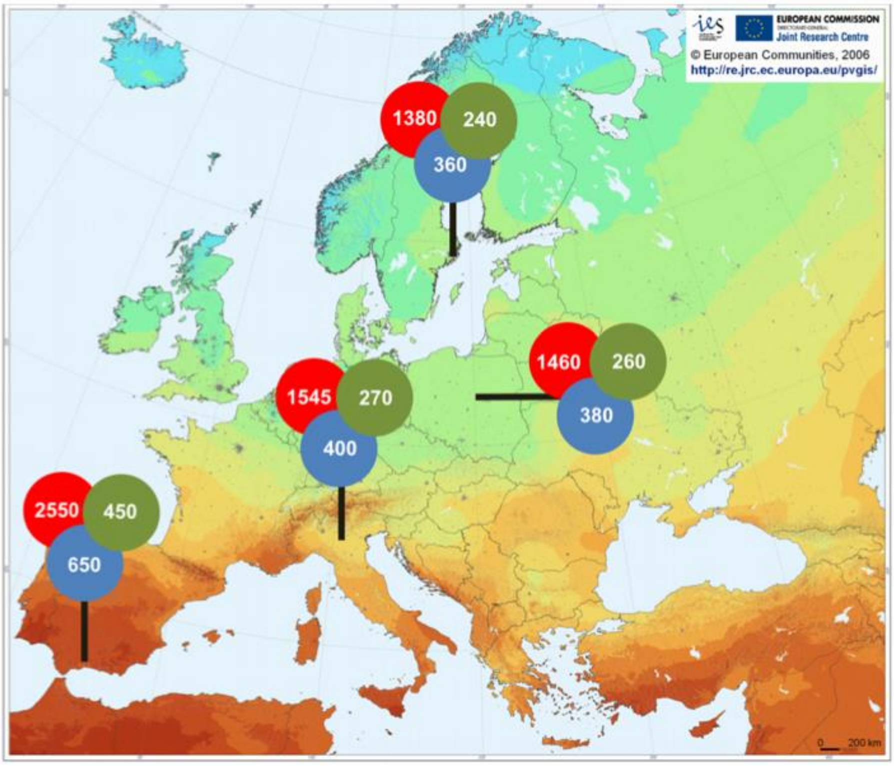

Fig. 7 European solar irradiation map. For selected cities at different latitudes (Malaga, Piacenza, Warsaw, Stockholm) **the maximum potential for CO_2 conversion is shown in red circles**, together with the estimated production (per hectare and year) of a sustainable fuel (ethanol: green circles) or chemical (ammonia: blue circles). A two-electron process is assumed, consuming two photons per excited electron, 90% photon absorption efficiency and 80% chemical conversion efficiency. Radiation data for individual cities are taken from http://wrdc.mgo.rssi.ru.

Table 2. Selected half reactions for the conversion of CO_2, H^+ and N_2 into chemicals and fuels. Minima and maxima refer to European regions with low and high annual solar irradiation. For details and assumptions made, see text.

Reaction	**Conversion rate AM1.5** [µmol $cm^{-2}s^{-1}$]	**CO_2 conversion potential** [tons ha^{-1} y^{-1}]	**Fuel/chemical production potential** [tons ha^{-1} y^{-1}]
$2H^+ + 2e^- \rightarrow H_2$	0.086	-	52 - 130
$CO_2 + 2H^+ + 2e^- \rightarrow HCOOH$	0.086	1120 - 2800	1182 - 2956
$CO_2 + 2H^+ + 2e^- \rightarrow CO + H_2O$	0.086	1120 - 2800	720 - 1799
$CO_2 + 4H^+ + 4e^- \rightarrow H_2CO + H_2O$	0.043	560 - 1400	386 - 964
$CO_2 + 6H^+ + 6e^- \rightarrow CH_3OH + H_2O$	0.029	378 - 945	274 - 686
$CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$	0.022	280 - 700	103 - 257
$2CO_2 + 12H^+ + 12e^- \rightarrow CH_3CH_2OH + 3H_2O$	0.014	378 - 945	197 - 494
$N_2 + 6 H^+ + 6 e^- \rightarrow 2 NH_3$	0.029	-	308 - 772

currently produces around 8 tons/ha of sugar and 5 tons/ha of ethanol annually through the direct conversion of atmospheric CO_2 to sucrose.

5.1 SUNRISE GOALS

The three SUNRISE Goals are: (1) the provision of sustainable **fuels** from renewable energy (solar fuels); (2) the synthesis of commodity **chemicals** from renewable energy (solar chemicals); (3) the development of efficient methods to **recycle CO_2** from the atmosphere (long term, 2050) (see Table 1). To fulfil these objectives, SUNRISE will pursue three Approaches beyond their current technological limitations, taking into account key bottlenecks such as EROI and the availability and durability of critical materials, warranting their scale-up at an affordable cost for materials and the Earth's surface. This synergistic approach gives SUNRISE an edge over the competition both within Europe and on a global level.

Table 1. Overview of SUNRISE Approaches and Goals. Present TRL levels are indicated. SUNRISE's ambition is to achieve TRL 9 for fuels and chemicals and at least 7 for CO_2 removal. [*repetition of Table 1 in §2.2*]

Approach	Present TRLs		
	Goal 1 Fuels	**Goal 2 Chemicals**	**Goal 3 CO_2 extraction and storage**
4. **Electrochemical conversion with renewable power** fuels and commodity chemicals from CO_2, H_2O, O_2, and N_2	**3-8**	**2-4**	**0-3**
5. **Direct conversion *via* photoelectrochemical systems** fuels and chemicals from CO_2, … N_2 and direct solar energy	**2-4**	**0-3**	**0-3**
6. **Direct conversion *via* biological and biohybrid systems** unconventional methodology for photochemical conversion of atmospheric CO_2 with high yields	**2-4**	**3-5**	**0-3**

5.2 SUNRISE APPROACHES

As summarized in Table 1, SUNRISE will address its goals across all TRLs using three Approaches.

APPROACH 1 – ELECTROCHEMICAL CONVERSION WITH RENEWABLE POWER

The fastest-growing electricity generation technologies are photovoltaic (PV) and wind power, with price expectations below 0.03 €/kWh for the foreseeable future (IHS Markit, Aug 2018). However, this input must be integrated into the existing energy system, alongside distributed and dynamic chemical energy storage, with large-scale electrocatalysis providing a mature technology that can be rapidly implemented.

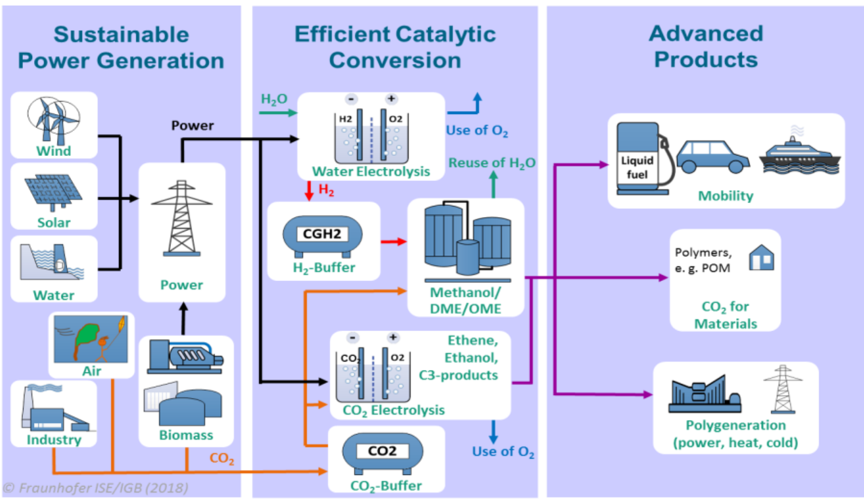

Fig. 8 The process chain for renewable power to hydrocarbons.

State of the art. Demonstration plants for power-to-hydrogen, power-to-gas, or power-to-liquid fuels by means of water electrolysis and subsequent thermal catalytic hydrogenation (*e.g.* Fischer–Tropsch) are currently being built on the MW scale; Fig. 8 schematically illustrates some examples. The energy conversion efficiency of commercial PV+electrolysis technology that can be deployed over large scale area is as high as 10%, using *e.g.* high-pressure electrolyzers and hybrid Si-based heterojunction solar panels. The cost for H_2 produced by a standalone PV+E system today has been estimated to about USD 10 kg^{-1}, ten times higher than the price of H_2 obtained by steam reforming natural gas, and twice the price of H_2 at a car fuelling station. The direct electrocatalytic conversion of CO_2 with Earth-abundant metals is a promising option that at present is at the lab research stage for both high-temperature (solid-oxide) and low-temperature (aqueous electrolyte and membrane-based) devices. The cost of electrolysis driven by intermittent power sources, with subsequent low-pressure CO_2 hydrogenation, is currently too high to be considered for practical use.

To make solar-to-H_2 and solar-to-fuels an economically attractive as well as environmentally and socially sustainable solution, SUNRISE will increase the energy conversion efficiency to 30% STH, in conjunction with lowered material and production costs by upcycling of waste streams. We will then showcase a system of distributed industrial production for a circular transaction economy, where value is created locally from CO_2 valorisation with an energy source characterized by distributed ownership (solar electricity) for industrial competitiveness. Already existing pilot plants will be taken as success stories to push the power-to-X technologies to the highest TRLs. Complementary to the existing processes, the gap of the production of jet fuels will be closed by the installation of the first of its kind demo plant using syngas or methanol as intermediates. We will also develop currently low-TRL electrocatalytic technologies for the synthesis of ethylene, propylene or ethanol from CO_2.[16] Developing such new processes represents a real opportunity for targeting chemicals with minimized impact on the environment. They will use concentrated electricity with CO_2 from point sources or PV coupled with Direct Air Capture technology. The development of CO_2 capture technologies that tcan be directly integrated in electrochemical devices is another research direction that will be followed within SUNRISE. Finally, ammonia synthesis (Haber-Bosch process) uses 1-2% of the global energy supply and contributes to *ca.* 3% of the global CO_2 release into the atmosphere to sustain agricultural crop yield. With electrochemical technologies for nitrogen fixation, fertilisers can be produced locally, lowering the costs and risks associated with transportation of large volumes, and providing solutions to limiting the amount of unused nitrogen fertilizer to rebalance the nitrogen cycle. Combined with CO_2 activation processes, the electrochemical production of N-based chemicals as well as N-rich polymers and materials will be made possible.

Table of problems and solutions for approach 1

Bottlenecks	**Research opportunities**
Finding stable and abundantly available low cost catalysts for the water oxidation reaction. Key specification is the resistance to oxidative and acidic degradation[17]	Alternative catalysts resistant to oxidative degradation (*e.g.* siloxanes, phosphates, polyoxometalates, and other main group oxides) will be used, supported by **HPC**, **machine learning, and multi-scale modelling**. Molecular knowledge (**bioinspiration**) will be transferred to materials science to integrate active catalytic sites within stable frameworks.
Development of selective and stable catalysts for multi-electron/multi-proton reductive processes for direct CO_2 reduction and N_2 fixation Tolerance of electrocatalysts to contaminated CO_2-feeds	**High-throughput screening** to discover materials coupled with experimental studies of **catalyst design** and function, thus opening up radical new avenues of electrocatalytic production for a whole range of platform products. Understanding degradation mechanisms (*e.g.* by **multi-scale modelling**). Strategies such as catalyst redeposition must be developed to keep the structure active. Develop **smart matrices** that can orient the selectivity and insure long-term stability as well as provide tolerance to O_2 and other impurities/poisons.

[16] Kätelhön et al. Proc. Natl. Acad. Sci. U. S. A. 2019, DOI: 10.1073/pnas.1821029116
[17] Z. Seh *et al., Science* **2017**, *355*, 146.

Scaling Solid Oxide Electrolyzers to MW size (*e.g.* limited reliability of cells leading to rejects in fabrication as well as failure in operation; cell performance enhancement necessary to minimize losses and required quantities of cells, thus, reducing cost; long term operation limited due to degradation by, *e.g.* catalyst migration, delamination…) requires producing several m2 of active area with high reliability cost-efficient production/stacking technology as well as low-cost housing materials	Increasing fracture strength and/or toughness by advanced materials, *e.g.* fiber-reinforcement, as well as utilizing proven mass scalable production technology being cost-efficient, *e.g.* tape casting, screen printing, deep-drawing, punching. **High-throughput screening** to discover high-performance materials with improved stability and tailored microstructures in order to improve performance, *e.g.* low electrolyte layer thicknesses, high electrode active surface areas. Understanding degradation mechanisms (*e.g.* by multi-scale modelling) and develop improved materials with low degradation and low contact resistance improving long-term performance.
Capital expenditure of electrolysers (> 500 €/kW) are above the permitted range	Reduction of costs by material engineering towards cheap BOM (bill of materials) through the development of novel materials (*e.g.* ion-conducting membranes, catalysts) and novel architectures optimized by device simulation.
Tolerance of catalysts for thermal reduction of CO_2 to feedstocks towards O_2 and H_2O, improving selectivity	Structure–conversion correlations will be established by advanced structural and mechanistic analysis and catalytic characterization assisted by **multi-scale modelling** from the atomic scale to mass transport phenomena in order to enhance product selectivity in, for example, Fischer–Tropsch-type processes.
Low turnover/volume ratio of gas diffusion electrode-based CO_2 and N_2 electrolysers	**Design and simulation** work will lead to scaling relationships being broken and higher currents being yielded (*e.g.* > 1A/cm^2) through alternative structural design, thus enabling, for example, a forced CO_2 feed to the catalyst.
Electrolysis of diluted CO_2-feeds	Develop **smart matrices** that can adsorb CO_2 selectively (separation from O_2) and drive it to catalytic centers;.Develop **novel electrolysers** integrating CO_2-capture and conversion in one reactor. **Redesign the materials systems of catalytic layers** to implement CO_2-reducing catalysts with conductive support, ionomer for proton transport and channels for substrate/product transport.
Electrification of fine chemical synthesis (further conversion of bulk chemicals)	**Develop and Design of new electrosynthetic processes** to allow the further conversion of synthesised bulk chemicals for the production of various fine chemicals, pharmaceuticals, agro chemicals, etc.

APPROACH 2 – DIRECT CONVERSION VIA INTEGRATED ARTIFICIAL PHOTOSYNTHETIC SYSTEMS

SUNRISE pursues an ambitious vision of artificial photosynthesis becoming a truly disruptive technology to displace fossil fuels. Plant leaves and microalgae use sunlight to convert CO_2 into carbohydrates on the Gt scale every year with two photosystems acting in tandem. Direct solar conversion, often referred to as artificial photosynthesis, mimics this process in dual band gap nano(bio)structures (Fig. 9), combining and hybridizing the best knowledge of biological, molecular, and materials sciences. Approach 2 aims to develop such integrated photoelectrocatalytic arrays to enable disruptive technologies for renewable fuel and chemical synthesis from photoexcited states of materials and/or (bio)molecular material , thus directly driving catalytic transformations. This is potentially more efficient than the PV + electro(cata)lysis scheme developed in Approach 1. Classic electrochemical approaches use electricity as a reactant near chemical equilibrium with the excited state of the semiconductors in a solar panel, thus limiting the conversion efficiency. In Approach 2, the catalyst directly extracts charge carriers from the excited state of the photosensitizer to achieve multi-electron/multi-proton chemical conversion. A cascade of redox processes enhances quantum efficiency by separating charge carriers in space, thereby preventing recombination pathways. In other words, the entropy changes for the two (PV and electrolysis) steps are combined in the photoelectrochemical device to minimize losses, and the entropy can be used for the release of gaseous products such as O_2, H_2 or CO. This opens up the potential for high performance by high yield and overcoming intermittency of renewable energy input.

This leads to lower materials and systems costs than for Approach 1, which thus leads to better capital and energy return on investment.

In order to reach the high operational level of systems with 90% absorption and 80% conversion, SUNRISE proposes developing artificial photosynthetic technologies employing two tandem photosystems that will combine designed (supra)(bio)molecular and/or nanoscopic structures, aided by photon-management systems to maximize light harvesting. Natural photosynthesis is highly compartmentalized occurring in integrated multifunctional units that are composed of organized protein-based pigments, redox and catalytic cofactors. Such "quantasomes" are then multiplicated in photosynthetic membranes.[18] Exploiting photoactive biological membranes or component or applying the quantasome concept to artificial photosynthesis is a highly promising way to overcome the low efficiency and limited (photo)stability bottlenecks of existing model systems. Artificial quantasomes to be developed in SUNRISE will exploit recently discovered physical phenomena and emerging concepts of efficient light-harvesting, excitation energy transport, as well as ultrafast and directional charge separation by vibration-assisted coherent evolution of reactants into products and coupling between structural and electronic dynamics, plasmonic light-absorption enhancement and reactivity (plasmonic catalysis), quantum electrodynamic effects in cavities (strong photon coupling). In natural photosynthesis, light-activation of proteins is structurally controlled and the primary charge separation occurs as an ultrafast directional process with a near-unity efficiency owing to coherent coupling with vibrations of the protein matrix.[19] Dynamic matrix response also directs electron transfer, stabilizes redox intermediates, drives charge separation to completion and prevents unproductive charge recombination. Driving photochemical reactions in a lossless non-adiabatic process converts energy with near-unity yield.[20] Vibration-induced delocalization between optically excited and charge-transfer states was also observed in synthetic materials.[21] Coupling between the charge-separation process and dynamic matrix response emerges as a promising design principle (Fig. 10).[22] Developing new selective catalytic sites for substrate (H_2O, CO_2, N_2) reduction and coupled water oxidation, and their integration into photosynthetic membranes or artificial quantasomes will be essential, together with designing interfaces and couplings between the active components. Combining the quantasome and responsive matrix concepts in designing artificial photosynthesis systems will integrate the three fundamental losses of photocatalysis (originating from charge recombination, driving catalysis of product formation, and O_2 in only one potential loss. To achieve high efficiency, the primary light harvesting and ensuing charge separation need to be ultrafast; and the *de novo* design of supramolecular as well as inorganic responsive matrices and quantasomes is a formidable challenge and a key goal of the SUNRISE initiative.

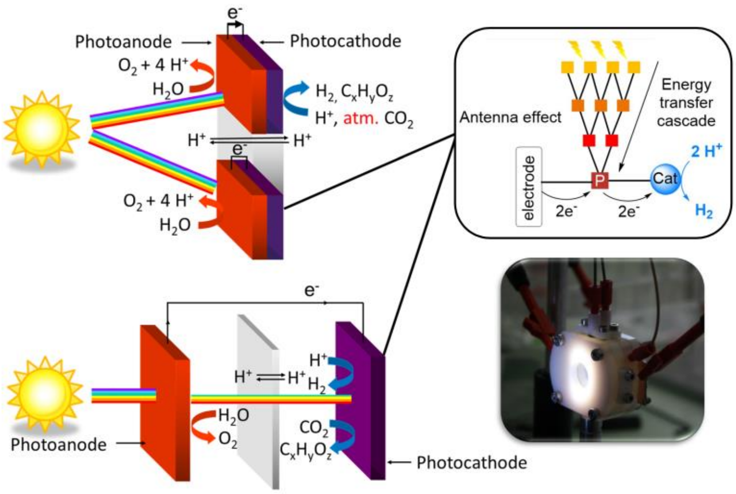

Fig. 9 Schemes of possible architectures of tandem photoelectrochemical cells for solar fuel and solar chemical production. The inset exemplifies light harvesting with antenna effect, charge separation at the photosensitizer (P), and catalytic conversion in the case of H_2 evolution (Source: CEA)

[18] Emerson, R.; Arnold, W. The Photochemical Reaction in Photosynthesis J. Gen. Physiol. Emerson and Arnold: The Photochemical Reaction in Photosynthesis 1932, 16, 191-205 and Park, R.B.; Biggins, J. Quantasome: Size and Composition Science 1964, 144, 1009-1011.

[19] Romero, E. *et al*. *Nature* **2017**, *543*, 355.

[20] T. J. Eisenmayer *et al., J. Phys. Chem B* **2013**, *117*, 11162; D. Polli *et al.*, *Nature*, **2010**, *467*, 440

[21] Falke, S.M. *et al*. *Science* **2014**, *344*, 1001

[22] Bredas, J.-L. *Nat. Mat.* **2016**, *16*, 35.

State of the art. The general idea of a compact, integrated device is an important driving force in the development towards sustainable solar-to-fuels. Direct solar-to-H_2 systems, including unbiased photoelectrochemical (PEC) cells, nanoparticle systems, and integrated PV-catalyst devices (so-called 'artificial leaves') have been demonstrated as lab-scale devices, with diverse materials and device architectures.[23] Semiconductor heterostructures and nanowire arrays for light-harvesting and charge separation have been integrated with catalysts for water oxidation and H_2 generation, and in some cases CO_2 reduction. Active photobioelectrodes combining biological light-harvesting modules with enzyme variant or synthetic catalysts have been reported. An artificial quantasome has been made and its water-oxidation demonstrated.[24] Many systems (such as photosensitized electrodes) operate well under diffuse light, making them suitable for mid- and northern latitudes of Europe. Enhancing light-harvesting efficiency by applying newly recognized physical concepts such as plasmonics, singlet fission, upconversion, and strong photon-matter coupling is currently an important direction of fundamental research in chemical physics. It is recognized that nano-structuring can improve light-capture and electron/hole collection efficiency. Low efficiency, which is sometimes caused by limited stability under solar irradiation, appears to be the main bottleneck of current systems of direct solar-to-fuels conversion. Many of the current challenges are similar between monolithic PV-catalyst and PEC solutions, such as achieving long-term catalyst stability, and tailoring the bandgap energies of the semiconductors/molecular photosensitizers used to both maximise solar utilization and operate at sufficient over-potential for catalysis to occur. The challenge of preventing recombination of charged intermediates in multi-electron photocatalysis is a specific challenge for PEC devices. Lab-scale demonstrations of monolithic PV-catalyst devices have currently reached close to 20% solar-to-hydrogen (STH) energy conversion efficiency in non-concentrated sunlight, albeit by utilizing rare and/or toxic elements, and materials that require expensive production processes.

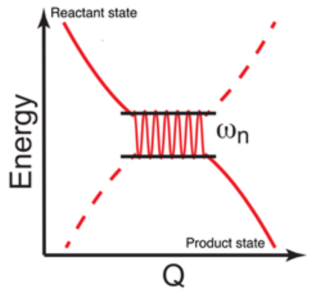

Fig. 10 Responsive matrices are chemically programmed for the high-yield conversion of reactants by conformational twisting along a quantum reaction coordinate (Q). An energy gradient drives the system through a conical intersection by means of a non-adiabatic (*i.e.* quantum coherent vibronic) process. Such reactions go beyond the Born–Oppenheimer characteristics of classic adiabatic photoelectrochemistry and (photo)catalysis.

In the SUNRISE project, we will change this situation by tailoring catalytic sites in advanced photoactive inorganic and supra(bio)molecular nanostructures exploiting or mimicking the functional compartmentalization of natural systems and optimizing the interfaces between light-harvesting, charge separation, and catalytic modules. Bottom-up supramolecular engineering of natural and artificial photosynthetic assemblies will be the key enabling technology in SUNRISE for developing the next-generation efficient solar-to-fuels energy conversion processes and systems. To achieve this, a robust function-based system engineering framework will be established for the design of artificial biomimetic systems that will aid in handling cross-scale models, identifying control points, and predicting system-wide effects of molecular components.

The research will be based on three guiding principles: (i) the integrated quantasome concept, (ii) vibration-assisted charge separation and transport involving coherence in responsive matrices, and (iii) kinetics synchronization and optimization between light harvesting, charge separation, charge-carrier transport, and catalytic conversion across interfaces. Semiconductor-based nanostructured photoelectrochemical systems (buried junctions, dye-sensitized n- and p- photoelectrodes coupled with catalytic sites…) will be developed as well, following similar design principles and sharing some of the catalytic units. The search for new materials will be guided by the computational and experimental screening of different elemental compositions. Semiconductor and catalyst development will be conducted in synergy with Approach 1, with the key challenge for Approach 2 being their integration.

SUNRISE will also consider enhancing light harvesting efficiency by employing newly emerging aspects of light–matter interactions: plasmonic enhancement of light absorption across the solar spectrum, singlet fission (to utilize high-energy solar photons while minimizing thermalization losses), up-conversion (to utilize

[23] C.R. Cox *et al.*, *PNAS* **2014**, *111*, 14057; D. Jia *et al.*, *Nat. Commun.* **2016**, *7*, 13237; Q. Wang *et al.*, *Nat. Mater.* **2016**, *15*, 611
[24] Bonchio, M. *et al. Nat. Chem.* **2019**, *11*, 146

abundant low-energy solar photons), and the strong photon coupling regime (polariton formation in cavities) to facilitate light harvesting over antenna systems by accelerating excitation-energy transfer to reaction centers. Coupling between electron transfer and matrix dynamics will be utilized to accelerate and direct the initial charge separation and charge-carrier transport to catalytic sites (coherence-driven and nonergodic electron transfer). Photosynthetic systems will be kinetically optimized, while minimizing recombination reactions that both limit the performance and can lead to material degradation. Improved stability will thus be an emerging property of the device. Integration of active components into functional compartmentalized units (quantasomes) will be a challenge requiring us to design active interfaces to provide controlled electronic coupling, proton transfer, and mass transport (reactants, products).

Bioinspiration will be the key driver of Approach 2. We will target materials, which (*i*) are based on Earth-abundant elements, for reasons of cost-effectiveness and possible global upscaling, (*ii*) have catalytic sites with very few metal ions (in comparison, only a small fraction of metal atoms in nanoparticle catalysts are surface-exposed and thus catalytically active), (*iii*) are highly selective and efficient in terms of energy conversion, and (*iv*) operate under ambient temperature and pressure conditions in aqueous media, thus reducing the environmental impact of manufacturing processes (*i.e.* green, safe processing).[25] Biomimicry of the active sites of metalloenzymes (hydrogenases, dehydrogenases, nitrogenases, laccases, *etc*.) will be used to design new catalysts for multi-electron/multi-proton reactions such as CO_2, O_2 water, and N_2 activation. (Supra)molecular and inorganic nanoparticle catalysts will be used, in combination with hybrid "matrices" and membranes, building on the current state of the art to control light-harvesting, charge separation, and catalysis. Photoactive bio-components (isolated photosynthetic reaction centers, photosynthetic membranes, redox cofactors) will be assembled with enzymes and synthetic catalysts in hybrid structures to enhance direct conversion processes. Photodriven catalytic protein systems ("photoenzymes"), which will combine photoreducing (or photooxidizing) and catalytic sites within a protein matrix will be investigated, developed, and explored. Mutants of natural redox proteins and enzymes with increased functionalities as well as *de novo* protein platforms, will be combined with photosensitizers or biological light-harvesting modules. Such artificial systems will allow for the efficient coupling of light harvesting and catalysis as well as the rapid separation of the products. Proteins also appear to be the first choice for responsive matrices, together with synthetic supramolecules, hybrid or inorganic membranes, and polymers. QM/MM/MD simulations and materials-oriented HPC will aid predicting functional materials, photoenzymes, and their assembling in artificial quantasomes. SUNRISE will also study and explore self-assembly, self-repair, and regulation of photosynthetic assemblies to gain a better understanding of how they create energy gradients, boost catalysis, and maintain integrity. These accomplishments will enhance efficiency (improvement of light-harvesting properties, optimization of electronic connection between photosensitizer and catalyst) and also address stability (development of smart matrices and protective coatings, disarming of triplet states and reactive oxygen species, and self-repair/self-healing mechanisms). Resulting functional direct-conversion devices will most probably be hybrid systems combining supra(bio)molecular quantasomes with nanostructured materials (semiconductors, 2D-materials, possibly 3D covalent organic frameworks and metal-organic frameworks), and/or with novel systems obtained through synthetic biology.

H_2O and CO_2 will be used as feedstocks for artificial photosynthetic systems, producing hydrogen, methane or syngas as 1st generation solar fuels and formic acid as 1st generation solar chemicals. Water oxidation should be coupled with fuel production, while alternative oxidative processes will be developed for the production of commodity chemicals (*e.g.* H_2O_2, epoxides) Based on the progress made in Approach 1, we will subsequently develop artificial photosynthetic systems that produce more complex solar fuels, solar commodity chemicals (*e.g.* ethylene, ammonia), and high-value compounds. This will align with recent advances with respect to photoredox catalysis in synthetic organic chemistry and will drive the transition to more sustainable, minimal waste, and circular chemical manufacturing processes.

[25] V. Artero, *Nat. Energy* **2017**, *2*, 17131.

In terms of the technological readiness, further development and integration with Approach 1 – systems into single photosynthetic units (buried junctions, sensitized photoelectrocatalysis) can be developed into applicable stage (TRL 6-8) within the next 10 years. *De novo* (*i.e.* contingent) systems engineering with bioinspired (bio)molecular-based modules utilizing the quantasome concept and novel physical principles to facilitate light harvesting, charge separation and transport present a major scientific and technological challenge and will lead to the next generation of artificial photosynthesis. TRL 4-5 is achievable in 10 years, provided that the corresponding development is supported by a critical mass of fundamental work that is genuinely cross-disciplinary across biology, chemistry and physics.

Table of problems and solutions for approach 2

Bottleneck	Research opportunities
Low conversion efficiency and stability of direct-conversion systems	1) Increase light harvesting efficiency, charge-separation and catalytic conversion yields by biomimicry and employing new physical concepts (coherence, responsive matrices, singlet fission and upconversion plasmonic, strong photon coupling) 2) Apply the quantasome concept to integrate light-harvesting, charge-separating, and catalytic sites, organized and responsive matrices in functional units 3) Enhance inherent robustness by facilitating productive steps, combine with self-repair processes.
Sunlight harvesting not sufficient in meeting the 90% absorption target across the relevant part of the solar spectrum	- Photon management in photosynthetic systems: singlet fission and NIR photon upconversion to utilize high- and low energy solar photons, plasmonics to enhance absorption in visible region -exploit biological light-harvesting modules with increased absorption cross-section - Multichromophoric antennas, use delocalized excitons - Facilitate excitation-energy collection and its channeling to charge-separating sites or heterojunctions by employing strong light-matter interactions (polaritons) - Spectrum-splitting ("Z-scheme" systems).
Inefficient charge-separation due to: - charge recombination - side reactions, charge trapping, excited-state decay - kinetics mismatch between charge transport and catalytic conversion	"Electron transfer beyond Marcus theory": - Utilizing hot excited states - Coupling electron transfer with matrix dynamics: nonergodic electron transfer, non-adiabatic conversion by adiabatic passage (NCAP), polaron-stabilization of charge-separated states - Coherence-driven electron transfer (directing and accelerating) - Charge separation directly from excited light-absorbers (avoiding antenna-to-reaction center energy transfer) - Integrating charge separation and catalysis in quantasomes.
Slow catalysis, poor selectivity, catalysts cost and availability	- New catalysts capable of multielectron/multiproton transfer, charge-carrier accumulation - genome mining for novel robust enzymes - "photoenzymes": synthetic photocenters and catalytic sites in a protein matrix - Responsive matrices to fine-tune proton-coupled ET - Plasmonic catalytic or electrocatalytic systems utilizing plasmon-generated hot charge carriers and electromagnetic near-fields, integrating light absorption and catalytic action - Photochemistry of earth-abundant elements - based photosensitizers that operate at moderate pH - Controlling and optimizing traffic of substrates and products.
Recombination, at the semiconductor/catalyst interface, and in the bulk, limits efficiency	- Engineering semiconductor/catalyst interfaces to allow for rapid adaptation of catalyst potential with the Fermi level of the semiconductor - Developing electron buffer materials to induce charge accumulation at high and low electrochemical potential

	- Kinetics optimization of electron-transfer pathways between charge-separating and catalytic sites in supramolecular as well at sensitized electrode and nanoparticle interfaces -oriented immobilization and nanostructuring of photoactive and catalytic modules with respect to electrode surfaces to minimise back reactions.
Poor cofactors integration into functional systems	- Compartmentalization based on replicated quantasomes - Membrane and responsive matrix design - Engineering of electron-, proton- and energy transfer pathways between cofactors - Combining supra/bio/molecular systems with structured semiconductor surfaces, nanostructures, 3D or 2D-materials, optimizing interfacial processes - Efficient and stable grafting strategies.
Limited (photo)chemical stability	- Increasing rate and directionality of primary charge separation - Improving catalyst selectivity - Compartmentalization (employing the quantasome concept) - Self-repair mechanisms - Stabilization by interfacial charge separation at semiconductor surfaces - Build-in disarming of reactive side products (ROS, O_2 shielding, organic triplet states) for photoprotection -exploring novel robust redox enzymes (though genome mining) and genetic engineering of the existing redox enzymes to improve their stability.
Instability of semiconductors in the presence of aqueous electrolyte	- Using HPC and modelling to develop protective/passivating strategies as well as optimizing kinetic stabilization. - Implementing self-healing and optimizing kinetic stabilization.
Photocatalytic back reactions destroying the generated products	Axiomatic design (theory and application) systems engineering of smart and responsive matrix architectures with differential affinity for reactant and product.
Leaching of photoabsorbers or catalysts during operation	Developing specific matrices in all-solid-state configuration to recapture these key components from the electrolyte or implement self-healing processes.

APPROACH 3 – DIRECT CONVERSION VIA BIOLOGICAL AND BIOHYBRID SYSTEMS

SUNRISE will employ two different types of systems – biological and biohybrid– which both involve living microorganisms and are capable of direct solar energy conversion and storage. In SUNRISE, different variants of explicit biological or biohybrid systems and microbial co-cultures will be exploited.

State of the art. The photosynthetic organisms use sunlight as energy source and raw materials such as CO_2, water and/or N_2 and some mineral nutrients for synthesis of various molecules. Photosynthesis allows application of algae and cyanobacteria for industrial production of different natural products using exclusively sunlight and CO_2 (*e.g.* industrial production in Europe Ecoduna, Algaenergy, Algosource, or in Japan Euglena Co Ltd). Dozens of engineered photosynthetic organisms hosting novel synthetic production pathways and enzymes are currently available. Yet, all the available prototypes

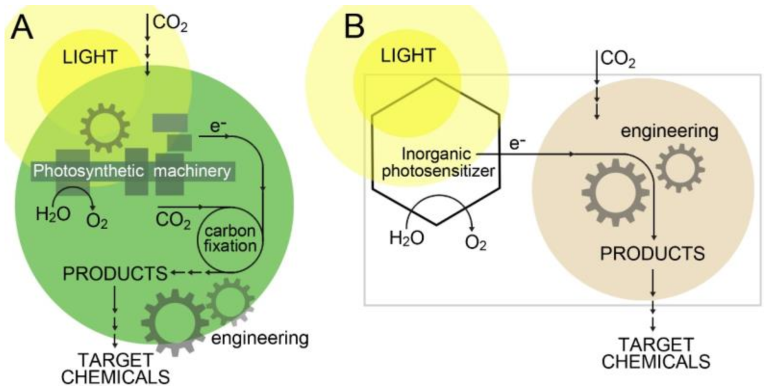

Fig. 8 Schematic representation of solar fuel and chemical production by photosynthetic microorganisms (living factories) (A) and by a biohybrid system comprising a man-made inorganic photosensitizer powering the fuel and chemical synthesis in heterotrophic bacteria (B).

have a low solar-to-chemicals conversion efficiency and need significant improvements to serve as industrial-scale production platforms. Exploitation of photosynthetic microorganisms to function as *microbial cell factories*, which catalyze the entire and direct process for production of solar fuels and chemicals, is becoming a reality along with development of strong synthetic biology technologies. Advanced and automatized synthetic biology toolboxes are currently becoming available at the advanced level for heterotrophic (non-photosynthetic) microorganisms systems (bacteria and fungi). Radical progress in development of synthetic biology tools also for photosynthetic microorganisms now opens great prospects for realisation of algal/cyanobacterial-based direct production of renewable and sustainable chemicals. Photosynthetic light-driven biotransformation by coupling specific redox enzymes (*e.g*. oxidoreductases) to light reactions provides a great potential for serving green chemistry by enabling a sustainable production of a wide range of desired bioproducts. The advantages of whole-cell biotransformation over the use of many industrial chemical catalysts, include the high selectivity, shorter synthetic routes, reduced toxic by-product formation and operation under physiological conditions. The proof-of-the concept for the ‘substrate in – product out’ photosynthetic biotransformation has been recently demonstrated, yet, the efficient and continuous platform requires further development.

The choice of the starting chassis and novel enzymes for photosynthetic cell factories is of critical importance in industrial platforms. Out of the thousands of known species of algae/cyanobacteria, only a few strains are currently being employed as a production chassis. Research must focus on *selecting robust strains* capable of high biomass yield in industrial mode of cultivation but also being equipped, with favourable metabolic characteristics.

The economic feasibility of the *microbial cell factories* technology still suffers from inherent problems of solar-based aquatic production systems, such as self-shading (leading to low light utilization and low production efficiency), excessive water consumption and requirements for energy-intensive mixing. Prolonged life time (*e.g*. avoiding the degradation of lipid reserves during the night) and optimization of secretion and separation of fuels and chemicals are also mandatory for biocatalysts to perform efficiently in photosynthetic cell factories.

There are already >> 30 successful **proof-of-concept** reports for direct production of a plethora of fuels and chemicals, including hydrogen, alcohols, diols, polyols, alka(e)nes, fatty acids, organic acids, terpenoids etc, using cyanobacteria or microalgae as host organisms. These systems and chemical production platforms will be further improved by the proposed SUNRISE technologies. Currently there are several small companies in Europe (*e.g*. Photanol) working towards SUNRISE objectives for demonstration of the economic viability of the specific direct production platforms within photosynthetic microorganisms. The technology with best production yields for specific chemicals (*e.g.* lactic acid in Photanol) is currently at TRL 4 using pilot system enclosed in a greenhouse environment, but with plans and funding to build an outdoor demo plant to run at TRL 7. SUNRISE will strongly boost the speed of increasing the TRLs of several different target production systems that now are at a proof-of-concept stage. Ongoing collaborations and joint research programmes already exist between SUNRISE and oil/ and gas companies, (*e.g*. Total) to accelerate progress on the selection and optimisation of microalgae strains for industrial application[26].

Biohybrid systems involve a material–microorganism interaction. They generally rely on the best man-made systems for solar energy conversion and provide this energy as reducing equivalents in a suitable form (*e.g.* electrons or H_2) to drive biosynthetic pathways in non-photosynthetic microorganisms, thus ensuring the direct, integrated solar-driven production of desired target chemicals and fuels. Proof-of-concept experiments were recently presented with integrated systems whereby microorganisms metabolize H_2, formed by *in situ* photoelectrochemical water splitting, to drive CO_2 fixation and production of, for example, large alcohols with promising H_2-to-alcohol conversion efficiencies. In other systems, bacteria or archaea feed directly on electrons produced by light-harvesting semiconductors and produce ammonia, methane or a variety of larger carbon compounds.

[26] https://www.total.com/en/energy-expertise/projects/bioenergies/pcv-algaeparc-qibebt-proving-and-harnessing-microalgaes-potential

In the SUNRISE project, the reducing power produced in the light reactions of photosynthetic microorganisms or in the man-made solar conversion devices of biohybrid systems will be efficiently coupled to maximize the CO_2 reduction capacity and the production of high-density, complex carbon products in microbial cells.

The biological production systems with photosynthetic microalgae or cyanobacteria as host organisms will be designed to function as living photosynthetic microbial cell factories that channel the maximum share of available resources (solar-based reducing equivalents and CO_2) for the production of target chemicals, while maintaining a minimal flux for necessary housekeeping functions and other cellular activities. Target products are either volatile or engineered to be stored in or "pumped" out of the cells in order to maintain the high-level strength of the intracellular electron sinks. Photosynthetic microbial cell factories will be designed and tailored with advanced synthetic biology tools. They will also be guided by interactive models, enabling maximal solar energy utilization for CO_2 reduction in every single cell for the high-yield synthesis of specialized products. Photosynthetic living factories will have also to grow on fresh, saline, and wastewaters, thus promoting a circular economy and ensuring a low impact on agriculture and arable land use.

SUNRISE will make use of extensive research on synthetic biology and metabolic engineering for a wide range of production pathways in model organisms, taking into consideration the holistic function of the host organisms on the production system. The project will also develop attractive industrial biotechnology platforms for direct solar energy storage in a wide range of renewable fuels and chemicals. Systems biology and physiological knowledge of cyanobacteria and green algae has significantly advanced over the past 20 years, hence SUNRISE can opt for the best strain selections and commercial production systems for its synthetic biology approaches.

Research into biohybrid systems for the direct conversion of solar energy, water and CO_2 into a wide range of products has only just begun but is highly promising if the key issues, such as long-term stability, can be resolved. SUNRISE will boost the development of biohybrid methodologies to create stable and viable bionic systems. This includes the construction of optimized interfaces between living systems and materials, solving the issues of importing non-biological material into cells, the possible impact of non-biological material on the metabolism, and the toxicity of the non-biological material for the cells.

In SUNRISE, advanced photobiological and biohybrid systems will be primarily employed for the production of complex molecules such as hydrocarbons (fatty acid, alkanes, terpenes and jet-fuels.), aromatics (as synthons for fine chemistry and production of artificial wood), and precursors for biodegradable plastic substitutes.

Table of problems and solutions for approach 3

Challenge	**Research opportunities**
Efficient production of photosynthetic reducing equivalents (Fd, NADPH, electrons and protons) and their coupling for bioproduction	Improvement of photosynthetic linear electron transport for efficient and homogeneous light harvesting and utilization in industrial-scale applications. Efficient coupling of reductants (i) with redox enzymes for a direct synthesis of targeted chemicals (including photobioproduction of H_2) *in situ* and (ii) with novel enzymes or engineered bacteria in the electrochemical devices. Minimize inhibition and damage of biocomponents.
Efficient coupling of harnessed solar energy with CO_2 reduction pathways in microorganisms and in biohybrid electrochemical devices	Enhanced carbon-concentrating mechanisms and CO_2 fixation, either by natural pathways or by introducing novel pathways by utilizing synthetic biology tools. Metabolic engineering of efficient "electron sinks", and elimination of competing metabolic pathways. Maintain a balance between production of photosynthetic reducing equivalents and ATP. Construction of optimized interfaces (on metabolic and material design level) between biocomponents and materials to ensure efficient electron transfer either via direct electron transfer or via electron mediators such as H_2. In order to achieve this an improved understanding of cathodic external electron transfer pathways and/or hydrogen metabolism is required.

Broadening the light-harvesting spectrum, optimizing light harvesting.	Utilization of sunlight across the entire PAR down to far-red region through the innovative use of natural and synthetic pigment systems. Application of plasmonics to boost functionality of (bio)catalysts. Minimize energy waste by lower useless light energy dissipating mechanisms.
Identification and selection of robust host organisms (chassis) and enzymes	Exploit biodiversity to select new strains with O_2 tolerant enzymes and enhanced robustness towards industrial productivity (enhanced biomass, NOx and SOx resistance, tolerance of elevated growth temperature and illumination, withstanding high CO_2 concentrations etc). Make use of natural biodiversity (genome mining) including identification of novel robust enzymes. Application of the adaptive laboratory evolution approach to select production organisms/enzymes with improved desired functionalities.
Improvement of the synthetic biology toolboxes, and rapid engineering of libraries of strain variants.	Computational design using HPC and reconstruction of metabolic models for selected production strains. Reiterative quantum modelling of electron-transfer processes including competing pathways. Design novel production pathways with strict cofactor balancing of the reactions and pathways, resulting in improved carbon yields. Automatization of synthetic biology processes. Systems Biology and 'omics' technologies to understand complex biological networks and systems.
Durability and lifetime of the microbial cell factories and biohybrid devices	Enhancement of durability and lifetime by optimizing biocomponent/synthetic material interfaces. Improvement of the longevity of host organisms by systems biology and physiological monitoring, with subsequent alleviation of constraints developed, and by investigating microbial co-cultivation opportunities. Elimination of toxicity of end-products and non-biological materials. Optimization of the import of external substrates and export and separation of products. Taking into account the reproduction of living cells.
Photobioreactor design	Apply engineering skills and machine learning for optimization of photobioreactor design in terms of light harvesting as well as product biosynthesis and collection. Successful up-scaling and valorisation of large-scale production platforms.

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NOVEMBER 2019

TECHNOLOGICAL ROADMAP

Sunrise

SOLAR ENERGY FOR A CIRCULAR ECONOMY

SUNRISE

Solar Energy for a Circular Economy

Technological Roadmap

November 2019

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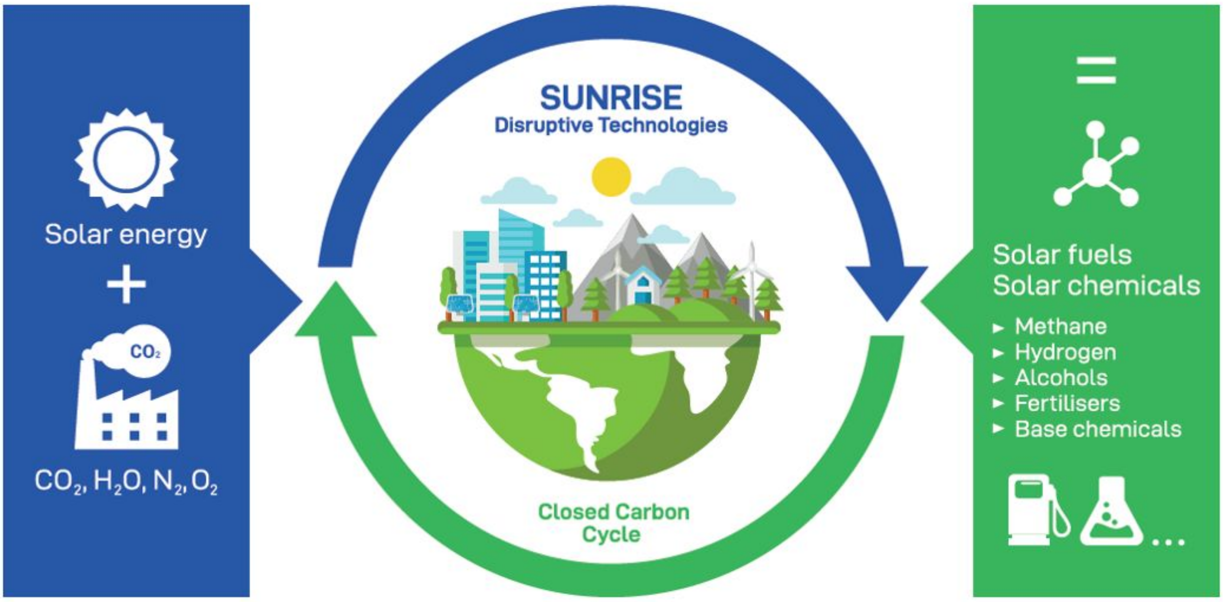
Executive Summary

Modern civilization thrives on a constant flow of energy and material goods obtained from natural resources such as fossil fuels. This leads to the production of large amounts of waste, increasingly difficult to handle. It represents a perfect example of a linear economic approach wrongly assuming that the Earth is an unlimited reservoir of resources and a bottomless dump. The ever growing increase in the consumption of fossil fuels and the ensuing release of carbon dioxide (CO_2) into the atmosphere – altering climate stability with vast environmental, societal and economic consequences – exemplifies this.

The SUNRISE action aims at promoting a large-scale research initiative to enable the transition from a linear to a circular economy: abundant molecules (carbon dioxide, water and nitrogen) are the material basis of a global economic system powered by sunlight. SUNRISE addresses the recycling of CO_2 into a variety of products, the combination of nitrogen with hydrogen to produce ammonia for fertilizers and, more generally, the direct solar-powered production of fuels and chemicals. SUNRISE will provide in a fully sustainable manner energy carriers for the transport and heating sector, the possibility of long-term storage of excess renewable energy in the power sector and fossil-free raw materials for the chemical industry. High efficiency will be necessary to make the transition economically viable and has to come out of an interdisciplinary team of scientists and engineers, handing it over to civil authorities and citizens.



SUNRISE will facilitate the transition to a circular economy and a carbon-neutral society. Abundantly available molecules – carbon dioxide, water and nitrogen (CO_2, H_2O and N_2) – replace fossil-based raw materials for the production of a broad range of chemicals and fuels. SUNRISE targets a sustainable CO_2 cycle, where the concentration in the atmosphere is decreased and then maintained at a level compatible with climate stability, committing to the sustainable use of natural resources and land.

The SUNRISE action will focus on the development of artificial photosynthesis in a broad sense, delivering important solutions for a novel energy system adapted to a circular economy:

- SUNRISE offers new options for **security of access to fuels and chemicals**, since the latter can be produced in Europe with solar energy and abundantly available resources.
- SUNRISE offers the possibility of **storing excess electrical energy at the long-term**, a growing problem with renewable electricity reaching significant shares.
- Some solar fuels, such as methane, can make **use of the existing transport and storage infrastructure** without significant modifications.
- SUNRISE aims at storing solar energy in chemicals with **yields tenfold-to-hundredfold higher than current biomass practice**. This key target allows to reduce the needed amount of land surface compared to biomass (currently the only viable renewable option for long-distance transport).

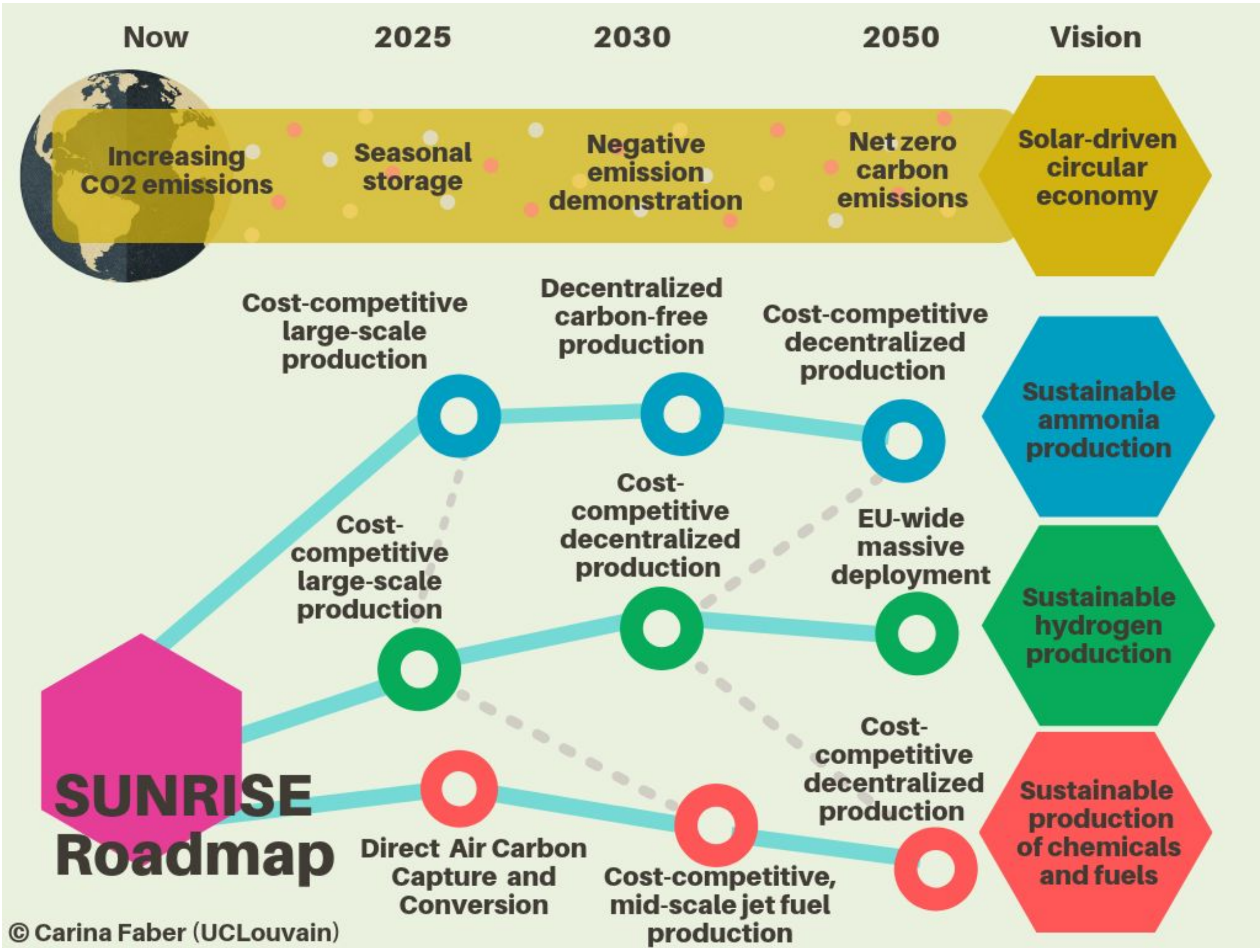
Efficiency of solar conversion	Surface per capita	Total area needed	
100 %	20 m^2	0.3 %	Thermodynamic limit
30 %	66 m^2	1 %	Artificial Photosynthesis
10 %	200 m^2	3 %	
1 %	2000 m^2	30 %	Biomass

Land area required for solar fuel production at different energy conversion efficiency levels. SUNRISE aims at delivering energy at the TW scale in 2050 with a 30% conversion efficiency, representing a massive leap forward compared to current biomass practice. For 2 TW and 700 million Europeans, it translates into ~66 m^2 per capita of surface required, which corresponds to ~1% of the European surface (on average, 25 MWh per year are then provided for every citizen).

The goal of SUNRISE is to develop competitive and green production pathways. In order to efficiently tackle climate change, one needs to address the manufacturing of commodity compounds consumed or produced by the industry. Those key intermediates are hydrogen, ammonia and carbon-based compounds. To reach this ambitious objective three approaches, with different timelines and use cases, are considered:

The SUNRISE action will capitalize on the current maturity and deployment of **solar electricity and electrochemical processes**, aiming at the development of innovative technological bricks adapted to the current infrastructures and business models by 2025. This will encompass green processes for the production of ammonia and carbon-based compounds. On a longer term, the development of **photo(electro)chemical, biological and biohybrid systems** will provide the direct conversion of solar into chemical energy with milder operating conditions, more straightforward processes and better selectivity towards specific products. The capture of **CO_2 from the atmosphere** will be combined with chemical conversion processes to reach high energy efficiencies. **These direct processes will allow to go from a centralized production of solar fuels and chemicals to a more decentralized approach by 2030, bringing better resilience to regions and favouring the development of a circular economy at a local scale.** Such technologies will be of primary interest for the development of areas where centralized infrastructures do not exist and will allow specific solutions adapted to local resources and needs. They will provide competitive prices for fuels and compounds, establishing a circular economy and, ultimately, enabling the capture of excess CO_2 in the atmosphere. Concerning fertilizers, not only a low carbon-emission production is targeted, but also a decentralized production on the small-scale, only delivering the needed amounts of ammonia and thus limiting an excessive use.

Beyond 2030, SUNRISE aims at providing a strong scientific and technological basis for negative emissions technologies, which will be then necessary to maintain the temperature increase below 2°C. Eventually, efficient solar energy conversion of carbon dioxide into long duration materials shall contribute to carbon dioxide removal, with the goal to reach a much lower land use than bioenergy-based technologies. The concomitant decoupling of economic growth from the depletion of resources is a much more appealing economical prospect than geological Carbon Capture and Storage [CCS].[1] **Finally, by 2050, SUNRISE will contribute to a CO_2-neutral circular economy, net climate neutral mobility for people and goods, as well as affordable negative emissions technologies developed at a significant scale.**



SUNRISE Roadmap: The vision of SUNRISE is a carbon-neutral society based on a circular economy driven by solar energy by 2050. The sustainable production of hydrogen, ammonia and carbon-based chemicals and fuels is key. Major milestones are *e.g.* the cost-competitive, mid-scale production of jet fuels in 2030 (700 000 barrels produced per year, *i.e.* delivering ~150 MW on 1000 ha).

[1] Since technologies for solar fuels and chemicals are an emerging field, detailed analysis comparing them with the more established bioenergy-based technologies and CCS approaches do not exist at present.

Context: what does the world look like today?

A roadmap is not an abstract object standing on its own, its purpose comes with its actual implementation and the solutions it brings to real-world challenges. It is crucial to analyze the specific context in which it will have to persist; what are today's drivers? What are the challenges we are facing? Even though it is a roadmap for research and innovation and not a business model, it is strongly dependent on non-technological enablers such as financing mechanisms, political support and social commitment. Some of the following trends will accelerate the development of the proposed solar-driven SUNRISE technologies, others will hamper them. The latter have to be anticipated and, if possible, circumvented.

Global challenges and drivers

Ecological drivers

Today's energy production system strongly depends on fossil-based energy sources and raw materials. Their intensive use over the last decades not only depleted the Earth's reservoirs, but also caused a significant increase of the carbon dioxide concentration (and other greenhouse gases) in the atmosphere. Among many worrisome consequences, a rise in the average global temperature is shattering.[2] Latest reports point out the tremendous consequences of the ongoing warming on ecosystems, resources and accordingly society in general.[3]

In the EU, the energy and transport sectors generate the major part of greenhouse gas (GHG) emissions, with 54% for energy-related and 24% for transport-related activities in 2016.[4] However, these sectors are central for economic growth, industrial competitiveness and quality of life. A decarbonization[5] of these sectors is urgently needed, decoupling economic benefits from the pollution of the environment. Concerning electricity production, much progress has been made in the last decade: wind and photovoltaic capacity worldwide is now an established alternative to fossil energy carriers thanks to technological developments and significant cost reductions. The electrification of society continues to grow, with the need for efficient storage solutions on the short-to-long term. For the transport and heating sectors, fossil fuels are still an unmatched energy source with a huge existing infrastructure. Chemical industry, one of the largest industrial GHG emitters in Europe, is also completely dependent on fossil-based raw materials and energy carriers.

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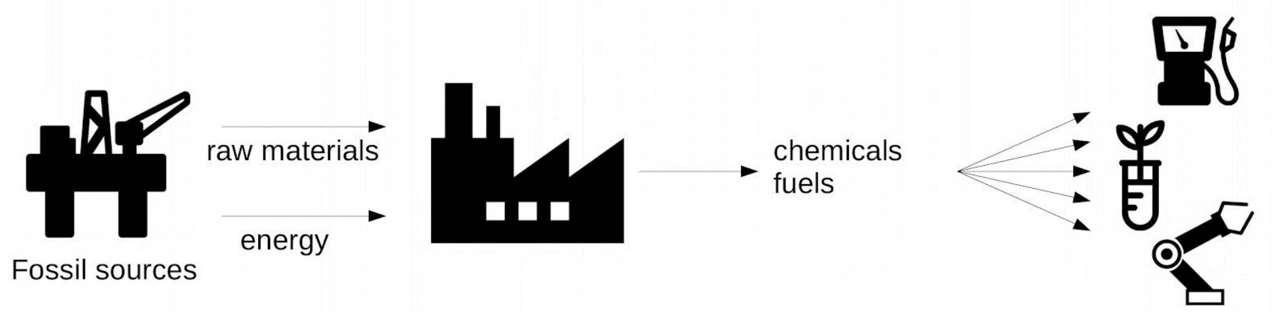
[2] The current increase in average global temperature is estimated to 1°C as compared to pre-industrial times.

[3] See subsequent chapter on scenarios

[4] https://ec.europa.eu/eurostat/statistics-explained/pdfscache/1180.pdf

[5] Since SUNRISE proposes to make carbon-based materials, indispensable to the economy, "defossilization" will be used later in the text to better describe the goal of the transition. Defossilization is a word newly associated with the energy transition (less than 50 occurrences in google-scholar, with a first one in 2010).



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Further global trends

In addition to ecological drivers, developments in politics, economy, legislation, technology and society at large are influencing the framework in which this roadmap needs to operate. An outline of the most striking ones is listed below, raising no claim to completeness:

Political: Nationalism, populism, lack of international cooperation, but overall positive political atmosphere on climate change mitigation; Sustainable Development Goals[6] adopted by all United Nations Member States in 2015 as international reference. Growing need for energy security and independence from imported energy.
Economical: Positive global economic trends, decreasing unemployment, overall EU economic growth, sinking interest rates, low employment in the oil sector, expanding global markets for sustainable technologies, policy incentives for investing in clean energy, large global business opportunities in clean energy sector, important share of the gross domestic product and jobs of energy and transport sector in Europe, decentralisation of energy production.
Societal: Rallies for climate change mitigation especially from younger generations, rising social awareness, positive Zeitgeist for global warming, democratization of knowledge, increasing standards of living coupled to increasing consumption, central role of social media.
Legislative: Paris agreement, Clean Energy for all Europeans legislative package.
Technological: Rapid developments in ICT and on-going digitalization; critical materials: research on substitution, recycling and materials efficiency; production processes: more efficient and less energy demanding.

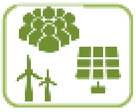
Technologies for the transition to a low-emission society are not available for a fully sustainable, massive deployment on a global scale today.

EU climate policy

With the **Paris agreement**, the European member states engaged to mitigate global warming and to play a leading role in the fight against climate change at an international level. The necessary reduction of CO_2 emissions implies profound societal changes and technological breakthroughs. The EU is at the forefront to drive international climate policies forward and an important actor to strengthen concerted actions. The

[6] https://www.undp.org/content/undp/en/home/sustainable-development-goals.html

EU takes responsibility in the global **Mission Innovation** initiative to accelerate clean energy innovation.[7]



At the European level, the **Strategic Energy Technology (SET) Plan** is driving forward research and innovation in low-carbon energy technologies. It aligns R&I efforts between the private sector, the European Commission and the Member States. The **Energy Union** targets a sustainable, low-carbon and climate-friendly economy. It provides the regulatory framework for achieving the EU's 2030 greenhouse gas emission reduction target of 40% as compared to 1990, where cost-efficiency and the modernization of the European economy are important drivers. The **Clean Energy for all Europeans package** and the **Clean Mobility packages** are legislative frameworks that imply major market transformations in the energy and transport sector by 2030. They focus on an increase in renewable energies, efficient storage and low-carbon mobility.

A replacement of fossil-based energy sources and raw materials are crucial for Europe's vision of a zero-emission society and the global competitiveness of its industry.

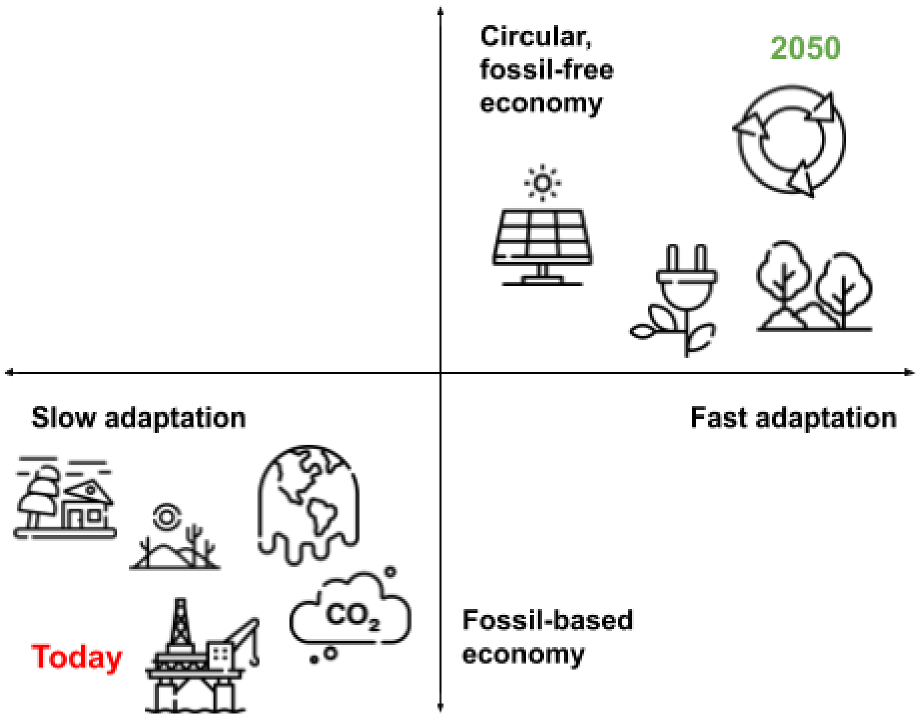
SUNRISE technologies directly address the above-mentioned challenges. They take inspiration from nature, mimicking the natural photosynthesis process. Energy from sunlight and raw materials abundantly available in the atmosphere (water, carbon dioxide, nitrogen) are transformed into green fuels and chemicals.
This allows for a defossilization of the energy and transport sector, as well as the chemical industry (including agrochemistry). SUNRISE technologies provide sustainable fuels with high energy content to the transport and heating sector, using existing infrastructure, while chemical industry profits from fossil-free raw materials and energy. Converting sunlight and electricity into chemical energy represents a safe and easy way of long-term storage for intermittent renewable energy sources. In the longer term, CO_2 is directly taken from the atmosphere and becomes a valuable raw material. When transformed into fuels and burnt afterwards, a net zero-carbon emissions cycle is established, while when transformed into long-lasting chemical products, such as polymers, net CO_2 reductions (negative emissions) are achieved.

Spurred by recent reports of the International Panel on Climate Change,[8] climate change mitigation is now increasingly recognized as one of the most pressing global challenges of our times. It necessitates an immediate coordinated large-scale effort to rapidly develop a broad portfolio of cost-effective and efficient fossil-free alternatives.

The speed for developing, upscaling, implementing and commercializing such innovative solutions strongly depends on the financial and political effort the EU R&I community will receive. It will strongly influence the EU's future economic competitiveness and is central to accelerate the transformation to a low-carbon society.

[7] http://mission-innovation.net/
[8] "Special Report: Global Warming of 1.5 ºC" 2018 and "AR5 Report Climate Change 2014"

Scenarios: what will the world look like in 2050?



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SUNRISE envisions the sustainable production of chemicals and fuels using solar energy and raw materials abundantly available in the atmosphere. Due to the high number of considered products (ranging from hydrogen to jet fuel) and the broad range of proposed technologies with different degrees of maturity, it is beyond the scope of this roadmap to model future scenarios based on current data. Instead, future needs of chemicals and fuels are estimated by analyzing different scenarios[9] described in the current literature. The scenarios described in the "2050 long-term strategy climate-neutral Europe" released by the European commission in 2018[10] play a central role. The aim of the SUNRISE roadmap is to deliver the needed technological milestones to enable the European Commission's vision for 2050. Also highly relevant for this work are recent reports of the International Panel on Climate Change.[11] A short overview of the main scenarios and forecasts as reported in these two key documents and the relevance for the SUNRISE initiative follow.

The 2050 long-term strategy climate-neutral Europe

The aim of this long-term strategy is to confirm Europe's commitment as a leader in global climate action and to present a vision for **achieving net-zero greenhouse gas emissions by 2050**

[9] More than 50 scenarios have been overviewed stemming from 11 roadmaps or strategic documents.
[10] 2050 long-term strategy climate-neutral Europe, European Commission, 2018, and support document: In-depth analysis in support of the commission communication COM(2018)773.
[11] "Special Report: Global Warming of 1.5 ºC" 2018 and "AR5 Report Climate Change 2014"

through a socially fair transition that opens up opportunities for decoupling economic growth from the depletion of natural resources.

The strategy mainly explores eight economy-wide scenarios, divided in three different categories depending on their levels of emission reductions, from 80% to 100%, in comparison to an initial baseline reflecting the 2030 European energy and climate policies and targets. The scenarios cover the potential range of required reductions for the EU to contribute its share to the Paris Agreement's temperature objectives (*"well below 2°C"* and *"1.5°C temperature change")*.

The analysed scenarios foresee the **deployment of carbon taxes**[12] and high shares of renewables in the power mix. In all these scenarios **renewables become increasingly competitive, reaching around 80% of the power mix by 2050**. Renewables deployment (wind and solar representing around 70%) is facilitated by **storage** through hydro-pumping, stationary and mobile batteries and, indirectly, in hydrogen and e-fuels as well as via demand side response. The analysis is complemented by modelling and by developing these multiple and differentiated scenarios (see table below). Especially for industry, a different model was used focusing on extremely innovative technology pathways. **In all scenarios the final energy consumption decreases, by minimum 26% to maximum 50% in 2050 as compared to 2005 values.**[13]

Economy-wide scenarios 2050

***** https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

** In comparison to 1990 values

Economy-wide Scenarios Long-term strategy climate-neutral Europe (PRIMES-GAINS-GLOBIOM model)	
Non-changing scenario "Baseline" Based on the Reference scenario 2016 (REF 2016) *	**"Baseline scenario":** developed to reflect the current EU decarbonisation trajectory based largely on agreed EU policies or policies that have been proposed by the Commission, but are still under discussion. It keeps the macroeconomic projections, fossil fuels price developments and pre-2015 Member States policies as implemented in REF2016. It assumes the achievement of the following energy and climate targets by 2030: (a) at least 40% cut in GHG emissions (from 1990 levels), (b) at least 27% share for renewable energy, and (c) at least 27% improvement in energy efficiency.

[12] The assumed carbon price increases significantly under all scenarios, reaching 28 EUR/tCO_2 in 2030 and then increasing to 250 EUR/tCO_2 in 2050 under the 80% reduction scenarios and 350 EUR/tCO_2 under the scenarios that achieve net zero GHG emissions by 2050. Real carbon prices will depend on the deployment of other policies and how they impact technology costs and development.

[13] Final energy consumption is foreseen to be reduced already in the Baseline scenario following the European 2030 target on energy efficiency (32.5% reduction compared to 2007). In the decarbonizing scenarios, the least reductions are achieved in those including alternative zero-carbon /carbon neutral energy carriers (ELEC, H2 and P2X). Globally, baseline trends show rises in final energy consumption, although scenarios including deployment of low-carbon technologies, based on renewable energy and energy efficiency, are also compatible with final energy demand reductions by 2050. See REmap Case in "International Renewable Energy Agency, IRENA (2019), Global energy transformation: A roadmap to 2050, International Renewable Energy Agency" or Beyond 2°C Scenario (B2DS) in "International Energy Agency, IEA (2017), Energy Technology Perspectives, Catalysing Energy Technology Transformations".

1st category decarbonization scenarios: - well below 2°C ambition - 80% reduction in GHG emissions by 2050**	**"Electrification - ELEC":** electrification of the energy demand is the driver and thus higher electricity supply and high deployment of storage (6 times today's levels) will be needed to deal with variability in the electricity system.[14]
	"Hydrogen - H_2": key action is the deployment of e-hydrogen in the energy demand sectors and thus hydrogen production on the supply side, it assumes timely deployment of the necessary hydrogen infrastructure and distribution.
	"Power to X - P2X": key action is the deployment of e-fuels (e-gas and e-liquids) in the energy demand sectors and thus e-fuels production on the supply side. Hydrogen becomes mainly an intermediate feedstock and e-fuels use in transport reduces the biofuel requirements for this sector, towards 2050, hydrogen is produced by electrolysis, e-gas in methanation plants and e-liquids via various chemical routes (*i.e.* methanol route and Fischer-Tropsch process).
	"Energy efficiency - EE": key action is deployment of strong energy efficiency measures in buildings, industry and transport. Energy consumption is thus reduced in all final consumption sectors and particularly in buildings.
	"Circular Economy - CIRC": key action is the development of a circular economy model in the industry and transport, assuming standardization of recyclable material and improved systems for waste collection. GHG emissions reduction are driven by resource and material efficiency.
2nd category decarbonization scenarios: - 90% reduction GHG emissions	**"Combination - COMBO":** it combines the actions and technologies of the previous scenarios (except the one of circular economy, for technical reasons). In this scenario, all before-mentioned pathways are assumed to be available and GHG reductions can be achieved through all of them, including LULUCF (Land Use, Land-Use Change and Forestry).
3rd category decarbonization scenarios: - 1.5 °C ambition - Net zero GHG emissions	**"1.5ºC Technical - 1.5TECH":** aims to further increase the contribution of all the technology options, and relies more heavily on the deployment of biomass associated with significant amounts of carbon capture and storage (BECCS).
	"1.5ºC Sustainable Lifestyles - 1.5LIFE": relies less on technology options, but assumes a drive by EU business and consumption patterns towards a more circular economy, translated in lifestyle changes and consumer choices more beneficial for the climate.

[14] Electricity becomes the dominant energy carrier and its share grows strongly in all scenarios, from 22% in 2015 to 29% in 2030 and then in 2050 ranging from 41% (P2X) to 53% (ELEC) with the scenarios achieving highest GHG reductions situated within this range.

The IPCC Special Report Global Warming of 1.5ºC

This report discusses the impacts of global warming of 1.5 ºC above pre-industrial levels and related GHG emission pathways. In pathways for limiting global warming to 1.5ºC, CO_2 emissions are reduced globally to net zero around 2050. All pathways examined use Carbon Dioxide Removal (CDR), but in different amounts. Four illustrative global model pathways are presented:

- **Pathway 1**: scenario with lower energy demand up to 2050, while living standards rise in the global South; rapid decarbonization of the energy supply is enabled. The only CDR option considered is afforestation.
- **Pathway 2**: scenario with a broad focus on sustainability, including healthy consumption patterns (including healthy diets with low animal-calorie shares and low food waste), low-carbon technology innovation and well-managed land systems.
- **Pathway 3**: a middle point scenario following historical patterns. Emission reductions achieved mainly by energy production changes, followed by reductions in demand to a lesser degree.
- **Pathway 4**: a high resource- and energy-intense scenario where emission reductions are achieved by strong use of CDR, especially through the deployment of BECCS (BioEnergy with Carbon Capture and Storage).

CHANGES IN 2050 (% rel to 2010)		Pathway 1	Pathway 2	Pathway 3	Pathway 4
	CO_2 EMISSION	-93	-95	-91	-97
	ENERGY DEMAND	-32	2	21	44
	RENEWABLE SHARE	77	81	63	70
PRIMARY ENERGY	FROM COAL	-97	-77	-73	-97
	FROM OIL	-87	-50	-81	-32
	FROM GAS	-74	-53	21	-48
	FROM NUCLEAR	150	98	501	468
	FROM BIOMASS	-16	49	121	418
	FROM NON-BIOMASS RENEWABLES	833	1327	878	1137

Global indicators in 2050 for four illustrative model pathways.

Implications of the analyzed scenarios on SUNRISE

The two mentioned reports show that the energy system transition is underway, analyzing and projecting different political, social, economic and technological developments that have seen immense improvement in recent years. However, the highest ambition level can only be achieved if all mitigation options are exploited: electrification, hydrogen, bio-based feedstocks and substitution. In several cases, carbon dioxide capture, utilization and storage (CCUS) would lead to the deep emissions reductions required in energy-intensive industries to limit warming to 1.5°C.

Current barriers to accomplish high decarbonization levels include institutional, economic and technical constraints. The hydrogen-based production of ammonia, methanol and other chemicals is hampered by high costs and infrastructure needs. **Research efforts to overcome these limitations and to develop associated processes for hydrogen production and its use as feedstock are therefore needed.** In the European strategy, the total hydrogen consumption is expected to reach approx. 30 Mtoe (around 350 TWh) for the P2X scenario and 150 Mtoe (around 1700 TWh) for the H2 scenario, as soon as consuming technologies are available (*i.e.* fuel cell vehicles).

2050 Long-term strategy climate-neutral Europe

Estimated consumption Europe 2050	SCENARIOS								
	Baseline	ELEC	H2	P2X	EE	CIRC	COMBO	1.5 TECH	1.5 LIFE
Mtoe*									
Hydrogen	8	15	150	30	15	15	50	70	80
Natural gas	250	125	120	125	100	100	75	60	50
e-gas**	-	-	-	90	-	-	50	40	40
e-liquids**	-	-	-	55	-	-	20	40	20

*Million tonnes of oil equivalent, approximated rounded values
** e-gas and e-liquids not produced in Baseline, ELEC, H2, EE and COMBO scenarios

Source: PRIMES-GAINS-GLOBIOM model

Consumption estimates of some energy carriers in the 2050 long-term strategy.

The SUNRISE roadmap encloses the deployment of the most advanced technologies for the conversion of renewables to electrolytic hydrogen and e-fuels by upscaling processes, aiming for cost and resources efforts alleviation. In addition, it also introduces the development of emerging research and technological alternatives based on the direct conversion of solar energy through "artificial photosynthetic" approaches. Currently, these innovative options with low technological readiness are not included in the described scenarios; however, their great impact, projected as 2 TW (17,500 TWh/year) for Europe alone, will determine the electricity demand and the decentralization for industry decarbonization.

Finally, some of the scenarios, such as the fourth illustrative pathway in the IPCC report largely rely on the deployment of BECCS, where biomass becomes an important energy carrier. The needed land area for bioenergy is expected to amount to 7.2 million km^2, globally, by 2050.[15] This

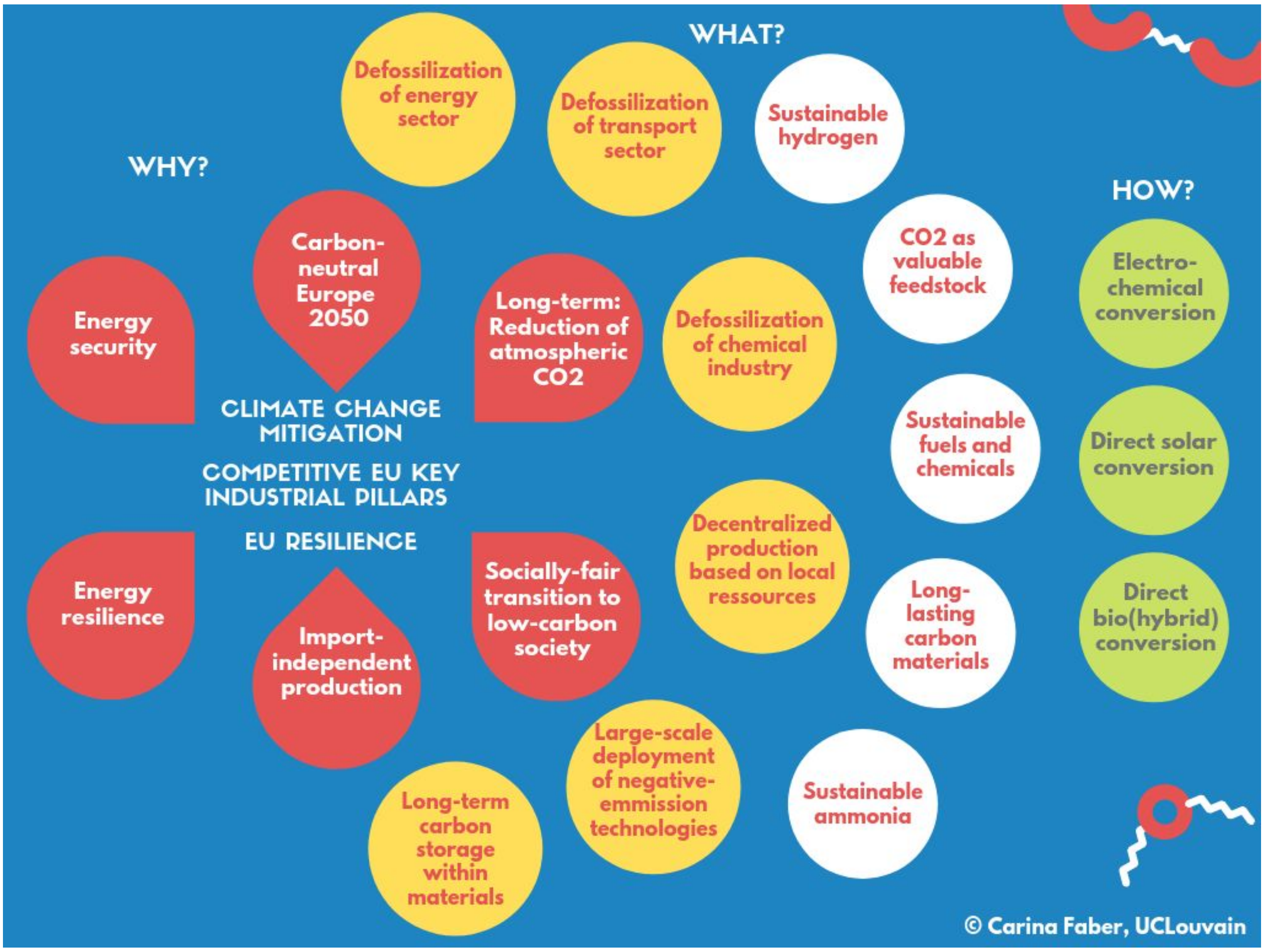
[15] For comparison, EU-28 surface is about 4 million km², geographic Europe (until the Urals) is slightly more than 10 millions km². Pathway 4 is the most extreme case: for pathway 1, land area of bioenergy crops in 2050 is estimated at 0.2, for pathway 2 at 0.9 and for pathway 3 at 2.8 (in million km²).

could have negative consequences on sustainable development, if the use of land competes with production of food or biodiversity conservation.

The development of technologies included in the SUNRISE portfolio alleviate the needs for land use, water and nutrients consumption, since they are based on decoupling of economic growth from depletion of resources, while high solar-to-fuel yields are targeted (see chapter "Needed resources and enablers beyond the scope of SUNRISE" for estimations on green electricity, land and water use).

SUNRISE Vision: how to get the future we want?

Overview



The vision of SUNRISE is to enable a circular economy of renewable fuels and chemicals on a global scale using abundant molecules as feedstocks (*e.g.* water, carbon dioxide, nitrogen) and, in the long term, sunlight as the sole energy source.

Urgent action is required: the latest IPCC reports underline the need to reduce anthropogenic carbon dioxide emissions to below zero within the next 30-40 years in order to reach the ambitious goals of the 2015 Paris agreement. Technologies enabling such a transition on the global level are still in their infancy. SUNRISE wants to develop artificial photosynthesis technologies in a broad sense, aiming at solar-to-products yields tenfold to hundredfold higher than current biomass practice. Using the smallest possible land area is a key objective in order to propose technologies compatible with other essential goals, in particular a sustainable food production system and the preservation of biodiversity.[16] Providing efficient devices is not enough: these devices have also to

[16] https://www.undp.org/content/undp/en/home/sustainable-development-goals.html

be conceived in accordance with society's needs, as further discussed in the "Social and environmental impact" chapter.

Why we need to act

Overarching drivers of the SUNRISE initiative are climate change mitigation, a competitive European industry and EU resilience in terms of energy and resources. From this, six high-level drivers are deduced:

- a carbon-neutral European society by 2050, in accordance with the EU policy goals,
- a socially fair and economically viable transition to a low-carbon society,
- an import-independent production for EU autonomy and sovereignty,
- energy security,
- energy resilience,
- and ultimately, reductions of the atmospheric carbon dioxide concentration.

What we can do

Six high-level solutions have been identified, promising to significantly contribute to the above-mentioned goals:

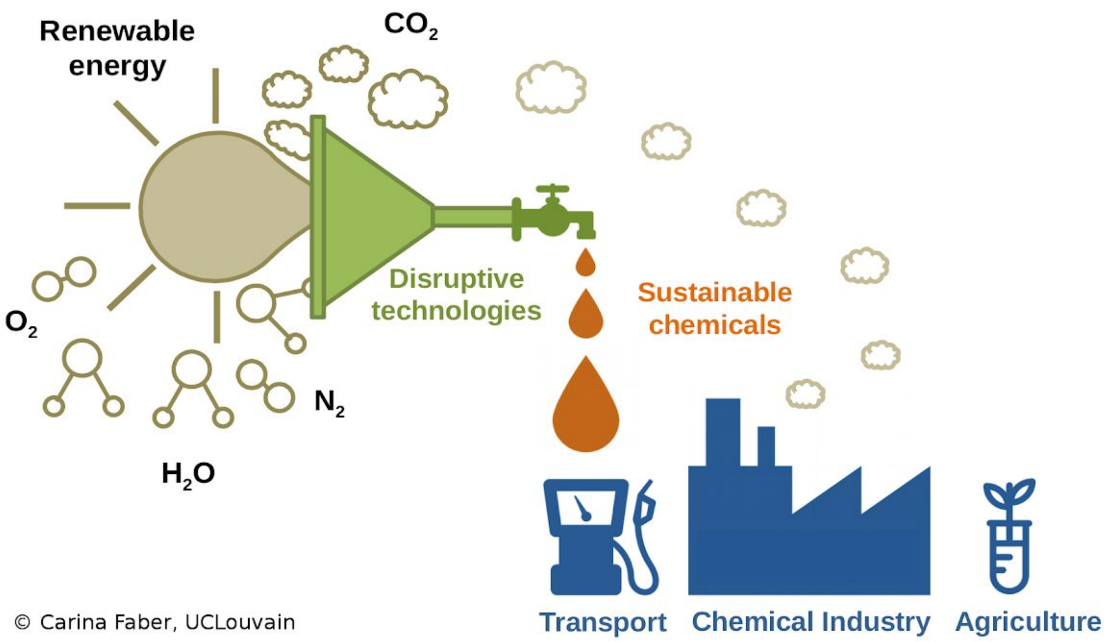
- the development, manufacturing and deployment of technologies for the long-term and large-volume storage of energy
- the manufacturing of primary energy carriers for a defossilization[17] of the energy sector, uncoupling the energy production from natural resource extraction,
- the manufacturing of feedstock for a defossilization of the chemical industry,
- the displacement of fossil fuels by renewables in the transport sector,
- a decentralized production system based on resources available everywhere
- a large-scale deployment of technologies for negative emissions combined with a long-term carbon storage within materials.

Solutions have to align with general goals of sustainability in terms of resources, land use and ecological impact. The SUNRISE vision is based on ubiquitous resources - sunlight and molecules from the atmosphere - thus enabling a purely decentralized and import-independent production system. SUNRISE will create substantial added value for all European countries by providing tailored solutions for each European region to achieve the best utilization of solar irradiance and site-specific resources.

A **sustainable production of hydrogen** with low carbon emissions is central to SUNRISE, since hydrogen is an important vector for the energy and transport sector, and a large-volume resource for chemical industry. **Turning carbon dioxide from a threat for climate stability into a valuable resource** for industry will also contribute to the defossilization of the mentioned sectors and drive the deployment of negative emissions technologies. The **sustainable production of carbon-based commodity chemicals and fuels** will provide the chemical industry with the needed energy and resources and represents a low-carbon alternative to the current use of fossil

[17] Defossilization, preferred to decarbonization, is a more recent expression now utilized by the transportation sector: *e.g.* the global alliance powerfuels, https://www.powerfuels.org/home, R. Schlögl, Angew. Chem. Int. Ed. 2019, 58, 343 - 348, and FVV fuel study: Options for the defossilization of the transportation sector (100 % scenarios), https://link.springer.com/chapter/10.1007/978-3-658-26528-1_1;

fuels. As carbon source, carbon dioxide from industrial processes or extracted from the atmosphere is used. Transformed into fuels and burnt afterwards, this allows to reach carbon neutrality. Transformed into **long-lasting carbon materials**, a net reduction of the carbon dioxide concentration can be achieved, achieving so-called negative emissions. With ammonia being one of the largest volume chemicals causing significant global carbon dioxide emissions, the SUNRISE vision also includes the **sustainable production of ammonia**, providing agriculture with low-carbon fertilizers.

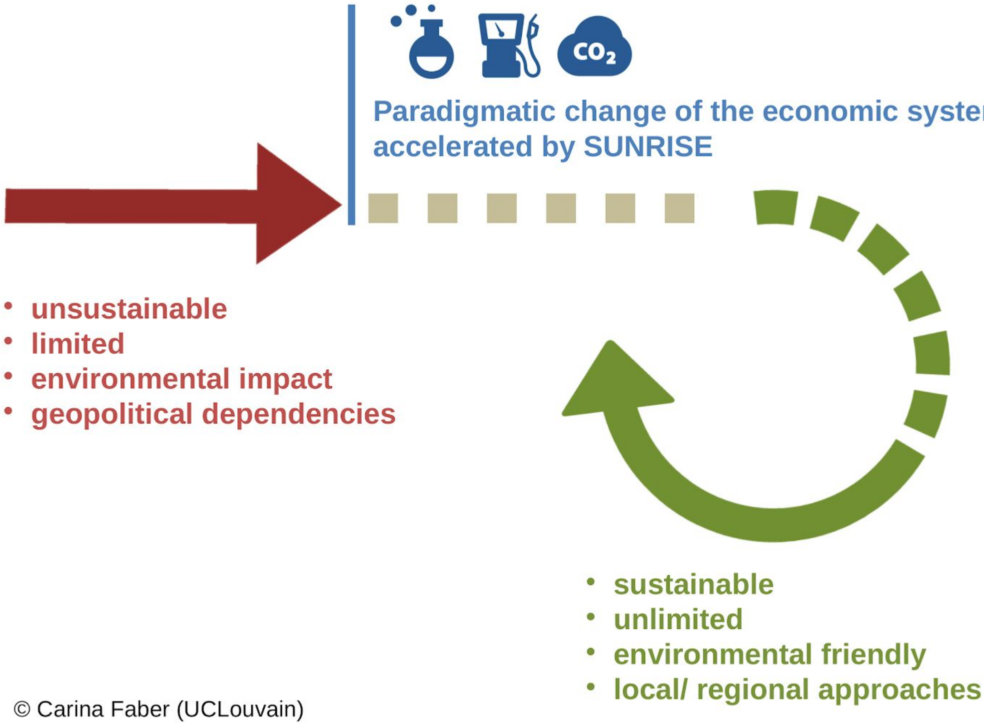


SUNRISE will foster the transition to a circular economy and a carbon-neutral society. Disruptive energy technologies will transform carbon dioxide, water, nitrogen and oxygen feedstocks into fuels, commodity chemicals and agrochemicals with the use of sunlight.

How we can do it

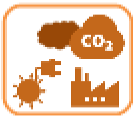
The production of chemicals by sunlight and widely available feedstocks (CO_2, H_2O, N_2 and O_2) is a key milestone towards a **circular economy**. In particular, we target **a sustainable CO_2 cycle**, where the concentration in the atmosphere is decreased and then maintained at a level compatible with climate stability, requiring the **sustainable use of natural resources and land**. The technology development will take into account key constraints such as the energy-return-on-investment (EROI) and the **availability and durability of critical materials**.

The transition from a civilization that is dependent on the consumption of fossil resources to one that is based on solar-powered manufacturing, and which uses ubiquitous and abundant molecules as raw materials in a circular manner, is one of the grandest scientific and technological challenges ever faced by mankind. The unifying goal of SUNRISE is to provide **disruptive technologies** to make sunlight and ubiquitous molecules the principal prime sources of energy and platform materials for modern society, and thus phase out fossil fuels.

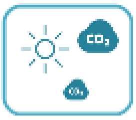


From a linear to a circular economic system.

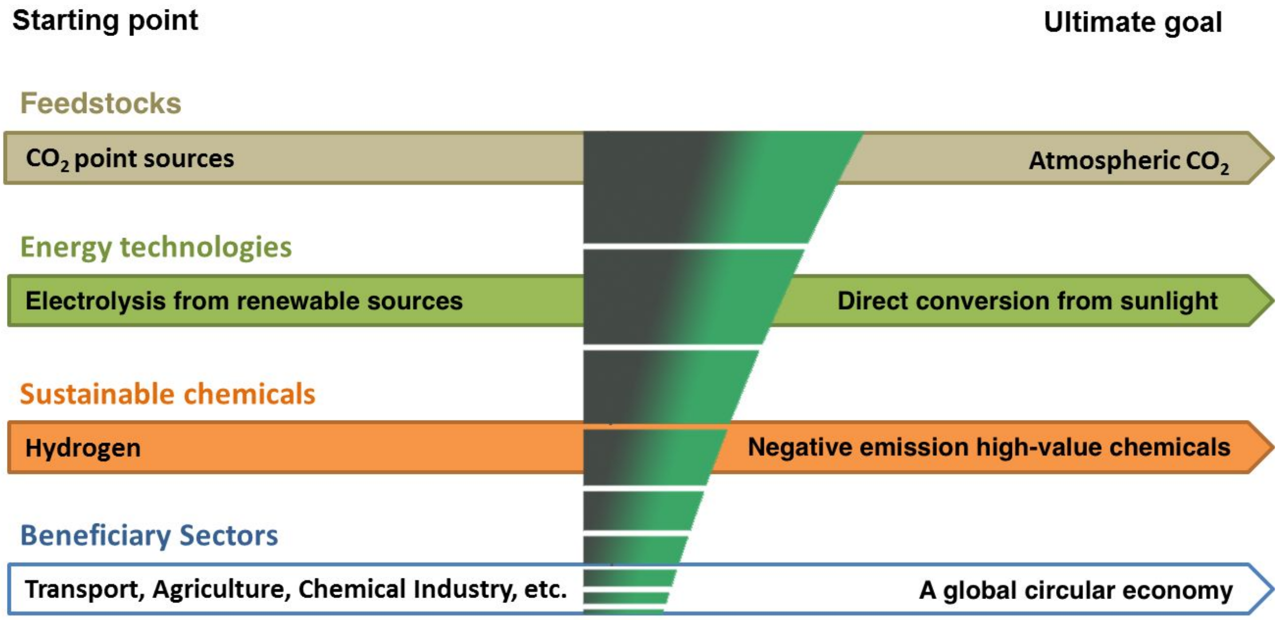
SUNRISE focuses on three approaches to deliver solutions for the replacement of fossil resources. These work on different timescales and a detailed description of the specific milestones follows in the subsequent chapter "SUNRISE Roadmap".



IN THE SHORT TERM, SUNRISE primarily aims at **using renewable electricity sources and waste CO_2** from industrial processes as raw material for the circular production of chemicals and fuels. The focus is on efficient and sustainable processes for the conversion and storage of **renewable power into liquid or gaseous fuels**, taking advantage of the continued growth of wind and solar electricity production. The energy return on energy invested (EROI), which is not yet maximized due to use of electricity at the intermediate stage, will be improved step by step.



IN THE MEDIUM TO LONG TERM, the energy input for the chemical processes is **directly provided by sunlight**. It drives novel technological approaches to transform CO_2, H_2O, N_2 and O_2 into fuels and base chemicals. Inspiration is taken from natural photosynthesis. Final target fuels can be concentrated to any desired level, going beyond the natural photosynthesis process with higher efficiency and a wide selection of target products. The CO_2 raw material will have to come ultimately from the atmosphere, deliberately reducing the level of greenhouse gases.



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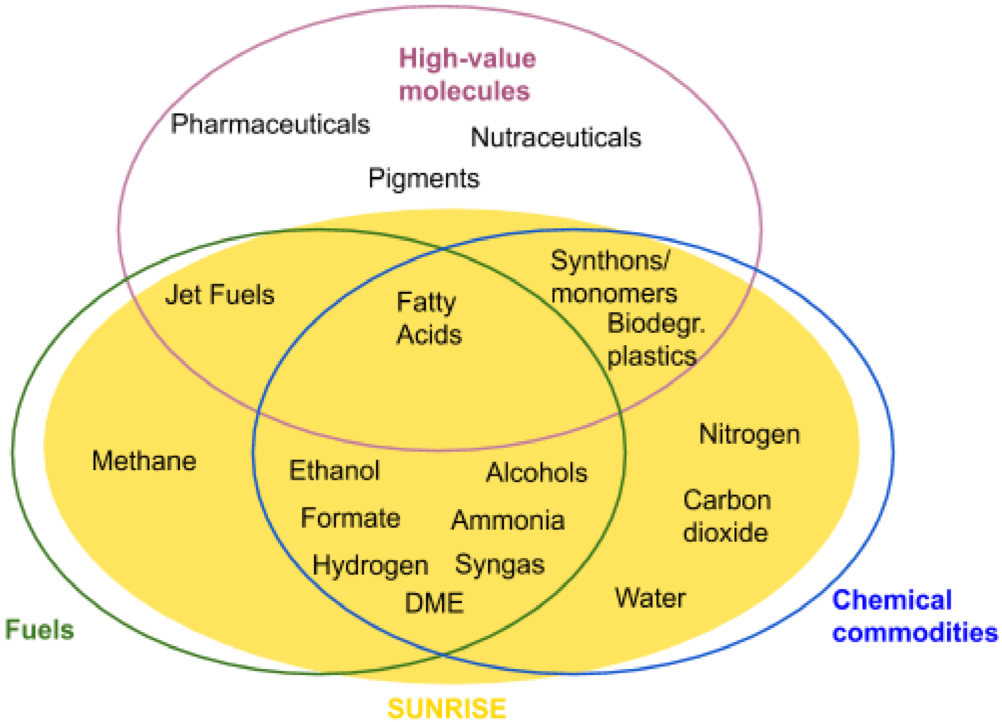
Fuels and chemicals enabling the transition to a sustainable future

Overview

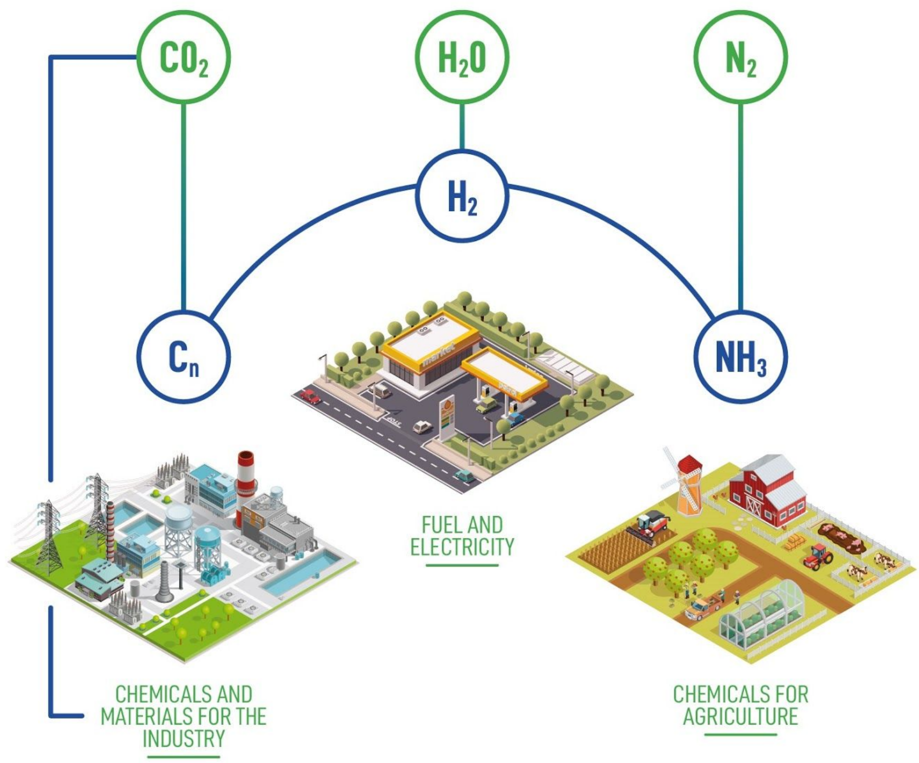
The **sustainable large-scale production of solar fuels and chemicals** is key to enable the SUNRISE vision. It is based on both point and distributed sources of carbon dioxide, the ultimate goal being the extraction of carbon dioxide from the atmosphere and its long-term storage in long-lasting carbon materials.

Given the vast variety of possible solar fuels and chemicals – ranging from small molecules, such as ammonia, to complex synthetic fuels – SUNRISE has to limit its efforts to special classes of products to ensure the efficiency of such a joint large-scale research effort. The universe of identified molecules is sketched below using three intersecting domains: one for fuels and energy carriers in general, one for chemical commodities and one for complex molecules. A few concrete examples have been included in this chart. SUNRISE focuses on fuels and chemical commodities which are needed and produced in large volumes today (millions of tons per year or more on a global scale), and sold at a small price (in the range of 1€ per liter). This market reality is a major challenge, calling for very efficient, simplified and durable processes. Ubiquitous low-energy species are extracted from the environment and upgraded with abundant renewables to energy carriers such as methane or to useful versatile commodities like ammonia, syngas or ethanol. High-value molecules, such as *e.g.* pharmaceuticals, are low volume markets (thousands of tons or less) and high-value chemicals. They do not constitute such a challenge and thus are not included in the scope of SUNRISE, except for those who also serve as fuel or commodity chemical (jet fuels, fatty acids, biodegradable plastics, etc.).



Key molecules considered in SUNRISE are highlighted in the yellow oval area, comprising fuels and chemical commodities, but not high-value molecules per se.
© Hervé Bercegol (CEA)

The scheme below illustrates the production and final utilization of the SUNRISE enabling chemicals, made with solar energy. For the sake of simplification, they have been grouped in three categories: hydrogen (H_2), ammonia (NH_3) and carbon-based compounds (C_n).



Hydrogen

Hydrogen is a highly important energy vector in the energy transition and in SUNRISE. Especially with respect to the transport sector, it is already a well-covered topic, with existing European large-scale structures such as the private public partnership *Fuel Cells and Hydrogen Joint Undertaking (FCH JU)* and their recently released *Hydrogen Europe Roadmap*. Therefore, in order to avoid a doubling of effort, many aspects, such as transport, storage, utilization and safety of hydrogen, are not the focus of this roadmap. Instead, we focus on the fully sustainable production from solar energy.

A sustainable, large-scale hydrogen production is central to the SUNRISE vision. As it is illustrated in the above scheme, hydrogen represents an **enabling molecule** in the production of ammonia and carbon-based fuels and chemicals. A fundamental aspect of the SUNRISE roadmap is that not only electricity-based hydrogen technologies with a high technology-readiness-level (TRL) are considered; less mature methods based on the direct conversion of sunlight into hydrogen have a prominent place. **A significant increase of the solar-to-hydrogen yield, high demands on sustainability and circularity in the systems and an economically-viable production of solar hydrogen are key drivers.**

Hydrogen Today

Hydrogen (H), the lightest chemical element, is largely abundant on Earth. Due to its high reactivity, it immediately forms bonds with other elements and thus only exists in a combined form (*e.g.* water or molecular hydrogen, H_2). Molecular hydrogen is a highly valuable energy carrier and in high demand in the chemical industry and for fuel-cell based transportation. However, it is scarce and its current production from fossil fuels generates large amounts of carbon dioxide emissions.

Hydrogen Impact

Today, 70 megatons of hydrogen are produced globally per year, of which 76% is from natural gas and 22% from coal, meaning that the production of hydrogen is responsible for carbon dioxide emissions of around 830 million tonnes per year. Merely 2% of the hydrogen is produced by electrolysis of water.[18] Major uses of molecular hydrogen include ammonia production via the Haber-Bosch process and fuel refining. Moreover, hydrogen is the most appealing and sustainable carbon-free solution for heavy-duty vehicles as well as personal long-range vehicles. Thus, a sustainable hydrogen production with low carbon emissions is crucial.

Beyond electricity-based routes, SUNRISE targets a large-scale production of molecular hydrogen by light-driven water splitting. Solar hydrogen can be used directly as fuel, as an energy carrier (electricity production via fuel cells) or as an intermediary step towards other molecules. Solar-to-hydrogen technologies at high efficiency will change the global energy balance. They will provide short-term as well as seasonal energy storage and thus allow for a large-scale implementation of technologies based on fluctuating renewable energy sources. Moreover, a renewable hydrogen economy can operate in both large-scale centralized facilities, as well as in small-scale distributed installations. The latter will allow on-site production and deployment without the need for a complex distribution infrastructure, with enormous economic benefits.

[18] IEA (2019), "The Future of Hydrogen", IEA, Paris, www.iea.org/publications/reports/thefutureofhydrogen/

Carbon dioxide as a valuable feedstock

Today, fossil hydrocarbons are the workhorse of our comfort, providing more than 80% of our energy supply and the major part of carbon-based chemicals and materials. Their combustion or oxidation releases almost 33 GTons of CO_2 every year in the atmosphere. This linear model being on the road to ruin, the overarching goal of SUNRISE is to establish a circular economy, focussing mainly on a closed carbon cycle.[19] In principle, such an economy is reachable and technologies to capture and convert CO_2 have been developed during the last decades. Under the name CCU (Carbon Capture and Utilization), technologies are comprised where carbon dioxide is reduced (in chemical language), turning CO_2 from a threat into a useful resource. A lot of attention is now focused worldwide on their further development, in Europe *e.g.* with CO2valueEurope[20], as well as in the USA[21] or Asia, gathered at the global level in the Mission Innovation Challenge 3.[22] While the technology exists or can be evaluated, the CAPEX is a major hurdle to overcome.

CO_2 utilization can first of all expand the present day industrial usage: besides direct utilization of CO_2 in food industry and agriculture, established processes include the production of urea (~110 Mt CO_2 per year), methanol (~2 Mt CO_2 per year), salicylic acid (~30 kt CO_2 per year) and cyclic carbonate (~40 kt CO_2 per year). But CO_2 uses must be taken further: in principle, every carbon-containing compound can be obtained from CO_2 from the atmosphere, ideally leading to carbon-neutral life cycles. A major obstacle towards this circular carbon economy is the high energy consumption of the processes involved: hence the insistence of SUNRISE on energy efficiency. This bottleneck has been clearly identified, for example in the ICEF roadmap,[23] which strongly recommends funding of catalysis research. Electrical, photolytic, biological and thermal catalysis are emphasized as key enablers of the CCU development,[24] both to decrease the energy needs and to allow economically viable conversion processes.

Large industrial emitters, including electricity and heat producers, are responsible for up to 20 Gton CO_2/year on the global scale. Currently, technologies for capture and utilization of CO_2 from their stationary point sources are already developed. Depending on the type of CO_2 source, CO_2 concentration can range from almost 100% (ammonia or ethylene oxide producers, hydrogen plants, biogas upgrading) to 70% for natural gas processing and down to 3-5% for gas-fired power

[19] A somewhat circular economy of carbon existed in the past, before the industrial revolution, when biomass was the main energy carrier. This was possible for a much less developed world with a global population about 10 times smaller than today. With a world-wide population soon to reach the 10 billion level, efficient conversion processes are deeply needed. CO_2 capture technologies will directly affect the performance of solar-to-energy conversion processes.
[20] Formerly SCOTproject
[21] Global CO_2 Initiative [GCI]
[22] The goal of IC3 is to enable near-zero CO_2 emissions from power plants and carbon intensive industries: http://mission-innovation.net/our-work/innovation-challenges/carbon-capture/ ; see a recent report : https://www.energy.gov/fe/downloads/accelerating-breakthrough-innovation-carbon-capture-utilization-and-storage
[23] ICEF Roadmap, Direct Air Capture of Carbon Dioxide, 2018, available online: https://www.icef-forum.org/pdf2018/roadmap/ICEF2018_DAC_Roadmap_20181210.pdf
[24] Sandalow, D., Aines, R., Friedmann, J., McCormick, C., & McCoy, S. (2017). Carbon Dioxide Utilization (CO2U) ICEF Roadmap 2.0. available online: https://www.icef-forum.org/pdf2018/roadmap/CO2U_Roadmap_ICEF2017.pdf

plants. Both the CO_2 concentration and the impurities present (*e.g.* NO_x and SO_x) will impact the capture process performance.

A long-term and technologically more challenging goal is to extract CO_2 from the atmosphere. Several teratons of CO_2 are available from the air, however with a low concentration of about 400ppm only. Already several industrial start-ups commercialize Direct Air Capture (DAC) units. These are integrated into projects expected to deliver in 2020-2025, where down-stream chemical processes will convert CO_2 into methanol or jet fuels.

DAC technologies[25] available today were mainly developed in view of the subsequent underground storage of CO_2 usually associated with the acronym CCS (Carbon Capture and Storage). The processes contain a final separation and concentration step, in order to deliver a concentrated gaseous stream of CO_2. However, with a growing interest for CCU instead of CCS, it seems smart to avoid this energy-intensive and costly step of CO_2 separation and concentration. Several recent research results show the possibility to produce syngas or methanol by implementing the chemical conversion process in the very medium of capture.[26,27] **Combining the capture and conversion of CO_2 in solar energy-efficient devices is one of the primary objectives of SUNRISE. Again, the goal is to demonstrate DACC (for Direct Air Capture & Conversion) overall conversion performances 10 to 100 times more efficient than today's biomass practices.**

Ammonia

Ammonia Today

Nowadays, global food production crucially depends on the use of fertilizers. Ammonia, NH_3, is by far the most used one, almost 90% of ammonia synthesized is applied in farmland; the rest serves for the production of chemicals (organic molecules such as amines). Ammonia is produced via the Haber-Bosch process using atmospheric nitrogen and hydrogen stemming from fossil fuel resources. **Although the Haber-Bosch process is highly optimized in terms of energy, it causes significant CO_2 emissions**. The annual global production of ammonia amounts to more than 150 Mtons, where 1 ton of produced ammonia generates 1.5 tons of carbon dioxide emissions.
In addition, the application of fertilizers is currently not very efficient: less than 40% of the nitrogen supplied as fertilizer is actually taken up by the cultivated crop. **Thus, the environment is heavily polluted with nitrogen compounds[28]**, resulting in extensive perturbations in the biogeochemical nitrogen balance, and consequently severe negative impacts on the environment and biodiversity.

Ammonia Impact

Reduced CO_2 emissions. The industrial ammonia production, mainly via the Haber-Bosch process, consumes 3-5% of the world's natural gas supply, contributing to around 1-2% of the

[25] ICEF Roadmap, Direct Air Capture of Carbon Dioxide, 2018, available online: https://www.icef-forum.org/pdf2018/roadmap/ICEF2018_DAC_Roadmap_20181210.pdf
[26] Li, Yuguang C., et al. "CO2 Electroreduction from Carbonate Electrolyte" *ACS Energy Letters* 4.6 (2019): 1427-1431.
[27] Kar, Sayan, Alain Goeppert, and GK Surya Prakash. "Combined CO2 capture and hydrogenation to methanol: Amine immobilization enables easy recycling of active elements." *ChemSusChem* (2019).
[28] Stevens, C. J., "Nitrogen in the environment", *Science*, **363**, DOI: 10.1126/science.aav8215

global CO_2 released into the atmosphere.[29] The proposed SUNRISE technologies providing ammonia from sunlight, air and water will save a substantial amount of fossil energy and will induce negligibly small carbon dioxide emissions. Moreover, they allow a switch from today's centralized large-scale production to a distributed on-site and on-demand ammonia production; this will also result in related savings for transport and storage. Beside its major use as a fertilizer, ammonia can play a role for storing hydrogen safely, or directly as a carbon-free fuel.

Precision farming. Approximately 90% of synthetic ammonia is used in agriculture as fertilizer, *e.g.* in the form of salts (such as ammonium nitrate, NH_4NO_3, or ammonium chloride, NH_4Cl). Precision farming provides a route to reduce ammonia pollution of soils and water. Nutrient management can be conducted by precise analysis of the actual resource needs of the agricultural land, by using ICT-based utilities. This allows for a targeted fertilization, limiting the amount of unused nitrogen fertilizer and leading to ecological recovery. SUNRISE technologies provide a way to a decentralized, on-site production of the needed amounts of fertilizers. Moreover, biological approaches represent a direct route to produce ammonium solutions, NH_4^+, valuable fertilizers without further transformation.

Commodity chemicals and (jet) fuels

Commodity chemicals and (jet) fuels Today

The production of fuels for the transport sector (road, rail, air, sea) consumes by far the largest share of the globally produced crude oil (about 4000 megatons per year). According to the International Energy Agency, a share of 64% of crude oil is refined into transportation fuels. Specifically, 49% of crude oil is consumed by road transport, 8% by aviation and 7% by navigation (marine shipping). This vast consumption of fossil resources directly translates into CO_2 emissions. For example, direct CO_2 emissions (from combustion of carbon-based fuels) of commercial aviation equate to more than 2% of the global anthropogenic CO_2 emissions;[30] the share in the EU amounts to even 3%.[31] This might appear small, but it has to be considered that these numbers relate only to direct CO_2 emissions from combustion, thereby neglecting the effect of non-CO_2 emissions, such as water vapour, soot and nitric oxide (NO), in high altitudes. Albeit with significant uncertainty, the effect of these non-CO_2 emissions is estimated to equal the effect of CO_2 emissions, *i.e.* doubling the climatic impact of aviation compared to CO_2 emissions alone.[32]

Fossil resources are not only used for energy purposes - they are also used for the production of carbon-based commodity chemicals (petrochemicals), that in turn are used to produce plastics, fertilizers, packaging, clothes and virtually everything that contains organic (*i.e.* carbon-based) compounds. About 3% of all fossil fuels (coal, crude oil and natural gas) and 10% of crude oil alone are refined into raw materials feeding the chemical industry.[33] This substantial consumption of fossil resources is naturally associated with substantial GHG emissions and other environmental

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[29] Tsang et al. https://doi.org/10.1016/j.chempr.2017.10.016

[30] Air Transport Action Group (ATAG), Facts & Figures, https://www.atag.org/facts-figures.html

[31] European Commission, Reducing emissions from aviation, https://ec.europa.eu/clima/policies/transport/aviation_en

[32] Lee D. S., Fahey D.,Forster P., Newton P. J., Wit R. C. N., Lim L. L., Owen B., Sausen R. (2009) Aviation and global climate change in the 21st century. Atmos. Environ. 43, 3520–3537.

[33] Friedrich Seitz: Raw Material Change in the Chemical Industry and the Role of Biomass. In: Malte Behrens and Abhaya K. Datye (eds.): Catalysis for the Conversion of Biomass and Its Derivatives, Max Planck Research Library for the History and Development of Knowledge, 2013, ISBN 978-3-945561-19-5.

burdens. According to the BP Energy Outlook 2019,[34] the “non-combusted use” of fossil fuels, *i.e.* as feedstock for the production of petrochemicals, shows highest growth rates of all sources of types of use. This development is particularly driven by a growing demand for chemicals.[35]

Commodity chemicals and (jet) fuels Impact

Growth as a challenge: The World’s population will continue to grow and is expected to reach 9.7 billion by 2050. At the same time, the standard of living in many of today’s developing and emerging countries will rise, resulting in an increasing demand for, *i.e.*, food and feed, energy and mobility (transport in general). The need of the chemical industry for commodity chemicals will also increase to meet the demand for plastics, pharmaceuticals, agrochemicals and many goods of daily life.

The long-term development of fuel demand is difficult to predict. Accelerating the electrification of road transport could lead to a decreasing demand for hydrocarbon fuels, despite an overall growing demand for mobility and transport. However, it is clear that large volumes of hydrocarbon fuels will continue to be needed by other transport modes. Most notably, aviation will remain highly dependent on liquid hydrocarbon fuels for many decades, as technical hurdles for introducing alternative energy carriers and propulsion systems in aviation are very high. Additionally, development cycles in aviation are extremely long. Aircraft manufacturers Boeing[36] and Airbus[37] forecast a global annual growth in air traffic of 4.7% and 4.4%, respectively, for the next 20 years. Even under optimistic assumptions regarding efficiency gains, such growth rates would result in substantially increasing fuel consumption of at least 3% per year. Similar figures can be expected in navigation (marine shipping) and heavy-duty road transport.

A strong growth in demand is expected from the petrochemical sector. According to a recent report by the International Energy Agency, production of petrochemicals (including plastics) are on their way to become the largest driver of global oil consumption.[38] This sector is expected to account for more than a third of the growth in oil demand by 2030, increasing further to almost 50% of global oil consumption by 2050, surpassing heavy-duty road transport, commercial aviation and marine shipping.

In conclusion, it is certain that there will be a large need for carbon-based commodity chemicals (petrochemicals) and transportation fuels in the long-term future, even considering a high degree of electrification of the road transport sector. The development and implementation of truly renewable production pathways towards commodity chemicals and fuels are crucial to achieve a carbon-neutral and sustainable circular economy by 2050 that is consistent with the climate protection targets agreed on by the United Nations in 2015 (the “Paris Agreement”).

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[34] BP Energy Outlook: 2019 edition, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf

[35] Persian Gulf countries are on the way to modify their refineries to make more chemicals and less fuels. See C&EN here: https://cen.acs.org/business/petrochemicals/future-oil-chemicals-fuels/97/i8

[36] Current Market Outlook 2017-2036, Boeing Commercial Airplanes, 2017.

[37] Airbus Global Market Forecast 2017-2036, Airbus S.A.S., 2017.

[38] The International Energy Agency, The Future of Petrochemicals - Towards more sustainable plastics and fertilisers, 2018.

SUNRISE Roadmap: how to go from the current state to the SUNRISE vision?

This technological roadmap is developed drawing on analysis and expert judgement to define the **activities, priorities and timelines required to reach the SUNRISE vision**. It addresses European policy makers and stakeholders from research and industry. It is conceived as a basis which will be extended later on onto the international level by the collaboration with Mission Innovation.[39]

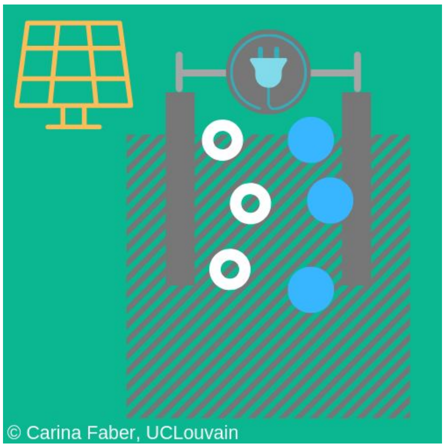
The unifying goal of SUNRISE is to provide key enabling technologies to make sunlight and ubiquitous molecules the prime sources of energy and materials for modern society, and displace fossil fuels by renewables on the terawatt scale. This objective has far-reaching consequences with global significance, such as (i) mitigating global warming, (ii) promoting the transition to a sustainable circular economy, (iii) reducing regional dependencies on energy and feedstock imports, and (iv) accelerating the phasing out of fossil fuels. SUNRISE addresses all these highly relevant issues simultaneously.

The transition from a fossil-fuel-dependent to a solar-powered, circular civilization is one of the grandest challenges of our times. Urgent action is required: the latest IPCC reports underline the need to reduce anthropogenic CO_2 emissions to net zero until 2050 to reach the ambitious goals of the 2015 Paris agreement. Technologies enabling such a transition are still in their infancy. Addressing such an enormous feat requires a multidisciplinary, intersectoral effort on a large scale with massive investment. This roadmap will serve as a guide for joint research efforts, providing a way to efficiently reach the Sunrise goals. It identifies priorities to significantly accelerate the development of solar conversion technologies.

[39] Common workshops and discussions are already scheduled.

Three main technological approaches

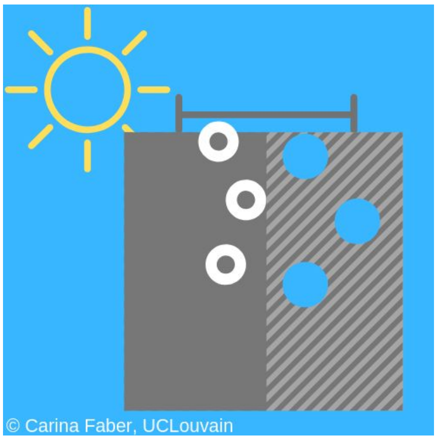
The goal of SUNRISE technologies is to enable a sustainable, low-emission production of chemicals and fuels. The proposed technologies take inspiration from nature, where - via photosynthesis - solar energy, water and carbon dioxide are transformed into chemical energy in the form of carbon-based compounds. In SUNRISE, these so-called artificial photosynthesis technologies comprise the following three approaches:[40]



Electrochemical conversion with solar power

In electrolysis, electricity provides the needed amount of energy to drive a given chemical reaction. The **electrochemical conversion of water** produces oxygen and more importantly molecular hydrogen, a key enabler in the SUNRISE vision. By using renewable electricity sources, hydrogen production becomes a sustainable source of fuel and chemical building blocks. The challenge is to scale up the production to reach the amounts needed to replace fossil-based hydrogen and also to compete with the costs of grey hydrogen (about 1-2€/kg[41] vs. 5-7 €/kg for green hydrogen produced in a centralized infrastructure).[42] It is necessary to find novel materials that can make this technology environmentally sustainable and economically feasible for a large-scale deployment.

The **electrochemical reduction of carbon dioxide** represents a promising route to convert hydrogen and CO_2 into fuels and valuable carbon-based chemicals using electrical energy. Even though the first examples of CO_2 electrolysis date from the 19th century, when carbon dioxide was reduced to carbon monoxide, this technology is still at the small scale today. A similar possibility exists to electrochemically **convert N_2 and H_2O from the atmosphere into ammonia (NH_3)**, by-passing the need for a prior H_2 production for the Haber-Bosch process. This is still in an early stage, with low efficiencies in the few demonstrated examples.[43,44]



Direct conversion via photo(electro)chemical systems

The second SUNRISE approach takes inspiration from nature. Photosynthetic organisms such as plants use the energy of the sun to produce complex chemical compounds out of simple

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40 In accordance with: "Artificial Photosynthesis: Potential and Reality", European Commission, 2016

41 IRENA (2019), *Hydrogen: A renewable energy perspective*, International Renewable Energy Agency, Abu Dhabi

42 These costs only include production. However, transport and compression significantly add up to actual hydrogen production costs, leading to hydrogen prizes at the fuel station of around 10€/kg. See 2018 Progress Report for the DOE Hydrogen and Fuel Cells Program..

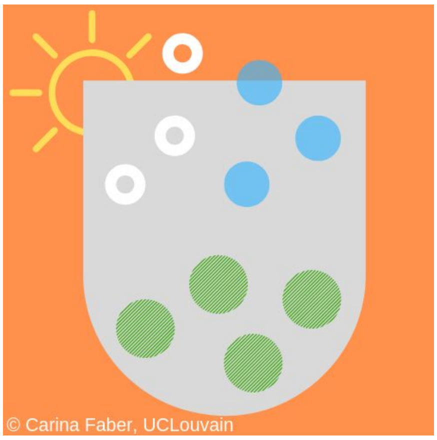
43 J. Nørskov, et al., 2016, DOI: 10.2172/1283146

44 Non-thermal plasma-assisted synthesis is an alternative for chemical conversions using electrical power. Thermochemical methods applying solar heat are on their way, reducing water and carbon dioxide to provide hydrogen or synthesis gas as building blocks for hydrocarbon fuel production.

building blocks, carbon dioxide and water. Photochemistry is a process in which the solar energy is absorbed and converted directly into fuels or other chemical compounds. Rather than using electricity from solar cells to enable the electrochemical production of hydrogen and carbon compounds, photo(electro)chemical systems combine everything necessary to go directly from sunlight to the final chemical product.

Research on photo(electro)chemical technology is still at the laboratory stage, but it bears important promises. The integration of all components into a single device can lower the total system cost and provide greater flexibility in the design. Compact, integrated devices which are independent of the electrical grid allow for a decentralized production of fuels and chemicals.

The main targets in SUNRISE are to develop novel light-absorbers and photocatalytic materials for integrated photo(electro)chemical systems and to increase solar-to-product efficiency beyond current levels. Photo(electro)chemical devices may operate as a solid state ”monolith” (buried junction cells or photoelectrochemical cells) or as a liquid phase suspensions of photochemical systems (photocatalytic nanoparticles or supramolecular assemblies).[45] Approaches hybridizing solid state and molecular active components (catalyst and light-absorber), including biological molecules extracted from living cells (bio-molecular systems) are also a promising route.



Direct conversion via biological and biohybrid systems

Photosynthetic organisms use sunlight as an energy source and raw materials such as carbon dioxide, water and mineral nutrients for the synthesis of oxygen and organic building blocks, supporting life on the planet. They do not need to be manufactured, but reproduce themselves. With the help of photosynthesis, algae and cyanobacteria can produce diverse products for industry. Dozens of genetically-engineered photosynthetic organisms hosting novel synthetic production pathways and enzymes are currently available for the production of desired chemicals.[46] Such production systems are called living photosynthetic cell factories. However, most of the available systems show low solar-to-chemicals conversion efficiencies and need significant improvements to serve as industrial-scale production platforms.

Biohybrid systems employ photosynthetic and non-photosynthetic living microbes wired to inorganic components (electrodes) to drive biosynthetic pathways. The photosynthetic microorganisms fuel the biosynthetic pathways with the energy captured from sunlight, whereas specific isolated enzymes or engineered non-photosynthetic microorganisms utilize this energy (in the form of water-derived reducing equivalents or electrons) to drive efficient CO_2 reduction into targeted organic molecules.

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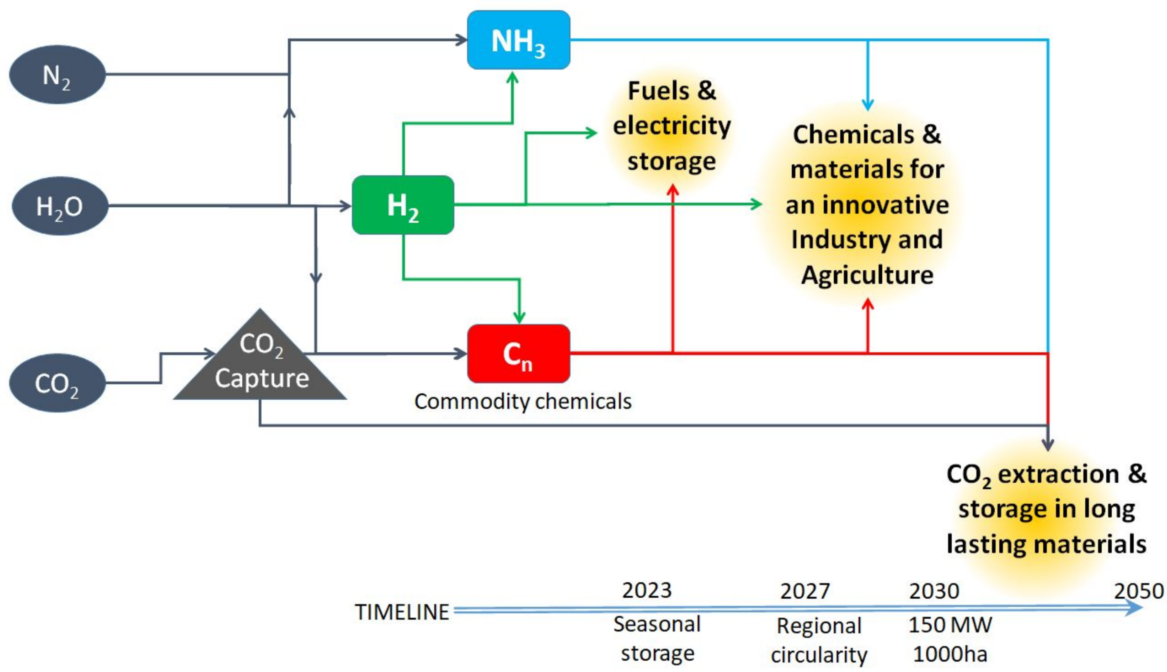
[45] Buried junction cells contain internal junctions between semiconductors, but no direct contact between the semiconductors and the catalyst/electrolyte. In photoelectrochemical cells, the light-harvesting components are directly interfaced with the catalysts/electrolyte, allowing for the catalyst to directly extract charge carriers from the excited state of the light-harvester to achieve multi-electron/multi-proton chemical conversion. The same applies in suspended or soluble photochemical systems.

[46] S. A. Angermayr et al. Trends Biotechnol., 2015, 33, 352–361.

Technological milestones to be achieved

Overview

Carbon, hydrogen, oxygen and nitrogen are the main atomic building blocks of commodity fuels and chemicals. This chapter presents a comprehensive and timely plan to unlock the path towards intermediary and final products, using atmospheric gases only as inputs, with a limited consumption of renewable energy flows. As shown in the figure below, water splitting is central, since molecular hydrogen, H_2, and water oxidation are key in the reduction of carbon dioxide and nitrogen. The timeline of future SUNRISE developments is discussed, with a first simplified time scheme in the figure below.



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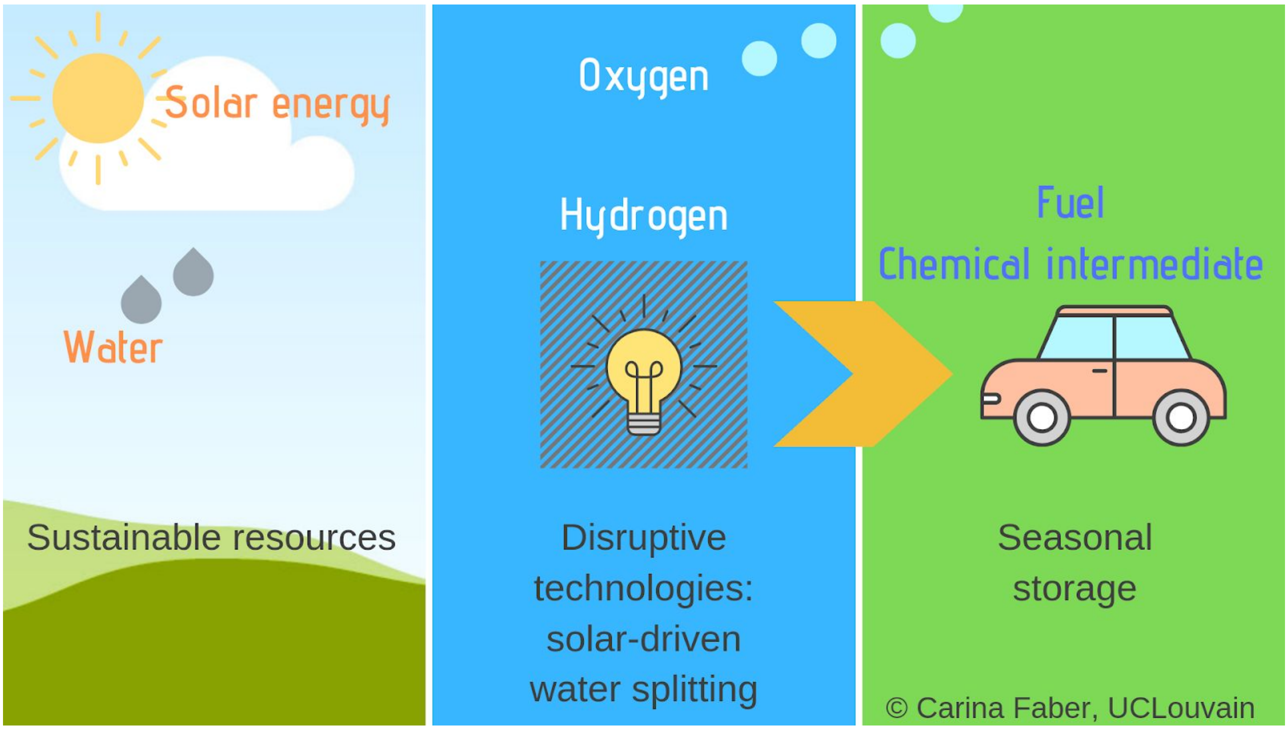
Atmospheric molecules (water, nitrogen, carbon dioxide) are converted using solar energy into hydrogen H_2, ammonia NH_3 and carbon-based chemicals C_n. H_2 is central in many processes. Carbon capture can be realized by physico-chemical devices or by photosynthetic microorganisms. Fuels and chemicals are targeted to be reached in the next decade; future progress in CO_2 and N_2 conversion will open new ways of storing atmospheric CO_2 in long-lasting carbon materials, here envisaged to reach market beyond 2030.

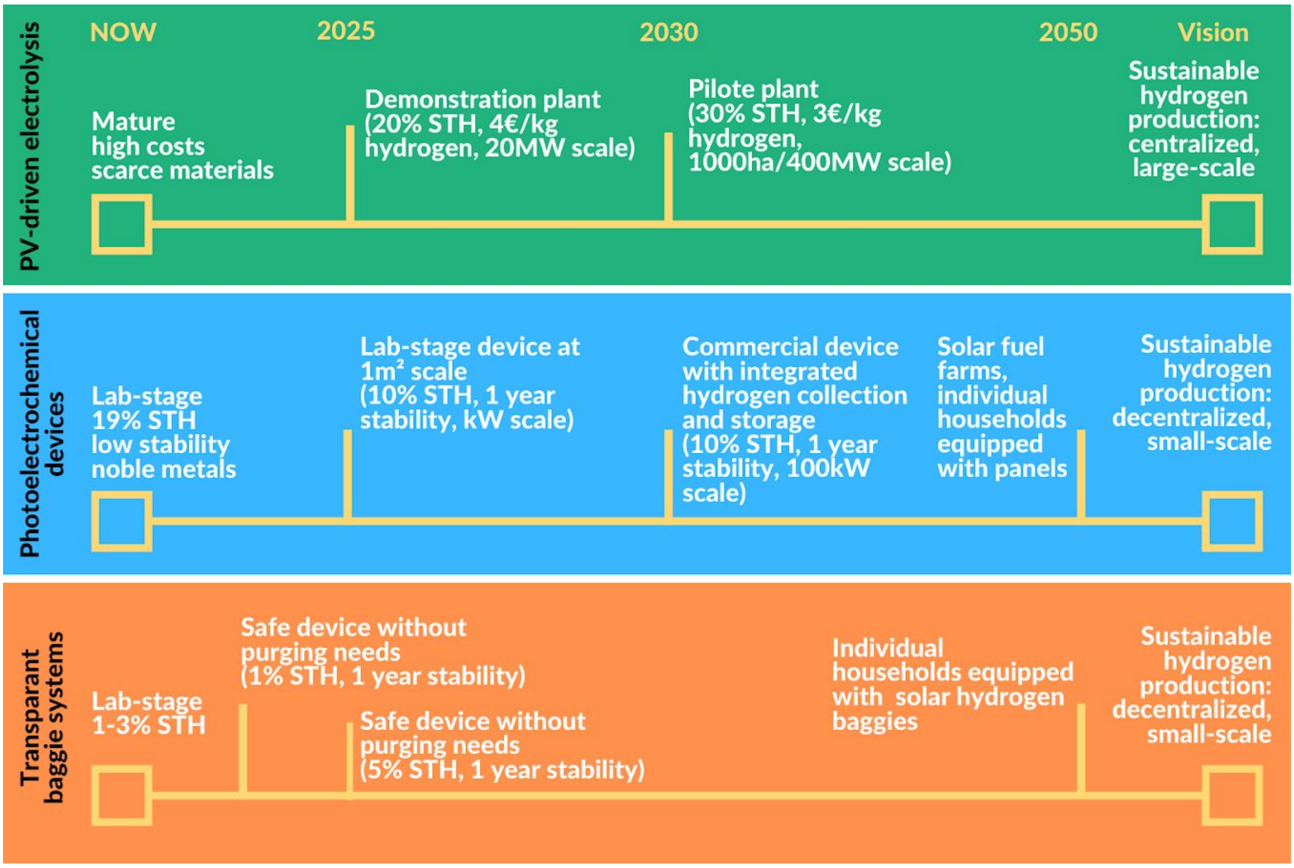
Sustainable hydrogen production

The SUNRISE vision is to produce green hydrogen in a fully sustainable and economically viable way by 2050, exclusively using solar energy and abundantly available materials and resources. Efficient solar-to-H_2 technologies will provide both short-term and seasonal solar energy storage capacity. A solar-to-H_2 transformation at a high efficiency will change the global energy balance and enable green CO_2 conversion. In addition, technological progress and achieved milestones in hydrogen production by SUNRISE technologies will directly translate into advances in solar ammonia and carbon transformation technologies.



Major milestones

Already mature technologies based on electricity-driven water splitting will provide a sustainable centralized production on the large-scale – given that system costs will significantly decrease and that bottlenecks related to upscaling will be solved. As a key milestone, an operational system of 1000 hectares to produce the equivalent to more than 90 tons per hectare per year of molecular hydrogen should be installed by 2050. Direct, light-driven approaches are currently at the lab stage, but once efficiency and stability issues are resolved, direct photo(electro)chemical technologies will provide an individual, decentralized production at the household scale. Safe and fully integrated devices (including hydrogen separation and storage) will allow for the equipment of individual house roofs or solar fuel farms and a completely local and autonomous hydrogen production. Such household equipment should also be deployable by 2050.



Major technological targets

Photovoltaics-driven electrolysis of water

Electrolyzers of different kinds are already available at advanced TRL levels (7-9). However, they show certain shortcomings: alkaline electrolyzers are available at scale, but suffer from intermittent energy supply; proton-exchange membrane (PEM) electrolyzers rely on scarce and precious metals as catalyst, which inhibits upscaling of the technology to the TW range. The most efficient high-temperature solid-oxide electrolyzers (SOE) are currently in the 20 kW range. Lifetime is always an important challenge, especially in a dynamic operation mode with rapid fluctuating power input. Current costs are high, mounting up to 1000€/kW for the electrolyzer device and 6€/kg hydrogen depending on the scale and localization of the plant. The electricity-to-hydrogen (LHV) efficiency is limited to about 60%.

Unique selling point: High technological maturity is one of the main advantages to pursue this approach and the first upscale to the MW range has been achieved. Research and discovery of new catalyst materials, based on earth-abundant elements and employed in electrolyzers, can advance and speed up the development of photoelectrochemical systems (cross-fertilization and knowledge transfer). Moreover, these systems are compact, necessitating no light management and thus enabling the stacking of the different units. They finally allow for an easy collection of already pressurized hydrogen (10-30 bars).

Vision for 2050: Photovoltaics-driven electrolysis allows for a centralized and efficient large-scale production of hydrogen. Compact systems are driven exclusively by renewable energy sources and based on abundantly-available materials and resources. Decentralized deployment of this solution at the household level will not be considered due to cost, operational and safety constraints that should not be leveraged by 2050.[47]

Working principle: The needed energy to split water molecules into molecular hydrogen and oxygen is provided by renewable solar electricity. Hydrogen and oxygen are produced at distinct electrodes coated with catalysts that are crucial to drive these chemical reactions and to avoid energy losses. Both electrodes are separated by a membrane (PEM and high-temperature electrolyzers) or a porous diaphragm (separating the electrode compartments filled with liquid alkaline electrolyte solution of potassium or sodium hydroxide in alkaline electrolysers) allowing gas separation.

Key research drivers: System costs, material scarcity, lifetime/degradation of catalyst material

Key enabling technologies: Advances in this field depend on technological breakthroughs in material science (noble-metal free catalysts and membranes, operating at different pH and impurity content), automated manufacturing technologies, system integration and upscaling.

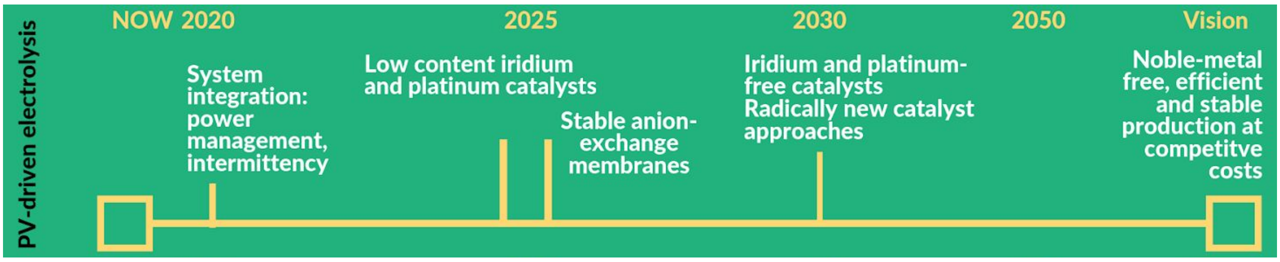
Present TRL: 4-6
TRL target 2030: 9

Major technological targets:

The goal is to provide **cost effective (100 €/kW)** and efficient electrolyzers (electricity to molecules **yield 80-90%**), where a major part can be operated **dynamically** to follow the intermittent supply of renewable energies. The required **scale of 100MW to 1 GW per unit** needs to be shown by first achieving TRL 5 and then building industrial demonstration units that go to TRL 8-9 based on an analysis of the value chain. All electrolyzers must be **user-friendly**, which means service intervals at a maximum of one year.
A challenge that needs to be solved in the polymer membrane technology is to develop **mechanically stable and highly conducting Anion Exchange Membranes** to allow the alkaline electrolyte regime to be utilized. This will also be needed for electrolyzers doing a direct conversion of carbon dioxide to hydrocarbons.
For the more dynamic neutral-acidic operation regime, a sustainable solution for replacing the scarce iridium catalyst (for the oxygen evolution reaction) and the expensive platinum catalyst (for the hydrogen evolution reaction) needs to be developed. The first approach to start demonstration will be a **dilution of the current catalyst**, e.g. on core-shell structures to reduce the catalyst loading from current 2 mg/cm² to 0.1 mg/cm². On the long-term, replacements for these materials need to be established; this will not be alternative metals or alloys, but **radically new approaches for nanostructured catalysts** using earth-abundant elements.
High-temperature solid-oxide electrolysis (SOE) will probably deliver the highest efficiencies (up to

[47] System cost analysis indicates that photovoltaics-driven electrolysis may not be competitive with electrochemical storage on decentralized (household) systems because of the high capital expenditure required for the electrolyzer, hydrogen storage system and fuel-cell.

100%), given centralized settings, where heat is available for the evaporation of the feed water. One main topic is the scaling of the membranes (currently only 100 cm²) by two orders of magnitude and increasing the dynamic operation power range. Novel ceramic technologies, such as fibre reinforcement and new construction principles to increase the stack size are promising here. Moreover, the modularity of SOE systems needs to be pushed following the example of photovoltaics to arrive at the scale needed. For both topics, the CAPEX has to be brought down by **advances in automated production technologies and power electronic environment**. In addition, **materials and interface design** will enhance performance as well as reliability and operation time (by lowering degradation) again leading to significant cost-savings.



For in-depth technical details, please refer to the technical annex (how-documents).

Photoelectrochemical devices

Techno-economic studies indicate that direct solar-to-hydrogen approaches can have both lower system costs and higher energy conversion efficiencies per active area than photovoltaics-driven electrolysis.[48] PEC systems permit a decentralized production, allowing for important savings in transportation costs (transport and compression significantly add up to actual hydrogen production costs, leading to hydrogen prizes at the fuel station of around 10 €/kg).[49] Lab-scale devices with different architectures have reached solar-to-hydrogen conversion efficiencies of up to 20%.[50]

Unique selling point:
Photoelectrochemical systems (PEC) are integrated and allow for large savings in terms of support and container as well as interconnecting electronics. As the surface of catalysis for water splitting is the same as the surface for sunlight collection, photoinduced current densities at the photoanode are up to two orders of magnitude lower than those required of classical electrolysis. This reduces the constraints on the used materials and allows for the use of abundantly available, cheap and non-toxic materials as catalysts. The overpotential losses are reduced by the integration of the PV and electrochemical stages in photocatalytic materials and components for PEC systems. In molecular systems, the very high surface to volume ratio and high extinction coefficient lead to very favourable materials efficiencies.

Vision for 2050: Photoelectrochemical devices will allow for a decentralized, local production of hydrogen, even down to the scale of single households. Systems will be fully autonomous, only depending on abundantly available sunlight. Water consumption is low.

[48] R.D. James *et al.* "Technoeconomic Analysis of Photoelectrochemical (PEC) Hydrogen Production" (2009) DOE Report, Contract Number: GS-10F-009J. Arlington, USA.
[49] 2018 Progress Report for the DOE Hydrogen and Fuel Cells Program, April 2019
[50] W.-H. Cheng et al. *ACS Energy Lett.* 2018, 3, 1795−1800.

Working principle: Photoelectrochemical cells are single devices that directly split water into hydrogen and oxygen, where the needed energy is provided by sunlight. Various architectures are possible but all of them combine light-harvesting materials (inorganic and organic semiconductors, molecular dyes or biological pigments) and catalysts for the hydrogen and the oxygen evolving reactions. Both reactions occur at separate (photo)electrodes or on different sides of a membrane allowing for easy gas separation.

Key research drivers: stability, efficiency, scalability. Total system cost, exclusive use of affordable and earth-abundant materials for light harvesting, charge separation and catalysis, ease of hydrogen collection. When mature, knowledge transfer to systems that produce other molecules than hydrogen.

Key enabling technologies: Advances in this field depend on technological breakthroughs in photon management technologies, nonadiabatic conversion of reactants into products, catalyst and semiconductor materials science and development. This field will largely profit from bio-inspiration (control of auto-assembly and charge photo-accumulation and transfer processes, development of responsive matrices and interfaces, development of self-repair/self-healing processes, discovery of noble-metal free and non-toxic catalysts inspired by enzymes, function-based systems engineering across length scales) resulting in devices with an increased efficiency.

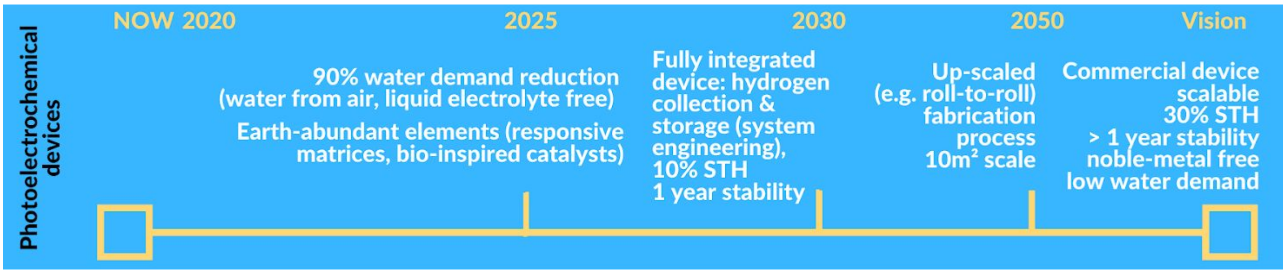
Present TRL: 2-4
TRL target 2030: 5-8

Major technological targets

Starting from the state-of-the-art, the first milestones (2025) will consist in (i) reducing the water demand of the devices by implementing components for water collection from the air and gelified membranes as the sole electrolyte in photo(electro)chemical devices; (ii) improving the stability of the devices (currently 1-30 days) through the development of improved interfaces as well as self-healing/self-repair processes for the active components responsible for light collection and conversion or catalysis; and (iii) achieving breakthroughs in materials research to design active components solely based on earth-abundant elements.

In parallel, efforts in chemical engineering shall allow to design a fully integrated system with 10% solar-to-hydrogen efficiency combining light-collection and hydrogen collection/storage at the m^2 scale and 1 year stability. Upscaling (e.g using roll-to-roll or equivalent processes) should allow the production of such devices at >$10m^2$ scale by 2050. Further optimization and full exploitation of the bioinspiration potential will allow to ultimately develop commercial devices at 30% solar-to-hydrogen efficiency.

For in-depth technical details, please refer to the technical annex (how-documents).



Transparent baggie systems (microorganisms and photocatalytic systems)

Techno-economical analysis have shown that suspended or surface coated systems in transparent baggies have the potential for competitive cost for hydrogen evolution.[51] Photosynthetic microorganisms (green algae and cyanobacteria) and inorganic photocatalytic systems (nanoparticles) are both able to directly produce molecular hydrogen from water under sunlight irradiation.
Solar-to-hydrogen conversion efficiencies are usually in the range of 1%. In such systems, oxygen, the co-product of the water-splitting reaction, is generally mixed with hydrogen in the output gas.

Unique selling point: Extremely low system cost, fast regeneration and long-term production capacity of living organisms (high stability) are the major advantages of this technology.

Vision for 2050: Transparent baggie systems allow for a decentralized, local production of hydrogen for single households and niche applications. Systems are fully autonomous, only depending on abundantly available sunlight. Preferably waste water is utilized.

Working principle: Very easy and cheap system consisting of transparent plastic bags, permitting solar energy to enter the system and to drive (bio)chemical reactions. Microorganisms (biological and biohybrid approach) or synthetic photocatalytic systems (*e.g.* nanoparticulate systems or supramolecular assemblies) are floating in water or attached to solid polymers (solid-state cell factory) and surfaces and split water into hydrogen and oxygen.

Key research drivers: Hydrogen separation, safety issues and production efficiency: currently with specific production protocols and with genetically-engineered algae, efficiency can be increased to 4% in lab scale,[52,53] while the theoretical limit of natural photosynthesis is 10-13%;[54] photocatalytic systems are currently limited by recombination processes (in the bulk of the materials and at their interfaces) and by unfavourable optical absorption profiles.

Key enabling technologies: Advances in this field depend on technological breakthroughs in system engineering for the separation, collection and storage of hydrogen, photobioreactor design, photon management, fundamental understanding of natural photosynthesis and cell metabolism, enzyme chemistry and material science and development, advanced theoretical and experimental techniques, synthetic biology toolboxes and other molecular technologies.

Present TRL: 3-4
TRL target 2030: 6-8

Major technological targets

A major milestone regards the separation of hydrogen from oxygen and overall safety. These issues can be fixed through efforts in chemical engineering by 2023-2024 (with *e.g.* membrane

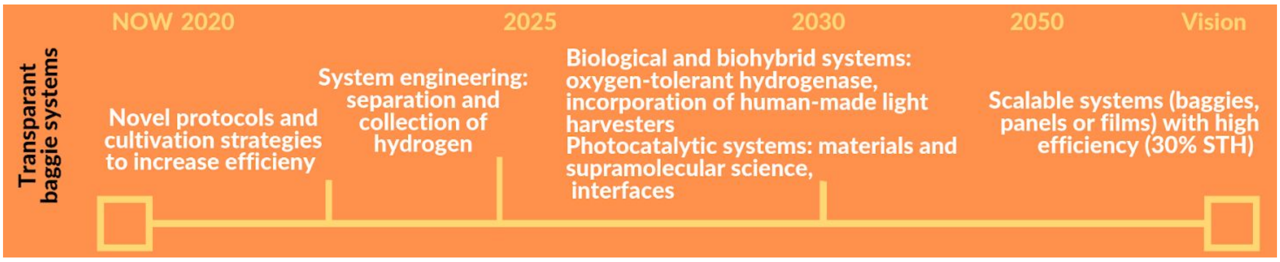
[51] Technoeconomic Analysis of Photoelectrochemical (PEC) Hydrogen Production 2009 DOE report; Domen et al., Nature Materials Vol. 15, 611-615 (2016); Domen et al., Joule Volume 2, Issue 3, 2018, 509-520

[52] Kosourov S. et al., Energy Environ. Sci. 1, 1431-1436 (2018)

[53] Nagy V. & Tóth SZ (2017) Photoautotrophic and sustainable production of hydrogen in algae, European Patent Application 17155168.2

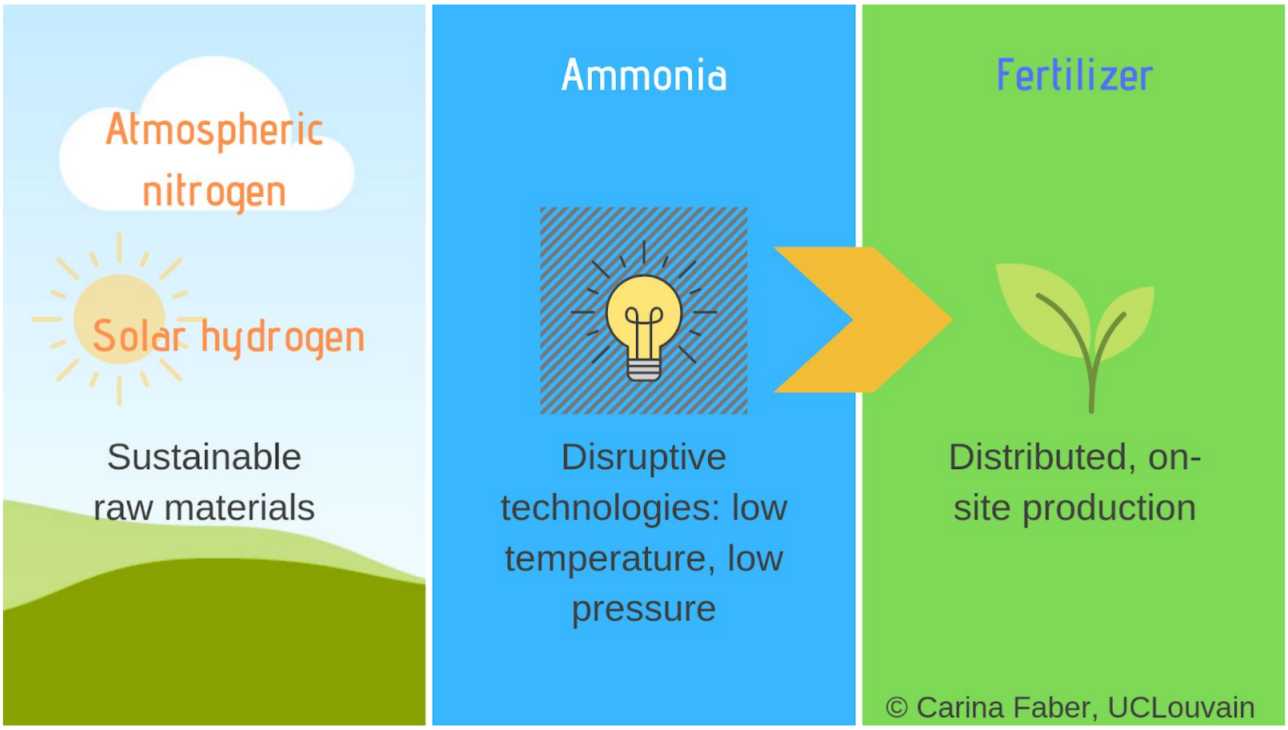
[54] Torzillo, G. et al. (2015), Crit. Rev. Biotechnol. 35, 485-96

technologies). The development of more efficient systems is a second milestone, which will require breakthroughs in: (i) unlocking photosynthetic control to funnel more electrons to hydrogen-producing enzymes; (ii) synthetic biology to incorporate and develop efficient and stable enzymes and photosensitizers in microalgae; (iii) materials sciences to develop highly efficient photocatalytic systems that overcome recombination losses.



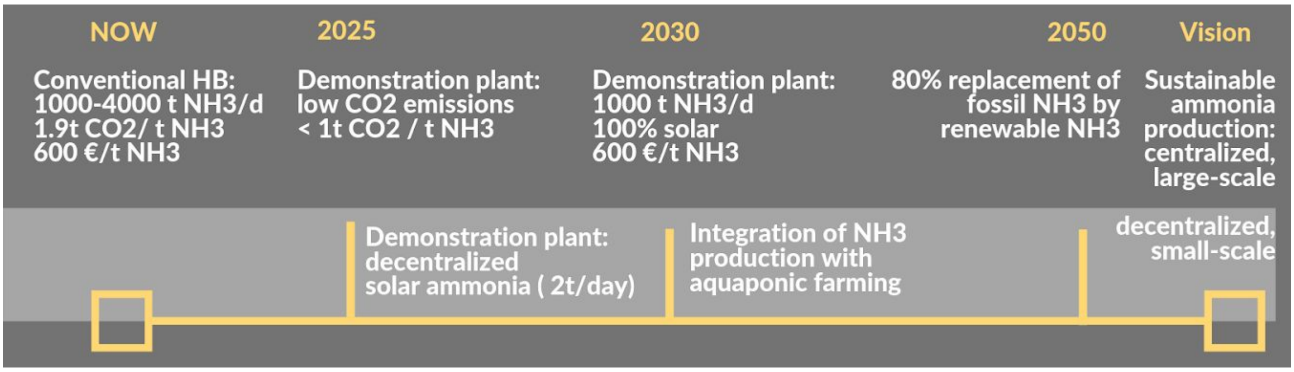
Sustainable ammonia production

SUNRISE aims at a sustainable production of ammonia by converting atmospheric nitrogen and sustainably produced hydrogen. One direction is to minimize carbon emissions related to the conventional production. This low-carbon Haber-Bosch process works at lower temperature and pressure and profits from the possibility to use already existing large-scale infrastructure. Another route is the decentralized, on-side demand production of ammonia using photo(electro)chemical and biological technologies. Within 2030, SUNRISE plans to set up pilot plants for a CO_2-neutral, centralized and decentralized solar ammonia production.

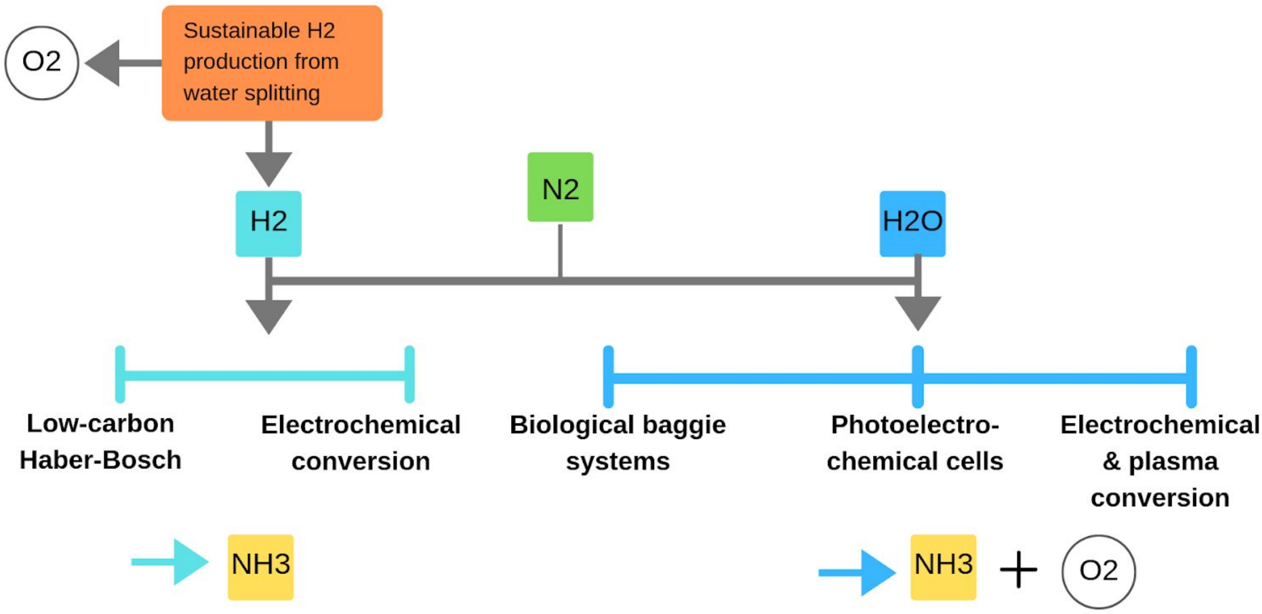


Major milestones

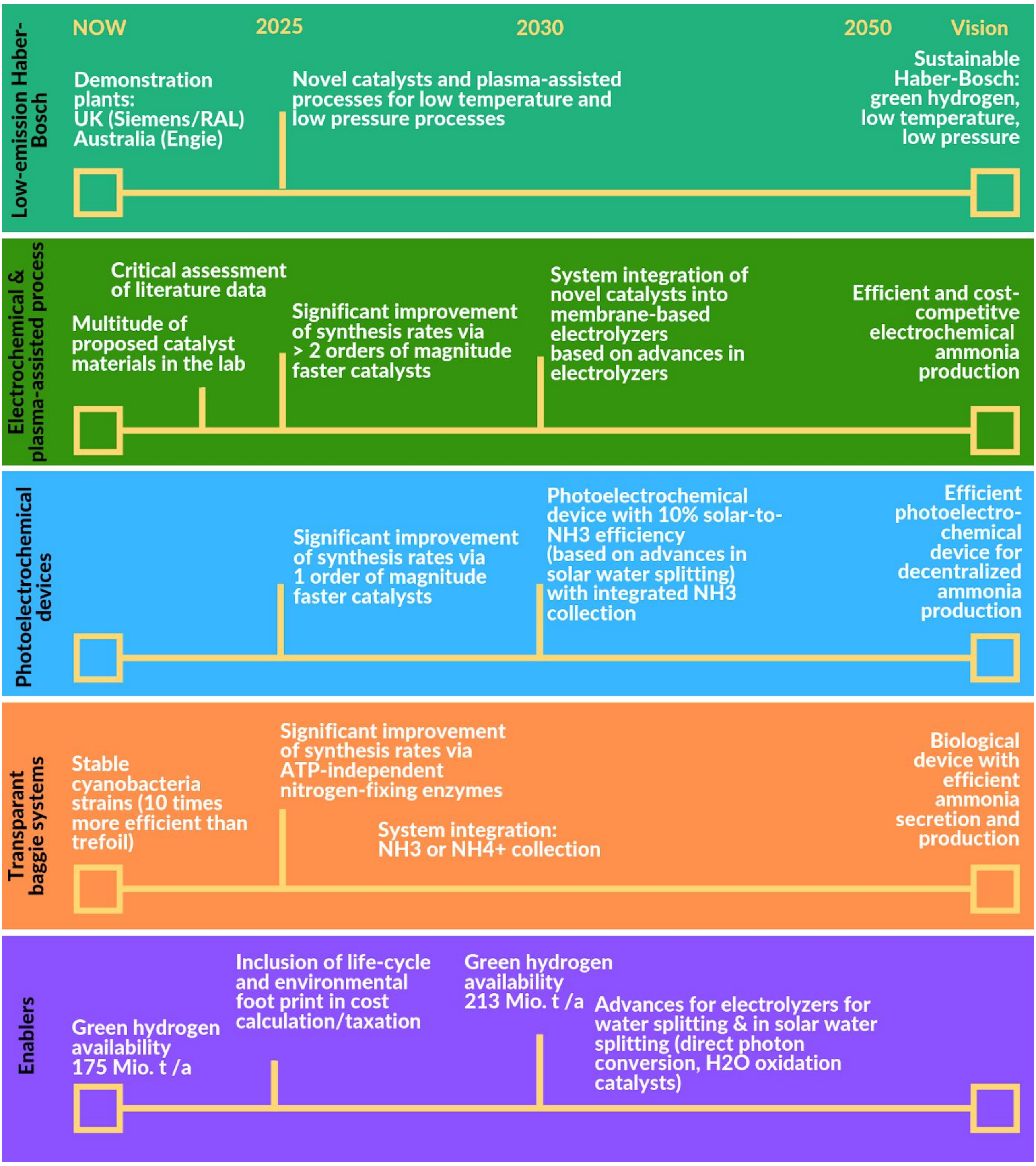
The SUNRISE vision is to produce green ammonia without CO_2 emissions and to enable an on-side production. This reduces CO_2 emissions caused by transportation and allows the integration of fertilizer production with aquaponic farming and precision farming. Starting from the currently deployed Haber-Bosch process, a first milestone consists in adapting it to the use of significant amounts of solar hydrogen so as to reduce its carbon footprint. A reduction by 50% of CO_2 emissions is targeted for 2025 and full decarbonization is expected for 2030. In parallel, the development of small ammonia production devices working at lower temperature and lower pressure will allow their tailored implementation and integration in sustainable agricultural practices. These two routes combined will allow for the replacement of >80% ammonia produced from fossil resources by renewable ammonia by 2050.



The following scheme summarizes the different technologies for ammonia production considered in this roadmap. Approaches using molecular hydrogen as a raw material include the low-carbon Haber-Bosch process and the electrochemical conversion. The large-scale deployment of these technologies strongly depends on the availability of sustainably produced green hydrogen. This possible risk is circumvented by approaches taking water as hydrogen source (transparent baggie systems with microorganisms, photo(electro)chemical cells, as well as plasma conversion).



Major technological targets



Low-emission Haber-Bosch

The conventional Haber-Bosch process is very efficient in terms of energy consumption. However, it currently relies on hydrogen produced at high pressure from natural gas or hydrocarbons and results in high CO_2 emissions (around 1.9 t CO_2 per 1 t NH_3). The use of renewable (solar) hydrogen produced on-site as input will allow the progressive defossilization of this process. In order to be fully compatible with green hydrogen production, it is necessary to bring down pressure and temperature demands of the Haber-Bosch technology from 300 bars and 600°C to <30 bars and <100°C, therefore reducing the needs for compression and heating.

Unique selling point: Technological maturity and the possibility to use existing infrastructure, together with the existing solutions to produce solar hydrogen, are the main reasons to pursue this approach.

Vision for 2050: Low-emission Haber-Bosch allows for a centralized, low-carbon large-scale production of ammonia. Existing infrastructure from conventional Haber-Bosch plants can be used. If the process is adapted to work at lower temperature and pressure, decentralized production of ammonia could also be deployed.

Working principle: The Haber-Bosch reaction (N_2 +3 H_2 ⇒ 2 NH_3) needs catalysts to proceed at an appreciable rate. The reaction is exothermic, but low conversion is obtained even at T=600° and p=300bar due to kinetic issues; Lowering the temperature and pressure is beneficial for thermodynamics, but detrimental to kinetics.

Key research drivers: catalyst development to drive processes at ambient temperature and pressure; combine catalysts with non-thermal (cold) plasma techniques to assist the cleavage of the N_2 molecule; decrease energy consumption of air supply unit for nitrogen extraction from the air.

Key enabling technologies: advances in green hydrogen production, high-throughput computing for materials science and development. Rational design of bioinspired catalysts for N_2 reduction derived from nitrogenases that operate at ambient temperature.

Present TRL: 5-6
TRL target 2030: 9

Major technological targets:
Two demonstration plants are under development, in Oxford, UK (Siemens/RAL) using wind as a primary energy and in Pilbara, Australia (Engie/Yara, to be commissioned in 2021 at the earliest) with a target of > 80 t of ammonia produced per day using a 50-60 MW electrolyzer coupled to a PV field and producing 10% of the hydrogen required. These plants use conventional high-temperature, high-pressure Haber-Bosch technology and it is expected that such plants can use up to 100% renewable hydrogen so as to cut direct carbon emissions. To further improve the energy efficiency of carbon neutral ammonia production, it will then be required to develop alternative catalysts working at lower pressure and temperature, possibly with the assistance of non-thermal (cold) plasma techniques to ease the cleavage of the N_2 molecule.
For technical details, please refer to technical annex (how-documents).

Electrochemical and plasma-assisted ammonia synthesis

The use of renewable electricity to produce ammonia encompasses two technological solutions. The first one relies on N_2 co-electrolysis with either water or solar hydrogen and requires the development of novel, possibly bioinspired, electrocatalysts for proton-coupled N_2 reduction

(Nitrogen reduction reaction, NRR; the second one uses plasma techniques to cleave the very stable N_2 molecule and allow for its conversion in the absence of catalysts.

Unique selling point: These technologies have the potential to allow for carbon-free ammonia production. They do not require high pressure or high temperature and can then be developed in a decentralized production system.

Vision for 2050: These technologies will allow a decentralized, low-carbon large-scale production of ammonia in field and even possibly at the foot of the plants.

Working principle: At the anode of electrochemical cells, water or renewable hydrogen will be oxidized delivering protons and electrons to the cathode electrocatalysts (solid-state materials, nitrogenases or molecular mimics of their active sites) to achieve the 6-electrons/6-protons reduction of N_2. The anode and cathode compartments are separated by a proton-permeable membrane to allow for easy separation of the ammonia product. A reduced (0.2-0.4 V) electrical potential is required when H_2 is used instead of water (>2.5 V) at the anode. The plasma-assisted process uses electrical power to create a cloud of atoms from a mixture of N_2 and water. These atoms then react together to form ammonia and oxygen. Water consumption is low but purification of nitrogen from atmospheric oxygen will be required.

Key research drivers: NRR catalyst discovery and non-thermal plasma assisted process development, proton conducting electrolyte developments.
Key enabling technologies: Regarding membrane and anode catalysts, electrochemical nitrogen reduction will strongly rely on advances in electrolyzers and fuel cells for hydrogen production and utilisation.

Present TRL: 1-2
TRL target 2030: 4-5

Major technological targets
The field of NRR catalysts seems nowadays very prolific but recent reports[55] by experts in catalysis seriously question the methodology used so far to assess NRR catalytic performances. A critical assessment of literature data is then needed urgently to establish the field on solid ground. The discovery of novel catalysts of NRR with performances at least two orders of magnitude higher than currently reported (*i.e.* allowing current densities of >100 mA/cm2) is required and will then be implemented into electrolysis cells, thanks to the knowledge gained in electrochemical hydrogen production and CO_2 valorization. Plasma processes will be developed in parallel with the aim of improving the yield of ammonia production and the energetic yield of the process.

Photoelectrochemical devices

Similarly to direct solar hydrogen production, photoelectrochemical systems have the potential to allow for decentralized ammonia production at lower cost compared to other techniques.

[55] "A rigorous electrochemical ammonia synthesis protocol with quantitative isotope measurements" S. Andersen et al., Nature 570, 504–508 (2019); "Role for Standardization in Electrocatalytic Ammonia Synthesis: A Conversation with Leo Liu, Lauren Greenlee, and Douglas MacFarlane" C. MacLaughlin ACS Energy Lett. 2019 46 1432-1436 and references herein.

Unique selling point: Photoelectrochemical systems are integrated and allow for large savings in terms of support and container as well as interconnecting electronics. As the surface of catalysis for water splitting is the same as the surface for sunlight collection, current densities at the photocathodes (10 mA/cm^2) are up to two orders of magnitude lower than those required for cost-effective electrolysis. This reduces the constraints on the used materials and allows for the use of abundantly available, cheap and non-toxic materials as catalysts. For the supramolecular photochemical systems, the intrinsically high surface to volume ratio leads to favourable materials efficiencies.

Vision for 2050: Photoelectrochemical devices will allow for a decentralized, on-site and on-demand production of fertilizers, down to the scale of greenhouses or fields. Systems will be fully autonomous, only depending on abundantly available sunlight. Water consumption is low, but purification of nitrogen with air-separation units will be required.

Working principle: Photoelectrochemical cells are single devices that directly split water and N_2 into ammonia and oxygen, where the needed energy is provided by sunlight. Various architectures are possible, but all of them combine light-harvesting materials (inorganic and organic semiconductors, molecular dyes or biological pigments) and catalysts for the ammonia-forming and the oxygen-evolving reactions. Both reactions occur at separate (photo)electrodes or in molecular reaction cascades embedded in membranes allowing for easy separation of the products. A flow of the cathodic electrolyte might be needed to recover the ammonia product.

Key research drivers: NRR catalyst discovery
Key enabling technologies: relies on advances in the development of photo(electro)chemical devices for direct solar water splitting and electrochemical NRR (see above);

Present TRL: 1-2
TRL target 2030: 4-5

Major technological targets
Although photoelectrochemical nitrogen fixation is still at its very infancy, rapid progress can be expected when actual catalysts for nitrogen fixation will have been discovered and 10% solar-to-ammonia efficiencies can be achieved in photo(electro)chemical devices with integrated collection of aqueous ammonia solution before 2030.
For technical details, please refer to technical annex (how-documents).

Microorganisms for direct fertilizer production
Some photoautotrophic microbes use solar energy to fix atmospheric N_2 to ammonia via a nitrogenase enzyme. The enzyme is oxygen sensitive, therefore oxygenic photosynthetic microbes known as cyanobacteria (*e.g.* trichome) produce ammonia in specialized micro-oxic cells, called heterocysts, or in micro-oxic niches inside of the cells. This enables the O_2-sensitive nitrogenase to perform N_2 fixation during photosynthetic oxygen evolution and under ambient air. In principle, a similar approach can be developed for synthetic photocatalytic systems.

Unique selling point: Different from Haber-Bosch, this process does not demand high temperature, high pressure or purified resources (N_2 and H_2). Green ammonia is produced from solar cultures of photosynthetic microbes, simultaneously with CO_2 sequestration. The living organisms are self-replicating which lowers system costs. The product can be directly used in precision farming and aquaponic culture (NH_4^+).

Vision for 2050: Precision agriculture (or organic farms and greenhouses) with co-cultivated cyanobacteria acting as N_2-fixing biocatalysts producing and secreting NH_4+.

Working principle: Baggie or photobioreactor systems allowing a decentralized, local production of ammonia for single households and niche applications**.** The technology will include newly identified and engineered photosynthetic microbes acting as N_2-fixing cell factories: the cells produce NH_4^+ from atmospheric N_2 and excrete it out**.** Integrated crop/ algae co-culturing in organic farms and greenhouses will enable a closed loop of nutrient cycling.

Key research drivers: high cultivation costs, low product efficiency, bottlenecks in product separation; fast assimilation of ammonium by cyanobacteria should be avoided, toxicity of the product at high concentrations, robustness of production strains.

Key enabling technologies: synthetic biology tools, special photobioreactor design and optimization, product separation, collection, modelling and development of control tools, scale-up modelling.

Present TRL: 1-2
TRL target 2030: 4-6

Major technological targets
Engineered cyanobacterial strains currently exist which produce and excrete ammonium ten times more than trefoil.[56] Application of new metabolic engineering strategies to develop novel and efficient ammonium producers, identification of efficient, low energy-demanding (or ATP-independent) and O_2 resistant nitrogenases via mining and introduction of these enzymes in living systems through synthetic biology will allow a significant improvement of productivity by 2025. System integration efforts will then be needed to design photobioreactors with integrated ammonia or ammonium separation and collection. Such photobioreactors should be able to be installed in field and greenhouses and supply fertilizers in a decentralized manner.
For in-depth technical details, please refer to the technical annex (how-documents).

[56] Bui et al. 2014 Isolation, improvement and characterization of an ammonium excreting mutant strain of the heterocytous cyanobacterium, Anabaena variabilis PCC 7937. Biochem Engineer J. 90: 279-285

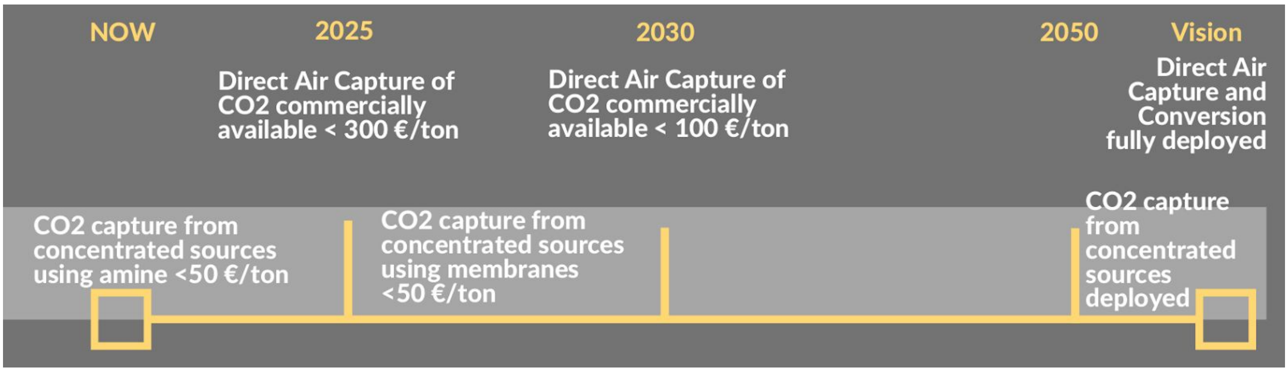
Sustainable carbon capture

Many policy and industrial drivers exist to activate the deployment of already mature carbon capture technologies. CCU actors and CCS promoters push for a large scale adoption and most of the effort will go on disconnected from SUNRISE S&T development. However, one topic will be directly impacted by SUNRISE ideas and is thus addressed in more details: the research towards combined processes of capture and chemical conversion.

Today, a large range of potentially attractive CO_2 sources is available, which can be divided into CO_2 point sources and atmospheric CO_2. The largest emitters are fossil-fuelled power plants. Other point sources include cement plants, the first largest industrial emitter (3.8 Gton CO_2/year), followed by the iron and steel industry (2.8 – 2.9 Gton CO_2/year), pulp and paper, refineries, steam crackers and chemical plants. Depending on the type of CO_2 source, CO_2 concentration can range from nearly 100% for ammonia / ethylene oxide / hydrogen plants and biogas upgrading, up to 70% for natural gas processing[57] and down to 3-5% for gas-fired combustion processes. Not only CO_2 concentration but also the impurities present will impact the performance of the capture process. Besides, the atmosphere is a potentially huge (teraton scale) CO_2 reservoir for decentralized systems, but with a concentration of only about 400 ppm. This will require highly efficient separation from oxygen and nitrogen, especially for electrochemical and photo(electro)chemical methods.

Different types of carbon capture technologies can be applied depending on the source of CO_2: for point sources, the most mature technologies consist in separating and concentrating CO_2 by chemical or physical absorption (*e.g.* utilizing amine solvent) or by adsorption (using a solid sorbent or membranes). Capturing from the atmosphere is termed Direct Air Capture (DAC).

Major milestones



CO_2 capture from concentrated sources

Among the different technologies existing for capturing CO_2 from industrial point sources, the most mature one is by chemical absorption (amine, ammonia…). This technology will likely develop at industrial scale (400000 ton CO_2/year for a large scale plant) with reasonable economics (capture cost < 50 €/ton CO_2) within the next 3 years. However, chemical absorption will have to face different challenges: reduction of the energy consumption (currently at 3.5 – 3.8 GJ per ton of CO_2

[57] Natural gas processing refers to dehydration and cleaning to make pipeline grade natural gas.

from point sources)[58], management of the environmental impact (risk of aerosols formation / amine emissions, solvent stability, chemical waste handling), scaling-down for smaller point sources. In the next 5-10 years, improvement in process design and solvent development (*e.g.* amino acids, demixing amines, ionic liquids, enzymes, …) can bring down the energy consumption to 1.5-2 GJ/ton CO_2 from point sources.

Concentrated point sources ([CO_2] > 20%) offer early opportunity for membrane capture deployment with performances equivalent to the amine process. Membrane technology presents the advantages of being modular and affords a smaller footprint, fully electrified, flexible, lower CAPEX, especially at small scale. Membrane capture is probably one of the best candidates for small scale, decentralized CCU. Its maturity is probably 5-10 years behind amine absorption. In the coming years, membrane development (*e.g.* facilitated transport, nanocomposite membranes or systems with higher permeability and selectivity) and better process integration (*e.g.* pre-treatment, configuration) can further increase their industrial application.

Besides post-combustion capture, other capture technologies such as oxyfuel combustion (*i.e.* with pure oxygen or oxygen enriched air), Calix's technology (development for cement industry: indirect heating of the limestone in the calciner in an enveloping vessel, allowing pure CO_2 release from the limestone calcination) or Smelting Reduction Process in the steel industry (Hirsana) will allow to obtain pure CO_2 without significant energy penalty. Industrialization of these latter processes are expected by 2030-2035.

Unique selling point: The high maturity and availability at short-term of these technologies are one of the main advantages to pursue this approach. Moreover, they produce a CO_2 stream with a high purity.

Working principle: CO_2 in the flue gas is separated and concentrated by chemical absorption/regeneration (amine technology) or by membrane technology using a physical or chemical mechanism.[59]

Key research drivers: Improvement of energy efficiency, environmental impact, scale-down, cost.

Key enabling technologies: Advances in this field depend on technological breakthroughs in new solvents development and process optimization to reduce the energy requirements and the environmental impact (higher stability of solvent, control of emission …).

Present TRL: 6-7
TRL target 2030: 9

For technical details: refer to technical annex (how-documents)

[58] A useful comparison for this energy by weight is obtained by considering how much energy is obtained while producing the waste CO_2. If this CO_2 is released from methane burning, about 19.6 GJ are obtained per ton, whereas about 13 GJ are gained in case of oil burning, and about 8 GJ only from the combustion of coal.

[59] Transport through a membrane can also be based on a chemical reaction.

Direct CO_2 Capture from the atmosphere

Direct Air Capture (DAC) can be applied for centralized or decentralized systems but mostly, it can deal with mobile sources, such as automobiles, ships, aircraft and other non-stationary sources.

Unique selling point: Technological maturity and the possibility to use this technology for decentralized systems are the main advantages to pursue this approach.

Working principle: Direct Air Capture (DAC) is the physical or chemical separation of CO_2 from ambient air. There are currently two main technologies in development: Absorption with a liquid strong base, referred to as High temperature DAC (Carbon Engineering), and adsorption on solid sorbent, referred to as Low temperature DAC (Climeworks, Global Thermostat, Antecy).[60]

Key research drivers: cost, energy demand, material stability and kinetics

Key enabling technologies: Advances in this field depend on technological breakthroughs in material science (improvement of sorbent/solvent (kinetics, stability and lower regeneration energy), process integration and identification of renewable sources of heat.

Present TRL: 6
TRL target 2030: 8-9

Major technological targets

At present, major challenges are (i) the high cost (today 300-600 €/ton CO_2, some technology providers have announced cost reduction down to 100 €/ton CO_2 on the short term, but this still has to be demonstrated) and (ii) energy consumption (today, 5-9 GJ/ton CO_2). This is mainly due to the low concentration of CO_2 in the atmosphere, roughly 0.04%. In order to be successful, DAC technology will need to achieve low total cost and high amounts of net CO_2 removal (reduce energy consumption[61] and use of low carbon energy). To reach these goals, research is needed for sorbent/solvent development (low regeneration energy, high CO_2 selectivity, fast reaction times and low degradation rates), process integration with low-carbon heat, improved process design and air contactors. This needs to play together with the size increase of the systems (economy-of-scale).

On the short-medium term (5-15 years), R&D to improve process design and integration will support reducing the cost and energy consumption of DAC. It is also foreseen that the number of demonstration projects will increase and confirm the scale-up potential (up to several hundred kton CO_2/year), establishing references systems, integrating the use of low carbon energy sources, validating cost and performance. By 2030-2035, a commercial portfolio of DAC systems with potential capacity of 100 Mton CO_2/year can be expected. Regarding the cost, according to providers, improved design and better solvent/sorbent development can reduce it to < 300 €/ton

[60] Solvent regeneration necessitates high temperatures (about 700°C), whereas solid sorbents can be regenerated at low temperatures (ca. 100°C).

[61] There is a lot of room for improvement, the thermodynamic limit being more than 10 times lower than present energy consumptions. See *e.g.* K.S. Lackner, *Energy*, **50** (2013) 38-46.

CO_2 on the short term (< 5 years) and with the expected deployment and mass production, it can be further reduced to < 100 €/ton CO_2 by 2030.

Direct Atmospheric CO_2 Capture & Conversion (DACC)

CO_2 capture technologies have in common one major challenge: the energy use. Most of the energy use is linked to the regeneration step where pure, gaseous CO_2 is released. The best strategy is to avoid this step and to develop a technology allowing the direct conversion from the captured CO_2 solution. This is called Direct Atmospheric CO_2 Capture & Conversion (DACC).

Unique selling point: Such a system will have the advantage to combine in one single-step the capture and conversion of CO_2 and in the long-term will enable the decentralized production of chemicals and fuels with highly efficient solar energy devices.

Working principle: CO_2 capture often uses alkali or amine solution and CO_2 is captured under the form of carbonates or carbamates. Captured CO_2 can serve as electrolyte or intermediate for direct reduction to CO or hydrocarbons. Such an approach has been found in different recent studies. Sargent et al have studied[62] the reactivity of K_2CO_3 solutions using an Ag catalyst for the direct conversion to syngas. Prakash et al. on the other hand have studied[63] the possibility of using amines grafted onto solid supports for tandem CO_2 capture and conversion to CH_3OH using homogeneous hydrogenation catalysts.

Key research drivers: reactivity of carbonates / carbamates, development of CO_2 selective catalyst, direct conversion of atmospheric CO_2 to syngas by thermochemical and photo(electro)-chemical routes.

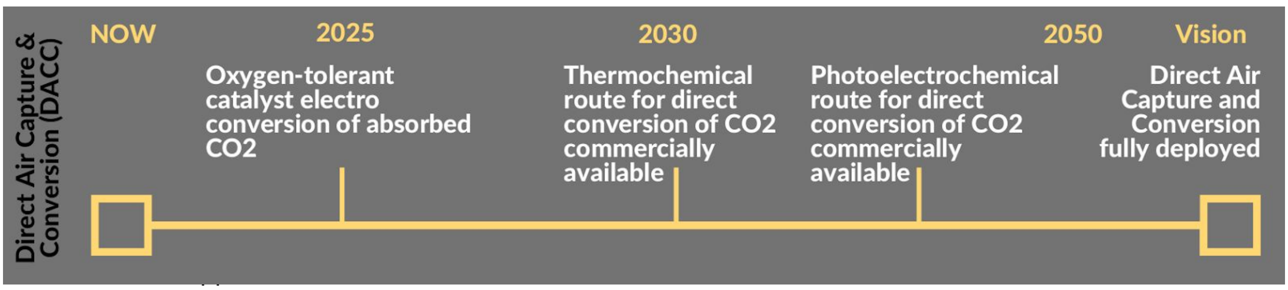
Key enabling technologies: Advances in this field depend on technological breakthroughs in material science (catalysts) to increase the selectivity and reactivity of carbonates / carbamates.

Present TRL: 1-2
TRL target 2030: 5-7

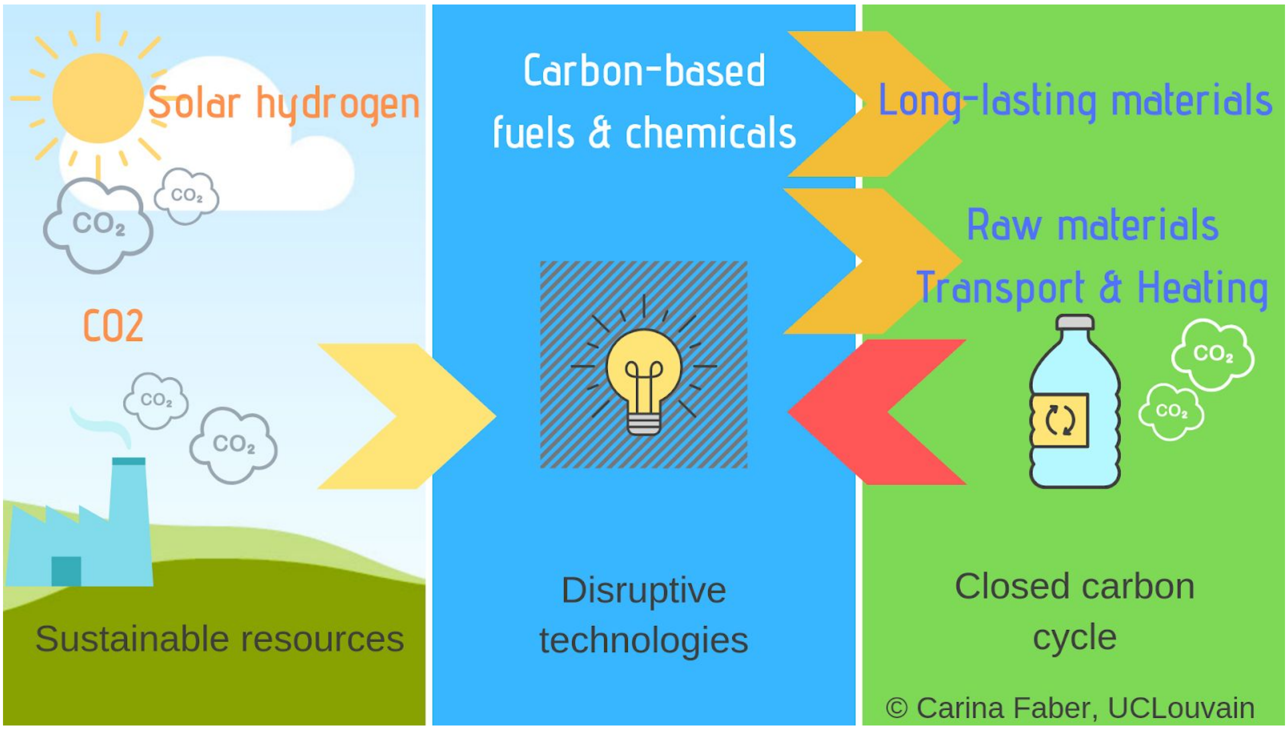
The following timeline is expected to achieve by 2035-2040 commercial solutions for DACC:

- In the next 5 years, study of oxygen-tolerant catalyst for photo/electro-reductive conversion of carbonates/carbamates: existing and development of new systems.
- Thermal chemical conversion route: direct conversion of atmospheric CO_2 to syngas TRL 5 in 2025, commercially available by 2030.
- Photo(electro)chemical conversion route: direct conversion of atmospheric CO_2 to syngas TRL 3 in 2025, TRL7 by 2035, commercially available by 2040.

Major technological targets



Sustainable production of commodity chemicals and (jet) fuels



Today, the overwhelming majority of carbon-based fuels and chemicals has fossil origin. Upon their combustion and utilization, large amounts of CO_2 are generated, contributing to global warming.

For many application scenarios, alternatives are currently developed. For instance, battery-electric and fuel cell vehicles are designed for road-based transportation. In certain cases, however, a very high energy density is required, which currently is only feasible using hydrocarbon-based fuels. This is especially important in aviation, where the energy density of hydrocarbon fuels is crucial to achieve intercontinental travel without refueling. CO_2 emissions account for about one third of the total adverse effect of aviation on the climate (with the other two thirds being caused by water vapor, NO_x-induced ozone production and induced cloud formation)[64]. By using renewable solar fuels, the effect of aviation on global warming could therefore be significantly reduced. In SUNRISE, we aim at the cost-competitive, mid-scale production of sustainable jet fuels (700 000 barrels produced per year, *i.e.* delivering ca. 150 MW, on 1000 ha) for 2030.

In principle, it is possible to produce and use carbon-based fuels and chemicals without net CO_2 emissions. This requires CO_2 capture from the air or industrial processes, followed by the synthetic production of carbon-based fuels and chemicals. Carbon dioxide is then either stored in long-lasting carbon materials on the long term (negative emissions) or directly released when the products are *e.g.* combusted using conventional technology. In the following, four different technological routes are detailed: Power-to-Liquid, solar-thermochemical conversion,[65] direct photo(electro)chemical conversion and bio-catalytic production.

[64] Lee et al., Atmos. Environ. 43, 2009, 3520-3537

[65] Solar-thermochemical conversion processes are not originally part of the three Sunrise approaches, yet they are a promising option for producing carbon-based compounds,They are thus briefly described in the following as additional approach in the SUNRISE Roadmap.

Power-to-Liquid: Electrochemical processes

Power-to-Liquid production pathways represent a group of processes converting water and CO_2 into liquid carbon-based products. They involve electrochemical reactions, typically the splitting of water into hydrogen and oxygen and/or the reduction of CO_2. Diverse organic compounds, such as formic acid (HCOOH), methanol (CH_3OH), ethylene (C_2H_4), methane (CH_4) and carbon monoxide (CO) can be produced via the electrochemical reduction of carbon dioxide, forming a versatile basis for a broad range of chemical products and fuels. Higher-order alcohols, such as ethanol and *n*-propanol, could be highly promising under future conditions.[66] Heavier hydrocarbon products, such as synthetic fuels, can be generated based on the primary electrochemical production of syngas (mixture of hydrogen, H_2, and carbon monoxide, CO), which is then converted into hydrocarbons via the thermochemical Fischer-Tropsch synthesis. This is a very attractive production route to liquid hydrocarbon fuels for the aviation sector, which will remain strongly dependent on such fuels for decades.

Power-to-Liquid pathways are often based on the electrochemical splitting of water generating hydrogen, which is then used for a subsequent chemical (thermocatalytic) conversion of CO_2. Alternatively, production pathways can also involve electrochemical reduction of CO_2. Both options will be briefly described in the following.

Electrochemical water splitting and thermocatalytic conversion of CO_2

Unique selling point: Hydrogen electrolyzers in the 1-10 MW are current industrial standard (see previous chapter). Thermocatalytic reactors and processes that use hydrogen to reduce CO_2 into energy containing molecules exist and are already used on a similar scale. Demonstrators to generate synthetic fuels are currently built and operate at the MW scale.[67] Given that these technologies are scaled-up and improved in efficiency, they will become the first available technology path for green fuels.

Working principle: The process basically consists of two steps. The first step is an electrochemical one, where renewable energy is used to generate high-energy intermediate products. This can be H_2 from electrolysis of water or CO/H_2 mixtures (known as synthesis gas, yielded from electrolysis of CO_2/water mixtures). The energy is stored in chemical bonds.
The second step consists of one or multiple thermo-catalytic reactions at elevated temperatures and pressures. Various reaction schemes are known: Dependent on the target product, this can be direct reaction of H_2 and CO_2 to *e.g.* methanol. The latter is a valuable intermediate product that can be used as a commodity chemical or further processed via thermo-catalytic reactions to olefins, gasoline or middle-distillates, such as jet fuel. The reaction can be steered towards methane (CH_4) as green replacement of natural gas. As an alternative to the production of methanol as an intermediate product, synthesis gas[68] can be converted into medium and

[66] Jouny, Matthew; Luc, Wesley; Jiao, Feng (2018-02-14). "General Techno-Economic Analysis of CO2 Electrolysis Systems". *Industrial & Engineering Chemistry Research*. **57** (6): 2165–2177. doi:10.1021/acs.iecr.7b03514

[67] *e.g.* The SPIRE project http://www.mefco2.eu/

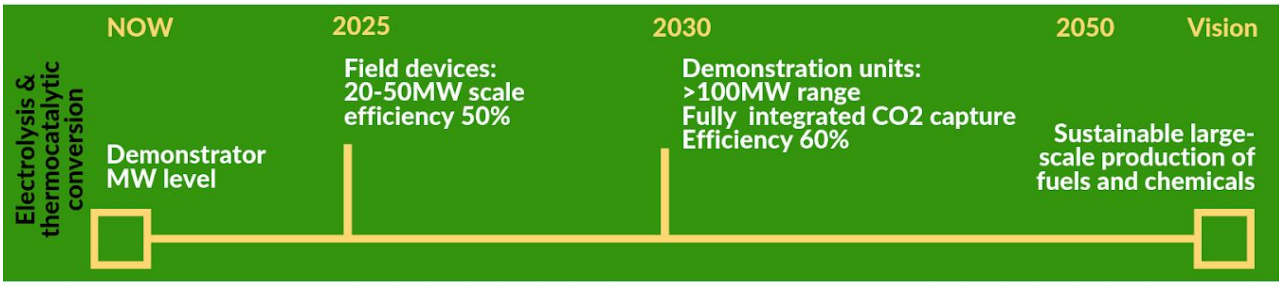
[68] A mixture of H_2 and CO directly generated from co-electrolysis of water and CO_2 or from water electrolysis with subsequent reverse water gas shift.

long-chain hydrocarbons by a thermo-catalytic reaction (Fischer-Tropsch synthesis). The products can subsequently be refined into (jet) fuel.

Key research drivers: Scale-up of electrolysers, optimization of thermo-catalytic reactions with catalysts showing improved energy efficiency and stability towards contaminations of the input, new and energy efficient thermo-catalytic reactions (*e.g.* direct electric heating with renewable energies), optimised product separation and purification technologies, process intensification *e.g.* by coupling reaction and separation and agility of the process (conventional chemical processes are run in steady state, they have to be modified to follow the intermittent supply of renewable energy sources).

Key enabling technologies: Catalysis research with ab-initio modelling and high-throughput screening, multi-scale modelling for thermo-chemical electrically heated reactors, systems engineering for dynamic life-cycle cost analysis, advanced manufacturing for new reactor concepts, systems engineering.

Present TRL: 6, first demonstrators built at the MW level
TRL target 2030: 9



Vision for 2025: Within the SUNRISE initiative, the technology will be fully demonstrated in field devices that work at the 20-50 MW scale. They will demonstrate the feasibility for scaling together with the dynamic integration of electrolysis and thermochemical processes and show the desired stability of the catalysts against possibly unavoidable concentrations of contaminants in the feed stream coming from a coupled CO_2 capture system. At this stage, an overall energy conversion efficiency (electrical energy to chemical products) of at least 50% is targeted with the agile process.

Vision for 2030: Fully engineered and designed demonstration units in the >100MW range that show the full dynamic and chemical robustness expected from an industrial system that is already fully integrated with a suited CO_2 capture system. By thermal integration and media management an energetic efficiency of >60 % will be obtained. This fully operable industrial demonstrator is expected to trigger investment decisions for the large-scale deployment of the technology.

<u>Direct electroreduction of CO_2</u>

Unique selling point: The direct electroreduction of CO_2 to hydrocarbons at low temperatures (<80°C) is the most simple process chain, with a homogeneous technology doing the full job. It promises to deliver already C_2-C_4 components with higher efficiencies compared to a two-step conversion with a subsequent thermochemical process (with high-temperature steps involved).

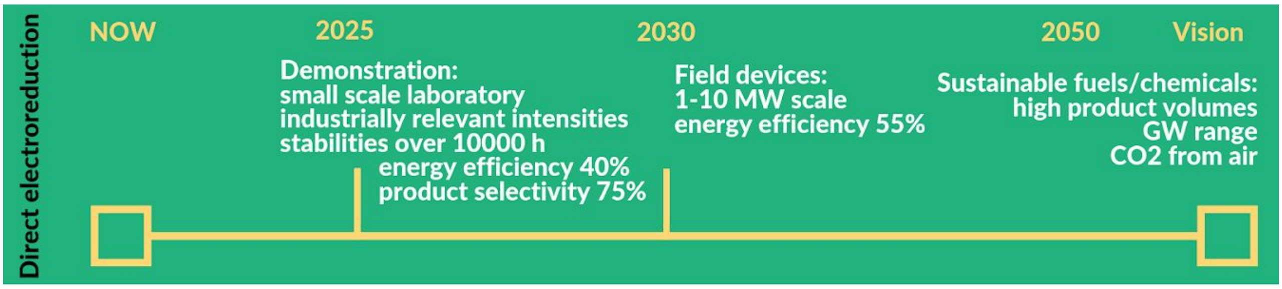
Working principle: CO_2 is fed together with water into a low-temperature electrolyzer at the cathode side. A special catalyst is employed that limits water reduction to hydrogen, while promoting CO_2 reduction. This catalyst has a high overpotential for water reduction and a low one for CO_2 reduction, driving the selective reduction of CO_2 to CO in a first step. The catalyst then needs to be able to keep the intermediate reduction product at its surface, allowing further reduction of the CO to hydrocarbon components; further, it needs to allow diffusion of the intermediate products on the surface to allow C-C bond formation to generate C_2-C_4 compounds.
Most promising in technical terms is to distribute the first step (generation of CO) and the second electrochemical step (further reduction of the CO to C_2-C_4 components) in separate cascaded electrolyzers to freely optimize both reaction parameters.

Key research drivers: Discovery of alternative catalysts for the reduction of CO_2 to hydrocarbons, overcoming the instability of copper-based catalysts (the surface morphology on atomic scale needs to be overcome by self repair or short regeneration pulses); understanding and modelling of processes in gas diffusion electrodes towards chemomechanical stability and media transport; development of alternative electrolyzer architectures; integrated system engineering of stacked gas to gas/liquid electrolyzers.

Key enabling technologies: Catalysis research with ab-initio modelling and high-throughput screening, in-operando analytical tools, multi-scale modelling, systems engineering, life-cycle cost analysis.

Present TRL: 3
TRL target 2030: 6

Major technological targets
Current research at laboratory-scale shows that mainly copper-based compounds are able to generate hydrocarbons and enable the C-C coupling. However, most of this work is done at current densities of 10-30 mA/cm²; this is two orders of magnitude below any practical application and nearly all experiments show severe degradation within a few hours. Stable catalysts need to be developed (several 1000 hours of operation, >80% product selectivity, 0.5-1 A/cm² current densities).
Moreover, novel electrolyzer architectures have to be developed that allow a sufficient supply of CO_2 to the catalyst. Ohmic losses in the electrolyte dissipate valuable renewable energy and have to be minimized. Pressurized electrolyzers that directly generate products at 30-50 bar have to be implemented to cut energy costs for a afterwards compression of products needed for further processing and storage. The electrolyzers need to have a high turnover referring to their volume to limit the CAPEX (capital expenditure), so they need to be able to work with industrially relevant current densities of (500-1000mA/cm²).



Vision for 2025: Demonstration of the feasibility of this efficient approach by long-term experiments at small-scale laboratory level (100 cm² electrode surface) that need to operate at industrially relevant intensities (current densities of 0.5 - 1 A/cm², temperature 70°C). They will prove the principle by obtaining stabilities over 10000 hours without degradation, showing product selectivities to hydrocarbon components of about 75% and a related energetic conversion efficiency of about 40%.

Vision for 2030: Within the SUNRISE initiative, the technology will be fully demonstrated in field devices that work at the 1-10 MW scale. They need to be fully engineered and designed in terms of thermal and media management. By optimisation of ohmic dissipation in the conduction channels, energetic efficiencies of about 55% will be reached.

Vision for 2050: These systems will be scaled up to the GW range in a dynamic system integration with volatile renewable energy supply and CO_2 capture from air and deliver product quantities matching volumes of future markets of fuels and chemicals. Intermediate C_2-C_4 products will be fed into refineries, where established petrochemical techniques are applied to convert them into transport-grade fuels and other marketable products.

Direct solar-thermochemical conversion of water and CO_2

As an alternative to the electrochemical options described above, an appealing pathway for CO_2 and H_2O splitting are thermochemical routes, which require an input of heat instead of electricity. The heat input can be delivered renewably by concentrating solar technology, which is already used in desert areas to produce electricity. Since heat is directly converted to chemical energy without an intermediate electricity production step, the theoretical efficiency of such processes is higher than in electrolysis.

Unique selling point: The combined thermochemical reduction of CO_2 and water is highly efficient, since solar heat is directly fed to the process instead of converting it to other energy forms such as electricity before. The intermediate products are manifold (composition and hydrogen/carbon ratio), enabling the production of all conceivable hydrocarbon products.

Working principle: The thermochemical cycle typically consists of two steps at different temperatures, mediated by an oxygen-carrying material (typically a metal oxide) as key element:

1. Oxygen release from the material: At high temperature (1350-1700°C), the material releases some of its chemically-bound oxygen. The energy required for this reaction is provided by solar heat.
2. H_2O/CO_2 splitting: At lower temperatures (600-1200°C), the oxygen-deficient material reacts with water (H_2O) and CO_2 by splitting these molecules and taking up oxygen from them, thus being re-oxidized. Thereby, H_2O is converted into molecular hydrogen and CO_2 to carbon monoxide (CO). This mixture of hydrogen and carbon monoxide is called syngas and can be used to produce hydrocarbons, such as jet fuel.
The process is entirely reversible, meaning that the mediating oxygen-carrying material is not consumed.

Key research drivers:
The two main factors to consider are efficiency and cost: in practice, large heat losses decrease process efficiencies drastically. A large amount of oxygen exchanging material has to be heated to very high temperatures in the reduction step and currently only a fraction of this heat can be recovered during cool-down and oxidation. Besides low efficiencies, another source of high costs is the fact that the reactors for this process are expensive, as they require advanced refractory materials to withstand the high temperatures.
This technology is still far from being economically competitive, compared to conventional (fossil) production, but also to today's Power-to-Liquid technologies. Larger-scale demonstration projects are required to show realistic potentials of this intriguing approach.

Key enabling technologies: Materials engineering, materials research with ab-initio modelling and experimental screening, solid particles technologies, membrane technologies, smart process control and interfaces.

Present TRL: 4-5
TRL target 2030: 6

Major technological targets
The targeted design of optimized solar-thermochemical materials includes:

- Solid-solid heat recovery rate > 60 %
- Steam heat recovery rate > 95 %
- Scale-up to improve efficiency
- Improved separation of products and reactants

Vision for 2025: Demonstration of the feasibility of this efficient approach by increasing the solar-to-fuel efficiency for solar-thermochemical hydrogen production to 15 % while demonstrating it at a scale of 250 kW (thermal) in a solar simulator or at a solar tower.

Vision for 2030: To reach competitiveness, a substantial decrease in cost per kg of jet fuel produced needs to be realised. Increasing the overall process efficiency is crucial for this capital-intensive technology, *e.g.* through reduced reaction temperatures and effective heat recuperation. Use of less expensive materials for reactor design and a decrease in cost of solar-thermal technologies (heliostats, towers) due to the implementation of concentrated solar power plants on a larger scale are also important drivers for overall cost reduction.

Vision for 2050: Commercialization of this technology through further efficiency increase to achieve lower cost. This is done by further optimizing solid-solid heat recovery (target: 80%), by decreasing temperature differences between reduction and oxidation through further materials optimization, by scale-up and therefore decreased component cost and by process optimization using experience from existing pilot plants.

Photo(electro)chemical devices

Similarly to direct solar hydrogen production, photo(electro)chemical systems have the potential to allow for a decentralized CO_2 valorisation at lower costs compared to PV-driven electrolysis.

Unique selling point: Photo(electro)chemical systems are integrated and allow for large savings in terms of support and container as well as interconnecting electronics. As the surface of catalysis is the same as the surface for sunlight collection, catalytic turnover is up to two orders of magnitude lower than that required for cost-effective electrolysis. This reduces the constraints on the used materials and allows for the use of abundantly available, cheap and non-toxic materials as catalysts. The large surface used for photon collection can also be used for atmospheric carbon capture.[38]

Vision for 2050: Photo(electro)chemical devices will allow for a decentralized, on-site and on-demand production of formic acid and hydrocarbons (methane etc.). In centralized facilities, products necessitating additional considerations on safety and utilization, such as CO, syngas or ethylene, will be obtained. Systems will be fully autonomous, only depending on abundantly available sunlight. Water consumption is low, but purification of CO_2 from atmospheric oxygen will be required.

Working principle: Buried junction cells and photoelectrochemical cells are single devices that directly split water and CO_2 into C-based products and oxygen, where the needed energy is provided by sunlight. Various architectures are possible, but all of them combine light-harvesting materials (inorganic and organic semiconductors, molecular dyes or biological pigments) and catalysts for CO_2 reduction and the oxygen evolving reactions. Both reactions occur at separate (photo)electrodes allowing for an easy separation of the products. A flow of the cathodic electrolyte might be needed to recover products if they are soluble in the electrolyte (as formic acid for example). Alternatively, photocatalytic reactor containing liquid phase suspensions of photochemical systems (photocatalytic nanoparticles or supramolecular assemblies) can be used. In that case, additional separation of the products from oxygen will be required.

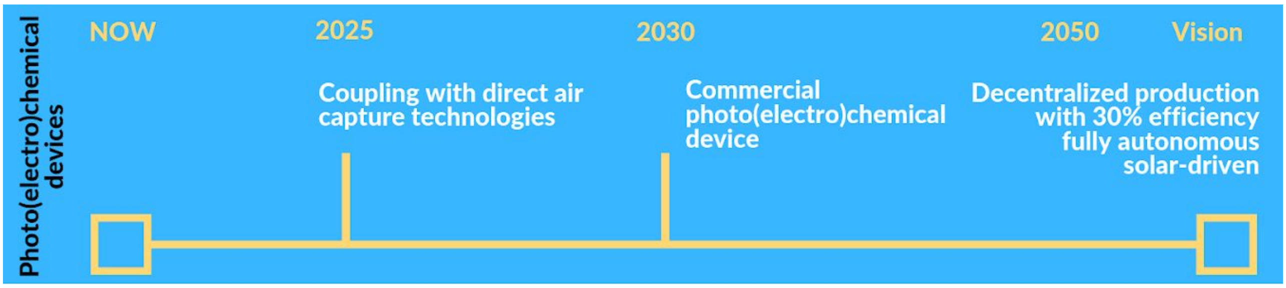
Key research drivers: CO_2 reduction catalyst discovery (O_2-tolerant catalysts are required if CO_2 is to be captured from the air), Direct Air Capture and Conversion technologies

Key enabling technologies: relies on advances in the development of photo(electro)chemical devices for direct solar water splitting and electrochemical CO_2 reduction (see above);

Present TRL: 1-3
TRL target 2030: 6-7

Major technological targets

Photo(electro)chemical cells for CO_2 valorization into CO or syngas are at the same stage of development as those for H_2 production and similar targets are expected in terms of the reduction of the water demand, the improvement of stability, breakthroughs to design active components solely based on earth-abundant elements and collection of gases. An important milestone will concern the coupling with direct air capture technologies by 2025 with commercial PEC devices with 10% solar-to-syngas efficiency available by 2030. Further optimization and upscale will allow to ultimately develop commercial devices at 30% solar-to-chemical efficiency.
For in-depth technical details, please refer to the technical annex (how-documents).



Biocatalytic production of carbon-based solar fuels and chemicals

Share of renewable bio-based raw materials for chemical industry is set to target 25% of the total volume of feedstock used by the chemical industry in 2030 in Europe.[69] Importantly, photosynthetic microorganisms, such as microalgae and cyanobacteria, are considered as third generation feedstock for the chemical and petrochemical industry. The photosynthetic microorganisms use sunlight, water and CO_2 to produce organic compounds and are also capable of hosting novel synthetic production pathways that allow the cells to function as living cell factories producing the desired carbon-based solar fuels and chemicals.
There are already dozens of proof-of-the-concept for direct production of chemicals in photosynthetic microbes.[70] Some production systems are functioning at TRL 4-5 (*e.g.* Photanol for lactic acid production). For new products, one needs to design metabolic pathways from scratch and engineer new strains. Moreover, obtained cells producing specific compounds can be further engineered to make the system more efficient and stable.

Unique selling point: Photosynthetic microorganisms are capable of synthesising complex organic compounds with high efficiency and selectivity, combined with the ability of self-replication (recovery) and of long-term operation under physiological conditions.[71] The biosynthetic products are excreted from the cells into the cultivation medium, from where they can be collected and subjected to downstream processing when necessary.
Working principle: By application of the techniques of synthetic biology and metabolic engineering, photosynthetic microorganisms can be designed to produce and excrete a wide range

[69] RoadToBio chemicals roadmap for the European Chemicals industry https://www.roadtobio.eu/uploads/publications/roadmap/RoadToBio_action_plan.pdf

[70] Santos- Merino et al. 2019 New applications of synthetic biology tools for cyanobacterial metabolic engineering. Front. Bioengineer Biotechnol, v 7, article 23

[71] D. Lips et al. Many ways towards 'solar fuel': quantitative analysis of the most promising strategies and the main challenges during scale-up (2018) *Energy Environ. Sci.* 11. 10

of chemicals and fuels (such as long-chain wax esters, fatty acids and hydrocarbons). The engineered microorganisms can be cultivated in photobioreactors. But also solid-state production platforms (artificial biofilms) are developed. In biohybrid approaches, inorganic photoelectrodes or light absorbers will transfer energy or reducing power to metabolically engineered organisms for the valorization of CO_2.

Key research drivers: High cultivation costs, tight regulation of photosynthetic apparatus that results in loss of absorbed solar energy into protective mechanisms, complexity of metabolic pathways that serves to cell fitness rather than product efficiency, instability of the production strains and losses in production efficiency.

Key enabling technologies: Efficient engineering and synthetic biology tools, combined with strain characterization and optimization. Engineered new strains with enhanced metabolic pathways for the synthesis and excretion of various chemical and fuel products. Construction of cost-efficient dedicated photobioreactors for cultivation and production phases. Improvement of photosynthetic performance and carbon metabolism; upscaling, including cheap bioreactor construction and operation as well as downstream processing.

Present TRL: 1 (for newly designed chemical pathways) to 6 (*e.g.* lactic acid production)
TRL target 2030: 4-9

Major milestones

Technological targets for 2025:
Selection and characterization of robust strains with high photosynthetic efficiency
Automated tools for fast and cheap construction of microbial cell factories
Scale-up challenges solved for several chemicals
Proof-of concept for newly developed production strains
High volumetric productivity and light-to-product conversion efficiency established
Redesign of photosynthetic apparatus for high yield
Novel strategies to avoid contaminations of production cells from foreign strains

Technological targets for 2030:
Engineering tools for a wide-range of natural organisms
Detailed theoretical models of fundamental photosynthesis established

Technological targets for 2050:
Automated DNA synthesis and construction ("cell designer")
Dozens of large-scale demonstration plants

Long-lasting carbon-based materials

Energy carriers, like methane, or commodity chemicals, like ethylene, will eventually release their carbon in the atmosphere in the form of CO_2, on timescales of a few months or years. These two kinds of CO_2 utilization are high on today's agenda to accelerate the phasing out of fossil fuels. By inventing new efficient and optimized ways to convert CO_2 into fuels and chemicals, and also by mastering nitrogen conversion, SUNRISE will develop catalysis concepts, skills and processes which will also be instrumental in the area of Negative Emissions Technologies (NETs).[72,73] Within NETs, which are crucial in most scenarios complying with the Paris agreement, CO_2 should be stored for long durations, *i.e.* centuries or more. Depending on the success of emissions reduction policies and on the targeted climate goal, NETs need to be ready for a global scale deployment by 2040 or 2050. Considering the long time necessary to validate and optimize technologies, it clearly appears that new processes should be ready on the market in the course of the 2030s.
Up to now, the main long-term disposal considered in scenarios is underground storage of gaseous CO_2 (CCS). This storage technology bore very high promises in the 2000s, but developed slowly, due to the limited availability of underground suitable sites i.a. requiring pipeline infrastructure from large CO_2 point sources to large storage reservoirs, and mainly economic and societal obstacles. A safe and reliable long-term storage can be provided when CO_2 enters a mineral composition. Such processes have been studied by reacting CO_2 with minerals (mined for themselves, mainly silicates rocks or found in mining or industrial wastes).[74] The resulting materials, where carbon is usually in a fully oxidized state, need a limited amount of energy to be produced, and are very interesting as aggregates[75] in concrete. CO_2 can also be utilized to improve the curing of cement, as demonstrated for example by the company *CarbonCure*[76]. Both utilizations are seriously considered by the construction industry, with very promising perspectives to use and store CO_2 on the Gigaton level in the next decade, according to recent roadmaps on CO_2 utilizations.[77]

When CO_2 intended for these exothermic mineralization reactions is captured directly from the atmosphere, the energy consumption of the capture process strongly impacts the overall performance of the product. As already mentioned earlier, one must optimize the process by combining steps and possibly by preparing CO_2 under the best chemical form for the reaction. Since CO_2 must be activated (thermally, with physical pressure or by any form of chemical activation), there is a clear interest in developing combined capture and conversion, associated with the mineralization processes.

Keeping in mind that large CO_2 volumes could be stored in structural materials, like aggregates in concrete, we foresee that there would be a major progress if those materials would need no input

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[72] Minx, J. C., et al. 2018; Negative emissions - Part 1: Research landscape and synthesis. Environmental Research Letters **13**(6):063001. https://doi.org/10.1088/1748-9326/aabf9b

[73] National Academies of Sciences, Engineering, and Medicine 2019. Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259

[74] Sandalow, D., et al. (2017). Carbon Dioxide Utilization (CO2U) ICEF Roadmap 2.0. available online https://www.icef-forum.org/pdf2018/roadmap/CO2U_Roadmap_ICEF2017.pdf

[75] See for example Carbon8 aggregates, now O.C.O. Technology Ltd: https://c8a.co.uk/our-process/

[76] See https://www.carboncure.com/

[77] See the contribution of CO_2 Sciences & Global CO_2 initiative, Global Roadmap for Implementing CO2 Utilization, November 2016, for the ICEF project. https://www.icef-forum.org/platform/upload/CO2U_Roadmap_ICEF2016.pdf

from mining at all, *i.e.* if their synthesis could be obtained by capturing raw materials in the local environment only. Such a prospect seems today beyond our programming horizon, but its potential contribution to NETs, needed by 2040, justifies its mention here. In the year 2030 and beyond, with atmospheric N_2 and CO_2 being readily, efficiently and commercially transformed to useful products, new processes could emerge to obtain structural polymers, able to replace mineral carbonates as long term storing materials.

In the long-run, SUNRISE technologies could also help another type of NET by a new form of artificial photosynthesis: Soil Carbon Sequestration[53]. The decentralized solar-driven synthesis of nitrogen- and carbon-based products could deliver materials for soil enrichment, thus contributing to the conversion of arid surface into fertile soils by performing long term storage of a significant amount of CO_2.

SUNRISE key enabling technologies

The future deployment of SUNRISE technologies at scale, providing net global GHG reductions, necessitates enabling resources, technologies and analyses.

Upscaling, *i.e.* bringing novel technological solutions from the lab to a global industrial scale, is a significant challenge for mature SUNRISE technologies. The overall sustainability, the availability of needed resources on a large scale and economic viability have to be ensured.

Novel materials will allow cost-competitive, efficient and durable solutions across the three proposed technological SUNRISE approaches.

Product separation, *i.e.* the conversion of a mixture of chemical substances into distinct products, is a crucial step once the desired solar fuel or chemical is produced by the artificial photosynthesis device; in most of today's devices product separation, purification and collection represent one of the major bottlenecks due to the energy consumed for production and operation.

The SUNRISE toolbox comprises advanced computational modelling, quantitative sustainability assessment, advanced experimental techniques and emerging concepts. **Computational materials modelling** guides experiment, avoiding tedious sequences of trial and error in the lab, and thus significantly speeds up the innovation process. Thorough **life-cycle, techno-economic and social impact analyses** will ensure the establishment of a sustainable carbon economy, viable business models and social acceptance of SUNRISE technologies. **Synthetic biology** opens enormous perspectives for the realization of an efficient algae/cyanobacteria-based production of fuels and chemicals. **Emerging concepts** transfer insights from nature to artificial systems and will be key for developing the next-generation efficient solar-to-fuels energy conversion processes based on molecular engineering.

Upscaling

The transformation of current laboratory-scale solar energy conversion devices into widespread, efficient industry-grade systems and installations is a grand S&T challenge that requires both scientific and technological breakthroughs. Laboratory experiments are in Watt scale, whereas the TW scale is needed for the energy system. This difference of 12 orders of magnitude outgoes the scale where physical effects can be easily described within the same methodology. To overcome this gap, two main approaches need to be undertaken :

The technologies need to be scalable. The use of *scarce or expensive materials* (like iridium or other rare chemical elements) has to be limited as much as possible and ways have to be investigated to produce these technologies in *highly automated factories* using controllable processes. The energy return on energy invested *(EROI)* has to be preferably above 10; moreover it has to be verified that *processing of huge areas* is feasible (e.g., nanostructures over 1000 km² done by photolithography are hard to imagine). Devices must not use toxic materials (like significant amounts of lead or mercury) in a chemical form that allows dissipation into the environment.[78] *Appropriate scaling concepts* have to be developed that might evolve as scale of individual devices, as well as use a high degree of modularity (example: today's photovoltaics production). Also the effect of the law of large numbers on production costs has to be estimated.

Scale-up is orders of magnitude more expensive compared to lab research and needs to be financed. A necessary investment in the billions euros range is unlikely to be financed by a single research program or national subsidies. These kinds of instruments are usually adapted for the MW range. On the contrary, upscaling projects need to be financed by investors, believing in the proposed technology. In order to attract investors, intermediate business cases have to be attainable with the SUNRISE technology. This might be the creation of some high-value green products, where the molecule value is higher than the energy content or – as alternative – a product where customers are willing to pay a higher price. This way, the technology can be scaled to the 100 MW to GW range; it matures, it demonstrates its sustainable potential and reliability and it attains bankability. When this step is finally reached, the investors' trust is available to propel the technology in the TW range.

An example: Photobioreactor design. The scale up of biological applications requires design, construction and easy operation of open or closed photobioreactor systems for algae and cyanobacteria cultivation and production stages. Large-scale closed photobioreactors at TRL 5 - 6, operating with engineered cyanobacteria for direct production of *e.g.* ethanol have already been reported.[79] By way of example, Ecoduna GmbH (Austria) operates 1 hectare vertical photobioreactors (total length 230 km) with an annual capacity of 100 tons of algae biomass production. The feasibility of upscaling the production of bio-based chemicals needs to address yet unsolved issues: Concerning EROI, the energy for producing/building/recycling the reactors, plus operation (pumping), plus the energy for product separation and cleaning has to be at least one order of magnitude below the energy content of the products. Moreover, contamination by predator bacteria, as well as the genetic stability of the engineered algae and bacteria needs to be researched and positively solved.
For further technical details, please refer to the technical appendix on Upscaling.

Novel materials

An important challenge is the development and optimization of materials for artificial photosynthesis. Today's catalysts and photo-absorbers have to be significantly improved in terms

[78] Lead glass or piezoceramics for example contain lead, but in a chemically bonded way that inhibits release.
[79] J. Dexter et al. *J. Appl. Microbiol.*, 2015, 119, 11–24

of efficiency and durability; novel materials are crucially needed that are earth-abundant and non-toxic in order to allow for a sustainable upscaling of the proposed technologies. Once efficient materials are found, these outcomes have to be tested in real device conditions and the nanoscopic scale has to be bridged to the macroscopic world.
The challenge is the intrinsic complexity of the considered thermo- and electrochemical, photoelectrocatalytic or bio-inspired systems, where one deals *e.g.* with complicated surface reactions, complex thermodynamic properties, the interplay between electrodes and electrolyte, photoabsorption and catalysis. Employed materials have to fulfill diverse requirements which are often competing and where a compromise has to be found. In order to allow for an efficient and targeted materials development, it is crucial to understand the underlying fundamental principles and reactions.

Product separation, purification and collection

Generating valuable and energy containing products from sunlight is one side of the trophy, separating and cleaning them into a state that allows further use is the other one. The energy required for the separation must not be underestimated. This is relevant for the refining of fuel components into fuel, and it is especially hard for commodity chemicals (such as ethylene, aromatics, propylene and alcohols), where usually a high purity is required.

The energy for separation cannot approach zero – even with the ideal technology – due to thermodynamic reasons. In existing, already optimized processes of the chemical industry, the relation of the energy needed for separation and the energy content of the products can vary from almost zero to more than 40%. It is thus crucial for the efficiency chain of SUNRISE products to consider the energy needs for separation.

Amongst possible options, distillation (especially cryogenic) is a powerful, but energy consuming process and may be limited to well mixable substances. Membrane separation – an energy efficient tool – is already employed in volume processes, but the selectivity needs to be improved. Temperature and pressure swing separation is mighty but restricted to several tasks. There is no universal technology for product cleaning in view of the varying output of the SUNRISE technology and the broad range of usable product options. Product separation must be optimized individually for the intended use cases of SUNRISE developments.

SUNRISE tool box

Advanced computational modelling: from novel materials to solar fuel devices

Design and discovery of materials and processes are cross-cutting key enablers for the entire range of SUNRISE technologies. However, translating new materials from the laboratory to the market can take 10 to 20 years and is very expensive.[80] According to the Energy Materials Industrial Research Initiative (EMIRI), advanced materials denote 50% of the manufacturing costs of clean energy technologies today and are expected to increase up to 80% in the near future. Significantly optimizing materials discovery needs scientific breakthroughs to optimally design matter from the atomic up to the device scale.

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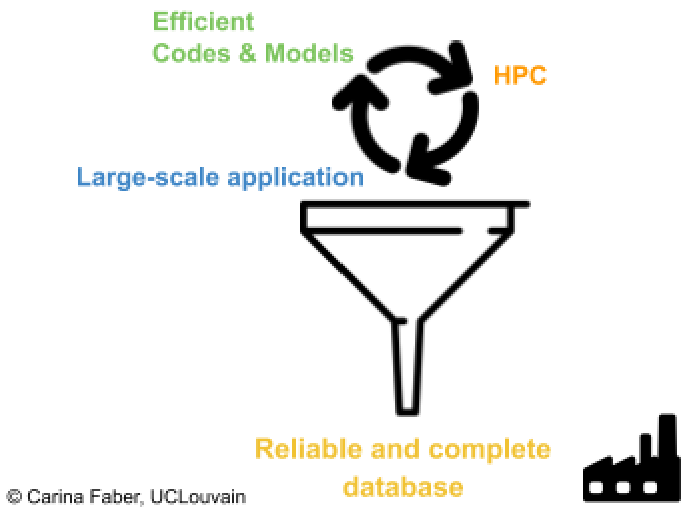
[80] Mission Innovation 6, Clean Energy Materials:
http://mission-innovation.net/our-work/innovation-challenges/clean-energy-materials/

Computational simulations can guide experiment, avoiding tedious sequences of trial and error in the lab; it significantly speeds up the innovation process and makes it much cheaper. Only the most promising materials are to be synthesized and tested in the lab and in solar fuel devices. Millions of hypothetical materials can be explored through high-throughput calculations and the most promising candidates are selected using artificial intelligence. Computational studies provide fundamental understanding enabling rational design. This accelerates the exploration, discovery and use of new high-performance, low-cost and non-toxic solar fuel materials.



Efficiently predicting the performance of materials and processes and translating these findings on the device level necessitates different dimensions which inherently depend on each other:

1) The development of theoretical models accurately describing complex, real-life processes in a simplified manner has to be pursued, as well as the improvement of computer codes solving equations in the most efficient way; this allows for the calculation of material properties both efficiently and accurately and to ultimately simulate real solar fuel device structures. Interfaces need special focus, since materials with an optimum property do not necessarily show the best performance in a device.
2) Innovation in high-performance computing facilities and the development of new algorithms and software with respect to these infrastructures allows to use resources in the best possible way and consequently to approach more complex systems, higher reliability and millions of calculations of material properties.
3) Simulations of artificial photosynthesis systems and the calculation of material properties on a large-scale will prove the reliability of the developed methods and deliver key quantities for experimental studies; machine-learning algorithms allow for automated calculations and the study of millions of novel materials (combined with high-performance supercomputers). The lack of understanding of how to profit most effectively from artificial intelligence approaches for materials discovery and especially artificial photosynthesis has to be overcome. New big data analyses and high-throughput screening based on interoperable complex workflows will retrieve the most promising candidates instead of only predicting properties.
4) Reliable and complete databases are the prerequisite of modern research and especially for machine-learning approaches. The establishment of a SUNRISE database with reproducible data on the most promising materials for artificial photosynthesis allows to

select the best candidates and prevents a doubling of research efforts. The establishment of commonly agreed on criteria (for data formats, the quality of results, details on how data is obtained) permits to easily search in multiple existing databases and to find suitable materials using artificial intelligence.

For further technical details, please refer to the technical appendix on Materials Modelling.

New methods and software tools for early quantitative sustainability assessment: bridging environmental, economic and social impacts

The rapid pace of technology development requires the development of new methods and software for the fast assessment of the environmental, economic and social impacts of emerging technologies. Life-cycle assessment (LCA) is a powerful tool to evaluate total energy requirements, net carbon emissions and overall environmental impacts (far beyond just carbon footprinting). It goes hand in hand with techno-economic analyses (TEA) which determine the technical and economic viability of a new technology and social impact assessment (SIA) studying the societal acceptance of a new technology.

Assessing the environmental, economic and social impacts of emerging technologies early in innovation is challenging due to the limited availability of data. However, it is crucial in an early stage since it allows steering technology development towards more sustainable pathways. The development of a new set of methods and tools will allow a more effective support of technology and application design, and will allow early go/no-go decisions as well as frame the conditions for producing, distributing, storing and using renewable chemicals and fuels.

Nevertheless, current technology assessments frequently do not provide the needed level of transparency, consistency and accessibility.[81] Existing methods lack integration and advances in technology evaluation tools need to take place in parallel with the development of SUNRISE technologies. Today's methods are able to assess existing, well-defined technological systems, but could be improved when emerging technologies need to be assessed and recommended. This is mainly due to two major gaps: first, there is a lack of data coverage for *e.g.* processes, environmental exchanges, market dynamics, social implications of technology diffusion or technology transition monitoring; second, all models assess emerging technologies only with existing methods, data and software tools.

For further technical details, please refer to the technical appendix.

Synthetic Biology

Synthetic biology is an emerging technology that aims at the genetic redesign of biological organisms to build up novel living systems, not existing in nature. Synthetic biology combines engineering, digitization, robotics and biology. This enables the reprogramming of living cells to function in a way that benefits the economy. The genetically engineered organisms act as *living cell factories* producing desired fuels and chemicals ranging from *e.g.* lactic acid to jet fuel.

Recent breakthroughs in plant science demonstrated that crops engineered with a synthetic photorespiratory shortcut are 40% more productive than natural plants in real-world agronomic

[81] Gaseous Carbon Waste Streams Utilization: Status and Research Needs, 2019, National Academy of Sciences

conditions.[82] A proof of principle for the highest 1-butanol production (a maximal rate of 0.3g/L/d) was recently reported in engineered cyanobacteria.[83] This offers realistic opportunities for further improvement in the near future. Importantly, besides the conventional CO_2 fixation pathway of oxygenic photosynthetic organisms, there are many more efficient CO_2 assimilating pathways recently discovered in other microbes.[84] Utilization of these previously unknown catalytic principles of CO_2 assimilation will allow for the development of even more efficient synthetic routes to convert CO_2 into complex organic molecules of industrial interest.

Robust and efficient modelling, systems biology and automatization of the synthetic biology tools (encompassing the design-build-test-learn cycle) are necessary to drive both photosynthetic and heterotrophic microorganisms towards commercially profitable cell factories. The current challenge is to fuse existing information and ongoing research to generate more efficient standardized synthetic biology practices for a wide array of robust microorganisms.
For further technical details, please refer to the technical appendix.

Emerging concepts

Plants and algae use natural photosynthesis to convert light energy into energy-rich organic building blocks. While replicating the photosynthetic apparatus in artificial systems is not viable, research on natural photosynthesis reveals physical quantum phenomena that enable *e.g.* highly efficient light harvesting. It also provides novel design principles for developing artificial photosynthetic systems.

Bottom-up molecular engineering of bio-inspired artificial photosynthetic assemblies will be a key enabling technology in SUNRISE for developing next-generation solar-to-X energy conversion processes and systems. Breakthroughs in the development of molecular-based artificial photosynthetic systems could be accomplished by combining fundamental concepts of natural photosynthesis and by applying them onto synthetic (supra)molecular or polymeric systems, molecular materials, nanomaterials, membranes, matrices and interfaces (including molecule-nanoparticle and molecule-semiconductor electrodes). This research will be based on three guiding principles: (i) independent building blocks (ii) vibration-assisted charge separation and transport (inner coherence), and (iii) responsive matrices.

Work on molecular design of artificial photosynthesis systems will reveal new ways of function-based systems engineering of biomimetic materials hierarchies with active cofactors incorporated in molecular units (such as the recently developed quantasomes) and extend the "quantum design" principles from natural photosynthesis to synthetic systems of considerably higher efficiency and stability. This research, together with developing new molecular materials, will lead to next-generation artificial photosynthesis technology to be developed in the SUNRISE project. Some of its aspects will have an impact beyond SUNRISE, *e.g.* in quantum technologies.
For further technical details, please refer to the technical appendix.

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[82] P. South et al. (2019) Synthetic glycolate metabolism pathways stimulate crop growth and productivity in the field, Science 363, eaat9077

[83] X. Liu et al. (2019) Modular engineering for efficient photosynthetic biosynthesis of 1-butanol from CO_2 in cyanobacteria. *Energy Environ Sci* DOI: 10.1039/C9EE01214A

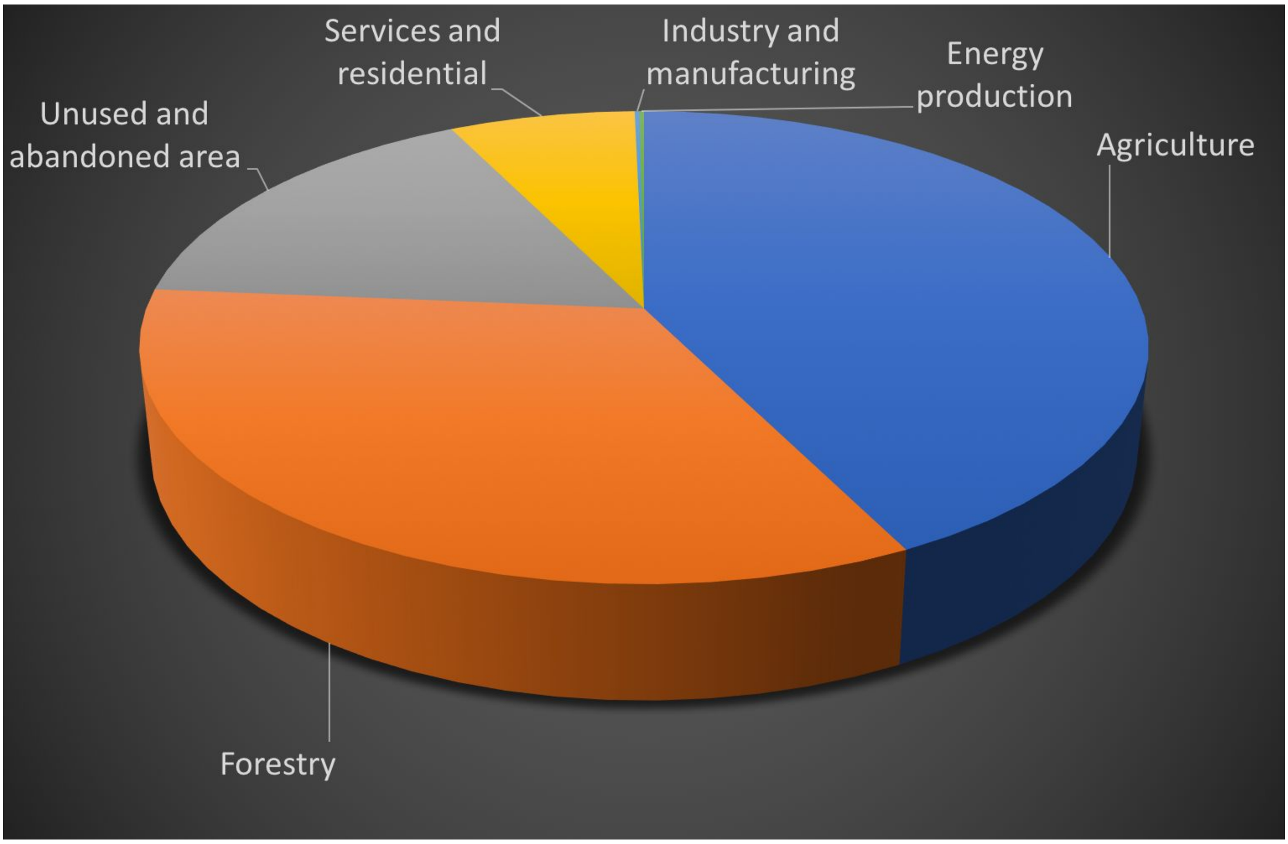
[84] T. Erb (2011) Carboxylases in Natural and Synthetic Microbial Pathways, *Appl Environ Microbiol* 8466-8477

Needed Resources and enablers beyond the scope of Sunrise

Social and environmental impact

Land use

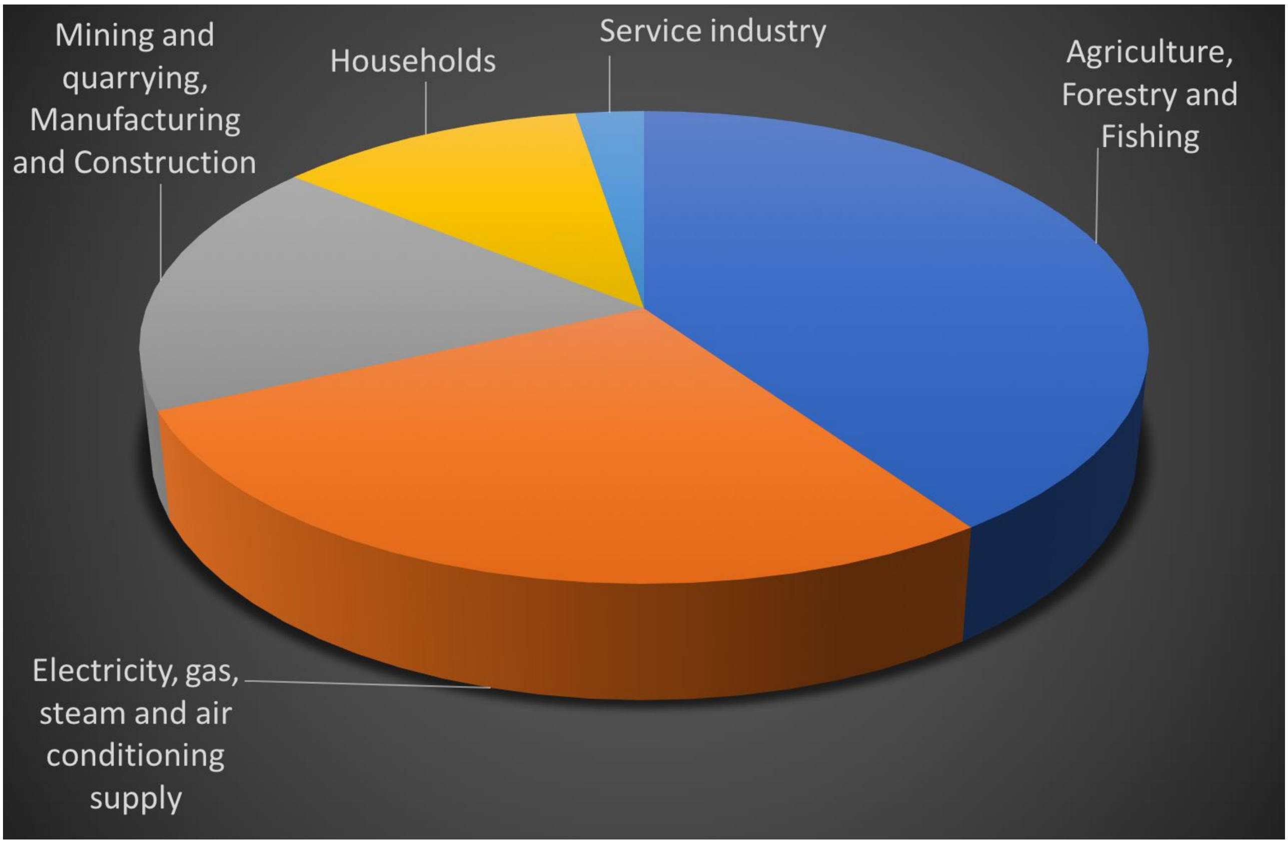
The European soil is one of the most intensively exploited in the world. With up to 80%, Europe has the highest proportion of land used for settlement, production systems (in particular agriculture and forestry) and infrastructure (European Energy Agency - Land use). Agriculture is the most common primary land use category in the EU-28, followed by forestry, unused and abandoned land, and services residential. Only a small portion is dedicated to energy production and industry/manufacturing. **The deployment of any new technology should carefully consider the additional land use demands in this context.**



Agriculture has the highest land use (41%, ca. 1 800 000 km²), followed by areas used primarily for forestry (33%, 1 400 000 km²), services and residential (7%, 295 000 km²), along with unused or abandoned land (16%, 690 000 km²), data from EUROSTAT - land use statistics. About 7 000 km² are dedicated to energy production and 7 700 km² to industry/manufacturing, 0.16% and 0.17% respectively.

Freshwater demand

Freshwater represents another precious resource. Water is essential for life, it is an indispensable resource for the economy and plays a fundamental role in the climate regulation cycle. The management and protection of water resources is one of the cornerstones of environmental protection. Water is provided either by public water supply (public or private systems with public access) or is self-supplied (for example, private drills). In Europe, around 223 000 megatons of water were abstracted in 2015 as off-stream to meet the demand of the European economy, 90 000 megatons were used and 142 000 megatons were returned back to the environment with a certain level of physical or chemical deterioration.



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Around 40% of total water use is accounted for by agriculture, forestry and fishing (38 000 Mt), followed by 28% (26 000 Mt) for electricity, gas, stream and air conditioning, and for mining and manufacturing (17 000 Mt, 18%). Public water supplies mounts to 14% (12 500 Mt), accounting for households (11.6%, 11 000 Mt) and service industry (2.6%, 2 400 Mt); European Energy Agency - Water use.

SUNRISE: estimated impact on land use and freshwater demand

SUNRISE targets the production of fuels and carbon-based chemicals, using abundant molecules as feedstocks (e.g., H_2O, CO_2, N_2) and sunlight as the primary energy source. As an example of how the SUNRISE technology would impact on the freshwater and land use scenario, the paradigmatic case of hydrogen is considered: its production, as envisaged by the SUNRISE vision, requires the highest freshwater demand among the targeted molecules.

Nowadays, the global hydrogen demand is around 70 Mt/y, which is almost entirely obtained from fossil fuels (ca. 76% from natural gas, 23% from coal) and <2% from water electrolysis. As a consequence, **the global production of hydrogen generates about 830 Mt/y of CO_2 emissions**, slightly lower than the total CO_2 emissions of Germany in 2015 (930 Mt/y). For comparison, EU-28 emits about 4 500 $MtCO_2$/y. Assuming that the total current hydrogen demand is supplied through water electrolysis (using water as feedstock), this would result in an annual electricity demand of about 3 700 TWh and a freshwater requirement of about 630 Mt_{H2O}/y. This is roughly one third of the current European freshwater use by the service industry (2 400 Mt/y), and 0.7% of the EU-28 annual global consumption. **If we consider that the hydrogen demand of Europe is about 15% of the global demand, it is evident that the electrolytic production of molecular hydrogen will not significantly impact on the availability of freshwater.** On the other hand, **if the electricity needs were provided by PV, it would require the deployment of 22 500 km^2, roughly corresponding to the surface of Slovenia (20 273 Km^2) or ⅔ of Belgium (30 528 km^2).**[85]

The situation is different when considering the **direct solar conversion of fuels and chemicals using photo(electro)chemical cells** as proposed by SUNRISE. Here, a yearly production of hydrogen of 52-130 tons/ha (average 90 tons/ha) is targeted. Based on this, a land use of <8000 km^2 (corresponding to a surface with a radius of 50 km) can be envisaged for the production of 70 Mt_{H2}. **Although this surface represent <0.2% of the total land use in Europe, it compares to that presently devoted to energy production and industry/ manufacturing, but is still much smaller than service & residential (see above). The aspect of land area has to be carefully taken into account, since it can potentially limit the deployment of SUNRISE technologies. A way not to limit SUNRISE technologies and to increase their social relevance resides in the development of decentralized devices deployed in urban or agricultural environments, meeting the needs of the inhabitants.**

The estimated environmental impact, in terms of land usage and freshwater demand, of the SUNRISE associated technologies is summarized in the table below, where the global annual production of the relevant product is taken into account. The European demand represents a fraction of these values.

Impact of SUNRISE technology on the environmental resources

	Today global production [a] [Mt / y]	Production potential [b] [tons ha^{-1} y^{-1}]	Land use [km^2][86]	Freshwater use [c] [Mt / y]
Hydrogen	70	52 - 130	13 500 - 5 400	630
Formic Acid	< 1	1 182 - 2 956	8 - 3	< 0.5
Formaldehyde	52	386 - 964	1 350 - 540	30
Methanol	75	274 - 686	2 700 - 1 100	85
Ethanol	95	197 - 494	4 800 - 1 900	110
Ammonia	176	308 - 772	5 700 - 2 300	280

[85] Considering an average PV output in Europe of 1 100 KWh/y per KWp and an average power density of 150 Wp/m^2 per PV panel;

[86] Land use is calculated following this example: for a production potential of, e.g., 52 ton/ha/y and an annual demand of 70 Mton/y, one needs a surface of (70000 / 52) ha of land.

[a] Hydrogen data from *IEA Hydrogen*; Formic acid data from *ULLMANN's Encyclopedia of Industrial Chemistry*; Formaldehyde data from *Merchant Research & Consulting ltd* (https://mcgroup.co.uk); Methanol data from *The Methanol Institute* (https://www.methanol.org); Ethanol data from *OECD-FAO AGRICULTURAL OUTLOOK 2018-2027*; Ammonia data from *World fertilizer trends and outlook to 2018*, FAO-UN. [b] Estimates for chemicals production are obtained under the following assumptions: (a) systems absorbing 90% of the photons and converting 80% into products (SUNRISE target); (b) two photons per electron transfer; and (c) maxima and minima based on average annual solar irradiation in Malaga (Spain) and Stockholm (Sweden), respectively. [c] Net usage, since some reactions considered by SUNRISE use hydrogen as a feedstock, obtained from water electrolysis, and produce water as product.

Overall, the impact on freshwater availability of SUNRISE is expected to be minimal (thus sustainable). However, depending on the local situation, it can become important to be able to use waste water or water vapor from the atmosphere. Therefore this sustainability criterion has been considered in the technological targets for the proposed approaches.
On the contrary, land use could be a key criterion and must be carefully assessed. From this side, actions should be put in place in order to increase the social adaptability of SUNRISE-based technologies. SUNRISE technologies target a ten to hundred times smaller land use than current bioenergy: the local deployment must be thought through wisely together with pertained communities. Since CAPEX is a major hurdle to overcome, co-culturing for reaping the benefits of high economic efficiency in urban and rural zones cannot be excluded.

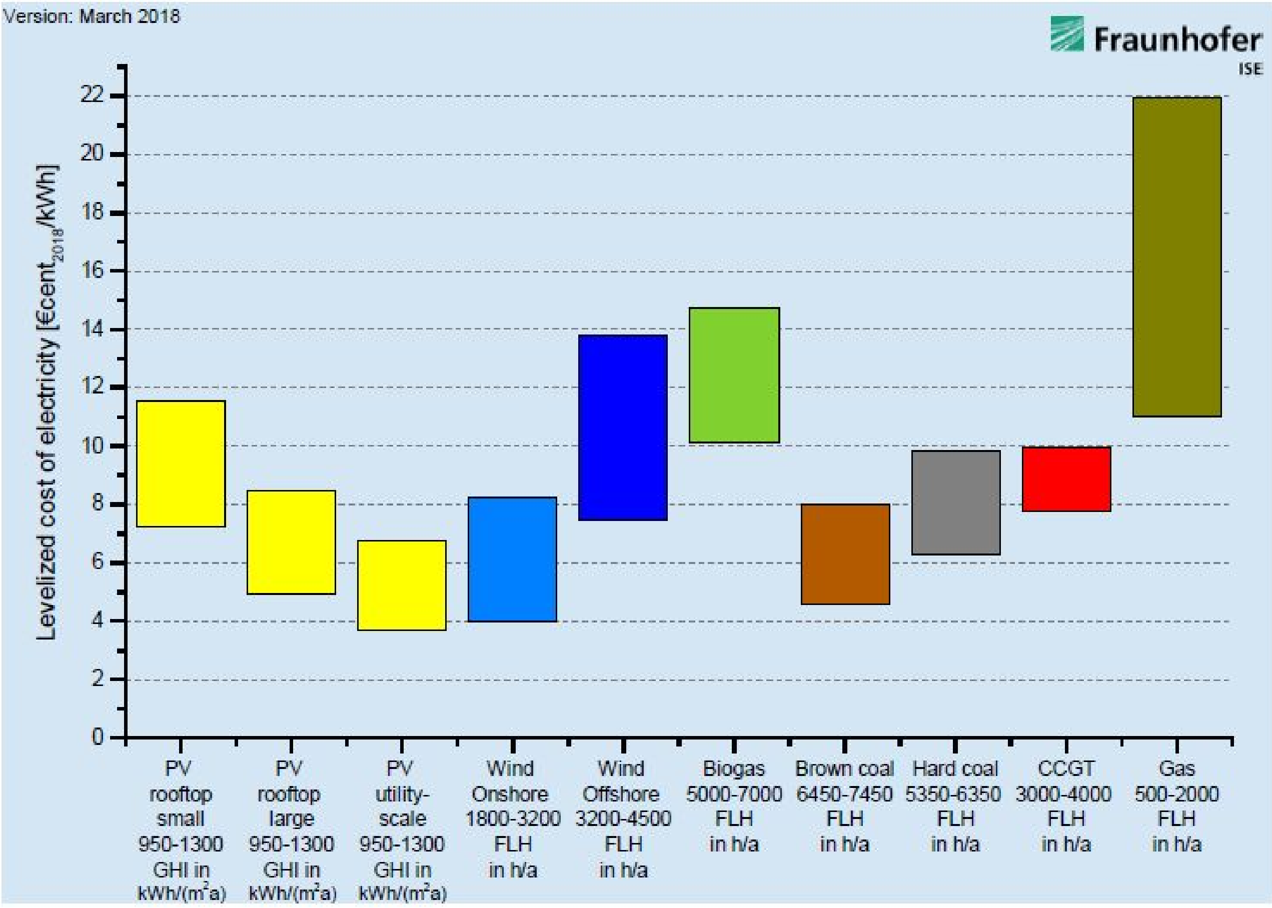
Green electricity

The share of renewables in the production of electricity is increasing at a constant rate. DNV-GL estimates that renewables will ultimately dominate the electricity production (photovoltaics, onshore wind, hydropower, and offshore wind, in the given order). Already mainstream today in many countries, these renewable energy sources will together account for 85% of the global electricity production in 2050.[87]

At the same time, the levelized cost of electricity achieved by those technologies (<22 €/MWh in 2018) already competes with the current price of production from fossil resources and will continue to decrease.[88] Depending on the location and weather conditions, this situation is already achieved, even in Europe.[89] This clearly emphasizes the need for efficient storage solutions to compensate production intermittency. SUNRISE technologies provide a promising way to chemically store intermittent renewable surplus energy on the medium and long term. Storage in chemical energy carriers complements the short-term storage provided by battery technologies and enables a loss-free long distance transport of energy using the already existing infrastructure of fossil fuels.
For SUNRISE technologies, the question arises if there will be enough renewable electricity to drive the proposed electrolyzer approaches. PV is the renewable energy growing at the fastest rate with wind being complementary in supply timing. Again, the case of hydrogen can serve as a valuable example. As stated above, today'sglobal hydrogen production through water electrolysis would result in an annual electricity demand of about 3 700 TWh. This is about 15% of the global

[87] DNV-GL "RENEWABLES, POWER AND ENERGY USE FORECAST TO 2050" Energy Transition Outlook (2017).
[88] IRENA "The Power to Change: Solar and Wind Cost Reduction Potential to 2025" (2016).
[89] C. KOST *et al.* "LEVELIZED COST OF ELECTRICITY RENEWABLE ENERGY TECHNOLOGIES", Fraunhofer Institute For Solar Energy Systems ISE, March 2018. (link)

annual electricity production (ca. 25 000 TWh), and more than the annual EU-28 production (3 100 TWh). If this energy would have to be generated entirely by PV, the installed power demand would be 3 400 GW, that is almost 7 times the global installed PV power at the end of 2018.[90] **Thus, the production capacity of the photovoltaics-driven electrolyzer approach will be severely limited by the availability of installed PV power. The SUNRISE approach based on direct conversion using photo(electro)chemical cells and ultimately photocatalysis can overcome these limitations.**



Levelized cost of electricity (LCOE) of renewable energy technologies and conventional power plants at locations in Germany in 2018. The value under the technology refers in the case of PV to the global horizontal irradiance (GHI) in kWh/(m²a), for the other technologies to the annual full load hours (FLH). Specific investments are taken into account with a minimum and maximum value for each technology. Ref.: C. KOST *et al.* "LEVELIZED COST OF ELECTRICITY RENEWABLE ENERGY TECHNOLOGIES", Fraunhofer Institute For Solar Energy Systems ISE, March 2018 (link).

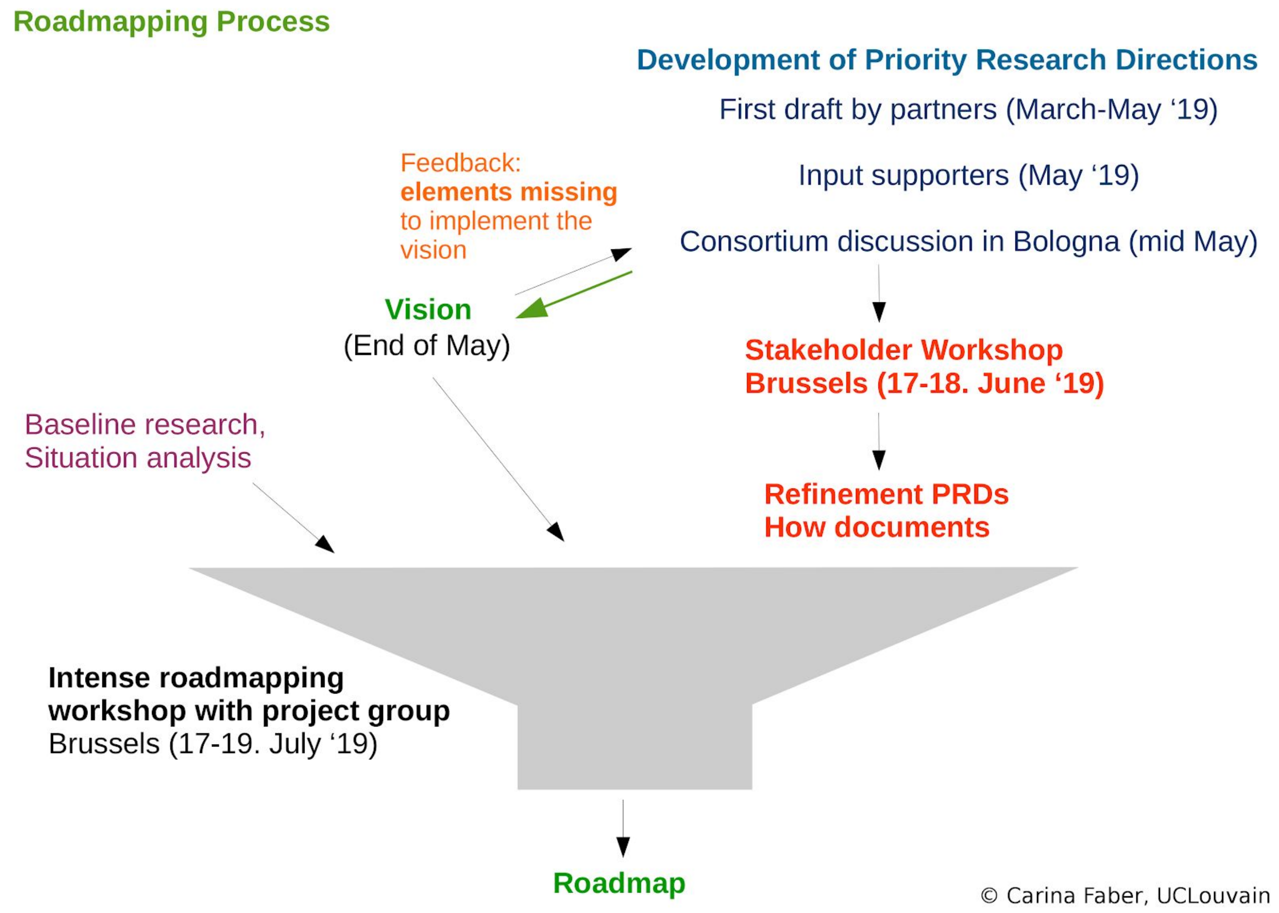
Supply chain optimization

The proposed technologies create the need for a regional and temporal optimization of supply chains, since the availability of all resources can change significantly (*e.g.* solar irradiation, water, CO_2 sources, N_2 sources and possibly O_2 sources). These decentralized solutions have thus to be coupled with electric and gas grid infrastructures on a wider scale to guarantee production security and higher efficiency in supply chains. In the future, networks of diverse energy carriers and material resources have to couple together to optimize consumption.

[90] REN21 Report, 2019

SUNRISE roadmapping process

This technological roadmap is developed drawing on analysis and expert judgement to define the **activities, priorities and timelines required to reach the SUNRISE vision**. It has been elaborated by the SUNRISE consortium, involving the entire SUNRISE stakeholder community. It addresses European policy makers and stakeholders from research and industry. It is conceived as a basis which will be extended later on. In particular the solar fuel topic shall be consolidated at the international level by the collaboration with Mission Innovation Challenge on Solar Fuels (Innovation Challenge 5).[91] As it is the nature of a roadmap, it is not a final document, but a dynamic process revisiting the set targets on a regular basis. It is a structured visual framework to understand dependencies and manage complexity.

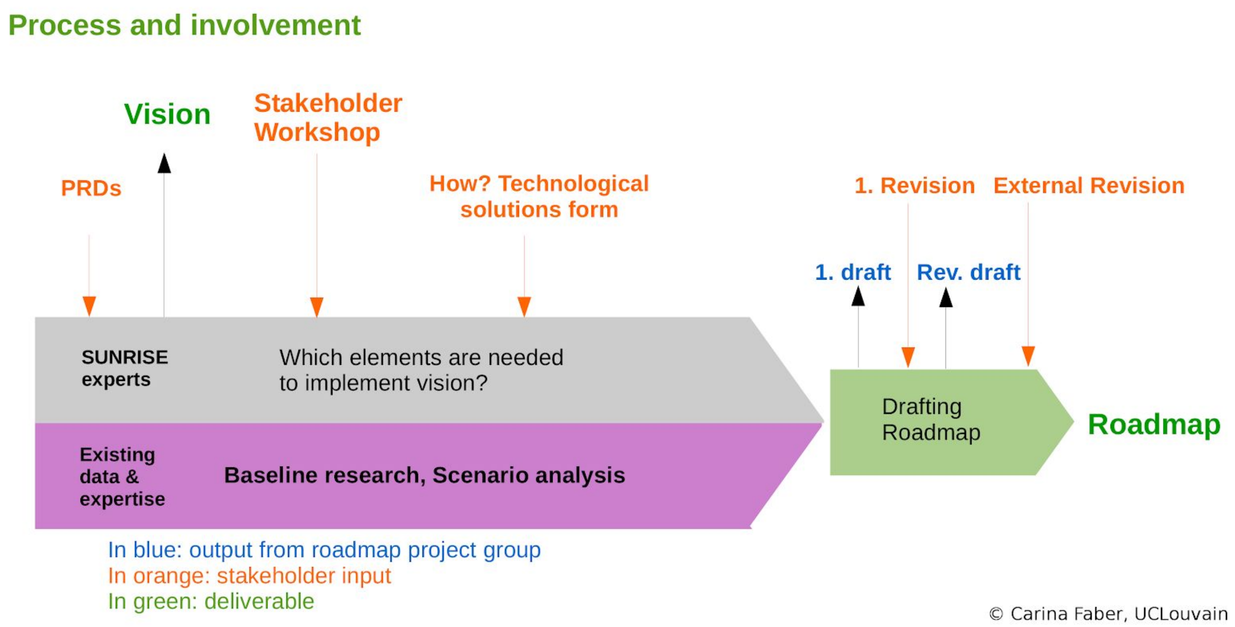


The roadmapping process identifies which technological elements are crucial to reach the SUNRISE vision. The latter has been established starting from the so-called Priority Research Directions (PRDs),[92] drafted by the SUNRISE partners from March to May 2019 and extended later on by the SUNRISE stakeholder community. Our ambition is to have a **consensus-based document** resulting from intense discussions between partners, stakeholders and policy makers.

[91] A common workshop is already scheduled for October 2019.
[92] https://sunriseaction.com/category/prd/

This is especially important in view of the lack of direct high-level political support and the missing prospect of a large-scale funding to implement the elaborated roadmap.
It is the creation of the roadmap where real insights lie, through discussions and the structuring of ideas. The roadmapping process included a dedicated workshop taking place on the second day of the general SUNRISE stakeholder workshop (17-18. June, Royal Academy of Science, Brussels).[93] This was followed by an intense 3-days workshop of the roadmapping project team.

Boundaries: from 2020 to 2050, in line with the European Commission's Climate Strategy for a Zero-carbon Europe in 2050
Scope: Artificial photosynthesis technologies, including electrochemical conversion for the short-term, photo(electro)chemical conversion and biological approaches for the mid- to long-term; biomass-based approaches are excluded because of the elevated demand for available land surface;



Stakeholder roadmapping workshop

The SUNRISE stakeholder event in Brussels has been an important opportunity for mining completely new approaches and ideas among the 170 participants. Two hours of this general ramp-up meeting of the project had been dedicated to roadmapping. After a short general introduction into the roadmapping process, the plenum has been asked to split into three groups as regards content: Hydrogen and ammonia, CO_2 capture and electrochemical conversion, and Direct conversion via bio-, biohybrid- and integrated photo(electro)chemical cells.
The first hour of the workshop was dedicated to a **landscaping exercise**. In small groups of around 10-15 people, the goal was to develop coherent storylines including major technological milestones to reach the vision (with discussion leaders from the SUNRISE partners). For this, the

[93] https://sunriseaction.com/if-you-missed-sunrise-stakeholder-workshop/

following questions served as a guideline, with the obligation to follow a timeline and to give quantified targets:

Drivers & Trends: *Why do we need to act? What is the need?*

Example: in 2050, carbon-neutral Europe

Abstract solution: *What can we do? What do we want to deliver to reach the vision?*

Example: Carbon-free ammonia production by 2030

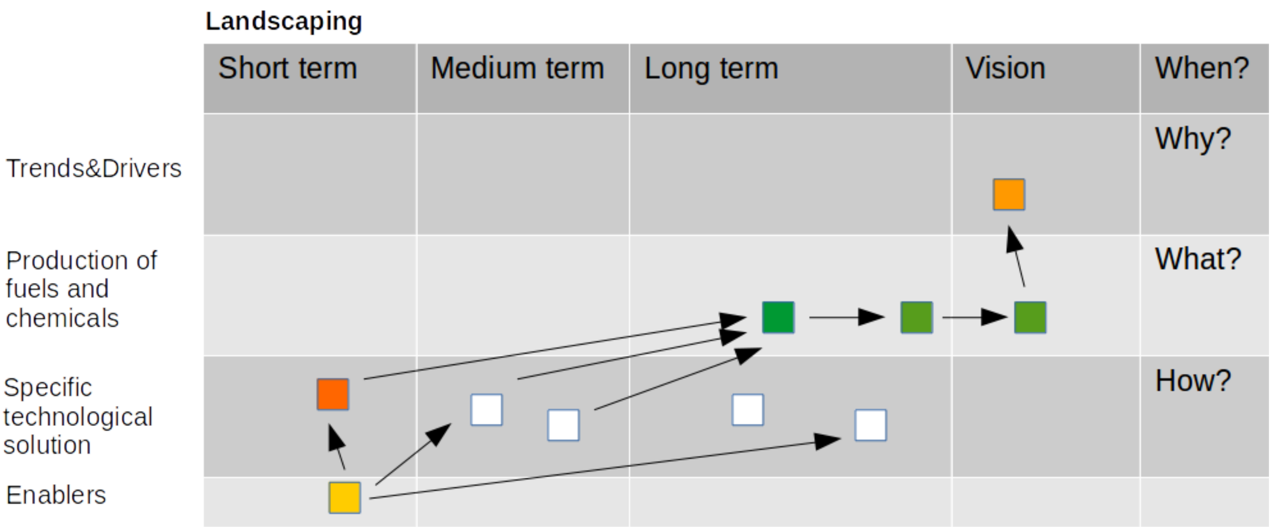
Concrete technological Solution: *How can we do it?*

Example: Low-carbon Haber-Bosch process at ambient temperature and pressure

Enablers: *What are the enablers? Which resources are needed?*

On the technological level, but also political (legislation), societal (acceptance), ..

After free brainstorming, similar ideas have been clustered and narratives leading to the vision have been created.



The second part was dedicated to **topic roadmapping**: groups of 2-3 people have been asked to choose one particular technological solution (how?) that needs to be unpacked to explore its potential. The goal was to articulate the *vision and potential application*, as well as the *current status and state-of-the-art*. Most importantly, a set of *deliverables* that provide a series of stepping stones from the current state to the future application/vision had to be defined, including an associated time dimension. Participants have also been asked to note their key learning points during this exercise and to provide a summary narrative of the technology using a Narrative Feedback template.

The postprocessing of the workshop results consisted in an in-depth analysis of the collected stakeholder input in the form of landscaping and topic roadmapping exercises and narrative feedback documents by the project leader. In general, various solutions for hydrogen production technologies have been provided, whereas a lack of input for CO_2 conversion via photo(electro)chemical approaches can be stated. The quality of the results was extremely varying from one working group to the other, sometimes missing a coherent storyline. However, one has to keep in mind that it has been a complex task for the groups to channel widespread ideas into common vision, given the very limited amount of time and the inhomogeneity of participants. In

our opinion, this roadmapping exercise has been a rich experience and we state a fruitful exchange of knowledge and ideas among different communities. We are confident that it contributed to reach consensus and to strengthen the SUNRISE goals. The received feedback was very positive and the provided contact list helped to further exchange with those interested in continuing the exercise.
The detailed analysis resulted in:

* the **mind map** (see chapter “SUNRISE vision”)
* a rich **basis for milestones and technological targets** (see chapter “SUNRISE roadmap”)
* the development of standardized technological solutions forms (so-called **How-documents**, see subsequent chapter).

SUNRISE stakeholder event (17.-18.06.2019, Brussels), roadmapping workshop.

Roadmapping workshop for the project team

During three days (17-19 July 2019), the project team met in the EERA premises in Brussels for an intense roadmapping workshop. This small group (14 people) mirrored the SUNRISE community with senior researchers for all three technological approaches and representatives from Siemens, Engie, Johnson Matthey and EMIRI. As workshop preparation, the PRD leaders had been asked beforehand to transfer and complete the content of the PRD they are responsible for into multiple How-documents. They have been free to engage experts outside the consortium and stakeholders. The PRDs are in general on the "what?"-level, containing diverse technological solutions and thus necessitating several How-documents (*e.g.* PRD "Sustainable hydrogen production" contains among others PV+electrolysis and bio-molecular PEC with quite different milestones and targets). This was an important step in order to obtain a collection of data and content as complete as possible. It represented an agreed-on basis the roadmapping team could efficiently analyze, filter and structure into a coherent roadmap.
The workshop followed a tight schedule: after a short introduction to the roadmapping process and the applied tools by the project leader, the team finalized the mind mapping. How-documents were analyzed, discussed and completed, missing elements and weak points identified. A thorough landscaping on hydrogen, ammonia, carbon-based fuels and chemicals, and CO_2 capture has been carried out in the plenum and later on in small experts groups, respectively. Moreover, the scenario analysis to estimate the future state and a STEEPLE[94] exercise for the current context have been initiated. This fruitful work has been continued afterwards via several virtual meetings in August and beginning of September for the actual drafting of the roadmap.

Revision

The first draft of the roadmap is revised by the SUNRISE managing board and the Quality and Impact Assurance team. Afterwards, an external review is planned based on a close-to-final document, by a group not having been involved so far (*e.g.* the SUNRISE advisory board).

Types of organisations and individuals participating

From the SUNRISE proposal it follows that UCLouvain coordinates the task, involving companies (Siemens, Engie, Johnson Matthey), research and technology organisations (CEA, Fraunhofer, Forschungszentrum Jülich) and associations (EMIRI, EERA) with consolidated experience in preparing scientific and industrial roadmaps. In addition, CNR is involved as leader of the entire work package. The University of Uppsala, Imperial College and the University of Warsaw volunteered to join forces given their involvement in Mission Innovation and their leading role in the SUNRISE Quality and Impact Assurance team, respectively. ICIQ is of precious help for the scenario analyses and dissemination activities related to the roadmap. Input from the policy side is provided by DG RTD which will also insure a close link to the roadmap development within Mission Innovation. As an additional dimension, the project team covers expertise for the three SUNRISE approaches.

The roles and responsibilities of organisations and individuals have been identified using a RACI [95] chart.

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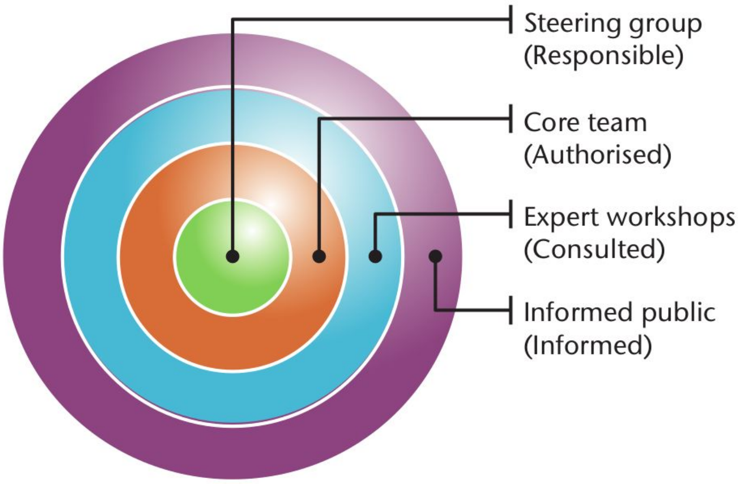
[94] STEEPLE stands for: Social, Technological, Economic, Environmental, Political, Legal and Ethical

[95] Responsible, Accountable, Consulted and Informed



Stakeholder involvement strategy following a RACI chart; taken from *Energy Technology Roadmaps, A guide to development and implementation, 2014, IEA*;

Steering group SUNRISE managing board Industry: Jan Mertens (Engie) Policy: Philippe Schild (EC, DG RTD)	This group is composed of senior representatives from policy, industry and research to assure the actual implementation.
Project team **Project leader: Carina Faber (UCLouvain)** Hervé Bercegol, Vincent Artero, Juliette Jouhet (CEA) Hélène Lepaumier, Han Huynhthi, Laurent Baraton (Engie) Max Fleischer (Siemens) Andrea Barbieri (CNR) Yagut Allahverdiyeva-Rinne (Turku University) Laura Lopez (ICIQ) Arne Roth (Fraunhofer) Anita Schneider (EERA) Robert Potter (Johnson Matthey) Leif Hammarström (Uppsala University, MI5) James Durrant (Imperial College, MI5) Marcel Meeus (EMIRI)	Core team that is actually undertaking the vast majority of the work on the roadmap; mirrors the composition of the steering group;
Consulted **SUNRISE Priority Research Direction Leaders** → lead Ann Magnuson (Uppsala University) **SUNRISE Quality and Impact Assurance Team** → lead Stefan Baumann (FZ Jülich), Joanna Kargul (Warsaw University)	This group channels the input from stakeholder experts participating in the writing of PRDs and workshops and insures the quality of the input; it typically includes expert representatives; Mandate: Attend workshops, provide reports, review roadmap drafts;
Informed SUNRISE community not actively participating.	More than 200 supporters from policy, research and industry.

Technical appendix: technologies and milestones

Separate documents

Sustainable hydrogen production

1. Large-Scale hydrogen production using PEM electrolysis
2. Hydrogen production using photoelectrochemical cell devices
3. Hydrogen via buried-junction photoelectrochemical cells
4. Hydrogen production by photosynthetic microorganisms
5. Hydrogen photoproduction by biomolecular technologies
6. Baggies with particulate systems

Sustainable ammonia production

1. Renewable Haber-Bosch process
2. Electrochemical ammonia synthesis
3. Direct photoelectrocatalytic ammonia synthesis
4. Ammonium production by photosynthetic microorganisms
5. Plasma-assisted ammonia synthesis

Sustainable carbon-based chemicals and (jet)fuel production

1. Dark electrochemical reduction of CO_2 to C1/C2/C3 products
2. Electrochemical production of hydrocarbon fuels
3. Thermochemical production of hydrocarbons and jet fuels
4. Biocatalytic production of chemicals by microorganisms
5. Carbon-based fuel production by biomolecular approaches

Carbon capture technologies

1. Amine-based carbon capture
2. Polymeric membranes based carbon capture
3. Low-Temperature Direct Air Capture
4. High-Temperature Direct Air Capture

Enabling technologies

1. Computational materials modelling: from novel materials to solar fuel devices
2. Development of new methods and software tools for early quantitative sustainability assessment of emerging SUNRISE technologies: bridging environmental, economic and social impacts
3. Redesigning photosynthesis for the biocatalytic production of chemicals and fuels
4. Synthetic Biology
5. Bottom-up chemical engineering of bioinspired artificial photosynthesis reactor materials and cascades
6. Upscaling artificial photosynthesis systems for a sustainable larger scale production of energy carriers
7. Oxygen evolution (Water oxidation)

SUNRISE Roadmap technical appendices: technologies and milestones

Separate documents can be found through the links displayed below.

Sustainable hydrogen production:
https://zenodo.org/record/3922239/files/sunrise_technological_roadmap_appendix1.pdf?download=1

Sustainable ammonia production:
https://zenodo.org/record/3923416/files/sunrise_technological_roadmap_appendix2.pdf?download=1

Sustainable carbon-based chemicals and (jet)fuel production:
https://zenodo.org/record/3923430/files/sunrise_technological_roadmap_appendix3.pdf?download=1

Sustainable carbon capture and SUNRISE key enablers:
https://zenodo.org/record/3923448/files/sunrise_technological_roadmap_appendix4.pdf?download=1

Solar Energy for a Circular Economy

Blueprint

Deliverable D1.3

The SUNRISE map: a public document identifying the necessary S&T resources, stateof-the-art EU facilities, available infrastructure & funding, and the criteria to make SUNRISE an open and inclusive initiative

Lead Beneficiary	ULEI/UU
Delivery date	30/04/2020
Dissemination level	Public
Version	2.0

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WP	1 – Vision, Roadmap and Blueprint

Version	Date	Author	Description
v0.0	Oct. 2019	H. de Groot	Proposal of blueprint concept
v0.1	28/11/2019	A. Magnuson, L. Hammarström	First draft sections 1 – 4
v0.2	17/01/2020	A. Magnuson, L. Hammarström	Revision in response to MB remarks
v1.0	02/02/2020	A. Magnuson, L. Hammarström	Revision in response to QIA remarks
v1.1	03/02/2020	H. de Groot, H. Kerp	Revision and update section 1, first draft section 5
v1.2	07/02/2020	H. de Groot, H. Kerp, input from consortium meeting	Update investment scenarios and framework of calls (section 5)
v1.3	21/02/2020	H. de Groot	Update section 5, added Figures 2 - 6
v1.4	27/02/2020	H. de Groot, H. Kerp	Update section 5, added some Manifesto texts
v1.5	28/02/2020	F. Chandezon	Update governance, section 4
v1.6	05/03/2020	H. Kerp	Revision S&T mapping (section 2), added supporter tables (Appendix)
v1.7	24/03/2020	H. Kerp, L. Hammarström, input from A. Schneider	Added data from EERA joint programs, EERA research infrastructure report
v1.8	27/03/2020	H. Kerp	Update Appendix after input from SUNRISE supporters
v1.9	30/03/2020	A. Magnuson, L. Hammarström, H. de Groot, H. Kerp, F. Chandezon	Update and review (all sections)
v2.0	30/04/2020	H. de Groot	Overall streamline and review

EXECUTIVE SUMMARY

To tackle the science and technology (S&T) challenges posed by the climate crisis and address the need for moving towards a renewable and sustainable economy, including the energy system and the chemical industry, SUNRISE-CSA prepares a science- and technology-driven, large-scale, multidisciplinary research initiative built around a visionary unifying goal to store solar energy as fuels and chemicals while utilizing atmospheric CO_2. One of the final steps of the SUNRISE CSA is to deliver the blueprint for the large-scale research initiative and trigger calls, open for all organizations that are active in the field, for implementing the SUNRISE large-scale research initiative and contribute to its SUNERGY follow-up. In the blueprint the overall collaboration and Science & Technology framework with openness is presented, along with the identification of necessary competencies and resources including infrastructure aspects. It presents the best practice approach to address three principle research directions (PRDs) toward impact: (1) how to combine water electrolysis with CO_2 capture, (2) to determine to what extent integration of steps gives better processes in terms of efficiency, selectivity and concentration over the value chain, and (3) to find out how to obtain all the hydrogen for the transition to a low carbon, clean technology economy. The blueprint builds on the four task areas defined in the SUNRISE roadmap, *i.e.* Sustainable Hydrogen, Sustainable Ammonia, Sustainable Carbon Capture, and Sustainable Chemicals and (Jet) Fuels, which provide a strong and broad basis for future innovation and economic exploitation, as well as novel benefits for society. The single prioritizing criterion for the S&T across the three PRDs is the demonstration of the value chain from source to final product. The overarching nature of SUNRISE/SUNERGY technologies implies that this initiative can only be realised through a collaborative, long-term sustained cooperation effort. The blueprint contains a broad initial overview of organizations that we have identified that are active in these areas, including, but not restricted to, SUNRISE and Energy-X supporters, and organizations from three relevant EERA joint programs.

Integration and European added value: to address its grand S&T challenge in terms of large-scale integration across disciplines, and the involvement of relevant stakeholders, SUNRISE has gathered a strong base of more than 200 supporters, from academia (*ca.*100), industry (55), local research networks and funding agencies. And together, SUNRISE and Energy-X partners and supporters reach the critical mass for research excellence and industrial capabilities in Europe needed to address the challenge to reach a carbon neutral energy system and chemical industry by 2050, as stated in the "A Clean planet for all" and the "Green Deal" European long-term strategies. The research initiative will need in the order of 100 M€ per year, to reach the objectives described in the Vision (D1.1) and Roadmap (D1.2). The aim is to reach a significant input of SUNRISE technologies across Europe by 2050.

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1. INTRODUCTION

This blueprint to implement a European large-scale research cooperation working on securing the supply side of the circular economy with renewable fuel and chemicals is a deliverable of SUNRISE CSA with input from its sister CSA Energy-X. It brings together a range of participants from academia, research organisations, society and from the private sector. With this blueprint we urge to complement the scope of existing European partnerships and enable the **full decoupling of economic growth from the utilization of resources** at the local, regional, national and European levels for a sustainable resilient growing economy that leaves no one behind. While current public-private partnerships focus on improvements on the demand side with limited impact, SUNERGY proposes **a pipeline of high impact technologies** that boost efficiency **on the supply side** with light-to-products and fuel conversion from atmospheric CO_2 at high yields up to **2500 ton/ha.yr.**

This represents a genuine best effort for Europe, since

- Decarbonization of the energy sector on the supply side paves the way for other sectors
- Why us: we are broad, application oriented, develop technology, and we have vertical integration, science-technology-industry, over the entire knowledge chain
- There are many national projects, and now it is time to initiate a European partnership to broaden from renewable power from photovoltaics and wind
- If we do not include this pathway to a low carbon, clean technology economy, we will lose the primary industry in Europe in what is by far the biggest market worldwide
- Priority: demonstrate the value chain from source to final product as the single prioritizing criterion
- By providing a new paradigm we create room for interpretation for other scientific disciplines and for socio-economic stakeholders

The combination of the SUNRISE and Energy-X initiatives, under the new name SUNERGY, has already received support from over 300 stakeholders all over Europe, and from outside the European continent. This blueprint describes the science and technology (S&T) structure to implement the strategy outlined in the SUNRISE roadmap. It describes how to balance overall project objectives with necessary competences and resources in a transparent process. It takes relevant elements of the Energy-X research agenda on board and builds on a synergistic framework of calls for bottom-up research and innovation actions (RIA) at TRL 0-5, innovation actions (IA), at TRL 6-9, demonstration projects to bridge between the RIA and IA, and demonstrators for dissemination and valorisation in the circular economy. The IA calls will need very strict criteria to maximize their impact, while the RIAs provide the means to nurture new ideas emerging bottom-up from the community. The work is open for new participants and is distributed based on open tenders and a fair selection of the best bids that are put forward in mutual competition by the members of our community and third parties. Resilient short, medium and long-term quality and impact assurance will be implemented to establish credible paths for disruptive change, with innovation pipelines delivering plug-in technologies for supplying fuel and chemicals manufactured from renewables at an affordable cost.

The purpose of this deliverable is to map the collaboration and S&T framework, in terms of necessary competencies and resources, including infrastructure aspects, that are needed for an implementation with openness. It provides a mapping of competencies and resources within Europe. The deliverable also considers the parameters for openness in the process of exploitation of results, both in exploiting scientific results with other scientists (Science-to-Science) and in the development of marketable materials, devices and processes (Science-to-Business). We also develop a "call scheme" over the course of 10 years with a number of calls needed to reach the SUNRISE goals. After submitting our blueprint the process will be 'out of our hands'. Next steps will be that DG Connect will review the outcome and engage in rounds of consultations with EU member states (MS).

1.1. Strategy and practices

The unifying goal of the SUNERGY large-scale initiative is to deliver a steady flow of targeted impact solutions for accelerating the transformation to a scalable energy and supply system. To sustain a circular economy with high economic efficiency, innovative value chains from source to product are needed. The S&T objective of manufacturing fuel and chemicals from abundant molecules in the atmosphere with renewable energy on a meaningful scale to decouple economic growth from utilization of natural resources is articulated in the SUNRISE consolidated vision. The companion strategic roadmap shows how the unifying goal can be realised and what the major milestones are. It situates the large-scale research initiative in the global landscape and identifies four task areas for the technology development of artificial photosynthesis towards societal impact, innovation and exploitation. These are (*i*) EU-wide massive deployment of sustainably produced hydrogen, (*ii*) Cost-competitive and decentralised sustainable production of ammonia, (*iii*) Sustainable carbon capture, and (*iv*) Cost-competitive and decentralised sustainable production of chemicals and fuels.

The large-scale research initiative will capitalize on the maturity of concentration of electricity from PV and wind, to foster deployment of electrochemical processes, and move forward to the development of innovative technologies enabling the centralized production of ammonia, hydrogen and carbon-based compounds. The scientific underpinning for this part is strengthened by the recent merger of SUNRISE with Energy-X. In addition, the large-scale research initiative will push the development of less mature, visionary photo(electro)chemical, biological and biohybrid systems that will provide the direct decentralized conversion of solar energy into chemical compounds. To reach the highest efficiencies, CO_2 capture and CO_2 activation will have to be integrated in a novel class of high-performance catalytic materials. On the European level the new technologies will provide competitive prices for fuels and compounds that can be concentrated to any desired level, for providing a carbon neutral supply to the circular economy and, ultimately, for enabling the capture and storage of CO_2 from the atmosphere.

The critical step for disruptive technologies is the emergence and growth of innovative value chains. All the high efficiency effort should aim for low investment cost and halving the product price compared to fossil resources. Hence the single prioritizing criterion across the entire S&T

framework (*i.e.* for both RIAs and IAs alike, as well as for demonstration projects and demonstrators) is the demonstration of the value chain from source to final product. Three global priority research directions (PRDs) bridging the gap between current capabilities and the unifying visionary goal have been identified as terms of reference for the SUNRISE strategy and practices:

- Combine water electrolysis with CO_2 capture, this gives the fully integrated value chain (PRD1).
- Does integration of steps (PV + electrolysis vs PEC vs molecular vs biological) gives better processes in terms of efficiency, selectivity/purity, concentration over the value chain (PRD2)?
- How do we get all the hydrogen to decarbonize, if we improve efficiency (PRD3)?

As innovation stepwise builds on invention, fundamental research, and valorisation, it will be important to create an environment where new concepts and approaches for converting sunlight into fuels and chemicals, developed in academic environments, can be made to harmonize with the drivers that are shaping society. This environment will ultimately depend on established academic networks and public-private partnerships and collaborations. The typical pathway is to have multiple RIA's (*ca* 5 M€ each) with a combination of bottom-up and top-down strategic elements followed by a larger demonstration project partnership (*ca* 10 M€) in a converging approach. A successful demonstration project is based on the best outcome of the preceding RIA stage. Limited redundancy at the RIA stage is used to mitigate risk of failure: successful elements of RIA projects that do not get an independent follow up are included in the demonstration project in a "graceful failure" strategy to build in fault tolerance. Following a go-no go decision, an IA will be the next stage, under top-down programmatic guidance and risk mitigation based on limited redundancy in the IA project plan. While the funding for RIA's will be supplied within the Horizon Europe (HE) framework, for funding the IA's participation of MS and associated countries (AC), with fair compensation for their contributions, will have to provide additional leverage. The mechanisms for compensation will be worked out on a case-by-case basis at the IA proposal stage, and will be subject to contract negotiations with the EU upon selection of the IA for funding prior to its start. In this blueprint, the total cost of the RIAs, demonstration projects, and IAs is initially targeted at *ca* 1.1 billion € from public and private sources. However, it is important to recall that a new energy technology - any new energy technology - requires globally 1 trillion € upfront to bring it to 10 % of its full potential, which should be reached in a time frame of the three decades until 2050. Considering that the European population is 10% the world, a proportional part of these resources, around 100 billion €, will have to be mobilized in due time. Thus, a further growth of a successful research program to a level of 10-20 billion € for the period between 2020-2030 supporting development by the member states and efficient innovation by the private sector, can be envisaged.

The SUNRISE S&T trajectories of RIA's and IAs will feed their results into large demonstrators to push innovation forward in decoupling of economic growth from utilization of resources:

- For pilot scale production of Jet fuel, a 300-500 million revolving fund with airlines is required.

- Pilot scale production for CO_2 capture from concentrated sources, and sequestration of CO_2 from the atmosphere will connect to the ongoing public-private initiatives for innovation in MS and AC.
- For decentralized residential and farming applications geographically distributed demonstration throughout Europe is the preferred action.

Since these demonstrators should operate at the production plant scale, significant funding, *e.g.* from the Green Deal, will be required.

In the view presented in this blueprint, the SUNRISE manufacturers will join the hydrogen valleys, and the demonstrators will lead to new businesses and joint ventures in the new pillar 3 "revolving fund" of HE when they end successfully. This will be equity financed, and not included in the budget for the large-scale research initiative. It is anticipated that a SUNERGY central management will only monitor progress, as the existing demonstrators operate on their own management.

In 2019, the European Commission also announced the launch of the Innovation Fund (IF). This large funding program, as a successor of the NER300 programme, is established by the EU Emission Trading System (EU ETS) Directive for the period 2021 to 2030 and may amount to about 10 billion € depending on the carbon price. The objective is to support the demonstration of highly-innovative low-carbon technologies which can lead to significant emission reductions in Europe. This program will focus on energy intensive industries (including products substituting carbon intensive ones) but also on Carbon Capture and Utilisation (CCU) and Storage (CCS) projects and innovative renewable energy and energy storage technologies, including highly innovative technologies and big flagship projects. The Fund is also open to small-scale projects with total capital costs under €7.5 million. The projects will be selected based on several criteria, *i.e.* the GHG emission reduction potential, degree of innovation, maturity, scalability, cost efficiency.

The Commission aims to launch the first call in 2020 but regular calls are expected until 2030. It is expected that 1.5 billion € will be the total budget of the first IF call mid-2020. This funding program can be an opportunity for demonstration and valorisation of the highest TRL technologies developed within the large-scale research initiative.

2. S&T NETWORKS

2.1 European network of SUNRISE facilities

The SUNRISE initiative will demonstrate source to product value chains in every area of the roadmap with basic, applied and industrial research. The proposed technologies span through a broad range of areas from synthetic chemistry and materials science as well as catalysis, photophysics and photochemistry, molecular biology and biotechnology, via electroengineering to power plant engineering, process technology and energy systems. The academic and engineering resources for the development of SUNRISE technologies cover more or less all academic institutions, and energy or environmental research organizations in Europe. However, not all of these will necessarily have the financial, physical and academic resources to meet the challenge of developing the SUNRISE initiative across all TRLs and on a meaningful scale, up to the level of pilot plants. While the principle challenge at the low TRL stages is to collect bottom-up the "unknown unknowns" with RIA's fostering academic progress, at the higher TRL IA's the emphasis will be on addressing "known unknowns" with strong support from the private sector to forge an efficient programmatic approach over the value chain from source to final product.

A large number of European academic institutions and research organizations are capable of contributing with knowledge and infrastructures, all of them having the experience and willingness to assume a leading role by building and coordinating international partnerships to perform the RIAs and IAs. The institutions and research organizations will pursue and increase critical mass by promoting new entrants joining the community from all over the globe.

Developing alternative energy carriers and sustainable raw materials is a game changer for today's energy system and for the chemical industry. At the higher TRLs a multidisciplinary, intersectoral, and strongly coordinated effort will be essential to achieve the emergence and growth of innovative value chains. Low investment cost and low product prices compared to fossil resources will require new paradigms for strong economic and systemic drivers in urbanized environments with high economic efficiencies. The fuel market is the world’s largest market by far, and the pillars of European industry are highly energy-intensive and rely significantly on the import of crude oil and gas. Beyond 2050, the value chains that derive from the products coming out of the SUNRISE/SUNERGY innovation pipeline should drastically reduce the reliance of the economy on fossil fuels, and shift the international upstream oil and gas market towards renewably produced fuels and chemical feedstocks. This will take cooperativity and strong incentives for this change to become persistent.

SUNRISE technologies create the need for a regional and temporal optimization of supply chains, depending on the availability of resources, such as sunlight, water, CO_2 and N_2 sources. Decentralized SUNRISE solutions thus have to be coupled with existing electric and gas grid infrastructures to guarantee production security and high efficiency in supply chains. In addition, with a diversity of processes and products, additional grid infrastructure is envisaged. This includes dynamic grids for enhanced integration and economic efficiency over the source to product value chain, for instance based on drones, to provide the right amount of resources at the right time and on the right location, and to balance production with demand. A number of local and regional municipal and governmental agencies and companies, that supply infrastructure for energy and water, have expressed their support for SUNRISE, and thereby showed readiness and willingness to comply with future infrastructural needs.

To create a true map of the core networks that SUNRISE can rely on for its development, the organizations and companies that have actively shown support for the SUNRISE and Energy-X initiatives will serve as the nucleus for further growth. These are complemented by cross-cutting organizations, such as KIC InnoEnergy and the European Energy Research Alliance (EERA), that bridge between different communities and support research coordination actions. Together they comprise all technological know-how that can be foreseen as necessary to propel the development according to the SUNRISE roadmap.

The four task areas of the roadmap consist of Sustainable Hydrogen, Sustainable Ammonia, Sustainable Carbon Capture, and Sustainable Chemicals and (Jet) Fuels. In the tables I to IV in the Appendix we present a first overview of organizations SUNRISE has identified that are active in the four areas, starting with SUNRISE and Energy-X supporters, and complemented with organizations from three relevant EERA joint programs, *i.e.* Advanced Materials and Processes for Energy Applications (AMPEA), Carbon Capture and Storage (CCS) and Fuel Cells and Hydrogen (FCH). In a large-scale research initiative with openness this community will grow further in the coming years.

3. IDENTIFICATION AND MAPPING OF COMPETENCIES

3.1 Required Competencies and identification of Key Partners

The Partner organizations of SUNRISE, together with the supporting organizations, represent a formidable competence base for carrying out the proposed large-scale project of SUNRISE. Below, we list the required competencies together with key Partners and Supporting Organizations that provide the respective competence. Some additional organizations that are not yet involved in SUNRISE or SUNERGY (a joint SUNRISE/Energy-X initiative, *vide infra*), but have an important competence and have contributed to the SUNRISE Roadmap, are also included.

Catalysis, homogeneous and heterogeneous. Solar fuels and chemicals from small molecules such as water and carbon dioxide require good catalysts that operate at high rate and selectivity, to form pure products at minimum energy cost. Scientific and technical understanding of catalytic reactions and processes are needed to design, evaluate and develop new catalysts that fulfil requirements of performance, durability and scalability.

Competence: Most universities, several research institutions and many companies, such as Johnson Matthey (UK), C&CS catalysts and chemical specialties (DE), Evonik (DE), Haldor Topsoe (DK), InCatT (NL).

Light-driven processes and reactions. This competence area includes the related but distinct fields of photophysics, photochemistry, natural photosynthesis, photocatalysis and photoelectrochemistry. They provide fundamental scientific knowledge of electronically excited states, charge separation and quantum behaviour in natural photosynthesis, molecules, microorganisms semiconductors, nanoscale and mesoporous systems. This is needed for synthesis and design of molecules, materials and devices, as well as for advanced characterization by experimental and theoretical methods.

Competence: Primarily universities and research institutions, but also companies such as Evonik (DE). Additional companies are found under "*(Photo)bioreactors and microbial cultivation*"

Electrochemistry. Electrochemistry is essential for electrocatalytic fuel formation, and for their use in fuel cells. It is needed to guide design of materials, devices and systems. Relevant competence is also available in the battery research and industry.

Competence. Most universities and research institutions, as well as many companies, such as Areva H2Gen (FR), Engie (FR), Esy-labs (DE), Hydrogenics (US, BE), Hydron Energy (NL), ITM (UK), Nel (NO), PowerCell (SE), SABIC (NL) and Siemens (DE). Many relevant academic and industrial partners are members of the European initiatives Battery 2030+ and the European Association for Storage of Energy, EASE.

Electrical systems engineering. Several SUNRISE technologies (electrolyzers; photoelectrochemical systems) depend on complex systems that include electrical and electronic components.

Competence. Many universities, research institutions and several companies, such as CEGASA (ES), Engie (FR), RWE (DE) and Siemens (DE).

Solar energy technologies. Current solar energy technologies include photovoltaics, CSP, and solar thermal technologies. SUNRISE technology development will benefit from synergies with this sector. This includes production, deployment an operation of systems and components.

Competence. Many universities and research institutions, and companies such as SUNRISE partners and supporters ENGIE (FR), Proheat Heattrace (ES, UK), PVH_Energy Storage (ES), Siemens (DE),

Synthesis and characterization of molecules and materials. Preparation of materials and components is an obvious need for SUNRISE.

Competence. This is a core competence at essentially every university and research institution involved in chemical and materials research. The chemical and materials industry is also very strong in the EU, organized though *e.g.* EMIRI, EuChemS and the EERA Joint Program AMPEA. Examples include additional SUNRISE Partners and Supporters, such as Johnson-Matthay (UK), Arkema France (FR), Avantium (NL), 3M, Spain (ES), Clariant (CH), Covestro (DE), Cristal Global (UK), Everest Coatings (NL), NOVAMONT (IT), Sulapac (FI)

Chemical, Materials and Process Engineering. For production of components and modules for the SUNRISE technology systems, as well as for the handling of products, engineering is required.

Competence. Many universities and research institutions, and companies such as Certech (BE), DECHEMA (DE), Plasmatechnologie GmBH (DE), Plasmatreat GmBH (DE), Dr Laure Plasmatechnologie (DE),

Membranes. Most design concepts for gaseous solar fuel formation include a membrane for separation of product gases, *e.g.* hydrogen or syngas from oxygen. At the same time, the membrane should allow for rapid proton transport from anode to cathode.

Competence. Several universities and research institutions, as well as European companies such as Solvay-Solexis (FR), Polymem S.A (FR) and Fumatech/Dupont de Nemours (FR) (membranes producers) and *e.g.* Axane (FR), Symbio FC (FR), Renault (FR), Toyota (J, BE) (end-users). The EERA Joint Programme AMPEA, and Fuel Cells and Hydrogen (FCH-JU) gather competence in the area.

Carbon dioxide Capture and Utilization. Capture of carbon dioxide from flue gas or ambient air is the first step in the cycle of carbon dioxide conversion to fuels and chemicals. Current prospects for direct air capture would result in large energy losses for the CO_2 capture and concentration. SUNRISE aims to drastically reduce those energy losses by novel concepts. By direct coupling of CO_2 capture to catalysis, optimally matching the CO_2 flow and photocatalytic reactions, thermodynamic losses can be minimized. This requires more research on new concepts.

CO_2 capture from point sources, such as industrial emissions, can significantly reduce the carbon footprint of major industrial sectors. The competences of many stakeholders are needed for the transition to a circular and CO_2 neutral economy.

Competence. A large number of companies are active in this area, including Aker solutions (NO), Antecy (NL), ArcelorMittal (LU), BASF (DE), Carbyon (NL), CRI_Carbon Recycling International (IS), Climeworks (CH), ENGIE (FR), Ineratec (DE), KT-Kinetics Technology SPA (IT), Lhoist (BE), Linde Engineering (DE), Liquid Wind (SE), Quantis Sàrl (CH), RWE (DE), Siemens (DE), Skytree (NL), Solvay (BE), Stena (SE) and ZEG Power A.S. (NO). CO_2 Value Europe is an organization for companies, universities and organizations active in the area of carbon capture and utilization. The EERA Joint Programme Carbon Capture and Storage is another one.

Water and air management. This is focused on the processes of chemically scrubbing carbon dioxide from industrial exhaust gasses, directly from ambient air, or from seawater. In addition, water is needed for water-splitting reactions of large-scale solar fuels technology, and the quality of water needs to be matched to the technological requirements. To achieve this in an efficient and economically viable manner, expertise is needed on emission detection technologies and the removal of contaminants from exhaust gas flows and the maritime environment.

Competence. Canal de Isabel II (ES), PlasmaAir AG (DE)

Genetic and metabolic engineering of microorganisms; synthetic biology, biotechnology. Genetic and metabolic approaches are widely used today to re-design microorganisms for efficient production of targeted solar fuels and chemicals. Synthetic metabolic pathways can be inserted into microorganisms to allow for production of the fuel or chemical of choice. Biotechology methods are enablers of this development.

Competence. Many universities and research institutions. Companies with competence directed towards solar fuels include Cyano Biotech (DE), Photanol (NL), H2WIN (FR) INGENZA (UK), Neste (FI) and PEPperPRINT (DE).

Computational chemistry/physics. Advanced theoretical chemistry and physics tools for computational investigation of the properties of molecules and materials including their dynamic structure are essential for materials discovery and characterization, elucidating reaction mechanisms in chiral systems etc.

Competence. Most universities and research institutions, as well as several companies, including SCM Amsterdam (NL).

Multiscale modelling. Solar fuels devices and systems need to integrate processes occurring on many different time- and length scales, from femtoseconds to days and from the nano- and mesoscale to at least several meters. Substrates and products in liquid and/or gaseous form need to be provided, transported and collected; electrons and protons need to be transferred, and transported, concentration gradients handled etc. Multi-scale simulations are vital for the design and analysis on both the device and the systems level, and an engineering theory for the bottom-up design of modular device concepts is urgently needed.

Competence. Several universities, research institutions and companies. The EERA AMPEA Joint Programme has a sub-programme dedicated to multiscale modelling of materials, processes and devices and gathers some of the key European actors in the field. There are also two European centres of Excellence gathering key European actors: MAX (MAterials design at the eXascale) and EoCoE (Energy Oriented Center of Excellence)

Informatics, AI. Bioinformatics is an important tool for understanding biological data. It can be used *e.g.* in the analysis of gene and protein expression and regulation, or to optimize metabolic pathways. Informatics, machine learning and Artificial intelligence (AI) will become more important in the near future also for *e.g.* materials discovery.

Competence. Several universities, research institutions and companies. The two above-mentioned centres of excellence MAX (MAterials design at the eXascale) and EoCoE (Energy Oriented Center of Excellence) are active in this field with key European actors.

Information technology. A large-scale research and development project requires strong IT solutions. Prototypes, demonstration and the final technology will need constant and remote monitoring of operation.

Competence. Several companies, including SUNRISE supporter PCM Technology Solutions (UK).

Handling of fuels. This includes handling, conversion (*e.g.* syngas-to-C_n compounds, H_2-formate interconversion), storage and transportation of gaseous and liquid fuels. The processes should be optimized for both small scale production of solar fuels on *e.g.* house roofs as well as for large-scale production of jet fuels.

Competence. Gas and oil companies, which are strongly represented in Europe, *e.g.* Shell (NL), TOTAL S.A. (FR), HyGear B.V. (NL), Linde (DE), Neste (FI), Repsol (ES), ST1 (FI) and ENAGAS (ES). R&D on fuel and chemicals interconversion processes involves several universities and research institutes.

Fertilizers. For deployment of fertilizers produced by SUNRISE technologies, companies that produce and distribute fertilizers today are key partners.

Competence. European companies include BASF (DE), Casale (CH), Stamicarbon (NL), Tara (NO) and Thyssenkrupp (DE).

(Photo)Bioreactors and microbial cultivation. Bioreactor and photobioreactor competence, and competence in cultivation of photosynthetic microorganisms, is needed for design and operation of large-scale production of solar fuels and solar chemicals. The competence is valuable for photoreactor design, also with non-biological approaches

Competence. Universities and research institutes, and European companies such as Ecoduna Eparella GmbH (AT), Photanol (NL), Subitec (DE), AlgoSource (FR), Algae for Future (A4F, PT), Electroarchea (DE).

Transportation. A major future end user of the SUNRISE technology products is the transportation sector, including personal and heavy ground vehicles, ships and air planes.

Competence. European companies are particularly strong in the transportation sector. This includes transportation companies, and vehicle and component manufacturing companies, such as SUNRISE supporters Copenhagen Airports, Toyota Motor Europe (BE), Fev GmbH (DE), Marion Technologies S.A (FR), Schaeffler (DE), Stena Line/Stena Rederi (SE).

Energy systems. When consumers and industries produce and exchange solar fuels and solar chemicals, new energy distribution systems and regulations have to be developed and put into place. To optimally integrate the use of renewables into existing networks, smart grids technology needs to be developed further, supported by information technology, policy regulations and market instruments.

Competence. Major European companies include the SUNRISE partners and supporters ENGIE (FR), Acconia (ES), CIC Energigune (ES), EDP Energia (ES), ENDESA (ES), Fortum Power and Heat Oy (FI), HUNOSA (ES), Petrogal SA (PT) and Uniper (DE). The EERA Joint Programme Energy Systems Integration also gathers many key European actors in the field.

Device and systems engineering. Devices, processes, and systems need to be optimized based on lab scale Proof-of-Concepts to lab-scale demos for making fuel from CO_2 and sunlight on a house roof. In parallel, large-scale Proof-of-Concepts will be obtained for running pilot production of jet fuel and further scale up at industrial sites. This includes computational design of devices considering *e.g.* fluid dynamics, heat management etc. as well as building hardware.

Competence. Several universities and research institutions, as well as many Companies, such as the SUNRISE partners and supporters Siemens (DE), Engie (FR) Atmostat-Alcen (FR).

Construction. Large-scale deployment of solar technologies will need the competence of construction companies.

Competence. Many European companies, such as SUNRISE supporter LafargeHolcim (FR)

Innovation, entrepreneurship. Research and innovation needs to be brought to products and the market. While several SMEs emerge active in solar fuel technology for small scale production on house roofs, farms and private gardens, the scale of the future solar fuels system demands involvement also of large companies.

Competence. Several technical Universities and Research Institutions have strong innovation competence. Several large companies are active in areas relevant for solar fuels: oil & gas (see above), energy technology (*e.g.* Siemens, Engie), materials (JM). Economic development agencies such as Innovation Quarter (NL) are needed to stimulate regional collaboration and implementation strategies.

Environmental and sustainability aspects, Life-cycle assessment (LCA) and techno-economic analyses (TEA). Analysis of climate and other environmental impact, as well as and sustainability, is vital for development and implementation of energy technologies. LCA is a standard tool to assess environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service. Life Cycle Energy Assessment (LCEA) is important to estimate the Energy Return on Energy Invested (EROI). For emerging technologies, it is important to develop predictive LCA together with techno-economic analyses as well as social aspects such as assessing public acceptance.

Competence. Several Universities and Research Institutions, as well as Companies, such as NOVATLANTIS (CH), Metabolic (NL), and several others.

Recycling and circular processes. This includes the activities and actions required to reuse product materials and manage waste streams in a circular manner, including the collection, transport, sorting, re-use and recycling of waste, supported by circular policy regulations and circular business models.

Competence. Companies focusing on recycling and circular industrial processes include EcoRecycling SRL (IT) and Nextchem – Maire Tecnimont (IT).

Outreach, Education and Public acceptance. New energy technologies need public acceptance for large-scale implementation. The SUNRISE technologies imply wide deployment of light harvesting infrastructures and new industrial facilities for production and distribution of fuels and chemicals, along with conversion of existing petrochemical facilities. Availability of raw materials for the new processes and facilities also needs to be carefully addressed. An industrial transformation of this size inevitably implies social and economic impact on a large scale. In case of success, such changes will be strongly beneficial for society, but this is not immediately obvious to citizens! Therefore, a substantial amount of human and financial resources needs to be mobilized to promote scientifically-grounded information on the vast industrial transformation. This needs to be handled very carefully, especially in a time when unscientific beliefs quickly spread across the web, particularly through social media. Every partner involved has to support a strong outreach and educational plan – also involving interaction with social sciences and humanities – in order to promote the SUNRISE technologies at all level of the educational system, *i.e.* all the way from elementary school to universities, as well as to involve the society at large and mass media professionals in particular.

Competence. All universities and research Institutions, as well as several Companies, have dedicated technical staff and even research personnel dedicated to education and outreach. Fruitful interactions with existing initiatives can be envisaged, for instance with KIC InnoEnergy, Climate-KIC and KIC Raw materials, which are funded by the EU through the EIT.

Legislative aspects, policy making, financing. Apart from a large-scale research initiative additional actions need to be implemented such as leveraging research and innovation funding from both the private sector as well as MS/AC investments. At present, EU RTD schemes do rarely go beyond the demonstration stage. For subsequent innovation steps, the much higher efficiency of the private sector compared to academia and research institutions is essential to nurture rapid progress. However, ambitious investments need to be financed if they are to be successful, and the supply of the enormous financial resources that are required upfront by the private R&D stakeholders in small scale financing operations is unrealistic. The only sector of the financial system that has in principle the capacity to finance an energy innovation effort is the global bond market. While this is globally the biggest source of capital, bonds are low yield, low risk financial instruments. To finance high risk innovation trajectories with green bonds, the EU and member state governments can implement derisking mechanisms were the state backs the risk to release the necessary financial resources on the required scale, following China that has taken the lead in greening its financial system already.[1] An important conclusion is that *ca* 15% of the financial resources can come from public, *i.e.* tax-based resources, with the remaining 85% of needed funding coming from the private sector. With a large-scale research initiative funded on the European level with 1 billion € from public sources, about 10-20 € billion will be needed from private sources for the period of 2020-2030, and around 80 billion € between 2030 and 2050.

Green bonds are on their way to becoming mainstream in tapping the immense investment potential of the financial markets.[2] Asian countries like Korea and also European member states like the Netherlands have demonstrated that institutional investors, pension funds and insurance funds, which have between them over 60 trillion € in investable funds and where capital shortage is not a problem, are willing to purchase green securities at investment grade from respectable banks. This will make the financing of aggregates of projects at low capital cost possible by low interest rates. It will allow governments to address the financing directly without any intermediaries, in contrast with carbon tax financing measures. By providing backing, governments put their credibility at stake to finance genuine green deals, since investors will perform due diligence and markets will immediately react in case of inefficiencies in the implementation and penalize the issuer of the bonds. Displacing fossil resources by renewables then becomes a government driven private investment, rather than a tax financed cost of mitigation.

[1] https://www.cbd.int/financial/privatesector/china-Green%20Task%20Force%20Report.pdf

[2] Global Green Shift: When Ceres Meets Gaia (2017) J.A. Mathews, Anthem Press, ISBN1783086408

In addition, legislative aspects such as liability and de-risking needs to be addressed, *e.g.* for the cross-national utilization of abundant resources (water, air) and in particular their potential pollution.

Competence. The EC and National Governments, as well as SUNRISE supporter organizations (*e.g.* WWF, EuCheMS, CO_2 Value Europe, Fonden Technologi (DK) and the Green-Win collaboration.

3.2 Infrastructure needs

a) Access to large (regional, national and trans-national) infrastructure is needed for the SUNRISE projects. Towards this need, ESFRI has a mission to support a coherent and strategy-led approach to policy-making on research infrastructures in Europe, and to facilitate multilateral initiatives leading to the better use and development of research infrastructures, at EU and international levels.

- Laser spectroscopy is key to investigate light-induced excited state processes in solar fuel components, materials and devices. **Laserlab Europe** is an Integrated Initiative of European Laser Research Infrastructures in 18 countries. This builds on European strength in the area to offer transnational access to top-quality laser research facilities in a highly co-ordinated fashion for the benefit of the European research community.

- Development of artificial photosynthesis reaction cascades critically depends on biomimetic nanotechnologies that lower transition states along adiabatic or nonadiabatic reaction coordinates by tuning of their ground state dynamic structure. Hybrid structure determination by computational integration of **cryo-EM, electron diffraction, solid state NMR** and other spectroscopic methods require state of the art infrastructure at the national and European level. Many countries have state of the art EM and NMR infrastructures in place that will contribute to the structural underpinning and provide mechanistic insight.

- Current researchers on solar fuels are already important users at **synchrotrons and free-electron laser (FEL) facilities**, and have to a large extent helped motivate the investment in FELs. There are several synchrotrons with top-class performance within MS and AC, and two FELs (out of five in the world) are in Europe, in Hamburg and in Switzerland. LEAPS – the League of European Accelerator-based Photon Sources – is a strategic consortium initiated by the Directors of the Synchrotron Radiation and Free Electron Laser user facilities in Europe.

- **Neutron scattering facilities** are also important, with several sources within EU. The European Neutron Scattering Association (ENSA) is an affiliation of national neutron scattering societies and committees, which directly represent users. The European Spallation Source (ESS) is currently under construction in south Sweden and will be the world's most powerful neutron source.

- **High-performance computing centers** are already used for both theoretical and computational chemistry and physics of molecules and materials, simulations and multi-scale modelling. Analysis of large amounts of experimental data, including data mining and meta-analysis also depends on high-performance computing. As AI and machine learning becomes more important, computing is expected to become more efficient; nevertheless, it is highly likely that computing demands will increase in the future.

- **Testing and certification centres**, as for *e.g.* photovoltaics, will have to be established also for solar fuels, *e.g.* the Helmholtz Energy Materials Foundry (HEMF). This will allow for rational comparison of systems and for certifying performance. However, standardisation of conditions is significantly more complicated than for solar cells, as substrate (feedstock) needs to be provided and different products need to be extracted.

- **Pilot and demonstration plants** need to be built, and because of their large-scale, funding from the private sector will be important.

- **Databases** and facilitated access will be important tools. The Pasteur Culture Collection (Paris) and Nordic Culture Collection (NordAqua, FI) provide high-quality biological material for the generation of reliable scientific results and technological innovations. This includes a large collection of photosynthetic cyanobacteria. There are many databases of materials, for example, NRELMatDB is a computational materials database with the specific focus on materials for renewable energy applications including, but not limited to, photovoltaic materials, materials for photo-electrochemical water splitting, thermoelectrics, etc. The main goal of NRELMatDB is to enable and facilitate the access and exchange of computational data between different research groups following the guidelines outlined in the Presidential Materials Genome Initiative. With the development of SUNRISE, there will be a need for developing materials databases comprising the research and technology needs of this field.

EERA has summarized existing databases comprising infrastructure in their report: "Sharing data, research infrastructure: summary report". The Joint Programs AMPEA, CCS and Fuel cells and hydrogen are the most relevant ones in the context of SUNRISE.

b) Local and regional large-scale infrastructure is also important, in the form of expensive experimental equipment (*e.g.* clean rooms, sterile rooms, advanced microscopy and spectroscopy resources, state-of-the-art bioreactors etc.) and computer clusters. This type of equipment is available in multiple copies over Europe, on a frequent basis to serve local and regional users.

4. OPENNESS OF THE INITIATIVE

4.1 Governance structure overview

As the Flagship partnership model is no longer an option, efforts of the governance team in SUNRISE are dedicated to exploring instruments and options (partnerships, missions) in the context of the next Framework Programme Horizon Europe (HE), in order to build a tentative scenario for launching a Large-scale European Research and Innovation Initiative (LSERI). All this is done in close collaboration with the CSA project ENERGY-X, with which SUNRISE has agreed to form a new, large-scale initiative called SUNERGY. All aspects of the new initiative are under discussion, including governance schemes. A partnership is presently the favoured option on the long term for SUNERGY, on the basis of which a scenario and timeline with intermediate steps has been built. In the long term of this scenario, which can be found in Deliverable 4.1, the SUNERGY partnership will be: "Fossil-free fuels, chemicals and materials for a circular economy (3FCM)". A co-programmed European public-private partnership (cPPP) appears as the most appropriate structure. However, the existing partnership schemes are limited from the point of view of financial leverage and from an efficiency perspective. Up to H2020, the EU programmes have stopped at the demonstration stage. With the advent of pillar 3 in HE, with equity financed innovation this is going to change. When institutional investors, pension funds and insurance investors participate in innovation based on due diligence, a high efficiency will be required to drive innovation. There are no adequate governance schemes yet for this purpose, which requires much stricter top-down governance than what is usually applied in settings with academic freedom to accumulate knowledge.

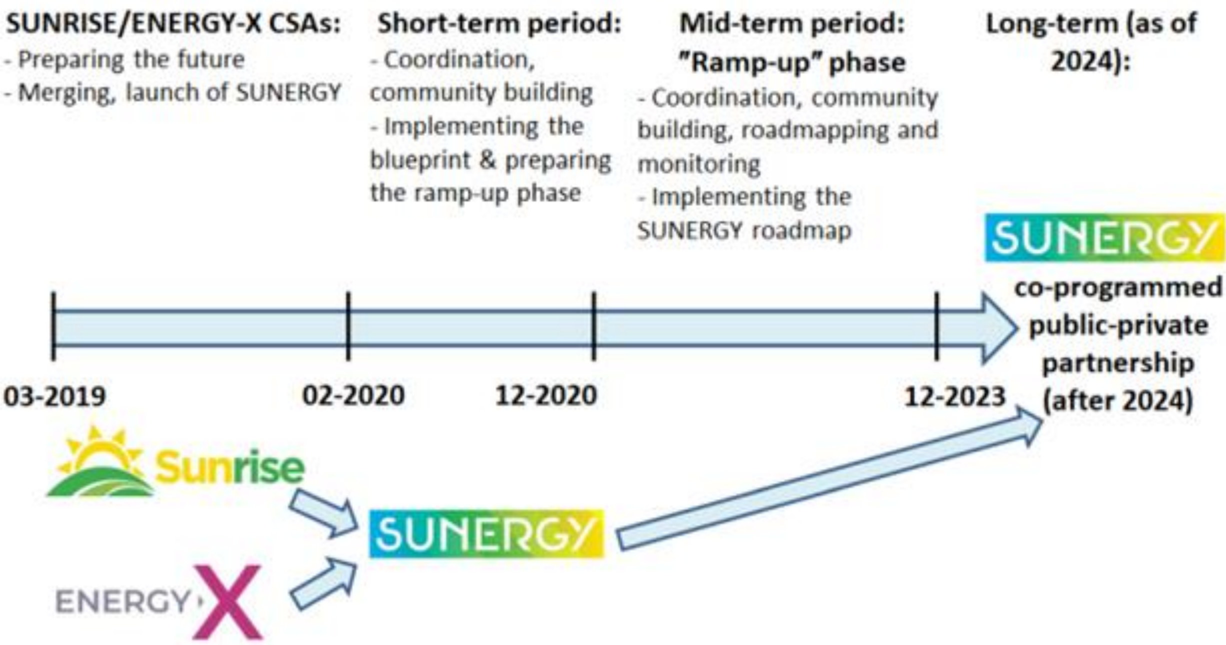


Figure 1: Tentative scenario and timeline for the SUNERGY large-scale European research and innovation initiative.

A team consisting of members from both SUNRISE and ENERGY-X have met and discussed an outline of a SUNERGY governance model and built tentative scenarios and the related timeline to have this SUNERGY co-programmed partnership starting in 2024. This is illustrated in Figure 1. The group identified the need to create a common academic board for SUNERGY, having a balanced composition from members from SUNRISE and ENERGY-X, as well as an industrial board, yet ensuring a global consistency of each board in terms of composition taking into account, whenever possible, aspects such as the types of organizations, the geographical distribution of members and gender. The two boards are, briefly:

- **Scientific executive board:** this board is responsible for the operational running of SUN-ERGY in this intermediate period with members having different roles and tasks which can be delegated whenever needed.
- **Industrial board**: the independent industrial board, separate from the scientific executive board, was deemed necessary to keep independency but at the same time working in close interaction together. The industrial board would have as a main role to bring the views of industry for the overall development and strategy of SUNERGY.

In addition to these, a strategic advisory board with a controlling function should also be appointed to give an external advice on the evolution of SUNERGY.

4.2 Openness in the governance structure of SUNRISE or SUN-ERGY

Openness in the initiative means both in respect to transparency of the organization and its governance, as well as the partnership being open for stakeholders to take part in the work. A major criticism against previous Flagships were the lack of openness in the available opportunities to participate in the work. SUNRISE seeks to avoid any situation which may limit or hamper open research and the rapid development of technology, by making sure that a future partnership will be open for all competitive initiatives

Openness to participation:

The activities of the future SUNERGY initiative will aim for creating the best possible environment for research and innovation for SUNRISE technologies. The SUNERGY partnership will prepare or support a multi-annual work programme for the SUN-ERGY Large-scale European Research Initiative (LSERI) with a series of calls; proposals for specific instruments for SMEs and start-ups could be part of this programme (liaison with the European Innovation Centre, EIC). These calls will be an instrument which is open for all stakeholders, provided that they are eligible for funding under the HE Work Programme, and is under the administrative control of the European Commission. The calls will be based on the SUNERGY roadmap, itself resulting from the merging of the roadmaps of SUNRISE and ENERGY-X, both roadmaps being the result of an open consultation with all stakeholders. The selected projects at these open calls will have a collaboration agreement with SUNERGY, *i.e.* its coordination activities as well as with all the other selected projects, in order to allow a monitoring and revision of the roadmap, again in an open process with the SUNERGY community. Furthermore, the partnership will work on a pragmatic contractual framework for the LSERI including questions on IP management, access to research results and rules for fair compensation of academic IP.

Transparency of the partnership:

To ensure openness and transparency, which is essential for enabling accountability and trust in the initiative, several mechanisms can be employed:

a) *Strategic Advisory Board*

A Strategic Advisory Board (SAB) can provide advice for strategic decision-making to the two boards (scientific and industrial). An SAB can provide feedback to the SUNERGY strategic research and innovation agenda, and monitor the initiative's progress towards its research, innovation, and commercialization goals, as well as education and outreach. The SAB should also include members representing the civil society. An SAB would also be able to propose Key Performance Indicators (KPIs) for the output and impact, and evaluate these on a regular basis. For these reasons SUNERGY will evaluate the possibility of having an SAB separate from the programming board in the future partnership governance scheme. The programming board would associate mandated expert members of the public and private stakeholders plus a funding board with representatives of EC and MS and ACs and would act as the main liaison body with the public partners and the coordination and implementation part of SUNERGY. The SAB would have an advising role with the EC and MS and the programming on the evolution and performance of the partnership. Further details can be found in the deliverables D4.1 and D4.2.

b) *Dissemination and communication*

Dissemination and communication with stakeholders, the broader scientific community, policy makers and the civil society needs a clear strategy and good coordination among communication and dissemination of related/initiated projects (*e.g.* organisation of an annual conference for relevant projects, newsletters, etc.) as well as for the executive boards, is critical for openness and trust in the initiative. More details are given in the SUNRISE Deliverable 3.1.

5. INVESTMENT SCENARIO

5.1 Comprehensive description for the priority research and implementation directions

Putting Europe's energy supply on a path to a sustainable future while leaving no one behind requires solving complex S&T challenges on the supply side. Figure 2 shows schematically how a commercially viable solar fuel can emerge which combines the almost infinite potential of solar energy with the versatility of hydrocarbon fuels. This figure summarizes the technology readiness (horizontally indicated with shades of green according to the vertical scale on the right) of innovation pipelines (vertical single and double arrows) for (bio)hydrogen, biofuels, electric power, and synthetic carbon-neutral hydrocarbons. TRLs range from 0 (white, center) to 9 (dark green, outer parts). The 1st generation biofuels with crops, and 2nd generation biomass and gasification for biofuels and biohydrogen are proven technologies. The 3rd generation biofuels and biohydrogen from algae are TRL 4-6, and 4th generation with synthetic biology pathways for direct conversion is under development at low TRL 1-3. On the right hand side the dark green fields connected by horizontal arrows depict the high TRL value chain of generation of renewable electricity from PV and wind for power that feeds into electrolysis for hydrogen production and hydrocarbon synthesis (Fischer Tropsch). Partial integration with thermolysis and photoelectrolysis (PEC) for hydrogen feeds into hydrocarbon synthesis are both at intermediate TRL. For the manufacturing of synthetic carbon-neutral hydrocarbons, capturing CO_2 is a major bottleneck. While CO_2 capture from concentrated sources is at intermediate TRL, CO_2 air capture and CO_2 activation are low TRL. Benefits are expected from integration of CO_2 air capture with activation (indicated with overlapping text blocks), and further integration with advanced and novel synthesis methods, presently at intermediate TRL, for the manufacturing of synthetic carbon-neutral hydrocarbons. The "artificial leaf" at the center combines the best of both worlds via biomimicry and nanotechnology (dashed horizontal arrows), both for hydrogen and for synthetic carbon neutral hydrocarbons and is at the lowest TRL. Horizontal arrows indicate existing connections (solid contours) or expected connections (dashed contours)

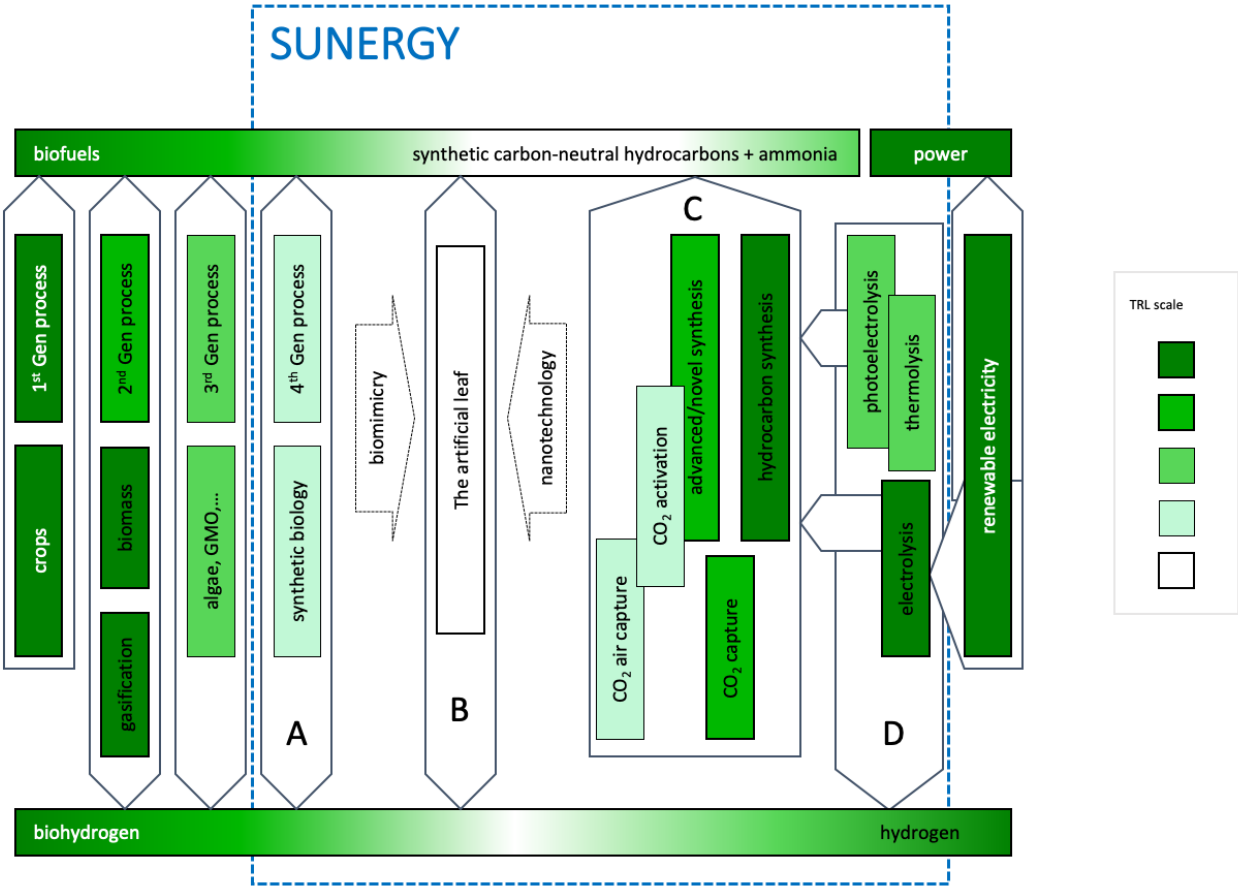


Figure 2. The broad field of technologies from biofuel to renewable power, and their TRLs (schematic). The large-scale research initiative is indicated with a dashed contour and covers the technologies ranging from (A) advanced biotech with synthetic biology, (B) the visionary "artificial leaf" based on advances in life sciences and nanotechnology in the center, and on the right (C) synthesis with activated CO_2 and (D) direct conversion with photoelectrolysis (PEC) or thermolysis, and conventional conversion of renewable electricity with electrolysis. Arrows A, B and D address PRD3, how to obtain all the hydrogen to decarbonize our economies. Arrow C concerns PRD1, how to combine water electrolysis with CO_2 capture. Finally, with arrows A,B, and C will be determined to what extent integration of steps gives better processes in terms of efficiency, selectivity and concentration over the value chain, i.e. PRD2. Adapted from Purchase et al., DOI: 10.1142/9789813274440_0003

5.1.1. The Science and Technology Case

The principle S&T challenge for SUNERGY is to find the technically novel optimal value chain(s) to combine the benefits of biofuels (*i.e.* a renewable hydrocarbon fuel) with the 'unlimited' availability of renewable electricity. The existing route to manufacture fuel and chemicals from atmospheric CO_2 is via biomass, and it provides roughly 10% of the world's primary energy supply. The existing 1st and 2nd generation source to product value chains on the biological side are well in line with the three priority research directions of this blueprint. First, biology already combines water splitting with the capture of atmospheric CO_2. Second, functional requirements (such as light absorption, water splitting and CO_2 conversion) have led to evolutionary selection of carefully engineered subcellular responsive matrix cascades (protein complexes, membranes, organelles) with sizes, reaction rates, and energetic properties optimized at internal interfaces for high yield, selectivity and concentration of energy. Third, in nature electrons and protons are separated, but never far apart, and hydrogen ions are available to generate biohydrogen or react with CO_2 for manufacturing hydrocarbons. However, while modern biomass technology is affordable and can be sustainable, the current as well as projected supply of biomass is insufficient to meet the need for fuel and chemicals. Additionally, biomass production for energy purposes will inevitably be limited by the boundaries imposed by required food supply and ecosystem services. This is why a separate large-scale research initiative is required.

With its comprehensive synergistic portfolio of technologies, SUNERGY provides justifiably high hopes for forging the tools for concentration and conversion of energy with a pipeline of high impact technologies that are scalable, affordable and sustainable, and can boost the supply side with light-to-products and fuel conversion from atmospheric CO_2 at high yields up to 2500 ton/ha p.a. In arrow block A, organisms will be tailored with synthetic biology for direct biosynthesis of biohydrogen and carbon-neutral hydrocarbons. This 4th generation direct conversion will have better efficiency, selectivity/purity, and concentration over source to product value chains than 1st, 2nd and 3rd generation processes. On the other end of the technology spectrum there is renewable electricity for power, with electrolysis, thermolysis and photoelectrolysis in block D providing hydrogen for the synthesis of hydrocarbons from CO_2 in block C. The source to - hydrogen - product value chain at highest TRL in D is conventional electrolysis from renewable power. However, a significant reduction of CAPEX is necessary to contribute to providing all the hydrogen we need. The more integrated hydrogen supply routes with direct photoelectrolysis or thermolysis in D can give better efficiency than conventional electrolysis, but further development is needed to raise the TRL. To decarbonize with *e.g.* Fischer Tropsch for hydrocarbon synthesis, the hydrogen from electrolysis, photoelectrolysis or thermolysis needs to be combined or integrated in C with capturing and activation of atmospheric CO_2, which is still a distant promise. For the CO_2 conversion in C, centralized point sources will be compared with decentralized integrated CO_2 capture and activation, and integration with novel and advanced hydrocarbon synthesis. R&D into new classes of advanced non-adiabatic biomimetic responsive matrix nanotechnology cascades in B inspired by photosynthesis, "the artificial leaf", is a vibrant area of low TRL, high impact research to determine if extensive integration of steps gives better processes in terms of efficiency, selectivity and concentration over the value chain.

5.1.2 Efficiency is key for the demonstration of source to final product value chains

According to the first law of thermodynamics, energy can neither be created, nor destroyed. So why do we bother about it so much? This is because of the second law, which states that every time energy is converted or concentrated, it becomes less useful, until in the end only entropy is left, thermal energy that is unavailable for doing useful work. While fossil resources have been slowly concentrated on a geological time scale in the earth's crust, renewables such as solar and wind are dilute and need conversion and concentration into fuels and chemicals that can be stored and handled for further use on the time scales of humans: a night, for days, seasonal storage, up to years. The higher the concentration, the faster the conversion, and the longer the storage time, the more entropy is produced.

The purpose of PRD2 is to determine to what extent integration of steps gives better processes in terms of efficiency, selectivity and concentration over the value chain. Air transport and heavy industry require large amounts of energy at specific locations, while for decentralized applications better efficiencies are obtained by avoiding too much concentration and subsequent dilution, balancing generation with demand over different locations and over time instead, and avoiding complex multi-step conversion networks as much as possible by converting renewables directly to the form in which they will be used. Since renewables are dilute by definition, their supply is more a concentration problem than anything else. Electric concentration of energy appears easy and looks attractive, but as a consequence also raw materials need to be concentrated, including CO_2 from the atmosphere. When CO_2 capture and CO_2 activation are integrated in one material, the higher efficiencies are obtained at lower rates. Exactly at thermodynamic equilibrium, there is no conversion and the losses for atmospheric CO_2 concentration vanish. In contrast, for combining CO_2 with conventional water electrolysis at high current density (PRD1) also high CO_2 conversion rates will be required, and typically half of the free energy will have to be spent on CO_2 concentration alone. For decentralized applications as with PEC, current densities are low, with less CO_2 concentration losses compared to centralized conversion. This is a strong argument against combining CO_2 capture with conventional electrolysis and in favour of decentralized direct air capture and conversion (DACC) with integrated PEC or artificial leaf technology. It is thus for good reasons that research attention internationally is shifting from conventional electrolysis to PEC and molecular systems, which can produce the required paradigm shift and impact on the supply side our economies are looking for.

For the demonstration of source to final product value chains at the best price, efficiency is key. It should be emphasized that for light to fuels and chemicals conversion the most important is to actually use incoming photons well, and therefore we consider *photon to product yields* of at least 70% as leading. Another way of stating this is: don't waste more than 30% of the incoming light, on reflections, internal recombination losses, side paths, light colour changes in the morning and in the evening, and so on. The critical technological hurdle in the development is to overcome the recombination losses, and develop nanostructured photoreactor cascades that can sustain 16 mA/cm^2 tandem photocurrent into product, in the laboratory under AM1.5 irradiation. The *energy efficiencies* follow from the yield. The thermodynamic optimum for photochemical energy storage is realized with integrated tandem photochemical cells, where every electron transported into the product requires two incoming photons. The 70% photon to hydrogen product yield then corresponds with a solar to hydrogen *energy efficiency* of 30%. Hydrogen is the most favourable case. There is, however, one other caveat: this should not lead to detrimental materials efficiencies to slow down conversion rates, as this generates entropy. In addition, large quantities of materials increase cost, especially when such materials are not very abundant in the earth's crust.

For many years scientists have been running up against a wall to achieve high energy efficiency *and* high yield *and* high materials efficiency simultaneously. Very recently, however, science has learned from natural photosynthesis how to achieve this. In the existing energy conversion technology the electrons are considered to be in equilibrium with their atomic surroundings and reactions are mostly probabilistic events. Natural systems do it differently, in the sense that proteins apparently can break the second law of thermodynamics temporarily with quantum instabilities (Figure 3). Since quantum networks are deterministic instead of probabilistic and self-select the fastest channel to the product, they form an attractive engineering concept for tailoring source to product value chains. With access to responsive matrices based on biomimicry and nanotechnology, extensive integration of steps to provide enhanced efficiency and better selectivity while keeping energy concentrated along the reaction cascades can become reality. This is the fundamental breakthrough for lowering the cost relative to current practice, since recent fundamental work has provided converging and convincing evidence that near-unity yields can indeed be achieved in man-made quantum conversion systems.

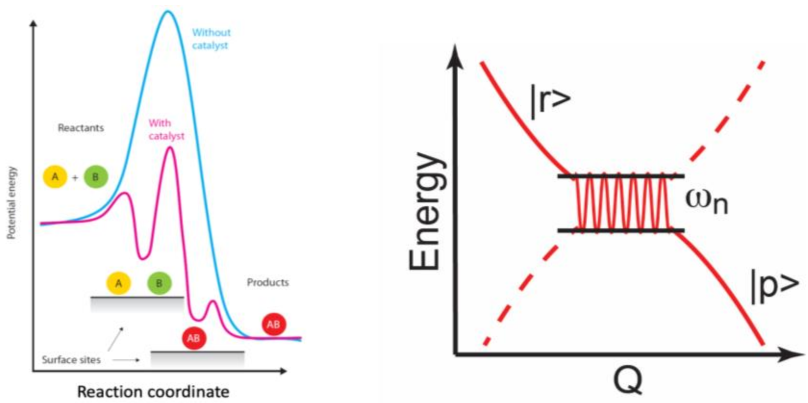


Figure 3. (a, from Energy-X) In adiabatic conversions, reactants A and B are on a catalyst surface that lowers the activation barrier. With the catalyst the reaction proceeds in steps along the reaction coordinate, driven over the barriers by e.g. thermal fluctuations or an electron motive force. Along the way, there are intermediate states until at the end the product is formed. The reactant, intermediates and product states are separated by energy barriers, the transition states. Along the entire path, the reactants are kept in equilibrium with the atomic surrounding in the catalyst with the driving force applied. (b, from SUNRISE) nonadiabatic reactions in - preferably chiral - responsive matrices proceed along a quantum reaction coordinate Q. Along the reaction coordinate sudden events occur, such as absorption of light, or release of protons, that trigger a rapid twisting response of the atomic surrounding that is nonadiabatic, i.e. too fast for the electrons to follow. When a reactant state is swept over a product state by a responsive matrix, a gap opens up, which is a well-known phenomenon known as avoided crossing. By coupling to a vibration from the environment, the reactant is converted into the product by quantum coherent tunneling through the barrier instead of over the barrier, and the tunneling channel closes afterwards. Since back reaction is prevented this way, the quantum mechanism breaks the time reversal symmetry and thereby the second law of thermodynamics that is rooted in time reversal symmetry.

In the roadmap presented by SUNRISE and the list of activities below, the efficiency is increased in steps:

1. Good efficiency can be obtained with electrochemical processes in bulk materials, where there are overpotential losses at the PV side and at the catalysis side. These systems use bulk

materials. The CO_2 capture potential is limited to 1500 t/ha p.a due to high concentration losses on the CO_2 side.

2. Better efficiency is obtained with photoelectrochemical (PEC) direct conversion since the losses from the PV stage and the catalysis stage are under one overpotential, thus eliminating the need for a second one. These systems also use bulk materials. The estimated CO_2 capture potential is ca. 2000 t/ha p.a.since CO_2 concentration losses are alleviated compared to conventional (co-)electrolysis at high current density.

3. The best materials efficiencies are accessible through photochemical materials, bioinspired, biological or biohybrid, that eliminate the electronic current intermediate by switching from bulk materials to molecules. This leads to the best materials efficiency, with CO_2 capture potential up to 2500 t/ha p.a. for fully developed non-adiabatic direct conversion tandem systems that can sustain 16 mA/cm^2 (AM 1.5) photocurrent into products.

The power of a pipeline for optimal economic efficiency while respecting our moral freedom

We want to domesticate energy, on our roofs, for our comfort and wellbeing, but not end up energy domesticating us or lead us into another era of neo-colonialism because of terrestrial requirements exceeding the capabilities of Europe. SUNRISE technologies will not compete with agriculture and have a high solar energy conversion efficiency, potentially reaching close to 30%, which is much higher than biomass production (typically less than 1%). Since fulfilling societal energy and commodities needs will be no longer a distant, out-of-sight activity but an activity close to one's household, distinguished by a highly decentralized character and spanning across densely populated urban areas, societal acceptance will dominate environmental benefits. Existing paradigms of nature as a resource to be exploited or of humans as passive consumers of natural resources are inadequate. For a full appreciation of the capacities and complexities of incorporating SUNRISE technologies in an existing ecosystem, their impact on human dignity will be evaluated and key stakeholders from society will be involved from the start in making strategic choices. Their input in filling in the innovation pipelines will optimize the overall societal and environmental impact by increasing the connection to the general public interests. A pipeline of plug-in technologies allows the connection to the existing technological infrastructure and strengthen its further development, defined by the economic efficiency requirements from the market and people's desires. The limited redundancy will help to find the best technological solutions by offering choices on the supply side of the circular economy, also to avoid potential environmental pitfalls and thus contribute to reducing costs and facilitating societal acceptance of the technology.

5.2 Overview of the priority research directions

The following sections provide short overviews of the pipeline of technologies for the main technological challenges to be resolved in Figure 2.

5.2.1 Combine water electrolysis with CO_2 capture for the fully integrated value chain

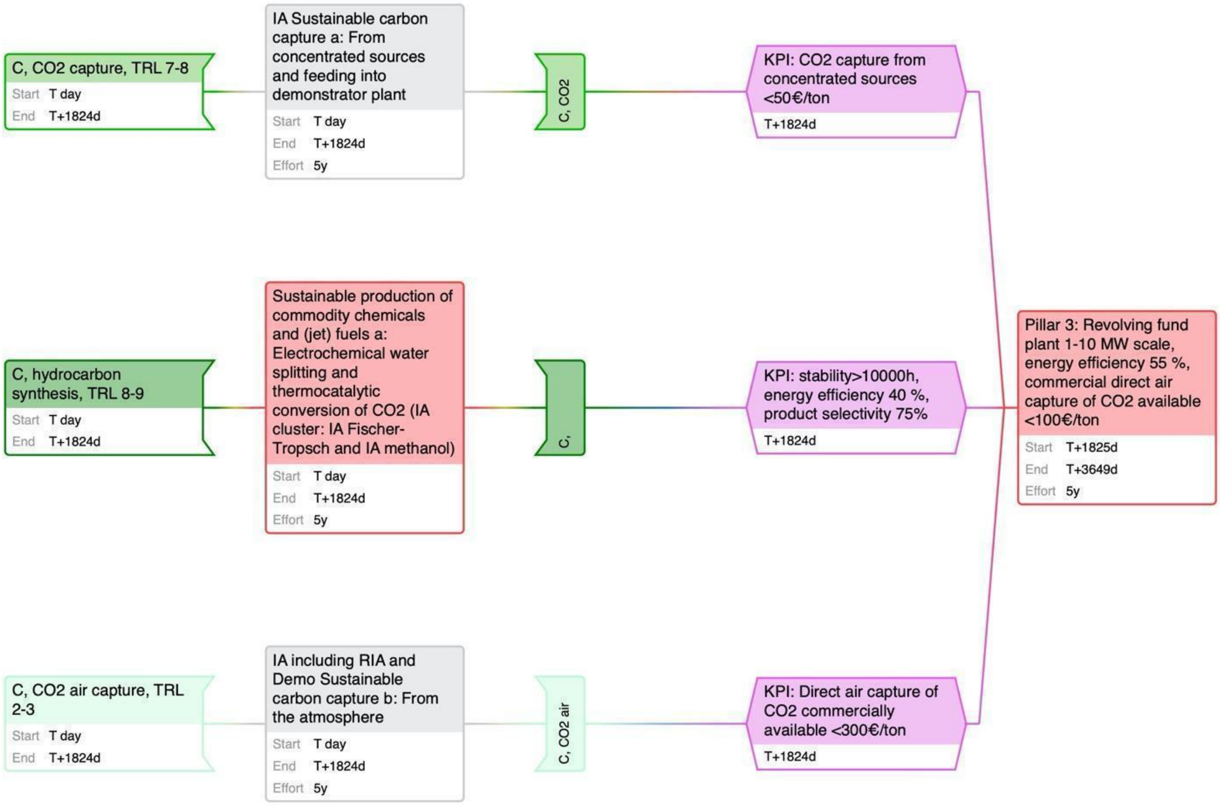
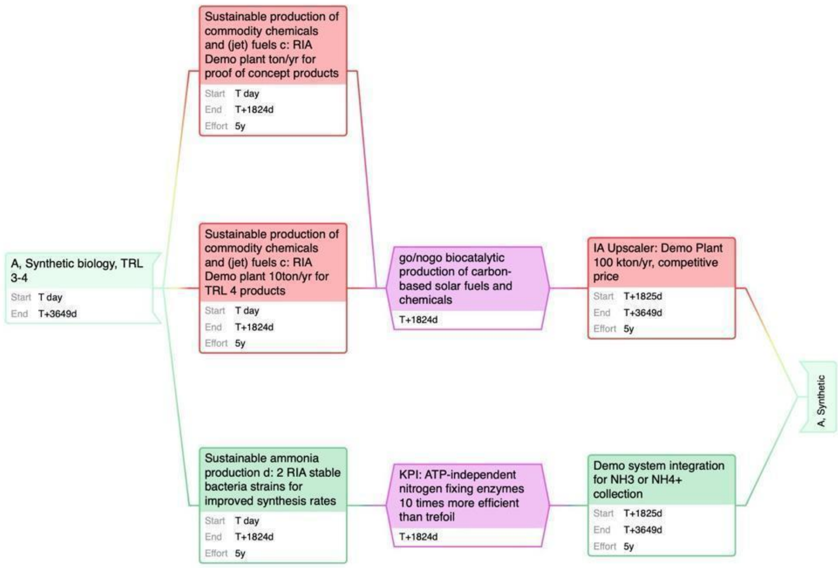


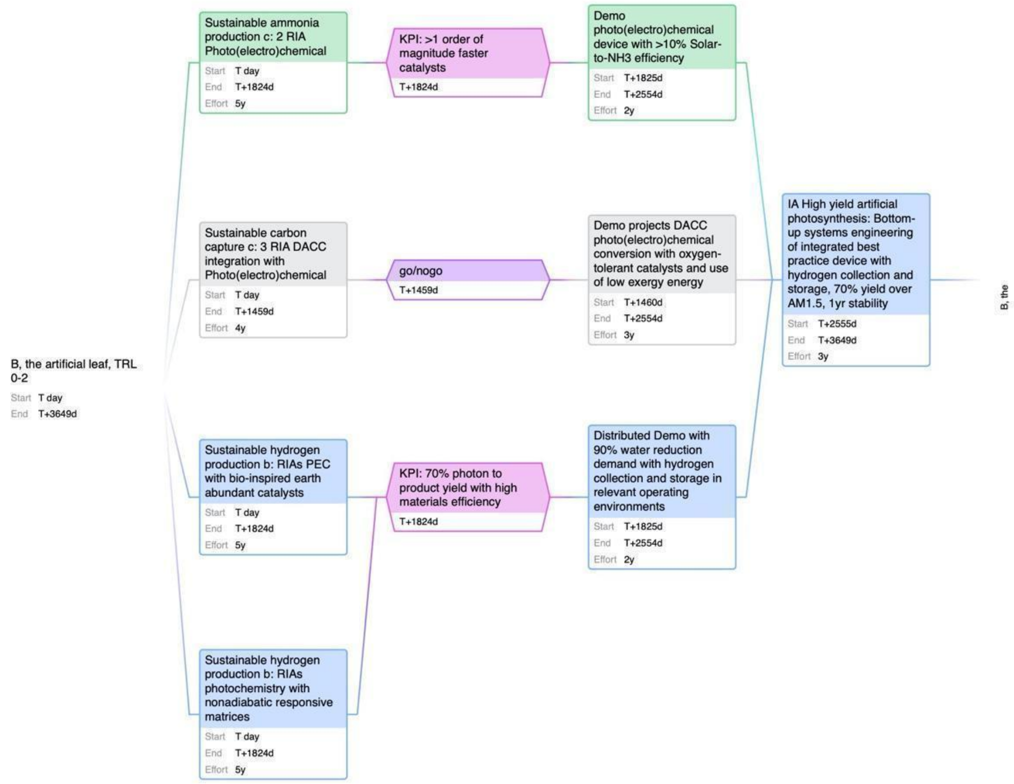
Figure 4. The innovation pipelines for the 1st PRD, conventional electrolysis with CO_2 conversion, worked out for the block arrows in Figure 2 with the technology routes from the SUNRISE roadmap.

The innovation pipeline for combining water electrolysis with CO_2 capture over the source to product value chain is shown in Figure 4. The pipeline encompasses a cluster of four IA's with KPIs (magenta) concentrating on technologies for the production of chemicals and (jet) fuels with adequate stability, efficiency and selectivity (red), for capturing CO_2 (silver) from concentrated sources at a price of 50€/ton or from the air at a price of 300€/ton. The IA cluster feeds into plant scale innovation by connecting to other initiatives in Europe for scaling up and with synergy for improving economic efficiency, for the commercial manufacturing of chemicals and (jet) fuel with direct air capture at a price of 100€/ton CO_2.

5.2.2 Does integration of steps (PV+electrolysis vs PEC vs molecular vs biological) give better processes in terms of efficiency, selectivity/purity, concentration over the value chain?

The innovation trajectories for the block arrows in Figure 2 with a grid of RIA's and IA's and KPIs (magenta) from the SUNRISE roadmap for resolving if integration of steps (PV+electrolysis vs PEC vs molecular vs biological) gives better processes in terms of efficiency, selectivity/purity, concentration over the value chain are shown in Figure 5. This PRD is very research intensive and photo(electro)chemically oriented, and starting TRLs are generally low. This is in line with international developments in the field (mainly from the US) where research attention is shifting from separate PV with catalysis to direct conversion. For hydrogen PEC (blue), the current state of the art is 50% photon to hydrogen yield (20% STH) due to detrimental recombination losses and


A, Synthetic biology, TRL 3-4
Start T day
End T+3649d
Sustainable production of commodity chemicals and (jet) fuels c: RIA Demo plant ton/yr for proof of concept products
Start T day
End T+1824d
Effort 5y
Sustainable production of commodity chemicals and (jet) fuels c: RIA Demo plant 10ton/yr for TRL 4 products
Start T day
End T+1824d
Effort 5y
Sustainable ammonia production d: 2 RIA stable bacteria strains for improved synthesis rates
Start T day
End T+1824d
Effort 5y
go/nogo biocatalytic production of carbon-based solar fuels and chemicals
T+1824d
KPI: ATP-independent nitrogen fixing enzymes 10 times more efficient than trefoil
T+1824d
IA Upscaler: Demo Plant 100 kton/yr, competitive price
Start T+1825d
End T+3649d
Effort 5y
Demo system integration for NH3 or NH4+ collection
Start T+1825d
End T+3649d
Effort 5y
A, Synthetic


B, the artificial leaf, TRL 0-2
Start T day
End T+3649d
Sustainable ammonia production c: 2 RIA Photo(electro)chemical
Start T day
End T+1824d
Effort 5y
Sustainable carbon capture c: 3 RIA DACC integration with Photo(electro)chemical
Start T day
End T+1459d
Effort 4y
Sustainable hydrogen production b: RIAs PEC with bio-inspired earth abundant catalysts
Start T day
End T+1824d
Effort 5y
Sustainable hydrogen production b: RIAs photochemistry with nonadiabatic responsive matrices
Start T day
End T+1824d
Effort 5y
KPI: >1 order of magnitude faster catalysts
T+1824d
go/nogo
T+1459d
KPI: 70% photon to product yield with high materials efficiency
T+1824d
Demo photo(electro)chemical device with >10% Solar-to-NH3 efficiency
Start T+1825d
End T+2554d
Effort 2y
Demo projects DACC photo(electro)chemical conversion with oxygen-tolerant catalysts and use of low exergy energy
Start T+1460d
End T+2554d
Effort 3y
Distributed Demo with 90% water reduction demand with hydrogen collection and storage in relevant operating environments
Start T+1825d
End T+2554d
Effort 2y
IA High yield artificial photosynthesis: Bottom-up systems engineering of integrated best practice device with hydrogen collection and storage, 70% yield over AM1.5, 1yr stability
Start T+2555d
End T+3649d
Effort 3y
B, the

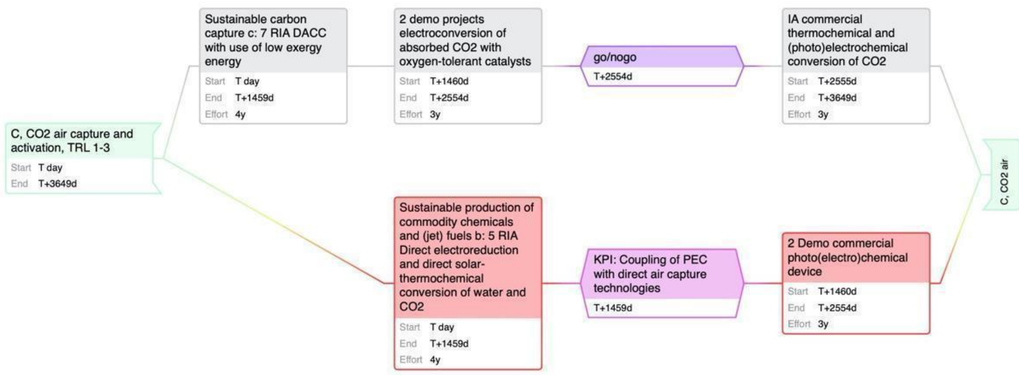

C, CO2 air capture and activation, TRL 1-3
Start T day
End T+3649d
Sustainable carbon capture c: 7 RIA DACC with use of low exergy energy
Start T day
End T+1459d
Effort 4y
2 demo projects electroconversion of absorbed CO2 with oxygen-tolerant catalysts
Start T+1460d
End T+2554d
Effort 3y
go/nogo
T+2554d
IA commercial thermochemical and (photo)electrochemical conversion of CO2
Start T+2555d
End T+3649d
Effort 3y
Sustainable production of commodity chemicals and (jet) fuels b: 5 RIA Direct electroreduction and direct solar-thermochemical conversion of water and CO2
Start T day
End T+1459d
Effort 4y
KPI: Coupling of PEC with direct air capture technologies
T+1459d
2 Demo commercial photo(electro)chemical device
Start T+1460d
End T+2554d
Effort 3y
C, CO2 air

Figure 5. The innovation pipelines for the 2nd PRD, integration, worked out for the block arrows in Figure x with the technology routes from the SUNRISE roadmap.

with poor materials efficiency. The target is to improve this with bottom-up systems engineering of responsive matrices and PEC with biomimetic catalysts to 70% photon to product yield (30% STH, 16 mA/cm^2 tandem current), beyond the adiabatic limit, with good materials efficiency, followed by a distributed demonstration in relevant operating environments, with reducing the water requirement. This is followed by an IA step for systems integration with hydrogen collection and storage. For the production of ammonia (green) further integration with PEC for one order of magnitude, and microorganisms with ATP independent nitrogen fixation enzymes for integration in hydroponic production value chains is investigated with three parallel RIA lines, followed by demonstrations in relevant operation environments of the best outcomes for integration of membrane based catalysts in electrolyzers, PEC with >10% solar to NH_3 efficiency, and system integration of NH_3 and NH_4^+ collection with microorganisms. A very important challenge is the development of DACC, which will start with a concentrated, all-out intensive effort of 10 RIAs running into 3 demonstrators for direct oxygen-tolerant conversion of CO_2 absorbed from the atmosphere. The next step is an IA to forge the manufacturing tools to make a thermochemical or PEC route for direct conversion of CO_2 commercially available. For the direct production chemicals and fuels 5 RIAs will provide coupling of PEC with direct air capture and demonstration of a commercial photo(electro)chemical device, while on the biology side demo plants for TRL4 chemical products (10 ton/yr) and proof-of-concept (POC) products (t/yr) will be scaled up to the 100 kt/y level for the production of chemicals and fuels at a competitive price.

5.2.3 How do we get all the hydrogen to decarbonize

The single prioritizing criterion across the entire S&T framework is demonstration of the value chain from source to product. To provide sufficient hydrogen to decarbonize, three innovation routes from Figure 2 are grouped under this innovation pipeline, sustainable hydrogen production with PV+electrolysis (blue), sustainable hydrogen production with microorganisms (blue), and Haber-Bosch with solar hydrogen (green) in Figure 6. For the PV+electrolysis, two demonstration projects are foreseen, to integrate with other renewables, mainly wind, and to use low exergy rest energy, from renewable waste heat, or from the recovery of exergy from the solar photons at the PV stage before thermalization takes place. The KPI (magenta) is improvement of the value chain (and reduction of CAPEX) by integration with wind and using renewable residual heat. This is followed by a broad effort to move away from the current practice of expensive Ir and Pt catalysts, where control over residual heat provides a route to solid oxide electrolysis at elevated temperatures to improve efficiencies. At this stage a PEC booster is added to connect to the PEC development in the pipeline focusing on the question if decentralized is to preferred over centralized conversion. The KPI at the end of this stage is an effective yield of 90 ton H_2/ha.yr at a cost price of 4€/kg H_2 operating at the 20 MW scale. Further upscaling is foreseen with a pillar 3 equity-financed plant scale demonstration effort for upscaling to the 1000 ha/400 MW scale at a cost price of 3€/kg of concentrated H_2.

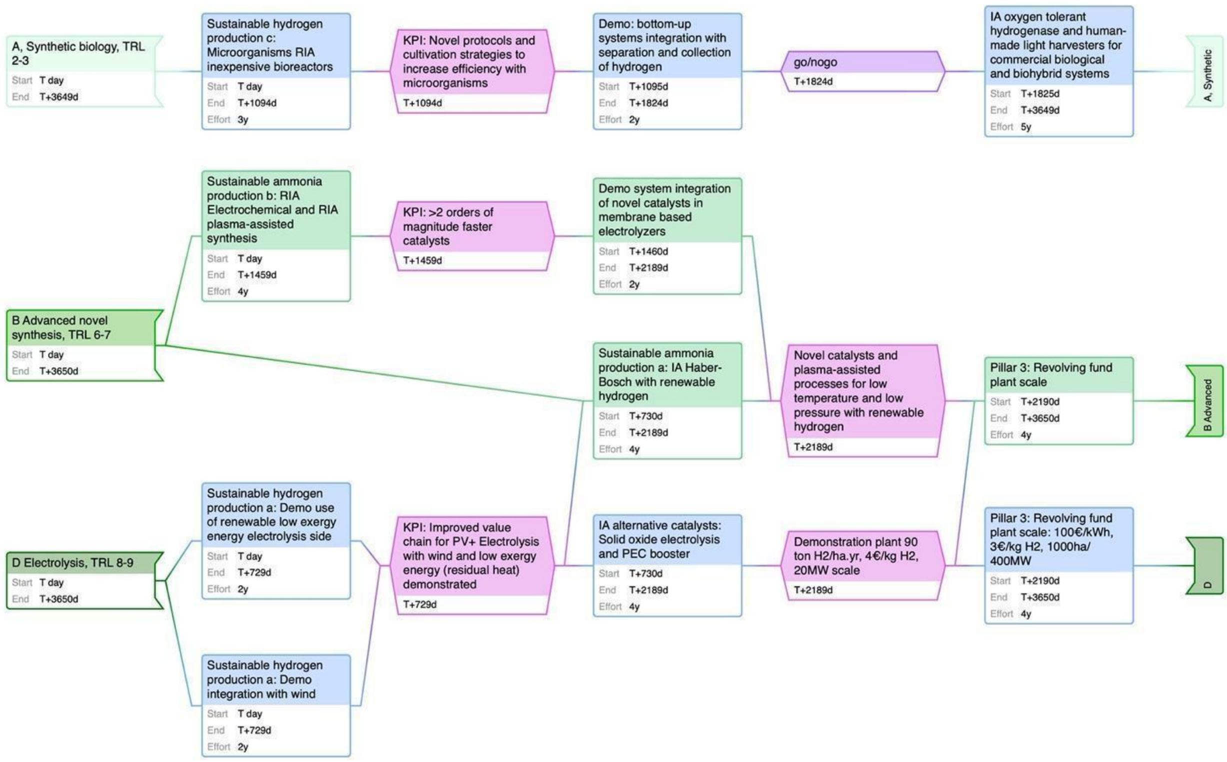


Figure 6. The innovation pipelines for the 3rd PRD, (bio)hydrogen, worked out for the block arrows in Figure 2 with the technology routes from the SUNRISE roadmap.

Also for the microorganisms the value chain in principle exists, with CAPEX and other limitations. An RIA stage focusing on novel protocols and cultivation strategies to increase efficiency (KPI) is foreseen. The lessons learned from this stage will also serve the innovation pipeline aiming for decentralized applications, as the technology is naturally suitable for domestic application. This is followed by demonstration of the bottom-up systems integration with separation and collection of hydrogen. Following positive evaluation and a go/no go decision, scale up will proceed with an IA focusing on a broad effort for improved enzyme catalysis with oxygen tolerant hydrogenase and improved light harvesting in biohybrid systems that incorporate human made light harvesters such as quantum dots or supramolecular structures. At the end of this stage such advanced biological and biohybrid systems should be commercially available (KPI). Since the single prioritizing criterion is demonstration of the source to product value chain, we have added with Haber-Bosch a route where a very mature existing, energy-intensive value chain needs decarbonization by running it from an alternative energy source and hydrogen is an important early intermediate. Following the demonstration of integration of wind and low exergy energy, an IA is started in Haber-Bosch with solar hydrogen aiming for novel catalysis and plasma-assisted processes for low temperature and low pressure. In parallel, an RIA and demonstration trajectory is planned for electrochemical and plasma-assisted processes to speed up catalysis by two orders of magnitude. This is followed by a pillar 3 upscaling that feeds into a global societal deliverable, which is 80% decoupling of economic growth from the use of natural resources.

5.3 Overview of the SUNRISE technologies

The roadmap provides four technological routes for innovation, for hydrogen, ammonia, carbon capture and production of fuel and chemicals, with key performance indicators for their development over 10 years.

5.3.1 Sustainable hydrogen production

The need:

Decarbonisation across sectors presents the potential demand for generating approximately 2,250 TWh of hydrogen in Europe in 2050, representing roughly a quarter of the EU's total energy demand. This amount would fuel about 42 million large cars, 1.7 million trucks, approximately a quarter of a million buses, and more than 5,500 trains. It would heat more than the equivalent of 52 million households (about 465 TWh) and provide as much as 10% of building power demand. In industry, approximately 160 TWh of hydrogen would produce high-grade heat and another 140 TWh would replace coal in steelmaking processes in the form of direct reduced iron (DRI). 120 TWh of hydrogen combined with captured carbon or carbon from biomass would also produce synthetic feedstock for 40 Mt of chemicals in 2050. Achieving this vision puts the EU on a path to reducing about 560 Mt of CO_2 emissions by 2050 – as much as half of the required abatement needed to achieve the 2-degree scenario. The EU needs to reduce its CO_2 emissions from 3,500 Mt today to 770 Mt in 2050. Deploying available technologies and existing energy and climate-related commitments from European countries would close approximately 60% of the gap (approximately 1,700 Mt in the Reference Technology Scenario). The use of hydrogen in end sectors could help reduce half of the remaining 1,100 Mt and achieve the 2-degree scenario. In addition, it could enable deep decarbonization of the power sector and hence indirectly reduce carbon emissions [reference: Hydrogen Roadmap Europe - A sustainable Pathway for the European Energy Transition, 2019].

The technologies:

Electrochemical conversion

The electrochemical conversion of water produces oxygen and molecular hydrogen, a key enabler in our vision. By using renewable electricity sources, hydrogen production becomes a sustainable source of fuel and chemical building blocks. The challenge, preventing the world from using this technology today, is to scale up the production to reach the amounts needed to replace fossil-based hydrogen and also to compete with the costs of hydrogen produced from natural gas (about 1€/kg vs. 5-7 €/kg for green hydrogen). It is necessary to find materials that can make this technology environmentally sustainable and economically feasible. We aim to tackle this challenge by inspiring the development of new, sustainable and non-toxic materials for large-scale deployment of electrolysis driven by power from renewable sources.

Direct conversion via photo(electro)chemical systems

Photoelectrochemical cells are single devices that directly split water into hydrogen and oxygen, using energy provided by sunlight. A variety of architectures combine light-harvesting materials and catalysts for the hydrogen and the oxygen evolving reactions. The integration of all components into a single device can lower the total system cost compared to electrochemical conversion, and provide greater flexibility in the design. Compact, integrated devices, which are independent of the electrical grid, allow for a decentralized production and important savings in transportation costs (transport and compression significantly add up to actual hydrogen production costs, leading to hydrogen prices at the fuel station of around 10 €/kg). Photo(electro)chemical systems will be fully autonomous, only depending on abundantly available sunlight, thus providing suitable solutions for on-demand, on-site production.

Devices for photo(electro)chemical hydrogen production are still at the laboratory stage, where some have reached solar-to-hydrogen conversion efficiencies of up to 20%. Ongoing research efforts are searching for ultimate combinations of light absorbing and catalytic materials, finding ways of making these materials stable under highly demanding photochemical conditions, and finding routes to the scaling up of integrated devices to pilot scale.

5.3.2 Sustainable ammonia production

The need:

Ammonia synthesis via the Haber-Bosch process ($N_2 + 3H_2 \rightarrow 2NH_3$) uses about 1% of all energy in the world with a comparable share of CO_2 emissions (since the H_2 comes from fossil sources), the latter of which will be substantially reduced using ‘green’ hydrogen. In addition, local fertiliser production will help alleviate issues related to ammonia transport and storage and allow the continuous application of fertilisers during the growing season, solving thereby the considerable environmental problems associated with fertiliser run-off.

This is required as an internal flexibility option to create a negative feedback when excessive renewable energy is available. Ammonia could be used as a fertiliser in Europe or as an energy transport vector with vanishing CO_2 footprint.

The technologies:

Electrochemical conversion

A similar possibility exists to convert nitrogen (N_2) from the atmosphere into ammonia (NH_3) that can be accomplished via electrochemistry, by-passing the need for prior hydrogen production. This is still in an early stage, with low efficiencies in the few demonstrated examples. Non-thermal plasma-assisted synthesis is an alternative for chemical conversions using electrical power.

Major ongoing scientific developments are making new, highly effective catalysts achievable. These include theoretical methods with predictive power, advanced catalyst synthesis with atom-scale precision, and operando characterization methods. These approaches can be integrated and combined with new machine learning methodology and artificial intelligence (AI) to enable radically accelerated catalyst and chemical process discovery.

Direct conversion via photo(electro)chemical systems

Similar to direct solar hydrogen production, photoelectrochemical systems have the potential to allow for decentralized ammonia production at lower cost compared to other techniques. Although photoelectrochemical nitrogen fixation is still at its very infancy, rapid progress can be expected as a result of the current expansion of this research field. The discovery of catalysts for nitrogen fixation will push the development of devices that can reach 10% solar-to-ammonia efficiency in integrated collections of aqueous ammonia.

5.3.3 Sustainable carbon capture

The need:
Many policy and industrial drivers exist to accelerate the deployment of carbon capture technologies.

The technology:

Direct air capture and conversion:
One topic will be directly impacted by SUNRISE ideas and is thus addressed in more details: the research towards combined processes of capture and activation of CO_2 for chemical conversion. At present, different types of carbon capture technologies are being developed that are based on the extraction of CO_2 from point sources. The most mature technologies consist of separating and concentrating CO_2 by chemical or physical absorption (*e.g.* utilizing amine solvent) or by adsorption (using a solid sorbent or membranes). Besides, the atmosphere is a potentially huge (teraton scale) CO_2 reservoir for decentralized systems, but with a concentration of only about 400 ppm. This will require highly efficient separation from oxygen and nitrogen, especially for electrochemical and photo(electro)chemical methods.

5.3.4 Sustainable production of commodity chemicals and (jet) fuels

The need:
The European chemical industry is globally leading, is one of the largest industrial greenhouse gas emitters accounting for the use of more than 10% of all fossil resources in Europe, and is completely dependent on fossil-based raw materials and energy carriers. The fossil fuel market is by far the largest market. European fossil fuel imports are 180 billion €/yr, and 225 billion €/yr downstream processes. In addition, the infrastructure replacement market is 150 billion €/yr globally.

The technologies:

Electrochemical conversion
Decreasing the CO_2 net emissions via electrochemical processes exploiting renewable electricity and water to produce synthetic fuels and valuable carbon-based chemicals is a promising pathway. Currently operating processes are at a TRL of 4-6 with more than 75% efficiency. Although the technologies are at an industrial relevant stage already, the stability of the catalysts is poor and

needs further improvement against poisoning and increase in stability forwards fluctuating operation conditions.

Direct conversion via photo(electro)chemical systems

Similar to direct solar hydrogen production, photo(electro)chemical systems have the potential to allow for a decentralized CO_2 valorisation at lower costs compared to PV-driven electrolysis. Photo(electro)chemical cells for CO_2 valorisation into CO or syngas are at a similar stage of development as those for H_2 production, with key drivers being discovery of CO_2 reducing catalysts that can be combined with light-absorbing materials, improvement of stability, designing active components solely based on earth-abundant elements, and collection of gases. An important target is to couple direct air capture (DAC) technologies with commercial PEC devices with 10% solar-to-syngas efficiency.

Direct conversion via biological and biohybrid systems

We recommend the domestication of a broad range of microorganisms that use solar energy for the sustainable biocatalytic production of diverse fuels and feedstock for the chemical industry. Until now, such cell factories live from a supply of biomass with high energy content. Although this can be made sustainable on a small scale, it is not scalable to produce the enormous quantities of fuels and chemicals. We therefore recommend the rational redesign of photosynthetic organisms by engineering them to have new abilities for converting atmospheric CO_2 into products with high at least 70% light to product yield, and design biohybrid systems that feed solar electricity, hydrogen, or carbon based feedstock into non-photosynthetic organisms for further downstream conversion with high yield, and using ambient CO_2 as the only carbon source. The first photosynthetic designer organisms are already coming out of scientific laboratories for testing in the field, but much improvement is still needed. A genuine rational engineering theory for smooth light conversion into rapidly growing product supplies is highly desired, synthetic biology requires further development, and the cost of bioreactors needs to be reduced while enhancing their performance. With the synergistic approach of a large-scale research program it will be possible to establish the first demonstrators for butanol or ethylene fuel at the kton scale and for selected chemicals such as lactic acid on the 10 kton scale by 2025. By 2030 production will be at industrial scale with plants producing 100 kton per year at a competitive price. This is estimated at replacing up to 10% per year of the existing refinery infrastructure, which is currently valued at €1700 billion worldwide.

5.4 Implementation with a synergistic framework of calls

SUNRISE technology	Current TRL	TRL target 2030	Companies involved	Private investments (estimate)	Public investments (estimate)	Comments
1. Sustainable hydrogen production						
1a. PV-driven electrolysis of water	4-6	9	Siemens (DE) Nel (NO) ITM (UK) Hydrogenics (US, BE) Areva H2Gen (FR)	40% C FI p.m.	30% EU 30% MS	IA Demo 2
1b. Photoelectrochemical devices	2-4	5-8	Engie (FR) Siemens (DE) SABIC (NL)	20% IA	100% RIA (MS) 80%IA (MS) 100% DD	RIA IA Distributed demo
1c. Transparent baggie systems (microorganisms and photocatalytic systems)	3-4	6-8	Mitsubishi (J) Hypersolar (US)	40% IA	100% RIA+D 60% IA	RIA lab demo (g/ng)IA
2. Sustainable ammonia production						
2a. Low-emission Haber-Bosch	5-6	9	Yara (NO) Casale (CH) Thyssenkrupp (DE) Haldor Topsøes (DK) Siemens (DE)	40	30EU 30MS	IA demo
2b. Electrochemical and plasma-assisted ammonia synthesis	1-2	4-5	n.a.		100 RIA (MS) 100 DP (MS)	2 RIA 1 Demo project
2c. Photoelectrochemical devices	1-2	4-5	n.a.		100 RIA (MS) 100 DP	2 RIA 1 Demoproject
2d. Microorganisms for direct fertilizer production	1-2	4-6	H2WIN (FR)		100 RIA (MS) 100 DP	2 RIA 1 Demoproject
3. Sustainable carbon capture						
3a. CO_2 capture from concentrated sources (concentrate on local value creation) co-adaptation of capture and catalytic conversion into long term deposits	6-7	9	ENGIE (F) (orchestrate) Fluor (US) Mitsubishi (J) Siemens (DE) Aker solutions (NO) Shell (NL) Solvay (BE) AirLiquide (US) MTR (US) RWE (DE) BASF (DE) LINDE Engineering (DE)	30% IA cluster Pipeline will feed into larger DEMOs	70% cluster	IA Demo upscaling link to 4.1 and 4.2 TEAM up with Separate Big 300 ME demo in pillar 3
3b. Direct CO_2 Capture from the atmosphere	6	8-9	Climeworks (CH) Antecy (NL) Global Thermostat (US) Carbon Engineering (Canada) Ineratec (DE) Carbyon (NL)	30% IA cluster Pipeline will feed into ongoing large demo	70% IA cluster	IA including RIA and Demo (Don't forget low exergy energy) link to 4.1 and 4.2 Don't forget negative emission (1MW scale)
3c. Direct Atmospheric CO_2 Capture & Conversion including PEC	1-2	5-7	n.a.	40 IA	100 (MS) 30 IA 30 MS IA	10 RIA 3 Demoproject g/ng IA (don't forget low exergy energy)

4. Sustainable production of commodity chemicals and (jet) fuels						
4a-1. Electrochemical water splitting and thermocatalytic conversion of CO_2	6	9	Airline Global Alliance Powerfuels Aireg (DE) Sunfire (DE) Ineratec (DE) Velocys (US) BASF (DE) Casale (CH) Total (FR) Synhelion (CH) Toyota (J, BE) Abengoa (ES) Brightsource (Isr) Helpe (GR)	30%	70%	2 IA clusters FT and methanol) feeding into Demo plant
4a-2. Direct electroreduction of CO_2	3	6			100 (MS)	4-5 RIA feeding into 2 demo
4b. Direct solar-thermochemical conversion of water and CO_2	4-5	6		40 IA	100 (MS) RIA 30 EU IA 30 MS IA	RIA demo g/ng IA upscaler demo plant
4c. Biocatalytic production of carbon-based solar fuels and chemicals	1-6	4-9	Photanol (NL) Ecoduna (AU) Synthetic Genomics (US) Euglena (J) Total (FR) Neste (FI)	40 IA	100 RIA (MS) 100 RIA (MS) 30 EU (IA) 30 MS(IA)	8 RIA and 3 demo and 1 small IA Demo plant 100 kt/yr

This list of calls corresponds to a full scenario for a large-scale research initiative under HE, equivalent to a full Flagship under H2020.

Notes from within the consortium:

- In this table, every IA initiative stands for *ca.* 100 M€ investment, RIA initiatives are typically 5 M€ per contract, and the scale of demonstration projects is up to 10 M€.
- In IA calls the costs of private partners are not fully reimbursed (only up to 70%) which means that actual corporate costs are higher. This has to be taken into account when making the split between private and public investments
- A distinction is made between 'small demonstrators' (*i.e.* working devices in operating conditions) in demonstration projects and 'full demonstrators' (*i.e.* large pilot plants) in IA's, the latter being far more important for companies.
- Central management of the projects will need to be steered by a CSA: Assuming a total project portfolio of 1 b€, 1% (10 M€) is assumed to be sufficient to run the CSA component at a level of 1 M€/year.
- Education and governance, including the programming and monitoring of progress, are organised in the central CSA.
- Infrastructure costs can be charged to projects.
- For specification and testing of technology bids will be called for from centers that will be qualified to perform this work. Budget: 10 M€ in total for 1-3 centers associated with either PV centers or hydrogen valleys, depending on the costs.
- Quantitative sustainability analysis is mandatory for every project with go/no go decisions from the QIA team and program board
- Dissemination is in every project, in addition there is global dissemination at the partnership level with the management
- Risk mitigation is by running multiple technologies in parallel, providing optimal cross-fertilization for maximum synergy benefits and establishing an open innovation environment with respect to founding and transferring IP. For example, in a power-to-ethanol demonstrator plant (IA) it is possible to exchange different electrolyzers. Another example is to aim for 'distributed demos', *e.g.* plants distributed over countries with low/high solar irradiation intensity.

- A mid-term review will be performed by an independent group of experts and QIA processes will be implemented to discuss the project results regularly (see also governance deliverable 4.1 that contains the procedures).
- The companies listed in the table were mentioned during the discussions at the consortium meeting on February 7, 2020. However, they do not necessarily represent a complete overview.
- Since a significant part of the work is performed on high TRL, we expect to get access to another billion in pillar 3, and in addition the innovation fund related to public money coming from the carbon tax 2020-2030. However, it must be noted that SUNRISE / SUNERGY will only control specific technology developments, such as PEC, and the rest we feed into:
    - For regional SUNRISE valleys, it is proposed that they could line up with hydrogen valleys. Pillar 3 could be sourced for the demonstrators when they end successfully. This will be equity or bond financed, *i.e.* not in our budget. In this case, central management will move out as they will operate on their own, central management will only monitor
    - CO_2 capture is already being done at large-scale. Best is to team up with ongoing efforts and focus on *e.g.* capture with integrated conversion.
    - Negative emissions are not covered in the Sunrise roadmap and in the blueprint.
- Table 4a: New fuel components will require certification for use in jet fuels, there are standard specifications in place for synthetic jet fuel components. The certification process takes many years and costs several M€.
- Table 4b: Several demonstrations are already out in the field. However, since these are relatively small-scale, we will aim for “upscaler demonstration plants”.

APPENDIX

Table 1: *Overview of selected European research organisations and companies interested to contribute to SUNRISE roadmap* ***task group 1: Sustainable hydrogen***

Organization name	**Country**	**Organization type**
University of Copenhagen	DK	University
Technical University Graz	AT	University
Technical University Berlin	DE	University
Technical University of Munich	DE	University
European Atlas of Universities in Energy Research & Education, EUA-EPUE	BE	University network
Psi-K	CH	Academic network
INSTM	IT	University network
PTChem	PO	Academic society
Societa Chimica Italiana, SCI	IT	Academic society
Société Chimique de France	FR	Academic society
F.R.S.-FNRS	BE	Academic network
Polish National Science Centre (NCN)	PO	Academic network
Czech Academy of Science	CZ	Academic network
Palacký University Olomouc - Regional Centre of Advanced Technologies and Materials	CZ	University
Ecole Polytechnique Federale de Lausanne	CH	University
University of Warsaw	PO	University
KU Leuven	BE	University
University of Milano-Bicocca	IT	University
Queen's University Belfast	UK	University
Uppsala University	SE	University
Freie Universität Berlin	DE	University
Imperial College	UK	University
Danish Technical University	DK	University
Universität Zurich	CH	University
University of Stockholm	SE	University
University of Antwerp	BE	University
University of Padova	IT	University
University Bari Aldo Moro	IT	University
University of Turku	FI	University
Leibniz Institute for Catalysis	DE	University
University of Tartu, Institute of Physics	EE	University
Leiden University	NL	University
University of Camerino	IT	University
TU Dresden	DE	University
University Bielefeld	DE	University
Ruhr-University Bochum	DE	University
University of Seville	ES	University
Lund University	SE	University
Mersin University	TR	University
Bogazici University	TR	University
University of Twente	NL	University
University of Freiburg	DE	University
University of Kiel	DE	University
University of York	UK	University
Technical University of Delft	NL	University
University of Cambridge	UK	University
Univ. Rey Juan Carlos	ES	University
University of Oxford	UK	University

University of Amsterdam	NL	University
Johannes Kepler University Linz	AT	University
Warsaw University of Life Sciences	PO	University
University of Umea	SE	University
University of Lorraine	FR	University
University of Crete, Chemistry Department	GR	University
University of Limerick	IRL	University
University of Bologna	IT	University
University of Ferrara	IT	University
National University of Ireland Galway (NUIG)	IRL	University
Tarsus University	TR	University
Uni. Oldenburg	DE	University
IASS Potsdam	DE	University
UK catalysis hub	UK	University network
UK Solar Fuels Network	UK	University network
NERA	NL	University network
LERU	BE	University network
Swedish Consortium for Artificial Photosynthesis	SE	University network
Max Planck Institute for Chemical Energy Conversion	DE	Institute
CIEMAT	ES	Institute
CNRS	FR	Institute
CERIC-ERIC Trieste	IT	Institute
DLR	DE	Institute
TNO	NL	Institute
ENEA	IT	Institute
IFP Energies Nouvelles, IFPEN	FR	Institute
Hellenic Mediterranean University	GR	Institute
IBPC	ES	Institute
VTT Finland	FI	Institute
CEA	FR	Institute
J. Heyrovsky Institute of Physical Chemistry	CZ	Institute
College de France	FR	Institute
Helmholtz-Zentrum Geesthacht	DE	Institute
Forschungszentrum Jülich GmbH	DE	Institute
Fondazione Bruno Kessler	IT	Institute
German Aerospace Center	DE	Institute
Paul - Scherrer Institute	DE	Institute
Fraunhofer Gesellschaft	DE	Institute
Helmholtz-Zentrum Berlin	DE	Institute
Italian National Research Council (CNR)	IT	Institute
SPF_Inst. Fuer Solar Technik (HRS Rapperswil)	CH	Institute
KTH	SE	Institute
ICIQ	ES	Institute
AIT - Austrian Institute of Technology	AT	Institute
EMPA	CH	Institute
DIFFER	NL	Institute
Biological Research Center_BRC, Laboratory of Photosynthetic Membranes	HU	Institute
IREC	ES	Institute
Tecnalia	ES	Institute

Ricerca Sisterna Energetico	IT	Institute
UKERC	UK	Institute
BAS	BG	Institute
CNH2	ES	Institute
IEN	PO	Institute
IK4	ES	Institute
IMPPAN	PO	Institute
MINES Paris-Tech	FR	Institute
NTNU	NO	Institute
TUBITAK	TR	Institute
Helmholtz centre for Environmental Research – UFZ, Leipzig	DE	Institute
Bauhaus Luftfahrt	DE	Institute
Austrian Centre of Industrial Biotechnology, ACIB	AT	Institute
Interuniversity Microelectronics centre, IMEC	BE	Institute
Johnson-Matthey	UK	Company
Evonik	DE	Company
Siemens	DE	Company
Engie	FR	Company
3M	ES	Company
Acciona Energy	PT	Company
EDP Energia	ES	Company
ENAGAS	ES	Company
H2WIN	BE	Company
Repsol	ES	Company
Schaeffler	DE	Company
ST1 Oy	FI	Company
Total S.A.	FR	Company
Toyota Motor Europe	BE	Company
Uniper	DE	Company
Shell	NL	Company
Arcelor Mittal	LU	Company
Copenhagen airports	DK	Company
Avantium	NL	Company
PCM	UK	Company
Carbon Recyclin International, CRI	IS	Company
Canal de Isabel II	ES	Company
CEGASA	ES	Company
Cyano Biotech	DE	Company
Esy-labs	DE	Company
Everest Coatings	NL	Company
Dr Laure Plasmatechnologie	DE	Company
Fortum	FI	Company
Hydron Energy	NL	Company
NOVAMONT	IT	Company
PEPperPRINT	DE	Company
Photanol	NL	Company
Plasmatechnologie GmbH	DE	Company
PowerCell	SE	Company
Proheat – Heat Traces	ES	Company
PVH_Energy Storage	ES	Company
SCM Amsterdam	NL	Company
Sulapac	FI	Company
InCatT	NL	Company
EuChemS - European Chemical Society	BE	Society

ANCRE	FR	Network organization
EMIRI	BE	Network organization
Association of Chemical Industry of the Czech Republic	CZ	Network organization
GDR Solar Fuels French Network	FR	Network organization
Innovation Quarter	NL	Network organization
MATERPLAT	ES	Network organization
Swedish Energy Agency	SE	Network organization
Swedish Research Council	SE	Network organization
DECHEMA	DE	Network organisation
Fonden Teknologirådet	DK	Funding agency
European Algae Biomass Association, EABA		Association
Hydrogen Sweden	SE	Public Private Partnership
Mariestad	SE	Municipality
Polish Ministry of Science and Education	PO	Ministry
Regional Ministry of E&R in communidad de Madrid	ES	Municipality

Table 2: *Overview of selected European research organisations and companies interested to contribute to SUNRISE roadmap **task group 2: Sustainable ammonia***

Organization name	Country	Organization type
University Perugia	IT	University
University of Freiburg	DE	University
Universitat Rostock for Biowissenschaften	DE	University
University Pau and Pays de l'Adour	FR	University
University of Turku	FI	University
Lund University	SE	University
Ege University (Bioengineering)	TR	University
Chalmers University of Technology	SE	University
TU München	DE	University
University of York	UK	University
University of Oxford	UK	University
European Atlas of Universities in Energy Research & Education, EUA-EPUE	BE	University network
Psi-K	CH	Academic network
INSTM	IT	University network
PTChem	PO	Academic society
Societa Chimica Italiana, SCI	IT	Academic society
Société Chimique de France	FR	Academic society
F.R.S.-FNRS	BE	Academic network
Polish National Science Centre (NCN)	PO	Academic network
Czech Academy of Science	CZ	Academic network
Uppsala University	SE	University
University of Stockholm	SE	University
Imperial College	UK	University
University of Warsaw	PO	University
Ruhr-University Bochum	DE	University
Adam Mickiewicz University in Poznan	PO	University
University of Iceland	IS	University
University Roma 3_Campus bio-medico	IT	University
University of Glasgow	UK	University
Technical University of Denmark	DK	University
Universität Hamburg	DE	University
University of Cambridge	UK	University
University of Nantes	FR	University
UK catalysis hub	UK	University network
NERA	NL	University network
LERU	BE	University network
University of Lorraine	FR	University
University of East Anglia	UK	University
University of Stuttgart	DE	University
University of Kiel - Botanical Institute and Garden	DE	University
University of Sheffield	UK	University
University of Limerick	IRL	University
National University of Ireland Galway	IRL	University
University of Bologna	IT	University
University of Ferrara	IT	University
University of Umea	SE	University
UKERC	UK	Institute
CIEMAT	ES	Institute
CNRS	FR	Institute
CERIC-ERIC_Trieste	IT	Institute

DLR	DE	Institute
AIT - Austrian Institute of Technology	AT	Institute
TNO	NL	Institute
ENEA	IT	Institute
IFP Energies Nouvelles, IFPEN	FR	Institute
IBPC	ES	Institute
SCK-CEN	BE	Institute
Fonden Teknologirådet	DK	Funding agency
VTT Finland	FI	Institute
Cyano Biotech	DE	Institute
Forschungszentrum Jülich GmbH	DE	Institute
Fundacion IMDEA Energia	ES	Institute
Max Planck Institute for Chemical Energy Conversion	DE	Institute
Lyon Sustainable Development Chair	FR	Institute
Biological Research Center_BRC, Institute of Plant Biology	HU	Institute
EMPA	CH	Institute
J. Heyrovsky Institute of Physical Chemistry	CZ	Institute
IREC	ES	Institute
Tecnalia	ES	Institute
ICIQ	ES	Insitute
Austrian Centre of Industrial Biotechnology, ACIB	AT	Institute
3M	ES	Company
Acciona Energy	PT	Company
EDP Energia	ES	Company
H2WIN	BE	Company
ST1 Oy	FI	Company
Avantium	NL	Company
Carbon Recycling International, CRI	IS	Company
Cyano Biotech	DE	Company
Esy-labs	DE	Company
Dr Laure Plasmatechnologie	DE	Company
NOVAMONT	IT	Company
Engie	FR	Company
PEPperPRINT	DE	Company
Photanol	NL	Company
Plasmatechnologie GmbH	DE	Company
SCM Amsterdam	NL	Company
Sulapac	FI	Company
Casale	CH	Company
Clariant	CH	Company
Haldor Topsoe	DK	Company
Stamicarbon	NL	Company
Yara	NO	Company
MATERPLAT	ES	Network organization
ANCRE	FR	Network organization
Association of Chemical Industry of the Czech Republic	CZ	Network organization
GDR Solar Fuels French Network	FR	Network organization
Innovation Quarter	NL	Network organization
Swedish Energy Agency	SE	Network organization
EuChemS - European Chemical Society	BE	Society

DECHEMA	DE	Network organisation
European Algae Biomass Association, EABA		Association
Polish Ministry of Science and Education	PO	Ministry
Regional Ministry of E&R in communidad de Madrid	ES	Municipality

Table 3: *Overview of selected European research organisations and companies interested to contribute to SUNRISE roadmap* ***task group 3: Sustainable carbon capture***

Organization name	Country	Organization type
Valladoid University Spain	ES	University
University of Bern	CH	University
Ecole Polytechnique Federale de Lausanne	CH	University
Uni Stuttgart_Institute of Chemical Technology	DE	University
Technical University of Delft	NL	University
Technical University of Denmark	DK	University
University of Szeged	HU	University
University of Zaragoza	ES	University
National University of Ireland Galway (NUIG)	IRL	University
Leiden University	NL	University
Johannes Kepler University Linz	AT	University
University of Ferrara	IT	University
University of Gothenburg	SE	University
JGU Mainz	DE	University
Bogazici University	TR	University
Dept. of Atomic Physics_BME	HU	University
Tampere University	FI	University
University of Nova Gorica	SI	University
Hasselt University	BE	University
Technische Universitat Kaiserslautern	DE	University
University of Milano-Bicocca	IT	University
Warsaw University of Life Sciences	PO	University
Lund University	SE	University
University of Strasbourg	FR	University
Centrale Lille University	FR	University
Queen's University Belfast	UK	University
University of Warsaw	PO	University
University of Paris Diderot	FR	University
University of Alicante	ES	University
University of Messina	IT	University
University of Duisburg-Essen	DE	University
Cardiff University	UK	University
Aachen University	DE	University
Hochschule Osnabrück	ES	University
Technical University of Denmark	DK	University
University of Utrecht	NL	University
Ghent University	BE	University
Karlsruhe Institute of Catalysis	DE	University
Ruhr-University Bochum	DE	University
Humboldt University	DE	University
University of Milano	IT	University
Wageningen University	NL	University
University of Manchester	UK	University
University of Firenze/UNIFI	IT	University
Politecnico di Milano	IT	University
University of Antwerp	BE	University
Maria Curie-Sklodowska University_UMCS_Gruszecki	PO	University
European Atlas of Universities in Energy Research & Education, EUA-EPUE	BE	University network
Psi-K	CH	Academic network

UK catalysis hub	UK	University network
NERA	NL	University network
LERU	BE	University network
INSTM	IT	University network
PTChem	PO	Academic society
Societa Chimica Italiana, SCI	IT	Academic society
Société Chimique de France	FR	Academic society
F.R.S.-FNRS	BE	Academic network
Polish National Science Centre (NCN)	PO	Academic network
European Materials Research Society, EMRS		Academic network
Leibniz Institute for Catalysis	DE	Institute
CIEMAT	ES	Institute
CNRS	FR	Institute
CERIC-ERIC_Trieste	IT	Institute
DLR	DE	Institute
TNO	NL	Institute
AIT - Austrian Institute of Technology	AT	Institute
ENEA	IT	Institute
IFP Energies Nouvelles, IFPEN	FR	Institute
Fundacion IMDEA Energia	ES	Institute
Institute of Microstructure technology	DE	Institute
Bauhaus Luftfahrt	DE	Institute
UKERC	UK	Institute
Fraunhofer Gesellschaft	DE	Institute
Forschungszentrum Jülich GmbH	DE	Institute
Leibnitz Institute for Catalysis	DE	Institute
Austrian Centre of Industrial Biotechnology, ACIB	AT	Institute
INL_Lyon Institute of Nanotechnology UMR-CNRS	FR	Institute
Fritz Haber Institute of the Max Planck Society	DE	Institute
CEA	FR	Institute
Institute of Physics of the National Academy of Sciences of Ukraine	UA	Institute
ICIQ	ES	Institute
Weizmann Institute of Science and Bar-Ilan University	IL	Institute
NPK ERHVERV	DK	Institute
National Institute of Chemistry	SI	Institute
Tecnalia	ES	Institute
Eindhoven University of Technology	NL	Institute
Institutt for energiteknikk (IFE)	NO	Institute
J. Heyrovsky Institute of Physical Chemistry	CZ	Institute
CENER	ES	Institute
Helmholtz-Zentrum Geesthacht	DE	Institute
ITQ Institute of Chemical Technology (CSIC-UPV)	IT	Institute
NTNU	NO	Institute
ETH Zurich	CH	Institute
SINTEF Energy	NO	Institute
CSIC-INCAR	ES	Institute
3M	ES	Company
Acciona Energy	PT	Company
EDP Energia	ES	Company
ENAGAS	ES	Company

H2WIN	BE	Company
Repsol	ES	Company
ST1 Oy	FI	Company
Total S.A.	FR	Company
Toyota Motor Europe	BE	Company
Uniper	DE	Company
Shell	NL	Company
Arcelor Mittal	LU	Company
Copenhagen airports	DK	Company
Esy-labs	DE	Company
Everest Coatings	NL	Company
Dr Laure Plasmatechnologie	DE	Company
Hydron Energy	NL	Company
NOVAMONT	IT	Company
PEPperPRINT	DE	Company
Plasmatechnologie GmbH	DE	Company
Proheat – Heat Traces	ES	Company
SCM Amsterdam	NL	Company
HUNOSA	ES	Company
Siemens	DE	Company
Johnson Matthey	UK	Company
Engie	FR	Company
LafargeHolcim	FR	Company
Lhoist	BE	Company
Solvay S.A.	BE	Company
Skytree	NL	Company
Carbyon	NL	Company
C&CS catalysts and chemical specialties	DE	Company
Petrogal SA	PT	Company
Arkema France	FR	Company
Stamicarbon	NL	Company
Atmostat - Alcen	FR	Company
GreenWin	BE	Company
Ingenza	UK	Company
Liquid Wind	SE	Company
PlasmaAir AG	DE	Company
Plasmatreat GmbH	DE	Company
Climeworks	CH	Company
Marion Technologies S.A	FR	Company
Polymem S.A	FR	Company
HyGear B.V.	NL	Company
EcoRecycling SRL	IT	Company
ZEG Power A.S.	NO	Company
Quantis Sàrl	CH	Company
KT-Kinetics Technology SPA	IT	Company
Oficemen	ES	Network organization
PTECO2	ES	Network organization
CO_2 Value Europe	BE	Network organization
MATERPLAT	ES	Network organization
Swedish Energy Agency	SE	Network organization
ANCRE	FR	Network organization
Association of Chemical Industry of the Czech Republic	CZ	Network organization

EMIRI	BE	Network organization
GDR Solar Fuels French Network	FR	Network organization
Innovation Quarter	NL	Network organization
DECHEMA	DE	Network organisation
Fonden Teknologirådet	DK	Funding agency
Polish Ministry of Science and Education	PO	Ministry
Regional Ministry of E&R in communidad de Madrid	ES	Municipality

Table 4: *Overview of selected European research organisations and companies interested to contribute to SUNRISE roadmap* ***task group 4: Sustainable production of commodity chemicals and (jet) fuels***

Organization name	**Country**	**Organization type**
University of Torino	IT	University
Technical University of Munich	DE	University
Technical University of Delft	NL	University
Aachen University	DE	University
University of Leipzig	DE	University
Polytechnic University of Milano	IT	University
Technical University of Eindhoven	NL	University
University Paris Saclay	FR	University
University of Lille	FR	University
Aarhus University	DK	University
University of Oslo	NO	University
Ghent University	BE	University
University of Groningen	NL	University
Jagiellonian University_Dept. of Chemistry	PO	University
Dept. of Economics_Univ. Roma Tre	IT	University
University of Amsterdam	NL	University
University Grenoble Alpes	FR	University
Tel Aviv University	IL	University
Univ. of the West of England, Bristol	UK	University
University College London	UK	University
Queen's University Belfast	UK	University
Bogazici University	TR	University
Lund University	SE	University
National University of Ireland Galway (NUIG)	IRL	University
University of Twente	NL	University
Warsaw University of Life Sciences	PO	University
University of Milano-Bicocca	IT	University
Technical University Berlin	DE	University
Abo Akademi University	FI	University
European Atlas of Universities in Energy Research & Education, EUA-EPUE	BE	University network
Psi-K	CH	Academic network
UK Solar Fuels Network	UK	University network
Swedish Consortium for Artificial Photosynthesis	SE	University network
UK catalysis hub	UK	University network
UK Solar Fuels Network	UK	University network
Swedish Consortium for Artificial Photosynthesis	SE	University network
INSTM	IT	University network
European Materials Research Society, EMRS		Academic network
French Academy of Sciences	FR	Academic society
PTChem	PO	Academic society
Societa Chimica Italiana, SCI	IT	Academic society
Société Chimique de France	FR	Academic society
F.R.S.-FNRS	BE	Academic network
Polish National Science Centre (NCN)	PO	Academic network
University of Montpellier	FR	University
KU Leuven	BE	University
University of Lyon	FR	University

University of Helsinki	DK	University
Ecole Polytechnique Federale de Lausanne	CH	University
Cardiff University	UK	University
Julius-Maximilians-Universität Würzburg	DE	University
Cambridge University	UK	University
Uppsala University	SE	University
Imperial College	UK	University
University of Copenhagen	DK	University
Italian National Research Council (CNR)	IT	Institute
ICIQ	ES	Institute
CIEMAT	ES	Institute
CNRS	FR	Institute
DLR	DE	Institute
TNO	NL	Institute
Flemish Institute for Technological Research VITO	BE	Institute
ENEA	IT	Institute
IFP Energies Nouvelles, IFPEN	FR	Institute
VTT Finland	FI	Institute
Bauhaus Luftfahrt	DE	Institute
ICIQ	ES	Institute
ICFO Institut de Ciències Fotòniques	ES	Institute
Institute of Electronic Materials Technology (ITME)	PO	Institute
MPI für Kohlenforschung Mülheim	DE	Institute
Forschungszentrum Jülich GmbH	DE	Institute
Karlsruhe Institute of Catalysis	DE	Institute
CEA	FR	Institute
Acconia	ES	Institute
CIC Energigune	ES	Institute
Max Planck Institute for Chemical Energy Conversion	DE	Institute
Helmholtz centre for Environmental Research – UFZ, Leipzig	DE	Institute
KTH	SE	Institute
ISPT	NL	Institute
DIFFER	NL	Institute
Austrian Centre of Industrial Biotechnology, ACIB	AT	Institute
D. G. de Investigación e Innovación Tecnológica	ES	Institute
IMEC	BE	Institute
3M	ES	Company
Acciona Energy	PT	Company
EDP Energia	ES	Company
ENAGAS	ES	Company
Repsol	ES	Company
Total S.A.	FR	Company
Toyota Motor Europe	BE	Company
Uniper	DE	Company
Covestro	DE	Company
Shell	NL	Company
Arcelor Mittal	LU	Company
Copenhagen airports	DK	Company

Avantium	NL	Company
Carbon Recycling International, CRI	IS	Company
Esy-labs	DE	Company
Everest Coatings	NL	Company
Siemens	DE	Company
Johnson Matthey	UK	Company
Engie	FR	Company
Fortum	FI	Company
Hydron Energy	NL	Company
PEPperPRINT	DE	Company
Photanol	NL	Company
PowerCell	SE	Company
Proheat – Heat Traces	ES	Company
PVH_Energy Storage	ES	Company
SCM Amsterdam	NL	Company
Photanol	NL	Company
Casale	CH	Company
Neste	FI	Company
Stena Line	SE	Company
Clariant	CH	Company
Haldor Topsoe	DK	Company
RWE Power	DE	Company
Nextchem – Maire Tecnimont	IT	Company
Arcelor Mittal	LU	Company
Stamicarbon	NL	Company
Yara	NO	Company
C&CS catalysts and chemical specialties	DE	Company
Petrogal SA	PT	Company
Arkema France	FR	Company
Atmostat - Alcen	FR	Company
CEGASA	ES	Company
Certech	BE	Company
Ecoduna Eparella GmbH	AT	Company
Fev GmbH	DE	Company
GreenWin	BE	Company
Ingenza	UK	Company
Liquid Wind	SE	Company
Mügge GmbH	DE	Company
KT-Kinetics Technology SPA	IT	Company
ANCRE	FR	Network organization
Association of Chemical Industry of the Czech Republic	CZ	Network organization
GDR Solar Fuels French Network	FR	Network organization
Innovation Quarter	NL	Network organization
Swedish Energy Agency	SE	Network organization
MATERPLAT	ES	Network organization
DECHEMA	DE	Network organisation
EuChemS - European Chemical Society	BE	Society
Fonden Teknologirådet	DK	Funding agency
Deutsche Energie Agentur DENA	DE	Funding agency
Polish Economic chamber of Renewable and distributed energy (PIGEOR)	PO	Government body
Polish Ministry of Science and Education	PO	Ministry

Regional Ministry of E&R in communidad de Madrid	ES	Municipality

SIEMENS

Siemens Gas and Power GmbH & Co. KG, Otto-Hahn-Ring 6, 81739 Muenchen

Prof. Huub de Groot
Leiden University

Per mail
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Our reference	MF
	24.3.2020

Our support for R&D projects following your blueprint document.

Dear Prof. Dr. de Groot,

On behalf of Siemens Gas and Power GmbH & Co. KG, I declare our interest to participate in selected SUNERGY proposals which will be submitted in the research calls proposed in the SUNRISE Blueprint document.
As Siemens AG, being a partner in SUNRISE, we have read the SUNRISE Blueprint in its current form and have been fully informed about the SUNRISE CSA project and its follow-up, under the name of SUNERGY, that will take shape in the remainder of Horizon 2020 and in Horizon Europe. We are very interested in participating in SUNERGY.
We have formed Siemens Gas and Power GmbH & Co. KG, as an integrated energy company with significant focus on the new energy system. We provide generation, grid transporation, oil and gas support and formed a new business segment New Enery Business to industrialize innovative products for a cyclic energy system with renewable e.g. our industrial grade Sielyzer Electrolyzer
Our interest relates to all four fields of your blueprint document with some focus to carbon capture and sustainable production of commodity chemicals and (jet) fuels.

Based on the SUNRISE Blueprint in its current form we consider contributing to SUNERGY. Our definitive contribution and its nature are dependent on the SUNERGY calls that will be published in the remainder of Horizon 2020 and in Horizon Europe, and on the formation of consortia upon application of the final proposals.

Kind regards,

M. Fleischer

Max Fleischer
(Chief Key Expert Energy Technologies)

Siemens Gas and Power GmbH & Co. KG
Power2X and Storage
Management: Armin Schnettler

Otto-Hahn-Ring 6
81739 Muenchen
Germany

Tel.: +49 (89) 636 00

Subject: Statement of intent

Brussels, 26th March 2020

Dear Prof. dr. de Groot,

On behalf of ENGIE I declare our interest to participate in selected SUNERGY proposals which will be submitted in the research calls proposed in the SUNRISE Blueprint document.

As ENGIE, being a partner in SUNRISE, we have read the SUNRISE Blueprint in its current form and have been fully informed about the SUNRISE CSA project and its follow-up, under the name of SUNERGY, that will take shape in the remainder of Horizon 2020 and in Horizon Europe. We are very interested in participating in SUNERGY.

ENGIE is a major energy utility company which operates in close to 70 countries on 5 continents (approximately 170 000 employees worldwide). It provides highly efficient and innovative energy and services solutions to residential, commercial and industrial customers. Willing to take a lead within the Energy Transition in Europe, ENGIE is highly involved in the development of sustainable and renewable energies from their production to their uses in cities and territories.

With a target of 1.5 billion euros invested in the development of new solar technology, ENGIE believes in conversion processes using CO_2, H_2O, N_2 and O_2 as feedstock and sun as energy source to produce sustainable fuels and chemicals. As addressed in different tracks in the SUNRISE blueprint document, ENGIE would be especially interested to participate in the technology development of sustainable H_2, NH_3 and fuels according to photo-(electro)chemical and biological processes. Integration of advanced Carbon Capture technologies for centralized and decentralized CO_2 sources with downstream conversion processes is also part of the R&D topics in which Engie wish to be involved.

Based on the SUNRISE Blueprint in its current form we intend to contribute to SUNERGY. Our definitive contribution and its nature are dependent on the SUNERGY calls that will be published in the remainder of Horizon 2020 and in Horizon Europe, and on the formation of consortia upon application of the final proposals.

Kind regards,

Prof. Dr. Jan Mertens

Scientific Director – ENGIE Research

Johnson Matthey
Inspiring science, enhancing life

Johnson Matthey
Johnson Matthey Technology Centre
Blount's Court
Sonning Common
Reading
RG4 9NH
T (0118) 9242248

Prof. dr. H. de Groot
Professor of Biophysical organic chemistry
Gorlaeus Building
Einsteinweg 55
2233 CC Leiden
Netherlands

Date: 11.03.2020 **Re: Statement of Intent for Sunergy Calls**

Dear Prof. dr. de Groot

On behalf of Johnson Matthey (JM) I declare our interest to participate in selected SUNERGY proposals which will be submitted in the research calls proposed in the SUNRISE Blueprint document. As a partner in SUNRISE, we have read the SUNRISE Blueprint in its current form and have been fully informed about the SUNRISE CSA project and its follow-up, under the name of SUNERGY, that will take shape in the remainder of Horizon 2020 and in Horizon Europe. We are very interested in participating in parts of SUNERGY.

Johnson Matthey is a sustainable technologies company whose vision is for a world which is cleaner and healthier, today and for future generations. Our products allow our customers to deliver more sustainable travel, food and energy. We apply our cutting-edge science to create solutions with our customers that make a real difference to the world around us

Many aspects of the Sunrise blueprint are relevant to JM's current and future products. We have a wide portfolio of hydrogen related technology, and also technology for making ammonia, chemical and fuels at scale. We are therefore interested in developing the next generations of sustainable processes for these important feedstocks, but equally our current expertise is an important part of that transformation too.

Based on the SUNRISE Blueprint in its current form we are planning to contribute to SUNERGY. Our definitive contribution and its nature are dependent on the SUNERGY calls that will be published in the remainder of Horizon 2020 and in Horizon Europe, and on the formation of consortia upon application of the final proposals.

Yours Sincerely

Dr. Peter Ellis
Senior Principal Scientist

Solar Energy for a Circular Economy

Deliverable D2.1
Innovation process

Lead Beneficiary	Fraunhofer (D2.1)
Delivery date	31/05/2019
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1. Innovation Process

The successful implementation of new ideas into technically and commercially viable products and services is a critical part of all modern economies. Unsurprisingly, it is a topic that generates continual discussion and debate although there is a broad consensus of distinct stages in any innovation process and what constitutes best practice for a particular business case. However, SUNRISE recognizes that for the transition to a circular economy we are dealing with something beyond the conventional commercial context. The problem to be solved is global in magnitude, albeit with a European epicenter. Consequently, we will need from the outset to build collaborative forums for all partners and stakeholders to meet and set priorities for addressing short, medium and long-term challenges for transitioning to a circular economy.

The most important aspect, dealing with disruptive technologies and the SUNRISE vision, is to bring fundamental research to the market through the fastest possible route. In Deliverable 1.1, the outline for the production of Hydrogen, Ammonia and Carbon-based feedstock is given in view of different possible technologies. As innovation is the sum of invention/fundamental research plus commercialization, SUNRISE will also put emphasis on the latter to push innovation forward. It is necessary to create an environment, where new start-ups are founded and funded in addition to the present industrial companies and SMEs to cover the TRL levels from TRL 4/5 to 7/8. For this, the investment climate for renewable energy solutions needs to be considered (Egli, Steffen et al. 2018). These TRLs often suffer from an absence of industrial partners, especially in the case of new disruptive technologies. Additionally, innovation cycles in the field of chemical feedstocks are quite large in the range of >10 years, as often high investments have to be made to introduce new processes or plants. Existing companies are often very risk-adverse.

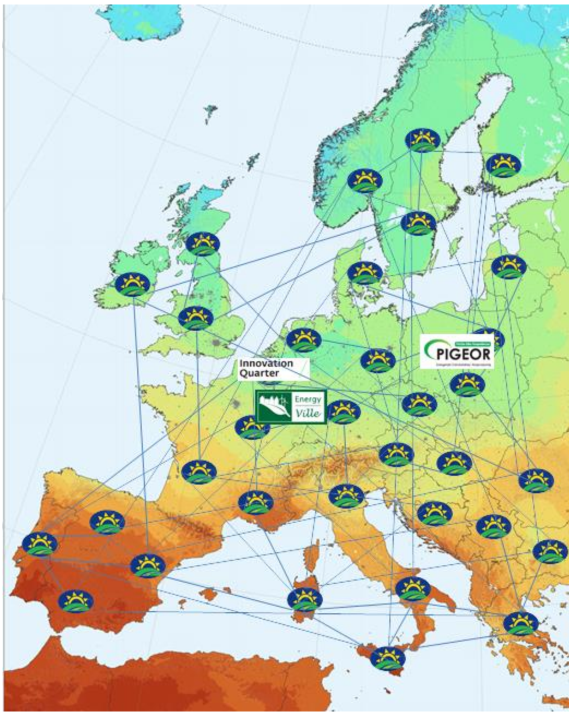

Figure 1: Network of SUNRISE valleys in Europe, having already interested SUNRISE supporters available.

To encourage SUNRISE technologies to flourish, the concept of a multitude of SUNRISE Valleys is introduced in the style of the Silicon Valley (see Figure 1). The SUNRISE Valleys constitute a Trans-European Network (TEN) and will fit in Europe's TEN policy (Marshall 2014). A comparable and readily existing initiative is the Hydrogen Europe network, which is spread across Europe. To further realize this concept and to reduce the innovation cycle time demand, the combination of public funding as well as private investments and a long-term commitment (minimum 10 years period) from the EC and the member states will be crucial to be able to engage private investments.

A harmonized and comparable infrastructure of SUNRISE valleys providing support with *e.g.*, business angels, venture capital companies, Intellectual Property (IP) support, business attorneys, marketing experts, accountants, etc. will enable a fast and focused development of technologies in a business-friendly environment. In cooperation with large industry, these technologies can be distributed on a global scale to ensure the acceleration in technology distribution (Figure 2).

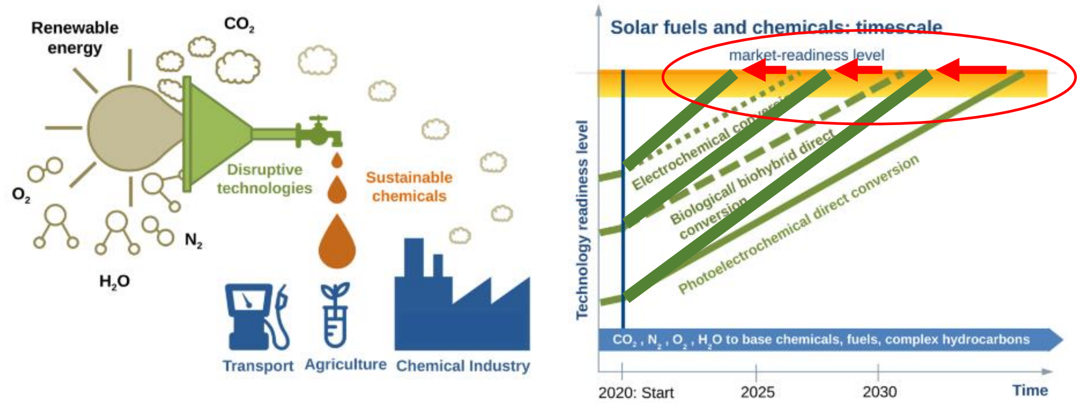

Figure 2: Acceleration in technology development and reduction of innovation cycle is indicated with red arrows.

Additionally, SUNRISE will do this by adopting best practices from other suitable sectors/economic regions for structuring the innovation process and for handling attendant information flow including intellectual property. In other words, SUNRISE will leverage the existing Member State 'innovation infrastructure' to provide local nodes for assisting the overall SUNRISE Innovation Process (SIP). The SIP will be built up using well-recognized stages (outlined below). From the outset, it will be vital to create an innovation environment where contributors are purposefully exposed to the views and opinions of all stakeholders so that new concepts and approaches to converting sunlight into fuels and chemicals are in sync with the drivers that are shaping our societies of the future.
SUNRISE will bring together an innovation team as part of, and reporting to, the governance structure. The innovation team will be specifically in charge of and responsible for organizing and running the SIP. The team is expected to evolve with time to reflect new developments in the political and social European landscape as they happen. The team will be tasked with leveraging relevant resource, assistance and advice from local, national and European organizations and institutions in building the SUNRISE innovation nodes. The frequency of webinars and physical meeting-forums will be adjusted in response to specific decision points embedded in the Roadmap.

2. Innovation Process stages

SUNRISE uses three principal approaches to develop solutions to the chemical and fuel-based needs of Europe's circular economy *i.e.* electrochemical, photoelectrochemical and biological/biohybrid processes. As well as having different product outcomes covering hydrogen, liquid hydrocarbons and ammonia, these approaches occupy different segments of the TRL range. Nonetheless, it is anticipated that the three approaches will share inter-related technical and commercialization challenges. We consider here five distinct stages of innovation that are generally applicable across the S&T landscape. The innovation process will be operated with sufficient flexibility to account for the different SUNRISE technology themes. For example, stages 4 and 5 will have more immediate relevance to the electrochemical production of hydrogen as this has already reached demonstrator stage, but lessons learnt here will have real value for passing onto the photoelectrochemical and biological/biohybrid operations.

Stage 1: Idea generation and refinement.
We need new ideas that cover all aspects of the circular economy from science and technology to funding and financing, legislation, social acceptance, and local societal needs. A series of webinars and 'town-hall' meetings will be put in place to give full exposure to the concept of the circular economy. Partnership and networking opportunities will be a feature of the physical forums to encourage cross-disciplinary interactions at an early stage. Even technologies at relatively high TRLs can benefit from new thinking and continuous refinement. A successful Stage 1 should therefore provide potential participants with a well-rounded view of the problem to be solved and what their technical projects should encompass to be relevant progressing the Roadmap.

Stage 2: Evaluation and selection
The governance structure of SUNRISE allows for the selection of projects for consideration for funding by the commission and other sources of finance from private and/or public bodies. In keeping with most R&D initiatives, 'call' gateways at this stage would typically include (i) Being within scope of a particular call, (ii) Having a well-defined technical challenge, (iii) Clarity of desired output, market potential and potential impact, (iv) A risk management strategy, (v) An appropriate team with well-matched resources and tasks, (vi) A logical cost basis and budget management plan and (vii) Clear quantifiable objectives and targets.
To build and retain credibility, the evaluation process must be transparent and standardized, as not every idea will survive close scrutiny and feedback should be constructive. The choice of reviewers for proposals must reflect the circular economy's stakeholders in addition to technical excellence.

Stage 3: Experimentation
The three SUNRISE technology approaches will be starting from different TRLs, and have specific targets that reflect a combination of ambition and realism in reaching for higher TRLs highlighted in the Roadmap. Likely, some projects will run into difficulties and some will achieve at least part of their principal objectives. In either case, provision must be made for interim, decision and end review points. Partners will be strongly encouraged to take *calculated* risks and to look for common-sense short-cuts to move science and technology as quickly as possible towards practical demonstration. The SIP team will provide continual sup-

port by providing a contact point at local nodes for advice and guidance covering technical and administrative issues including how to deal with arising IP issues and conflicts, partner changes and accessing national and European S&T infrastructure such as advanced physical characterization methods.

Stage 4: Commercialization
In the approach to the commercialization stage, the SUNRISE partners should continuously consult end-users to verify that the innovation actually solves problems that are relevant to industry and society as a whole. Partners will need to carefully analyze the costs and benefits of rolling out the innovation. As the TRL increases, new people and partnerships may need to be involved. This can necessitate the decoupling from academic input and moving towards commercialization through business operations that cover the spectrum from spin-offs to large multinationals. Many factors come into play depending on the nature of the business endeavor such as spin-off vs large industrial company, member state and EU-level financial incentives, subsidies or taxation, fossil-fuel prices, potential carbon taxes, and possible rapid market shifts such as change in plastics usage.

Stage 5: Implementation
Implementation is typically the most challenging stage as the required investment levels rapidly increase, as do the associated risks of not achieving anticipated sales revenues. The full commercialization of processes aiming at the production of fuels and chemicals from solar/CO_2/N_2/H_2O will take time and the SUNRISE partners view the roll-out pathways as evolutionary with early targets focused on local customer bases where conditions are the most conducive to mitigate costs and maximize benefits. In this respect, SUNRISE expects to build on the lessons learnt from the rapid growth of renewable energy generation (wind, solar etc.) and electrification of automotive drive-trains. Importantly, there will be a strong emphasis on using the nodes to seek and exploit early revenue opportunities to build credibility with stakeholders.

3. The SIP action plan

Creation of the SIP Team

SIP Team members will be drawn from SUNRISE members and in particular from WP 2 contributors.

Design of webinar and forum contents

Topics will include experts speaking on

- (i) The circular economy
- (ii) Cities of the future
- (iii) The future of plastics
- (iv) Hydrogen infrastructure
- (v) The carbon credit/tax landscape
- (vi) Agriculture for the future

and other topics with a timetable that dovetails with the Roadmap requirements.

Selection of national SUNRISE nodes

The SUNRISE Innovation Process team will use local knowledge from the representative Member State SUNRISE supporters to quickly establish national SUNRISE nodes. We emphasize that the opportunities for Europe to capitalize on the circular economy depend both on our will and ability to innovate and on how rapid we can translate innovative technological solutions into large-scale industrial processes.

Information flow and intellectual property matters

To encourage free-thinking and exchange of ideas amongst the SUNRISE community and stakeholders, rules of engagement for each event will be made clear. Protection of IP in partnerships will be based on the European Commission's DESCA template. Attention will be paid to on-line dissemination as well as traditional publication routes and so participants will be encouraged to use the SUNRISE website where appropriate.

Egli, F., B. Steffen and T. S. Schmidt (2018). "A dynamic analysis of financing conditions for renewable energy technologies." Nature Energy **3**(12): 1084-1092.

Marshall, T. (2014). "The European Union and Major Infrastructure Policies: The Reforms of the Trans-European Networks Programmes and the Implications for Spatial Planning." European Planning Studies **22**(7): 1484-1506.

Solar Energy for a Circular Economy

Deliverable D2.2

S2S (Science to Science) & S2B (Science to Business) Exploitation plans and IPR consortium guidelines structured

Lead Beneficiary	JM
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v 0.2	211119	Y. Wich/ H. Bercegol	Add-ons and comments
v 0.3	261119	P.R. Ellis	Revision
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v1.0	081219	P.R. Ellis	Executive summary, updating, final editing

EXECUTIVE SUMMARY

This Deliverable Report considers Intellectual Property (IP) structures and Exploitation Methods within the Sunrise partnership. A clear and efficient management system for IP is critical for the successful commercialisation and implementation of inventions within Sunrise, and hence is one of the keys to the project having impact on the energy transition. At Project level, the proposed IP system is based on current practice in collaborative projects such as Horizon 2020, where partners share background IP when relevant, and arising IP is owned by the inventing party with licences granted to other parties. Sharing of IP across the Sunrise partnership is seen to be desirable, but the mechanism for this is not yet defined. The challenge to be overcome is to allow IP sharing between projects, but without deterring commercial parties from participating due to loss of control over IP they generate.
Two forms of Exploitation are envisaged: Science-to-Science (S2S) and Science-to-Business (S2B). The mechanisms of Exploitation are different at different TRLs due to a number of factors such as the lack of clear vision as to whether the IP will be valuable (at lower TRLs) and the need for demonstrators at scale (for higher TRLs). S2S exploitation will be based on efficient communication between scientific partners (such as *via* conferences and publications) whilst S2B exploitation is founded on the early engagement and exploitation of commercial partners who might implement technology at a later date.

List of acronyms and abbreviations

SIP – Sunrise Innovation Process

TRL – Technology readiness level

1. Introduction

Execution of the Sunrise blueprint for a circular economy will bring together a diverse range of participants from academia, research organisations, society and industry. As with any multi-partner consortium, there will be a need to balance individual partner needs with overall project objectives, and over the years various forms of Legal Agreements have been constructed to deal with intellectual property matters in such situations. Although Agreements vary in detail, there are basic ground-rules that have served well in the process of handling information flow and partner expectations. It is the purpose of this deliverable to outline those ground-rules within a general guideline structure that partners can adopt for their own particular requirements. The deliverable also describes basic considerations about the exploitation of results generated in an open innovation environment, with a focus on exploiting scientific results with other scientists (Science-to-Science) and to develop commercialisable materials, devices and processes (Science-to-Business).

2. Basic IPR governance structures

All projects require an over-arching governance structure and any Legal Agreement in a partnership will need to reflect this. We recommend a similar governance structure for IP whereby all partners have a representative on an 'IP Management Committee' (IPMC) that should oversee the processes of publishing, patenting, managing the flow of technical and scientific information into and out of the partnership, reviewing the IP landscape relevant to the project objectives and dealing with any disputes. The IPMC should contribute to any regular reviews within the project.

It is very important that from the outset that there is clarity in respect of the rules of engagement that partners will be expected to abide by. This will facilitate both scientific information flow and the translation of acquired knowledge into practical, commercially viable technology. In particular, where there are potential conflicts of interest, such as the academic imperative to publish against the need to protect know-how that might lead to commercial exploitation, ground-rules must be in place to help resolve potential issues at an early stage. Good note taking at meetings is a 'must' so that correct attribution in respect of inventorship of an idea, problem-solving etc, is recorded and made transparent. Finally, a word of caution in that trust between partners, critical to a successful project, can be quickly eroded unless potential disputes are dealt with in a timely and effective manner. Being alert to signs of discontent as well as potentially patentable results will be amongst the key functions of the IPMC.

3. Typical IP Agreement layout

We provide for reference the layout of a typical IP Agreement suitable for multiple partner projects. Any Agreement should give provisions for the ownership, transfer, protection, use and dissemination of results, so-called "foreground". The basic points should encompass:

- Foreground resulting from the project is owned by the participant generating it.

- When foreground is generated jointly (*i.e.* where the separate parts of some result cannot be attributed to different participants), it will be jointly owned, unless the participants concerned agree on a different solution.
- Valuable foreground should be protected, especially when it is capable of industrial or commercial application, even if it is at an early technology readiness level (TRL). It is for the protecting party to determine what is valuable, considering future opportunities and the cost of writing, filing and maintaining the patent.
- Protection is not mandatory in all cases, though the decision not to protect foreground should be made in consultation with the other participants, who may wish to take ownership.
- An appropriate definition of Background IP. This needs to be carefully defined and any access rights clearly laid out. Note that this is a particularly sensitive area for industrial partners who are likely to request careful control regarding who has access and under what terms to their background IP. For Sunrise, background IP would be listed at project level whenever a new project starts.

4. IP Objectives

The objectives of a typical IPR strategy should follow general principles such as:

- Recognize at an early stage where valuable results are being generated.
- Help focus the research towards the highest priority areas.
- Ensure effective protection of IP rights
- Avoid work on research topics where the application is hindered or blocked by existing patent positions or prior art.

Knowledge of the IP landscape will need to be collated and mapped out for partners so that potentially troublesome areas *e.g.* where competitor activity is at a high level, can be identified and a suitable strategy can be put in place to modify planned work programmes or devise a work-around. Many industrial organisations use specialist software to analyse IP landscapes with visual tools that facilitate understanding of existing activity in the field, and where exploitable gaps may lie. Such tools can be very useful and are to be encouraged. However, the information will necessarily lag real-time as it can take several years for granted patents to appear in the public domain. Also, the choice of search terms can sometimes prove difficult to rationally construct so that useful information is either missed or buried in excessive 'noise' from irrelevant items.

In the context of Sunrise, IP issues generally occur at the project level, between parties who are engaged to co-operate. It is desirable to create interactions between the projects within Sunrise, but this leads to difficulties for commercial parties who then would be discouraged from participating.

For example, a company participating in a project within Sunrise would not want to share IP with a competitor who is participating in a project which also falls under the Sunrise umbrella but is otherwise unrelated. One possible route forward would be for parties to offer suitable licenses to other projects within Sunrise. There could be a role for the consortium in facilitating this process, maybe through creating contacts between projects or by setting out a standard template for the licenses. Overall, wider sharing of the IP which arises within Sunrise across the consortium is desirable, but it needs to be managed in a way which is acceptable to all partners, and does not discourage the participation of all kinds of businesses.

5. Effective Exploitation of the Results

One of the principal reasons for failure of technology commercialization ventures is related to a failure to understand the market properly. Accordingly, each Partnership project will need to conduct an analysis of the market needs related to the commercial use of the technology in question. For Sunrise and its intended technology goals dictated by the roadmap, most of the initial challenges are likely to relate to early TRLs such as proof of principle for a novel CO_2 reduction process or an improved catalyst for nitrogen reduction. Consequently, there may be little prospect of commercializing inventions beyond niche-type applications in the early stages.

In particular, where the intended exploitation relates to the displacement of fossil-fuel based commodity chemicals, it will be, at least initially, extremely difficult to compete on price unless there is a corresponding national or regional fiscal policy that essentially subsidizes 'green' products or, correspondingly, penalizes green-house gas release to provide a level playing field, as current pricing of fuels is economically complex and regulated with taxation (VAT) at the end of the value chain to finance discounts at the source to stimulate economic activity and efficiency. It follows therefore, that as part of the market analysis, due diligence must be done on understanding the existing and projected pricing, discounting and taxation frameworks across European and other economies.

Attention should also be paid to the likely supply-chain requirements for developing a particular technology. This should cover everything from raw-materials supply to end-of-life disposal. Scale-up issues should also be under scrutiny as although the technology development sequence should run as performance, then reliability, then cost, early identification of cost-effective, scalable ways of making key materials or components, will pay dividends. Indeed, where it is envisaged to exploit the technology by linking into an existing industrial process – for example by blending green hydrogen into natural gas feeds – then a good knowledge of the end-user specification such as tolerance of impurities, reliability and quantities of supply, will be essential.

As already introduced with the idea of "Sunrise Valleys" in report D2.1, full open innovation is envisaged within the individual projects of the Sunrise initiative, with full disclosure and a strong interaction between the partners in order to achieve the greatest progress. This is naturally easier at lower TRLs where individual partners have less at stake (have spent less on IP, have smaller-scale facilities etc.) than at higher TRLs where there can be significant business risk, for example in building a demonstrator facility (Figure 2).

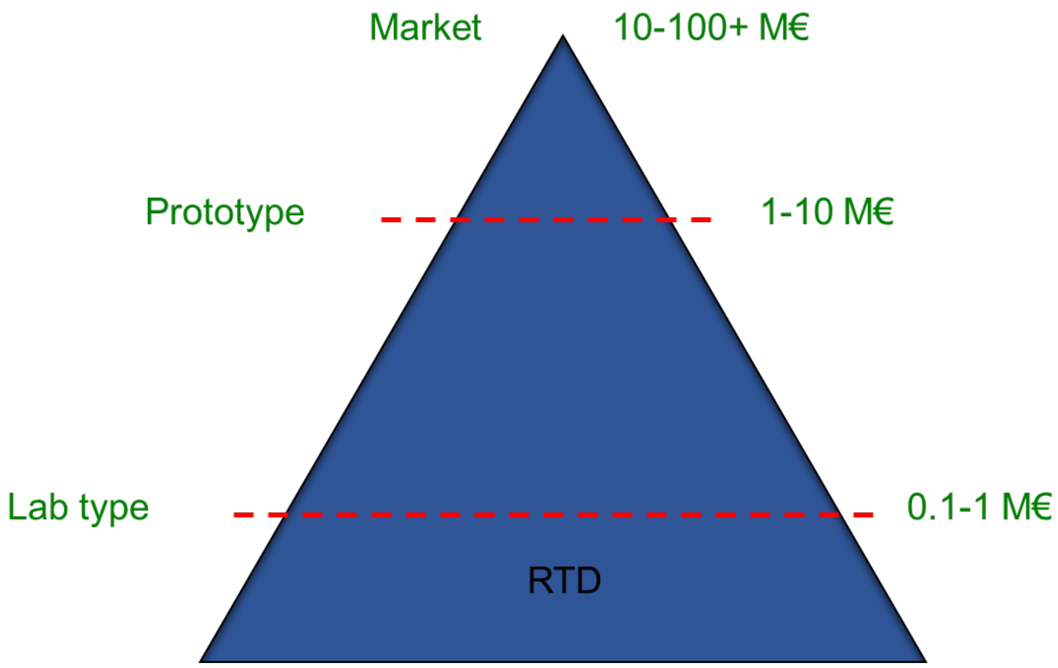

Figure 2. Relationship between the number of projects and the individual project cost.

Innovation Protocols

Different strategies for innovation are needed at different stages of a project's life, from conception through to commercialisation. The different approaches can be categorised by the different project TRLs:

Low TRLs
Low TRL working is characterised by triggering new studies and ideas and evaluating novel concepts. It's important to be able to assess whether a concept offers any chance of success quickly and efficiently in order to avoid wasting time and resources. However, it's equally important to generate basic scientific work where fundamental barriers persist and not to terminate projects without a clear understanding of why they are being stopped. One successful approach is to identify the biggest obstacle to a project's success based on evaluations at regular time intervals, and work for a limited time under reservation and close monitoring to either overcome the obstacle or stop the project. Alternative approaches to problems can often be conceived whilst working on a project, and so a stopped project can give way to a new, improved approach. The value of collaboration in low TRL activities is in the contribution to innovation. Often, partners with different backgrounds will regard the problem in different ways which allows superior solutions to be found.

Mid TRLs
Working in the middle TRLs is moving the project from the lab through a range of increasingly realistic demonstrators. The approach here is quite different to low TRL working and can involve different partners. The key issues are often in the robustness of the proposed process or material, and formulation can be important, for example in converting powders to electrodes or cells. In the mid-TRL range, an iterative approach is often used alongside improving understanding. Materials or systems characterisation can often be important. The partners involved at this stage will typically be a blend of those involved in the lower TRL work with new partners who can manufacture components at the scale needed for testing. Also important at this stage is understanding the complete system using tools such as life-cycle assessment and technoeconomic analysis. These Such tools allow the project to be directed in beneficial directions before it is too mature for changes to be made.

High TRLs
A high TRL project is the final step before commercialisation. Here the investment costs are highest; often new facilities need to be built or existing facilities adapted to allow the project to take place. The objective is usually to demonstrate a process or material to allow investment to take place. Demonstration of a project for a significant period of time (*e.g.* 6 months) lowers the risk and so can be pivotal in achieving a successful project. Again, the mix of partners will have changed significantly from the lower TRL parts of the project, with emphasis on collaborators who can manufacture components at scale, and who have the facilities and access to feedstock to host the actual demonstration.

Exploitation Strategies

The Sunrise Roadmap envisages activities across the TRL scale from fundamental research to demonstration activities between the present time (2019) and 2050. Some of the technologies are already demonstrated (*e.g.* water electrolysis) whilst others are at much lower TRL such as direct electrochemical ammonia synthesis. Development of successful commercialized systems is going to require the skills and expertise of a range of actors all working together to achieve the best systems.

Considering the above, it is appropriate to consider separate strategies for exploiting science with other scientists to create better science in the future, and exploiting science to develop commercialisable materials, devices and processes. These are the science-to-science (S2S) and science to business (S2B) exploitation plans respectively. It is key to transfer meaningfully both to scientists and to businesses in order to generate impactful products in the short, medium and long terms and so to meet economic, climate and other policy goals.

Science to Science (S2S)

The main impact of S2S exploitation will be at low and mid TRLs through development of the science produced within Sunrise by scientists outside the consortium. The benefit of this is a broader fundamental understanding of relevant areas and will lead to the development of improved processes and materials in the future. Even if the TRLs of the work are low, the impact is still expected to be high, for example through the development of new materials for important applications, or in fundamentally understanding a relevant concept or phenomenon.

To engage a broad community towards the blueprint goals, scientific results relevant to progress along the multiple paths of the roadmap must be disseminated. Scientists are generally aware of the results in their field. What needs to be communicated are the specific **milestones** that have been reached and the remaining **bottlenecks** which will have to be overcome in order to fulfill the objectives. Since SUNRISE will develop its research in a wider environment, in Europe and worldwide, new important publications external to SUNRISE will also be scrutinized, and disseminated to a large community.

This dissemination plan shall include regular oral communications at scientific conferences both within and external to Sunrise. Also, special web conferences, and open discussions webinars shall be organized to increase the awareness of scientists concerning S&T barriers on the SUNRISE roadmap. One of the Human Resources possibility is to have a dedicated team take care of following the advances on the multiple fronts, then report and disseminate.

Science to Business (S2B)

The transfer of science to business is also important because it will lead to better processes and materials in the short-to-medium term. The role of science is important at the low TRL stage of a project lifetime where innovation is taking place to determine the best solution. It is also important at the mid-TRL stage where fundamental understanding is required to help make better devices and to understand and resolve degradation problems.

To gain the maximum impact from Sunrise's scientific output, it is important to engage the business community and to create structures where businesses can be involved. Key issues such as IP need to be managed in a way which is appropriate for both commercial and academic partners and recognizes the early-stage input of research institutes and academic groups appropriately. It is important to acknowledge that there is no one-size-fits-all approach for businesses, whose needs will vary depending on size, market sector and the business model they are using. Early buy-in of commercial organisations is also important to secure funding for later, larger scale, projects. It is worth remembering that every commercial organisation will have its own identity and priorities and a one-size-fits-all approach is unlikely to be successful. Only through good understanding of these priorities can meaningful relationships be developed.

There are a number of vehicles for S2B interactions, and selecting the correct one for a project can make a significant improvement to the chances of success. For example, working at low TRLs a short proof-of-concept project might be the most appropriate, rather than initiating a Ph.D. project which might not yield results for a number of years. However, for a competency-building activity, a Ph.D. might be the perfect mechanism since it offers regular interactions over a long period of time and the opportunity to build a knowledge base.

There are a number of successful approaches to product development, such as the pipeline shown in Fig. 1. Here, the process starts with idea generation and evaluation. Between each stage there is an evaluation stage, to check whether the idea or project is on track. Key questions are asked, such as whether customers are interested, what the IP implications are, health and safety issues and so on. The questions become more detailed as a project moves through the pipeline. The activities evolve as the project moves through the process; from research and ideation through development and scale up to manufacturing.

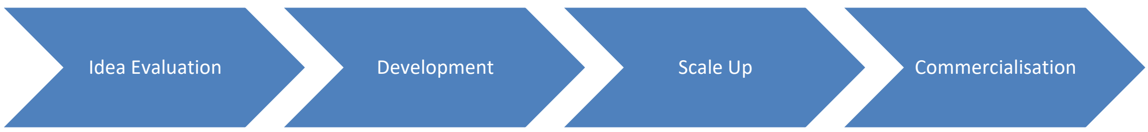

Fig. 1. A pipeline model for product development

The advantages of a pipeline approach are in visibility and in sign-off: the stage-gate reviews between each section involve inputs from a range of disciplines such as EHS, operations and commercial teams. Projects which don't pass the sign-off either stay in the previous stage for further work and re-review, or are stopped.

One particular bottleneck in development can be demonstration of a technology. It is typical for a technology's robustness to be demonstrated in the application for an extended period of time, such as six months or more. This lowers the risk associated with the project and so helps financiers support the project. Finding a host for a demonstrator project can be challenging, especially for new processes which are not yet commercialized and where side-stream reactors on existing plants do not exist. It is reasonable to think that to achieve the ambitious goals of the Sunrise Roadmap demonstrators will need to be constructed and operated with the associated costs.

Solar Energy for a Circular Economy

Deliverable D2.3

Innovation and Exploitation plan fully developed and IPR consortium guidelines updated

Lead Beneficiary	Siemens
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PREAMBLE

The particular embodiment and funding instrument(s) for the SUNRISE Large Scale European Research Initiative are under discussion at the time of writing of this document. Due to the termination of new Flagships in Horizon Europe, SUNRISE merged with the parallel CSA ENERGY-X founding SUNERGY in early February 2020 in order to join forces towards the ambitious goals common for both CSAs. Therefore, the proposed innovation and exploitation plan and the IPR guidelines - reported here for SUNRISE - should be considered as provisional and need to be refined once the applicable boundary conditions for SUNRISE / SUNERGY are clarified.

EXECUTIVE SUMMARY

This Deliverable Report updates and details the guidelines for Intellectual Property (IP) management and the Innovation & Exploitation schemes for the SUNRISE partnership based on the previous deliverable D2.2. As outlined there, the proposed IP system on individual project level will follow the established framework for funding programs such as Horizon 2020. This implies that project partners share background IP as needed, and that newly generated IP is owned by the inventing party (or parties) with conditional access and licensing rights for other parties.

While the possibility to transfer of IP across the SUNRISE partnership is considered as beneficial in order to achieve the overall SUNRISE targets, a coercive mechanism would highly discourage private parties from participating in SUNRISE. Therefore, it is proposed that SUNRISE creates an environment which facilitates the transfer of IP on voluntary basis and that SUNRISE actively encourages IP sharing by its community members.

As far as the Exploitation plan is concerned, different approaches for Science-to-Science (S2S) and Science-to-Business (S2B) exploitation will be used – also depending on the maturity of the development activity. Key for both S2S and S2B is making information timely and consistently available – either regarding interim or final development results or regarding market or business needs and requirements. Furthermore, the failure to commercialize technology is often largely related to a poor understanding of the market. It is hence proposed that project teams are actively coached by SUNRISE in order to build their business case, and that the progress of the projects is continuously monitored in order to ensure their quality and impact, and hence their subsequent exploitability.

List of acronyms and abbreviations

SIP – SUNRISE Innovation Process

TRL – Technology readiness level

S2S – Science-to-Science

S2B – Science-to-Business

IP – Intellectual Property

IPR – Intellectual Property Rights

H2020 – Horizon 2020

LSERI – Large Scale European Research Initiative

S&T – Science and Technology

IPMC - IP Management Committee

1. Introduction

In the previous deliverables D2.1 and D2.2, the innovation process as well as the exploitation and IPR guidelines for the SUNRISE partnership have been defined and structured. Since the transition to a circular economy - as it is envisaged in SUNRISE – is beyond the typical scale and timeline of "normal" technology development efforts, the most important task in terms of innovation is to bring fundamental research and disruptive technologies to the field through the fastest possible route and to ensure their subsequent marketability.

The key challenges here are the fact that the innovation cycles in the energy and chemical industry are often very long (particularly if innovations in material sciences are considered), that high investments are needed to bring technologies to scale (*e.g.* TRL 7/8 often requires the construction of new plants) which implies the risk of substantial monetary losses in the case of failure, and that products made from renewable sources are - at least at the moment – often more costly than their conventional counterparts. In order to maximize the commercial prospects of the partnership's technology developments, the SUNRISE Innovation Process (SIP) has been defined including the concept of innovation clusters ("SUNRISE Valleys") which provide infrastructure and a favorable innovation environment (cf. deliverable D2.1).

As far as the handling of newly generated IP along the innovation process is concerned, the guidelines on project level will follow the established practice for H2020 / Horizon Europe, whereas on partnership level, a balance between the benefits of widespread IP and information sharing on the one side and IP control for commercial partners on the other side has to be found. While making information and IP available to a large community will boost the generation of knowledge and enable new ideas and cooperation, commercial partners will not participate in such an effort without control over the IP they generate. Consequently, the partnership will struggle for impact without substantial involvement of the private sector.

Another prerequisite for the generation of impact are effective exploitation protocols, both regarding Science-to-Science (S2S) and Science-to-Business (S2B) exploitation. For the former, prompt sharing of scientific progress with others active in the research field (and preferably also in adjacent fields) based on familiar dissemination channels is required. For the latter, different methods and structures are needed to engage the business community. It is important to recognize that there is no one-size-fits-all approach for S2B, since business needs will vary depending on size, market sector and the business models. Nevertheless, it is recommended that S2B exploitation for the development of new commercial products and processes should be compatible with one of the established industry standards in product development to ensure later marketability and bankability. This implies that low-TRL activities are prepared to stop if the given requirements cannot be met, that mid-TRL activities operate in increasingly realistic environments and that high-TRL projects focus on demonstration and production-related topics and risk-reduction strategies.

2. Exploitation Plan

Following the definition of "exploitation" according to H2020 as "the use of results in further research activities other than those covered by the action concerned, or in developing, creating and marketing a product or process, or in creating and providing a service, or in standardisation activities", the approach for the SUNRISE partnership should be twofold:

- **On the individual project level, the respective exploitation plans have to be in line with the overall SUNRISE roadmap which reflects the prioritized research and development directions based on multi-stakeholder feedback**.
  Since the roadmap has been elaborated by the SUNRISE consortium (involving the entire SUNRISE stakeholder community) and addresses European policy makers and stakeholders from research and industry, successive short-, mid- and long-term exploitability (both S2S and S2B) will be ensured by requiring compliance of the specific project objectives with the roadmap targets. In order to achieve and maintain that accordance during the life span of a project, a continuous coaching/outreach approach to the projects should be applied in combination with a stage-gate process to review the project progress. A comparable approach has for instance been piloted for the projects awarded under call LC-SC3-RES-2-2018 (*"Disruptive innovation in clean energy technologies"*) via InnoEnergy. Accordingly, calls addressing SUNRISE targets should contain concurrent terms, for example:

  > *"Proposals need to demonstrate a clear technology development roadmap for their solutions, including a strong exploitation plan presenting their business opportunities and impact potential.*
  >
  > *The technological development risks need to be clearly identified and relevant mitigation measures given. Life cycle analysis shall be considered.*
  >
  > *Projects selected under this pilot will follow a stage-gate approach based on milestones and periodic reviews. A first review by the Commission - with the help of independent experts - will take place after 12 months, based on an assessment by SUNRISE of the feasibility and innovation potential of the proposed solution or application, analyzing amongst others the business and innovation strategy, the technology readiness level of the proposed application, the consortium's freedom to operate (e.g. background, foreground, IP), and the market.*
  >
  > *This review will lead to a first go/no go decision. Throughout the duration of the Grant Agreement, and agreed therein, SUNRISE will be involved in providing support to innovation and business development, including completing the market uptake supply chain, using external expertise, with the aim to strengthen the consortium's innovation performance."*

- **On the SUNRISE partnership level, exploitability can be ensured by i)linking the SUNRISE-related projects to associated SUNRISE Valley nodes and ii)subsequently bringing together potential users / sponsors / investors with the owners of IP & know-how via the SUNRISE Valley network**.
  As described in deliverable D2.1, the SUNRISE Valleys are collaborative forums for discussion, exchange of information and alignment on future requirements and priorities between all stakeholders. They are organized de-centrally (so that new nodes can easily be added, for example within a newly awarded project) and provide the necessary infrastructure for fostering innovation and exploitation. In order to make the input of each node available to the entire partnership, the nodes will feed common databases (*e.g.* on IP, results, requirements and exploitations, categorized according to the roadmap targets) in alignment with the corresponding stakeholders to identify additional exploitation opportunities and to provide structured input for continuous updating of the roadmap. If required, the access to those databases can be restricted via a nominal fee to avoid improper use of the data. A schematic illustration of the relation between the roadmap, the projects, the nodes and the stakeholders is shown in Figure 1.

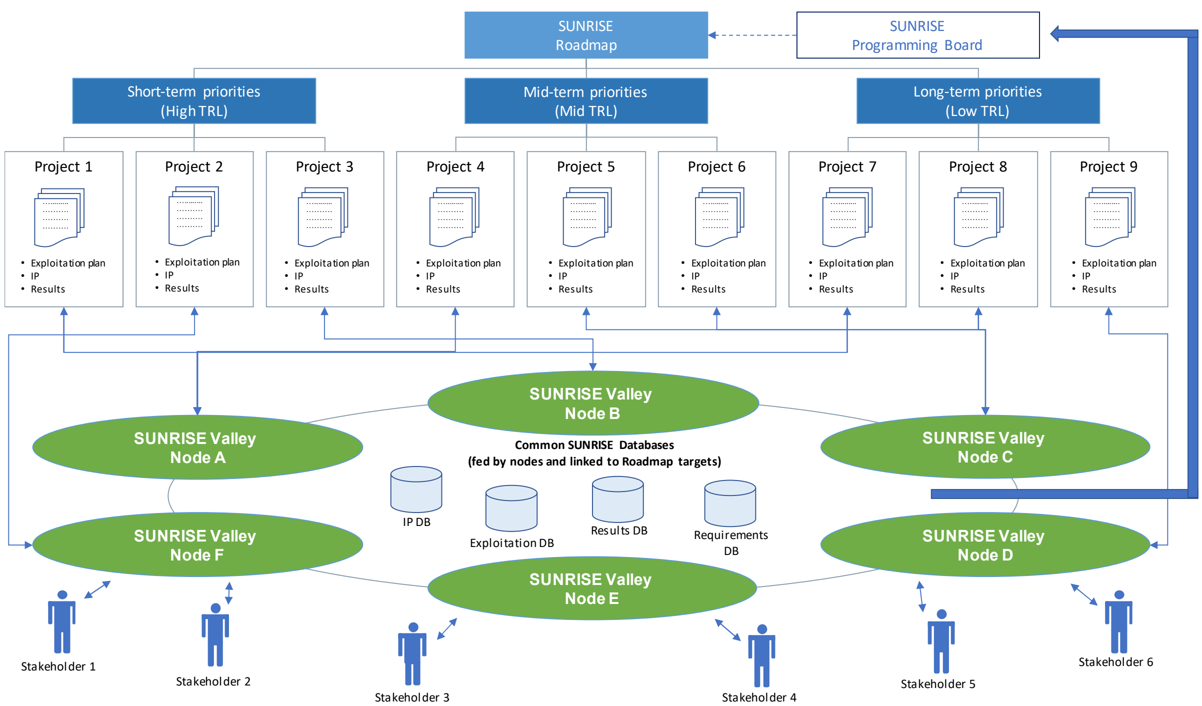

Figure 1: Relationship between the SUNRISE roadmap, SUNRISE projects, SUNRISE Valley nodes and the SUNRISE stakeholders to enable exploitation across the partnership

It is planned to establish test pilots of the valleys during the ramp-up phase of SUNRISE (cf. also deliverable D4.2) so that a basic structure is available at the start of the planned Large Scale European Research Initiative (LSERI) and hence the exploitation on partnership level is then possible. The tasks for setting up test pilots of the valleys will comprise the study of best practices from other sectors, the identification of relevant stakeholders, a subsequent demand analysis and the evaluation of funding possibilities (based on the combination of public funding and private contributions).

Regarding the short-, mid- and long-term commercialization strategy of SUNRISE's developments, it should be kept in mind that the creation of any new business inherently requires the availability of a complete and functional technology stack. Regarding the SUNRISE roadmap, the following phases can hence be distinguished:

- Short-term commercialization will primarily focus on high-TRL technologies, *e.g.* PV-driven electrolysis. Since demonstrator plants and pilot plants in the multi-MW range will have to be built, there is a significant business risk due to the high capital investment needed. Hence, in order to finance such projects and bring the corresponding technologies to the market, a coordinated financial engineering for de-risking needs to be applied, which considers - in addition to the private investments - the following funding sources:
    - R&I funding (*e.g.* Horizon Europe)
    - Regional / national / EU structural funds (for the infrastructure-related aspects)
    - European Investment Bank (*e.g.* Risk Sharing Finance Facility)
    - European Fund for Strategic investment (EFSI)

- Mid-term commercialization will be relevant for already proof-of-concept technologies (*i.e.* with current TRL 4 – 6), in terms of the SUNRISE roadmap *e.g.* for biological / biohybrid direct conversion of sunlight. The commercial exploitation of the advancements in efficiency and long-time stability will either be done by established SMEs or industrial players that can upload those results into their own product developments, or by start-up companies that carry the development further with support from early-stage investors. It is particularly important to realistically (re-)assess the viability of the business perspectives during the course of the development and to identify and involve future off-takers for those mid-TRL projects.

- For the long-term commercialization of low-TRL technologies, for example photoelectrochemical devices which enable the direct conversion of sunlight, there are understandably many uncertainties regarding the evaluation of the business potentials. While the generation of knowledge is the primary task for such projects, and the development directions might change based on new insights, it is nevertheless important to benchmark the achieved results and the future potential versus established and other emerging solutions. Such a benchmarking can be done as a part of the SIP with the aid of experts from industry, which would also support the subsequent uptake of promising results and/or an efficient re-allocation of resources.

3. Innovation Plan

In order to achieve the required innovation performance, SUNRISE will employ the SUNRISE Innovation Process (SIP), *i.e.* a stage-gate approach as illustrated in Table 1 below.

Table 1: SUNRISE Innovation Process (SIP)

	Idea generation	Evaluation, Selection	Experi-mentation	Commer-cialization	Imple-mentation
Objectives and Character-istics	• Networking, forums for discussion & exchange on topics related to circular economy • Provide participants with holistic view of the challenge and what their technical projects should encompass to be relevant to progressing the roadmap	Selection of projects for funding based on typical 'call gates': ▪ Being within scope of a particular call ▪ Well-defined techn. challenge ▪ Clarity of desired output & impact ▪ Risk mgmt.. strategy ▪ Appropriate team with well-matched resources and tasks ▪ Logical cost basis and budget management plan ▪ Clear objectives and targets	• Trial, error, success, failure • SIP team will give support by providing contact point at local nodes for advice and guidance w.r.t. technical and administrative issues, arising IP, partner changes, accessing national S&T infrastructure (*e.g.* advanced analytical techniques)	• Involving end-users, analyzing costs and benefits • Involving new partners and partnerships, decoupling from academic input, moving towards commercialization • Further progress depending on nature of business endeavor such as spin-offs vs. large industrial company, state and EU-level financial incentives or subsidies, fossil-fuel prices, possible market shifts	• Most challenging stage as the required investment levels and risks rapidly increase • Commercialization and implementation of chemical processes take time ➔ evolutionary roll-out, first focus on local customer bases where conditions are most conducive to mitigate costs and maximize benefits • Use lessons learnt from rapid growth of renewable energy generation and electrification of drive trains
Deliverables (exemplary)	• Requirement specifications for technology (and future products) • List of stakeholders and cooperation partners • Market potentials • Technology ideas & concepts	Proposals including: • Technology design specification • Milestone & Review Plan • References to SUNRISE roadmap • Metrics for progress eval. • Risk assessment • Resource plan	• Technology specifications and test results • Technology capability evaluation (incl. benchmarking vs. established solutions) • Review documentation • (Scaled) Prototypes • IP	• List of potential markets and customers • Commercialization and financing plan • Market strategy and market entry documents • Implementation preparations (*e.g.* sourcing, manufacturing, validation)	• Full-scale prototypes • Qualified systems • Requirement definitions for S&T based on operational experience • Evaluation of product operation • Identification of basic S&T

The SIP forms the overall framework for innovation management on the SUNRISE partnership level. Within the specific SUNRISE-related projects, a corresponding stage-gate methodology for project execution should be applied, cf. also chapter 2 – "Exploitation plan".

The SUNRISE projects should preferably follow a development process which is compatible with established industry standards in the respective field, so that an easy exploitation and commercialization of the results is possible. Since the particular development routines differ from one industry to another and also depend on the specific development task, no one-size-fits-all approach can be applied on project level. It is therefore necessary to outline the review and gate requirements and schedule individually for each project during the project definition phase.

Furthermore, since unsuccessful exploitation and commercialization is often (partly) caused by a failure to understand the market properly, end-user requirements need to be considered already in the very early innovation stages. For a consistent (quantitative) view on the market chances of new developments across the whole SUNRISE technology development portfolio, it is considered as beneficial to have a common baseline regarding the overall market to enable an objective and transparent assessment. However, since again every SME or industrial participant in SUNRISE projects might use a slightly different market model by default, requiring the mandatory use of a particular market scenario is not regarded as practical.

A possible solution to this problem is to put the market assumptions for each project in relation to public reference scenario(s), for example the scenarios "Modern Jazz" and "Unfinished Symphony" from the World Energy Council (WEC). The reference of the individual project scope and impact to such widely accepted scenarios will be helpful in terms of attraction of investments, bankability of the technology and the alignment of research priorities with governments.

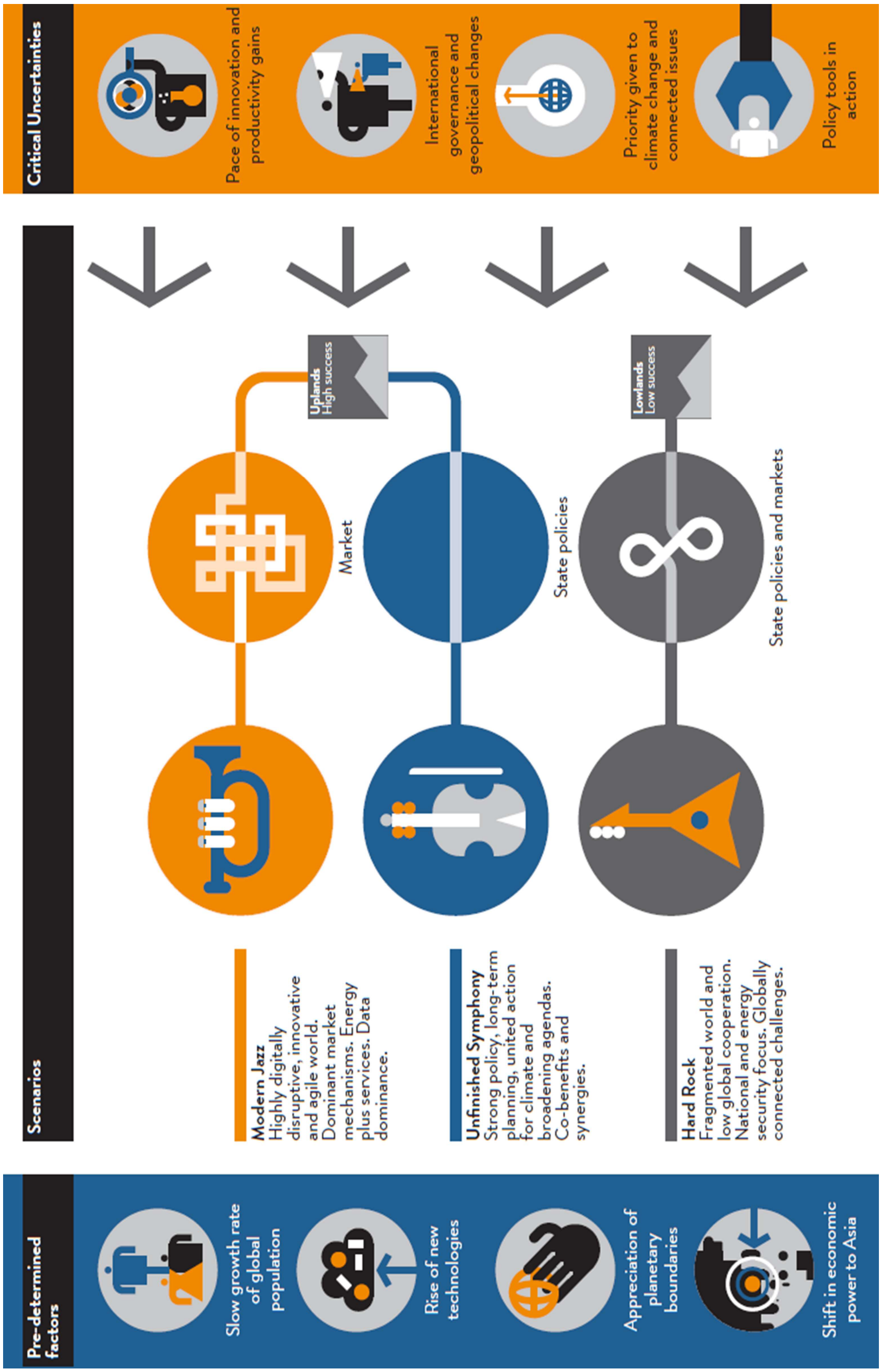

Figure 2: Baseline scenarios of the World Energy Council
(Source: http://www.worldenergy.org/assets/downloads/Scenarios_Report_FINAL_for_website.pdf, p. 13)

4. Updated IPR Guideline

General IPR guidelines for the SUNRISE partnership have already been outlined in D2.2 regarding:

- Basic IPR governance structures
- Typical IP Agreement layout
- IP Objectives

The DESCA template can serve as baseline for the contractual handling of IP ownership provisions, joint ownership rules and access rights provisions, although for higher TRL projects, also other templates (like MCARD) can be used to address the specific needs of projects that are close to commercialization (*e.g.* regarding access rights for affiliated companies, or regarding protection periods). That means that project partners share background IP as needed, and that newly generated IP is owned by the inventing party (or parties) with conditional access and licensing rights for other parties.

In order to leverage the full potential of SUNRISE, the possibility to transfer IP across the partnership and between projects is regarded as beneficial. However, an automatic (conditional) transfer mechanism would discourage private parties from participating in SUNRISE, since they would lose control over the IP they generate. For owner-managed companies, such a mechanism would at least be undesirable (but theoretically possible if it is approved by the owner), while for corporations, it is practically impossible to consent to any default transfer of their immaterial assets without infringement of fiduciary duties.

Therefore, it is proposed that SUNRISE creates a framework which facilitates the transfer of IP on voluntary basis and that SUNRISE actively encourages IP sharing between and beyond its community members on fair conditions. The specific terms for IP sharing need to be negotiated case-by-case between the owner(s) and the user(s). To keep track of the IP information that was generated, and hence to be able to connect IP holders and potential users across the partnership, a central database should store relevant IP information (*i.e.* not only newly generated IP, but also results from IP reviews and clearings that were performed in the projects). The input to the database can be provided via the SUNRISE Valley nodes in alignment with the SUNRISE projects / partners, cf. also chapter 2 – “Exploitation Plan”. It should be kept in mind that such a database can primarily serve as a central IP directory for SUNRISE technologies, but in general cannot contain business information.

Finally, the ‘IP Management Committee’ (IPMC) - a SUNRISE governance body that oversees the processes of publishing, patenting, and managing the flow of S&T information into and out of the partnership - should actively promote, support and mediate the sharing of IP within the partnership when this is seen as beneficial from the partnership’s point of view.

Sunrise

Solar Energy for a Circular Economy

Deliverable D3.1
Dissemination, Communication and Education Plan

WP3. Dissemination, Communication and Education

Lead Beneficiary	ICIQ – Institute of Chemical Research of Catalonia
Delivery date	17 March 2020
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v 3.0	17/03/2020	Laura López, Artur Braun, Frédéric Chandezon, Harald Kerp	Changes and updates, final revision

EXECUTIVE SUMMARY

This document, the final update of deliverable D3.1 Dissemination, Communication and Education Plan, is a joint deliverable of the SUNRISE (Solar energy for a circular economy – www.sunriseaction.eu) and ENERGY-X (Transformative chemistry for a sustainable energy future – www.energy-x.eu), which are funded by the European Union’s H2020 Programme under Grant Agreements No. 816336 and No. 820444, respectively. The Dissemination, Communication and Education Plan identifies the main dissemination and communication objectives of the upcoming initiative **SUNERGY** project and the activities and tools that will be defined and implemented in the new action and in future endeavours according to the target audiences.

The plan includes an evaluation of the initial KPIs (Key Performance Indicators) to be considered in the short-term concerning the ramp-up phase and long-term, the large initiative phase. In addition, an evaluation annex (Annex 1) is attached to the current document, containing the evaluation of the dissemination and communication activities carried out during the SUNRISE action. This strategy serves as the basis to define the backbone of the future plans for dissemination, communication and education within the SUNERGY initiative.

In the ramp-up phase of the upcoming project, keeping the current momentum achieved by the SUNRISE and ENERGY-X communities will be the main challenge. Reaching further the general public and policy makers will also be one of the main objectives. As the funding resources for this first part of the project are not yet ensured, cheap and free-of-charge promotional online campaigns and competitions, as well as supporting audiovisual materials (official video, newsletters, slides, etc.) will be developed in order to fulfill the conditions needed for the success of the dissemination and communication strategy, complying with three conditions: 1. Continuous operation of communication tools; 2. Up to date and adapted content to address the different target audiences; 3. Active engagement at European and member states level.

This ramp-up phase will be crucial in order to reach the second phase of the SUNERGY project: becoming a large-scale research and innovation initiative. Developing a large-scale project will be a great opportunity to reach a larger community that will involve changes in the dissemination and communication actions as future goals will have to be agreed.

The short-term objectives defined in this plan are based on the current challenges at the end of both CSAs. The long-term objectives are based on the initial plans for both SUNRISE and ENERGY-X communities to develop a European large-scale initiative and will need to be further reviewed by the SUNERGY consortium at the end of the ramp-up phase.

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1. PURSUE OF THE DISSEMINATION, COMMUNICATION AND EDUCATION PLAN

The SUNRISE Dissemination, Communication and Education Plan is one of the deliverables of the WP3: Dissemination, Communication and Education. The current document is the update at the end of the CSA project, February 2020, including the common communication plan agreed with the ENERGY-X CSA consortium.

Following the official announcement of the merger of the two CSAs SUNRISE and ENERGY-X in August 2019, both initiatives saw a great opportunity to reach a larger community that involve changes in the dissemination and communication actions, future common goals and the need for a new image and brand position: SUNERGY. Several joint actions have already been put in place in the last months of both initiatives.

The SUNERGY joint communication & dissemination strategy plan intends to continue bringing together both SUNRISE and ENERGY-X communities and their 30 committed organisations, backed by an initial supporting community of approximately 300 stakeholders from academia, industry and society. SUNERGY brings together interdisciplinary academic research (chemistry, biology, engineering, information & communication science, social science) with cross-industrial technological expertise to provide a platform for future Chemical energy conversion technology in Europe.

Both SUNRISE and ENERGY-X communication teams started working together since the merger announcement in order to increase the synergy between both project members and to consolidate the SUNERGY joint communication and dissemination work plan including the following short-term objectives (ramp-up phase):

- Consolidate a visual identity and develop website and social media tools
- Keep increasing policy makers and citizen’s involvement
- Strengthen collaboration with decision-makers and other international initiatives

The plan is built on the initial KPIs (Key Performance Indicators) analyses and dissemination and communication strategies of both initiatives and proposes common changes and additions to be considered in the short and long-term of the joint continuation action.

Promotional online campaigns and competitions, as well as the organisation of national stakeholder face-to-face meetings and supporting audio visual materials (videos, infographics, slides, etc.) will be crucial to fulfill the conditions needed for the success of the SUNERGY dissemination and communication strategy, complying with three conditions: 1. Continuous operation of communication tools; 2. Up to date and adapted content to address the different target audiences; 3. Active engagement at European and member states level.

2. SHORT-TERM OBJECTIVES

For the ramp-up phase, the main objective will be to keep the momentum among the SUNERGY supporters to ensure the continuation of the initiative. The short-term dissemination, communication and education plan will be built towards the following specific objectives:

- ***Consolidate a visual identity and develop website and social media tools***: bring the two communities together, trying to drag reached followers and supporters in the continuation initiative and minimizing costs and efforts reusing all possible tools. In addition, an Instagram account has already been opened as this is a useful branding tool to increase project's visibility among the lay public and the youth in particular and it could be interesting for sharing pictures of future experiments and demonstrators (https://www.instagram.com/sunergy.eu/).

- ***Strengthen the SUNERGY support and community by adapting and increasing the dissemination and communication tools and actions***: increase the dissemination and communication tools' exploitation aiming to reach a broader audience, providing relevant and adapted contents. The reinforcement of the internal coordination among the communication departments of the different partners will be also key to better spread the word about the initiative. For the next months, the different planned actions intend to increase not only the number of followers and supporters, but also their engagement.

- ***Establish a platform for dissemination of related topics***: in order to strengthen the current community and steer the communication among the different stakeholders, SUNERGY's dissemination and communication actions and tools should include dedicated spaces to present related projects and initiatives and disseminate, as well, their objectives and achievements. In this way, the initiative will start to act as a coordinating partnership bringing together an interdisciplinary community.

- ***Reach policy makers and industrial supporters***: a broad promotion campaign among partners and supporters will be planned, including the involvement of experts and market mavens to further up hold action's key messages among the required audiences. In addition, other actions, like participation in local outreach activities, appearances and interviews in local media, organization of online contests and live activities, etc. will further help to reach the lay public's attention and get new supports.

- ***Strengthen collaboration with decision-makers and other international initiatives:*** identify different campaigns from the European Commission, associations, and NGOs, in order to cooperate with them, with special emphasis in attracting the lay public.

- ***Develop outreach and training activities dedicated to citizens stakeholders***: analyse the actions carried out with a more educational character and study their planning in a future large-scale initiative, getting the support of specialized organisations (*i.e.* schools, university associations, foundations) and opening it to the inclusion of social sciences, ethical and legal aspects.

3. SHORT-TERM DISSEMINATION, COMMUNICATION AND EDUCATION TOOLS AND ACTIONS

3.1. Dissemination objectives and audiences

The main goal behind the dissemination actions is to disclose the progress and results of the project to other professionals, within the scientific, technological and policy fields. Actions to raise awareness about the initiative and raise support from different sectors will be continued, to promote project knowledge, while actions to announce new updates, attendance to conferences, workshops, etc. are used for the promotion of project outcomes.

The four main target audiences A-D can be further divided in the following dissemination groups:

- Consortium members
- Scientific community
- Industrial stakeholders
- Other related projects and platforms
- Local, Member States and European policy actors
- Associations, NGOs

3.2. Dissemination tools and actions

- **Publications**: the upcoming initiative will release important publications, for instance both CSAs have been working in a joint Manifesto. Appropriate dissemination of these and other upcoming publications using the website, social media tools, newsletters and presentations at conferences and workshops will be key to raise awareness around the documents and get interested stakeholders' feedback and endorsement. In addition, it is important that news of the project keep appearing in specialized media to reach awareness of the initiative.

- **Presentations at conferences/workshops/networks/exhibitions**: The presentation of SUNERGY and its goals at key dissemination events is of great importance to increase the visibility and support of the project. Dissemination material like template slides and leaflets will be available for all partners on the intranet site.

- **Presentations at EU Events and Funding Agencies**: Participation to EU related events will be targeted, as well as meetings with policy representatives, both at EU and national level.

- **SUNERGY Events**: one main community event has already been organized, the SUNERGY public kick-off event, February 2020, which served as well as the joint closing meeting for the two CSAs SUNRISE and ENERGY-X. The organization of national SUNERGY Stakeholders meetings will be key to organize the initiatives supports at national level, identify innovation hubs, get more visibility and reach local and national policy makers. When possible, collaboration with specialized supporters *i.e.* EuChems, E-MRS, etc. will also be sought.

3.3. Communication objectives and audiences

The main goal behind the communication and outreach actions is to promote the project itself and its outcomes to other professionals within the scientific and technological fields, as well as to the society at large. To do so, the Communication Plan will schedule different actions aiming to reach general audiences beyond the scientific, industrial and policy communities. The plan includes activities to raise awareness of the project, project knowledge, actions to announce new updates, events, etc. and campaigns for stakeholder's involvement like activities online and offline to boost the followers and supporters' active participation and engagement in the project.

In addition to the communication tools, outreach activities will also be developed to increase public engagement. The major goal of the outreach activities will be to attract the younger generations to learn more about the project and communicate the advances on the use of alternative energy sources among future end-users.

The four main target audiences A-D can be further divided in the following communication and outreach groups:

- Consortium members
- Scientific community
- Industrial stakeholders
- Other related projects and platforms
- Policy makers
- Associations, NGOs
- Students
- General public

3.4. Communication tools and actions

- **Website and social & professional media tools**: the SUNERGY initiative will have a public website since March 2020. The website will be accessible at www.sunergy-initiative.eu and will be the main dissemination and communication tool of the project containing all relevant information about the initiative goals, events and updates, addressed to all the target audiences. The first version of the website will be progressively adapted to the ramp-up phase needs, including a direct link to an intranet, a password-protected site for sharing working documents.

  The action will also count with profiles on social networks to promote the content of the project's webpage, related projects and relevant news:

  - Instagram: https://www.instagram.com/sunergy.eu
  - Twitter

- LinkedIn
- YouTube
- ResearchGate

These tools will be further developed and adapted to the target audiences in the following months, monitoring contents views and interactions. These will be also key to develop interactive actions.

- **Newsletters:** Public newsletters will serve to further facilitate quick access to all SUNERGY stakeholders about the major news and outcomes of the project. The newsletters will be distributed every three months among the subscripts interested in the project (free subscription will be available on the webpage). The newsletters will also be available on the webpage.
- **Multimedia material:** videos and podcasts will be generated in a visual and easily understandable way to present the initiative goals and achievements. Future goals include the generation of interviews with experts and the promotion of the participation of SUNERGY in different events, including the ones organized within the action. The consortium members will be encouraged to produce audiovisual material to be freely distributed through the webpage and the SUNERGY YouTube channel. Other external videos related to the project will be posted on the project's website to attract the lay public's attention to the topic. Finally, partners' interviews with external media are encouraged.

  The joint actions within SUNRISE and ENERGY-X in the last months have already allowed the production of two videos and a third one, which will be the official SUNERGY one, is also under preparation:

  - Promotional video for the SUNERGY kick-off: https://youtu.be/u9V-SNqazO4
  - SUNERGY kick-off video: https://youtu.be/BYznGjkMXwM

- **Promotional material:** several support materials will be prepared to promote the project (online and offline): document templates, factsheets, posters, slides templates, etc.
- **Press releases & media clippings**: press releases will be prepared for important actions within the initiative, such as organization/participation in important events. These press releases aim to facilitate the appearance of the project in specialized and general media. Interviews and reports on external media, especially on local media, will be encouraged to reach the society at large.

4. PARTNER'S RESPONSIBILITIES

All SUNERGY partners will contribute to public engagement and disseminate and communicate the SUNERGY initiative.

Partners will must use the project's logo in all their dissemination and communication activities.

SUNERGY will count with academic and industrial boards that will be in charge of appointing partners responsible for developing the dissemination and communication aspects of the initiative, including:

- Managing and updating the webpage and social networks both with self and external contents in coordination with the management team;
- Releasing the newsletters (every 3-4 months);
- Provide partners with appropriate dissemination, communication and outreach materials;

- Support the SUNERGY boards and other partners in the preparation of the SUNERGY events;
- Be in charge of videos' production and main documents design;
- Generating, collecting, evaluating and archiving press releases, dissemination and communication activities developed during the SUNERGY ramp-up phase;
- Organise and moderate online activities, *e.g.* contests, chats, etc.

5. ACTIVITIES EVALUATION (short-term)

To evaluate the impact of the dissemination and communication activities developed during the project different indicators will be collected, as follows:

Table 1. SUNERGY KPIs

Tool	KPI	Target at the end of the first year
Website	Number website sessions	>10,000
Newsletter	Number subscribers	>1,000
Social/Professional networks	Number of followers	>2,000
	Interactions (shares, likes)	>8,000
Videos	Number views (YouTube channel)	>2,000
Initiative's Events (symposium, industry workshops and meetings, outreach activities, etc.)	Attendees SUNERGY central events	>200 (in total)
	Attendees national Stakeholder workshops	>200 (in total)
	Attendees outreach actions	>200 (in total)

In addition, qualitative values (such as number of visited pages per visit to the website, most viewed posts, etc.) and other values such as the number of interviews with consortium members in radio/TV, etc. will also be monitored through the action.

6. SUNRISE AND ENERGY-X JOINT ACTIVITIES

Here below, a list of joint events and activities, that have already been performed since the official announcement of the SUNRISE and ENERGY-X merger (since August 2019).

6.1. Joint events following the merger of both initiatives

Event	Associated news from ENERGY-X and SUNRISE websites
Official announcement of SUNRISE and ENERGY-X merger on the EUROPACAT Conference, in Aachen, Germany, on August 26, 2019	https://www.energy-x.eu/news/sunrise-energy-x-2/ https://sunriseaction.com/sunrise-and-energy-x-announce-a-joint-cooperation-at-europacat-2019/
SUNRISE France Stakeholder Workshop, in Paris, France, on October 8, 2019	https://www.energy-x.eu/news/sunrise-france-stakeholder-workshop/ https://sunriseaction.com/sunrise-france-stakeholder-workshop/
The potential of a Sustainable Production of Fuels and Key Chemicals, lunchtime conference organized by the Directorate General for Energy, on October 24, 2019	https://www.energy-x.eu/news/the-potential-of-a-sustainable-production-of-fuels-and-key-chemicals/ https://sunriseaction.com/the-potential-of-a-sustainable-production-of-fuels-and-key-chemicals/
Stakeholder Workshop, in Frankfurt, Germany, on December 2, 2019	https://www.energy-x.eu/news/invitation-stakeholder-workshop/ https://sunriseaction.com/energy-x-stakeholder-workshop/
SUNERGY policy lunch event at the European Parliament: Decarbonising Europe: How large-scale R&I initiatives on fossil-free fuels and chemicals can contribute to the European Green Deal, European Parliament, Brussels, February 5 2020	https://www.energy-x.eu/news/SUNERGY-kick-off-meeting/ https://sunriseaction.com/event/SUNERGY-kick-off-meeting/
SUNERGY kick-off, in Brussels, on February 5 & 6, 2020	https://www.energy-x.eu/news/SUNERGY-kick-off-meeting/ https://sunriseaction.com/event/SUNERGY-kick-off-meeting/

6.2. Joint dissemination activities

Activity	Associated news from ENERGY-X and SUNRISE websites
Launch of a public poll for making the final decision of the name of the joint initiative: SUN2X or SUNERGY? That is the question	https://www.energy-x.eu/news/sun2x-or-SUNERGY-that-is-the-question/ https://www.energy-x.eu/news/announcing-the-winning-name-for-energy-x-and-sunrise-upcoming-joint-initiative-SUNERGY/ https://sunriseaction.com/sun2x-or-SUNERGY-that-is-the-question/ https://sunriseaction.com/announcing-the-winning-name-for-energy-x-and-sunrise-upcoming-joint-initiative-SUNERGY/
SUNERGY Photo Contest	https://www.energy-x.eu/news/SUNERGY-photo-contest/ https://www.energy-x.eu/news/announcing-the-winner-of-our-sun-ergy-photo-contest/ https://sunriseaction.com/sun-ergy-photo-contest/ https://sunriseaction.com/announcing-the-winner-of-our-SUNERGY-photo-contest/
SUNERGY logo	https://sunriseaction.com/introducing-sunergys-official-logo/
SUNERGY kick-off event dissemination activities	https://www.energy-x.eu/news/if-you-could-not-make-it-for-the-sunergy-kick-off-event/ https://www.energy-x.eu/news/kick-off-of-the-sunergy-initiative/ https://twitter.com/ENERGYX_PROJECT/status/1218199842322821122 https://sunriseaction.com/kickoff-sunergy-initiative/ https://sunriseaction.com/if-you-could-not-make-it-for-the-sunergy-kick-off-event/ https://twitter.com/sunriseaction/status/1218077460669050880

7. SUNERGY VISUAL IDENTITY

As mentioned previously, both communication teams from SUNRISE and ENEGY-X started working together since the merger of both CSAs projects in order to:

- increase the synergy between both communities;
- unify the message and the vision of the joint initiative; and
- create the SUNERGY visual identity.

In a first moment, the joint communication team launched a public poll for making the final decision of the name of the joint initiative, choosing from the two final options, as previously decided in an internal poll within both consortia: SUN2X or SUNERGY. After a week of a tight race between the two proposed acronyms, the winning name was SUNERGY! This option counted with the support of 55% of the votes, against the 45% that voted SUN2X.

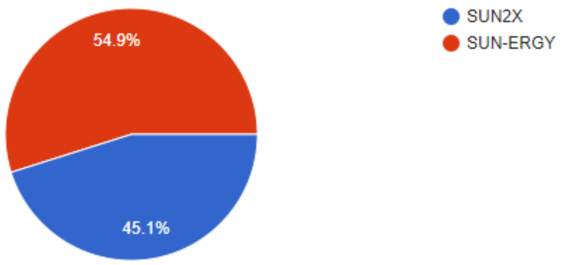

Figure 1. Results of the public poll for choosing the joint initiative name

After the definition of the name of the joint initiative, the communication teams started working on the visual identity of the SUNERGY. In total, nine different propositions were evaluated by the SUNERGY boards and the final decision is presented below:

Figure 2. Round and horizontal version of the SUNERGY logo.

As pointed above, SUNRISE and ENERGY-X have already collaborated in the production of two videos on the joint final event, which was at the same time the kick-off meeting of SUNERGY. One of the videos is about the celebration of this joint meeting, with a major focus on the two closing initiatives, while the other one aims at being the official video of the upcoming initiative including its future goals, main actors and actions.

Figure 3. Frame of the SUNERGY kick-off video.

One of the joint actions of both initiatives was also related with this final joint event: the **SUNERGY photo contest**. The idea of the contest has evolved from a first idea regarding a slam video contest, which at the end was simplified for having a better and quicker reaction to become a photo contest addressed to young researchers. The contest was launched at the end of December, offering to participants the opportunity to show their research using a free style picture along with an abstract. The received pictures were voted in the new SUNERGY Instagram account and the three most "liked" were evaluated by a SUNERGY panel, which chose the winning entry. The winner of the contest, Amedeo Agosti, U. Bologna was awarded with a travel grant to attend the joint meeting and give a presentation about his research work. All the eleven entries that took part in the contest were displayed through an exhibition at the Representation of the State of Hessen to the EU, during the SUNERGY kick-off event in Brussels.

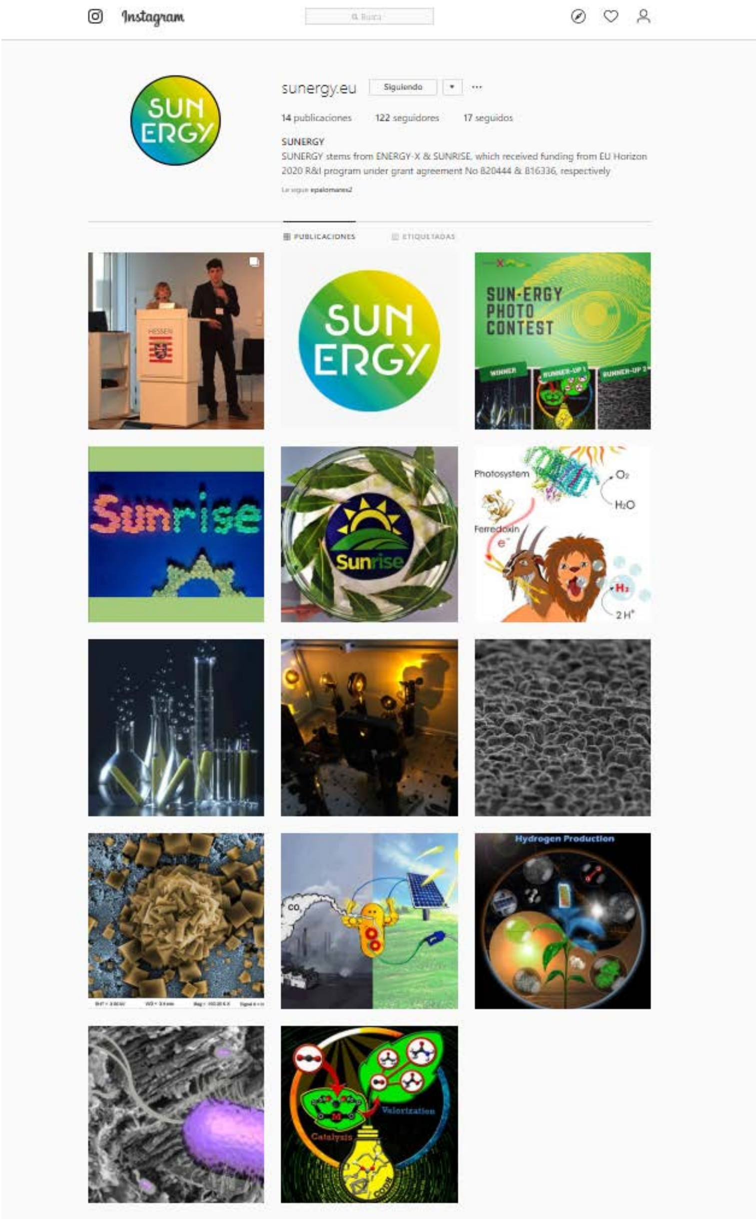

Figure 4. Image of the Instagram account showing the pictures sent by participants of the photo contest and picture of the winner giving his presentation at the SUNERGY kick-off event.

8. LONG-TERM OBJECTIVES

Additional objectives will need to be considered for planning a long-term dissemination, communication and education strategy within a large-scale initiative. Nowadays the model to be followed to develop the future initiative is still uncertain and future strategies will need to be agreed, nevertheless some of the possible long-term objectives for a large partnership include:

- ***Develop a deeper stratification by working communities***: set a functional organization that allows providing appropriate materials and contents by working groups (*i.e.* special news for material/catalysts development, biohybrid development, etc.). Especially important for the organization of different specialized workshops and/or central events with satellite symposiums and for reaching industrial stakeholders with potential interest in the new developed technologies.

- ***Keep increasing policy makers and citizens' involvement***: continue with the dissemination work at large scale, including projects results presentation to European and national policy makers and their involvement, for instance in the definition of new policies and standardization to deploy the new technologies. Keep developing communication tools to reach society at large (*i.e.* simultaneous live events, interviews in local media, videos, development of gaming and informative smartphone applications) and increase citizen's involvement by the introduction of social sciences studies, such as standardized surveys to compare technologies awareness and inclination to use the new technologies by EU countries, etc.

- ***Develop joint actions with decision-makers and other international initiatives****:* establish cooperation and symbiosis strategies with other European and international actions, *i.e.* Mission Innovation, European Energy Research Alliance (EERA) and its Joint Programmes, International Solar Energy Society – ISES, Joint Center for Artificial Photosynthesis – JCAP, European Association for Storage of Energy – EASE, International Partnership for Hydrogen and Fuel Cells in the Economy – IPHE, etc. to launch and participate in global initiatives and establish joint calls.

- ***Create an open access portal***: establish tools to efficiently manage the generation of new publications and their sharing to quickly provide the latest updates to the involved community.

- ***Create the project's own outreach resources***: develop outreach materials and demonstrators, in addition to organize projects actions in cooperation with interested actors, *i.e.* itinerant expositions in science museums.

- ***Develop the project's educational plan***: establish connections with relevant stakeholders, *i.e.* universities and industrial associations, to create *ad-hoc* training materials and a system of calls for young researchers and workshops organization.

9. LONG-TERM DISSEMINATION & COMMUNICATION PLAN

Both SUNRISE and ENERGY-X communication teams decided to keep most of the tools and actions of the current action at a minimum cost after the end of the two CSAs in order to develop SUNERGY website, social media tools, dissemination at related events, etc. Depending on the following SUNERGY project format and funding, different options are possible. The basic backbone of the long-term dissemination and communication plan is shown in the following table:

Target Public	Actions & Tools	Aim
Research community	o Website & social media o Dissemination at related events & specialized initiative workshops o Travel & workshops grants and education materials o Participation in research networks o Newsletters & leaflets o Press releases & videos	o Website & social media o Create awareness of new results and advances o Increase critical mass and avoid duplication of efforts o Establish contact with other research projects; enhance synergies and collaborations o Create an Open Access Portal
Industrial sector	o Website & social media o Dissemination at related events & specialized initiative workshops o Travel & workshops grants and education materials o Newsletters & leaflets o Press releases & videos o Publications in industry journals	o Create awareness of the disruptive potential of the project's technologies o Identification and investigation of novel business opportunities and partners o Identification of standardization needs for implementation of solar fuels o Create an Open Access Portal
Policy makers	o Website & social media o Dissemination at Energy-related European and national events o Newsletters & leaflets o Press releases & videos o Outreach activities and surveys	o Create awareness of the project and its potential impact o Secure governmental support and coordinated investment in solar-to-fuel, power-to-X and solar-to-chemicals technologies o Favorable policies and required standardization o Create an Open Access Portal
Multiple advocacy groups	o Website & social media o Newsletters & leaflets o Press releases & videos o Outreach activities and surveys o Gaming and information phone apps	o Increase public engagement and social contribution o Involve different disciplines and attract new users o Increase awareness of the role of EU funding in supporting innovative research on carbon-neutral technologies o Create an Open Access Portal

ANNEX 1

Analysis of the SUNRISE Dissemination and Communication Actions, M12

Table of contents

1. THE SUNRISE COMMUNITY

One of the main goals of the CSA project is to build a growing supporting community. Table 1 shows the total number of subscribers/followers that the action has reached in the first year (up to 29 February 2020).

Table 1. Global community

	April 2019	February 2020
Platform	Number subscribers/ Followers*	Number subscribers/ Followers*
Twitter	144	618
Research Gate	49	131
Facebook Page	5	412
LinkedIn Page	17	324
YouTube Channel	N/A	51
Newsletter	342	672
TOTAL	**477**	**2208**

*Cumulative data at the end of each month.

The data analysis starts in April 2019 once all the social media (except the You Tube channel) were created and goes until the end of the year of the CSA, end of February 2020. The Twitter account (December 2018) and the Research Gate page (February 2019) were already working before the CSA project started and counted with some followers, while Facebook and LinkedIn pages were created once the action started in March 2019. The number of followers of the social media tools have heavily increased in the first months of the action and kept growing at a slower pace throughout the year.

A SUNRISE YouTube channel was also added to the communication tools. This channel was not included in the first proposal plan, but it was created having a pivotal role as a repository to easily share the CSA's videos and podcasts among the SUNRISE community.

Regarding the newsletter subscribers, the first newsletters were sent to keep a close communication with the different stakeholders that had sent supporting letters to back the initiative. In April 2019, the CSA had received official endorsement of around 150 institutions worldwide. Currently, the action has received 242 letters of support. Therefore, the supporting community, including stakeholders from academia, industry, and society counts already with 262 organisations, an overview can be found in the following table:

Table 2. Overview of the SUNRISE working community

	Academia	Industry	National Network	European Network	Funding body	Miscellanea/ NGO/ Ministry	Total	#Countries
Partners	15	3	-	2	-	-	20	13
Supporters	147	61	11	6	3	14	242	25
TOTAL	162	64	11	8	3	14	262	25

The number of the newsletter subscribers has been growing in the first months of the CSA, including new supporter contacts, registered attendees at the "SUNRISE Stakeholder Workshop" held in Brussels (June 2019) and spontaneous subscriptions through the webpage and the SUNRISE Facebook page. Different newsletter updates have been sent, depending on the audience (if only partners, supporters and External Advisory Board (EAB) or broader audience) and the message (see more information on point 3.4).

2. EVALUATION FIRST YEAR DISSEMINATION AND COMMUNICATION PLAN

As part of the Dissemination, Communication and Education Plan, one of the main goals of the SUNRISE CSA has been to create a growing SUNRISE community that can contribute to work towards SUNRISE's goals. The dissemination and communication actions served to attract new interested stakeholders and keep a fluid communication and interaction with the already numerous supporters and followers, contributing to create a growing ecosystem around the initiative. The actions are addressed to four main target groups: (A) research community, (B) industry sector, (C) policymakers, and (D) advocacy groups including citizens and students as well as NGOs and associations dedicated to sustainable and renewable technologies and solar conversion applications. Several strategies and tools have been put in place to effectively disseminate and communicate the progression and outcomes throughout the year.

The continuous evaluation and analysis of actions is key to increase support for the project by involving more stakeholders and consolidate the blueprint dissemination and communication plan. KPIs were set as measurement tools in the proposal stage and, during all the project, website and social media data have been collected in order to know whether the target audiences are being reached or not, according to the different KPIs, *e.g.* number of website visits, number of newsletter subscriptions, number of social media followers, etc. The main tools utilised to collect these metrics are Google analytics for the SUNRISE website, and the different free-of-charge available tools of each social network: Twitter analytics, Facebook insights, YouTube analytics, LinkedIn analytics, and ResearchGate stats.

During the mid-term update of the Dissemination, Communication and Education plan and KPIs analysis, the different indicators were compared with the initial KPIs set in the proposal stage. This comparison and the trends identified in the analysis, allowed for a modification of the different indicators to better adapt them to the updated dissemination and communication actions. A comparison among the updated target KPIs at the end of the CSA and the final figures obtained can be seen in the table below:

Table 1. Analysis KPIs

Tool	KPI	Target at the end of CSA	Evaluation at the end of the year
Website	Number website sessions	>15,000[a]	15,597
Newsletter	Number subscribers	>500[b]	674
Social/Professional networks	Number of followers	>2,500[a]	1,564
	Interactions (shares, likes)	>10,000[b]	11,791
Videos & podcasts	Number views (YouTube channel)	>2,500[c]	2,962
CSA Events (symposium, industry workshops and meetings, outreach activities, etc.)	Attendees SUNRISE central events	>350 (in total)[d]	350
	Attendees national Stakeholder workshops	>200 (in total)[c]	260
	Attendees outreach actions	>200 (in total)[d]	1,500
Letters/statements of support	Number	>250[b]	244
Press releases & clippings in media	Number	>50[b]	103

[a] Decreased number respect to figures at the proposal stage, in accordance with the mid-term analysis; [b] Increased number respect to figures at the proposal stage; [c] New KPI; [d] Reformulated KPI.

In addition, qualitative values (such as the number of visited pages per session to the website, most viewed posts, etc.) and other values such as the number of interviews with consortium members in radio/TV, etc. have also been monitored through the action.

These KPIs and the analysis of the dissemination and communication actions (see following points) gives us some interesting information to shape the future goals and activities.

In the first place, SUNRISE has achieved to bring together a large and engaged community. The number of organisations officially endorsing support to the initiative is around these expected at the end of the action (242 supporters by 25 February 2020) and they have actively contributed to the SUNRISE events and actions. The growing community effect can also be seen in the large number of newsletter subscribers that account not only for partners and supporters contacts, but also for other interested stakeholders and that at the end of the CSA counted with more than 650 contacts.

One of the actions key to enlarge the community is the large number of events (conferences, workshops, meetings) where the SUNRISE partners have introduced the initiative (see following Table 3).

The deployment and continuous update of the project's website, social media tools, videos and an active communication campaign including different online activities, press releases and partners interviews in specialized and mass media has also been crucial to create an open community and reach different audiences. Regarding the number of followers in social media, although the final numbers of followers are lower than expected, the number of interactions is large, showing a very active and engaged community behind.

Finally, the action has participated in large outreach events, *i.e.* the Big Challenge Science Festival in Norway, the European Sustainable Energy Week in Brussels, the COP25 in Madrid, etc., reaching a large number of attendees, especially young students, largely overcoming the expected results.

It is clear that during the action social media networks have become the real interaction points with the SUNRISE community, the new KPIs introduced in the mid-term analyses, like tools to monitor the impact of the released videos in the project's YouTube channel have been proven to be highly relevant.

The mid-term analysis also showed that other qualitative KPIs are also important to show the value of the current digital ecosystem of SUNRISE:

1. **Posts' engagement:** the most engaging posts both on Twitter and Facebook are those related to SUNRISE events and news, rather than the external news that are shared on a regular basis. *e.g.* in this CSA year, the 3 top news in terms of page views were the one presenting the SUNRISE technological roadmap with 1,290 views, another one on the SUNRISE stakeholder workshop in June 2019 in Brussels (534 views), and a third one SUNERGY photo contest (471 views). This means that throughout the whole year, SUNRISE's audience has been interested in the SUNRISE's updates and that our followers are committed to the initiative.
2. **Number of newsletter's opens:** the first public SUNRISE newsletter was submitted on July 2, 2019 to 585 subscribers and it obtained 34,7% opens. Different newsletter updates have been sent to different recipients, obtaining different opening numbers, up to 45%. The opens have been monitored to see recipients' interest and try to deal with problems encountered, like spam issues.
3. **Average website visit duration**: the average website visit duration between the past months, since May, has been of 3:20 minutes. Likewise, the average number of pages per visit has been of 4, which tells that users are interested in more than one single item when they visit the SUNRISE website.

3. DISSEMINATION TOOLS AND ACTIONS

3.1. List of events where the SUNRISE project has been presented

SUNRISE partners have been very engaged and active introducing the initiative in the numerous conferences, workshops and meetings where they have participated, more than 50 (see following Table 3). The initiative has also been successful in the organisation of its own events:

- "*SUNRISE Community Building Event*": it was organized before the launch of the CSA to present the initiative to the supporting entities, already counted with around 90 participants (Brussels, 15 November 2018).

- "*SUNRISE Stakeholders Workshop*" (ramp-up meeting): it took place at month 4 of the CSA joining a big representation of supporters and followers with around 170 participants, in connection with the European Sustainable Energy Week, bringing together also policy representatives and interested individuals (Brussels, 17 and 18 June 2019).

- "*SUNERGY Kick-off Event*": this has been the final closing symposium for both SUNRISE and ENERGY-X that have organized it jointly and has served as well to present the new joint initiative: SUNERGY. The event counted with about 120 participants and it was divided in a high-level policy event a Lunch discussion in the European Parliament "Decarbonising Europe: how large-scale R&I initiatives on fossil-free fuels and chemicals can contribute to the European Green Deal" and a public event with both SUNRISE and ENERGY-X communities (Brussels 5 and 6 February 2020).

The initiative has also organized several consortium meetings:

- Kick-off meeting, March 2019, Brussels (EERA): initial consortium meeting with participation of SUNRISE partners, key for the management of the action. The meeting also included a streamline session for supporters on PRDs (Priority Research Directions).
- Consortium meeting, May 2019, Bologna (University of Bologna): consortium meeting with participation of SUNRISE partners. The advances on the different WPs (Work Packages) were discussed and further work on the Vision, Roadmap, Governance and Business documents distributed. The meeting also worked for shooting the different videos that have been used during the action and included an open session to Italian supporters, with a presentation by Prof. John Mathews (Macquarie University, Australia).
- Consortium meeting, October 2019, Brussels (EERA): consortium meeting with participation of SUNRISE partners. The meeting included a mid-term review of the action with feedback from some of the members of the external advisory board and also a coordinated session with the Mission Innovation initiative aiming to build synergies in the roadmapping strategies.
- Final meeting, February 2020, Brussels (EERA): final consortium meeting to review the work of the action and final points towards the final deliverables, with a special focus on the final blueprint and the different scenarios for the continuation action.

Regarding the participation of partners in other conferences and meetings, although most of the events where the initiative has been presented are scientific conferences targeting academic and industrial researchers (see following Table 3), it is worth highlighting that policy actors have also been present in some of the events. For instance, SUNRISE actively participated in the European Sustainable Energy Week, EUSEW. Its Stakeholder Workshop (17-18 June 2019) was organised in connection with the event, being one of the actions within the Energy Days and including a governance session with European Member States and European associations and foundations representatives. In addition, SUNRISE participated in the EUSEW conference, on June 20, the initiative's coordinator Huub de Groot took part in the panel session 'Energy storage to boost EU decarbonisation and competitiveness,' together with representatives of the European research initiatives BATTERY 2030+ and ENERGY-X. SUNRISE also held a stand at the Networking Village. Together with ENERGY-X, the project also participated in a lunchtime conference organized by the Directorate General for Energy (DG Energy) on October 24, 2019. Finally, SUNRISE also had a dedicated session in the 9th EuroNanoforum (Bucharest, June 2019).

SUNRISE national events have been organized in different member states and other ones are planned in the following months. These meetings are key for the organization of the initiative at the different countries and for getting supports from the member states, representing a unique opportunity for the dissemination of the initiative. See the list below (also in Table 3):

- United-Kingdom: UK Solar Fuels Network Meeting, 28 March and Mission Innovation action plan meeting, 25 March, Cambridge
- France: meeting of the GDR solar fuels, 13-15 May, Saclay.
- Spain: FOTOFUEL meeting (Spanish network on research lines for the obtainment of solar fuels), 13-14 May, Móstoles.
- Italy: Bologna, 16 May 2019.
- Poland: SUNRISE Stakeholders Workshop: Warsaw, 5-6 June 2019.
- Switzerland: SUNRISE Stakeholders Workshop: Empa Zürich, 27 September 2019.

- France: SUNRISE and ENERGY-X Stakeholders Workshop: Maison des Universités, Paris, 8 October 2019.
- Netherlands: Eindhoven, Symposium "Solar to Products", 6 November 2019
- Finland: SUNRISE Stakeholders Workshop: Turku, 9 December 2019.

Further actions were promoted during the CSA for the dissemination of the project and the main objectives to advance towards a large-scale initiative:

During the month of April, the SUNRISE initiative organized a "Young researchers travel grant" contest among partners and supporters to cover the travel costs (up to 400€) of three young researchers (PhD students and up to 4 years postdoctoral researchers) to attend a scientific event to disseminate their research. Candidates should present an accepted abstract to the call in a research theme related to one of the three SUNRISE approaches. The three awarded researchers have delivered oral talks (see events in the table above) and used social media or blog posts to announce the talk, mentioning the SUNRISE action in the acknowledgements.

In collaboration with E-MRS, a SUNRISE supporter, the initiative sponsored a poster prize in the Symposium A "*Latest Advances in Solar Fuels*", at the European Materials Research Society (E-MRS) Spring meeting 2019 held in Nice, France. The winner poster was entitled "Ni-modified β-FeOOH(Cl) nanorod for water oxidation toward solar-driven CO_2 reduction system combined with Mn-complex catalyst". Authors: Tomiko M. Suzuki, Takeo Arai, Shunsuke Sato, Keita Sekizawa, *Takeshi Morikawa Affiliations: Toyota Central R&D Labs., Inc.

Table 3. Events where SUNRISE was introduced during the first CSA year:

Event	Partners involved & dissemination material used	Estimated No. attendees
15 November 2018, Brussels. SUNRISE Meeting	Consortium members and supporters / slides	90
26 January 2019– 1 February, Oslo. CoE NordAqua – Nordic Bioeconomy Program Meeting	Eva-Mari Aro (University of Turku) / slides	-[a]
21-22 March 2019, Brussels, SUNRISE Kick-off meeting	Consortium members + PRD session online	22 partner representatives + ~40 supporters online
25-27 March 2019, Cambridge. Artificial Photosynthesis Faraday Discussion & Mission Innovation action plan meeting	Leif Hammarström (Uppsala University), James Durrant & Ernest Pastor-Hernandez (Imperial College), Víctor A. de la Peña (IMDEA Energy) / poster & leaflets	-[a]
28-29 March 2019, Cambridge. UK Solar Fuels Network Meeting	James Durrant (Imperial College)	-[a]
16 April 2019, Lahti. BioFuture 2025, Academy of Finland	Eva-Mari Aro & Yagut Allahverdiyeva-Rinne (University of Turku) / slides	-[a]
22-26 April 2019, Phoenix, Arizona. MRS Spring Meeting 2019	Artur Braun (Empa) / slides for three different presentations	~150 in the Symposia (around 4,000

		overall)
9 May 2019, Bologna. EERA Workshop: R&D pathways and opportunities in Fuel cells, Hydrogen and Bioenergy	Nicola Armaroli (CNR) / slides	-[a]
13-14 May 2019, Móstoles. FOTOFUEL Workshop: Current challenges in solar fuels production	Victor A. de la Peña (Organiser, IMDEA Energy), Maximilian Fleischer (Siemens), Carolina Gimbert (ICIQ) / Poster, slides, leaflets	~ 150
13-15 May, Saclay. Meeting of the GDR solar fuels	Vincent Artero (CEA) / slides	-[a]
13-17 May 2019, Rome. Energy Materials Nanotechnology conference, EMN Rome 2019	Joanna Kargul (University of Warsaw) / slides	~ 80
15-16 May 2019, Bologna. SUNRISE Consortium Meeting.	Consortium partners and invited Italian supporters	30 partner representatives + ~15 supporters in the final session
17 May 2019, Helsinki. Meeting of Finnish Research Foundations.	Eva-Mari Aro (University of Turku) / slides	-[a]
22-24 May 2019, Turku. Nordic Photosynthesis Congress NPC14	Eva-Mari Aro & Yagut Allahverdiyeva-Rinne (University of Turku) / slides	-[a]
27-31 May 2019, Nice. E-MRS Spring Meeting, sponsoring a poster within the symposium: Materials for Energy – Latest advances in solar fuels	Antoni Llobet (ICIQ), Artur Braun (Empa), Mariam Barawi (IMDEA Energy), Carlota Bozal-Ginesta (Imperial College, SUNRISE Young Researchers Travel Grantee) / slides, poster + sponsor poster prize	~200 for lectures & poster session symposium A (2700 full conference)
27 May 2019, Donostia-San Sebastian. Spanish Royal Society of Chemistry Biennial Meeting 2019- Light Symposium: Light controlled materials and processes: from medicine to artificial photosynthesis	Victor A. de la Peña (Co-organiser Symposium, IMDEA Energy), James Durrant (Imperial College)/ slides	-[a]
29 May 2019, Vancouver. Clean Energy Ministerial meeting, CEM10	Ann Magnuson (Uppsala University) / leaflets	-[a]
5 June 2019, Grenoble, Seminar of the Institute for Interdisciplinary Research of Grenoble (IRIG)	Vincent Artero (CEA), Frédéric Chandezon (CEA)/ slides	~50

5 June 2019, Warsaw. SUNRISE Poland Stakeholder Workshop	Organisers: Joanna Kargul & Renata Solarska (University of Warsaw), SUNRISE Speakers: Yagut Allahverdiyeva-Rinne (University of Turku) + Hervé Bercegol (CEA) / video, slides, leaflets	~60
13 June 2019, Mersin University. International Conference "Solar / Fuel Cells: Energy Systems"	Artur Braun (Empa) / slides, roll-up	-[a]
12-14 June 2019, Bucharest. 9th edition of EuroNanoForum	Joanna Kargul (University of Warsaw), Laurent Baraton (ENGIE) / video, slides	-[a]
13 June 2019, Mersin University. International Conference "Solar / Fuel Cells: Energy Systems"	Artur Braun (Empa) / slides, roll-up	-[a]
17-18 June 2019, Brussels. SUNRISE Stakeholder Workshop	Consortium partners and stakeholders	~170
17 June 2019, Brussels, Global Alliance for Powerfuels panel	Artur Braun (Empa) as panel speaker	~70
20 June 2019, Brussels. EUSEW Session: ENERGY STORAGE TO BOOST EU DECARBONISATION AND COMPETITIVENESS	Huub de Groot (Leiden University)	~600
23-27 June 2019, Aachen. 17th International Conference on Carbon Dioxide Utilization – ICCDU 2019	Hélène Lepaumier (ENGIE) / poster (winner poster prize), leaflets	320 (full conference)
24-26 June 2019, Lipari. UK-IT Joint Meeting on Photochemistry 2019	James Durrant (Imperial College), Tony Vlcek (J. Heyrovsky Institute of Physical Chemistry-UCL)	-[a]
26-30 June 2019, Portoroz-Portorose. 6th European Conference on Environmental Applications of Advanced Oxidation Processes	Fernando Fresno (IMDEA Energy) / slides	-[a]
1-3 July 2019, Brussels, ENERGY-X "Research need" Workshop	Huub de Groot (Leiden University), Vincent Artero (CEA), Ann Magnuson (Uppsala University), Maximilian Fleischer (Siemens), Eva-Maria Aro (University of Turku), Julio Lloret-Fillol (ICIQ), Carina Faber (UCL) / leading/participate in the	~180

	different discussion panels	
5-12 July 2019, Paris. 47th IUPAC World Chemistry Congress & 50th General Assembly	Vincent Artero (co-organiser symposium 2.3, CEA) / leaflets	-[a]
8-10 July 2019, Marseille. Quantum BioInorganic Chemistry Conference (QBIC-V)	Andrey I. Konovalov (Leiden University, SUNRISE Young Researcher Travel Grantee) / slides	-[a]
21-26 July 2019. Newry. 2019 Photosynthesis Gordon Research Conference	Yagut Allahverdiyeva-Rinne (University of Turku) / slides, leaflets	-[a]
30 July 2019, University of Pretoria. Talk SUNRISE Project	Artur Braun (Empa) / slides, roll-up, leaflets	-[a]
31 July – 02 August 2019, Pilanesberg National Park, South Africa Energy Storage and Industry 4.0: Challenges and Prospects (ENSTIN 2019)	Artur Braun (Empa) / slides, roll-up, leaflets	-[a]
4-9 August 2019, Durban. 70th Annual Meeting of the International Society of Electrochemistry	Artur Braun (Empa), Renata Solarska (University Warsaw) / slides, roll-up, leaflets	-[a]
18-23 August 2019, Aachen. 14th European Congress on Catalysis, EuropaCat 2019	Frédéric Chandezon (CEA), Hervé Bercegol (CEA), Maximilian Fleischer (Siemens AG) / leaflets	> 1500 (full conference)
25-30 August 2019, Barcelona. World Congress on Light and Life	Eva-Mari Aro (University of Turku) / slides	-[a]
27-30 August 2019, Donostia-San Sebastian. Photo- and ElectroCatalysis at the Atomic Scale	Franziska Hegner (ICIQ, Young Researchers Travel Grantee) / slides	-[a]
28 August 2019, Galway. 8th International Conference on Biotechniques for Air Pollution Control & Bioenergy	Joanna Kargul (University of Warsaw) / slides	-[a]
3 September 2019, Warsaw. 62nd Annual Scientific Meeting of the Polish Chemical Society	Joanna Kargul (University of Warsaw) & Dorota Rutkowska-Żbik (ENERGY-X representative from Haber Institute in Cracow) / video, slides	-[a]

9-13 September 2019, Venice. 1st International e-conversion Conference	Joanna Kargul (University of Warsaw) / slides	-[a]
19 September 2019, Brussels. Workshop on CCU Innovation Fund and other EU Funding Opportunities, by CO_2 Value Europe	Anita Schneider (EERA) / slides	> 90
21 September 2019, Leiden. Nacht van Ontdekkingen	Huub de Groot (U Leiden) / slides	~ 40
22-23 September 2019, Tarragona. 4th EuCheMS Conference on Green and Sustainable Chemistry	Antoni Llobet & Julio Lloret & Elisabet Romero (ICIQ, local advisory board) / slides, roll-up	> 300
26 September 2019, Brussels. ENERGY-X Research Roadmap Launch event	Carina Faber (UCL) / Participation in the discussion panel	~ 70
27 September 2019, Dübendorf. SUNRISE Switzerland Stakeholder Workshop	Organisers: Artur Braun & Rita Toth (Empa), together with the Swiss supporters: Pierdomenico Biasi (Casale) and Sophia Haussener (EPFL). Presentation SUNRISE by Frédéric Chandezon (CEA) / video, slides, roll-up	> 30
30 September -1 October 2019, Brussels. EABA Algae Based Biofuels Workshop	Yagut Allahverdiyeva-Rinne (University of Turku) / slides, leaflets	> 30
2-3 October 2019, Móstoles. Aportando Valor al CO_2 (Increasing value of CO_2)	Victor A. de la Peña (IMDEA Energy), Laura López (ICIQ) / poster, slides, leaflets	~ 150
2-4 October 2019, Rome. Biophysics of Photosynthesis	Eva-Mari Aro & Yagut Allahverdiyeva-Rinne (University of Turku) / slides	-[a]
5-6 October 2019, Barcelona. Maker Faire Barcelona	Amelia Ochoa & Laura López (ICIQ) / leaflets, infographics, demonstrators	> 200
8 October 2019 – Paris – SUNRISE & ENERGY-X France Stakeholder Workshop	Organisers : Hervé Bercegol (CEA), Frédéric Chandezon (CEA), Simon Perraud (CEA) /slides, leaflets	~ 75
9-11 October 2019, Brussels. SUNRISE Consortium meeting & Meeting with Mission Innovation	Consortium partners + representatives Energy-X + EAB + Mission Innovation (IC6)	~ 40
24 October 2019, Brussels. Lunch time conference DG ENER – Towards a sustainable, carbon-neutral energy system by 2050	Huub de Groot (U Leiden), Frédéric Chandezon (CEA), Joanna Kargul (U Warsaw), Maximilian Fleischer (Siemens), Ann Magnuson (U Uppsala), Marco Rignanese (UCL), Carina Faber (UCL), Hervé Bercegol (CEA), Anita Schneider (EERA) / slides	~ 50

5 November 2019, Rotterdam. 3rd CO_2 Value Day	Huub de Groot (U Leiden), Hervé Bercegol (CEA) / slides	~ 25
5 November 2019, Rome. EERA Workshop on Hybrid Energy and Energy Storage Systems.	Frédéric Chandezon (CEA) / slides	-[a]
6 November 2019, Eindhoven. Symposium "Solar to Products"	Huub de Groot (U Leiden), slides & demonstrator	~ 150
13-15 November 2019, Helsinki. SET-Plan Conference 2019.	Anita Schneider (EERA), Philippe Jacques (EMIRI) / stand with videos	-[a]
18-20 November 2019, Graz. European Summit of Industrial Biotechnology (ESIB 2019).	Yagut Allahverdiyeva-Rinne (University of Turku) / slides	~ 450
20-24 November 2019, Hiroshima, (Japan). 3rd International Solar Fuels Conference and the International Conference on Artificial Photosynthesis-2019 (ISF-3/ICARP2019).	Vincent Artero (CEA), James Durrant (Imperial), Leif Hammarström (U Uppsala) / slides	> 400
25-26 November 2019, Warsaw. Internationability of Polish Science and Higher Education.	Joanna Kargul (U Warsaw), Stefan Baumann (Jülich) / slides	-[a]
3 December 2019, Frankfurt. ENERGY-X Stakeholder Workshop.	Hervé Bercegol / slides	-[a]
5-7 December 2019, Madrid. COP25 2019.	Victor de la Peña, Fernando Fresno, Marta Liras, Mariam Barawi, Freddi Oropeza (IMDEA Energy), Álvaro Reyes, Lorena Tomás, Amelia Ochoa, Laura López (ICIQ)	~ 800
9 December 2019, Turku. SUNRISE Finland Stakeholder Workshop	Organisers: Eva-Mari Aro & Yagut Allahverdiyeva-Rinne (University of Turku), speakers: Frédéric Chandezon (CEA), Arne Roth (Fraunhofer), Joanna Kargul (U Warsaw) / slides	~ 65
9 December, Noordwijkerhout, Annual M2i Conference	Huub de Groot (U Leiden), slides	~ 150
10 January, Delft. Visit Diederik Samson Green Village TU Delft.	Huub de Groot (U Leiden), Harald Kerp (M2i) / slides	~ 25
3-4 & 6-7 February, Brussels. SUNRISE Final Consortium Meeting.	Consortium partners	~ 25
5-6 February, Brussels. SUNERGY Kick-off Meeting.	SUNRISE + ENERGY-X consortium partners + stakeholders	~ 120

12-14 February, Padova. ENERCHEM-2	Vincent Artero (CEA), Maximilian Fleischer (Siemens Energy) / slides	-[a]

[a] Data not available.

Finally, in addition to the presentation in conferences and other events, the SUNRISE initiative has also appeared in relevant scientific publications. A description of the project was included in the "News Flash" section in the last edition of the European Photochemistry Association Newsletter, June 2019 (invitation through Leif Hammarström, Uppsala University). The Poland SUNRISE Stakeholders Workshop published a Book of abstracts and the Switzerland SUNRISE Stakeholders Workshop a report: "Conference Report: Swiss Stakeholder Workshop for the SUNRISE H2020 FET- Flagship Project, Chimia 73 (2019) 952-956", doi:10.2533/chimia2019.952.

SUNRISE has also been mentioned in other articles in Nature (replicated in Scientific American), Science Magazine and Chemistry World, together with the other preparative actions and related projects. A publication about the six preparative actions and a news about the SUNRISE Stakeholder Workshop also appeared in the Digital Single Market portal from the EC.

Finally, the initiative is preparing two special issues on circular economy and energy policy and regulation. Specifically, Empa partners Artur Braun and Rita Toth are guest editors for the call for papers for "Circular economy: national and global policy" within the special issue in "Clean Technologies and Environmental Policy" (Springer Nature) having already 10 confirmed authors, and they are also guest editors in a special issue in MRS Energy & Sustainability inspired by the SUNRISE action with 11 confirmed authors.

3.2. Smartphone app

One of the objectives of the dissemination plan is to develop a new smartphone app to share scientific publications. During the CSA a demo version has been developed (http://events.tickaroo.com/projectsunrise/). This system is thought to be a new tool to support open access strategies. The demo was presented at the SUNRISE Stand during the Energy Week and a final survey among SUNRISE partners was also prepared to have feedback among these first users. This is key to develop a future public version in a future advanced development. According to the survey results the main aim of the application might be reformulated in future development. Most of the participants expressed their interest in developing an App and thought it would be useful, however, most of them would not like to receive the latest research articles in their phones. Other appropriate contents suggested are: open calls and events in the field and outreach materials. According to the suggestions, to improve the design, a searching tool should be added, allowing for search information in different sections, i.e. news, events, calls, etc. Finally, participants found interesting to keep developing the App as soon as possible within the continuation action SUNERGY.

3.3. SUNRISE Password Protected Site

The project's website has been the main tool for dissemination and communication purposes and a better description can be found in point 3.2. Especially relevant for the dissemination purposes has been the password-protected site: https://sunriseaction.com/priority-research-directions-prd-vision/, which contained the PRDs and other working documents at the beginning of the action. Only the initiative's partners and official supporters were given the password to access it (sent through informative newsletters). This site has been an important tool during the firsts months of the action to keep a strong interaction with the growing SUNRISE community, developing the PRD documents that later on served as a basis for the technical annexes within the SUNRISE roadmap. The site was one of the most visited pages of the SUNRISE website during the first months of the action.

3.4. Poster and slides

A poster titled 'SUNRISE: Solar energy for a circular economy' has been created to showcase the project in different events. It is available in the intranet PLAZA of the project's website together with standard slides for presentations.

In addition, the SUNRISE poster won the 'Best Poster Award' at the 17th International Conference on Carbon Dioxide Utilization (ICCDU), which took place on June 23 – 27, 2019, in Aachen, Germany.

4. COMMUNICATION TOOLS AND ACTIONS

4.1. Project logo and visual identity

A logotype was designed to advertise the project at the time of the proposal preparation. The SUNRISE logo is the visual element that represents the project and promotes instant public recognition. The logo was designed with a simple and dynamic look representing a sun rising over the fields, directly related with the claim of the project: solar energy for a circular economy.

The SUNRISE logo together with the EU emblem and the sentence "This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 816336" must be included by all partners in all the communication and outreach documents and events.

Regarding the SUNRISE logo, at the beginning of the project a Twitter contest was launched offering the possibility to vote between the existing logo and two more options. This action aimed to increase involvement of followers and supporters in the action and attract attention to the Twitter account. The majority of participants voted to keep the current option and SUNRISE mugs were sent to participants that voted in the second leg of the poll.

Figure 1. Logo twitter poll

Regarding the name and logo for the SUNRISE continuation action SUNERGY, common efforts with ENERGY-X have been done to choose the name, logo and visual identity (see Dissemination and Communication Plan above and also Deliverable D3.3 Dissemination and Communication Resources).

4.2. SUNRISE Website

The SUNRISE website is accessible at: www.sunriseaction.eu and www.sunriseaction.com. The website is the main online dissemination and communication tool of the project. It contains information on the project, the consortium and its members, projects achievements, related events, audiovisual resources and current activities. This information is addressed to all sorts of audiences, from scientists and industrial researchers to the general public.

The website has been designed following a responsive web design (RWD) to enable optimum visualization independently of the size of the screen (PC, tablet and mobile) or web browser one is viewing with. It has been updated frequently as required by ICIQ.

The platform has been created to serve as a project content management system on two levels: (1) external communication and dissemination of the project objectives and results, and (2) internal Communication Platform within the consortium. The public section displays the following sections:

- **Home**: basic title and description of the project, highlights of the latest news, events and videos, contact information, access to the other web sections and to the project social networks (Facebook, Twitter, YouTube, LinkedIn and ResearchGate).
- **About us**: information about the CSA, the project's vision, FAQ about the initiative, and the list of all partner institutions taking part in the project, linking to their short descriptions. Every partner is briefly described in terms of research quality, groups participating in SUNRISE and people responsible for the project.
- **Newsroom**: pieces of news about the project, interviews with experts, SUNRISE meetings, related events, opportunities, and useful resources, such as publications, presentations, graphic materialsand videos.
- **Blog**: brief updates about SUNRISE communication and outreach activities.
- **Support us**: general contact form to become a supporter and a banner with all the current supporters' logos.
- **Media**: collection of the press releases, media appearances and coverage of SUNRISE news published in general and specialized newspapers and magazines, interviews (radio and TV), videos, etc.

In the website, there is a direct link to the intranet site PLAZA: https://sunriseaction.com/intranet/ and is managed by M2i. It can only be accessed by the project's consortium members and has been created to exchange documents, files and other confidential information between the project partners. The intranet is the main tool for storage and exchange of documents between partners, such as:

- Complete contact list including names and e-mail addresses of all the participants
- Templates
- Minutes of the meetings
- Progress reports
- Deliverables

More details about the web design can be found in the public project's deliverable "D3.2. Project website, App and social media tools". Although the action counted with a public website since September 2018, evaluation of the website traffic and audience has not been done until May 2019, once the new web has been designed and Google Analytics tools properly displayed.

The information tracked by the analytics tool shows that the page had 15,597 visits between May 2019 and February 2020 as counted by the number of sessions, which gives the estimate of the number of times visitors opened the website. The number of users for the same period is 10,751 showing that some of the visitors have opened the website more than once in this period of time, and even more importantly, the page visitors spent long times at their visits generally seeing more than one page, giving therefore large page views numbers.

It is also interesting to see that beyond the landing page, the most visited pages include the Consortium page, where the partner organizations are displayed. This indicates a big interest in the project's main actors.The events page showing events taking place with partners and supporters participation, as well as the SUNRISE initiative page showing the CSA's goals are also of interest for the SUNRISE community.

Location overviews show a big interest from United States visitors, highlighting the international relevance that the project. This fact has been important when setting social media campaigns, as some have been directed towards the American public.

Table 4. Website traffic analysis (Google Analytics)

Website statistics	**May 2019**	**June 2019**	**July 2019**	**Aug. 2019**	**Sept. 2019**	**Oct. 2019**	**Nov. 2019**	**Dec. 2019**	**Jan. 2020**	**Feb. 2020**
Sessions	1137	1785	1536	960	1402	1654	2033	1458	2175	1457
Users	618	985	963	720	1018	1139	1547	1102	1625	1034
Page views	6508	8308	9684	3595	6207	7016	6098	3380	5353	5177
Pages/session	5,72	4,65	6,3	3,74	4,43	4,24	3	2,32	2,46	3,55
Average Session Duration (min:sec)	0:05:25	0:04:52	0:05:14	0:03:22	0:03:31	0:03:23	0:02:33	0:01:55	0:02:45	0:03:28
Location overview										

Country #1	Spain	Belgium	United States	United States	United States	United States	United States	United States	United States	United States
Country #2	Italy	France	Spain	Germany	France	France	France	Spain	Germany	France
Country #3	France	United States	France	France	Germany	Germany	Germany	France	France	Germany
Top 3 pages										
Page #1	Landing	Landing	Landing	Landing	Landing	Landing	Landing	Landing	Landing	Landing
Page #2	PRDs,	PRDs,	Consortium	Consortium	Events	Consortium	Roadmap news	Consortium	SUNERGY photo contest	Presentations
Page #3	Events,	Events,	Past events,	Past events	Consortium	SUNRISE Initiative	Consortium	SUNRISE Initiative	SUNRISE Initiative	Consortium

4.3. Social Networks

Social networks were used to promote the content of the project's webpage, related projects and relevant news concerning the artificial photosynthesis. Each social media has been further analysed through its own analytic tools (Tables 5 to 9):

Table 5. Twitter Account Analysis (Twitter Analytics, https://twitter.com/sunriseaction)

	April 2019	**May 2019**	**June 2019**	**July 2019**	**Aug. 2019**	**Sept. 2019**	**Oct. 2019**	**Nov. 2019**	**Dec. 2019**	**Jan. 2020**	**Feb.2020**	**Total**
Num. of tweets	50	96	144	38	36	102	176	128	98	67	72	1007*
Impressions	40200	77600	135000	79700	86400	79700	86400	98800	70570	98400	70570	923340
Engagement rate	1,7%	0,9%	1,5%	1,7%	2,08%	1,5%	0,99%	0,79%	1,40%	1,90%	0,90%	-
Replies & likes	154	336	615	265	250	330	619	363	499	266	437	4134
Retweets	50	110	175	89	65	144	188	140	155	90	164	1370
Link clicks	152	251	471	206	148	99	209	246	258	197	168	2405
Total Interactions	356	697	1261	560	463	573	1823	749	912	553	769	7909

*The total number of tweets since December 2018, when the account was opened, is 1170.

Table 6. Research Gate Analysis (Research Gate stats, https://www.researchgate.net/project/SUNRISE-Solar-Energy-for-a-Circular-Economy-EU-H2020-CSA-Ref-816336)

	Feb. - Apr. 2019	May 2019	June 2019	July 2019	Aug. 2019	Sept. 2019	Oct. 2019	Nov. 2019	Dec. 2019	Jan. 2019	Feb. 2019	Total
Num. of updates	16	5	11	3	11	7	12	14	6	30	5	118
Recommendations	21	20	31	30	19	39	94	69	34	34	10	401
Reads	454	76	174	370	181	189	218	216	116	221	140	2405
Total Interactions	471	96	205	400	200	228	312	285	150	255	150	5329

Table 7. Facebook Page Analysis (Facebook Insights, https://www.facebook.com/sunriseaction)

	April 2019	May 2019	June 2019	July 2019	Aug. 2019	Sept. 2019	Oct. 2019	Nov. 2019	Dec. 2019	Jan. 2020	Feb. 2020	Total
Num. of updates	2	23	21	18	14	31	35	28	15	17	13	220
Impressions*	76	46032	120718	129837	19156	129837	19156	3087	1116	1180	930	471125
Likes	1	49	103	58	38	75	140	85	51	85	20	705
Shares	0	5	12	12	5	20	14	10	7	10	2	97
Total Interactions	1	54	115	70	43	95	154	95	58	95	22	802

*Cumulative data (sum of all impressions of the page) at the end of each month.

Table 8. LinkedIn Page Analysis (LinkedIn Analytics, https://www.linkedin.com/company/sunriseaction)

	April 2019	May 2019	June 2019	July 2019	Aug. 2019	Sept. 2019	Oct. 2019	Nov. 2019	Dec. 2019	Jan. 2020	Feb. 2020	Total
Num. of publications	13	12	16	11	16	16	31	23	16	14	11	52
Impressions	978	2090	3130	1946	3130	2377	5578	16460	7501	3767	4631	51588
Engagement rate	5,8%	6,8%	8,3%	6,4%	8,29%	5,77%	3,2%	4,32%	4,77%	4,84%	7,74%	-
Clicks	43	62	158	62	158	71	214	199	401	91	231	1690
Reactions	14	60	67	57	67	73	128	120	141	153	100	980
Total Interactions	57	122	225	119	225	144	342	319	542	244	331	2670

Table 9. You Tube Channel Analysis (YouTube analytics, https://www.youtube.com/channel/UCWBoKlQrVNn_cJsTSwGz0pA)

	Apr. 2019	May 2019	June 2019	July 2019	Aug. 2019	Sept. 2019	Oct. 2019	Nov. 2019	Dec. 2019	Jan. 2020	Feb. 2020	Total
Num. uploaded videos & podcasts	N/A	2	1	3	0	3	3	5	1	2	1	21
Impressions	N/A	45	267	618	1100	1300	1400	2400	1700	2500	2400	13485
Views	N/A	107	886	291	140	340	331	588	448	547	260	2962

The analysis shows that social media have been very active and generating the desired interactions with the SUNRISE community. The Twitter account, being the first social media to be active, has turned the main social media tool of the action with the major number of followers and interactions. Actually, these tools, together with the password-protected site in the website and newsletters (see following point) have proved to be the real interaction points with the SUNRISE community, substituting the initial idea of a discussion forum in the website.

Another interesting point is that posts with most engagement both on Twitter and Facebook are those related to SUNRISE events and news, rather than the external news that have been shared on a regular basis, meaning that SUNRISE's audience is interested in the project's updates and followers are committed to the initiative.

4.4. Newsletters

To establish a good communication with the action supporters, regular newsletters have been sent to the organization's contacts. A marketing management tool, such as Mailerlite or Mailchimp, has been used to centralize and manage the communication to a large number of contacts. In this way, the SUNRISE community members have been invited to participate in the SUNRISE organized events. The registration link, agenda and any logistic information has been shared though this channel. Furthermore, supporters have been invited to contribute to the definition of the PRDs, Vision and Roadmap through informative newsletters, providing them access to the working documents.

To further facilitate quick access to all SUNRISE stakeholders and keep growing the ecosystem around the project, a public newsletter has also been prepared to inform subscribers about the latest news and advances of the project. Mailchimp is used as the marketing platform, allowing recipients to unsubscribe at their will. The first public newsletter was submitted on July 2, 2019 to 585 subscribers and it obtained 34,70 % opens. The second public newsletter was submitted on October 7, 2019 to 614 subscribers (34,30% opens),the third one on January 14, 2020 to 654 subscribers (32,20% opens). The final newsletter at the beginning of March (March 9, 2020) included a one year's wrap-up andwas sent to 674 subscribers (35% opens).

4.5. Videos and podcasts

The project has produced a general video to socialize the initiative's objective. The video was released in June and had more than 1,324 views in the YouTube channel at the end of February 2020. A direct link is also available in the project website (home and resources section) and has been pinned in the other social media tools, having 1,200 views in the LinkedIn page (29 February). This main video has been translated to 5 languages (text and subtitles): French, Italian, German, Spanish and Polish.

Other videos include:

- Facebook live interviews: with the SUNRISE Deputy Coordinator, Hervé Bercegol (CEA) in occasion of the International Day of Light (1,600 views on Facebook Page, 31 views on YouTube channel), and with Antonín Vlček (45 views on Facebook Page, 39 views on YouTube channel).

- Promotional videos: SUNRISE Stakeholders Workshop (132 views YouTube channel, 326 views Twitter); SUNRISE Technological Roadmap (66 views YouTube channel, 602 views Twitter); SUNRISE stand at the COP25 (45 views YouTube channel, 1,100 views Twitter); and the SUNERGY kick-off meeting (35 views YouTube channel, 860 views Twitter).

- Interviews with experts: with Nicola Armaroli (213 views YouTube channel, 158 views LinkedIn page); with Hélène Lepaumier (247 views YouTube channel, 1,675 views LinkedIn page); with Huub de Groot (191 views YouTube channel, 123 views LinkedIn page); and with Katrin Mueller (78 views YouTube channel, 208 views LinkedIn page).

In addition, SUNRISE partners have been invited to radio interviews, podcasts of the last interviews to Victor de la Peña (IMDEA, in Spanish), Nicola Armaroli (CNR, in Italian) and Elisabet Romero and Julio Lloret (ICIQ, in Catalan and Spanish) are also available in the YouTube channel.

Other external videos related to the artificial photosynthesis are also posted on the project's website to attract the lay public's attention to the topic.

4.6. Templates and branding elements

Templates for word documents, letters, slides, etc., containing layout and styles used to create standardized documents have been designed to ensure a unified corporate image. The templates are available in the intranet PLAZA of the project's website.

In addition, a factsheet, a leaflet and roll-ups containing the project's logo, title, consortium members, social media channels and a call to action have been used through the action in consortium meetings, workshops, industrial fairs, congresses, etc. as branding materials.

4.7. Press releases and media presence

Four official press releases have been launched by the SUNRISE initiative:
Press release announcing the action (1 February 2019)
Press release about the SUNRISE Stakeholders Workshop (21 June 2019)
Joint press release with ENERGY-X about plans to merge the two initiatives (27 August 2019)
Joint press release with ENERGY-X about the SUNERGY Kick-off meeting (13 February 2020)

These press releases have been published in the partner's websites and translated to 10 languages: English, French, German, Dutch, Italian, Czech, Polish, Finnish, Swedish and Spanish. Press releases replications, links or SUNRISE mentions in the partners' websites, related institutions websites and external general media and specialized magazines and online portals have been collected in the deliverable D3.3.Dissemination and Communication Resources. Press releases have also contributed to get partners interviews, in online publications: Uppsala University website (Swedish), Chemistry World (English), Industriemedien (German publication available for Austrian subscribers, English version in the blog section of the webpage) and InnovaSpain (Spanish); and also on radio shows: RAC1 (Catalan), Radio Internacional (Spanish), RadioCittadelCapo (Italian), Radio 3 & Radio 5 (Spanish).

4.8. Outreach activities

SUNRISE partners have been encouraged to introduce the SUNRISE project in participatory events where they already contribute, *i.e.* open days, Pint of Science festival, European Researchers' Night, etc. Empa partner, Artur Braun, visited several Universities to present the SUNRISE project (University of Mersin, University of Taurus, University of Pretoria). He also hosted students from the Burg Giebichenstein Kunsthochschule Halle University of Art and Design interested in design needs for renewable energy technologies and SUNRISE project ones. While, other partners have an active role participating in educational events by their universities, for instance, Huub de Groot, from Leiden University, participated in the WND Noordwijkerhout, Conference 'energy in transition' for high school teachers (December 2018), Lunchlezing lectures during lunch for master students Chemistry and LST (March 2019) and the Leiden University Researchers' Night (September 2019).

In addition, SUNRISE has participated with five stands in big events:

- SUNRISE stand at the Big Challenge Science Festival

On June 16-19, researchers from SUNRISE partner NTNU held a stand at the Big Challenge Science Festival in Trondheim (Norway). Visitors, mostly children and teenagers, but also researchers and administrative staff from NTNU, could learn about artificial photosynthesis and the SUNRISE project. Researchers from the Koch group received visitors in an interactive stand where they could watch the official video, play with an online App showing how photosynthesis and artificial photosynthesis works and watch live experiments. One of the experiments showed how a toy car can run with hydrogen generated from a fuel cells and solar panels, while another one was performed by researchers coming from the Kargul group in U. Warsaw showing how solar cells made with algae pigments can harvest solar energy. In total, the stand counted with around 120 visitors.

- SUNRISE stand at the EU Sustainable Energy Week

On June 20, SUNRISE participated in the EU Sustainable Energy Week with a stand in the Networking Village. Visitors, around 25, mostly professionals from the industrial and policy sectors, could learn about the SUNRISE project through the vision of the SUNRISE official video and other branding materials such as the official leaflet. In addition, visitors could see and give their opinions about the SUNRISE App demo.

- SUNRISE stand at the Maker Faire in Barcelona

On October 5-6, the SUNRISE partner ICIQ held a stand in this faire that aims at joining researchers and practitioners from Universities, Research Centers and Socially Innovative Companies. SUNRISE was selected as an interesting project in the area of Circular Economy and Resilence and Creativity. Visitors of the stand, around 200, mainly families with young children and teenagers, could learn about the project using leaflets and infographics, as well as model cars and play with an online App showing how photosynthesis and artificial photosynthesis works.

- SUNRISE stand at the 13th SET-Plan Conference

On November 13-15, the SUNRISE partner EERA held a stand at the 13th SET-Plan Conference “R&I in the energy sector to enhance European industrial leadership”. This conference brought together high-level policy-makers, industry, research centers, international organisations and academia. Prime Minister of Finland Antti Rinne opened the conference together with European Commission’s representatives. The stand served to present the projects Energy-SHIFTS and SUNRISE, by the exhibition of the projects videos and roll-ups.

- SUNRISE stand at COP25

SUNRISE was selected as one of the projects with a booth in the last COP25 2019, the big event that finally took place in Madrid, 02-13 December 2019. The SUNRISE stand was settled for three days, from 5 to 7 December with the help of IMDEA Energy and ICIQ volunteers and received lots of visitants (800 estimated). The official SUNRISE video and interviews with experts’ videos were showcased, together with leaflets, posters, infographics, a gaming app and lots of live experiments to show water electrolysis, a fuel cell, a photoelectrocatalytic device, etc.

In addition to these big events, the project also planned and organized **interactive actions**: online events to celebrate International days, like an online interview with Hervé Bercegol, SUNRISE deputy coordinator, on the occasion of the International Day of Light, and a Twitter chat on occasion of the World Environment Day. The twitter online discussion was organized on occasion of the World Environment Day on June 5, 2019. The main objective of the chat was to discuss about the role of renewable energies in reducing air pollution. The one-hour online discussion started had four subject experts from various backgrounds related to the sustainable energy field (**Kate Black**, Communications Director at **Metabolic;** 2. **Julio Lloret**, Group Leader at the Institute of Chemical Research of Catalonia (**ICIQ**); 3. **Marcella Bonchio**, Full Professor of Advanced Organic Chemistry and Coordinator of the Nano & Molecular Catalysis Laboratory (NMC LAB), at the **University of Padova;** 4. **Philippe Schild**, Senior Expert of the Renewable Energy Unit of the Directorate General (DG) of Research & Innovation at the **European Commission).** Besides the four participants, other users took part in the conversation by sharing their views on the different tweeted questions. A wrap-up of the session can be found on the website blog (https://buff.ly/2MynWfC).

Other interactive actions include the organization of contests. A good opportunity for interaction has been choosing a new name and logo for the new initiative resulting from joining SUNRISE and ENERGY-X. A public contest was organized for choosing the new name: SUNERGY. In addition, the two initiatives also organised the SUNERGY photo contest. Applicants sent a free style picture together with an abstract to explain their research. The pictures were voted through the new SUNERGY Instagram account and a panel by SUNERGY members chose the winner from the most voted three entries. The winner was awarded to attend the SUNERGY Kick-off (incl. travel costs), to present his research in front of both communities.

5. BASIS FOR THE EDUCATION PLAN

The outreach activities developed during the action are the basis for the future education plan to be fully developed within a large-scale initiative. Some of the included activities have an educational character and analysis of these activities and their future application will constitute the skeleton of the future plan, actions of interest might include:

- **Young researchers travel grants**: providing opportunities to young researchers to attend dissemination events to present their results and interact with the scientific community is of great value for their formation. Therefore, calls for travel grants should be included in the Education plan. Moreover, in a future large-scale project, ***specialized workshops*** should be organized devoted to new technological advances and other subjects such as innovation, economic and life cycle analysis, gender issues, legal concepts, etc. Special ***workshops for young students*** should also be taken into account and even ***summer stages*** for undergraduates and high school students could be a good option.

- **Leaflets and infographics**: these are also relevant materials that can contribute to educational aims. Extension to broader subjects and technical leaflets could also be part of the Education plan.

- **Interactive Contests**: interactive actions with the participation of students might encourage their engagement in the project and knowledge sharing. This has been explored with the SUNERGY photo contest, to bring the initiative closer to young researchers, keeping these kind of actions is also of interest.

- **Visits to schools and Universities**: strategy for having project's representatives participating in schools and universities' events to present the large-scale initiative goals and participation opportunities. This might have a large impact towards the engagement of young students and is an option to be explored in the future plan for a large initiative.

The major goal of a future education plan will be to identify the training needs for the new technologies to be developed within a big research and innovation project and develop a myriad of actions to cover them. This identification will need to be run together with specialized academic institutions (*i.e.* LERU – League European Research Universities and EUA – European Universities Association are SUNRISE supporters) and industrial associations (EMIRI is a partner). Therefore, complementary actions, like organisation and participation in Erasmus+ programmes and other related ones, should also be explored.

6. ALIGNMENT WITH THE DMP

The SUNRISE action dissemination, communication and education actions have been developed in line with the data strategy and procedures described in the D3.4 Data Management Plan (DMP). Specifically, these are the main following points that have been taken into account:

- Data storage and security: the main storage tool is the Project website, including the main internal information exchange tool, the intranet PLAZA (managed by M2i). All the dissemination and communication material must be available on the SUNRISE website and ZENODO repository.

- Data access, sharing and reuse: all data related to personal information, mainly person contact names from partners and supporters and e-mail addresses, is kept under the password protected intranet site. Personal data collected has been kept under a minimum, following GDPR rules, including user consent and information access, especially relevant for subscription to newsletters, using a marketing platform (Mailchimp).

- Data preservation and archiving: the SUNRISE public website will be maintained for at least 3 years after the project start. Dissemination and communication materials will also be uploaded to public repositories, *i.e.* ZENODO, for preservation and for sharing and reuse.

Solar Energy for a Circular Economy

Deliverable D3.2
Project website, App and social media tools

WP3. Dissemination, Communication and Education

Lead Beneficiary ICIQ – Institute of Chemical Research of Catalonia
Delivery date 31 May 2019
Dissemination level Public
Version v0.4

This Project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 816336

Document Information

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Authors	Amelia Ochoa, Laura López, Tobias Gärtner
Deliverable number	D3.2
Deliverable name	Project website, App and social media tools
WP	3. Dissemination, Communication and Education

Version	Date	Author	Description
v 0.1	02 May 2019	Amelia Ochoa, Laura López	Writing first draft
v 0.2	03 May 2019	Tobias Gärtner	Revision and additions
v 0.3	09 May 2019	Amelia Ochoa, Laura López	Revision after management team approval
V 0.4	29 May 2019	Robert Potter, Amelia Ochoa, Laura López	Final revision after Quality and Impact Assurance Team approval

EXECUTIVE SUMMARY

The report Deliverable D3.2 describes the website created for external and internal communication. It delineates the motivation behind the concept of the website and names the parties responsible for the website and benefiting from it. The document firstly describes the content of the public section, highlighting the ideas and objectives behind it. Then, it shows the private section designed for the exchange of information between partners. The report also defines the social media tools used and the development of a new smartphone application focused on the sharing of scientific and technological information. The final aim of the document is to define the expected impact of these communication tools for the project consortium and the whole community.

TABLE OF CONTENTS

1. INTRODUCTION

Within HORIZON 2020 SUNRISE coordination and support action (CSA), a work package on Dissemination, Communication and Education (WP3) has been considered in order to carry out the internal and external activities related to the project in these areas. The main objectives of WP3, as described in the Grant Agreement, are to create consciousness of the project, stimulate dissemination of the project actions, organize dissemination activities and contribute to the creation and growing of a SUNRISE community. In order to meet these objectives, the available existing communication tools will be used, and a series of activities organized.

Deliverable D3.2 “Project website, App and social media tools” describes the key points of design, execution, content, usage, and communication strategy behind the internet platform of the SUNRISE large-scale research initiative.

The URL of the website is www.sunriseaction.eu and it has been online since September 20th, 2018. The website was first hosted and maintained by partner Université Catholique de Louvain, managed by Dr. Carina Faber until the beginning of May, 2019. The website was reworked, hosted and maintained from 6th of May, 2019, by partner Institute of Chemical Research of Catalonia (ICIQ) and it will be weekly updated with the latest novelties. The social media accounts of SUNRISE were created between December 2018 and March 2019 on four platforms: Twitter (December 2018), Facebook (March 2019), LinkedIn (March 2019), and ResearchGate (February 2019). Both the website and social media networks constitute key communication tools to increase project visibility and impact towards industrial communities, researchers, policymakers, advocacy groups and general public. They are also key tools for sharing information between all SUNRISE partners. Additionally to already existing digital platforms, a smartphone App is currently under development for sharing scientific as well as technological contents among the SUNRISE community. The App is based on a system actually used in sports and news broadcasting and will be adapted to the needs of SUNRISE.

2. INTERESTED PARTIES

Deliverable D3.2 is the responsibility of ICIQ as a part of the Work Package 3. The final version of the website was developed by an external company hired by ICIQ, Avellana digital, and shared with all consortium members for improvement before publication.

The role of both the website and social media networks is to provide information concerning the project to a very broad community. The following target groups have been identified:

The general scientific community and R&D industrial departments, − the European Commission, − journalists, general public and stakeholders, − companies in Energy, Oil&gas, Chemistry and Materials sectors (among others), − Venture Capital, − other private or public organizations.

The main objective of the website and social media networks is to successfully disseminate the activities and documents generated from all Work Packages during the lifetime of the initiative. Therefore, all partners are engaged with the website. In particular:

1) all consortium members are responsible for regularly contributing to the contents of the website;

2) consortium members are asked to share all the documents necessary for the project with the whole consortium via the Intranet (PLAZA);

3) consortium members are engaged to support the SUNRISE website by disseminating it through their own websites/social media.

3. COMMUNICATION TOOLS DEVELOPMENT AND DESCRIPTION

3.1. Website

SUNRISE website is accessible at: www.sunriseaction.eu and www.sunriseaction.com.

The platform has been created to serve as a project content management system on two levels: (1) external communication and dissemination of the project objectives and results, and (2) Internal Communication Platform within the consortium.

The SUNRISE public website was developed to act as an information hub about the project's aims, goals, activities and results. The website works as a prime public dissemination tool making available the project published results. The public section provides the following content:

a) general information about the project, including initiative description and vision
b) recent news about the project
c) description of events organized within the framework of the project
d) description of consortium members taking part in the project
e) support materials and public deliverables
f) press releases
g) contact information and e-mail address (contact@sunriseaction.eu)
h) supporters logos and community contributions
i) blog
j) links to social media
k) appropriate acknowledgment and reference to the European Union's Horizon 2020 Framework Programme

The first SUNRISE website was designed to inform about the project and attract the attention of viewers to the content of the website and act as a repository of the different news, calls and events related to the initiative (Figure 1). Information about the project has been continuously generated and updated, maintained and adapted to the new designed web.

Figure 1. Landing page of SUNRISE first website

In the new designed web, reshaped once the project was approved, the landing page is designed to attract the attention of viewers by exposing the project logo and banner, listing the content of the website (Figure 2).

All sections of the website have on top the SUNRISE logo and the menu bar enabling quick orientation through the search. All sections also provide addressing and contact information, reference to Horizon 2020 and European Commission (EC) support and a disclaimer excluding EC responsibility (once the project was approved).

The General info page presents the project at a glance, describes its objectives and highlights news and events.

Figure 2. Landing page

The About us section provides information about the SUNRISE initiative (Figure 3.1), the large-scale project's vision (Figure 3.2), and a list of all partner institutions taking part in the project (Figure 3.3), linking to their short descriptions. Every partner will be briefly described in terms of research quality, groups participating in SUNRISE and people responsible for the project.

Figure 3.1. SUNRISE initiative page

Figure 3.2. SUNRISE's vision page

Figure 3.3. Consortium page

The Newsroom section provides the current information about advances in the field, recent meetings, and public deliverables in the form of News (Figure 4.1). It also offers information about related events (Figure 4.2), opportunities (Figure 4.3), and useful resources, such as publications, videos, and infographics. Besides, it links the most important new content from the blog section.

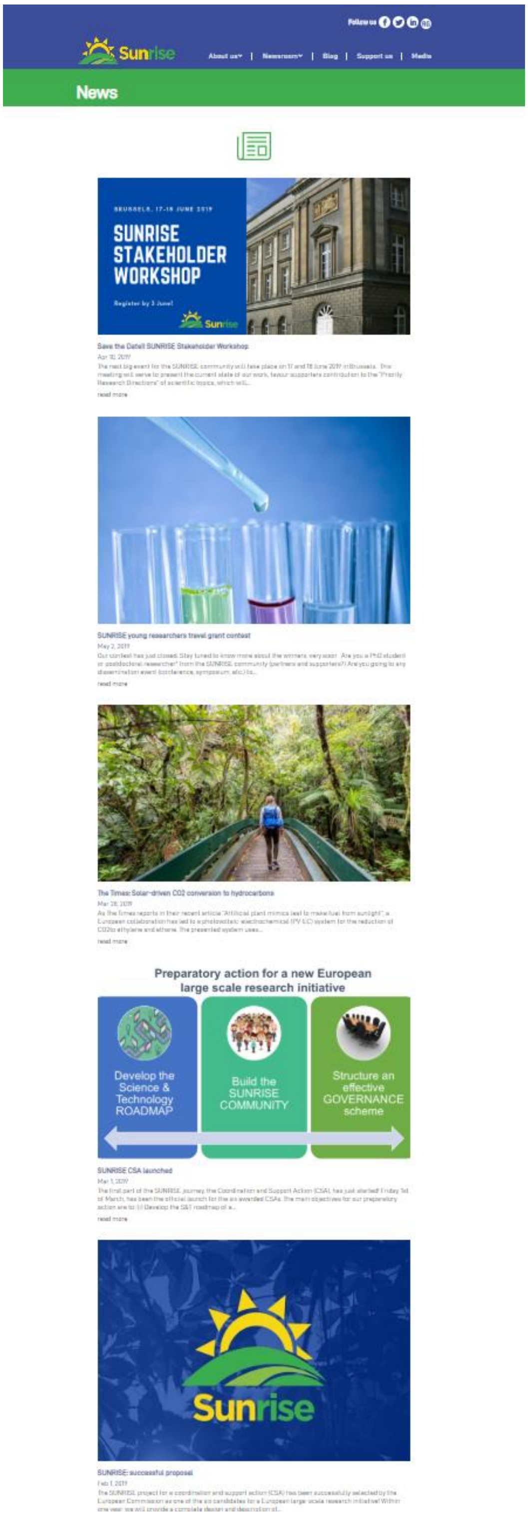

Figure 4.1. News page

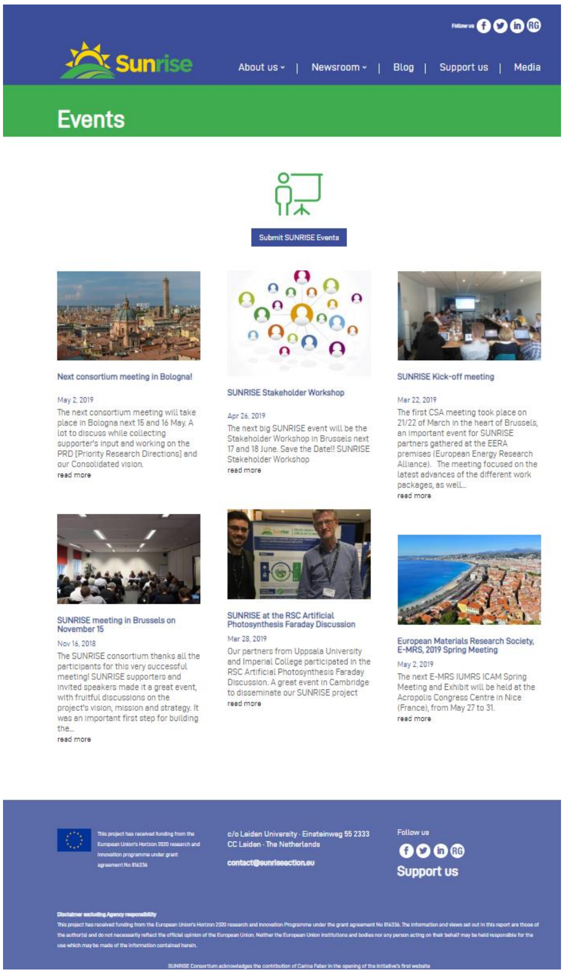

Figure 4.2. Events page

Figure 4.3. Opportunities page

The Blog page will include a live blog developed by a communication company, [Tickaroo](), where supporters and followers will be invited to send their news and stories. It is intended to be an interactive part of the web where experts could also answer common questions.

The "Support us" page (Figure 5) is a call dedicated to research community industry sector, policymakers, and advocacy groups including citizens and students, as well as NGOs and associations dedicated to sustainable and renewable technologies and solar conversion applications who might be interested in being supporters of the initiative. It also displays a banner with all the current supporters, which will be regularly updated when new support letters are received.
This page will also serve as an interaction site where followers and supporters could reach the consortium with their ideas. For this contact form, as well as for the subscription to the public newsletter, a GDPR (General Data Protection Regulation) compliance form will display.

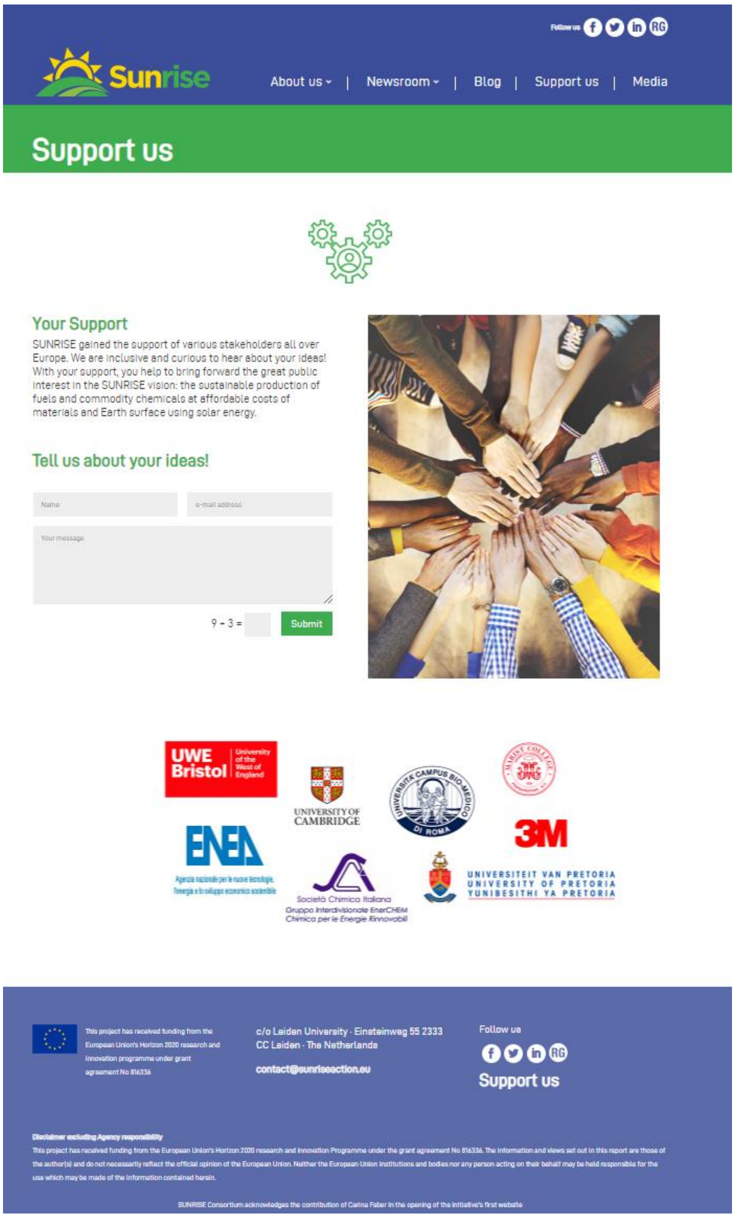

Figure 5. Support us

The Media section (Figure 6) records all the materials published about SUNRISE project. These include both press releases from SUNRISE in the media, and news from partners.

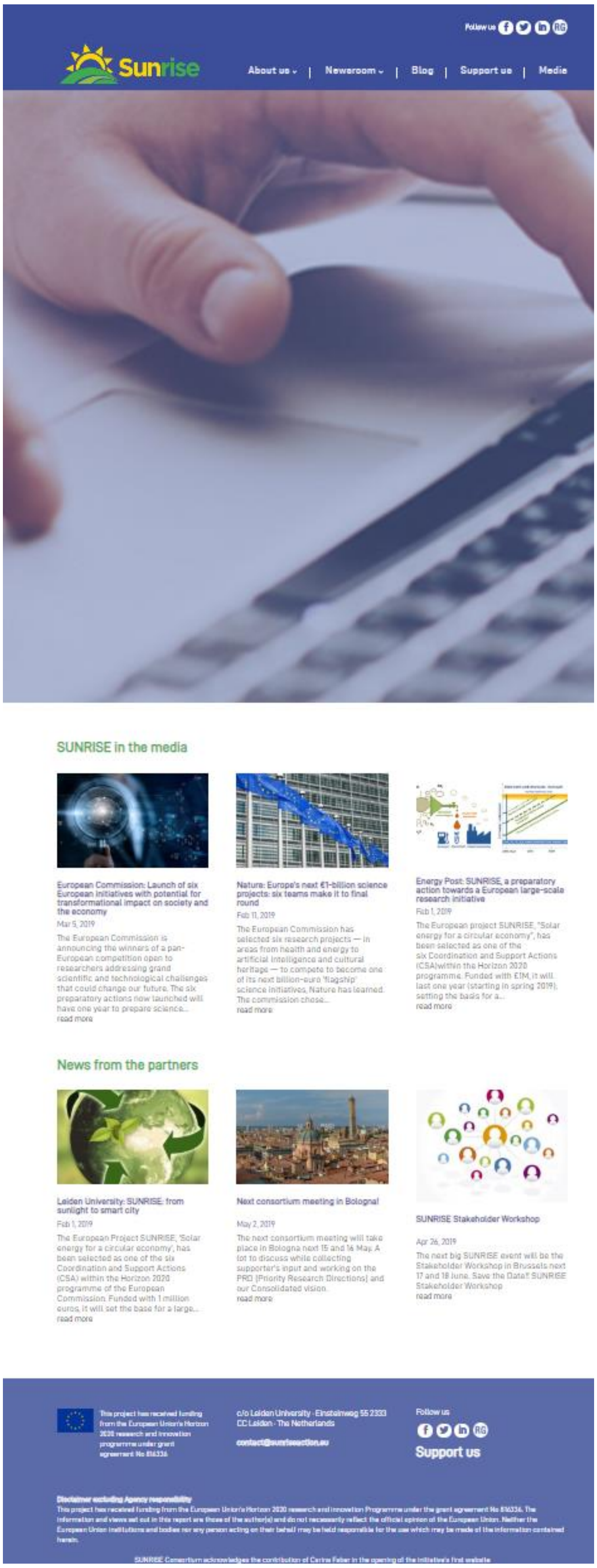

Figure 6. Media page

Finally, the consortium has an intranet page to share all the relevant information among all partners. The intranet used, PLAZA, has been developed by M2I (Materials Innovation Institute), the organization in charge of SUNRISE project's management, within the management team. This is an internal tool they have developed to share information with partners in their multiple projects.

A direct link to the intranet is found in the home page, with restricted access to validated users (Fig 7). Partners can find all the information relevant to the development of the project organized in different folders (Fig 8).

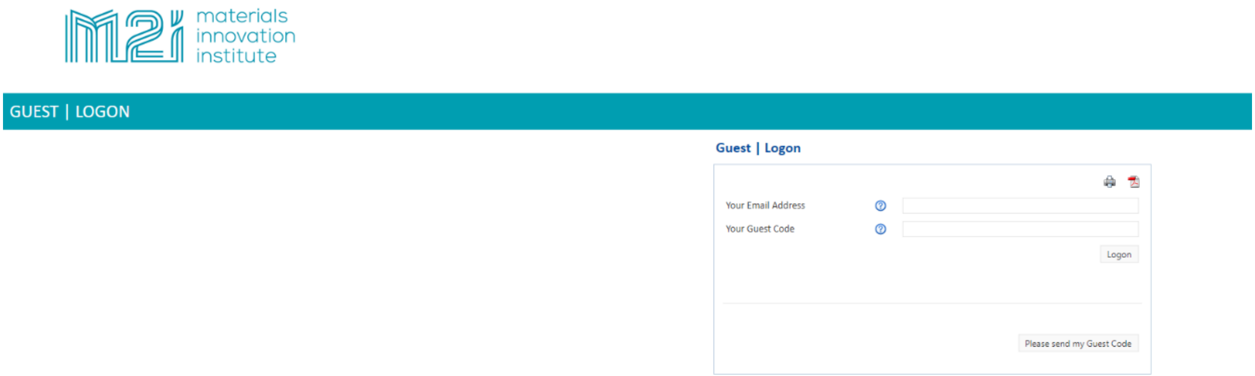

Figure 7. Logon on the PLAZA system

Figure 8. Files distribution for SUNRISE project within the PLAZA system

3.2. Social media networks

The four SUNRISE social and professional media networks aim at spreading and disseminating the latest information about advances in the field, recent meetings, and public deliverables. They also offer information about related events, opportunities, and useful resources, such as publications, videos, and infographics. Besides, they serve as means of communication with the general audience, as they can contact SUNRISE team via the four different channels.

Facebook page

It serves to promote the initiative's actions. It has a more formal tone and emphasizes SUNRISE news. It also promotes other external related items (Figure 9).

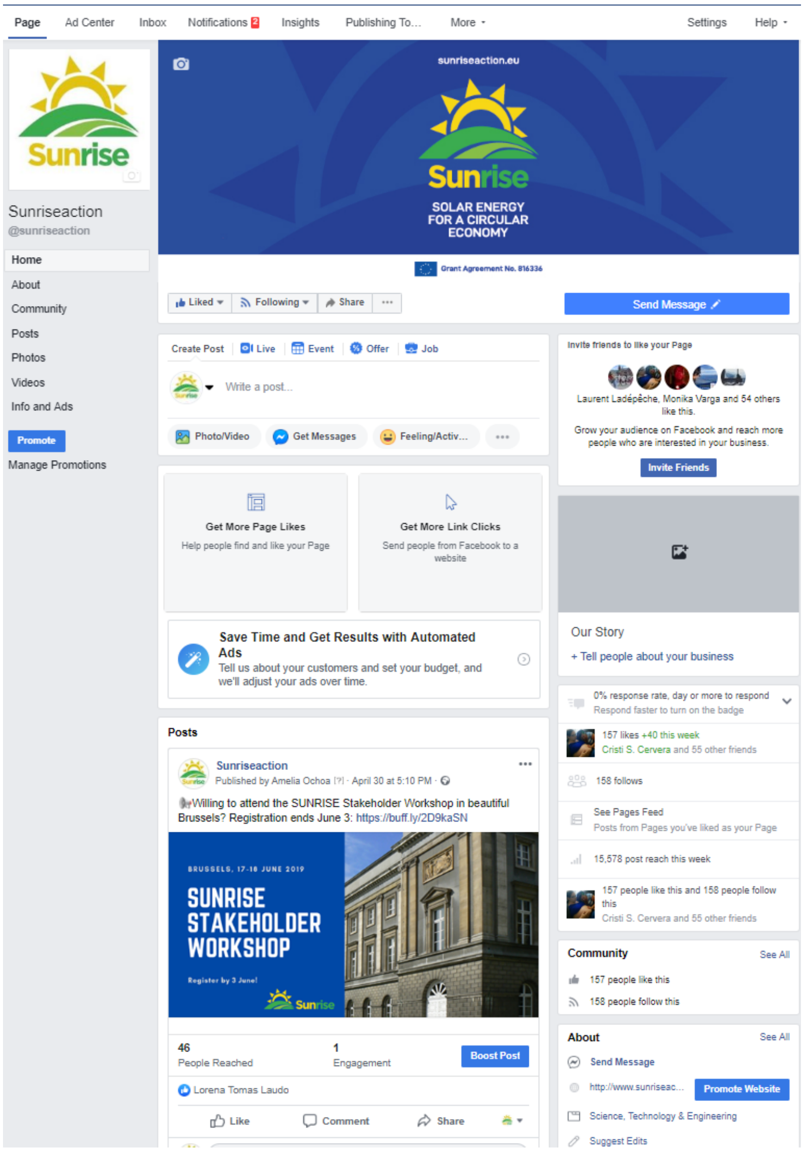

Figure 9. Facebook page

Twitter page

It serves to boost the project's visibility among the general audience, researchers, companies and partners, massively, and interact with them (Figure 10).

Figure 10. Twitter page

LinkedIn page

It serves to promote the initiative among a specialized community. It emphasizes SUNRISE news and events, as well as other relevant items (Figure 11).

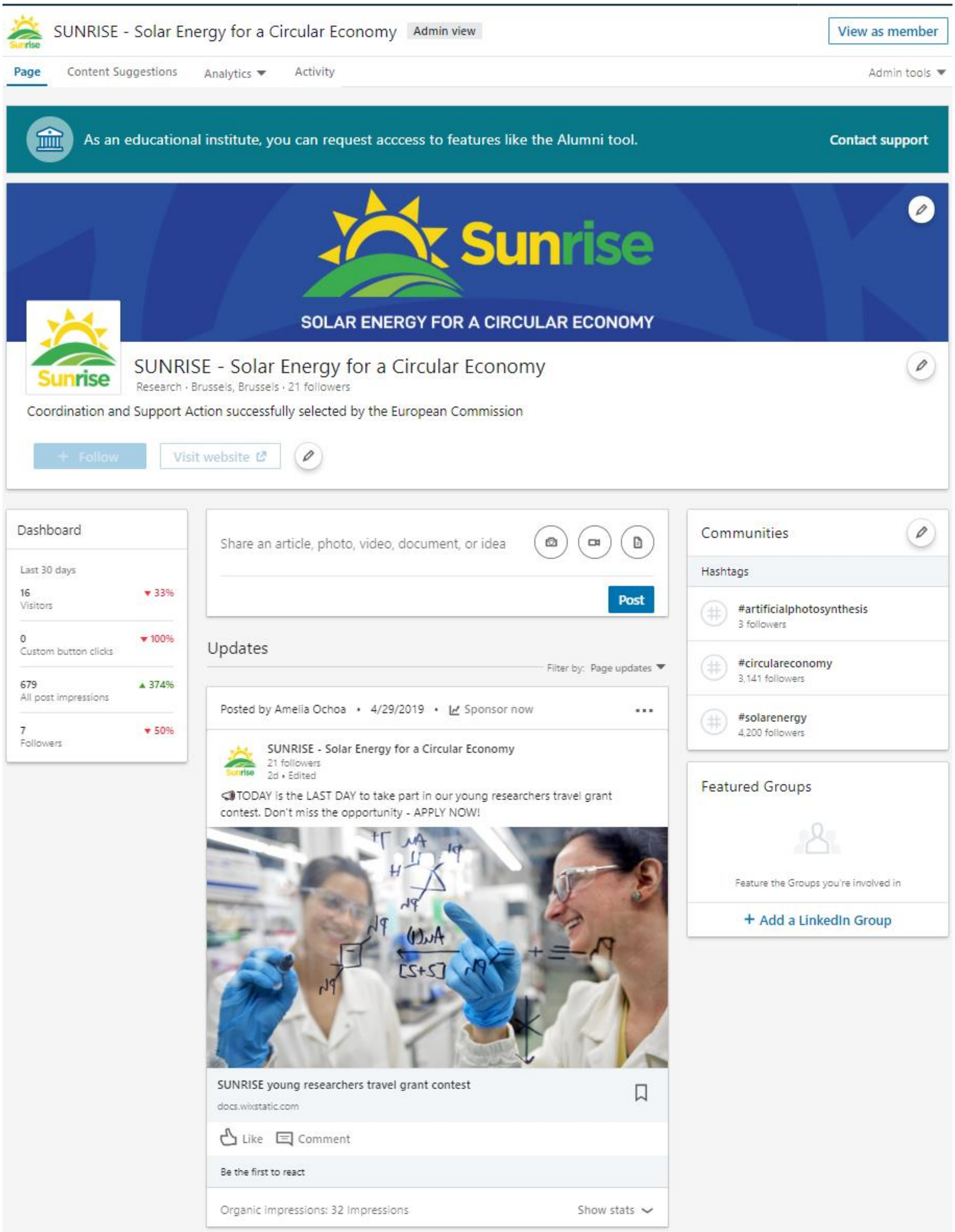

Figure 11. LinkedIn page

ResearchGate page

It serves to boost the project's visibility among the scientific community. It emphasizes both SUNRISE news, and scientific papers related to the field (Figure 12).

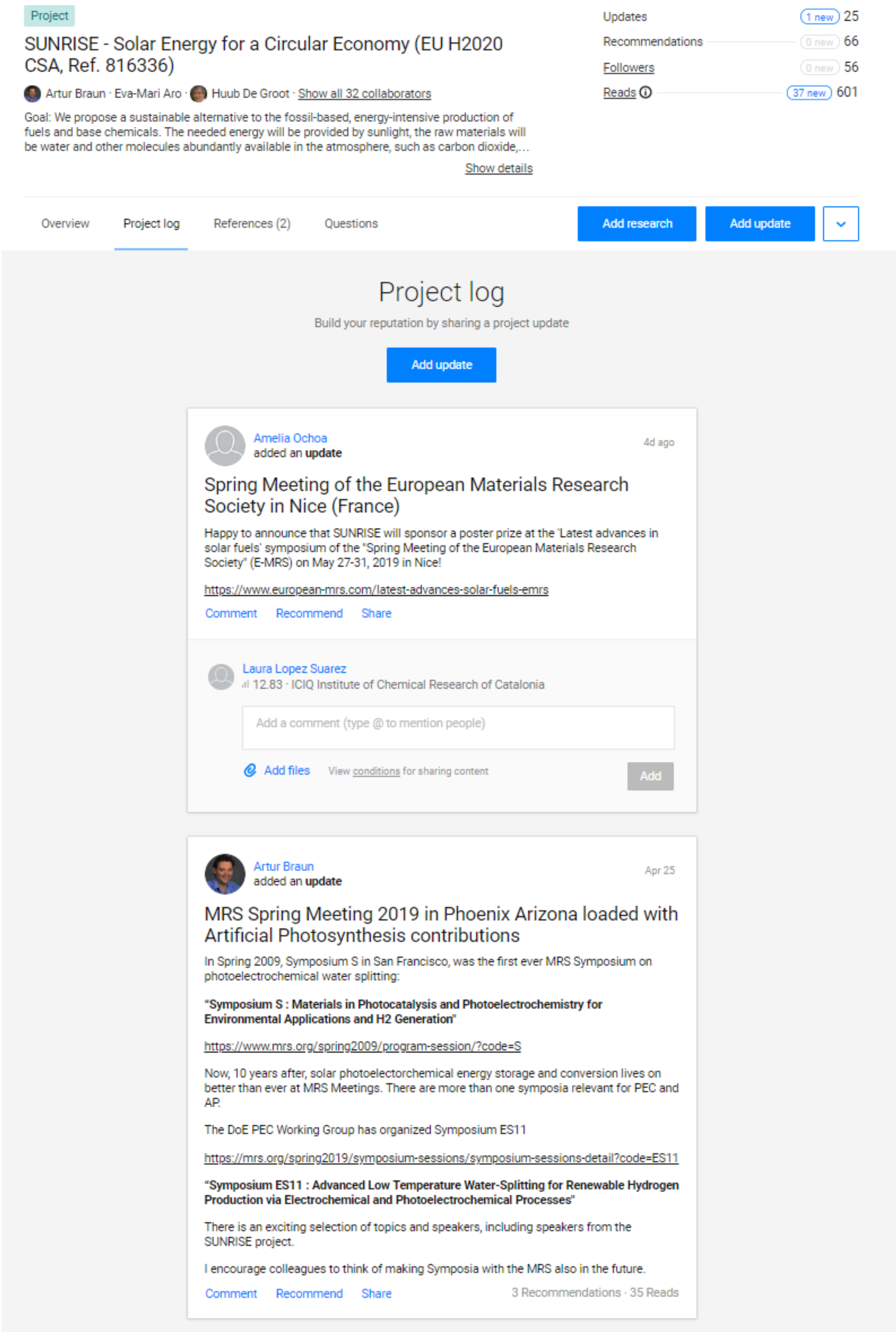

Figure 12. ResearchGate page

3.3. App

Fraunhofer is in charge of developing a new concept of application for smartphones devoted to the sharing of scientific information. The development is being done in cooperation with Tickaroo, a third partner. The key feature of the App will be the delivery of scientific and technological content in relationship to SUNRISE. Therefore, it will be possible to get access to cross-technological information, which boosts the SUNRISE developments as distribution pathways will be shortened. Qualified persons throughout all areas of science and engineering as well as economy will act as authors at the "author-end" of the SUNRISE App, while the whole SUNRISE-community acts at the "recipient-end", therefore involving the overlap of the two groups.

This will provide the highest level of scientific openness required to ensure high-quality decisions as well as advice to the governance structure for impact-oriented actions in the large-scale initiative stage, including the avoidance of efforts being duplicated and the mitigation of intrinsic risks, for example risk of market failure.

At a first stage, the app will be internally designed and used within the consortium. Continuous user input will be collected to improve its performance, so at the end of the CSA a robust interface, useful for the scientific and industrial community will be developed. A first demonstrator will be ready to be presented during the European Sustainable Energy Week. The SUNRISE consortium will be present at the Networking Village, with a stand where visitors could contribute to its development answering a short survey about how to improve the application and involvement of different sectors in the project. In Figures 13-15 the live blog system by Tickaroo is described visually.

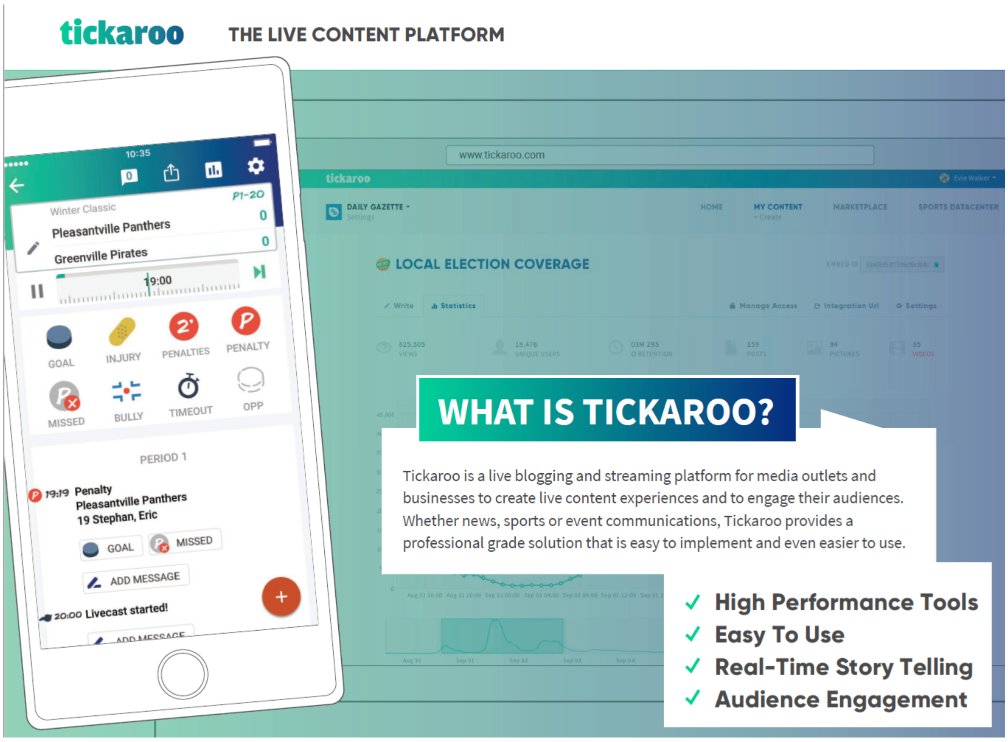

Figure 13: The company tickaroo is providing the live content platform.

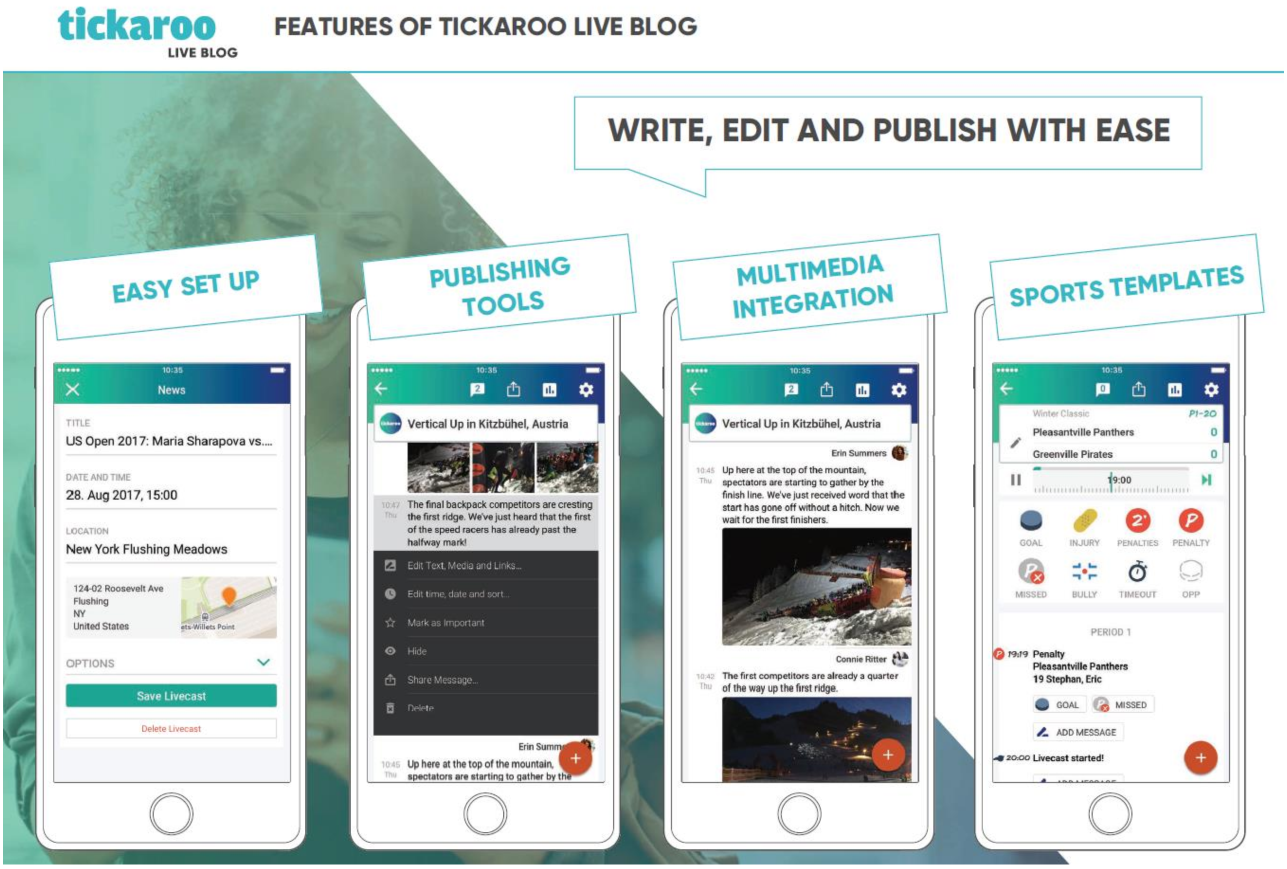

Figure 14: Features of the tickaroo live blog system.

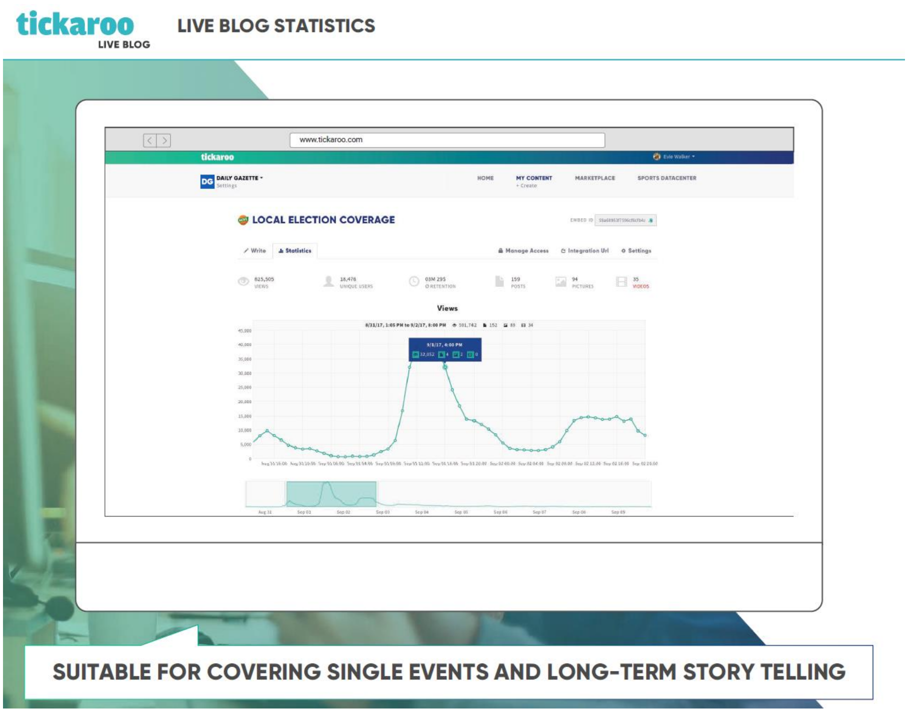

Figure 15: tickaroo offers the possibility to follow live blog statistics.

4. IMPACT & CONCLUSIONS

SUNRISE website is the main online tool to present and disseminate all the results and events under the framework of the project. It will be regularly updated by ICIQ in coordination with the management team in order to provide the latest news, relevant results and breakthroughs. It will remain available after the end of the CSA. Both the website and social media networks are carefully designed to address the identified target groups in the most effective way, and it is the easiest way to ensure the visibility of the project for the EU as well as target audiences, consortium, stakeholders and general public. The expected outcome using an online communication strategy includes a large number of stakeholders being more aware of ideas and technologies for efficiently using and storing solar energy in the form of fuels and commodity chemicals. The SUNRISE website was designed as an interactive tool for public information and communication among partners and stakeholders. It will also be a repository for communication and training materials, deliverables and a work area for the project participants to share information between each other. It can be continuously improved and updated, in order to maximize the results and share the results with target audiences.

Regarding SUNRISE social media channels, they were also designed as appealing tools for public information and interaction with the different partners and stakeholders. They will also work as hooks to promote and give visibility to the project. They can be continuously improved and updated, in order to increase SUNRISE community and engagement.

Finally, the new App to be developed during the CSA will be a new concept for intersectoral scientific information exchange, contributing to the "Open Access" strategy.

Solar Energy for a Circular Economy

Deliverable D3.3
Dissemination and communication resources

WP3. Dissemination, Communication and Education

Lead Beneficiary UW
Delivery date 28 /04/2020
Dissemination level Public
Version v3.0

This Project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 816336

Document Information

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Authors	UW
Deliverable number	3.3
Deliverable name	Dissemination and communication resources
WP	3 – Dissemination, Communication and Education

Version	Date	Author	Description
v 0.1	18/11/2019	Amelia Ochoa, Laura López	Creation first draft
v 0.2	20/11/2019	Joanna Kargul	Revision, additions and final edits
v 0.3	21/11/2019	Amelia Ochoa, Laura López	Final additions
v 1.0	22/11/2019	Joanna Kargul	Final revision
v2.0	02/12/2019	Carina Faber, Hervé Bercegol, Laura López	Final edits
v2.1	20/02/2020	Amelia Ochoa, Laura López	Updates of the document including the last materials.
v2.2	18/03/2020	Laura López	Final additions
v2.3	19/03/2020	Joanna Kargul	Final revision
v3.0	21/04/2020	Laura Lopez	Update media

EXECUTIVE SUMMARY

The report on Deliverable D3.3 describes the dissemination, communication and education promotional and training resources and materials generated up to date. The document firstly describes the promotional materials including mugs, slides templates, posters, roll-ups, factsheets, leaflets, infographics, promotional videos, podcasts, and newsletters that have been released throughout the past months. Then, it describes the different press releases that have been published so far. Finally, it includes the agenda of the SUNRISE Stakeholder Workshop and SUNERGY kick-off event and the list of participants who attended these milestone events. The document will be updated at the end of the Coordination and Support Action (CSA) with the final materials.

So far, the CSA has reached a large number of supporters and followers, especially within the scientific community, both from academic and industrial sectors. The main dissemination and communication tools planned have all been deployed with a strong commitment and involvement of the consortium partners. The current supporting community has been very active. However, further reaching of the general public and policy makers remains as one of the main ongoing challenges.

The release of promotional and training resources – particularly, supporting audiovisual materials, such as videos, infographics, slides, etc. – as well as the organization of the SUNRISE Stakeholder face-to-face workshop have all been crucial to fulfill the conditions required for the success of the dissemination and communication strategy, complying with three conditions: (1) Continuous operation of communication tools; (2) Up to date and adapted content to address the different target audiences; and (3) Active engagement at the European and member states level.

The upcoming merging of SUNRISE and ENERGY-X initiatives will provide a great opportunity to reach a much larger community. Consequently, the merger will involve changes in the dissemination and communication actions as the new image and brand position are being established. Moreover, the future goals for the newly established joint large-scale research initiative will have to be agreed by both CSA consortia.

Table of Contents

1. PURPOSE OF THE SUNRISE PROMOTIONAL MATERIALS

Following the Dissemination and Communication plan, firstly drafted at the proposal stage and updated through the development of the CSA, see D3.1, several promotional materials have been produced to facilitate the targeted dissemination, communication and education goals.

The promotional materials include templates for the presentation of the initiative and its outcomes: slides, posters as well as flyers, infographics, newsletters and videos. In addition, a list of press clippings, including replication of press releases and media interviews to project partners is also included, as well as the public agenda and registration list of both the SUNRISE Stakeholders Workshop organised in Brussels in June 2019 as one of the EUSEW (European Sustainable Energy Week) Energy Days and the SUNERGY kick-off event jointly organised with ENERGY-X as the closing event for both CSA initiatives.

2. LIST OF DISSEMINATION AND COMMUNICATION MATERIALS

2.1. Mugs

At the beginning of the CSA, SUNRISE mugs were generated as promotional material. The mugs have been shared among partners and speakers at SUNRISE meetings and other gatherings attended by SUNRISE members. Besides, some SUNRISE mugs have been used as “prizes” for contributors in SUNRISE fair stands and contests, they were sent to participants that voted in the second leg of the poll for the SUNRISE logo and were given away to participants answering a survey about the SUNRISE App at the EUSEW stand (see Fig. 1).

Figure 1. SUNRISE mugs.

2.2. Slides Templates

SUNRISE partners have been very engaged and active introducing the initiative at the numerous conferences, workshops and meetings in which they have participated. To this end, a series of standard slides for presentations were created including a general presentation layout and blank slides. For events at which only one slide or very few ones could be shown, a one-slide summary or a three-slide presentation were also made available to the consortium partners in order to get a snapshot of SUNRISE initiative. These are accessible for SUNRISE partners from the PLAZA intranet created for the project partners (see Figs 2-4).

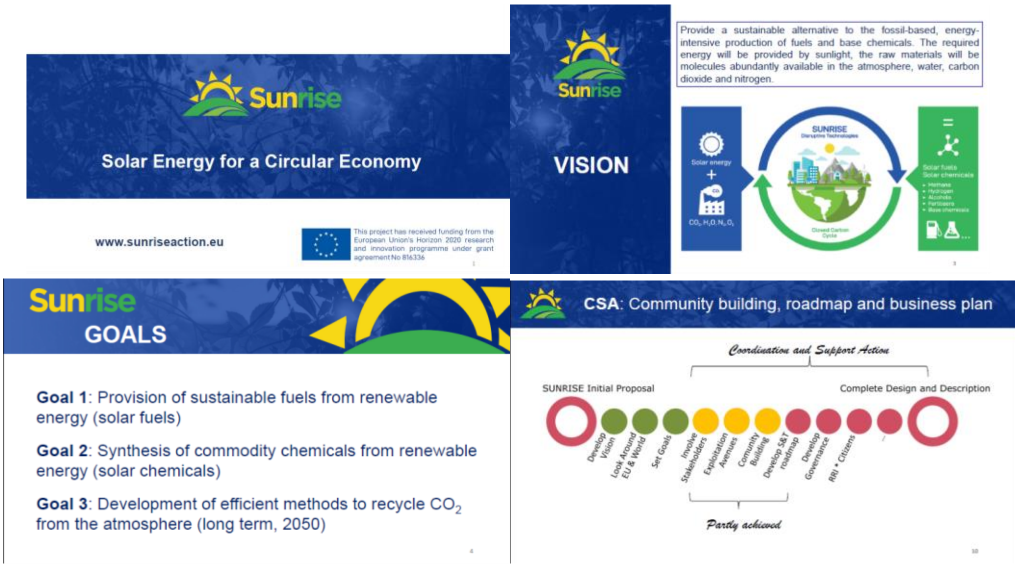


Figure 2. Examples of slide templates

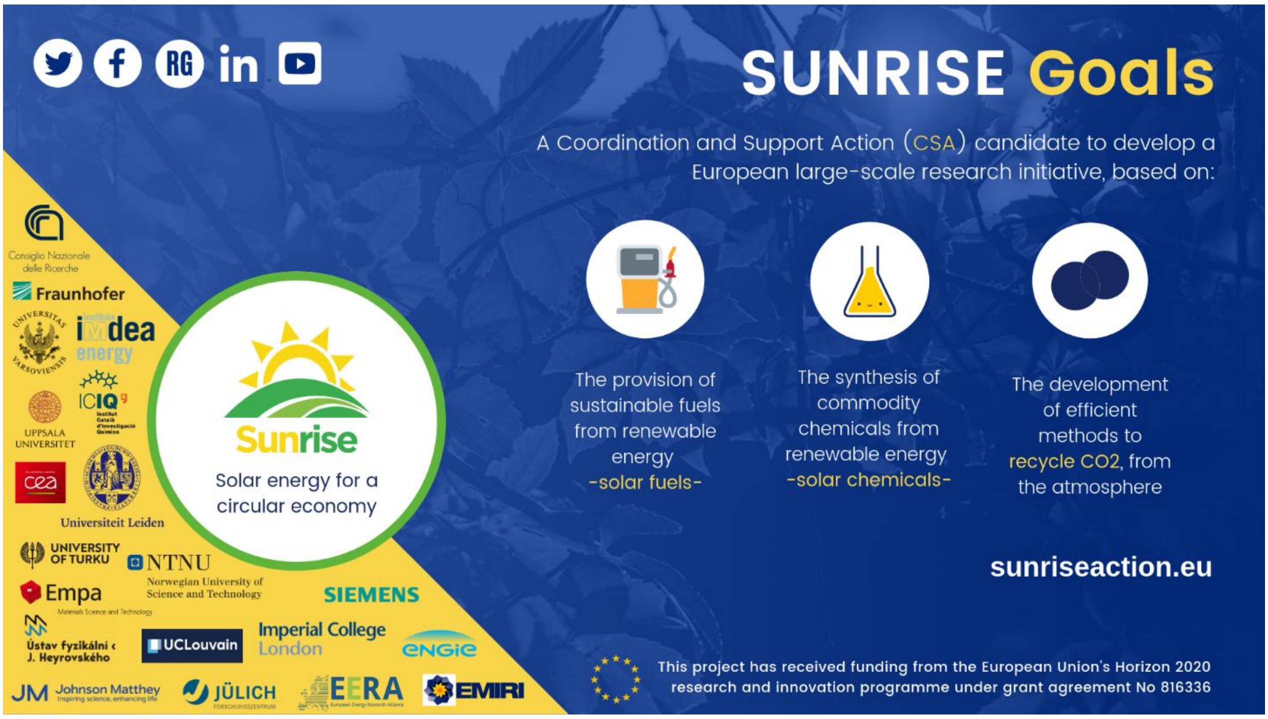


Figure 3. General summary one-slide template

Figure 4. General summary three-slide template

2.3. Posters

A poster titled 'SUNRISE: Solar energy for a circular economy' was created to showcase the project at various events (see Fig. 5). It is also available to all the partners from the PLAZA intranet of the project's website. Notably, the SUNRISE poster won the 'Best Poster Award' at the 17th International Conference on Carbon Dioxide Utilization (ICCDU), which took place on June 23 – 27 2019, in Aachen, Germany (https://sunriseaction.com/sunrise-poster-wins-best-poster-award-iccdu/).

Figure 5. SUNRISE poster awarded at ICCDU, 2019.

The poster has been presented at different events, *e.g. RSC Artificial Photosynthesis Faraday Discussion*, Cambridge, 25-28 March 2019 (https://sunriseaction.com/event/rsc-artificial-photosynthesis-faraday-discussion/), *SUNRISE POLAND Stakeholder Workshop*, Warsaw, 5-6 June 2019 (http://sunrisepoland.cent.uw.edu.pl/) and *Bringing value to* CO_2, Madrid, October 2-3, 2019 (https://sunriseaction.com/event/aportando-valor-al-co2/). Pictures below:

Figure 6. Pictures of SUNRISE poster exhibited at the *RSC Artificial Photosynthesis Faraday Discussion* and at *Bringing value to CO_2,* respectively

2.4. Roll-ups

Two different roll-ups were designed to be used at the consortium meetings, workshops, industrial fairs, congresses, etc. as branding materials. While the main one contains the project's logo, title, consortium members, social media channels and a call to action, the second one explains the artificial photosynthesis process and it has been designed to be displayed at fairs and outreach events. These are also available at the PLAZA intranet. See pictures below:

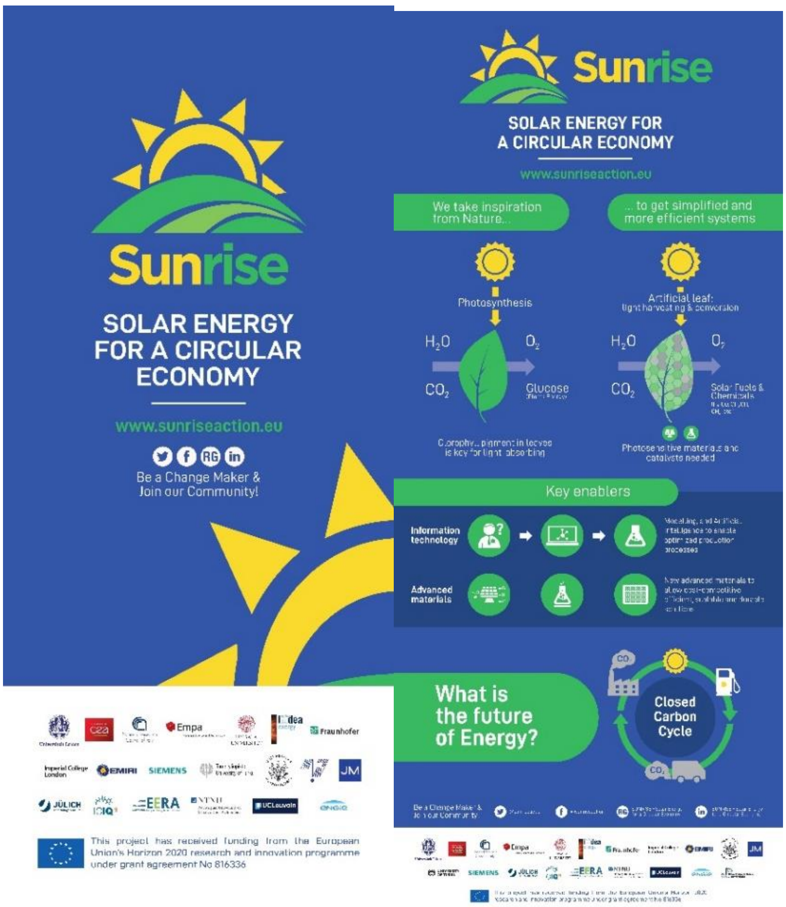


Figure 7. SUNRISE roll-ups.

Both roll-ups have been used at all the different SUNRISE national stakeholder workshops, as well as at the initiative's consortium meetings, fairs, and other gatherings attended by SUNRISE members, *e.g.* during a visit of the SUNRISE consortium partner Artur Braun (Empa) at the University of Pretoria (https://sunriseaction.com/sunrise-on-the-road-towards-circular-secular-economy-south-africa/). Example pictures are included below:

Figure 8. Pictures of SUNRISE roll-ups at the Big Challenge Science Festival in Trondheim, and at the SUNRISE consortium meeting in May 2019 in Bologna (Italy), respectively

Figure 9. Pictures of SUNRISE roll-up at the Stakeholder Workshop in Brussels, and at the University of Pretoria, respectively

The second roll-up that explains the artificial photosynthesis process was also used in a poster format at the COP25 on December 5-7, 2019. See the picture below:

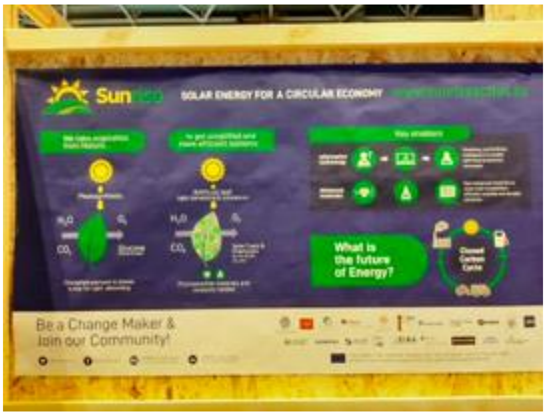


Figure 10. SUNRISE roll-up in poster format at the COP25.

Besides these roll-ups, two beach flags were also developed for the SUNRISE Stakeholder Workshop, held in June 2019 in Brussels, to indicate the venue direction to the participants.

Figure 11. One of the two SUNRISE beach flags at the venue entrance of the Stakeholder Workshop

2.5. Factsheet, leaflet and infographics

A factsheet and a leaflet containing the project's logo, title, consortium members, social media channels and a call to action were developed to be used at the consortium meetings, workshops, industrial fairs, congresses, etc. as branding materials. They are also available on the SUNRISE website (https://sunriseaction.com/resources/) and in the PLAZA intranet to be downloaded and printed by the partners. See pictures below:

Figure 12. SUNRISE leaflet

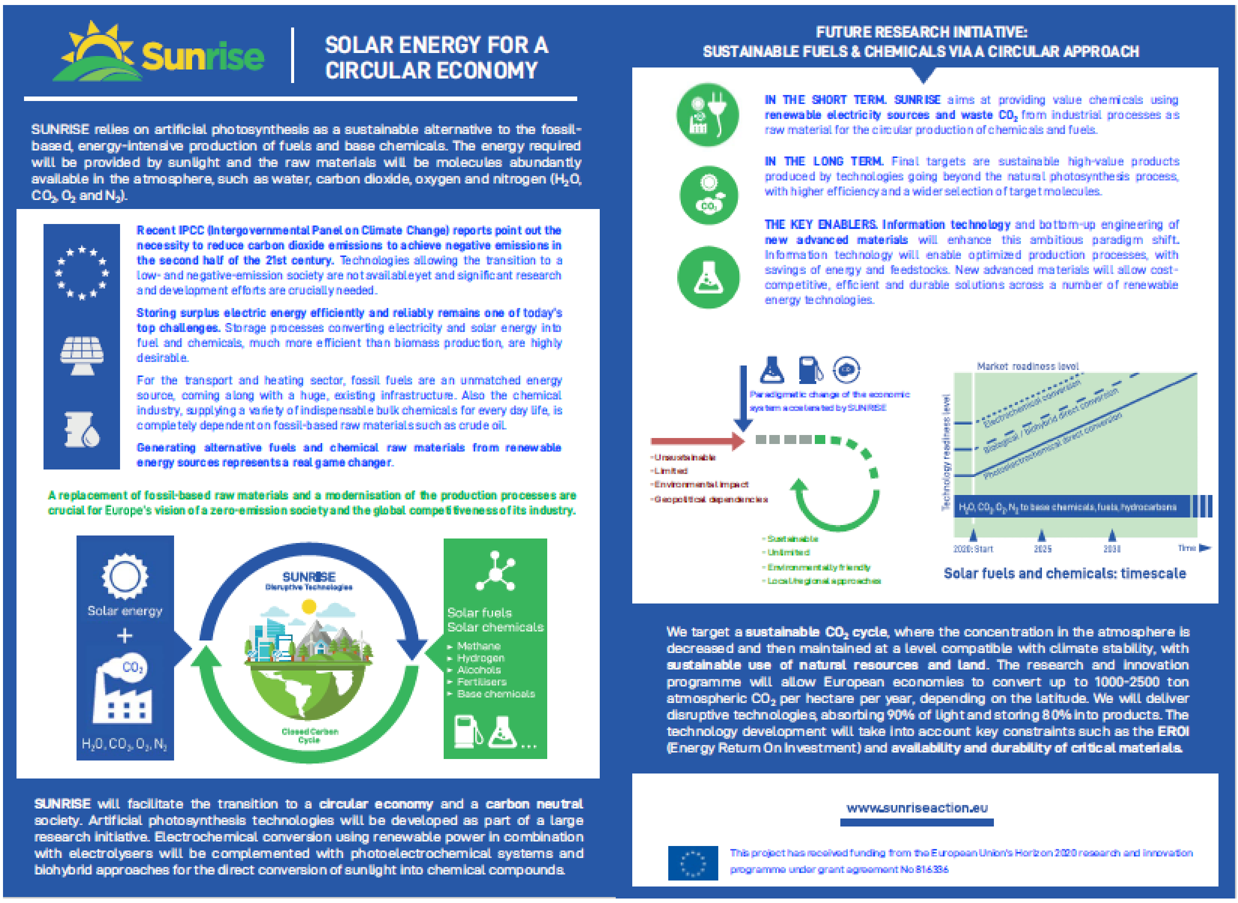


Figure 13. SUNRISE factsheet

Figure 14. SUNRISE leaflets at the SUNRISE Stakeholder Workshop

In September 2019, a collection of three infographics was developed to promote a better understanding of the concept of circular economy as opposed to the linear economy. See the pictures below:

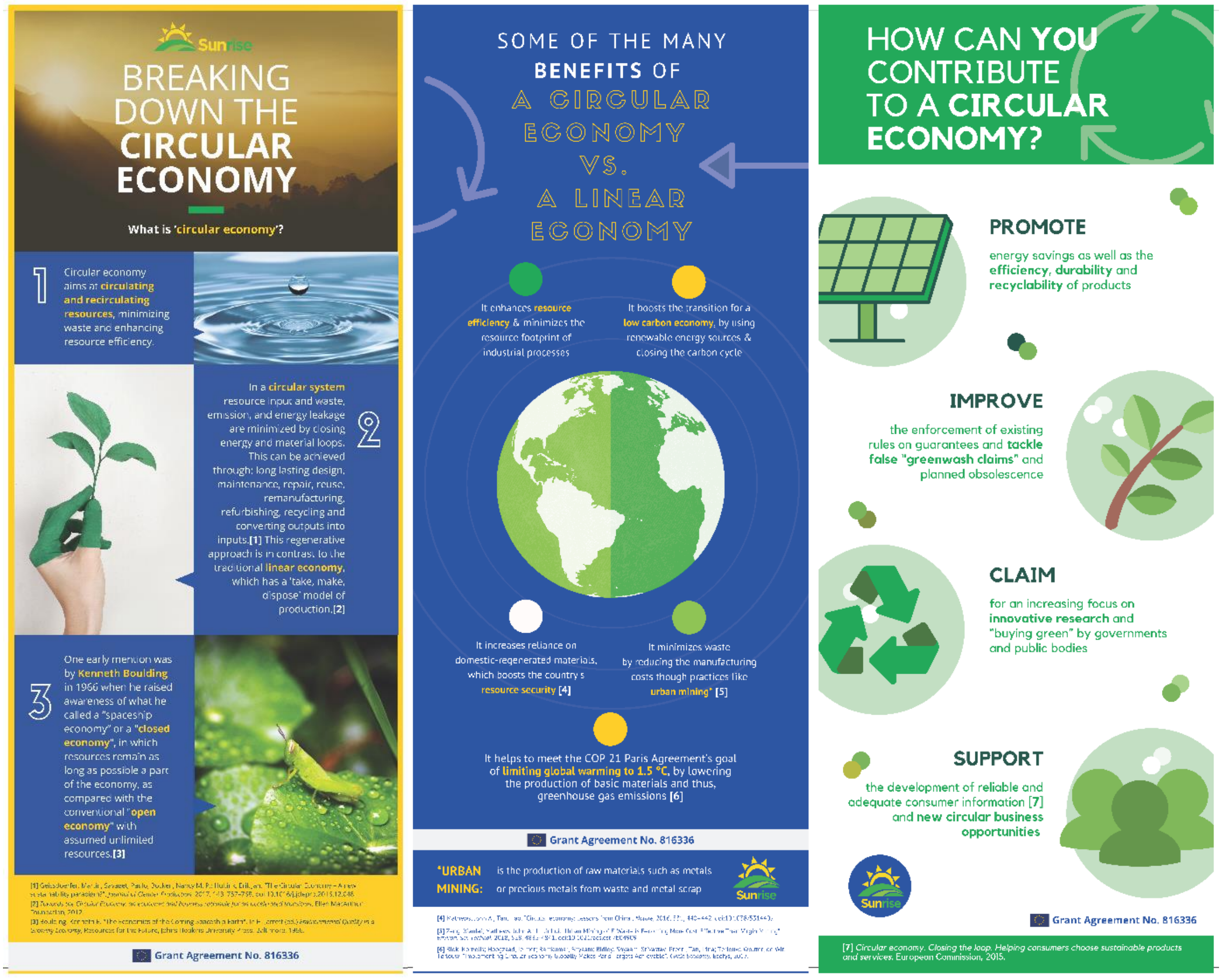


Figure 15. SUNRISE infographics on the circular economy

These illustrations have been shared at fairs and meetings ever since. Besides, they are also available on the SUNRISE website to be downloaded and printed (https://sunriseaction.com/sunrise-infographics-breaking-down-circular-economy/).

Figure 16. SUNRISE infographics on the circular economy at the Maker Faire Barcelona 2019

One more infographic has been released at the end of the action concerning the main facts and figures of the SUNRISE CSA. This illustration will serve to show the main highlights of the SUNRISE roadmap, in order to disseminate it among both the media and the lay public.

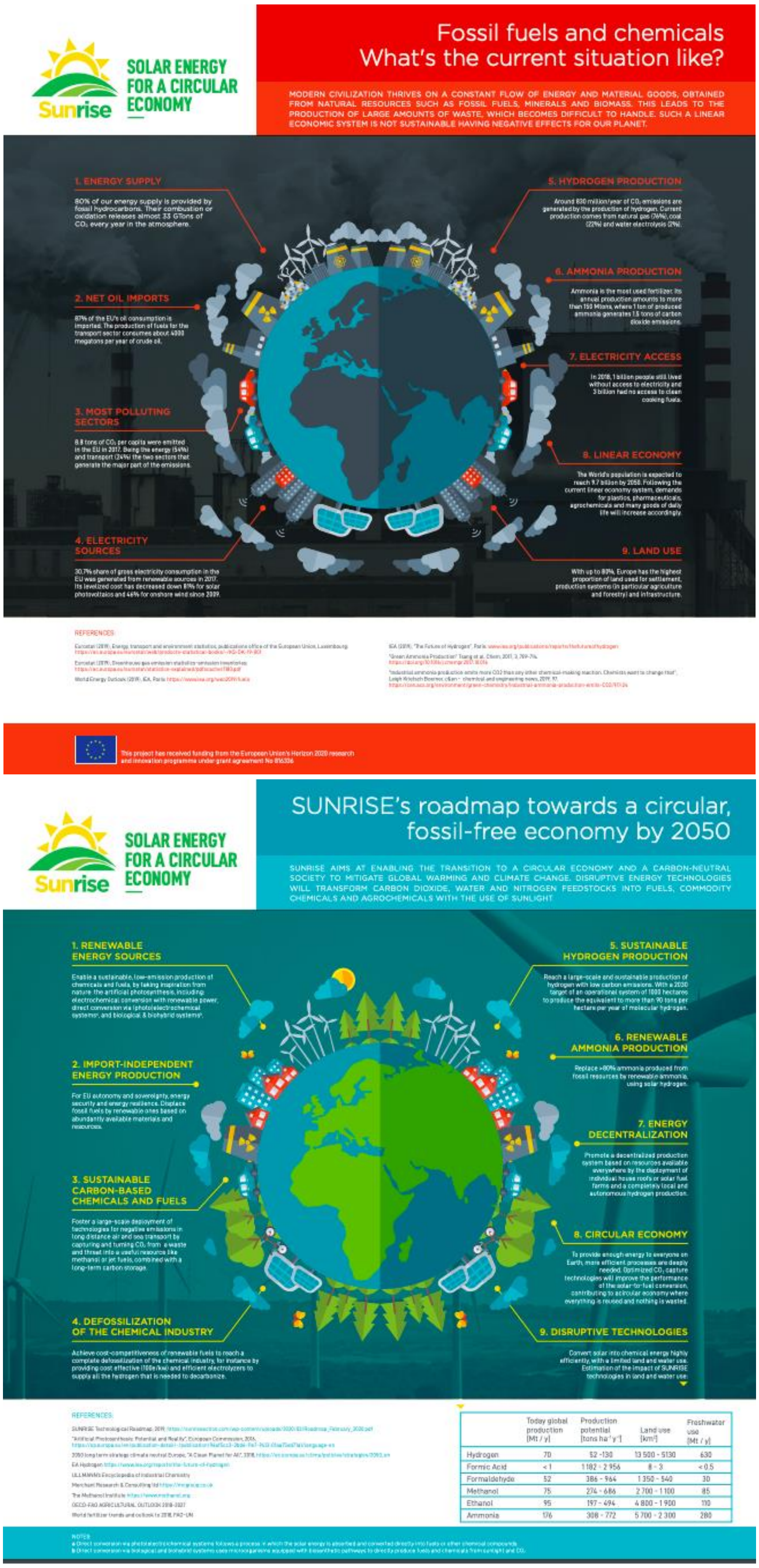


Figure 17. SUNRISE infographics to illustrate the current challenges towards a fossil-free economy by 2050 and SUNRISE roadmap.

2.6. Videos and podcasts

The project has produced a general video to promote the initiative's objectives. It has been also used to promote the SUNRISE initiative at various events and meetings. The video was released in June 2019 and had its premiere at the EuroNanoForum 2019 conference on June 12-14 in Bucharest where it was presented during the invited talk of SUNRISE partner Joanna Kargul. To date, the promo film has reached more than 1,000 views on SUNRISE YouTube channel (https://youtu.be/TTI98tcIyRw) and 1,200 views on the LinkedIn page. A direct link is also available on the SUNRISE website (both landing and resources' pages).

Figure 18. SUNRISE video playing at the SUNRISE stand in the EUSEW 2019

The video has been translated to several languages to facilitate its sharing within local communities.

- Spanish (https://youtu.be/mD3yko0s70I),
- Italian (https://youtu.be/rUQ0QimTCz8),
- French (https://youtu.be/D1PXgzDdYEk),
- Polish (https://youtu.be/6DqxNKB14GY),
- German (https://youtu.be/TTI98tcIyRw).

Figure 19. Frames of SUNRISE official video in Spanish, Italian, French, Polish and German, respectively

Besides this video, SUNRISE has released other videos, which include:

- Two Facebook live interviews with the SUNRISE Deputy Coordinator, Hervé Bercegol (CEA) on the occasion of the International Day of Light (https://www.facebook.com/sunriseaction/videos/424227408130413/), and with SUNRISE partner Antonín Vlček (J. Heyrovsky Institute of Physical Chemistry) on the occasion of SUNRISE consortium meeting in October 2019 in Brussels (https://www.facebook.com/sunriseaction/videos/3140475342660490/).

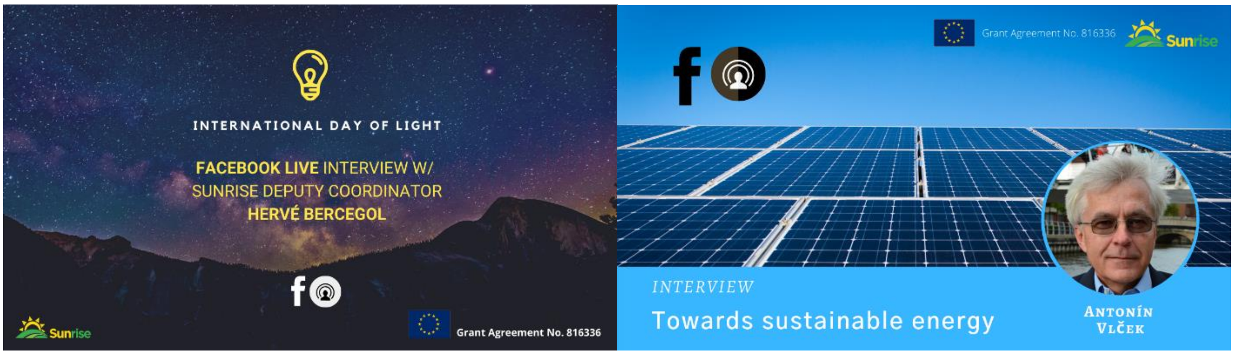


Figure 20. Facebook live interviews with Hervé Bercegol and Antonín Vlček, respectively

- Four promotional videos were produced for the SUNRISE Stakeholder Workshop (https://twitter.com/sunriseaction/status/1140242756067106817), the release of the SUNRISE technological roadmap (https://twitter.com/sunriseaction/status/1195015920403525632), the participation of the project at the COP25 (https://www.youtube.com/watch?v=sHQyKE7Wxo0) and the final project event, together with ENERGY-X that was also the presentation of the joint initiative SUNERGY (https://www.youtube.com/watch?v=u9V-SNqazO4).

Figure 21. Frames of promotional teasers for: SUNRISE Stakeholder Workshop, SUNRISE technological roadmap, participation at the COP25 and SUNRISE & ENERGY-X final joint event, SUNERGY kick-off.

- Four video interviews with SUNRISE partners Nicola Armaroli (CNR),Hélène Lepaumier (ENGIE), Huub de Groot (Leiden University) and Katrin Mueller (Siemens) on the circular economy (https://youtu.be/iIxUxxlPgmI), renewable fuels (https://youtu.be/wXEB3O16zcQ), breaking down the artificial photosynthesis (https://www.youtube.com/watch?v=hyXG3m3bWlQ) and solar energy for a carbon-neutral society (https://www.youtube.com/watch?v=_n_1-iEO-Sk), respectively.

Figure 22. Frames of SUNRISE video interviews with Nicola Armaroli, Hélène Lepaumier, Huub de Groot and Katrin Mueller.

Given that some SUNRISE partners have been invited to radio interviews, podcasts out of these interviews have been generated and are also available on the SUNRISE YouTube channel. So far, there are three podcasts with SUNRISE partners Victor de la Peña (IMDEA Energy) (https://youtu.be/SwW6-uM5daY, Spanish), Nicola Armaroli (CNR) (https://youtu.be/rx-Wx2Rn_W0, Italian), Julio Lloret and Elisabet Romero (ICIQ) (https://youtu.be/fcVx5VB71os, Spanish and Catalan) on the artificial photosynthesis.

Other external videos related to the artificial photosynthesis have been posted on the project's website (https://sunriseaction.com/videos/) and saved on the SUNRISE YouTube channel as a playlist (https://www.youtube.com/playlist?list=PLW3cKWoAeHgZPlsGqkfQkRoSyIPYss06-) to attract the lay public's attention to the topic.

A wrap-up video presenting views of different SUNRISE partners on the first year of the CSA project was released at the beginning of February, for the final SUNRISE consortium meeting.

Figure 23. Frame of the Bye, bye SUNRISE video.

2.7. Newsletters

The project has produced four public newsletters to facilitate quick access to all SUNRISE stakeholders about the major news and outcomes of the project. The first public newsletter was sent on 2 July 2019, the second one on 7 October 2019, the third one on 14 January 2020 and the final one was released on 9 March 2019. They are available on the 'resources' page of SUNRISE webpage (https://sunriseaction.com/resources/). Free subscription is available on the webpage – homepage and 'support us' page –, and on the SUNRISE Facebook page.

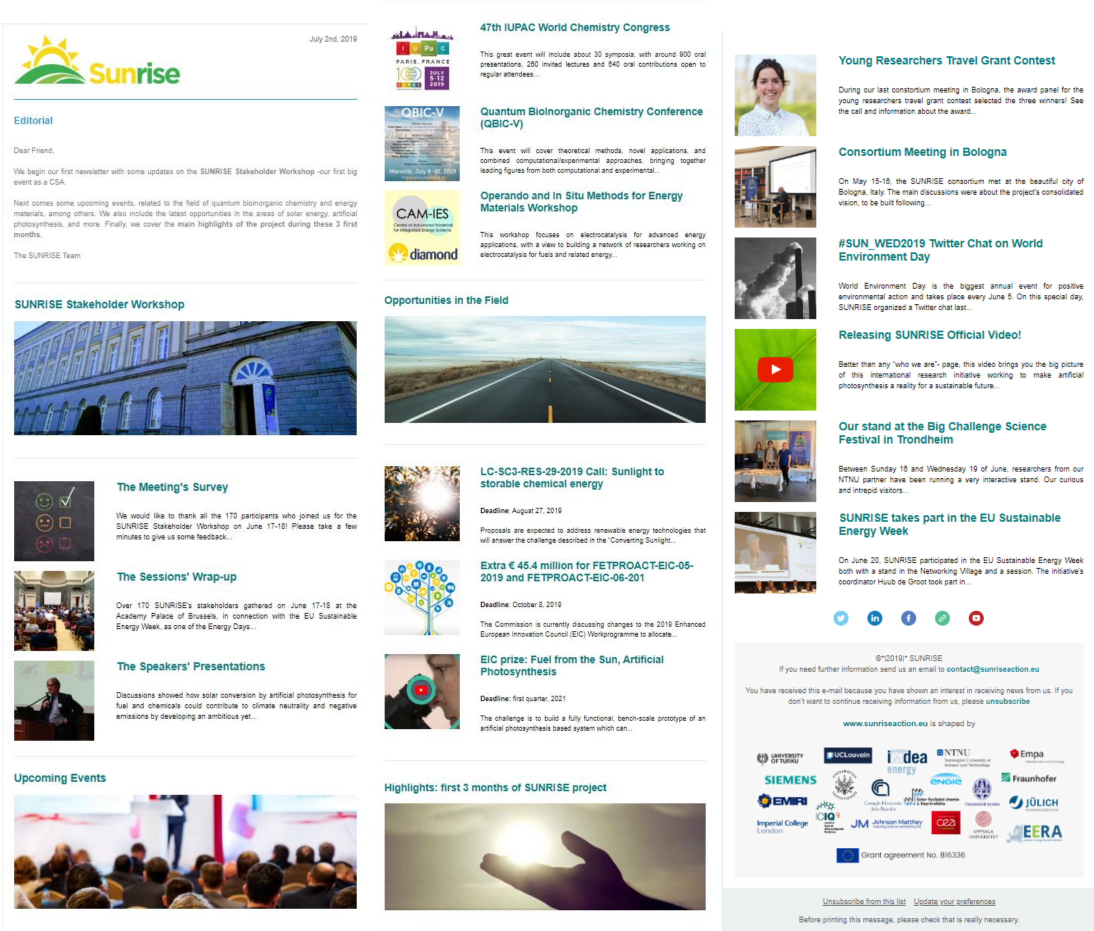


Figure 24. SUNRISE first newsletter

The final newsletter contains the year wrap-up in the form of a digital story, to summarize the main important actions throughout the year of the CSA.

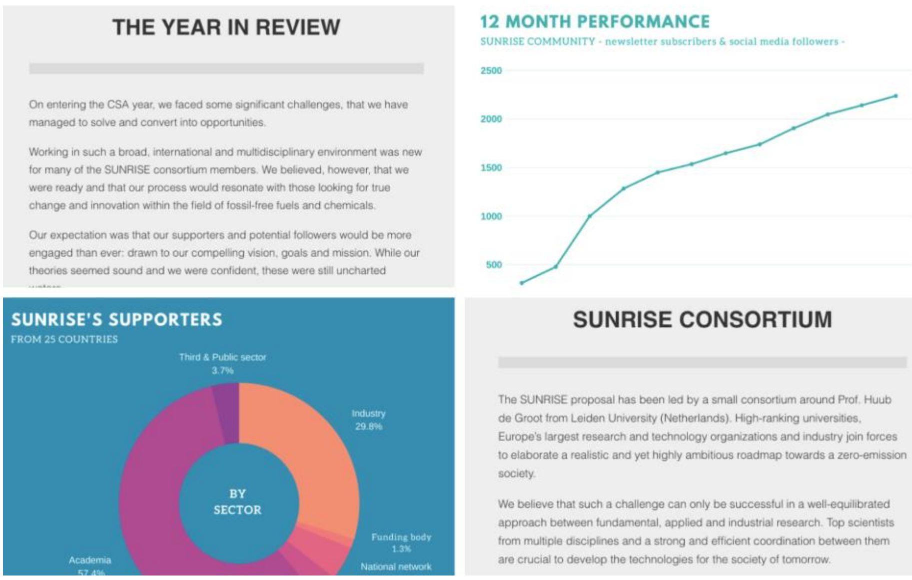


Figure 25. Frames of the year wrap-up included in the last SUNRISE newsletter.

3. COOPERATION WITH ENERGY-X, JOINT MATERIALS

3.1. SUNERGY name, logo and visual identity

Since the announcement of the joint cooperation of ENERGY-X and SUNRISE in August 2019 at EuropaCat, both communication teams from SUNRISE and ENEGY-X have worked together in order to:

- increase the synergy between both communities;
- unify the message and the vision of the joint initiative; and
- create the SUNERGY visual identity.

In a first moment, the joint communication team launched a public poll for making the final decision of the name of the joint initiative, choosing from the two final options, as previously decided in an internal poll within both consortia: SUN2X or SUNERGY. After a week of a tight race between the two proposed acronyms, the winning name was SUNERGY. This option counted with the support of 55% of the votes, against the 45% that voted SUN2X (https://sunriseaction.com/announcing-the-winning-name-for-energy-x-and-sunrise-upcoming-joint-initiative-sun-ergy/).

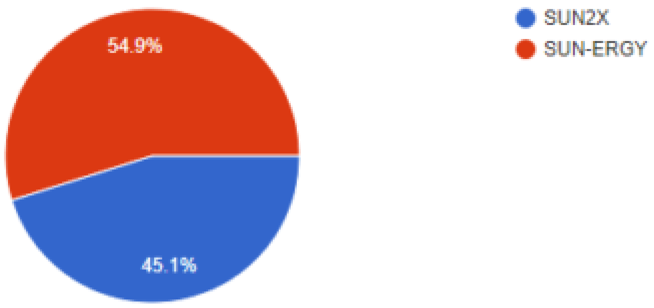


Figure 26. Results of the public poll for choosing the joint initiative name

After the definition of the name of the joint initiative, the joint ENERGY-X and communication teams worked on the visual identity of SUNERGY. In total, nine different propositions were evaluated by the SUNERGY boards and the final decision is presented below:

Figure 27. Round and horizontal versions of the SUNERGY logo.

One of the joint actions of both initiatives was also related with this final joint event: the **SUNERGY photo contest** (https://sunriseaction.com/sun-ergy-photo-contest/). The idea of the contest has evolved from a first idea regarding a slam video contest, which at the end was simplified for having a better and quicker reaction to become a photo contest addressed to young researchers. The contest was launched at the end of December, offering to participants the opportunity to show their research using a freestyle picture along with an abstract. The received entries were voted in the new SUNERGY Instagram account (https://www.instagram.com/sunergy.eu/) and the three most “liked” were evaluated by a SUNERGY panel, which chose the winning one. The winner of the contest: Amedeo Agosti, U. Bologna was awarded with a travel grant to attend the joint meeting and give a presentation about his research work (https://sunriseaction.com/announcing-the-winner-of-our-sun-ergy-photo-contest/)

Figure 28. Image of the Instagram account showing the pictures sent by participants of the photo contest and picture of the winner giving his presentation at the SUNERGY kick-off event.

3.2. SUNERGY videos

SUNRISE and ENERGY-X have also collaborated in the production of two videos on the joint final event, which was as well the kick-off event for SUNERGY. One of the videos is about the celebration of this joint kick-off meeting, with a major focus on the two closing initiatives, while the other one, aims at being the official video of the upcoming initiative including its future goals and actions.

Figure 29. Frame of the SUNERGY kick-off event video.

3.3. SUNERGY 2 pager and manifesto

Among the different materials developed jointly by SUNRISE and ENERGY-X there are the SUNERGY two-pager and a manifesto. The two-pager serves as a factsheet that draws to a great extent on the joint partnership proposal, summing up the goals, impact and means to be used by the upcoming initiative towards a climate-neutral EU by 2050.

Instead, the scope of the joint manifesto is to address scientists, industry, policymakers and citizens alike, and to be used both in policy and broader dissemination actions.

Figure 30. First page of the SUNERGY two-pager and the cover page of the manifesto

4. PRESS CLIPPINGS

4.1. Press releases

Four press releases have been published and are available for downloading from the webpage (https://sunriseaction.com/press-releases/)

- 1st Press release: 1 February 2019, to announce the CSA project

SUNRISE
Solar energy for a circular economy

PRESS RELEASE

Brussels, 1st February, 2019

SUNRISE, a preparatory action towards a European large scale research initiative

- The European Project SUNRISE, "Solar energy for a circular economy", has been selected as one of the six Coordination and Support Actions (CSA) within the Horizon 2020 programme. Funded with €1M, it will last one year (starting in spring 2019), setting the basis for a European large scale research project.
- The SUNRISE Vision is a radical and ambitious scientific and technological approach for solar energy conversion and storage to provide a sustainable alternative to fossil-based, energy-intensive production of fuels and base chemicals. This is fully aligned with the recently released European Commission long-term strategy for a climate neutral Europe by 2050.
- SUNRISE joins together stakeholders from academia, industry, policy and society, including NGOs and global players in the energy, chemicals and automotive sectors, to develop the S&T roadmap of a large research initiative in the Energy, Environment and Climate Change area.

Six CSA projects have been selected for the 2018 call "FETFLAG-01-2018" within one of the three main research areas proposed: Information and communication technology (ICT) and Connected Society; Health and Life Sciences; and Energy, Environment and Climate Change. These actions aim at preparing new European large scale research initiatives to be potentially supported in the next European research and innovation framework programme, Horizon Europe. The selected proposals are urged to set the basis for large visionary, science-driven, long-term research projects focused on addressing the major European societal challenges and turning scientific advances into concrete innovation opportunities, growth and jobs.

SUNRISE, as part of the Energy, Environment and Climate Change area, gathers players from academia, industry, policy-making and society to prepare a strategic long-term research roadmap and a consolidated vision of a future large research project. SUNRISE aims at providing a sustainable alternative to the fossil-based, energy-intensive production of fuels and chemicals, based on solar energy conversion and widely available feedstock (CO_2, H_2O, N_2). A sustainable CO_2 cycle, which leads to an atmospheric CO_2 concentration decrease and stabilisation at a level compatible with climate stability, is the main target behind this approach, which also aims for a sustainable use of land and natural resources to implement a circular economy.

> "*SUNRISE goal is to change the way fuels are produced, and provide chemicals and much more for the circular economy with very high yield directly from abundant solar energy and atmospheric gases. In the foreseeable future, a portfolio of SUNRISE technologies will fuel carbon neutral industries in smart liveable cities that go well beyond current imagination. We will provide seasonal energy storage in a zero waste society while reducing CO_2 emissions*" – Prof. Huub de Groot, SUNRISE coordinator.

Follow us on

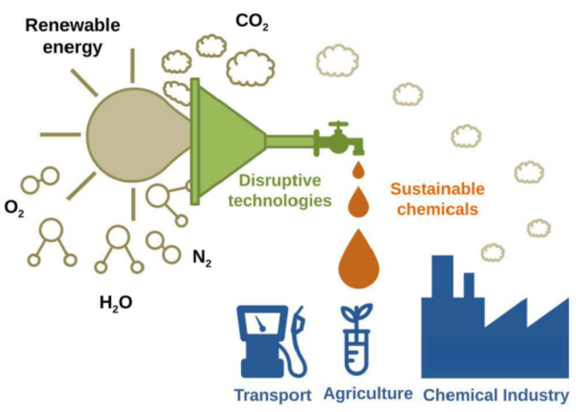
www.sunriseaction.eu

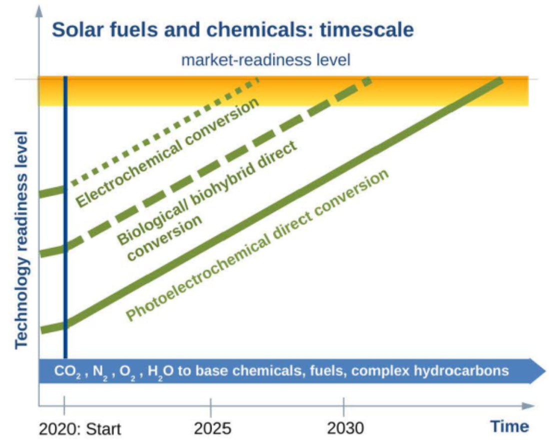
SUNRISE
Solar energy for a circular economy

SUNRISE is coordinated by Prof. Huub de Groot from Leiden University (the Netherlands) and brings together a multidisciplinary consortium of 20 partners from 13 European countries. The SUNRISE consortium includes: seven universities (Leiden University, University of Uppsala, Imperial College London, University of Turku, University of Warsaw, Norwegian University of Science and Technology and University of Louvain); eight research centres (French Alternative Energies and Atomic Energy Commission (CEA), Italian National Research Council (CNR), Swiss Federal Laboratories for Materials Science and Technology (Empa), IMDEA Energy Institute, Fraunhofer-Gesellschaft, Forschungszentrum Jülich GmbH, J. Heyrovský Institute of Physical Chemistry and Institute of Chemical Research of Catalonia); two European associations (European Energy Research Alliance, EERA; Energy Materials Industrial Research Initiative, EMIRI); and three companies (Siemens AG, Johnson Matthey and ENGIE).

On November 15th 2018, the consortium organised a SUNRISE meeting gathering around 90 members of the SUNRISE community in Brussels. Fruitful discussions on the project's vision, mission and strategy were held by project partners and supporters (the detailed agenda and copies of the presentations are available for download under www.sunriseaction.eu). This has been the first step for building a strong and actively growing "SUNRISE ecosystem", which will be essential to achieve the ambitious objectives of a future long-term research project. Currently, the SUNRISE initiative already counts with the support of more than 150 institutions worldwide, including academic centres, industrial companies, strategic networks, funding bodies, ministries and NGOs.

At the end of the CSA, the SUNRISE community will release a blueprint for the implementation of the SUNRISE large scale initiative, including a description of the short to long-term objectives, resources needed and the criteria to be followed for being an open, inclusive and cross-disciplinary effort following the Responsible Research and Innovation (RRI) principles.





SUNRISE will facilitate the transition to a circular economy and a carbon neutral society. The technologies to be developed as part of a large research initiative will transform carbon dioxide, water, nitrogen and oxygen feedstock into fuels and chemicals using sunlight. Electrochemical conversion using renewable power in combination with electrolysers will be complemented with integrated artificial photosynthetic systems and biohybrid approaches for the direct conversion of sunlight into chemical compounds.

Media contacts

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- 2nd Press release: 21 June 2019, to summarize the SUNRISE Stakeholder Workshop during the EUSEW

SUNRISE - Press release

SUNRISE's first big event takes place during the EU Sustainability Energy Week

Brussels, June 21, 2019

Over 170 SUNRISE's stakeholders gathered on June 17-18 at the Academy Palace of Brussels, in connection with the EU Sustainable Energy Week, as one of the Energy Days. Renewable energy experts from Academia, Industry and Policy addressed the current state of the initiative and its priority research directions.

Discussions showed how solar conversion by artificial photosynthesis for fuel and chemicals could contribute to climate neutrality and negative emissions by developing an ambitious yet realistic roadmap, and aligning action in research, innovation and industry policy – while ensuring the involvement of all the stakeholders. This was SUNRISE's first big event since it became a Coordinated and Support Action (CSA) in March 2019.

SUNRISE's vision and governance

During the first day, speakers shared their latest advances and their fit into SUNRISE's vision towards a clean energy future. Researchers like Jens Nørskov or Marcella Bonchio pointed out the importance of real collaboration between Industry and Academia, as well as the need of financial support. **"It is a Sputnik moment for Europe, we need to approach politicians and convince them that Europe can lead the way of the renewable sector,"** stressed **Jens Nørskov**, Professor at the Technical University of Denmark.

Policy makers of the European Commission, Member States, Industry and funding bodies representatives also joined the meeting by taking part in a panel debate. The discussion tackled the governance and funding steps of large-scale research initiatives under the coming framework programme Horizon Europe. "Besides doing research, it is important to make the people dream of your goal. Branding is key in order to get visibility towards public authorities and decision makers and thus, increase the chances of getting financial support," explained Jean-François Buggenhout, head of the Flagship unit at DG Connect.

On the way to a handy roadmap

Invited keynote speakers like former IPCC vice-chair Jean-Pascal van Ypersele from UCLouvain, and Harvard University Professor Daniel Nocera were present on the second day. While the Belgian researcher stressed the need for a transition to a net zero emissions' economy through CO_2 storage, the American scientist gave a lecture on carbon-neutral fuels and renewable-based fertilizers. **"The world depends on an existing energy infrastructure that has already been paid off. In industrialized countries, renewable energies can piggy-back on it, while in**

developing countries stand-alone and distributed devices will be more effective," highlighted Daniel Nocera.

The talks were followed by an innovation workshop and three parallel roadmapping sessions, where participants were challenged to nurture collectively a comprehensive science and technology roadmap towards a climate neutral economy. The direct exchange with the stakeholders was at the centre of the roadmapping activity. Ongoing discussions should allow the **research initiative to adopt and release a dynamic first roadmap's draft by the end of August 2019**. With this document, SUNRISE's stakeholders will ensure the EU can continue to show leadership in the renewable energy sector.

Energy storage and decarbonisation

On June 20, SUNRISE participated in the EU Sustainable Energy Week both with a stand and a session. The initiative's coordinator Huub de Groot took part in the panel session 'Energy storage to boost EU decarbonisation and competitiveness,' together with representatives of the European research initiatives Battery2030+ and Energy-X.

"We are not yet in the money with solar to fuel, but the market potential is there, on the scale of hundreds of billions yearly. **We have to team up with fundamental, applied and industrial research to be there in time learning how to manufacture solar fuels and chemicals for a zero and negative emissions' circular economy," concluded Huub de Groot.**

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- 3rd Press release: 26 August, 2019, joint press release with ENERGY-X to announce the two initiatives cooperation following the official announcement at Europacat 2019.

SUNRISE & ENERGY-X - Press release

SUNRISE and ENERGY-X joint cooperation: a major step towards building a climate neutral EU

Aachen, August 26, 2019

Representatives from the EU Horizon 2020 Coordination and Support Actions (CSAs) SUNRISE and ENERGY-X announced their joint cooperation on August 20, 2019 during the 14th European Congress on Catalysis, EuropaCat 2019. The two initiatives will continue to pursue their roadmapping actions until February 2020, when they plan to merge in a new initiative, with a new name.

The two projects have already started to coordinate on joint actions. SUNRISE and ENERGY-X representatives took part in the panel discussion of the session: "The Energy-Chemistry Nexus: Towards a European Sustainable Energy & Catalysis Research Initiative", held by ENERGY-X on August 20. Professor Jens Nørskov, coordinator of ENERGY-X, said: ***"It is of utmost importance to unite the efforts within Europe to lay the scientific foundation as well as to foster technological breakthroughs to develop a more sustainable society."***

Both projects share common goals for the conversion of renewable energies into alternative fuels and chemicals. Currently, both initiatives are working together towards a common Manifesto. *"We need to think long-term and overcome fragmentation"*, explained SUNRISE coordinator Professor Huub de Groot. ***"Several solutions are needed to fight climate change and for that all types of research should team up"***, he added.

Background

SUNRISE and ENERGY-X are two out of the six CSA projects that were selected for the Horizon 2020 call "FETFLAG-01-2018" within the research area of Energy, Environment and Climate Change. Both initiatives received €1 million from the European Commission to develop a detailed proposal for a large-scale research initiative during one year, from March 2019 to February 2020.

Both SUNRISE and ENERGY-X aim to develop sustainable approaches for the storage of renewable energy (solar and wind) through its conversion to fuels and commodity chemicals using abundant molecules such as carbon dioxide, water and nitrogen. The two projects bring together 30 committed organisations, backed by an initial supporting community of approx. 300 stakeholders from academia, industry, and society.

The replacement of fossil fuels and the modernisation of the production processes are crucial to meet the COP 21 Paris Agreement's mission of tackling climate change. A European large-scale initiative is urgently needed to address these key challenges and drive forward major global transformations led by new disruptive technologies.

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- 4th Press release: 13 February, 2020, joint press release with ENERGY-X for the two initiatives joint final event as the SUNERGY kick-off.

SUNRISE & ENERGY-X - Press release

Kick-off of the SUNERGY initiative

Brussels, February 13, 2020

Over 100 stakeholders of the Coordination and Support Actions (CSAs) SUNRISE and ENERGY-X gathered on February 5-6, 2020 in Brussels for the kick-off meeting of SUNERGY, a large-scale research and innovation (R&I) initiative in the area of fossil-free fuels and chemicals. Renewable energy experts from academia, industry and policy addressed the current opportunities and challenges towards decarbonizing the European industry and society over the next 30 years.

The launch event was organized in two sessions: a high-level lunch discussion at the European Parliament (EP) on February 5, and a public two-day conference. The TownHall Europe hosted the afternoon session on February 5, while the morning session on February 6 was hosted by the Representation of the State of Hessen to the EU.

Large-scale R&I initiatives to decarbonize Europe

MEP Morten Helveg Petersen hosted the high-level lunch discussion at the EP. Representatives from both initiatives debated on how large-scale R&I initiatives in the area of fossil-free fuels and chemicals can contribute to meeting the targets of the Paris Agreement. Keynote speakers were Cristian Silviu Bușoi (ITRE Committee Chair), Hélène Chraye (Directorate Clean Planet of Directorate General Research & Innovation), Mark van Stiphout (Directorate General Energy), Bert Weckhuysen (SUNERGY coordinator), and Maximillian Fleischer (Siemens Energy).

SUNERGY coordinator Bert Weckhuysen: The SUNERGY initiative comes at a time when greater attention to climate and energy issues and on-going developments at European level offer the right framework for action and a great opportunity to join efforts towards reversing climate change.

A common vision to close the carbon and nitrogen cycles

During the public kick-off meeting, the CSAs SUNRISE and ENERGY-X presented their achievements throughout the past year, and proposed their joint vision on providing sustainable and competitive alternatives to fossil fuels by 2050. Keynote speakers like Peter Dröll (Director Prosperity, Directorate General Research & Innovation) highlighted the strong support of the European institutions towards R&I to achieve the ambitions of the European Green Deal.

SUNERGY deputy coordinator Frédéric Chandezon: This kick-off meeting has served as a key step towards unifying the SUNRISE and ENERGY-X research communities and defining directions for a European large-scale R&I initiative around SUNERGY, within the new European R&I framework Horizon Europe.

Background

SUNRISE and ENERGY-X are two out of the six CSA projects that were selected for the Horizon 2020 call "FETFLAG-01-2018" within the research area of Energy, Environment and Climate Change. Both initiatives received €1 million from the European Commission to develop a detailed proposal for a large-scale research initiative during one year, from March 2019 to February 2020.

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Media contacts:

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4.2. Press clippings

4.2.1 Partners' channels

The SUNRISE partners have broadly used their communication channels, and those of their associated institutions, to replicate the press releases, promote the initiative's actions and publish interviews with the involved experts.

English

➢ Leiden University:

- SUNRISE initiative's first stakeholder meeting (21 June 2019): https://www.universiteitleiden.nl/en/news/2019/06/sunrise-initiatives-first-stakeholder-meeting

➢ Uppsala University:

- SUNRISE selected for European large-scale research initiative (02 February 2019): https://www.kemi.uu.se/nyheter/enskild-nyhet/?tarContentId=773130
- Swedish Consortium for Artificial Photosynthesis, The first SUNRISE stakeholder meeting –EU project (17-18 June 2019): http://www.solarfuel.se/Press/

➢ IMDEA Energy:

- The Sunrise Stakeholder Workshop took place in Brussels last June 17-18, 2019 (19 June 2019): https://www.energia.imdea.org/eventos/2019/sunrise-stakeholder-workshop-took-place-brussels-last-june-17-18-2019

➢ Imperial College:

- Project SUNRISE and accreditation success: News from the College (01 February 2019): https://www.imperial.ac.uk/news/190087/project-sunrise-accreditation-success-news-from/
- SUNRISE teams up with ENERGY-X (30 August 2019): https://www.imperial.ac.uk/news/192726/refugee-mental-health-malarial-mysteries-news/#Sunrise

➢ Fraunhofer IGB:

- Kick-off of the SUNERGY initiative (14 February 2020): https://www.igb.fraunhofer.de/en/press-media/press-releases/2020/kickoff-sunergy-initiative.html

➢ Uniwersytet Warszawski:

- SUNRISE's stakeholders first meeting (03 July 2019): http://en.uw.edu.pl/sunrises-stakeholders-first-meeting/

- SUNRISE and ENERGY-X joint cooperation: a major step towards building a climate neutral EU (20 August 2019): http://en.uw.edu.pl/sunrise-and-energy-x-joint-cooperation-a-major-step-towards-building-a-climate-neutral-eu/

➢ ICIQ:

- SUNRISE: Solar energy for a circular economy (06 February 2019): http://www.iciq.org/sunrise-solar-energy-for-a-circular-economy/
- CERCA: SUNRISE: Solar energy for a circular economy (06 February 2019):
- SUNRISE's first big event (06 July 2019): http://www.iciq.org/sunrises-first-big-event/
- CERCA: SUNRISE's first big event (03 July 2019): http://s368784504.mialojamiento.es/devel/cerca/sunrises-first-big-event/
- BIST: BIST centre ICIQ part of SUNRISE: Solar energy for a circular economy (09 July 2019): https://bist.eu/bist-centre-iciq-part-of-sunrise-solar-energy-for-a-circular-economy/
- SUNRISE and ENERGY-X joint cooperation: a major step towards building a climate neutral EU (30 August 2019): http://www.iciq.org/sunrise-and-energy-x-joint-cooperation-a-major-step-towards-building-a-climate-neutral-eu/
- CERCA: SUNRISE and ENERGY-X joint cooperation: a major step towards building a climate neutral EU (30 August 2019): http://s368784504.mialojamiento.es/devel/cerca/sunrise-and-energy-x-joint-cooperation-a-major-step-towards-building-a-climate-neutral-eu/
- SUNRISE releases its technological roadmap to a clean energy EU (21 November 2019): http://www.iciq.org/sunrise-releases-its-technological-roadmap-to-a-clean-energy-eu/
- BIST: SUNRISE releases its technological roadmap to a clean energy EU (21 November 2019): https://bist.eu/sunrise-releases-its-technological-roadmap-to-a-clean-energy-eu/
- Kick-off of the SUNERGY initiative (18 February 2020): http://www.iciq.org/kick-off-of-the-sunergy-initiative/

➢ EERA:

- SUNRISE, a preparatory action towards a European large-scale research initiative (01 February 2019): https://www.eera-set.eu/press-release-sunrise-a-preparatory-action-towards-a-european-large-scale-research-initiative/
- Thank you to all participants at the SUNRISE Stakeholder Workshop! (20 June 2019): https://www.eera-set.eu/thank-you-to-all-participants-at-the-sunrise-stakeholder-workshop/
- SUNRISE and ENERGY-X joint cooperation: a major step towards building a climate neutral EU (28 August 2019): https://www.eera-set.eu/press-release-sunrise-and-energy-x-joint-cooperation-a-major-step-towards-building-a-climate-neutral-eu/
- Kick-off of the SUNERGY initiative (13 February 2020): https://www.eera-set.eu/news-resources/612:kick-off-of-the-sunergy-initiative.html

➢ M2i (third party in charge of SUNRISE project management):

- Kick-off SUNERGY (13 February 2020): https://www.m2i.nl/kick-off-sunergy/

Dutch

➢ Leiden University:

- SUNRISE: van zonlicht tot smart city (01 February 2019): https://www.universiteitlei-den.nl/en/news/2019/02/sunrise-from-sunlight-to-smart-city
- Brandstoffen maken uit zonlicht en CO_2: https://www.universiteitleiden.nl/research-dossiers/duur-zame-energie/brandstoffen-maken-uit-zonlicht-en-co2
- De kracht van de zon: interview Huub de Groot in Leidraad (07 October 2019): https://www.univer-siteitleiden.nl/nieuws/2019/10/interview-huub-de-groot-in-leidraad

French

➢ CEA:

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- *Ràdio Ciutat Tarragona*, Crear energia a partir de fotosíntesi artificial (09 October 2019): https://rctgn.cat/crear-energia-a-partir-de-fotosintesi-artificial/

- *Ràdio Cambrils,* Ones de ciència. (23 October 2019): http://radiocambrils.alacarta.cat/onesdeciencia/capitol/ones-de-ciencia-capitol-3-amb-laura-lopez-i-amelia-ochoa

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5. SUNRISE STAKEHOLDERS WORKSHOP

5.1. Agenda

SUNRISE Stakeholder Workshop Agenda, June 17-18, 2019

Dates: 17-18/06/2019

Location: Brussels

Address: Palais des Académies, rue Ducale 1, 1000 Bruxelles

Monday, June 17

9:30 – 10:00 am

Welcome, coffee

10:00 – 10:15 am

Opening address
Huub de Groot | Leiden University

10:15 – 12:45 pm

SUNRISE Consolidated vision
Chair: Nicola Armaroli |National Research Council of Italy (CNR)
Speakers:

- Marc Fontecave | College de France, Paris
- Roel van de Krol | Helmholtz-Zentrum Berlin
- Marcella Bonchio | University of Padova
- Jens Nørskov | Technical University of Denmark

Wrap-up session

12:45– 2:00 pm

Lunch

2:00 – 4:00 pm

SUNRISE Roadmap
Chair: Hervé Bercegol | French Alternative Energies and Atomic Energy Commission (CEA)
Speakers:

- Damien Dallemagne | CO_2 Value Europe
- Niek van Hulst | The Institute of Photonic Sciences (ICFO)
- Sophia Haussener | École Polytechnique Fédérale de Lausanne
- Michel Gimenez | LafargeHolcim

Wrap-up session

4:00 – 4:30 pm

Coffee break

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SUNRISE Stakeholder Workshop Agenda, June 17-18, 2019

4:30 – 6:00 pm

SUNRISE Governance workshop

This session aims at addressing the governance of a large-scale research initiative, for example a future mission under Horizon Europe. It will start with an introduction followed by a panel discussion with representatives of the European Commission, member states and associated countries, representatives of industry and flagship – also involving the audience.

Chairs: Frédéric Chandezon (CEA) and Laura Lopez | Institute of Chemical Research of Catalonia (ICIQ)

Speakers:

- Jean-François Buggenhout | DG Connect, European Commission
- Lars Klüver | Danish Board of Technology Foundation
- Paulina Styczeń | Department of Innovation and Development of the Poland's Ministry of Science and Higher Education
- Andreas Förster | DECHEMA
- Marcel Hoek | Dutch Research Council (NWO)
- Max Lemme | Scientific Secretary of the Strategic Advisory Council and former leader of the Graphene Flagship Partnering Division

6:00 – 8:00 pm

Networking dinner

Tuesday, June 18

8:30 – 9:00 am

Welcome, coffee

9:00 – 9:30 am

The urgency of the climate challenge: Why zero net emissions are needed?
Jean-Pascal van Ypersele, Former IPCC Vice-Chair, Full professor of climatology and environmental sciences at UCLouvain, Belgium, and Member of the Belgian Royal Academy.

9:30 – 10:30 am

Views from the SUNRISE community: Pitches from SUNRISE supporters
Chairs: Anita Schneider | European Energy Research Alliance (EERA) and Frédéric Chandezon (CEA)
Speakers:

- Robert Kourist | TU Graz
- Merja Penttilä | VTT Technical Research Centre of Finland
- David Waroquiers | MaDeSo
- David Ayme-Perrot | Total
- Marc Robert | Université Paris Diderot

SUNRISE Stakeholder Workshop Agenda, June 17-18, 2019

- Hannah Johnson | Toyota Motor Europe
- Klaas J. Hellingwerf | Photanol
- Martin Roeb | DLR Institute of Solar Research
- Christoph Beuttler | Climeworks
- Pierdomenico Biasi | Casale SA
- Elisabet Romero | Institute of Chemical Research of Catalonia (ICIQ)
- Paolo Bombelli | University of Cambridge
- Astrid Björnsen | Wald Schnee und Landschaft WSL

10:30 – 11:00 am

Coffee break

11:00 – 12:45 pm

Innovation workshop
Chairs: Antonino Ardilio | Fraunhofer and Elfriede Simon | Siemens

- Introduction
- SUNRISE Innovation Strategy | Yvonne Wich | Fraunhofer
- SUNRISE Innovation Process Design

12:45 – 2:00 pm

Lunch

2:00 – 2:30 pm

Scientific presentation
Daniel Nocera | Harvard University

2:30 – 4:00 pm

Road mapping workshop
Chair: Carina Faber | UCLouvain

Three parallel sessions:

- **Hydrogen and ammonia production**
  Salle Roi Baudoin
- **CO2 capture and electrochemical conversion**
  Patio
- **Solar direct conversion via bio-, biohybrid- and integrated photoelectrochemical devices**
  Salle Prigogine

4:00 – 5:00 pm

Closing Coffee, networking

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5.2. Registration list

SUNRISE Stakeholder Workshop – List of Attendees

First Name	Last Name	Organisation
Alessandro	ABBOTTO	Univ. Milano-Bicocca
Stephan	ABERMANN	AIT - Austrian Institute of Technology
Yagut	ALLAHVERDIYEVA-RINNE	University of Turku
Teresa	ANDREU	Catalonia Institute for Energy Research (IREC)
Antonino	ARDILIO	Fraunhofer IAO
Nicola	ARMAROLI	CNR
Eva-Mari	ARO	University of Turku
Vincent	ARTERO	CEA
David	AYME-PERROT	TOTAL SA
Stefan	BAUMANN	Forschungszenrtum Jülich GmbH
Patrick	BEHR	Forschungszentrum Jülich GmbH
Thierry	BELMONTE	Université de Lorraine
Herve	BERCEGOL	CEA
Christoph	BEUTTLER	Climeworks
Michal	BIALKOWSKI	CASALE SA
Pierdomenico	BIASI	CASALE SA
Anja	BIEBERLE	DIFFER
Laurent IPad	BILLON	IPREM UMR 5254
Astrid	BJÖRNSEN GURUNG	Swiss Federal Research Institute WSL
Jonathan	BLOH	DECHEMA-Forschungsinstitut
Paolo	BOMBELLI	University of Cambridge
Audrey	BONDUELLE	IFP Energies nouvelles
Artur	BRAUN	Empa
Jean-François	BUGGENHOUT	European Commission, DG CNECT
Urs	CABALZAR	Empa
David	CANNELLA	Universite Libre de Bruxelles
Thibault	CANTAT	CEA, Université Paris-Saclay
Aura	CARAMIZARU	JRC
Flavia	CASSIOLA	Shell New Energies Research & Technology
Daniela	CAVALCOLI	University of Bologna, Physics and Astronomy Dept
Christine	CAVAZZA	LCBM-CEA Grenoble
Federico	CERNUSCHI	RSE
Stephane	CHAMPLONG	Solvay, Corporate R&I
Frédéric	CHANDEZON	CEA
Murielle	CHAVAROT-KERLIDOU	CEA
Athanassios	COUTSOLELOS	University of Crete
Kilian	CRONE	Deutsche Energie-Agentur GmbH (dena)
Damien	DALLEMAGNE	CO2 Value Europe
Simon	DE CORTE	Ghent University
Lieve	DE DONCKER	UHasselt
Huub	DE GROOT	Leiden University
Iulia	DEGERATU	Materials Innovation Institute (M2i)
Jean-Paul	DELATTRE	ICE France
Herve	DESVAUX	CEA

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SUNRISE Stakeholder Workshop – List of Attendees

First Name	Last Name	Organisation
Mmanstsae Moche	DIALE	SARCHI: Clean and Green Energy
Stefania	DOPPIU	CIC energuGUNE
Simon M.-M.	DUBOIS	CNRS
James	DURRANT	Imperial College London
Selma	ERAT	Mersin University
Emilie	ETOUNDI	GreenWin
Carina	FABER	UCLouvain
Pau	FARRÀS COSTA	NUI Galway
Verena	FENNEMANN	Fraunhofer-Gesellschaft
Giovani	FINAZZI	CEA
Maximilian	FLEISCHER	Siemens AG
Marc	FONTECAVE	College de france
Andreas	FÖRSTER	DECHEMA
Laia	FRANCESCH	UPPA
Fernando	FRESNO	IMDEA Energy
Vinciane	GAILLARD	European University Association
Michel	GIMENEZ	LafargeHolcim
John	GREGOIRE	Joint Center for Artificial Photosynthesis, Caltech
Alexa	GRIMM	Utrecht University
Elena	GUARNERI	Technical University of Denmark DTU
Kirstin	GUTEKUNST	University of Kiel
Katja	HAAS-SANTO	Karlsruhe Institute of Technolgy - KIT
Ken	HAENEN	Hasselt University
Leif	HAMMARSTRÖM	Uppsala University
Anna	HANKIN	Imperial College London
An	HARDY	Hasselt University
Sophia	HAUSSENER	EPFL
Klaas Jan	HELLINGWERF	Photanol BV
Patrick	HENDRICK	ULB
Benjamin	HERZHAFT	IFPEN
Marcel	HOEK	Dutch Research Council (NWO)
Winfried	HOKE	European Climate Research Alliance (ECRA)
Holger	IHSSEN	KIT
Philippe	JACQUES	EMIRI
Paul	JANSSEN	SCK•CEN
Hannah	JOHNSON	Toyota Motor Europe
Christoph	JUGEL	Deutsche Energie-Agentur GmbH (dena)
Andreas	KAFIZAS	Imperial College London
Joanna	KARGUL	University of Warsaw
Harald	KERP	M2i
Sachin	KINGE	Toyota Motor Europe
Lars	KLÜVER	Danish Board of Technology Foundation
Henrik	KOCH	NTNU

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SUNRISE Stakeholder Workshop – List of Attendees

First Name	Last Name	Organisation
Matthieu	KOEPF	CEA
Robert	KOURIST	TU Graz
Mark	KOZDRAS	Natural Resources Canada
Winfried	LEIBL	CEA
Max	LEMME	RWTH Aachen University / AMO GmbH
Fabrice	LEMOINE	University of Lorraine / CPU
Hélène	LEPAUMIER	ENGIE Laborelec
Axel	LÖFBERG	Univ. Lille
Laura	LOPEZ	ICIQ - Institute of Chemical Research of Catalonia
Philippe	LORGE	H2WIN S.A.
Ann	MAGNUSON	Uppsala university
Aizhan	MAMYRKHANOVA	EERA
Haresh	MANYAR	Queen's University Belfast
Bonchio	MARCELLA	University of Padova
Jordi	MARTORELL	ICFO
Sergio	MASTROIANNI	Solvay
Kim	MCKELVEY	Trinity College Dublin
Marcel	MEEUS	EMIRI
Sen	MEI	SINTEF
Juergen	MEINHARDT	Fraunhofer-Gesellschaft
Tahar	MELLITI	Atmostat
Jan	MERTENS	ENGIE
Carmen	MILLAN CHACARTEGUI	INEA
Francesc	MOLINS	HS Osnabrueck
Engin	MOLVA	CEA & ANCRE
Joan Ramon	MORANTE	IREC
Paul	MOREUX	TEK4Life
Alberto	NALDONI	RCPTM-Palacky University Olomouc
Amin	NASIRI	LEITAT Technological Center
Daniel	NOCERA	Harvard University, US
Timothy	NOEL	Eindhoven University of Technology
Greta	NOELKE	Fraunhofer IME
Federico	NORIS	IREC
Jens	NØRSKOV	Technical University of Denmark
Amelia	OCHOA	ICIQ
Fabrice	ODOBEL	CEISAM-CNRS
Christian	OEHR	Fraunhofer IGB
Raffaele	OSTUNI	CASALE SA
Deepak	PANT	Flemish Institute for Technological Research (VITO)
Alessandro	PARENTE	Université Libre de Bruxelles
Thomas	PELLERIN-CARLIN	INSTITUT JACQUES DELORS
Merja	PENTTILÄ	VTT Technical Research Centre of Finland
Anastasios	PERIMENIS	Université libre de Bruxelles
Tomasz	POPRAWKA	PolSCA - Polish Science Contact Agency

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SUNRISE Stakeholder Workshop – List of Attendees

First Name	Last Name	Organisation
Gian-Marco	RIGNANESE	Université catholique de Louvain
Marc	ROBERT	Université Paris Diderot
Martin	ROEB	DLR
Elisabet	ROMERO	Institute of Chemical Research of Catalonia
Arne	ROTH	Bauhaus Luftfahrt e.V.
Saida	SAHRARI	Umicore
Manel	SANMARTI	IREC
Cosimo	SBANO	IChemE Clean Energy SIG
Philippe	SCHILD	EC DG R&I
Thomas	SCHLEKER	European Commission
Anita	SCHNEIDER	EERA
Paul	SCHREURS	VLAIO
Anastasia	SENDREA	European Commission
Sharavanan	SHANMUGAM	Deutsche Energie-Agentur GmbH (dena)
Ian	SHARP	Technical University of Munich
Amin	SHAVANDI	Université libre de Bruxelles
Guilherme	SIEPIERSKI	Solvay
Elfriede	SIMON	Siemens AG
Abdelilah	SLAOUI	CNRS
Yoan	STANEV	European Energy Research Alliance
Ludmilla	STEIER	Imperial College London
Véronique	STERCK	SOLVAY R&I Centre Brussels
Paulina	STYCZEŃ	Department of Innovation and Development of the Poland's Ministry of Science and Higher Education
Tekla	TAMMELIN	VTT Technical Research Centre of Finland Ltd
Geoff	THORNTON	University College London
Marc	TORRELL	IREC
Rita	TOTH	Empa
Roel	VAN DE KROL	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH
Bart	VAN DEN BOSCH	Avantium
Jarl Ivar	VAN DER VLUGT	University of Amsterdam
Niek	VAN HULST	ICFO - Institute of Photonic Sciences
Jean-Pascal	VAN YPERSELE	UCLouvain
Antonin	VLCEK	J. Heyrovsky Institute of Physical Chemistry, Prague
Thomas	VRANKEN	Hasselt University
David	WAROQUIERS	Materials Design Solutions
Yvonne	WICH	Fraunhofer IAO
Petra	ZAPP	Forschungszentrum Juelich GmbH
Dirk	ZIEGENBALG	Ulm University

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6. SUNERGY KICK-OFF MEETING (Final joint event SUNRISE & ENERGY-X)

6.1. Agenda

SUN-ERGY KICK-OFF EVENT

AGENDA

SUN ERGY

SUNERGY policy lunch event at the European Parliament

- Decarbonising Europe: How large-scale R&I initiatives on fossil-free fuels and chemicals can contribute to the European Green Deal

Focus of the event

To facilitate a broader discussion between decision makers, academia, industry and other key stakeholders

- Hosted by Morten Helveg Petersen (MEP, Denmark)

5 February 13.00 – 14.30   European Parliament

By invitation only

SUNERGY public kick-off event

- Fossil-free fuels and chemicals for a climate-neutral Europe

Focus of the event

Focus will be on the operational side, looking at the roadmaps and achievements of the ENERGY-X and SUNRISE CSAs and presenting how cooperation will continue through SUN-ERGY (envisaged roadmap of the initiative, ways to involve stakeholders etc.).

Preliminary programme:

Day 1: February 5, 16.00 – 18.00

TownHall Europe, Square de Meeus, Brussels, 5 February: 16.00 – 18.00 – followed by a networking reception

15.30 – 16.00	Registration and coffee
16.00 – 16.10	Welcome (Bert Weckhuysen, SUNERGY coordinator, Utrecht University)
16.10 – 16.30	SUNERGY (Frédéric Chandezon, SUNERGY deputy coordinator, CEA)
16.30 – 17.00	Perspective from industry - Jan Mertens, ENGIE
17.00 – 17.30	Perspective from European Commission - Peter Dröll, Director Prosperity, DG RTD
17.30 – 17.55	Q&A
17.55 – 18.00	Wrap-up
18.00 – 20.00	Networking reception

ENERGY-X

Sunrise

ENERGY-X and SUNRISE projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 820444 and 816336, respectively.

SUN-ERGY KICK-OFF EVENT

AGENDA

Day 2: February 6, 9.00 – 14.00

The Representation of the State of Hessen to the EU, Brussels, 21 Rue Montoyer

9.00 – 9.30	Registration and coffee
9.30 – 9.40	Opening Address (Johannes Bade, Head of Unit Higher Education, Research and the Arts, Representation of the State of Hessen to the EU)
9.40 – 10.00	SUN-ERGY Vision (Bert Weckhuysen, SUNERGY coordinator, Utrecht University)
10.00 – 11.00	SUN-ERGY Implementation approach - Ramp-up phase leading to a large scale initiative (Gabriele Centi, ERIC) - Starting point of implementation: key elements of SUNRISE and ENERGY-X roadmaps (Hervé Bercegol, CEA) - Q&A
11.00 – 11.30	Coffee Break
11.30 – 11.50	Presentation Photo-contest winner (Amedeo Agosti, University of Bologna)
11.50 – 13.00	Short presentations by recently awarded projects in the area followed by a round table discussion (Moderator: Joanna Kargul, Warsaw University): - CE-NMBP-25-2019: Photocatalytic synthesis, awarded project 'DistributEd Chemicals And fuels production from CO2 in photoelectrocatalytic Devices' (Siglinda Perathoner, ERIC) - LC-SC3-RES-29-2019: Converting Sunlight to storable chemical energy, awarded project 'Novel photo-assisted systems for direct Solar-driven redUctioN of CO2 to energy rich CHEMicals' (Huub de Groot, Leiden University) - ITN-2019: Awarded project 'Training the next generation of scientists in solar chemicals for a sustainable Europe by hybrid molecule/semiconductor devices' (Pau Farràs, NUI Galway) - ITN-2016: Awarded project 'Electrochemical Conversion of Renewable Electricity into Fuels and Chemicals' (Petr Krtil, J. Heyrovsky Institute of Physical Chemistry) - LC-SC3-CC-1-2018: Social Sciences and Humanities (SSH) aspects of the Clean-Energy Transition, awarded project 'COllective action Models for Energy Transition and Social Innovation' (Merce Almuni, VITO-Energyville)
13.00 – 14.00	Lunch

With the friendly support of the Representation of the State of Hessen to the European Union

HESSEN

6.2. Registration List

First Name	Last Name	Organisation
Alessandro	ABBOTTO	University of Milano-Bicocca
Stephan	ABERMANN	AIT Austrian Institute of Technology
Amedeo	AGOSTI	University of Bologna
Marten	AHLQUIST	KTH Royal Insitute of Technology
Yagut	ALLAHVERDIYEVA-RINNE	University of Turku
Michele	ARESTA	IC2R srl
Nicola	ARMAROLI	CNR
Eva-Mari	ARO	University of Turku
Vincent	ARTERO	CEA
Nicolas	AUGE	CEA
Oytun	BABACAN	Imperial College London
Corsin	BATTAGLIA	Empa
Stefan	BAUMANN	Foschungszentrum Jülich GmbH
Didier	BELOIN-SAINT-PIERRE	Empa
Hervé	BERCEGOL	CEA
Davide	BERTUCCIO	freelance
Astrid	BJÖRNSEN	Swiss Federal Research Institute WSL
Patrick	BOURREL	European Commission
Søren	BØWADT	European Commission
Artur	BRAUN	Empa
Lars	BRÜCKNER	DTU
Gabriele	CENTI	ERIC aisbl
Frédéric	CHANDEZON	CEA
Arnold	CHOI	ExxonMobil
Sacha	CORBY	Imperial College London
Athanassios	COUTSOLELOS	University of Crete
Estibaliz	CRESPO	CIC Energigune
DAMIEN	DALLEMAGNE	CO2 Value Europe
Giovanna	D'ANGELO	University of Messina
Simon	DE CORTE	Ghent University
Lieve	DE DONCKER	UHasselt
Huub	DE GROOT	Leiden University
Gaelle	DECROIX	CEA
Angela	DIBENEDETTO	CIRCC
Stefania	DOPPIU	CICenergiGUNE
Nicholas	DUMMER	Cardiff University
Nicolas	DUPUY	Université de Lorraine
James	DURRANT	Imperial college london

SUN-ERGY KICK-OFF EVENT

LIST OF ATTENDEES

First Name	Last Name	Organisation
Peter	ELLIS	Johnson Matthey
Carina	FABER	UCLouvain
Umar	FAROOQ	jamia millia islamia
Pau	FARRAS	NUI Galway
Max	FLEISCHER	Siemens
Fernando	FRESNO	IMDEA Energy Institute
Manuel	FRONDEL	RWI - Leibniz-Institute for Economic Research
Jelizaveta	GAMALEJEVA	Eurideas
Sebastian	GOEKE	Applied Materials
Gideon	GRADER	Technion
Alexa	GRIMM	Utrecht University
Elena	GUARNERI	Technical University of Denmark
Anna	HANKIN	Imperial College London
Jan Erik	HANSSEN	1-Tech SPRL
Sean	HENNESSEY	NUI Galway
Han	HUYNH	ENGIE Laborelec
Holger	IHSSEN	Helmholtz Association
Philippe	JACQUES	EMIRI
Paul	JANSSEN	SCK•CEN
Nicolas	JEULAND	SAFRAN
Pablo	JIMENEZ-CALVO	Solid States Laboratory, University Paris Saclay
Joachim	JOHN	IMEC
Hannah	JOHNSON	Toyota Motor Europe
Marcus	JUVANCIC	Fraunhofer e.V.
Joanna	KARGUL	Centre of New Technologies, University of Warsaw
Stanisław	KARPIŃSKI	Warsaw University of Life Sciences, Institute of Biology
Pasi	KEINÄNEN	Tampere University
Harald	KERP	M2i
Florian	KIEFER	Empa
Andrej	KOBE	EC DG ENV
Petr	KRTIL	J. Heyrovsky Institute of Physical chemistry
Michael	KYRIAKOPOULOS	European Commission
Lars	LAUTERBACH	Technische Universität Berlin
Julio	LLORET	ICIQ - Institut of Chemical Research of Catalonia
Axel	LÖFBERG	Univ. Lille
Laura	LOPEZ	ICIQ
Ann	MAGNUSON	Uppsala university
Haresh	MANYAR	Queen's University Belfast

SUN-ERGY KICK-OFF EVENT

LIST OF ATTENDEES

First Name	Last Name	Organisation
Guy	MARIN	Ghent University
Roeb	MARTIN	DLR
BERTA	MARTÍNEZ	CSIC
Jordi	MARTORELL	ICFO
Ivan	MATEJAK	EERA aisbl
Jan	MERTENS	ENGIE CC
Joan Ramon	MORANTE	IREC
Poul Georg	MOSES	Haldor Topsoe
Sabrina	MÜLLER	DECHEMA e.V.
Sophia	NEUMANN	Representation of the State of Saxony-Anhalt to the EU
Huu Chuong (Bob)	NGUYEN	Institute of Chemical Research of Catalonia (ICIQ)
Kathrine Bjerregaard	NIELSEN	Technical University of Denmark
Andrea	NOGOVA	Palacky University Olomouc, Regional Centre for Advanced Technologies and Materials
Jens	NØRSKOV	Technical University of Denmark
AMELIA	OCHOA	ICIQ
Bart	ONSIA	imec
Bilal	OUTIRBA	Université Libre de Bruxelles
Alessandro	PARENTE	Université Libre de Bruxelles
Luca	PASQUINI	University of Bologna
Siglinda	PERATHONER	ERIC aisbl
Anastasios	PERIMENIS	CO2 Value Europe
Simon	PERRAUD	CEA-Liten
LORGE	PHILIPPE	H2WIN SA
Virginia	POGGI	Università di Bologna
Tomasz	POPRAWKA	PolSCA
Martina	RÁDLI	Utrecht University
Gian-Marco	RIGNANESE	UCLouvain
Bruno	ROBERT	CEA
Martin	ROEB	DLR
Dorota	RUTKOWSKA-ZBIK	Jerzy Haber Institute of Catalysis and Surface Chemistry PAS
Svetlana	SAMSONOVA	Port of Antwerp
Alessandra	SANSON	CNR-DSCTM
Micheal	SCANLON	University of Limerick
Philippe	SCHILD	European Commission - DG Research and Innovation
Anita	SCHNEIDER	EERA

SUN-ERGY KICK-OFF EVENT

LIST OF ATTENDEES

First Name	Last Name	Organisation
Paul	SCHREURS	VLAIO
Alessandro	SENOCRATE	EMPA
Guilherme	SIEPIERSKI	Solvay
Alexandra	SIMON	WindEurope
Minas	STYLIANAKIS	Hellenic Mediterranean University
Piotr	SWIATEK	New European Energy
Ludovic	TROIAN-GAUTIER	Université libre de bruxelles
Annette	TRUNSCHKE	Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin
Yoed	TSUR	Technion - Israel Institute of Technology
richard	VAN DE SANDEN	DIFFER-TU/e
Alexander	VAN DER MADE	Shell Global Solutions International B.V.
Barend	VERACHTERT	European Commission
Walter	VERMEIREN	TOTAL Petrochemicals R&D Belgium
Tatiana	VILARINHO	CEA-Liten
Sara	VINKLATOVA	Leitat Technological Center
Bert	WECKHUYSEN	Utrecht University
Helge	WESSEL	European Commission
Michael	WESSEL	Project Management Jülich
Małgorzata	WITKO	Jerzy Haber Institute of Catalysis and Surface Chemistry PAS
Benjamin	WYNIGER	CEA/EERA

Main changes in the updated version :

Page 3 & 5. Final closing event, the SUNERGY kick-off, added to the executive summary and purpose paragraph.

Page 9. Figure 10 added, poster format of the outreach roll-up.

Page 14. Figure 17, new roadmap infographic added.

Page 16-18. Description and captures of the last videos released, added.

Page 19. Last newsletter and captures of the one-year wrap-up added.

Page 20-22. Point 3. Cooperation with Energy-X, joint materials point added.

Page 29-30. Last press release, 4th, added.

Page 31-42. Update of press clippings.

Page 50-51. Capture of the SUNERGY Kick-off agenda added.

Page 52-55. Capture of the SUNERGY Kick-off registration list added.

Solar Energy for a Circular Economy

Deliverable D3.4

Data Management Plan (DMP)

Lead Beneficiary	ULEI
Delivery date	xx/03/2020
Dissemination level	Public
Version	v3.0

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Document Information

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Authors	ULEI
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Deliverable name	Data Management Plan (DMP)
WP	3 – Dissemination, Communication and Education

Version	Date	Author	Description
v 0.1	29/07/2019	Laura López, Amelia Ochoa	First draft creation
v 0.2	20/08/2019	Angela Noble	Corrections
v 0.3	21/10/2019	Huub de Groot	Revision
v1.0	22/10/2019	Laura López, Amelia Ochoa	Update
v1.1	29/10/2019	Huub de Groot	Executive summary and editing
v1.1	1/11/2019	Ann Magnuson	Quality and Impact assurance remarks
v1.2	6/11/2019	Laura López and Huub de Groot	Revision in response to QIA remarks
v2.0	14/02/2020	Laura López	Revision and updates
v3.0	17/02/2020	Huub de Groot	Final Revision

EXECUTIVE SUMMARY

The Data Management Plan (DMP) presents the main elements of the data management policy used by the Consortium during the CSA project. The plan has evolved during the lifespan of this project to include additional datasets, and to adapt to changes. It describes the types of data, how they will be preserved and if they are shared or confidential. The DMP provides an overview of the datasets. Initially data management will build on the existing infrastructure with the partners. Data produced by the consortium will be made available through the SUNRISE website and on the PLAZA intranet, maintained by project management. The publication and data repository for the project outcomes have been gradually shifted to ZENODO hosted at the Conseil Européen pour la Recherche Nucléaire (CERN) by partner ICIQ. This is the last version of the plan delivered at the end of the CSA and intended to be the basis to support future actions.

Table of Contents

1. INTRODUCTION

The purpose of the Data Management Plan (DMP) is to provide an overview of the main elements of the data management policy that is used by the Consortium concerning the project data. A DMP is not a fixed document but it evolves during the lifespan of projects. New versions are created whenever important changes to the project occur due to inclusion of new data sets, changes in consortium policies or other external factors.

The DMP covers the complete research data life cycle. It describes the types of research data that will be collected, processed or generated during the project, how the research data will be preserved and what parts of the datasets will be shared or kept confidential.

This document includes an overview of the datasets to be produced by the project and the specific conditions that are attached to them. This is the updated version in Month 12, at the end of the CSA project, of the mid-term DMP version (delivered on November 2019). The main changes are listed at the end of the document, aimed to extend information regarding the DMP of a European large-scale research initiative.

This Data Management Plan describes the **SUNRISE** strategy and practices regarding the provision of Open Access to scientific publications, dissemination and outreach activities, public deliverables and research datasets that will be produced.

Categories of outputs that **SUNRISE** has given Open Access (free of charge) and have been agreed upon and approved by the Management Board (MB), during the CSA period, include:

- Project reports and publications (publications, conference proceedings, workshops, etc.)
- Dissemination and Outreach material (leaflets, roll-ups, infographics, videos, etc.)
- Deliverables (public)

Any dissemination data linked to exploitable results will not be put into the open domain if this compromises its commercialization prospects or has inadequate protection. Intellectual Property (IP) issues and results protection will be in accordance with the Innovation Plans and agreements developed in WP2 (Innovation & Exploitation). This will be especially important for research results within a future large scale research initiative.

Treatment of personal data will be done following the General Data Protection Regulation (GDPR) [1] and will not be made public without written consent.

1.1. **SUNRISE** strategy and practices

The decision to be taken by the project on how to publish its documents and data sets will come after the more general decision on whether to proceed with public dissemination directly or to seek first protection by registering the developed IP. Open Access must be granted to all scientific publications resulting from Horizon 2020 actions. This will be done following the Guidelines on Open Access to Scientific Publications and Research Data in Horizon 2020 (15 February 2016) [2] and any other following Open Access policy within Horizon Europe.

Concerning publications, the consortium will provide open access to the scientific publications coming out of the action. Open access will be guaranteed following either the 'Gold' model, where an article is immediately released in Open Access mode by the scientific publisher, or according to the "Green" model, where the authors make their publications available with a freely accessible institutional or specialist repository. A copy of the publication will be deposited in a public repository, OpenAIRE, and ZENODO or those provided by the host institutions, and available for downloading from the **SUNRISE** webpage. The associated costs will be covered by the authors of the publication, their institutions, or funding agencies.

Concerning research data, the main obligations of participating in the Open Research Data Pilot are:

1. To make it possible for third parties to *access*, *mine*, *exploit*, *reproduce* and *disseminate* - free of charge for any user - the following:
   (i) the published data, including associated metadata, needed to validate the results presented in scientific publications, as soon as possible
   (ii) other data, including raw data and associated metadata, as specified and within the deadlines laid down in the data management plan; and
2. To provide information about *tools* and *instruments* at the disposal of the beneficiaries and necessary for validating the results.

SUNRISE follows the Guidelines on Data Management in Horizon 2020 (15 February 2016) [3]. Following guidelines within Horizon Europe will be complied by the **SUNRISE** continuation action **SUNERGY** (coming from the association of the preparatory actions SUNRISE and ENERGY-X) in the scenario of a large European research and innovation initiative, such a public-private partnership.

The consortium has chosen ZENODO as the central scientific publication and data repository for the project outcomes. Released documents and data are progressively being added to the database. This repository has been designed to help researchers based at institutions of all sizes to share results in a wide variety of formats across all fields of science. The online repository has been created through the European Commission's OpenAIREplus project and is hosted at CERN.

ZENODO enables users to:

- easily share the long tail of small data sets in a wide variety of formats, including text, spreadsheets, audio, video, and images across all fields of science
- display and curate research results, get credited by making the research results citable and integrate them into existing reporting lines to funding agencies like the European Commission
- easily access and reuse shared research results
- define the different licenses and access levels that will be provided

Furthermore, ZENODO assigns a Digital Object Identifier (DOI) to all publicly available uploads, to make content easily and uniquely citable.

A new community within ZENODO has been created for SUNRISE (https://zenodo.org/communities/sunrise/?page=1&size=20) where the public outcomes have been uploaded and linked with the European Commission grant reference: SUNRISE - Solar Energy for a Circular Economy (816336). The same or very similar procedures will be followed with future actions in the framework of a SUNERGY large scale research and innovation initiative.

2. DATA COLLECTION

2.1 Use of existing and third party data

SUNRISE CSA will use abundant existing and third-party data to generate the six main project outputs:

- **Vision (D1.1).** Consolidated vision: SUNRISE technical report with: (i) quantitative S&T targets on the short (2022), mid (2025) and long term (2030); (ii) definition of instruments and benchmarks to assess the impact of SUNRISE on the economy, the environment and the society; (iii) description of the technological demonstrators and their expected evolution over time, also beyond 2030.
- **Roadmap (D1.2).** Global Roadmap for the large scale research initiative.
- **Blueprint (D1.3)** The SUNRISE map: a public document identifying the necessary S&T resources, state-of-the-art EU facilities, available infrastructure & funding, and the criteria to build an open and inclusive innovation pipeline for the demonstration of source to product value chains of SUNRISE/SUNERGY technologies.
- **Governance Plan (D4.1) and Terms of Reference (D4.2)** Proposal for the organizational structure and processes of the Large Scale Research Initiative and Terms of reference for the governance of the Large Scale Research Initiative.
- **Innovation and Exploitation plan (D2.3).** Innovation and Exploitation including IPR consortium guidelines.

Together with the dissemination and communication plan, and an executive summary in the form of a manifesto, this provides a comprehensive description of the prospective large scale research initiative.

To produce these documents, previous publications, and reports from partners, supporters and other actors in the field have been taken into account. Therefore, the consortium connected to several databases containing the reference documents. Depending on the needs of the different working groups in charge of the SUNRISE reports to be delivered, the information exchange has been done through different channels, for instance using free online sharing and editing tools (*i.e.* Dropbox, Google Drive, etc.). Nevertheless, the main channel for information exchange and data storage between consortium partners is the intranet PLAZA. Access to this archive system is provided to all partners by the company in charge of the project's management M2i (Materials Innovation Institute). For future actions in the SUNERGY context an intranet tool for sharing of information and documents should also be available.

The consortium has a wide interaction with different stakeholders forming part of the SUNRISE community. Communication with supporters and followers is based on social media and e-mails and/or newsletters sent using the MailChimp e-mail marketing service (see section 4).
The consortium has collected input from the different partners and supporters to create Priority Research Directions (PRDs) among the three main research approaches that were defined at the proposal stage, see table 1. These documents have been useful during the road mapping process, which implied further interactions with the supporting community (the roadmap was open to supporters input after the first version release in November 2019).

Table 1. List of PRDs collected within SUNRISE CSA

Approach 1. ***Electrochemical conversion with renewable power***	Generic PRD Approach 1
	Hydrogen PRD
	CO_2 to chemicals
	Ammonia
	Jet Fuels
	Electrifying chemical synthesis
Approach 2. ***Direct conversion via integrated artificial photosynthetic systems***	Generic PRD Approach 2
	Complex molecular systems
	Photon management
	Hydrogen
	CO_2 to chemicals
	Ammonia
	Jet Fuels
Approach 3. ***Direct conversion via biological and biohybrid systems.***	Generic PRD Approach 3
	Biocatalysts
	Biohybrid systems
	Hydrogen
	CO_2 to chemicals
	Ammonia
	Jet Fuels

Key Enabling Technologies	Modeling
	Quantitative Sustainability Assessment (QSA)

2.2 Data collection and creation mechanisms

For the creation of new documents such as deliverables from the project, the responsible people in charge collected the corresponding bibliography documents needed to compare and contrast relevant information. Following documents' analysis and partners' and supporters' expertise, new data has been generated and collected in the resulting action documents, according to the project's objectives.

Several members of the consortium have been selected as the contact person to receive and collect inputs from interested supporters to be included in the PRDs and other project documents as the Vision and Roadmap.

Databases containing the contact information of official supporters, newsletter subscribers, and social media followers have also been generated during the CSA period and will remain available. More data will be generated in the continuation action.

Also, dissemination and communication material has been created and will continue to be generated:

- Conferences: academic partners of **SUNRISE** attend the most relevant conferences and will present the project and its objectives through oral talks and/or posters.
- Workshops: two workshops were organized in M4 and M12 to promote awareness of the **SUNRISE** objectives and results and merger with ENERGY-X under the SUNERGY name (data produced: presentations and posters).
- Dissemination material: flyers, videos, public presentations, **SUNRISE** newsletter, press releases, tutorials, etc.
- Communication material: website, social media, press releases, audiovisual material. Outreach activities for the project's promotion to the general public.

Finally, input and opinions from the various audiences reached by the events organized by SUNRISE have been collected, for instance by surveys (*i.e.* surveys for outreach activities and exhibitions, surveys after meetings and workshops, etc.), these are preferably anonymous and created in a case-by-case scenario using free online tools (such as Google forms, formsite, etc.)

3. DATA STORAGE AND SECURITY

3.1 Measures to comply with the security requirements and to mitigate data risks

The main storage tool has been the project website: www.sunriseaction.eu. The current website has been hosted in the internal servers of the work package 3 (WP3) leader, ICIQ and in the internal servers of the web development company (Avellana Digital). In both cases the current policy for back-ups consists of daily recovery of the full server in case there is any technical problem and it needs to be restored. An agreement between ICIQ and the web development company will allow the website to be open and accessible free of charge for 3 years after the beginning of the action, hosted in the web developer servers, including all the information and documents publicly available.

On the website, there is also a direct link to the intranet site PLAZA. As mentioned before, this is the main tool for internal information exchange within the different working groups of the project. The site is managed by M2i, the current policy is to arrange for daily back-ups and deleted files are kept in a separate folder so that they can be recovered without the need to mount a backup structure or file system. Also, there are weekly, 4-week and 6-month backups kept. Currently, the site stores relevant information for the SUNRISE partners, such as the generated working documents, data related with the project's implementation, minutes and agendas of meetings, data about related projects, results, etc., information about supporters' names and contacts and copies of letters of support. This information is only accessible to designated contacts from each of the partner institutions. A login page needs to be filled in for access, requiring an identified e-mail address and a personalized random password. This protection is needed for confidentiality issues, especially related to the protection of personal data and any intellectual property.

The PRDs and any other confidential information to be shared with the stakeholders can be accessed through a password-protected site on the project's website: https://sunriseaction.com/priority-research-directions-prd-vision/.

The documents associated with all the public deliverables defined in the Grant Agreement (Table 2), will be accessible through the project's website free of charge. The present document, the **SUNRISE** Data Management Plan, is one of the public deliverables that after submission to the European Commission and approval will be released in open access mode in the **SUNRISE** webpage, CORDIS website (https://cordis.europa.eu/project/rcn/221651/factsheet/en) and ZENODO.

Table 2. List of Public Deliverables

Deliverable (number)	Deliverable name	WP	Short name of the lead participant	Type	Dissemination Level	Updated delivery date (in months)
D1.1	Vision	1	CEA	Report	Public	2
D1.2	Roadmap	1	UCL	Report	Public	6
D1.3	Blueprint	1	ULEI	Report	Public	14
D2.1	Process	2	Fraunhofer	Other	Public	2
D2.2	Structure	2	JM	Other	Public	6
D2.3	IE Plan	2	SIEMENS	Report	Public	14
D3.1	Dissemination Plan	3	ICIQ	Report	Public	6

D3.2	Website & App	3	ICIQ	Other	Public	2
D3.3	Resources	3	UNIWARSAW	Report	Public	8
D3.4	Data Management Plan	3	ULEI	ORDP: Open Research Data Pilot	Public	6
D4.1	Governance Plan	4	CEA	Report	Public	8
D4.2	Terms of Reference	4	CEA	Report	Public	12
D5.1	Midterm Review	5	ULEI	Other	Public	6
D5.2	Symposium	5	ULEI	Other	Public	11
D5.3	Final Report	5	ULEI	Report	Public	14

For future scientific publications the "Gold Open Access" policy will be preferably followed, in addition to uploading them into open access repositories (*i.e.* ZENODO, OpenAIRE, institutional repositories). Moreover, during the CSA and as part of the Dissemination and Communication strategy, a new smartphone app has been created to enable partners to share their latest publications. The application is now under validation (http://events.tickaroo.com/projectsunrise/), consortium partners can share their important publications offering quick access to novelties in the field, this system has been tested among partners during the CSA and an open version will be created in future actions based on the feedback of first users, collected in a survey. This feedback will also be important to decide if such an App might also be used in the future as an outreach platform to reach the general public.

All the SUNRISE dissemination and communication material will be available (during and after the project) on the SUNRISE website and ZENODO.

4. DATA DOCUMENTATION

4.1 Dataset Description

Whenever needed, instructions to name files and folders will be delivered to ensure data control and future re-use. For instance, in the PLAZA site, all documents related to the different work packages can be found under the Implementation folder.

For PRDs, specific templates and names have been provided to ensure information exchange and versions management while collecting input from numerous authors.

When the data is collected in a public deliverable this format will be used:

D.X.Y SUNRISE_ Title of the Deliverable

4.2 Digital Object Identifier (DOI)

The DOI uniquely identifies a document. This identifier will be assigned by the publisher in the case of scientific publications in journals. In the case of other publications or documents (deliverables, dissemination and communication materials) uploaded into the ZENODO repository, an automatic DOI is created by the system. Items deposited in ZENODO, including all the scientific publications, are archived and retained for the lifetime of the repository, which is currently the lifetime of the host laboratory CERN (at least for the next 20 years).

5. DATA ACCESS, SHARING, AND REUSE

5.1 General Data Protection Regulation (GDPR)

The main restriction for the sharing of data generated during the CSA comes due to GDPR. All data related to personal information, mainly person contact names from partners and supporters and e-mail addresses, is kept under the password-protected intranet site, only reachable for selected individuals related to the project, upon invitation by M2i. Additionally, contact details could be stored in personal folders from the partner institutions or temporarily in folders that are shared online while an event is organized, as long as these data are not made public, only shared with authorized personnel from the consortium and not used for commercial purposes.

The amount of personal data collected will be kept to a minimum, is in most cases only names, employing institutions and e-mail addresses. Whenever this kind of information is requested, explicit consent will be required from users. For instance, the following statements are used:

- Filling formularies or registration forms: a mandatory option to be filled is included, for example:

I am aware that the organization committee will not share my data with any third party nor use it for commercial purposes. *

◉ Yes

- Making public a registration list: explicit consent is requested by an optional option to be filled in the registration form, for example:

I authorize the organization committee to include my name and organization in the list of attendees available at the workshop.

◉ Yes

- Getting new subscribers to the SUNRISE public newsletter or contact by new possible supporters: a mandatory option needs to be ticked before the contact information can be sent when subscribing via the SUNRISE website:

◉ **I have read and accepted the GDPR policy**

Interested users have access to read the GDPR policy described in the website:

"Marketing Permissions

The *SUNRISE Project will use the information you provide on this form to be in touch with you and to provide updates on our activity by e-mail. To comply with the General Data Protection Regulation (GDPR) we need your approval. Please let us know if you would like to hear from us by ticking the following button: "Please, keep me updated on SUNRISE news and events".*

You can change your mind at any time by clicking the unsubscribe link in the footer of any email you receive from us, or by contacting us at contact@sunriseaction.eu. We will treat your information with respect. By clicking below, you agree that we may process your information in accordance with these terms.

We use Mailchimp as our marketing platform. By clicking below to subscribe, you acknowledge that your information will be transferred to Mailchimp for processing. Learn more about Mailchimp's privacy practices here."

In addition to ask for user's approval, information about the marketing platform used (Mailchimp) is also provided. This platform is used for sending newsletters and informative e-mails to partners, supporters, followers and other related contacts.

To comply with the regulations governing cookies under the GDPR and the ePrivacy Directive, users will also find a pop-up message at the beginning of the website session, which can be either accepted or ignored. It reads as follows:

This website uses cookies to provide you with the best browsing experience. Find out more or adjust your settings.

These or very similar GDPR policies will be kept in the continuation action and increased as needed according to policy updates and the type of data collected/generated.

5.2 Data sharing and reuse

As explained in previous sections, public free-of-charge access to deliverables and documents generated through the project is done through:

- The **SUNRISE** website, after approval by the quality and impact assurance team. If the document is subsequently updated, the original version will be replaced by the latest version.
- The CORDIS website, will host all public deliverables as submitted to the European Commission.
- The ZENODO repository.

These websites will also provide access to communication and dissemination materials.

6. DATA PRESERVATION AND ARCHIVING

Open Access, through the **SUNRISE** public website will be maintained for at least 3 years after the project start.
All public deliverables will be archived and preserved on ZENODO and will be retained for the lifetime of the repository.
Internal information kept in the intranet site PLAZA will be available to consortium partners for at least 6 months after the project finishes, then important information will be kept in an internal server and a hard copy by the project coordinator in Leiden University.

7. RESPONSIBILITY FOR THE IMPLEMENTATION OF THE DMP

The consortium made a selection of relevant information, ensuring that the data generated was carefully analysed before giving open access to it in order to be aligned with the exploitation policy described in the Consortium Agreement (CA). Therefore, data sharing in open access mode can be restricted as a legitimate reason to protect results expected to be commercially or industrially exploited. Approaches to limit such restrictions will include agreeing on a limited embargo period or publishing selected (non-confidential) data.

Each partner of the consortium is responsible for the storage and backup of the data produced in their respective host institutions. Furthermore, each partner is responsible for uploading all the relevant data produced during the project to the **SUNRISE** intranet PLAZA (restricted to the members of the consortium). ICIQ as leader of the Dissemination, Communication and Education Work Package (WP3) is in charge of collecting all the public documents and upload them in the **SUNRISE** public website and ZENODO. The final responsibility to ensure that guidelines within this Data Management Plan are correctly pursued lies with the coordinator, Leiden University.

8. FUTURE ACTION

A continuation of the CSA preparative action within the joint initiative SUNERGY will include a DMP based on the **SUNRISE** strategy and practices described in point 1.1. Main points are:

- Specific guidelines about making public or not documents and data from a following **SUNRISE** action will be collected in future Consortium Agreements, including specific Innovation & Exploitation and IPR sections. Data sharing in open access mode can be restricted as a legitimate reason to protect results expected to be commercially or industrially exploited.

- Any research project within a large scale European research action will need to comply with the relevant European guidelines on Open Access for scientific publication and research data.

- Concerning publications, the consortium in charge of any research project following **SUNRISE** CSA will guarantee open access within the embargo periods foreseen by the European Commission (EC). Copies of the publications will be deposited in public repositories, being ZENODO the main option.

- Concerning research data, any data needed to validate the results presented in scientific publications, including metadata, will be made public in accordance with the European guidelines of the moment. ZENODO will be the central data repository. In particular, regarding computational data coming from simulations, several large material databases containing properties of millions of existing and hypothetical materials have already been identified within the modelling PRD (Pseudo Receptance Difference) that will provide an autonomous platform for accelerated material design, development and system integration (within key-enablers). These databases are currently freely accessible:
    - the AFLOW distributed materials property repository
    - the Harvard Clean Energy Project Database
    - the Materials Cloud
    - the Materials Project (including the use of MPContribs)
    - the NoMaD (Novel Materials Discovery) Repository
    - the Open Quantum Materials Database
    - the Computational Materials Repository
    - the Data Catalyst Genome
    - the ioChem-BD Platform

  New concepts for materials on demand will be made available to the public for R&D.

- Concerning personal data, the amount of personal data collected will be kept to a minimum and mainly related to contact databases. Nevertheless, in the context of a broader initiative, social sciences studies might also need access to further data. In all cases, GDPR policies will be strictly followed and appropriate access permissions and security measures will be put in place.

- Specific measures for data sharing and data archiving and preservation will be defined for each research project.

9. REFERENCES

[1] Regulation (EU) 2016/679 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data. This text includes the corrigendum published in the OJEU of 23 May 2018.
Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02016R0679-20160504&from=EN

[2] Guidelines on Open Access to Scientific Publications and Research Data in Horizon 2020, 15 February 2016.
Available at:
http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hioa-pilot-guide_en.pdf

[3] European Commission, Guidelines on Data Management in Horizon 2020, 15 February 2016. Available at:
http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hioa-data-mgt_en.pdf

Main changes in the updated version :

Page 2. The executive summary has been modified to highlight that this is the final version of the document.

Page 4. Changes in the introduction also to clarify that this is the updated version.

Page 5. References to future actions and policies have been added.

Page 6. Information about the SUNRIES zenodo community is provided.

Page 7. References to the future initiative and participatory action for the roadmap.

Page 8. Updated information regarding contact databases and content of the workshops.

Page 9. Additional information about the SUNRISE website has been added, the expected delivery dates have been updated in table 2.

Page 12. Further indications for future actions included regarding GDPR.

Solar Energy for a Circular Economy

Deliverable D4.1
Proposal for the organisational structure and processes of the SUNRISE large scale initiative

WP4. Governance and processes

Lead Beneficiary	CEA – Commissariat à l'énergie atomique et aux énergies alternatives
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v 0.1	27/10/2019	F. Chandezon	Creation template for the deliverable.
	29/11/2019	M. Meier	Contribution of M. Meier on Task 4.1 (section 2)
	12/12/2019	H. de Groot	Contribution Rocket Governance draft
V1	16/12/2019	F. Chandezon	1st draft of the deliverable.
V2	02/01/2020	F. Chandezon	2nd version
V3	08/01/2020	F. Chandezon	3rd version
V4	26/01/2020	F. Chandezon, M. Fleischer, H. de Groot, M. Meier	4th version
V5	29/01/2020	F. Chandezon, H. de Groot	5th version
V6	28/02/2020	F. Chandezon	6th version

EXECUTIVE SUMMARY

This document, D4.1: *Proposal for the organisational structure and processes of the SUNRISE large scale initiative*, is a deliverable of the **SUNRISE** Project, which is funded by the European Union's H2020 Programme under Grant Agreement No. 816336. The original aim of the Deliverable D4.1 was: "*Proposal for the organisational structure and processes of the SUNRISE large scale initiative*". One key fact led to an adapted D4.1 compared to the original plan: the decision of SUNRISE and ENERGY-X consortia, who were both granted under the call FETFLAG-01-2018, is to merge in a new initiative, SUNERGY, at the end of the current CSAs as both share common challenges and objectives.

Efforts of WP4 were dedicated to exploring instruments and options (partnerships, missions) in the context of the next Framework programme Horizon Europe (HE) in order to build a tentative scenario for launching a Large Scale European Research and Innovation Initiative (LSERI) based on SUNERGY vision and challenges. All this was done in close collaboration with ENERGY-X, including regarding governance.

The deliverable presents first the analysis of the governance structure of running Flagships (Task T4.1, lead: FZ Jülich) and other European large scale initiatives *e.g.* partnerships to learn from best practices for the future SUNERGY initiative. It afterwards presents a tentative scenario and its timeline based on the various instruments in HE, *i.e.* partnerships and missions. While current prospective HE public-private partnerships (PPP's) focus on improvements on the demand side with limited impact, SUNERGY proposes **a pipeline of high impact technologies** that boost efficiency **on the supply side** with light-to-products and fuel conversion from atmospheric CO_2 at high yields up to **2500 ton/ha/yr**. To achieve this, a programmatic effort is highly recommended and a proposal entitled "*3FCM: Fossil-free fuels, chemicals and materials for a circular economy*" was put forward.

We thus urge to complement the scope of existing European partnerships and enable the **full decoupling of economic growth from the utilization of resources** at the local, regional, national and European levels with supply of renewables for a sustainable resilient growing economy. The possibility for SUNERGY to join other existing communities in the frame of new partnerships to be launched in 2021 was also considered, including "*Carbon neutral and circular industry*" (follow-up of SPIRE) or "*Clean hydrogen*". Because of the tilt towards the demand side and to narrow focus this did not appear a feasible scenario. Since these communities are already well established this would lead to a fragmentation and marginalization with lack of focus on the supply side. Additionally, splitting into different communities and candidate partnerships would not allow for a programmatic effort addressing all aspects of the SUNERGY. This would inevitably lead to a loss of the global disruptive vision and approach of SUNERGY and thus a loss of impact. Nevertheless, there are ongoing discussions with the candidate partnerships that could have links with SUNERGY.

The other option considered are the missions of HE, where there is a strong bottom-up approach to engage citizens and the society. Based on the five missions to be launched in 2021 and their associated keywords, it appears that SUNERGY could have links with at least 3 of these missions:

"*Adaptation to climate change, including societal transformation*", "*Climate neutral and smart cities*" and "*Soil health and food*". As discussed above for partnerships, this appeared not to be a long-term scenario for SUNERGY due to the risk of fragmentation.

We thus recommend for a SUNERGY large-scale research and innovation initiative the <u>co-programmed public private partnership (cPPP)</u> instrument in Horizon Europe. Due to the flexibility of the cPPP, it can include both the programmatic and the bottom-up components under a single governance terms of reference framework with a program board of mandated experts that are personally responsible for assuring quality and impact facilitating rapid progress, without transfer of authority from the member states (MS) and EC, rather than a new mission built on the SUNERGY vision be launched that is disconnected from the programmatic efforts. Besides having both public and private partners, the cPPP instrument also allow to have MS involved via the signature of memoranda of understanding to allow aligning national priorities with the SUNERGY roadmap. It should be noted that the exact details of the participation of MS in cPPPs is still under discussion with the EC at the time of writing this report.

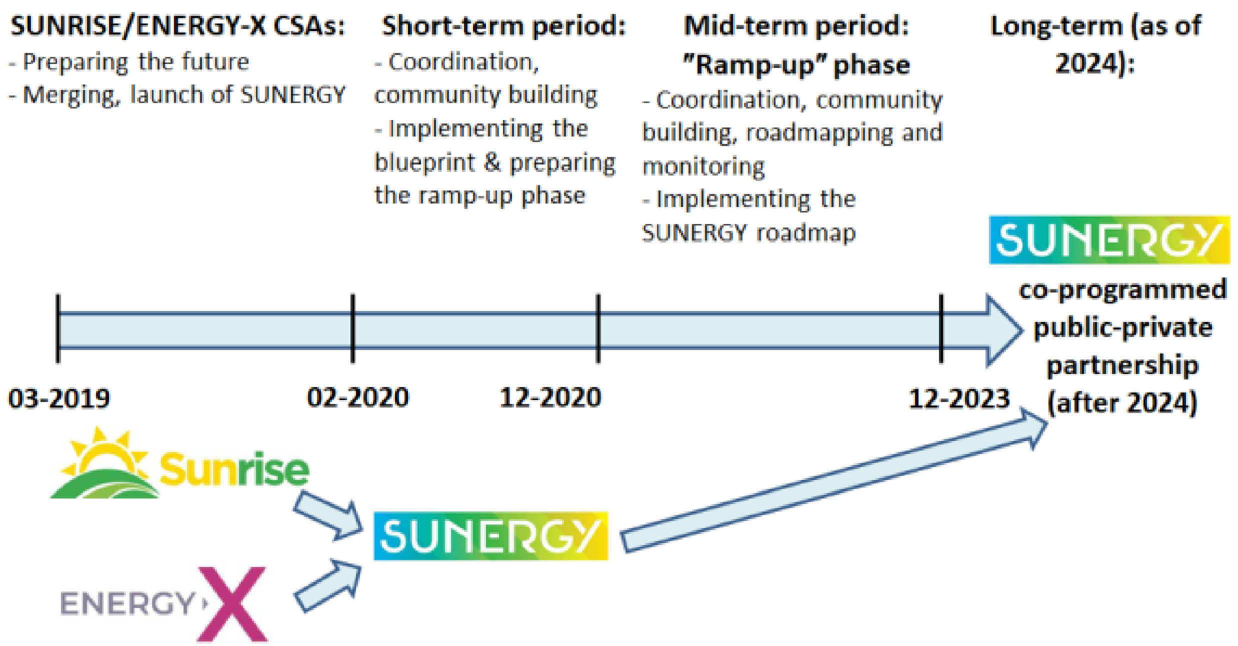

Figure: Tentative scenario and timeline for the SUNERGY large scale European research and innovation initiative.

A tentative scenario and timeline to build and launch into action such SUNERGY large scale European research and innovation initiative is presented in the figure above. The main steps are:

- **Short term (2020)**: this period starts at the end of the two SUNRISE and ENERGY-X CSAs with the evaluation of the results of the two projects, until a new project is launched. This period will be used to implement the blueprint and prepare the next "ramp-up" phase (*e.g.* strengthening the community, writing proposals, proposing topics for the work programmes of HE based on the SUNERGY roadmap,…);
- **Mid-term (2021-2023)**: **"*ramp-up phase*"** towards a SUNERGY LSERI partnership with common coordination activities done in the frame of a common CSA (Coordination and

Support Action) backed by several RIA (Research and Innovation Actions) and IA (Innovation Actions) open calls based on the roadmaps of SUNRISE and ENERGY-X. All the granted RIA and IA projects would conclude a collaboration agreement with SUNERGY and the CSA to contribute to the activities of the whole initiative and would be subject to mid-term review and evaluation at the end by a program board of experts with mandates from the MS and the EC to assure quality and impact without transfer of authority away from the MS and EU. This period would also be dedicated to develop and strengthen the SUNERGY community (academia, industry and society) and to pave the way towards the SUNERGY partnership with the contribution of the different stakeholders.

- **Long-term (after 2024)**: this corresponds to the start of a SUNERGY partnership "*Fossil-free fuels, chemicals and materials for a circular economy (3FCM)*". Regarding the type of partnership, with bottom-up (RIA) and programmatic (IA) components, a co-programmed European partnership (cPPP) appears as the most adapted.

Along its course, SUNERGY will also interact with other communities and, including the candidate partnerships and the missions mentioned above. Finally, it can be emphasized that discussions around the future partnerships in Horizon Europe are still ongoing, which might lead to possible changes and evolutions of the scenario. This will be closely followed in particular during the short-term phase, right after the end of the SUNRISE and ENERGY-X CSAs and before the ramp-up phase is launched. As the volume of the programmatic part increases over time, in the longer term the cPPP could evolve into an institutionalized partnership.

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1. SCOPE OF THE DELIVERABLE D4.1 "Proposal for the organisational structure and processes of the SUNRISE large scale initiative"

D4.1 is one of the two deliverables of the Work Package (WP) 4 "Governance and processes" of the SUNRISE CSA. The scope of this WP is to establish the organisational structure and the related operating and decision processes of the future Large Scale European Research and Innovation Initiative (LSERI). Those shall ensure an effective scientific leadership and governance structure, taking into account the lessons and best practices learned from the existing Flagships and other LSERI such as partnerships. This WP is structured into three tasks and two deliverables:

- Task T4.1 (M1-M2): Analyse the governance structure of running Flagships and other European large scale initiatives ;
- Task T4.2 (M3-M8): Developing the organisational structure and processes of the future LSERI;
- Task T4.3 (M9-M12): Set-up the organisational structure and processes of the LSERI.

The original aim of D4.1 was: "*Proposal for the organisational structure and processes of the SUNRISE large scale initiative*". It is related to Tasks T4.1 and T4.2. Two facts led to an adaptation of D4.1 compared to the original plan:

1) **Flagship instrument**: this instrument no longer exists in Horizon Europe;

2) **Merging of SUNRISE and ENERGY-X consortia**: SUNRISE and ENERGY-X, were both granted a CSA under the call FETFLAG-01-2018 and share common challenges and objectives. They agreed in August 2019 to merge at the end of the two CSAs (in March 2020) and to launch a new initiative, SUNERGY (see Appendix 5.2 for a brief description of SUNERGY), and to join efforts to pave the way towards a Large Scale European Research and Innovation Initiative (LSERI) based on SUNERGY vision and challenges.

The first point led to the adaptation of D4.1 with the idea to explore possibilities and propose scenarios to have a LSERI based on SUNRISE (and now SUNERGY) fitting into the landscape of Horizon Europe. Several options were explored, mainly related to missions and partnerships, and actions were launched in this sense in the past months. In particular, a first draft for a common partnership proposal called "*Fossil free fuels, chemicals and materials for a circular economy (3FCM)*" was jointly prepared by the SUNRISE and ENERGY-X (see Appendix 5.5) and was brought to the attention of the partnerships programme committee in June 2019. With already an established list of partnerships discussed between the European Commission (EC), the Member States and Associated Countries (MS & AC) to be launched at the start of Horizon Europe in 2021, such an additional partnership can be discussed for the next round of partnerships that could be launched in 2024. With that perspective in mind, a tentative scenario and timeline is presented in section 4 of the present document.

Regarding the second key fact mentioned above, *i.e.* the merging of SUNRISE and ENERGY-X consortia, the governance scheme and scenarios for both ENERGY-X and SUNRISE beyond the two current CSAs will both fall under the new initiative, SUNERGY. They are thus prepared in common between the groups in charge of governance in the two CSAs. Further information on SUNERGY, its current organization, challenges and objectives is given in section 3. More precisely, to work on governance schemes and tentative scenarios, the CSA joined efforts in the following way:

- Teleconference meetings joining the teams in charge of governance in both CSAs are regularly organized (approx. monthly) and jointly since September 2019;
- A physical meeting gathering representatives of both CSAs was jointly organized on October 22 at Roissy Charles de Gaulle Airport to work on governance schemes on the so-called short-, mid- and long term scenarios. Further details on these tentative scenarios and the outcomes of this meeting are given in section 4 and in the Appendix 5.3.

The present document is structured as follows. In **section 2**, the analysis of the governance structure of running flagships and other European large scale initiatives is detailed. **Section 3** will detail the new context for the future of SUNRISE with the creation of SUNERGY and present the actions that led to the merging plus the new organization and joint work led for building the future of SUNERGY. In **section 4**, the different scenarios envisioned for the future of SUNERGY on the short-, mid- and long-term are presented together with some indication of the proposed organization. Section 5 explains the partners responsibilities in the relevant Tasks T4.1 and T4.2 of the SUNRISE CSA related to this deliverable. It also presents the organization for these Tasks and different steps that led to building common scenarios presented in section 4 and how the work was organized jointly with the governance team of the ENERGY-X CSA. Finally, various documents mentioned in the present text can be found in the **Appendixes**.

As a final general remark, it turns out that there are still ongoing discussions with the European Commission (EC), the Member States and Associated Countries (MS & AC) and the SUNRISE, ENERGY-X and thus SUNERGY communities around some options mentioned in the present document. In particular, SUNERGY is structuring the community both at the European and national levels with dedicated events to discuss its vision, roadmap, governance and blueprint.

An additional governance workshop was thus organized on 20 February 2020 at DECHEMA in Frankfürt, with representatives of the teams in charge of the governance work packages in ENERGY-X and SUNRISE. The workshop aimed at discussing and if needed refining the governance schemes and to ensure alignment for the two CSAs and to prepare the future terms of references.

Thus and if needed, an updating on the scenarios, the governance schemes and thus to this deliverable will be made at the end of the CSA.

2. ANALYSIS OF THE GOVERNANCE STRUCTURE OF RUNNING FLAGSHIPS AND OTHER EUROPEAN LARGE SCALE R&I INITIATIVES

This section summarizes the results of Task 4.1 of the SUNRISE CSA (lead Forschung Zentrum Jülich). There is a similar task in the ENERGY-X CSA. The main outcomes of the ENERGY-X analysis is presented in the deliverable D5.1 "*SWOT analysis of existing governance models*" (lead DECHEMA) and a brief outline was also discussed during the SUNRISE and ENERGY-X governance meeting (Roissy, 22 october 2019, see minutes in section 5.2).

In the case of the SUNRISE CSA, at first, the governance structures of the current FET flagships, which will continue as co-funded European Partnerships in HE, were analysed and compared: *i.e.* the Graphene, Human Brain and Quantum Flagships. Next, we extended our analysis to existing European large scale R&I initiatives with a private component, including the recently launched Battery 2030+ initiative as well as two different types of public-private partnership (PPP), namely the SPIRE co-programmed public private partnership (cPPP) and the FCH joint undertaking (JU). The governance schemes of these different flagships and partnerships are presented in Appendix 5.1 of the present document.

In all governance schemes for the running Flagships (Appendixes 5.1 a to c), the directorate plays the central role and together with different boards decisions for *e.g.* budget or strategic scientific directions are made. Since we found many differences in the governance structures we decided to search the pros and cons in direct contact with involved people.

Thus, in a second step, interviews with different members of the three running flagship initiatives were performed to get insights in learnings, findings, dos and don’ts regarding the various governance and organisational structures. Interview partners have been:

- Prof. Katrin Amunts - Scientific Research Director of the Human Brain Flagship and sub-program leader (SP 2 "Human Brain Data"),
- Prof. Tommaso Calarco – Coordinator of the Quantum Support Action of the Quantum Flagship.
- Prof. Max Lemme – Scientific secretary of the Strategic Advisory Council and former leader of the Partnering Division of the Graphene Flagship.

The main findings from the interviews relevant for the future SUNERGY LSERI are summarized below.

In all interviews, it was found that a General Assembly is one of the most important bodies in large scale research programs. Participants with different roles in the projects *e.g.* from the management team, from scientific advisory boards, from the stakeholder boards *et cetera*, share information, discuss strategic routes, agree on budget plans, view the latest research results and keep each other updated and in touch. This is highly important for the transparency in large projects and large initiatives.

An Ethics Board in combination with a professional dissemination strategy is a must for large scale initiatives. Since the research content is of very high public relevance and interest, the results and the focus strategy of the research route of large scale projects must be communicated in a professional way, such that society can follow *e.g.* the decisions made. The Ethics Board in parallel has to debate about the research route and the alignment between the needs and wishes from the public.

Clear decision-making processes and roles of the boards must be defined from the beginning as terms of reference. The processes should be transparent, understandable and explicit for the involved people in the project, such that discussions about the decision-making processes during the running initiatives are avoided.

Innovation routes and IP issues must be defined from the beginning. Since there will be industrial partners involved in large-scale research initiatives or industrial partners should get on-board during the running project, both academia and industry stakeholders must clear views about the IP strategy. Furthermore, it is very much appreciated (not only for society) if there is an exploitation plan of the research results, which can be a payback of investments made *e.g.* by tax payers. Structures which deal with innovation and IP issues should be visible in the governance.

Strategic decisions for future research routes must be made on the basis of scientific expert's opinions. Therefore, one option is to build scientific strategy working groups which make the scientific strategic decisions on a common basis. This guarantees that all relevant scientists speak with one voice and conflict of interests are levelled out. An independent moderator for decision-making processes in the working groups is helpful to find best solutions. The outcomes and decisions of the different working groups can be presented to all partners and stakeholders and validated during the general assembly.

One of the strong hints in all interviews was that the coordinator should be independent in large scale research initiatives. It means that, the coordinator and with him the management of the project (*i.e.* members of an executive board) should induce *e.g.* budget distribution decisions on the basis of advice from a strong scientific advisory board. The coordinator should work more like a moderator and should have no scientific interest. Regarding that fact, the role of the coordinator and the management in the project is to set up and guarantee tools and processes, such that the best strategic decisions can be made for the needs from society and on the basis of the results from the science. Therefore, it is highly appreciated that the coordinator is independent from the scientific community but brings professional management tools in the project. Conflict of interests in decision-making processes must be avoided, which should be guaranteed by the coordinator.

Finally, the voice from society should be involved from the beginning. This helps to focus the research on the relevant needs of the public. A society board, in which *e.g.* people with sociology background or people from the public sectors are involved, can be integrated in the governance.

Regarding the **Battery 2030+ initiative**, it comprises three main bodies: the general assembly, an executive board and an advisory board. The **general assembly** is the ultimate decision-making body. It includes the project coordinator and the deputy project coordinator and one representative of each of the 17 members of the consortium which are leaders in their respective countries in the field of batteries. The **executive board** is the body responsible for the proper execution and implementation of the decisions of the general assembly. It is also in charge of monitoring the progress of the initiative. Finally, there is also an **advisory board** composed of European and national organizations. It plays the role of providing input to run the initiative as well as help aligning its results with expectations of the different communities involved (academic, industrial, member states and associated countries and society).

Presently, in the so-called "ramp-up phase", the Battery 2030+ initiative is supported by a coordination and support action (CSA) which runs for a period of 3 years. Related to this, are also several open competitive calls - Research and Innovation Actions (RIA) and Innovation Actions (IA) - which are in-line with the roadmap of Battery 2030+. All selected projects are linked between them and to the CSA in the sense that they must conclude a written collaboration agreement with the CSA and other projects selected. Thus, they contribute to the common activities of the CSA and more globally to the Battery 2030+ initiative. Such schemes ensures that all projects are part of the global initiative, and not disconnected projects working separately. The results and outcomes of the RIA and IA projects will also contribute in updating the roadmap of the initiative. Such an organization with an "umbrella" CSA complemented by a set of different and connected open calls appears quite efficient to run a global large-scale initiative pursuing a global vision. It ensures that the two following key aspects are met:

(i) with the CSA: to maintain and update a global vision and roadmap for the Battery 2030+ initiative, in close coordination with the European actors from academia, industry and society and the EC, MS & ACs;

(ii) with the set RIA and IA open calls: to implement the roadmap of the initiative with open competitive calls complying with the rules of Horizon Europe, including openness, but also contributing to the global initiative via an agreement of cooperation with the CSA and with the other projects.

Such a coordination and cooperation scheme can be extended to the national level via cooperation of the global initiative with national actors including national funding agencies.

Regarding the analysis of the **governance schemes of partnerships**, we focused on SPIRE[1] and FCH-JU[2] that were implemented under Horizon 2020. The governance schemes of these two PPPs are presented in Appendix 5.1.d (SPIRE) and 5.1.e (FCH-JU). Generally speaking, PPPs are joint initiatives of the European Commission and actors of the private sector to support the research and innovation in domains of strategic importance to the economy and competitiveness of the European Union or to address key societal challenges, whenever these cannot be efficiently addressed using the other instruments of the framework programme. In H2020, PPPs are functioning either as contractual public-private partnerships (cPPPs) or as Joint Technology Initiatives, JTIs (also called Joint Undertakings, JU). SPIRE is one example of the first type (cPPP), whereas FCH-JU is a JTI.

A cPPP in H2020 will be a **co-programmed European partnership in HE**. The activities of a cPPP are implemented and operated in different parts of H2020 with open calls and thus follow the rules of the framework programme. In the case of SPIRE, the governance structure is composed of three blocks (see Appendix 5.1.d):

- The **partnership board** is the central board connecting the public and private partners of SPIRE;
- The **European Commission** as the public partner;
- The **Association A.SPIRE**, an aisbl representing the private partners of SPIRE.

[1] Sustainable Process Industry through Resource & energy Efficiency (SPIRE) : https://www.spire2030.eu/intro
[2] Fuels Cells & Hydrogen Joint Undertaking (FCH-JU) : https://fch.europa.eu/page/governance

The roles of **A.SPIRE** are multifold. It acts as an advisory body to the partnership board by elaborating the SPIRE roadmap and strategic research agenda (SRA) based on which calls topics are proposed for the work programmes of H2020. It also ensures an operational role with the **executive director** of SPIRE supported in this task by the A.SPIRE office. Finally, it also ensures an implementation role by forming consortia to apply to calls of interest to SPIRE. A.SPIRE has a board of elected directors representing the various industry sectors involved. This **board of directors** manages and prepares the consolidated work programme of A.SPIRE. The **Industrial Research and Innovation Advisory Group (IRIAG)** assists the board of directors by contributing to the elaboration of the SRA and of the call topics proposed to the SPIRE partnership board. The A.SPIRE General Assembly is the representation of all SPIRE members and validates the overall strategy of A.SPIRE. The **partnership board** is the body associating the public and private (represented by IRIAG) stakeholders of SPIRE. It is chaired by an EC representative and co-chaired by the IRIAG chair. The partnership board has a strategic and advisory role to the EC and the initiative by discussing priorities and call topics based on the SPIRE SRA. It also ensures monitoring progress of the overall partnership. Finally, the **EC** has a decision-making role by developing the work programmes and publishing open calls of interest to SPIRE.

In a recent report on cPPPs[3], this governance structure was favorably evaluated. Several shortcomings were nevertheless noted, in particular a lack of transparency of the management processes and the roles and involvement of stakeholders in cPPPs as well as a lack of openness. Other noted shortcomings were the insufficient involvement of SMEs as well as an unbalanced regional coverage of the European Union with a lesser representation of EU-13 countries[4].

FCH-JU is one the 7 JTIs currently operating in H2020. JTIs are institutionalized partnerships governed by Articles 185 or 187 of the Treaty on the Functioning of the European Union (TFEU)[5]. JTIs are long-term initiatives (up to 10 years) which aim at integrating national and European research programmes in a given field of strategic importance for European industry and competitiveness. JTIs elaborate their own research agenda and multi-annual work programmes and thus launch their own open calls and award funding. Members of JTIs are the European Commission, Member & Associated States, a not-for-profit industry led-association. SMEs, academia (universities and RTOs) can also participate in JTIs. JTIs will continue as Institutionalised European Partnerships in HE.

The governance scheme of the FCH-JU includes **two executive bodies**, the **governing board** and the **executive director assisted by the programme office**, and **three advisory bodies**, the **scientific committee**, the **states representatives group** and the **stakeholder forum**. The **governing board** is the main decision-making body of the FCH JU and has the overall responsibility for its operation. All three stakeholders are represented in the governing board of the FCH-JU, namely Hydrogen Europe (industry grouping referred to as IG in the governance

[3] Mid-term review of the contractual Public Private Partnerships (cPPPs) under Horizon H2020. Report of the independent Expert Group (European Commission 2017).
[4] EU-13 countries : 13 european countries which joined the EU since 2004 : Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia.
[5] https://eur-lex.europa.eu/summary/glossary/joint_undertaking.html

scheme), the EC and the Hydrogen Europe Research (RG in the governance scheme) representing the academia involved. The **Executive Director** is the legal representative of the FCH-JU. He is assisted by the **Programme Office** and both are in charge of the day-to-day management of the Joint Undertaking. Regarding the advisory bodies, the **Scientific Committee** is an independent advisory body to the Governing Board. The members reflect a balanced representation of world-class experts from academia, industry, SMEs, non-governmental organizations and regulatory bodies. The **States Representatives Group (SRG)** consists of one representative of each MS and AC. The SRG has an advising role to the Governing Board. Its members act also as an interface between the FCH JU and the relevant stakeholders within their respective countries. The **Stakeholder Forum** plays the role of a general assembly and gathers representatives of all stakeholders involved in the Joint Undertaking. The governance scheme of the six other JTIs follow a similar scheme.

Overall, this governance scheme was evaluated as effective[6]. Some concerns noted by the evaluators are about the limited role and impact of the advisory groups on the executive bodies and therefore on the main strategic decisions of the FCH-JU. The interactions between the advisory and executive bodies should be improved, the governance structure itself being judged as satisfactory. It is in particular key to strengthen the role of the SRG in order to ensure a better alignment of national priorities with that of the JTI. In another report[7], experts also suggested not to limit the role of the SRG only to an advisory role in order to reinforce the weight of MS & AC in the decisions, *e.g.* by participating in the governing board. As for cPPPs, it was pointed that the participation of SMEs and EU-13 countries could be improved.

The above-discussed two PPPs operate under H2020. In Horizon Europe where the landscape of partnerships will evolve with a simplified and rationalized landscape of partnerships where openness and transparency are better addressed. Therefore, a future SUNERGY LSERI as a partnership, which would operate under Horizon Europe, should be considered in this new landscape. This is discussed in more details in section 4.3 of the present document.

Finally, the result of this analysis was shared during a governance session of the SUNRISE stakeholder workshop held on 17-18 June 2019 in Brussels. The session began with an introduction by the work package leader on the analysis of existing governance models. Then a discussion followed between panellists representing different stakeholders involved in LSERI:

- Jean-François Buggenhout | DG Connect, European Commission
- Lars Klüver | Danish Board of Technology Foundation
- Paulina Styczeń | Department of Innovation and Development of the Poland's Ministry of Science and Higher Education
- Andreas Förster | DECHEMA
- Marcel Hoek | Dutch Research Council (NWO)

[6] Commission Staff Working Document : Interim Evaluation of the Joint Undertakings operating under the Horizon 2020 (European Commission 2017).
[7] Final report by the ERAC Ad-hoc working group on partnerships on the recommendations on increasing the efficiency of implementation of partnerships (european research area and innovation committee, 2018).

- Max Lemme | Scientific Secretary of the Strategic Advisory Council and former leader of the Graphene Flagship Partnering Division

The session was organized with a list of questions to the panellists on different topics followed by open questions from the audience. The topics addressed covered the future for SUNRISE in the new context of Horizon Europe and its new instruments (missions, partnerships), the cooperation with ENERGY-X, what to learn from best practices in the governance of LSERIs, the role of EC and industry in LSERIs. Several recommendations were given by the panellists with a strong focus on the cooperation with ENERGY-X. This is addressed in the next section. More details on this session can be found in the minutes of this SUNRISE stakeholder workshop.

3. UPDATE ON THE CSA, THE CONTEXT AND LAUNCH OF SUNERGY

The SUNRISE CSA, launched on March 1st 2019 for a duration of one year, was one of the 6 projects granted in the frame of the call FETFLAG-01-2018. Besides SUNRISE, another CSA was selected under the same sub-area "*Energy, Environment and Climate change: Radically new Energy Production, Conversion and Storage devices and systems*": ENERGY-X (www.energy-x.eu).

ENERGY-X is coordinated by the Danish technical university. It gathers a total of 13 partners from academia, RTOs and industry. ENERGY-X aims at developing technologies to replace fossil resources for the future European energy mix as well for the European chemical industry by converting renewable power (*e.g.* photovoltaic, wind) under chemical form, either as a fuel of base chemical for the chemical industry. To do so, one core activity of ENERGY-X is the development of a new generation of catalysts with improved performances, durability and composition as compared to the current state of the art. This goes together with novel integrated conversion approaches to reach technologies that can be upscaled in an economically viable energy system. To do so, ENERGY-X has an interdisciplinary approach for academic research with cross-fertilization with industry. To demonstrate the feasibility of the approaches developed in ENERGY-X, two demonstrator projects are planned, one for the manufacturing of carbon-neutral aviation fuels and the second decentralized production of fertilizers with zero-CO_2 footprint.

SUNRISE and ENERGY-X have several aspects in common. First of all, they aim both at solving the following three grand challenges:

- Storage of renewable energies as liquid fuels,
- Production of basic chemicals for the industry and agriculture without fossil resources,
- Negative CO_2 emission technologies.

to be achieved by using abundant and ubiquitous molecules (H_2O, N_2, CO_2) as feedstock and renewable energy sources (*e.g.* sunlight, wind), *i.e.* resources abundant in Europe and with an overarching circular economy approach.

To solve these grand challenges, both communities SUNRISE and ENERGY-X explore different technological routes with different TRL levels and which can be summarized as follows:

- **Conversion of renewable power to a chemical form (fuels and chemicals)** via electrochemical and thermochemical processes. It is also referred to in the literature as Power-to-X;
- **Direct conversion of solar energy to a chemical form (fuels and chemicals)** using a photoelectrochemical, biohybrid or biological approach.

ENERGY-X is mainly focused on the above-mentioned Power-to-X routes, whilst SUNRISE, besides exploring electrochemical processes, has also a strong focus on the direct conversion approaches.

Finally, SUNRISE and ENERGY-X also have common partners and supporters. Overall, the CSAs gather a total of 30 partners (from academia, industry, national and European networks and alliances) from 14 different countries : Belgium, Czech Republic, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Poland, Spain, Sweden, Switzerland, United-Kingdom. When taking into account the supporters, *i.e.* the organizations that expressed interest via a letter of support, this amounts to total community of approx. 300 organizations from academia, industry (approx. 50 companies so far), NGOs, governmental and local authorities from more than 25 countries across Europe and beyond. This community is meant to develop and strengthen in the future, one objective being to reinforce the participation of the industry in view of the future LSERI.

Building on these common aspects and synergies, SUNRISE and ENERGY-X maintained regular contacts at different levels in the CSAs. In particular, the need to join efforts was in fact realized very early in view of building a common future in the new context of Horizon Europe, to be a stronger community and thus to have more impact. One of the first actions launched jointly was to elaborate a partnership pre-proposal as an option for a future LSERI gathering SUNRISE and ENERGY-X. This joint pre-proposal entitled « *Fossil free fuels, chemicals and materials for a circular economy (3FCM)* » was proposed in the context of the discussions between the EC and the member states for future partnerships in Horizon Europe (see section 4.3 and appendix 5.5 for more details). The action was led in SUNRISE by the team in charge of the work package WP4 on governance. The representatives of the MS and ACs represented in the two CSAs and involved in the discussions in Brussels around new partnerships were contacted for supporting this partnership proposal. While the possibilities for having a new partnership in 2021 are very limited as there is already an established list of candidate partnerships discussed by the EC and MS & AC, upon favourable evaluation of the SUNRISE and Energy-X CSAs, and provided ample private support can be mobilised, the path to a future SUNERGY partnership can open, up. One important option to be further explored would be to have such a 3FCM launched in 2024 in a second wave of new partnerships of Horizon Europe. Other common actions between SUNRISE and ENERGY-X included participating and contributing to the stakeholder's workshops organized by each CSA.

Shortly after this common partnership proposal, the two consortia decided to merge at the end of the two CSAs to form a new and single initiative aiming at having a LSERI. This was announced at the Europacat 2019 conference (18-23 august 2019) during a dedicated session with participants from both CSAs. The new initiative is called *"**SUNERGY** : fossil-free fuels and* *chemicals for a circular economy*". Thus in March 2020, when the two CSAs SUNRISE and ENERGY-X have ended, the whole community will be gathered under the umbrella of the SUNERGY initiative. From an operational point of view, there will be a temporary governance structure, functioning to keep the community gathered and active until a new contractual frame is launched under H2020 or Horizon Europe and to pave the way towards a future LSERI. The envisioned scenarios with their timeline are detailed in the next section.

Nevertheless, not waiting until March 2020, SUNRISE and ENERGY-X are already joining efforts on some common aspects of the future SUNERGY LSERI, including preparing a blueprint and a governance structure for SUNERGY. Regarding governance, meetings are held since September 2019 with the participation of the ENERGY-X partners in charge of the governance work package.

4. SCENARIOS FOR THE FUTURE OF SUNERGY

In order to build tentative scenarios to pave the way towards a future SUNERGY LSERI based on the 3FCM proposal, a dedicated workshop was held on 22nd of October 2019 (Roissy Charles de Gaulle Airport). It was organized by the SUNRISE WP4 with support and participation from ENERGY-X members and it gathered 13 participants, 8 from SUNRISE and 5 from ENERGY-X. The Roissy workshop aimed at providing recommendations for the governance structure for this SUNERGY LSERI as well to work on possible options to implement this LSERI and launch into action after the end of the SUNRISE and ENERGY-X CSAs. These options were considered in the new frame of Horizon Europe and its structure and instruments.

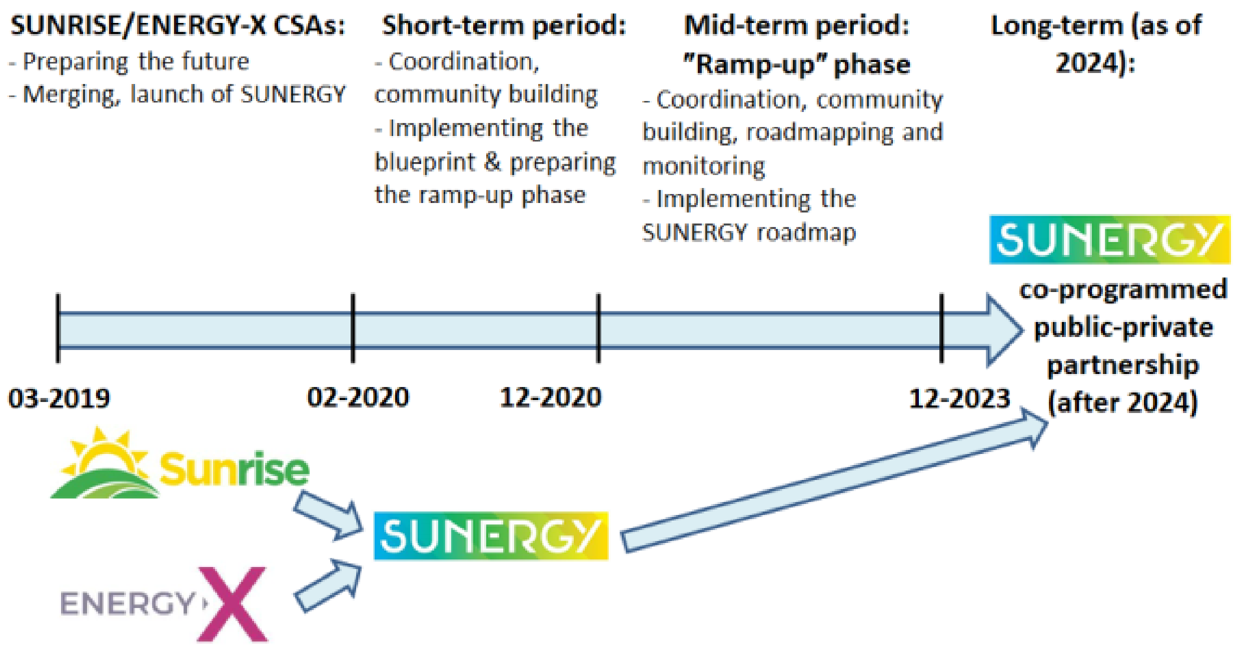


Figure 1: Tentative scenario and timeline to bridge between the two SUNRISE and ENERGY-X CSAs and a future large scale European research and innovation SUNERGY initiative.

In this process, three so-called short-, mid and long-term periods were identified:

- **Short term (2020)**: this period starts at the end of the two SUNRISE and ENERGY-X CSAs with the evaluation of the results of the two projects and what they have delivered. This period and the outcomes of the evaluation will be critical to launch the next "ramp-up phase".
- **Mid-term (2021-2023)**: ***"ramp-up phase"*** towards a SUNERGY LSERI partnership with common coordination activities backed by several RIA (Research and Innovation Actions) and IA (Innovation Actions) open calls based on the roadmaps of SUNRISE and ENERGY-X. All the granted RIA and IA projects would conclude a collaboration agreement with SUNERGY to contribute to the activities of the whole initiative and would be subject to mid-term review and evaluation at the end by a program board of experts with mandates from the MS and the EC to assure quality and impact without transfer of authority away from the MS and EU. This period would also be dedicated to develop and strengthen the SUNERGY community (academia, industry and society) and to pave the way towards the SUNERGY partnership with the contribution of the different stakeholders.
- **Long-term (after 2024)**: this corresponds to the start of a SUNERGY partnership as discussed above. Regarding the type of partnership, a co-programmed European partnership (cPPP) appears as the most adapted to the SUNERGY initiative due to its flexibility and possibility to accommodate both bottom-up and programmatic efforts with maximum synergy between the two. This type of partnership allows to have both public and private partners as well as participation of member states according a memorandum of understanding (see section 4.3 for more details).

An overview of these three periods and timeline is presented in Figure 1. The main conclusions and recommendations of the Roissy workshop for each of these periods are given below together with a proposition for a governance structure for the selected scenario.

4.1. Short-term scenario (2020): after the end of the two CSAs

Context

- *Objective*: after the end of the ENERGY-X and SUNRISE CSAs (February 2020), there is the need to define a short-term strategy and framework to support SUNERGY activities and keep the community together
- *Timing*: the short-term scenario starts *from now* (to ensure continuity after the end of the CSAs) to the start of the operations through the "*bridge funding*" (medium-term period), *i.e.* the "ramp-up phase" towards a LSERI, the main objective for the long-term period.

Main conclusions on the governance and organization for the short-term period from the Roissy governance workshop:

The working groups during this workshop identified the following aspects as key for implementing a governance and organization for this short-term period.

As a general comment, there is the need to define a lean and mean structure to prepare the ground for the post-CSA. Thus, during the remaining course of the two SUNRISE and ENERGY-X CSAs, the groups in charge of governance must join efforts and coordinate their work in proposing a common structure.

The group identified the need to create two boards for SUNERGY, each having a balanced composition from members from SUNRISE and ENERGY-X yet ensuring a global consistency of each board in terms of composition taking into account, whenever possible, aspects such as the types of organizations, the geographical distribution of members and gender to provide an optimal embedding for gaining support from member states.

- **Scientific executive board**: this board is responsible for the operational running of SUNERGY in this intermediate period with members having different roles and tasks which can be delegated upon need (*e.g.* development of joint Manifesto, outreach to EC/advocacy…). Presently this board, already created counts 8 members, 4 from SUNRISE and 4 from ENERGY-X. These are:
  - **SUNRISE**: Prof. Huub de Groot (Leiden University, SUNRISE CSA coordinator), Dr. Frédéric Chandezon (CEA), Prof. Joanna Kargul (Warsaw University), Dr. Carina (Faber, Université Catholique de Louvain);
  - **ENERGY**-X: Prof. Jens Nørskov (DTU, ENERGY-X CSA coordinator), Prof. Bert Weckhuysen (Utrecht University), Prof. Robert Schlögl (Max Planck Society, Fritz-Haber Institute and Max Planck Institute for Chemical Energy Conversion), Prof. Gabriele Centi (European Research Institute of Catalysis).
- **Industrial board**: it was suggested to create an independent industrial board separate from the scientific executive board to be effective while at the same time working in close interaction together. The industrial board would have as a main role to bring the views of industry for the overall development and strategy of SUNERGY. It was proposed to have a board counting 7 members, 3 suggested by SUNRISE and 3 by ENERGY-X. This board would be chaired by Prof. Maximilian Fleischer (Siemens) presently involved in the SUNRISE CSA. A tentative list of the other members of this industrial board has been established by Prof. Fleischer and discussed with the scientific executive board. The identified persons are presently contacted for having their agreement to join the board.

Then these two boards will be directed by a coordinator and deputy:

- Prof. Bert Weckhuysen (Utrecht University) as the coordinator of SUNERGY;
- Dr. Frédéric Chandezon (CEA Grenoble) as the deputy coordinator of SUNERGY.

They will have the responsibility of running the overall SUNERGY initiative based on the decisions of the two boards and also to prepare the next period and in particular the implementation of the “ramp-up phase” for the mid-term period (see next section). This would include in particular:

- Preparing a coordination and support action (CSA) for coordinating the overall SUNERGY initiative during the ramp-up phase. Propositions for topics are under discussion either in the frame of H2020 or for the first work programmes of Horizon Europe;

- Coordinating the preparation of RIA and IA topics based on the SUNRISE and ENERGY-X roadmaps for the first work programmes of Horizon Europe with a group of members from different organizations in SUNRISE and ENERGY-X, group to be implemented;
- Coordinating the preparation of a large Innovation Action, based on a topic presently under discussion with the EC.

The coordinator and deputy will be supported by a team for day-to-day management, dissemination aspects, communication and liaison with the EC, organization of events. Presently, the persons of this support team are: Kathrine Bjeregaard-Nielsen (DTU), Elena Guarneri (DTU), Laura Lopez (ICIQ) and Anita Schneider (EERA),

Furthermore, overall this period, a regular contact will be maintained with the SUNERGY community built on the SUNRISE and ENERGY-X ones. This could be done mainly via regular information sharing on the advancement of the initiative with a SUNERGY newsletter and could be done as well on a consultation of the overall community. All this is summarized in Figure 2.

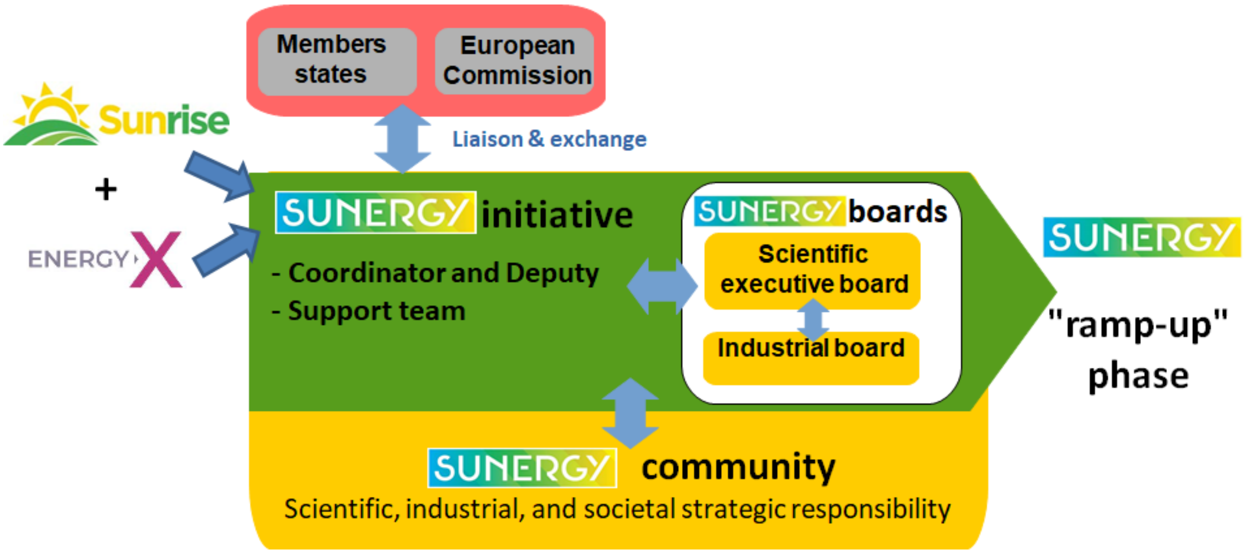


Figure 2: Proposed governance structure for the SUNERGY "after CSAs" short-term period.

4.2. Mid-term scenario (2021-2023): the "ramp-up" phase of SUNERGY

Context

This "ramp-up phase" would be the intermediate period to bridge towards a SUNERGY LSERI partnership after 2024 and not a goal *per se*.

Main conclusions on the governance and organization for the mid-term "ramp-up phase" from the Roissy governance workshop:

Further preparation for the SUNERGY LSERI without any funding was perceived as being not possible especially if this LSERI starts operating in 2024. Two options were identified to coordinate and support this intermediate period: a single follow-up coordination and supporting action (CSA) and/or an ERA-NET. A CSA appears to be a very suitable option in terms of integration at the European level with some of the key leaders in European MS & AC acting as national nodes for the national communities in the fields covered by SUNERGY. The duration of the project should ideally be 3 years to ensure bridging with the LSERI with a budget of a minimum 3 M€ (1 M€/year).

The coordination project should provide a number of key overarching functions for the SUNERGY community, including:

- Communication and dissemination services for SUNERGY related/initiated projects (*e.g.* organisation of an annual conference for relevant projects, newsletters, etc.);
- Community-building and networking platform for stakeholders to enlarge the scientific and industrial commitment;
- Continuation of the Scientific Board and the Industrial Board as well as installation of a Board representing the Civil Society;
- Proposal of SUNERGY topics for the HE work programmes 2023/24;
- Preparation or support of a multi-annual work programme for the SUNERGY LSERI with a series of calls; proposals for specific instruments for SMEs and start-ups could be part of this programme (liaison with the EIC);
- Updating of the Strategic Research Roadmap including the integration of the SUNRISE and ENERGY-X roadmaps into one combined SUNERGY roadmap;
- Liaison with Member State (MS) Governments and the European Commission to work on the alignment of programmes and secure MS and EU funding for the LSERI respectively; this activity shall lead to additional commitment from the MS, (by analogy to the Board of Funders of the H2020, see section 4.3 below);
- Finalisation and implementation of the Governance Structure for the LSERI; this should reflect the anticipated wide range of TRLs covered by SUNERGY actions and ensure fair and non-discriminative participation of stakeholders from all member states;
- Work on a pragmatic contractual framework for the LSERI including questions on IP management, access to research results and rules for fair compensation of academic IP
- Furthermore, the project should deliver a number of standardised tools that will be essential for quality assurance and coherency and comparability of research results. This includes the set-up of a harmonized Life Cycle Analysis (LCA) framework tailored to the needs of SUNERGY. This should reflect social aspects of the intended transformation of the energy and industry system and include forecast and predictive modelling tools to assess impacts of individual new technologies. Another key requirement is the standardisation of testing and characterisation methodologies to ensure that research results of different projects or groups

are comparable (for example standardized procedures for (photo)catalyst testing). This might also include development of appropriate methodologies and could also lead to a network of central testing and characterisation facilities.

One recommendation for this coordination part is about the consortium composition. Whilst it appears clear that it will differ from the current consortia of the SUNRISE and ENERGY-X CSAs, it appears nevertheless essential to keep key partners to ensure a certain continuity in the overarching functions described above.

Following those conclusions, several options are presently under discussion including for a CSA call for the H2020 work programme 2020 or alternatively for the first calls of Horizon Europe. The former option is the preferred one, as it would ensure start of the project in early 2021. It received the support of several member states. If this is not retained, then the call topic could be proposed for the first work programmes of Horizon Europe, thus meaning an additional delay to start the mid-term period as the CSA could not start before at least end of 2021. The text of the CSA topic proposed is given in Appendix 5.4. Additionally, an ERA-NET could be a way to ensure a good alignment with national priorities. This is also presently under discussion.

For the implementation of the SUNERGY roadmap, this coordination part should complemented by several research and/or innovation actions (RIA/IAs). These calls of different sizes would be launched as open competitive calls based on the priorities identified in the roadmap of SUNERGY (itself built by merging the SUNRISE and ENERGY-X roadmaps) and proposed by the SUNERGY initiative during the preparation of the work programmes of Horizon Europe in early 2020, as discussed in the previous section. The calls would follow the rules of Horizon Europe (or H2020 if there are possibilities for adding SUNERGY topics in the WPs based on remaining budget) thus ensuring a fair and open competition. All the granted projects would have to conclude a written collaboration agreement with the SUNERGY CSA and the other selected RIA and IA projects, and both the midterm review and the end evaluation of these projects will be performed by the SUNERGY board operating under a mandate from the MS, AC and EC to prevent separation of authority from responsibility. Keeping the authority over the end result with the MS, AC and EC will ensure that both the RIA bottom-up components and the IA programmatic components contribute to the activities of the global SUNERGY in synergy. It also appeared during this Roissy governance meeting that, besides regular small projects, having a very large project (budget minimum 100 M€) in this intermediate period could help in gathering a significant number of European actors around a core project, giving further visibility to the SUNERGY initiative vis-à-vis the European Commission, the Member States and the society. All this portfolio of European RIA and IA projects could also be complemented by national funded projects.

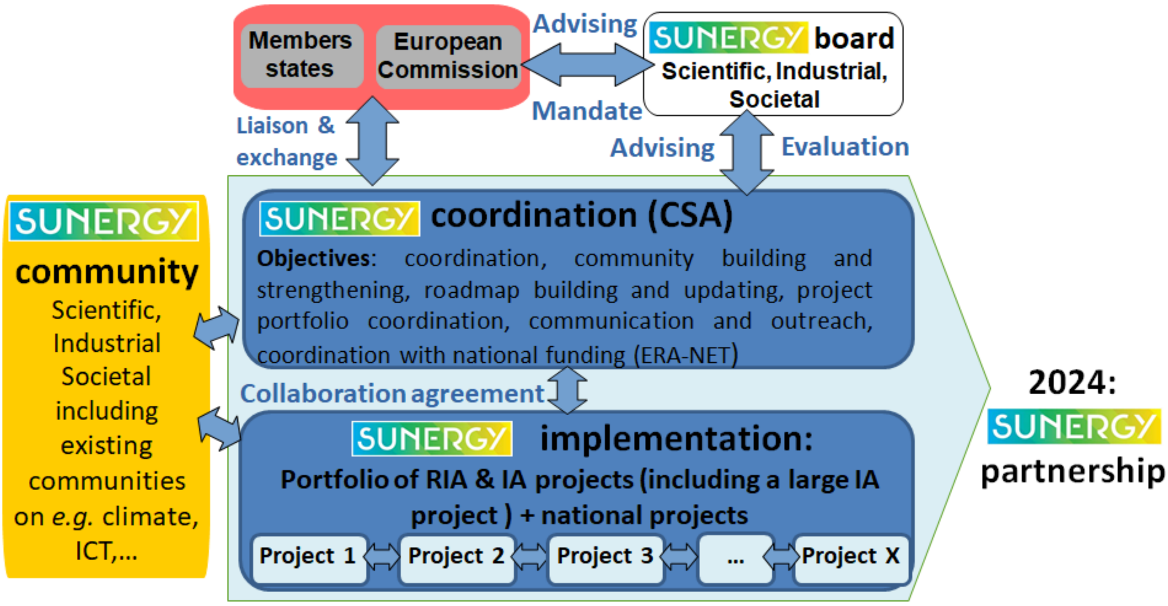


Figure 3: Proposed governance structure for the SUNERGY "ramp-up phase" mid-term period.

An overview of a governance scheme following this option is presented in **Figure 3**. In this scheme, the coordination of SUNERGY is ensured by a CSA, possibly complemented by an ERA-NET to ensure coordination and alignment with national funding. The SUNERGY board, including the scientific and industrial boards, launched during the short-term period could be continued, complemented by a societal component. Such a board would have an advisory role both to the SUNERGY coordination and to the European Commission and Member States. Alternatively, these boards could be merged in a single strategic advisory board.

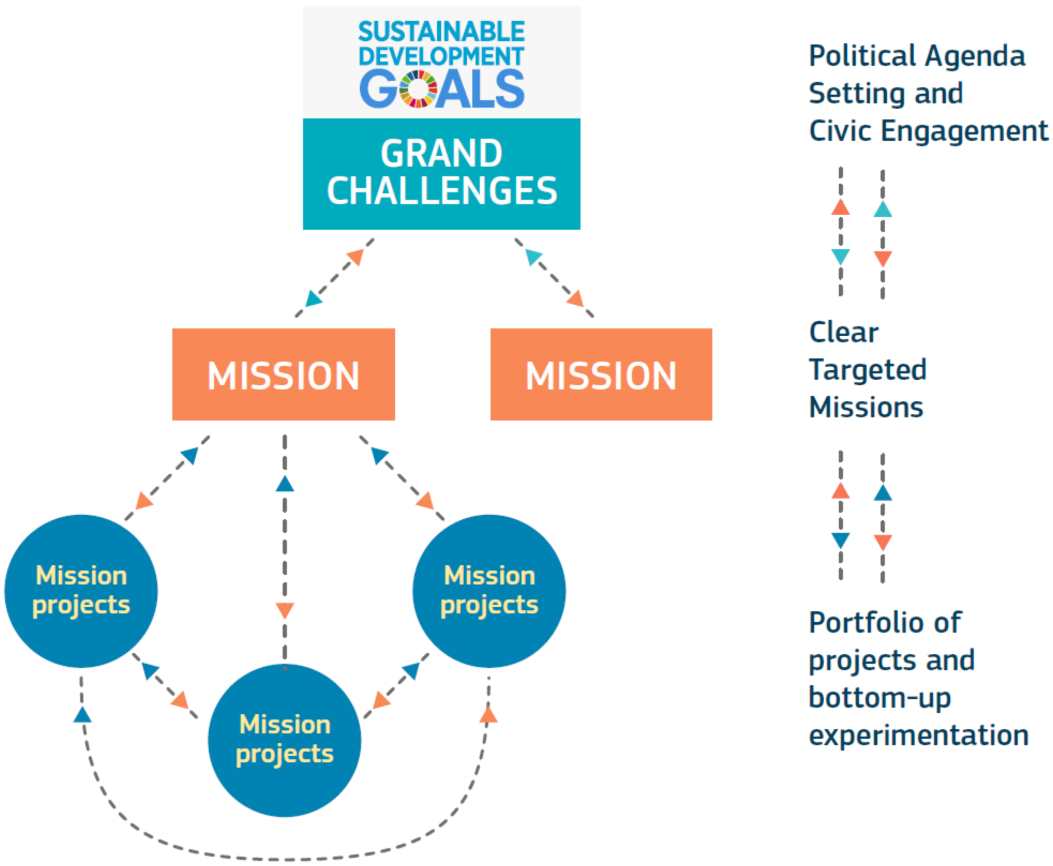
It should also be emphasized that there might a delay between the start of the CSA (depending when a call is published) and some of the RIA and IA projects, *i.e.* the "ramp-up" phase could start even if the CSA has not started using the organization structure and processes established during the short-term period (Figure 2).

An alternative option to the above-discussed scheme - where coordination and research and innovation aspects of the SUNERGY are done using dedicated separate instruments of H2020 and Horizon Europe - would be to merge the two aspects in a single large project with a budget of 100-200 M€ and a period allowing to bridge with the LSERI. The community development could be achieved with an extended dissemination component. As dissemination is mandatory anyway, it could focus on dedicated community building, triggering new calls, and anything else that a CSA could contribute, with the added advantage that the difficult task of securing 80% private funding is leading and puts the primate with serving society (*i.e.* the market) over serving science (*i.e.* academic knowledge gathering). Presently no such instrument exists in H2020 and Horizon Europe. Such option has the main advantage of being an extremely visible single action for the SUNERGY initiative both at the European and National levels, it bridges into action and it gives freedom for programmatic steering and limited redundancy. The main drawback is a lack of flexibility and the openness. For such a call, there could only be one single project and thus one consortium selected. It doesn't seem reasonable to embark every interested member of the broad SUNERGY community (presently around 300+ members) in such a project. Thus for the non-selected members, this would block for them possibilities to join European SUNERGY-like projects. There is a high risk then that some partners "leave" the community whilst it needs to be reinforced and strengthened especially in view of launching for the long-term period a SUNERGY LSERI. Thus, such a scheme appear as non-optimal to ensure the required openness of SUNERGY during this key "ramp-up" phase to embark all the community in the future LSERI.

4.3. Long-term scenario (after 2024): the SUNERGY Large Scale European Research and Innovation Initiative

Context

This corresponds to the start of the SUNERGY LSERI. During the course of the SUNRISE and ENERGY-X CSAs, several options were considered including the **mission** instrument to be implemented in Horizon Europe and **partnerships**. One key aspect was to have an option and instrument that avoids fragmenting the SUNERGY initiative into several existing projects and communities. This would lead to the loss of momentum and efficiency and weaken the global initiative.



- **Figure 4**: From challenges to missions. From *Mission-oriented research and innovation in the European Union : a problem-solving approach to fuel innovation-led growth*, Mariana Mazzucato (2018).

Missions are a new instrument to be implemented in the frame of Horizon Europe. They are based on a problem-solving approach around a so-called **Mission Area** to fuel research and innovation around a global challenge of broad societal interest, with specific and measurable targets to be achieved with a portfolio of research and innovation measures within a given period. There is a strong emphasis on public engagement. Thus, a mission will be structured with a portfolio of R&I projects falling in a work programme proposed to the EC by a **Mission Board** for each mission area (see Figure 4). Each mission board is composed of world-class experts appointed by EC following an expression of interest and should reflect the diversity of disciplines and expertise relevant to the Mission Area[8]. SUNRISE and ENERGY-X launched a joint action to have experts applying to some of the mission boards for missions areas relevant to both initiatives (see below). More details on the concept of missions and some insights on their governance can be found in several reports[9,10].

Five Missions Areas were selected for the first round of missions, to be launched in 2021 at the start of Horizon Europe:

- *Adaptation to climate change, including societal transformation*;
- *Cancer;*
- *Ocean, seas, coastal and inland waters;*
- *Climate neutral and smart cities*;
- *Soil health and food*".

Although the exact outline of the mission will be defined by the mission boards, some details on their scope were given in the call for applications for the members of the mission boards with a list of keywords[11]. It appears that SUNERGY has potential connections to a various extent with 3 mission areas: "*Adaptation to climate change, including societal transformation*", "*Climate neutral and smart cities*" and "*Soil health and food*". It thus appeared that Missions were not an optimal solution as a long-term scenario for a SUNERGY LSERI due to the risk of fragmentation already discussed above, unless a new mission built on the SUNERGY vision is launched in the future. Nevertheless, connections between the SUNERGY LSERI and the above mentioned relevant missions areas will be initiated in the mid-term "ramp-up" phase. Additionally, in the future if a new round of Missions is launched, there is the possibility of having a mission area corresponding to the SUNERGY vision. There is presently no guaranty, as the EC and the MS will first evaluate the achievements and the impact of the five missions before launching new ones.

[8] Call for applications for the selection of the mission boards : https://ec.europa.eu/digital-single-market/en/news/help-us-shape-horizon-europe-mission

[9] Missions : Mission-oriented research and innovation in the European Union : a problem-solving approach to fuel innovaztion-led growth, Mariana Mazzucato (2018). https://ec.europa.eu/info/sites/info/files/mazzucato_report_2018.pdf

[10] Governing Missions in the European Union, Mariana Mazzucato (2019). inhttps://ec.europa.eu/info/sites/info/files/research_and_innovation/contact/documents/ec_rtd_mazzucato-report-issue2_072019.pdf

[11] Call for applications for the selection of the mission boards : https://ec.europa.eu/digital-single-market/en/news/help-us-shape-horizon-europe-mission

Regarding **partnerships**, there is a new approach in Horizon Europe as compared to H2020. This is summarized in Figure 5. The general approach is to have a simplified and rationalized landscape of objective-driven and impact focussed partnerships in support to of the EU policy objectives. Partnerships are instruments to be used whenever other instruments of the framework programme are not sufficient to give the required impact.

In this new HE landscape, three types of partnerships will co-exist;

- **Co-programmed European Partnerships**: between the Commission, MS & AC and private and/or public partners. Such partnerships will be based on memoranda of understanding and/or contractual arrangements. Compared to H2020, they are similar to the cPPP model, such as for the SPIRE partnership (see section 2). Co-programmed partnerships in Horizon Europe follow a roadmap and a strategic research and innovation agenda (SRA). The contribution of the EU will be implemented via open calls in the Horizon Europe Work programmes based on propositions of topics following the partnership roadmap and SRA. This ensures openness of the initiative. The partners implement their commitments (*i.e.* activities and contributions) under their own responsibility, following pre-defined objectives. The progress of the initiative is monitored using key performance indicators. Such a co-programmed partnership can be supplemented by coordination and support actions. Co-programmed is a flexible type of partnership in its setting-up and its implementation, in terms of composition of partners, its objectives and activities that can evolve as the partnership goes. Commitments are based on common and agreed efforts between the partners and not legally binding. It is adapted to initiatives addressing large communities with a broad range of disciplines as is the case for SUNERGY.

  It should be emphasized that compared to the previous cPPPs of H2020 which was used for partnerships with industry, **co-programmed partnerships in Horizon Europe will allow to have both Member States and Industry**. The participation of Member States implies the signature of Memoranda of Understanding between MS representatives and the Commissioner, the main objective being to align national priorities of participating MS with the partnership roadmap. The exact details on the type of activities from participating states are still under discussion. Ongoing discussions indicate that this could be done via national and/or transnational calls, via the research and innovation activities of national research organizations or via other activities at the national and regional levels, provided that these activities contribute to the achievement of the roadmap and the strategic research agenda of the overall partnership.

- **Co-funded European Partnerships** are based on a joint programme agreed by the partners. These partnerships associate EC with MS and AC with research funders and other public authorities at the core of the consortium. Funding of the partnership is ensured by a blending of EU and national public (*e.g.* national funding agencies) and/or other R&I funding sources. The funding rate of the EU is 30 % and up to 70 % in justified cases and the typical duration will be 5 to 7 years. The core partners are mainly national programme owners and managers form MS & AC. The implementation is ensured based on annual work programmes with rules agreed by the partners. In H2020, FET Flagships, ERA-NET and EJP cofunds were co-funded partnerships.

- **Institutionalised European Partnerships**: they include Public-to-Public partnerships (P2P) where the EU participates in R&I funding programmes that are undertaken by a number of EU countries. They are based on article 185 of the Treaty on the Functioning of the European Union (TFEU). They can also be public-private partnerships established under Article 187 TFEU, such as joint undertakings (as FCH-JU) or EIT Knowledge and Innovation Communities (KICs). Such institutionalised partnerships are best suited for partnerships addressing long-term challenges and priorities with a stable consortium of core partners bringing substantial contributions. They call for establishing dedicating entities for their implementation thus meaning a substantial effort to set-up the partnership and imply legal binding commitments. The flexibility is rather limited as changing objectives, partners require amendment to the legislation.

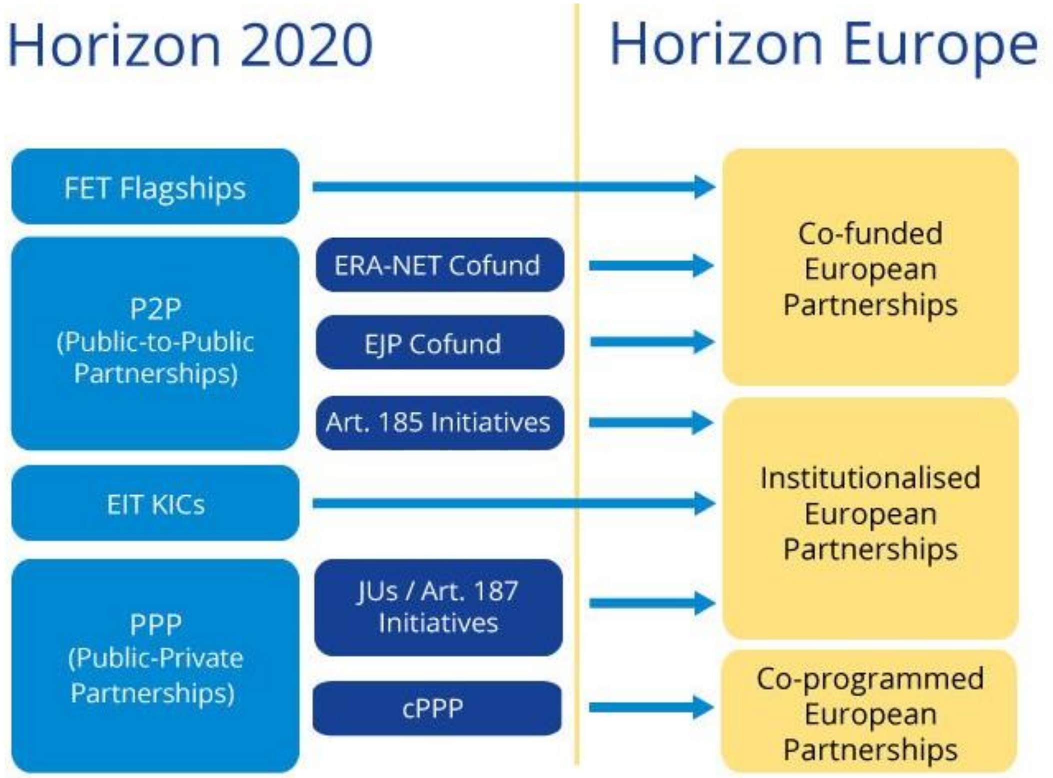


Figure 5: Approach to partnerships in Horizon Europe compared to H2020. From https://www.era-learn.eu/partnerships-in-a-nutshell/r-i-partnerships/transition-to-horizon-europe.

As already discussed above, a proposition was jointly prepared by the SUNRISE and ENERGY-X CSAs and communities and proposed as a topic for the first round of new partnerships to be launched at the beginning of Horizon Europe, in 2021: "*Fossil free fuels, chemicals and materials for a circular economy (3FCM)*" (see Appendix 5.5). Unfortunately, it could not be selected as there was already a list of new partnerships proposals established and under discussion between the EC and the MC & ACs. One option proposed for the 3FCM proposal was to join existing communities proposing a candidate partnership having connections with SUNERGY, especially

"*Circular and climate neutral industry*" (follow-up of the SPIRE, co-programmed partnership) or "*Clean hydrogen*" (follow-up of FCH-JU, institutionalized partnership). If there are clear connections between these two proposals and SUNERGY, these do not cover all aspects of the SUNERGY vision as they mostly focus on the demand side (applications) whilst SUNERGY focus is on the supply side, *i.e.* fossil-free fuels and base chemicals. Thus, there is a risk of only incremental impact due to the fragmentation and gaps in the vision of SUNERGY when joining established communities compared to the option of having a SUNERGY dedicated partnership. This option for a SUNERGY LSERI was thus considered as not being a suitable one.

To conclude, **the scenario which is proposed for a SUNERGY LSERI on the long-term is to have a dedicated partnership based on the "*Fossil free fuels, chemicals and materials for a circular economy (3FCM)*" proposal** (Appendix 5.5). This will be rediscussed in the coming years with the MS & AC and the EC upon favourable review of the outcomes of the SUNRISE and Energy-X CSAs.

Key aspects that must be addressed in the governance structure of the future partnerships are the shortcomings identified in the mid-term evaluations of cPPPs[12] and Joint Undertakings[13] and already discussed in section 2. This includes having clear and transparent processes of the different bodies and stakeholders in the governance structure of the partnership. It is in particular important to establish a strong connection between the advisory and executive bodies so that the former can impact the decisions of the latter. In the future SUNERGY partnership, industry should have a very active role both in the governance and in the implementation. Such a partnership is indeed expected to have a leveraging effect with industrial investments, in particular in promoting high technology readiness levels (TRLs) of the initiative. Besides large companies, a special focus should be given on embarking SMEs. It will be also important to ensure a balanced regional coverage of the European Union with a good representation of the EU-13 countries. In general, the governance and processes should ensure permanent openness of the initiative with the possibility of new partners to join the initiative as it goes (and open the possibility to some partners to leave), with clear participation processes and requirements. A strong emphasis must also be given to the role of MS & AC and to allow proper alignment with national priorities. One possibility would be not to limit the role of MS & AC to an advisory role but allow them to participate in the governance.

Regarding the type of partnership for the future SUNERGY LSERI, as mentioned above, co-programmed or institutionalized are suitable for public-private partnerships (Figure 5). Co-programmed is a type of partnership that is rather flexible during its implementation in terms of composition of partners of its objectives and activities and that can evolve as the partnership goes. The commitments are not legally binding but based on common and agreed efforts between the partners of the partnership. It is suited to partnerships addressing broad communities as is SUNERGY. Furthermore it allows, to have the participation of private partners **and** Member States. It requires a limited effort to set-up and implement compared to the other types of

[12] Mid-term review of the contractual Public Private Partnerships (cPPPs) under Horizon H2020. Report of the independent Expert Group (European Commission 2017).
[13] Commission Staff Working Document : Interim Evaluation of the Joint Undertakings operating under the Horizon 2020 (European Commission 2017).

partnerships. On the other hand, institutionalized partnerships have legally binding commitments and thus require significant efforts to prepare. During its course, it shows also a limited flexibility as changing *e.g.* partners or objectives require amending the legislation.

To summarize, **it appears that the most-suited type of partnership type for a SUNERGY LSERI would be a co-programmed partnership**. I has the advantage of allowing to have both public and private partners as well as member states in the same instrument. This alter aspect thus allows to answer one the shortcomings mentioned above with the need to align national priorities with those at the European level. The mid-term “ramp-up phase” discussed above will be dedicated to strengthen the community, in particular the participation of industry. As the contribution of Horizon Europe for a co-programmed partnership will be implemented via open calls in the work programmes of Horizon Europe, it also shows a continuity with the proposed “ramp-up phase” with its portfolio of RIA and IA projects, ensuring a certain continuity between the different phases and thus a better efficiency. This “ramp-up phase” would also be dedicated to further develop the relation with MS and their participation in the future partnership, based on the connections already established during the course of the two CSAs.

In terms of governance for a SUNERGY co-programmed partnership, the structure established for the mid–term “ramp-up phase” (Figure 3) could evolve in a structure suited for such type of partnership (see *e.g.* the example of SPIRE in Appendix 5.1.d). The EC and MS would represent the public bodies while the SUNERGY board of the “ramp-up phase” could evolve into a single programming board associating mandated expert members of the public and private stakeholders plus a funding board with representatives of EC and MS and ACs. Generally speaking, the programming board would act as the main liaison body with the public partners and the coordination and implementation part of SUNERGY. A tentative structure is displayed in Figure 6. In the SPIRE cPPP, industry established the association A.SPIRE, an aisbl representing the private partners. This option should be considered whether it is suitable in the case of SUNERGY during the short-term and “ramp-up” mid-term phase.

In the case of a cPPP, the SUNERGY governance model should be an open community structure that on the one hand allows nurturing new ideas at low TRL levels while on the other hand it can deliver on time at the higher TRL levels in a coherent manner (Figure 6). It aims to cover the hole in the Paris agreement, how to genuinely proceed towards zero and negative emission technology on the supply side, which is insufficiently covered by the existing partnerships. It is surprising that virtually all effort in the existing partnerships is on the demand side, while upstream, at the beginning of the conversion chain, the decoupling of economic growth from utilization of resources will have to be realized. In addition, direct air capture is thus far a distant promise, and currently the technology conundrum that biomass can do CO_2 assimilation but is not scalable, while human made technology is scalable but is not affordable/sustainable needs to be addressed in a thorough manner. Probably the only way forward is to go beyond the current practice of adiabatic conversion chains where losses factorize, and explore on a massive scale information in systems approaches. Since time is pressing, the only way forward is by covering the entire TRL range 0-9.

Past experience with partnerships (such as SPIRE and the flagships) has shown that

- Only bottom-up programming is insufficient to achieve rapid progress;
- Continued support from the member states requires a fair redistribution of resources put in by these states.

To achieve this, SUNERGY proposes for the future LSERI a governance structure where a programming board is central. In this programming board, experts with a mandate from their state have the responsibility to plan the work and perform scouting in the community for new ideas worth to be developed further. As it doesn't appear feasible to have experts mandated from all MS/ACs, the experts should reflect the geographic diversity of EU with a significant representation of EU-13 countries and they could be changed during the course of the partnership. The programming board steers the implementation towards its higher goals with a mandated program with large scale efforts at higher cost that need to be finished on time, and a bottom-up program that is bringing in the new developments. Both parts are monitored on a two-year basis. Once the expert program board has decided on a new program element to be necessary for achieving the goals, it will be presented for funding to the member states through the funding board, and the community of researchers will be asked to bring out bids.

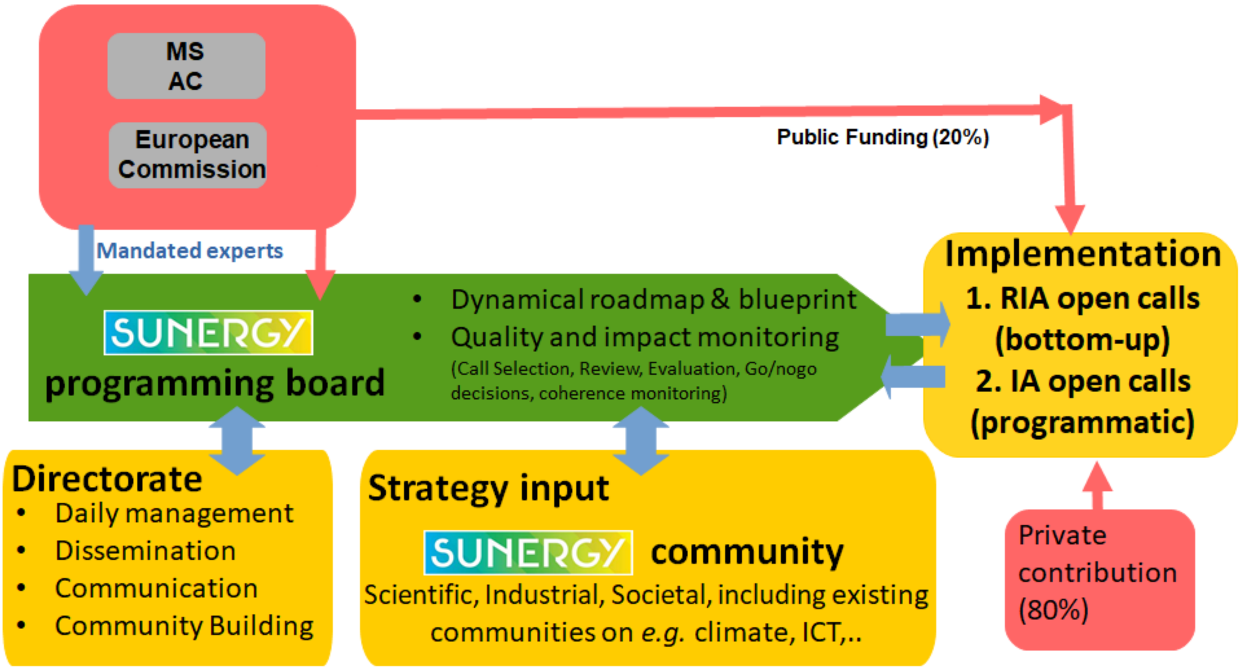


Figure 6: Tentative governance structure for the SUNERGY co-programmed public-private-partnership cPPP partnership.

Central to the governance is graceful failure. Limited redundancy will be built in to mitigate the risk of overall failure. Every project contributing to the program is awarded for four years, and after two years the mandated experts perform mid-term evaluations, to assure quality and impact, and decide whether the work is on track. Based on this the assessment is green, which means it progresses well and a new program can be expected after the four year term, orange, which means that it is in danger and will be stopped after four years if nothing changes, or red, which means there is immediate danger and affirmative action is necessary.

Limited redundancy is actually beneficial for mitigating risk, while at the same time it also allows for improving fairness in redistribution of resources brought in by the member states. This can be achieved in two ways: for the mandated program, different member states can put up manufacturing infrastructure in parallel. For instance, there can be a demonstrator in France, but also in Germany, and the best elements of both will then serve to fuel a next stage development. Second, personnel performing the work will be recruited from the member state bringing in the financing, so that the resources flow back to state citizens that represent their taxpayers community.

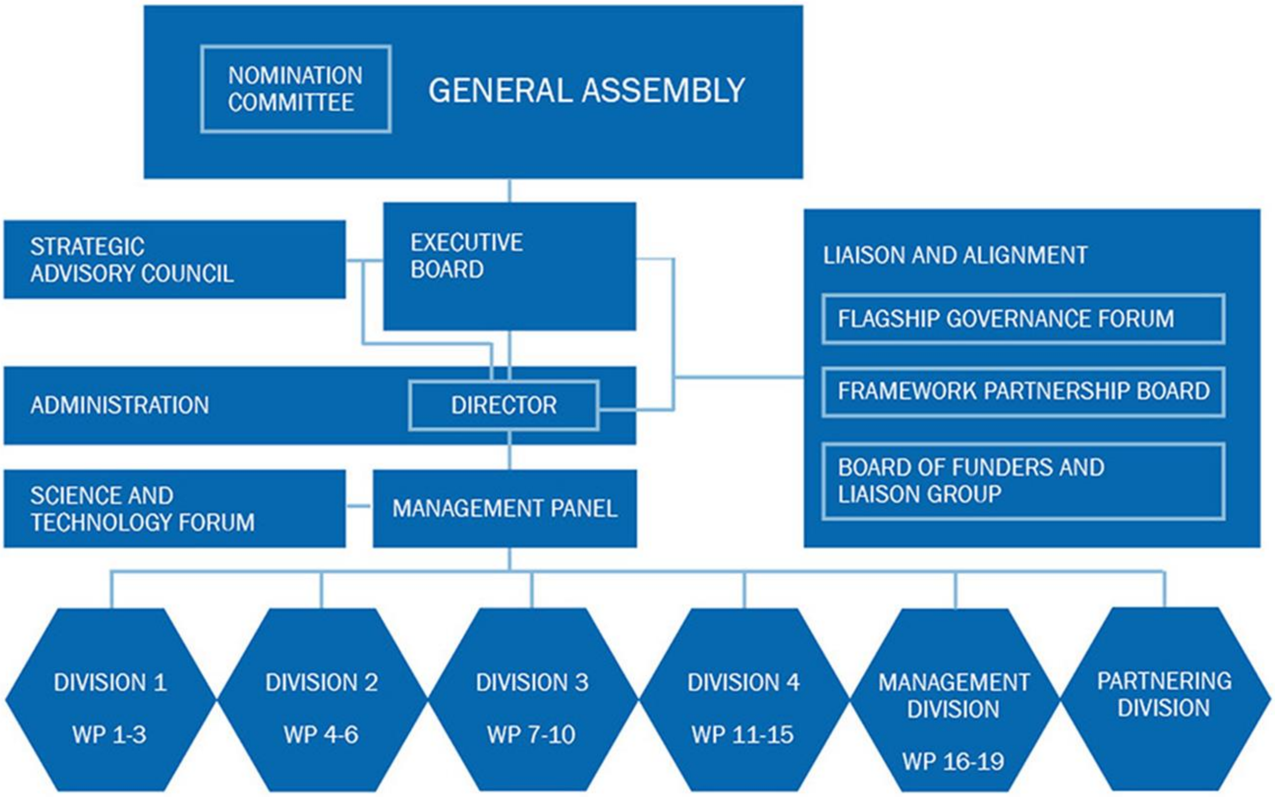
This model is roughly based on the ESA structure, which is operational for almost 50 years and has brought Europe to the forefront of space research.

As a final remark, a governance workshop was organized on 20 February 2020 at DECHEMA in Frankfürt, with representatives of the teams in charge of the governance work packages in ENERGY-X and SUNRISE. The workshop aimed at discussing, if needed refining the governance schemes in order to ensure alignment for the two CSAs and to prepare the future terms of references to be discussed in the D4.2 deliverable. The above-discussed governance schemes were used as a starting point and any evolutions following this workshop will be described in deliverable D4.2.

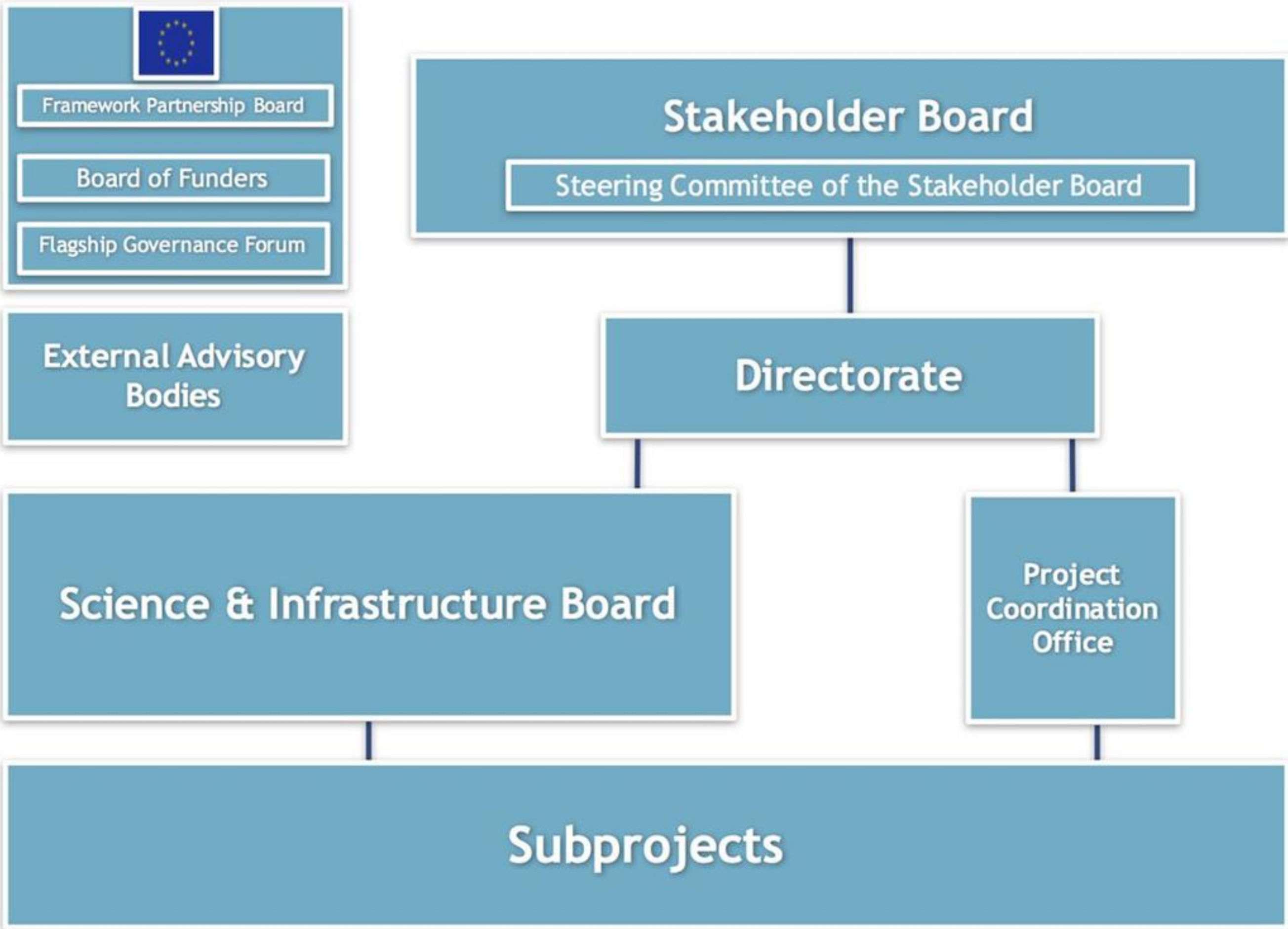
5. APPENDIXES

5.1. Governance schemes of running Flagships and other European large research initiatives

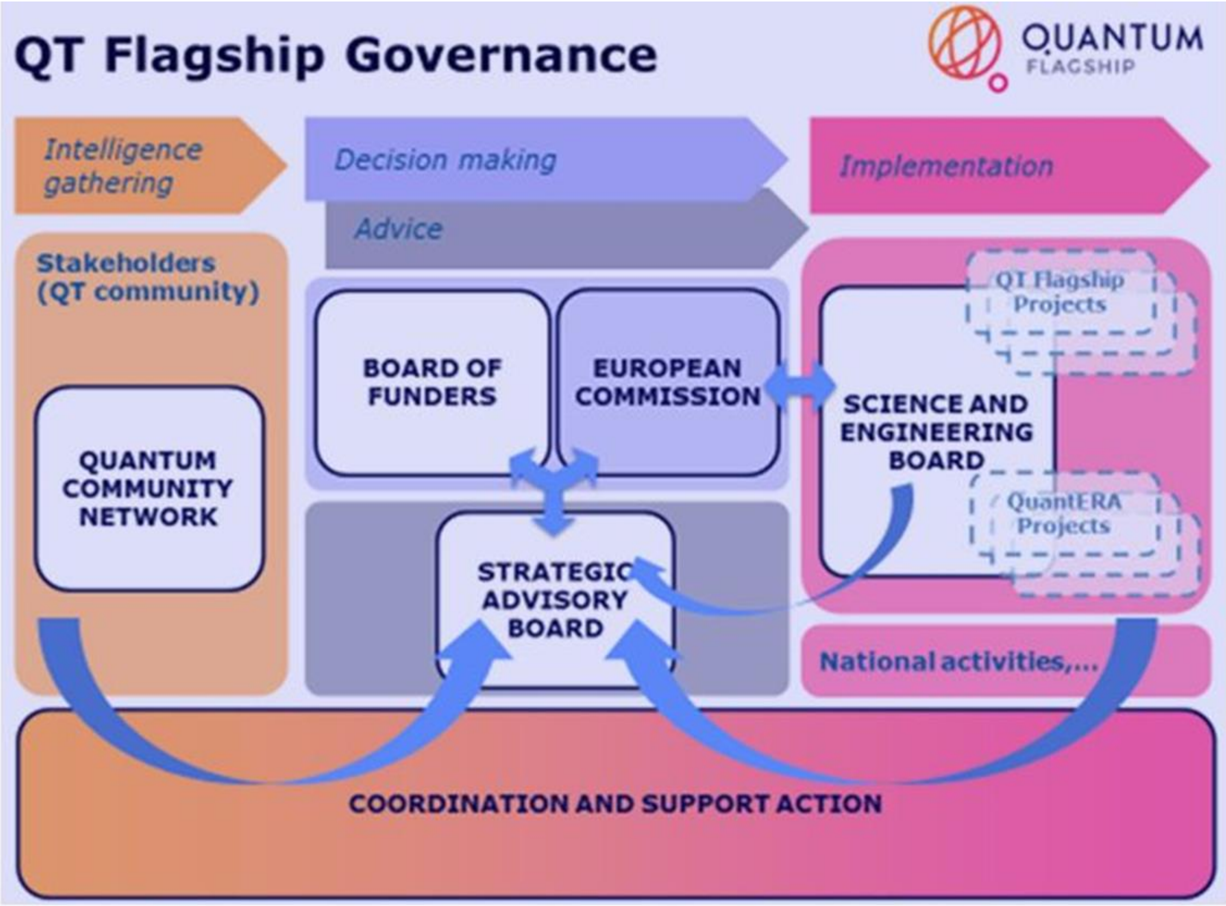
5.1.a Governance structure of the graphene Flagship


NOMINATION COMMITTEE
GENERAL ASSEMBLY
STRATEGIC ADVISORY COUNCIL
EXECUTIVE BOARD
LIAISON AND ALIGNMENT
FLAGSHIP GOVERNANCE FORUM
FRAMEWORK PARTNERSHIP BOARD
BOARD OF FUNDERS AND LIAISON GROUP
ADMINISTRATION
DIRECTOR
SCIENCE AND TECHNOLOGY FORUM
MANAGEMENT PANEL
DIVISION 1
WP 1-3
DIVISION 2
WP 4-6
DIVISION 3
WP 7-10
DIVISION 4
WP 11-15
MANAGEMENT DIVISION
WP 16-19
PARTNERING DIVISION

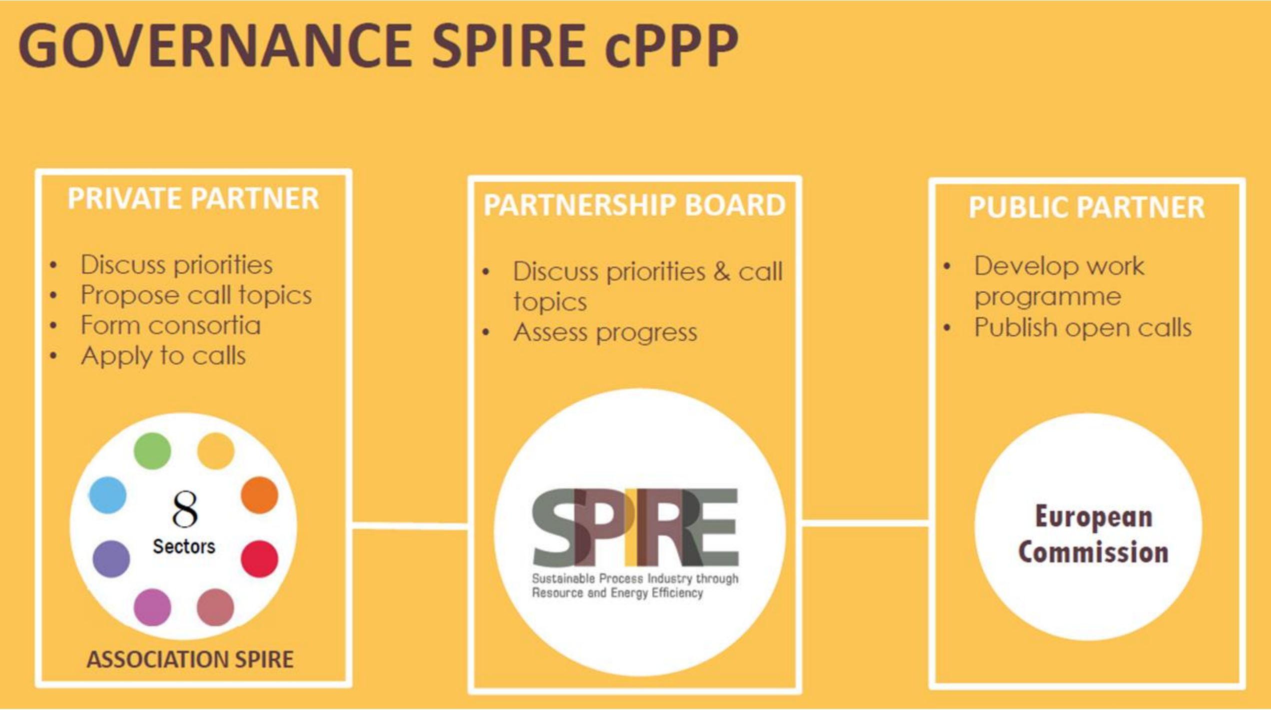
5.1.b Governance structure of the Human Brain Flagship



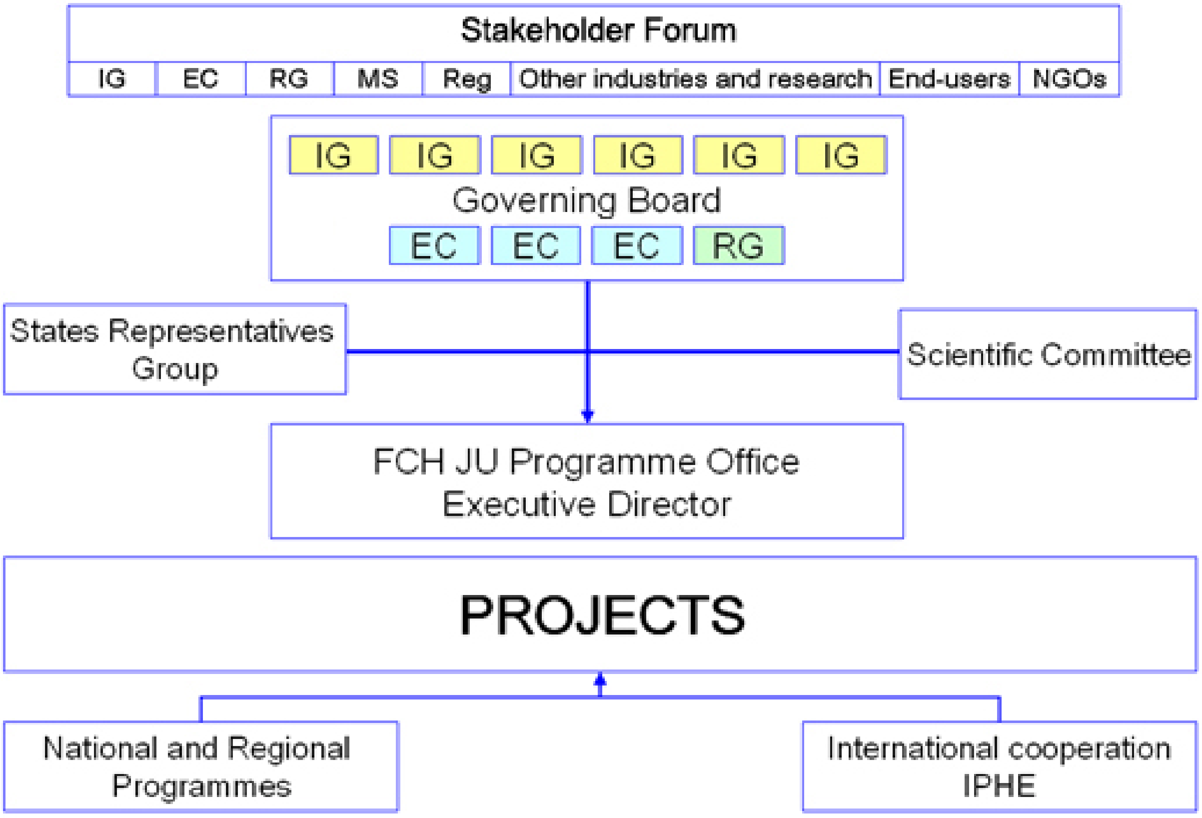
5.1.c Governance structure of the Quantum Flagship



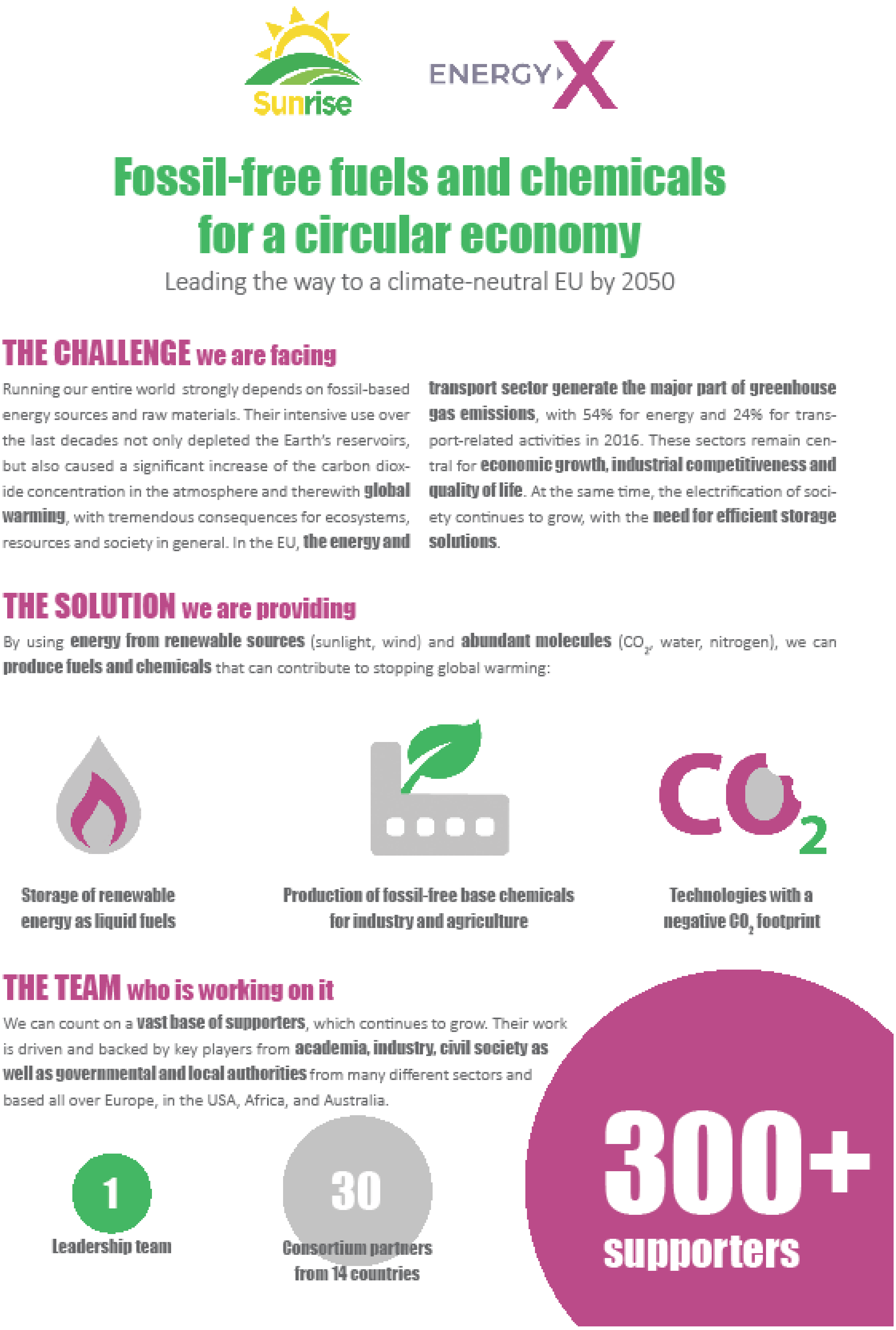
5.1.d Governance structure of the SPIRE PPP



5.1.e Governance structure of the Fuel Cells and Hydrogen Joint Undertaking (FCH-JU)



5.2. Brief description of the SUNERGY initiative.



Sunrise ENERGY X

Fossil-free fuels and chemicals for a circular economy

Leading the way to a climate-neutral EU by 2050

THE CHALLENGE we are facing

Running our entire world strongly depends on fossil-based energy sources and raw materials. Their intensive use over the last decades not only depleted the Earth's reservoirs, but also caused a significant increase of the carbon dioxide concentration in the atmosphere and therewith **global warming**, with tremendous consequences for ecosystems, resources and society in general. In the EU, **the energy and transport sector generate the major part of greenhouse gas emissions**, with 54% for energy and 24% for transport-related activities in 2016. These sectors remain central for **economic growth, industrial competitiveness and quality of life**. At the same time, the electrification of society continues to grow, with the **need for efficient storage solutions**.

THE SOLUTION we are providing

By using **energy from renewable sources** (sunlight, wind) and **abundant molecules** (CO_2, water, nitrogen), we can **produce fuels and chemicals** that can contribute to stopping global warming:

Storage of renewable energy as liquid fuels

Production of fossil-free base chemicals for industry and agriculture

Technologies with a negative CO_2 footprint

THE TEAM who is working on it

We can count on a **vast base of supporters**, which continues to grow. Their work is driven and backed by key players from **academia, industry, civil society as well as governmental and local authorities** from many different sectors and based all over Europe, in the USA, Africa, and Australia.

1 Leadership team

30 Consortium partners from 14 countries

300+ supporters

5.3. Minutes of the SUNERGY governance meeting, Roissy Charles de Gaulle Airport, 22 october 2019.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 816336

This project has received funding from the European Union's Horiz 2020 research and innovation programme under grant agreement 820444.

Minutes of the SUN-ERGY governance meeting
Roissy Charles de Gaulle Airport
22 october 2019

Elena Guarneri (DTU), Kathrine Bjerregaard-Nielsen (DTU), Maximilian Fleischer (Siemens), Alexis Bazzanella (DECHEMA) and Frédéric Chandezon (CEA),

Participants:

Present:

- SUNRISE: H. Bercegol (CEA), F. Chandezon (CEA), C. Faber (UCL), M. Fleischer (Siemens), H. de Groot (Leiden U.), J. Kargul (Warsaw U.), Ann Magnuson (Uppsala University), A. Schneider (EERA)
- ENERGY-X: A. Bazzanella (DECHEMA), L. Bruckner (DTU), K. Bjerregaard (DTU) E. Guarneri (DTU), B. Weckhuysen (Utrecht Univ., by Skype at 10 H 00-11 H 00 and 16 H 10 – 16 H 25)

Invited: L. Klüver (Danish Tech Foundation)

Organization of the meeting:

- SUNRISE: F. Chandezon (CEA, chair of the meeting), M. Fleischer (Siemens)
- ENERGY-X: L. Bruckner (DTU), K. Bjerregaard (DTU)

Supplementary material:

- **20191022_SUN-ERGY_Governance_Meeting_Background_Slides.pdf**: slides presented for introducing the meeting, the context plus background material
- **DG_ENER_Lunch time conference_Agenda _Concept.pdf**: agenda of the meeting at DG ENER on October 24
- **20191022_SUN-ERGY_Governance_Meeting_Sessions_Conclusions.pdf**: slides summarizing the outcomes for the brainstorming sessions for the short-, mid- and long-term plans
- **June 2019 Partnership proposal SUNRISE-ENERGY-X.pdf**: joint SUNRISE and ENERGY-X partnership proposal "*Fossil Free Fuels, Chemicals and Materials for a circular economy (3FCM)*"

5.4. Proposal for a CSA topic for the mid-term "ramp-up" phase scenario.

1.1 Proposed topic for upcoming call

The proposed CSA topic is related to a proposal for the first WPs of HORIZON EUROPE of a large-scale research and innovation initiative SUNERGY on Fossil Free Fuels, Chemicals and Materials for a circular economy. It will be backed by several RIA and IA type calls within the beginning of HORIZON EUROPE that will conclude a collaboration agreement with this CSA project in pursuing common challenges within the SUNERGY roadmap. The SUNERGY initiative gathers a community of around 300 key players from academia, industry and civil society as well as governmental and local authorities. SUNERGY results from the merging of the two projects SUNRISE and ENERGY-X that were granted a CSA (March 2019 → February 2020) in the frame of the call FETFLAG-01-2018 for preparing a large scale European research and innovation initiative.

The objectives are:

- To build a strongly networked European "Fossil free" community around common goals defined in a strategic research agenda,

- To create the European ecosystem that will deliver the knowledge, technologies and open research infrastructures and testbeds necessary for the development of a world-leading knowledge based industry in Europe, leading to long-term economic, scientific and societal benefit.

The present CSA proposal falls within the scope of the fight against climate change and aims:

- at structuring/developing in the short term the European ecosystem in order to speed up technologies to move from the laboratory to industry (this would be done mainly through the IA topics of the large-scale research initiative, and also the CSA which will network and coordinate the activities and the stakeholders),

- at tackling long-term research challenges in the field (this would be done mainly through the RIA topics of the large-scale research initiative, with coordination of the research activities by the CSA).

Because of their ambition, their scale and their interdisciplinary nature, these challenges can only be realised through a long-term, coordinated and sustained effort at European level, by building on large-scale research cooperation across academia and industry and with other research initiatives at regional, national and European level, and by mobilising Europe's best researchers around an ambitious research agenda.

Overall, this CSA together with the related selected projects of the related RIA and IA calls will be part of a ramp-up phase of the SUNERGY initiative to prepare a large scale European research and innovation initiative after the CSA, as a partnership or another instrument to be discussed and agreed together with the EC and the MS and AC.

Specific challenge

- To coordinate the research activities and the relevant stakeholders (academia and RTOs, industry, NGOs and governmental and local authorities) participating in this large-scale research and innovation initiative for the specific purpose of establishing an effective and proactive bridging pipeline between low TRL 0-3 and high TRL 7-9 and to contribute to the broader efforts in line with the EU energy strategy and the European Green Deal around the three grand challenges:

- Storage of renewable energies as liquid fuels;
- Production of basic chemicals for the industry and agriculture without fossil resources;
- Negative CO_2 emission technologies.

These 3 grand challenges must be tackled/addressed by using abundant and ubiquitous molecules (H_2O, N_2, CO_2) as feedstock, renewable energy sources (*e.g.* sunlight, wind) and an overarching circular economy approach.

• To develop and structure (with creation and implementation of a roadmap) the European ecosystem that will deliver the knowledge, technologies and open research infrastructures and testbeds necessary for the development of a world-leading knowledge-based industry in Europe, leading to economic, scientific and societal benefits (see context below).

• To help speed up the technologies to move from the laboratory to industry with concrete prototype applications and marketable products while advancing at the same time the fundamental science basis, in order to continuously identify new applications and find better solutions for solving scientific or technology challenges.

Context
• European Green Deal;
• Links with the European Energy Research Alliance (EERA) and its joint programmes;
• SET-Plan and the key action areas renewable fuels and bioenergy, carbon capture and storage and energy efficiency for industry;
• Links with future Missions of Horizon Europe: Mission areas 1 (Adaptation to climate change including societal transformation), 4 (Climate neutral and smart cities) and 5 (Soil health and food:
• Climate change as a geopolitical, social and economic threat;
• Europe's high dependence on imports of climate-threatening fossil fuels as the main form of energy storage to be delivered on demand (*e.g.* jet fuels);
• Limits of renewable electricity due to intermittency;
• Storage of renewable energy fluxes as a key challenge for the ecological transition;
• Fostering new clean manufacturing industries in the context of a circular economy;
• Need to develop alternatives to fossil-based fuels for transportation including for aviation;
• Need to establish a new agricultural model, rooted in decentralized, renewable based, production of inputs, in smart farming practice towards a rebalanced nitrogen-related planetary boundary.

Beyond the European Union, there are links with four out of the seven innovation challenges (ICs) of Mission Innovation, namely: Converting Sunlight IC5 (led by EU and Germany), Carbon Capture IC3; Sustainable Biofuels IC4, Clean Energy Materials IC6.

Scope :

Proposals should aim at coordinating the research activities and the relevant stakeholders (academia and RTOs, industry, NGOs and governmental and local authorities) participating in this large-scale research initiative. In particular, it is expected:
- to implement a governance structure and provide support for its governance,
- to facilitate dialogue and cooperation on crosscutting topics, to establish a communication platform,
- to consolidate a unified roadmap based on the 2 roadmaps delivered by SUNRISE and ENERGY-X CSAs (with identification of priorities) ; this roadmap may serve as an input for the preparation of Horizon Europe calls (especially Clusters « Climate, Energy and Mobility », « Digital, Industry and Space », « Food, bioeconomy, natural resources, agriculture and environment ») as well as being inspiration for ERC projects.
- to provide a continuous revision of the roadmap according to new scientific and technological results,
- to coordinate and promote joint activities with the selected projects of the related RIA and IA calls,
- to promote the objectives of the large-scale research initiative and monitor the progress,

- to communicate and exchange on this progress and the major evolutions of the roadmap to a wide community of scientists and engineers,
- to organize outreach events (including addressing the impact of technology development on economy and society),
- to identify training and education needs,
- to identify and coordinate relevant standardisation, IPR actions, and international collaboration and help networking of respective national and international activities in the field.

It is expected that such an activity is driven by the relevant actors of the field including academia, RTOs and industry, in particular the ones gathered in the CSA actions for FET Flagships SUNRISE (https://sunriseaction.com/) and ENERGY-X (https://www.energy-x.eu/) now merged in the new initiative SUNERGY.

Note that special Grant Conditions will apply for project granted under this topic. In particular, the project partners will need to conclude a collaboration agreement with the other projects selected from the RIA and IA topics of the large-scale research initiative.

Expected impact :

- Coordinating a large scale European research and innovation initiative on storage of renewable (solar) energies in chemical form involving all relevant stakeholders and linked with relevant international, national and local programmes and initiatives;
- Building and updating a long-term SUNERGY roadmap beyond the current CSA based on the SUNRISE and ENERGY-X roadmaps;
- Facilitating cooperation and communication between the stakeholders of the initiative on cross-cutting topics;
- Developing the SUNERGY community with all relevant stakeholders (academia and RTOs, industry, NGOs and civil society) across EU;
- To strengthen the engagement of the European industrial stakeholders in particular in view of engaging in a LSRI beyond the CSA;
- Fostering the technological, economic and societal impact of the initiative and paving the way to industrial exploitation of the technologies in the field of energy, transport and climate;
- Speeding-up and increasing the positive impacts of technologies on climate change and protection of environment;
- Spreading of S&T excellence across Europe, increased awareness of European activities;
- Addressing international cooperation in particular with other relevant actions (e.g. Mission Innovation);
- Preparing a large-scale research and innovation initiative beyond the CSA, as a partnership or another instrument to be discussed and agreed together with the EC and the MS and AC.

Integration and European added value: Enhanced Europe´s competitiveness on the global scale, support the development of European competitive industries and SME in the field, fostering the development of new applications, products and decrease the dependency of Europe on external resources;

Type of action: ☒ Coordination and Support Actions

Proposed starting year and duration: End of 2020 for 3-4 years

Expected contribution from the EU: 3-4 M€

5.5 Proposal for a partnership around the SUNERGY vision and challenges.

General information	
Preliminary title of the European Partnership	**Fossil Free Fuels, Chemicals and Materials for a circular economy (3FCM)**
Short description of the partnership	Solve the following 3 grand challenges: - Storage of renewable energies as liquid fuels; - Production of basic chemicals for the industry and agriculture without fossil resources; - Negative CO_2 emission technologies, to be achieved by using abundant and ubiquitous molecules (H_2O, N_2, CO_2) as feedstock, renewable energy sources (e.g. sunlight, wind) and an overarching circular economy approach.
Services directly involved	DG RTD DG ENER DG CLIMA DG MOVE DG ENV DG AGRI
Context and problem definition	• Climate change as a geopolitical, social and economic threat • Europe's high dependence on imports of climate-threatening fossil fuels as the main form of energy storage to be delivered on demand. • Limits of renewable electricity due to intermittency • Storage of renewable energy fluxes as a key challenge for the ecological transition • Opportunity to foster new clean manufacturing industries, in the context of a circular economy. • Need to establish a new agricultural model, rooted in decentralized, renewable based, production of inputs, in smart farming practice towards a rebalanced nitrogen-related planetary boundary.
Objectives and expected impacts	The overall goal of 3FCM is to provide in a clean and climate-friendly way all the value and services presently obtained from fossil resources which in addition are essentially imported from outside Europe. Although it will take at least 30 years to achieve a global ecological transition, 10 years will be sufficient to kick-start key technologies, and turn into attractive commercial activities the most advanced existing industrial processes. The 10-year objective of the 3FCM partnership is to enable the progressive displacement of fossil resources, using renewable energy to convert molecules from the environment (H_2O, N_2, CO_2) into valuable products. This grand challenge will be realised by inventing, developing, improving, engineering, socially adapting and commercially deploying devices for the provision of fuels, commodity chemicals, base chemicals and monomers for the synthesis of fertilizers, plastics, and building materials. On the longer term, 10-30 years, the partnership will aim at the deployment of economically viable and energy efficient negative emission technologies. To replace fossil stocks, we will use the same primary resources as Nature did on geological times to produce coal seams as well as oil and gas fields. Thus, 3CFM aims at using solar energy for recycling atmospheric gases, especially CO_2, the most voluminous waste of over 200 years of global economic development. The effective concentration of solar energy into chemical species may be accomplished by several conversion routes depending on location (latitude), targets (fuel, commodity chemicals, long-term storage of carbon) and technological maturity. Wind or PV electricity in temperate climates combined with electrochemistry and

	advanced catalysis is an open route, whereas direct sunlight conversion can operate in regions with abundant sunshine employing photoelectrochemistry, bioinspired photocatalysis or biological (biohybrid) systems. Technologies to concentrate waste or atmospheric gases, mainly CO_2 and H_2O, are also part of most strategies to be developed. Three key performance indicators of the viability of these technologies will be: • sober use of abundant and cheap raw materials in a circular economy approach; • maximization of the overall Energy Return On energy Invested (EROI); • minimal use of land. About this 3rd criterion, conservative estimates allow optimistic projections on the use of mostly already artificialized areas, such as industrial and commercial districts, or urban areas. The technological benefits will be assessed quantitatively in a systemic approach including economic, social and environmental studies. Beyond the profit of avoided CO_2 emissions, climate science will be involved in the partnership to guide the overall development of the technologies and avoid any unintended environmental consequence. The 3FCM partnership will have a tremendous impact on the society, economy and the environment. On the economical and industrial side, we foresee: • Enhanced investment in CO_2-neutral energy technologies • Decrease of the carbon footprint of heavy industrial emitters • Opportunity of making economically attractive CO_2 storing materials.
Necessity test: rationale for a European Partnership	The two initiatives SUNRISE and ENERGY-X have been already funded as CSAs for future FET Flagships. As the Flagship instrument will not be replicated in Horizon Europe, the support to large scale research initiatives is at stake - the domain to be covered by the **3FCM** partnership is presently scattered between various instruments (including partnerships such as FCH-JU, MCSA, FET and ERC) at the detriment of a coordination of efforts. No current partnership fully addresses the challenges and expected impacts as presented above. The two initiatives are already based on strong research-industry links - a partnership would enhance Europe´s competitiveness on the global scale, building on the excellence of research and leading role of Europe´s chemical industry.
Relevant for the following parts of Horizon Europe	Pillar II 'Global Challenges and European Industrial Competitiveness' ☒ Cluster Climate, Energy and Mobility ☒ Cluster Digital, Industry and Space ☒ Cluster food, bioeconomy, natural resources, agriculture and environment
Currently identified links with other partnership candidates /union programmes	There are evident links with the following candidate partnerships: **Climate, energy and mobility**: - Clean Energy Transition - Clean Hydrogen - Clean Aviation - Towards Zero-emission Road Transport - Built Environment and Construction **Digital industry and space**: - Circular and Climate Neutral Industry Similarly, there are links with the future Missions of Horizon Europe: Mission area 1 (Adaptation to climate change including societal transformation), 4 (Climate neutral and smart cities) and 5 (Soil health and food). Additionally, there are potential links with several of the Joint Programmes of EERA: Advanced Materials and Processes for Energy Applications (AMPEA), Bioenergy, Carbon Capture and Storage (CCS), Economic, environmental and social impacts (JP e3s), Energy Storage, Fuel Cells and Hydrogen, Photovoltaic Solar Energy, and Smart Cities At a global scale, there are links with three out the seven innovation challenges (ICs) of Mission Innovation, namely: Converting Sunlight IC5, Carbon Capture IC3; Sustainable Biofuels IC4, Clean Energy Materials IC6

Does the proposed partnership build on currently active ones?	This partnership builds on two ongoing CSA actions for FET Flagships: - SUNRISE: Solar Energy for a Circular Economy (https://sunriseaction.com/) - ENERGY-X: https://www.energy-x.eu/
Expected type and composition of partners	The partnership would gather academia, research organizations and industry stakeholders, based on the still growing community of the two currently active CSAs. These communities also include NGOs, governmental and local authorities. Overall, the partnership will have all the relevant stakeholders, including end-users, to address the whole value chain. Currently, the SUNRISE and ENERGY-X communities collectively gather over 300 key players from academia, research, industry, national and European networks and alliances, funding bodies, NGOs and other stakeholders.
Contributions and commitments expected from partners	In-kind contributions (usage of research infrastructures and facilities, etc.) from academia, Research and Technology Organisations (RTOs) and industry. Industry will also participate in building exploitation strategies for securing early revenues.
Currently envisaged implementation mode(s)	☐ Co-programmed European Partnership ☒ Co-funded European Partnership ☒ Institutionalised European Partnership ☐ Article 185 ☐ Article 187 ☐ EIT-KIC
Justification of the implementation mode	
Proposed starting year	2021

Solar Energy for a Circular Economy

Deliverable D4.2

Terms of Reference for the governance of the SUNRISE Large Scale Research Initiative

Lead Beneficiary	Siemens/CEA
Delivery date	30.04.2020
Dissemination level	Public
Version	1.1

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Authors	Siemens
Deliverable number	4.2

Deliverable name	Terms of Reference for the governance of the SUNRISE Large Scale Research Initiative
WP	4

Version	Date	Author	Description
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v0.2	200408	F. Chandezon, M. Meier, S. Baumann	Review of WP team members
V1.0	200416	T. Soller, J. Kargul	Review from Quality & Impact Assurance team
V1.1	200429	T. Soller H. de Groot	Final version

PREAMBLE

Due to the termination of new Flagships in Horizon Europe, SUNRISE and the parallel CSA ENERGY-X merged in August 2019 and concertedly founded the SUNERGY initiative which was officially launched in February 2020. This was done in order to join forces towards the ambitious goals common for both CSAs. The particular embodiment and funding instrument(s) for the future SUNERGY Large Scale European Research and Innovation Initiative (LSERI) are under discussion at the time of writing of this document. Therefore, the proposed Terms of Reference for the future governance of SUNRISE / SUNERGY should be considered as provisional and need to be refined once the applicable boundary conditions are clarified.

This deliverable was created in close alignment with ENERGY-X to avoid a duplication of efforts for developing the future governance scheme. Consequently, the described governance structures in this deliverable are conforming with the governance setup in the corresponding report of the ENERGY-X consortium (Deliverable D5.3: Proposal on the ENERGY-X Governance structure).

EXECUTIVE SUMMARY

This report amends the previous deliverable D4.1 - “Proposal for the organisational structure and processes of the SUNRISE large scale initiative” by providing further details and Terms of Reference for the identified governance bodies, both for the transition phase between the end of the SUNRISE CSA and the beginning of the SUNERGY LSERI (*i.e.* for the period from 2020 – 2024, termed “transition phase” or synonymously “ramp-up phase” in the following), and for the future LSERI itself (*i.e.* from 2024 onwards).

During the transition phase, the SUNERGY initiative will establish an interim governance structure based on a joint Executive Board (supported by a coordination office) and consultative Industrial & Scientific Boards to keep the stakeholder community actively involved and to continue the advocacy for a circular economy with sustainable fuels and chemicals. In order to fulfill those tasks, it is crucial to seamlessly implement the corresponding interim management bodies immediately after the end of the CSAs and maintain them until the boundary conditions and funding schemes for the future LSERI are clear. Funding of the transition phase will be accomplished on one side by collaborative research projects based on European calls and/or national instruments complemented by a CSA for the coordination activities. Before the start of the CSA (which is expected to start no earlier than 2021 with a dedicated call in Horizon Europe Work Programmes currently under discussion), the coordination activities of the SUNERGY initiative will be supported by a voluntary membership fee of the SUNERGY supporters complemented by in-kind contribution from some of the organizations involved the coordination of the overall initiative and/or national instruments for coordination activities.

For the long-term period, the temporary governance structures of the transition phase need to be amended and transformed into persistent bodies which can deal with the requirements of a LSERI. Based on the current assumption that the SUNERGY LSERI will be a co-programmed public-private partnership (cf. D4.1), the core elements of its governance scheme will be a Programming Board (for dynamic roadmapping as well as quality and impact assurance), an Executive Directorate (for the administration and the operational implementation of the overall initiative) as well as a common advisory board (for scientific, industrial and societal aspects) and a Funding Board.

For the Terms of Reference, a proper representation of all relevant stakeholders (*e.g.* from academia, industry, funding organizations) and – to the extent currently possible - compliance with the future HE framework was targeted. Nevertheless, further refinements of the governance structure and processes will be needed during the transition phase including well-defined mechanisms for joining or exiting the initiative.

List of acronyms and abbreviations

AC - Associated Countries

CSA - Coordination and Support Action

DTU - Denmark Technical University

EC - European Commission

ESA - European Space Agency

EU - European Union

HE - Horizon Europe

IA - Innovation Action

LSERI - Large Scale European Research and Innovation Initiative

MPG - Max-Planck-Gesellschaft

MS - Member States

MoU - Memorandum of understanding

R&D - Research and Development

RIA - Research Innovation Action

1. Introduction

In the preceding deliverable D4.1, the governance structure of running Flagships and other European large scale initiatives was analysed and - after the decision to discontinue the Flagship instrument in the next Framework programme Horizon Europe (HE) – a tentative scenario for launching a SUNERGY Large Scale European Research and Innovation Initiative (LSERI) was explored based on other instruments and options (partnerships, missions) in the context of HE. That scenario formed the basis for the development of the Terms of References discussed in this deliverable.

In particular, the proposed scenario in deliverable D4.1 comprises:

- **a short-to-mid-term transition and "ramp-up" phase (2020-2024)** which will be used for i) implementing the blueprint, ii) strengthening and further developing the community including common coordinated activities according to the roadmaps and based on RIA & IA open calls complemented by national calls, and iii) the preparation of the subsequent LSERI. Since the conduction of those activities will not be possible without funding, a successor CSA project should be established with a duration of 3 years to bridge the time until the launch of the LSERI.
- **a long-term LSERI phase (after 2024)** which corresponds to the start of a SUNERGY partnership "*Fossil-free fuels, chemicals and materials for a circular economy*". Regarding the type of partnership, with both bottom-up (RIA) and programmatic (IA) components and the necessary flexibility in terms of composition of partners, objectives and activities, a co-programmed European partnership (cPPP) appears as the most suitable option. Besides having both public and private partners, the cPPP instrument also allows to have MS involved via the signature of MoUs and hence, to align national priorities with the SUNERGY roadmap.

The activities to develop the governance structures and processes for both the transition phase and the long-term phase were jointly performed between the ENERGY-X and SUNRISE consortia after the official announcement of the merger of the two CSAs in Aachen (Germany) on 20th August 2019. Two physical workshops and several electronic meetings were held between the teams dealing with governance definition to develop the joint proposal for the future organization of the SUNERGY initiative.

Consequently, the deliverables D5.3 ("Proposal on the ENERGY-X Governance structure") of ENERGY-X and the present SUNRISE deliverable D4.2 ("Terms of Reference for the governance of the SUNRISE Large Scale Research Initiative") are a co-production of both CSAs and were hence shared between the two consortia to make sure that both deliverables are consistent. Each consortium provided the necessary resources and did not duplicate the work done by the other.

This report hence uses the same figures and descriptions of the governance bodies as D5.3 of ENERGY-X, with minor updates (particularly regarding the Industrial Board) that emerged after the submission of ENERGY-X's report.

2. Terms of Reference during the transition phase (2020-2024)

The proposed Governance structure for the transition phase with its respective bodies and instruments is schematically shown in Figure 1 and further described in the following paragraphs:

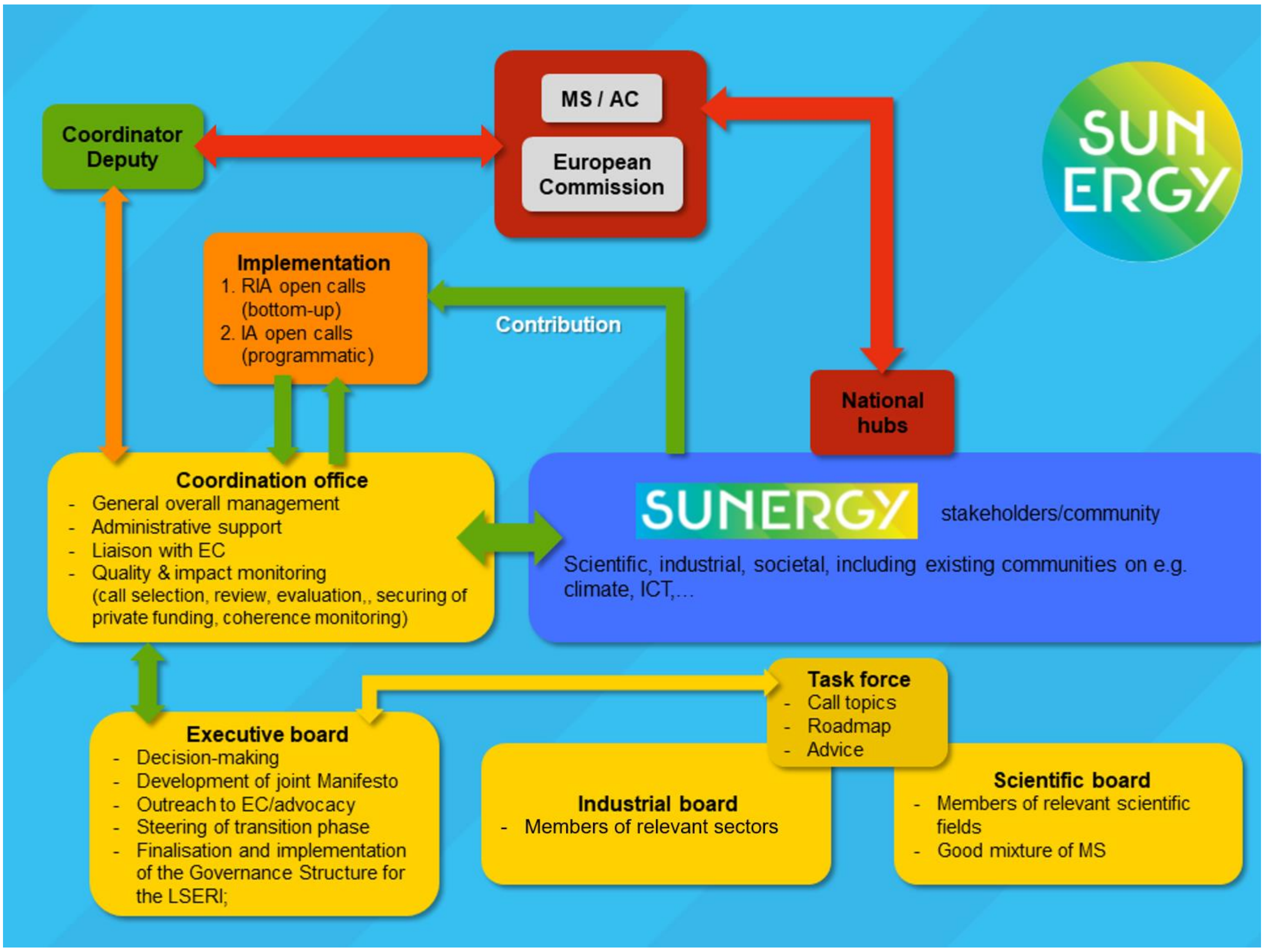

Figure 1. Scheme of the Governance structure for the transition "ramp-up" project phase, starting at the end of both CSAs until 2024.

Executive Board

<u>Mandate of the Executive Board:</u> The tasks and responsibilities of the Executive Board are the operational running of the SUNERGY initiative in the intermediate period with members having different roles and tasks which can be delegated upon need, *e.g.*:

- Development of a joint Manifesto,
- Outreach to EC/advocacy,
- Decision-making,
- Steering of transition phase,
- Finalization and implementation of the governance structure for the LSERI.

<u>Composition of the Executive Board:</u> So far, the two CSAs ENERGY-X and SUNRISE have mutually decided on the implementation of an active SUNERGY Executive Board for the transition

phase with 8 members: The Coordinator, Deputy Coordinator and 3 additional members of each consortium.

Coordinator:	Prof. Bert Weckhuysen	(ENERGY-X, Utrecht University, NL)
Deputy Coordinator:	Dr. Frédéric Chandezon	(SUNRISE, CEA, FR)

The other members of the Executive Board are:

ENERGY-X:	Prof. Gabriele Centi	(University of Medina, IT)
	Prof. Jens Nørskov	(DTU, DK)
	Prof. Robert Schlögl	(MPG, DE),
SUNRISE:	Prof. Huub de Groot	(Leiden University, NL)
	Prof. Joanna Kargul	(Warsaw University, PL)
	Dr. Carina Faber	(Université Catholique de Louvain, FR)

Coordination Office

Mandate of the Coordination Office: The interim coordination and management office is situated at Utrecht University providing administrative support and liaising with the EC and the SUNERGY community. All participating partners will be asked to financially support the initiative by paying a voluntary membership fee which will be utilized for management and coordination of the initiative and for communication activities. This membership fee will be maintained at least until other support for coordination activities is obtained, *e.g.* with another CSA.

Composition of the Coordination Office: The Coordination Office will be staffed with a Programme Coordinator who will be involved in developing, coordinating and implementing the strategic plan of the SUNERGY consortium, and who will function as the administrative right hand of the SUNERGY Coordinator and Deputy Coordinator.

Industrial Board

Mandate of the Industrial Board: The main role of the Industrial Board is to provide the views of industry on the overall development and strategy of SUNERGY. General coordinating tasks of the industrial board include:

- Alignment of the R&D program in SUNERGY with the industrial/economic needs (on short- to long-term time scale);
- Giving credibility to the need for the SUNERGY initiative and mobilization of industrial participation;
- Generation of proposals for the implementation projects (*e.g.* Innovation Actions).

Fulfilling these objectives include the following activities:

- Investigation of the market needs and forecasts as input to steer the scientific developments and joint R&I actions;

- Provide input on pricing of synthetic molecules, expected quantities and economic needs, Capex/Opex/Efficiencies;
- Work on the desired value chain including handover points of molecules and needs for purification (and its costs) between the stakeholder. Define respective products and evaluate how the different industrial sectors can collaborate on industrialization;
- Work on modelling of the European energy system; provide input on energy storage needs;
- Align a European perspective on the circular economy with the worldwide view (e.g., what to harvest in Europe; future role of international energy exports etc.);
- Review the content of proposed research projects in view of market needs, time to market and acceptance of project outcomes for industrial and societal acceptance, focus to IA, accompany RIA;
- Monitor ongoing R&D activities (also on other frameworks) to avoid activities redundancy;
- Work with investors to help in making the output of the research bankable, which will provide the basis for an uptake of the research results in our future economy;
- Clearly communicate the economic value of the developments to national and trans-national funding agencies.

The industrial board will be actively involved in the discussion of the status and the developments of the SUNERGY research activities and technologies. Regular electronic meetings and yearly personal meetings (with the participants who can make themselves available) are going to ensure the communication and information sharing amongst the members of the Industrial Board. A copy of the meeting minutes will be shared with the Executive Board and the Scientific Board.

Composition of the Industrial Board: The composition of the Industrial Board should include all industrial fields of the SUNERGY value chain starting from the conversion of resources using system processes to base chemicals and fuels and their end use. The Industrial Board comprises 9 members including the chair. The members are proposed by the chair of the Industrial Board and validated by the Executive Board, and the composition can evolve after proposition from the chair validated by the Executive Board. The Chair of the Industrial Board is also member of the Coordination Office. The current composition of the Industrial Board is given below:

Chair:	Maximilian Fleischer	(Siemens Energy, DE)
Members:	Christoph Gürtler	(Covestro, DE)
	Marie-Godard Pithon	(VICAT, FR)
	Poul Georg Moses	(Haldor Topsøe, DK)
	Jan Mertens	(Engie, FR)
	Anastasios Perimenis	(CO_2 Value Europe)
	Philippe Jacques	(EMIRI)
	Andreas Förster	(DECHEMA, DE)
	Alex van der Made	(Shell, NL)

Scientific Board

Mandate of the Scientific Board: Analogous to the Industrial Board, the Scientific Board shall provide inputs from the academia regarding the directions and future course of action of the SUNERGY initiative. This includes, amongst others, strategic advice on basic research priorities for the overall SUNERGY roadmap, identification of collaboration opportunities, and coordination activities concerning the generation of proposals for the relevant Research Innovation Actions.

Composition of the Scientific Board: The Scientific Board will contain members of the Member States (MS). They will join upon invitation from the Executive Board. All the SUNERGY relevant scientific fields, from fundamental to applied research, are going to be represented by various academic partners from all over the EU MS.

Task Force

Mandate of the Task Force: For active involvement of the Industrial Board and the Scientific Board a task force will be implemented. The Task Force will provide input and specific expertise for calls, assist in writing the research roadmap of the SUNERGY initiative and generally provide advice that aids the forthcoming of the project. The Task Force will report on the fulfillment of its responsibilities to the Executive Board.

Composition of the Task Force: The size and the setup of the task force will be decided by the Executive Board and can be revised on an as-needed basis.

SUNERGY Community

The SUNERGY initiative is additionally supported by a large group of stakeholders and supporters currently counting more than 300 institutions, companies, associations, governmental and local authorities, NGOs etc. SUNERGY will set up a community-building and networking platform for stakeholders to enlarge and strengthen the scientific, societal and industrial commitment. The SUNERGY community is always open for new members to get actively involved.

In order to support SUNERGY in terms of lobbying, networking and visibility enhancement activities, a small contribution in the form of a voluntary membership fee will be requested. The terms and regulations for participation are yet to be defined.

The Community will meet during an annual event/general assembly during which, the Coordinator, Deputy and members of the Executive and Industrial Boards will present and discuss the achievements and the general strategy to the community of stakeholders and supporters. Similarly, events will be organized at the national level gathering the national SUNERGY communities with participation of governmental representatives and whenever possible, the members of the SUNERGY boards.

Implementation of the SUNERGY Roadmap

The SUNERGY roadmap will be implemented by merging the two existing roadmap documents from SUNRISE and ENERGY-X into a single document. The research objectives and activities defined therein can be complemented by RIA/IA calls at the European level plus calls at the national level based upon the content of the SUNERGY roadmap. The framework and conditions for the calls will be determined by Horizon Europe (or H2020 if there are possibilities for adding SUNERGY topics based on the remaining budget).

All the granted projects should conclude a written collaboration agreement with the SUNERGY CSA and the other selected RIA and IA projects, and both the midterm review and the end evaluation of these projects shall be performed by the SUNERGY Executive Board operating under a mandate from the MS/AC and EC to prevent separation of authority from responsibility. Keeping the authority over the end result with the MS/AC and EC will ensure that both the RIA bottom-up components and the IA programmatic components contribute to the activities of the SUNERGY initiative.

Furthermore, for the communication and information sharing between the SUNERGY partners and for interested entities outside the initiative a comprehensive dissemination strategy plan for the joint SUNERGY initiative has been prepared together with the ENERGY-X communication partners.

3. Indicative Terms of Reference for the future SUNERGY LSERI (from 2024 onwards)

For the long-term period, the SUNERGY initiative plans to form an LSERI. The co-programmed public-private partnership was identified as one suitable instrument in the frame of Horizon Europe but could not start earlier than 2024. Due to the funding uncertainty, as discussions are still ongoing with EC and MS, all of the following considerations and descriptions of governance bodies are only indicative building blocks of the future SUNERGY LSERI governance structure. They need further detailing regarding the specific arrangements, processes and legal setup during the transition phase (2020-2024) by the Executive Board.

The proposed governance model of the future SUNERGY partnership is derived from the ESA structure. A schematic overview (cf. Figure 2) and a short, general description of its bodies and mandates are given below.

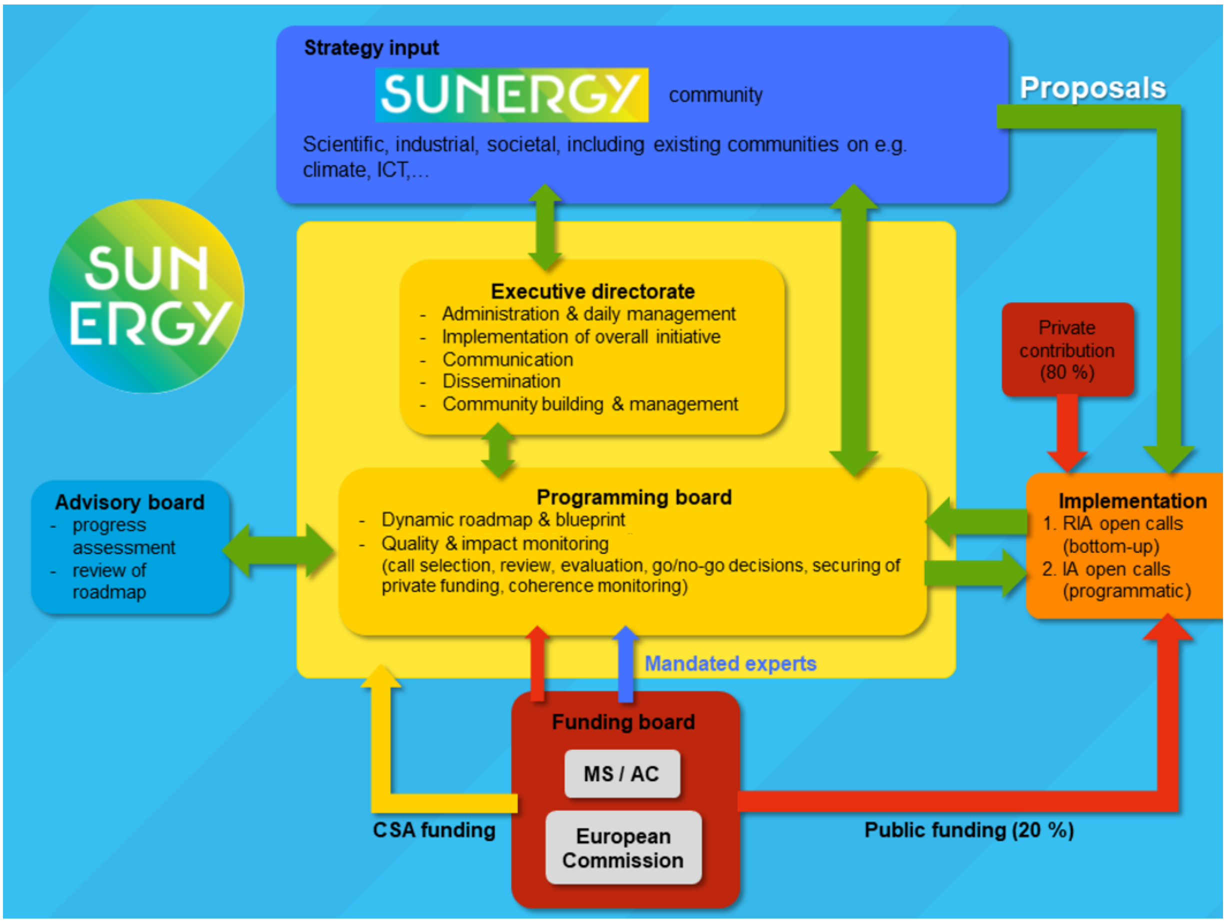

Figure 2. Tentative scheme of the Governance structure for the SUNERGY Large Scale European Research Initiative, starting in 2024

Funding Board

The Funding Board consists of the main public funders of SUNERGY, namely representatives from the MS/AC of Horizon Europe and the Commission. The main role of the Funding Board is to discuss and possibly plan the financial support to SUNERGY for the whole duration of the partnership. The Funding Board is open to all MS/AC that are interested in SUNERGY, irrespective of whether they have SUNERGY-related policies and programs or not. Key objectives include:

- Exchanging information on the overall direction and strategy of SUNERGY;
- Linking SUNERGY roadmaps and blueprints to innovation policies at national and European level;
- Fostering synergies between SUNERGY and related activities funded at national, regional or transnational levels;
- Fostering international collaboration.

Programming Board

The Programming Board is central and acts as the main liaison body with the funding board, the SUNERGY community, the coordination body (*i.e.* the Executive Directorate) and the implementation part. It associates mandated expert members of the public and private stakeholders to plan the work and performs scouting in the community for new ideas worth to be developed further. The Programming Board steers the implementation towards its higher goals based on a mandated program with large-scale efforts (at higher cost) that need to be executed on time, and a bottom-up program that is bringing in the new developments. In order to have a balanced view, the Programming Board consists of representatives from EC and MS/AC, from academia and from industry (either via associations or single companies). As far as the latter, two stakeholder groups are concerned whose representatives can be chosen via an election process through the SUNERGY community for a temporary term.

Key objectives of the programming board are:

- Updating the overall roadmap and blueprint of SUNERGY based on the overall results obtained on the implementation part;
- Quality and impact monitoring, which includes selection of calls, review of proposals, evaluation of project progress incl. go/no-go decisions, and coherence monitoring;
- Securing of engagement and funding from the private sector.

Advisory Board

The Advisory Board could emerge from the Scientific and Industrial boards launched during the transition "ramp-up" period and should be complemented by a societal component. Such a board would have an advisory role both to the SUNERGY coordination and to the EC and MS. In addition, it would support and counsel the Programming Board regarding scientific, industrial and societal aspects. It consists of high-level independent experts and opinion leaders from academia, industry and NGOs and provides strategic advice and recommendations to the Programming Board. This includes the independent assessment of the SUNERGY progress and the review of the overall SUNERGY roadmap. The Advisory Board is open to participants from non-EU countries to enable global benchmarking of SUNERGY versus relevant activities outside the EU. The maximum number of non-EU participants is limited to less than half of the overall size of the Advisory Board for keeping focus on EU priorities.

Executive Directorate

The Executive Directorate, headed by the Executive Director, is the coordination body of SUNERGY and acts as an intermediary between the SUNERGY community and the Programming Board. All administrative efforts regarding SUNERGY are handled via the Executive Directorate. This includes:

- Coordination, collection and processing of strategy input from the community via an open, transparent process;
- Regular communication and dissemination activities toward the SUNERGY community and the general public;
- Methodical support for the Programming Board;
- Holding of elections;
- Fostering networking and community building, for example via organization of an annual general assembly of the whole SUNERGY community.

The Executive Director will be supported by operational management staff (executive office). As operational day-to-day management of a LSERI is expected to be complex, it is likely that the executive office will run under an independent legal entity yet to be founded.

SUNERGY community

The SUNERGY community consists of scientific, industrial and societal stakeholders of SUNERGY's vision and mission. The community is always open for new members to get involved. In order to enter the community and take advantage of the benefits of SUNERGY in terms of lobbying, networking and visibility, applicants must sign a Memorandum of Understanding to confirm that they comprehend and acknowledge the principles of the partnership. The Memorandum of Understanding particularly stipulates common rules and criteria for the membership, *e.g.* regarding consortium formation, branding, information exchange, involvement and supporting of the Programming Board or resigning from the community. The SUNERGY community members contribute to the implementation of the overall SUNERGY LSERI roadmap and blueprint via participating in RIA and IA European calls or via national/local funding opportunities.

Solar Energy for a Circular Economy

Deliverable D5.1
Mid-term Evaluation Report

WP5. Management

Lead Beneficiary: UL – Leiden University
Delivery date: 31 October 2019
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Executive Summary

This document, D5.1 Mid-term Evaluation Report, is a deliverable of the SUNRISE Project, which is funded by the European Union's H2020 Programme under Grant Agreement No. 816336.

Members of the Scientific Advisory Board were invited by the SUNRISE consortium to review the work produced within the first six months of operation, materialised in several deliverables, with a focus on the SUNRISE Roadmap, defining the research needs for the development of solar-based products on short, medium and long term. The mid-term evaluation had two components: a remote, written evaluation and an in-depth discussion with the SUNRISE consortium during the SUNRISE Consortium meeting organised in Brussels on 9-11 October 2019. The discussion was documented, and the outputs presented further in this document.

The following main recommendations resulted from the mid-term review sessions on the 9th October and the joint Roadmapping session with Mission Innovation MI IC5 on the following day:

- Enhance the cohesion between the three technology approaches, which is currently less obvious in the roadmap.
- (for Approach 1) Consider other primary energy sources, apart from solar power
- Inform the policy makers at an early stage that SUNRISE *can* in 10 years deliver the technology for direct conversion of solar energy to fuels and chemicals.
- Give sufficient attention to the economic impact, and ensure the technology proposed is affordable for the end-user by developing high efficiency PEC
- To differentiate among various technology platforms in the European landscape, SUNRISE should emphasise the highly novel aspect of the Direct Atmospheric Carbon Capture (DACC) technology.
- Relative to the more established methods in approach 1, where the principle hurdle is CAPEX, stress the importance of breakthroughs in PEC for high efficiency and Biological/biohybrid for diverse products
- Continue the dialogue with Energy-X, essential in order to cover the entire technology readiness spectrum and develop disruptive technologies from concepts to full scale in a very challenging timeframe.

The parallel sessions during the joint event with Mission Innovation IC5 led to very specific feedback, which is listed in the Annexes 5-7 and will be incorporated in the final version of the SUNRISE Roadmap. Since the roadmap is globally competitive, it is recommended that the consortium participates with its roadmap in global agenda setting and policy making.

The recommendations resulted from the mid-term review are also summarised in section 3. The overall conclusion was that SUNRISE has pioneered the transition towards a new energy system, based on abundant raw materials and solar energy as the sole energy source.

To ensure the success of the future large-scale research initiative and address the entire TRL spectrum, the SUNRISE consortium was strongly encouraged to continue collaboration with Energy-X and involve at an early stage political and industrial stakeholders.

1. The mid-term evaluation process

The following members of the SUNRISE Scientific Advisory Board (SAB) were invited by the SUNRISE consortium to review the SUNRISE deliverables:

- Prof. Harry Atwater (Caltech);
- Prof. Walter Leitner (Max-Planck Institute for Chemical Energy Conversion);

- Prof. Geert-Jan Kramer (Utrecht University);
- Dr. Gaël Giraud (Agence française de développement);
- Prof. Roberta Croce (Vrije Universiteit Amsterdam); and
- Prof. Jean-Pierre Sauvage, Nobel Prize Laureate for Chemistry in 2016.

The former three agreed to contribute remotely to the mid-term evaluation, whereas the latter three had to decline due to prior commitments or health issues. In addition, Prof. Daniel Nocera (Harvard) reviewed the consolidated vision in June, at the occasion of the Stakeholders Workshop.

The documentation was provided on the shared workspace (Plaza) hosted by M2i, and included:

1. SUNRISE deliverables:

- SUNRISE Consolidated vision (deliverable D1.1);
- Roadmap (Deliverable D1.2), accompanied by its technical appendix;
- Innovation process (Deliverable 2.1);
- Dissemination plan (Deliverable 3.1);
- Data management plan (Deliverable 3.4, draft);
- First outline for governance, in the form of a Joint Partnership Proposal on Fossil-Free Industry, proposed jointly with Energy-X.

2. SUNRISE proposal, as background information against which the deliverables could have been evaluated.

The core document for the mid-term review was the SUNRISE Roadmap, paving the route towards achieving commercial maturity level (TRL 9) for sunlight-based fuels and chemicals and at least demonstration level (TRL 7) for CO_2 removal, via three technological approaches:

1. Electrochemical conversion using renewables as energy source,
2. Direct photoelectrochemical conversion – and
3. Direct conversion via biological and biohybrid systems.

The selected SAB members were asked to provide a **written evaluation of the SUNRISE deliverables**, with a focus on the SUNRISE Roadmap. The evaluation should be provided as a two-page document with a structure of choice, before or during the mid-term evaluation sessions in Brussels, on the 9th and 10th of October.

Following the evaluation by the SUNRISE SAB members, on the 11th October, the Roadmap was debated with the experts of the Mission Innovation IC5 “Converting sunlight”, listed as follows:

- Julius Scholz, NOW-GmbH;
- Peter Vach, German Federal Ministry for Economic Affairs and Energy;
- Winifred Leibl, Commissariat à l'énergie atomique et aux énergies alternatives;
- Pau Farras, National University of Ireland Galway;
- Mehdi Jafarian, University of Adelaide;
- Roel van de Krol, The Helmholtz Association of German Research Centres;
- Philippe Schild, European Commission;
- Nigel Taylor, European Commission/ Joint Research Center.

2. Mid-term evaluation meeting: inputs and discussion

The mid-term evaluation meeting was organised in the frame of the SUNRISE Consortium meeting. The event was scheduled over three days, starting on the 9th October at noon and ending on the 11th October at noon, at EERA in Brussels, 72 rue de Namur. Remote web-based sessions were organised with Prof. W. Leitner on the 9th of October and with Prof. Geert-Jan Kramer on the 10th of October.

Prof. Harry Atwater declined participation to a remote session, nevertheless had discussed during a prior meeting with Prof. A. Vlcek (Heyrovsky Institute, member of the SUNRISE consortium) the status and perspectives of SUNRISE. A brief account is presented further below, along with the other relevant sections of the event minutes.

Furthermore, another SAB member, Prof. Daniel Nocera, discussed his findings during a working dinner on June 18th, following the Stakeholders Workshop ("ramp-up meeting"). Prof. Nocera recommended to engage with private partners to concentrate on the long-term impact, as the private sector can only justify participation in low TRL research when the expected long-term impact is high. In particular, he suggested to keep a sharp focus on the business opportunities, as stated in the proposal:

- Targeting 10% of global crude oil and gas production, the total of which represents a value of €250 billion per annum in the upstream sector, even at the current low-price level;
- Targeting 10% of global investment costs in traditional refineries for upgrading existing plants and building new ones that transform SUNRISE products into certified fuels amounts to an estimated €17 billion per annum for Europe, based on a 10% reinvestment rate per year.

Day-1: Wednesday, October 9th

Opening words by Huub de Groot (LU, coordinator SUNRISE CSA).

The SUNRISE coordinator Huub de Groot (UL) presents briefly the status of the SUNRISE deliverables. The following deliverables have been produced and submitted: *D1.1 Consolidated vision*, *D2.1 Innovation process*, *D3.1 Dissemination plan*. Three other pending deliverables (*D1.2 Roadmap*, *D2.2 Innovation structure* and *D3.2 Data management plan*) are currently being drafted, the Roadmap and the Data management plan having in the meantime been finalised.

Midterm review – session 1

Debrief Mid-term review

Huub de Groot informs the consortium that several members of our Scientific Advisory Board were contacted to perform a mid-term review of the SUNRISE deliverables, primarily the Roadmap. Three members of the SAB reacted positively to this invitation: Prof. Walter Leitner (Max Planck Institute), Prof. Geert Jan Kramer (Copernicus Institute, Utrecht University) and Prof. Harry Atwater (Caltech/JCAP) but eventually only the former two could participate during live, remote sessions. Harry Atwater had a discussion with Prof. A. Vlcek (Heyrovsky) in the US, who also gave a short account via email:

> *"Harry Atwater was interested in the latest status of SUNRISE, merger with ENERGY-X, etc. I made it clear that, while the merger is going on, the two CSAs are separate and will follow their respective plans until March. Interestingly, he told me that the US Senate agreed that DoE will fund largely fundamental research in solar fuels by 20M USD per year for a period of five years. The emphasis will be on liquid solar fuels, that is CO_2 to methanol, ethanol, propanol, possibly dimethylether, liquid hydrocarbons and N_2 to liquid ammonia. DoE stresses direct conversion (photoelectrochemistry), saying that the science behind electrocatalytic conversion (like ENERGY-X) is largely known. Long-term stability of materials (photoelectrodes) and dual-function materials (a photoelectrode that would also have catalytic activity) are stressed as priority topics. Other aspects of direct conversion ("soft" bioinspired and biohybrid) systems are considered as well.*
>
> *This new DoE funding will be awarded based on an open competition. Caltech will compete, as a possible continuation of JCAP, which will finish in September 2020. If they get it, they would be interested in collaborating with us."*

Two skype sessions were planned in the afternoon and the morning of the next day, respectively. At the beginning of the review session, Huub de Groot proposed several questions to guide the discussion with the external reviewers:

- Is there a risk that "the level goes down", as this is a risk related to any emerging funding opportunity?
- Considering the limited availability of the few experts on artificial photosynthesis for roadmapping processes, is there a risk that "non-experts take the lead"?
- "White spots", such as for example insufficiently covered priority research directions (*e.g.* direct conversion of CO_2) or *ex-ante* impact evaluation.

After this introduction, the SUNRISE WP leaders gave individual presentations on the status of their respective work packages.

Summary of WP status by WP leaders

WP 1 Strategy and Structuring: Nicola Armaroli (CNR)

The first major deliverable, "SUNRISE Consolidated vision", was an extension of the vision from the proposal. The work was initiated by CNR (Dr. Nicola Armaroli and Dr. Andrea Barbieri) and further developed by CEA (Dr. Hervé Bercegol and Dr. Vincent Artero). The next step was to develop the SUNRISE Roadmap, which has the solar-driven circular economy as target for mid-century, with several milestones. The roadmapping required an impressive amount of work, coordinated by Dr. Carina Faber (UCL), whom Nicola thanked on behalf of the consortium.

Q W. Leitner: How did you involve the representatives of large companies (Siemens, Johnson Matthey) – and was that performed at the level of technical people or was the upper level of the hierarchy involved?

A. N. Armaroli: The companies were deeply involved in the discussion and provided important input. A. Huub: When working with companies, it is important to have a deeply committed individual inside the company, a so-called champion – not necessarily from the upper management. We have identified such champions in Engie and Siemens, hence we selected them for the proposal. We also have many industrial supporters.

WP 2 Innovation and exploitation: Arne Roth (Fraunhofer)

The first deliverable, SUNRISE Innovation Process (SIP), introduced the concept of the "SUNRISE valleys", *i.e.* "collaborative forums for all partners and stakeholders to meet and set priorities for addressing short-, medium- and long-term challenges for transitioning to a circular economy".

A first Innovation workshop was organized during the Stakeholders Workshop (Brussels, 17-18 June), which led to the identification of the following steps for an innovation process:

1. Trend analysis: high-level targets, drivers and societal needs; create & analyse scenarios;
2. Idea generation: ways to generate interesting ideas; some stakeholders expressed concerns regarding the protection of IP;
3. Idea evaluation: system-level performance assessment; evaluation of the economic potential; advisory committees and/or external evaluation;
4. Experimentation: use of computational tools, suitable funding, market potential and social acceptance;
5. Commercialization: regulatory issues; compliance with standards – potentially blocking innovation.

Arne presented a SWOT analysis of the SUNRISE Valleys concept. The following weaknesses were mentioned: exclusive ("what about the rest?"); imbalance (too many scientists); internal competition; lack of impact on policymaking due to limited geographical scope. As threats: lack of financial/political support, unstable legislative situation, lack of social acceptance ("not in my backyard" attitude). The upcoming deliverable is the development of the S2S and S2B exploitation plans (due by Month 6, still pending, responsible CEA & JM). Arne suggests the creation of an Innovation team to complete this work. The team would mainly involve the partners involved in WP 2.

Q Leif Hammarström (UU): there was a comment on the lack of a clear path towards the SUNRISE Valleys, the plan towards creating them still needs to be worked out.

Comment W. Leitner: The SUNRISE roadmap aims at TRL 9 in 10 years, this definitely requires industry support and industry needs should be involved early-on. It seems that Energy-X plans to involve industry at a later stage. Industry support does not seem to be fully aligned in both initiatives. The industry needs to plan the implementation justifying the research. Organizing funding commitment for the next 10 years is a challenge. Politicians will need to be convinced that industry commits itself to bring the technology to market. Reaction C. Faber (UCL): TRL 9 comes from the industry partners. Our industry partners (Engie, Siemens) are confident they can reach it within 10 years. Comment Huub: even at TRL 9, there is still innovation/optimization to be performed.

W. Leitner: Your industrial partners are not necessarily experienced in the production processes for the envisaged chemicals (e.g. ammonia synthesis). Reaction L. Baraton (Engie): yes, but we are building this knowledge, Engie has recently invested in expertise on Haber-Bosch and started a pilot project in Australia. There is industrial commitment to go fast towards TRL 9. Reaction E. Simon (Siemens): Indeed, Siemens is not ammonia producer, but we are interested in the conversion of solar energy (production of electrolysers). We are exchanging with specialized partners along the value chain and agree these partners are very important.

W. Leitner: it is important define the products ("X") you are targeting, and use their specifications for a specific market to drive the innovation. For this, it is crucial to involve end-users, otherwise the science cannot make it to the market. Other demonstrators can be considered, even without subsidies, for example local production of formic acid (from CO_2 and H_2) locally, at small scale – "the lighthouse project", as proposed in the written review – action Arne Roth to explore this idea.

W. Leitner also recommends to pursue the original idea of the jet fuels, building on the momentum of pressing regulatory demands for aviation. European air carriers (e.g. Lufthansa) are under pressure to reduce emissions and to introduce significant shares of renewable jet fuel. A. Roth (Fraunhofer) indicates that the Aviation Initiative for Renewable Energy in Germany (aireg) aims at reaching a share of 10% renewable jet fuel in the Germany jet fuel mix by 2025[1]. Arne comments such a target is unrealistic, since only bio jet fuel is presently available as sustainable fuel alternative for aviation. Such public commitments will most probably trigger a fast development of alternative fuels. Several airports (Dusseldorf, Amsterdam Schiphol and Rotterdam) expressed interest in getting involved in pilot projects for alternative fuels. W. Leitner advises to pursue the idea of an airport demonstrator originally proposed in Energy-X. Action: discuss it with J. Nørskov or B. Weckhuysen (action Huub).

WP 3 Dissemination, communication and education: Laura Lopez (ICIQ)

Dr. Laura Lopez (ICIQ) presents the results of the dissemination tools created and deployed so far. There has been a massive dissemination effort in the scientific community, supported by the partners at national levels. From now onwards, the strategy will slightly shift towards reaching the public and the policy makers. Its goals were presented as follows:

- Strengthen the SUNRISE community

  Actions: continue and improve running actions with stakeholders; release video interviews with partners (a first one already launched, with Nicola Armaroli, on circular economy); sharing publication highlights from partners on the blog, increase online presence through contests, events etc.

- Increase involvement of policymakers and citizens

  Actions: social media campaigns, features in general media (on roadmap and manifesto), national stakeholders meetings, facts&figures infographics, translation of official video in several EU languages.

- Inclusive plan to reach younger generation

  Actions: visits to schools/ universities etc.

[1] https://aireg.de/en/topics/current-projects/the-goals-of-aireg-until-2025/

- Joint communication actions with Energy-X

Laura Lopez also presented a web statistic, showing good outreach: the SUNRISE community now counts 1.650 members.

> *Comment W. Leitner: The general public can be very difficult to address without a concrete output that they are able to judge.*

WP 4 Governance: Frédéric Chandezon (CEA)

A public debate was organized with representatives from EU and national governments on the 17th June at the Stakeholders Workshop in Brussels. The key take-away messages were:

- Join efforts with ENERGY-X (in the meantime materialised in a joint initiative prospectively named SUN-ERGY);
- Build visibility through a SUNRISE brand, with wide dissemination;
- Involve associate NGOs and general public;
- Involve industry right from the start and clarify the IP management;
- Activate member states and national communities. There were national SUNRISE events, organized in Italy, Poland, Switzerland, France. SUNRISE was also presented in third- and associated countries, during events in South Africa and Turkey (as per information from Artur Braun, EMPA). Upcoming national events: Netherlands, November 6th; Finland, December 8th.

Status of the SUN-ERGY initiative:

The two consortia (SUNRISE and Energy-X) put forward a Joint Partnership Proposal "3FCM: Fossil Free Fuels, Chemicals and Materials for a circular economy". The outcome of the previous consultations held at the EC level was that no room is left for a new partnership in the 2021 round, leaving the following alternatives:

1. *Join existing partnerships: this option was discussed during the first SUN-ERGY board meeting in Aachen on 20 August. Both consortia (SUNRISE and Energy-X) agreed that joining the existing programmes would lead to fragmentation of R&I efforts and therefore, this option was dismissed.*
2. *Promote a single initiative during the second round of call for partnerships (2024) – the option agreed by all. There are co-programmed, co-funded and institutionalised partnerships. SUNRISE is considering the latter two options, with a preference for institutionalised partnerships.*

WP 5 Management (CSA): Huub de Groot (UL)

The coordinator Huub de Groot states that the consortium is now in a "living strategy" mode. The final and critical step is "bridging into action". In this context, it is important that representatives of both consortia submit proposals to the relevant, currently open calls organised by the EC, such as the FET Proactive call "Emerging paradigms and communities" (FETPROACT-EIC-05-2019), closing on the 13th November. Joint teams SUNRISE/Energy-X should be setup to organise proposals for such calls, to show the interest of the community. The next steps for "bridging into action":

- Comprehensive description of the future plan (blueprint of a large-scale research initiative), with a manifesto covering the six documents;
- Mission Innovation connects to the Blueprint;
- Governance connects to Energy-X;
- Develop a joint innovation plan, to cover the full spectrum of technology readiness, from TRL 0 to TRL 9.

A final event (symposium) should be organised in February 2020, across a few days, and include a working session, as well as a larger event for the SUNRISE community, at a prestigious location.

Midterm review – session 2 with Walter Leitner

Prof. Walter Leitner congratulated the consortium for the work delivered in such a short period of time. The Roadmap requires further work, based on further discussion with Energy-X. With regard to the roadmap content, it is important to couple "Power-to-X" to the needs of each sector, whereby the challenges are very different: Electricity, 2018: 647 TWh (38% renewable), Mobility & Transport, 2017: 663TWh (5% renewables); Chemical industry, 2016: 20 Mt raw materials (13% renewables). For aviation, only hydrocarbons can be considered (Fischer-Tropsch) – see Annex 1 and Annex 2.

For the future large-scale initiative, it is important to engage the society and gain its acceptance at an early stage. This is crucial not so much for the scientific developments, but for the upscaling and implementation:

Q H. Bercegol: One of the arguments in the roadmap is to increase the efficiency of converting the solar input, which translates into a productivity increase per unit of land area and unit of time. How can we integrate other sources (different from direct solar) in the productivity indicator?

W. Leitner: we need to identify the areas where we have sufficient solar influx and for a sufficiently long period of time - this is the case for any conversion process. Hybrid/combined solutions should also be considered (and actually are, to a certain extent) in the roadmap.

Comment N. Armaroli: we need renewable electricity in each country, based on the sources that are available in those particular countries. Our deployment targets in 10 years (1.000 ha) are an extremely bold claim, considering we start from very small devices. PV took decades to progress from cm to m. Even if we are now in a different technology area – scaling up to the scale we promised is still a very hard challenge.

Q. W. Leitner: do you aim at large scale or decentralised operations? Or both? Huub: We will scale up operations gradually: in 10 years we want to demonstrate that it is possible to fly a plane. And achieve 80% of circularity for the target molecules.

Q. Hervé: You were not convinced about DACC (Direct Air Capture & Conversion of CO_2) and its link with rest of the project. Carbon capture activity was integrated later in the proposal in a system view of CCUS and due to the important energy loss encountered in DAC (Direct Air Capture of CO_2). Then it appeared that a major gain could come from the merging of the two steps: capture and conversion. Is your analysis different? A. W. Leitner: You have three major technology approaches, centred around conversion, and carbon capture seemed as a separate point, not influenced by/coming out of the other approaches. Hervé: DAC has not been optimised yet, as it has only been developed to provide CO_2 gas for CCS. We need to know in what form (chemical) the product will be it come; indeed, we will need to adapt CC for the technological approaches.

Day-2: Thursday, October 10th

Wrap-up of previous day

H. Bercegol (CEA) gave a brief account of the discussions from the previous day, followed by a discussion in the consortium on how those points are/can be addressed in the roadmap:

H. de Groot (UL): In his written review, W. Leitner also conveyed a very important point, that we should not consider a single renewable energy source (wind). Synergies should be sought, we should think of our position towards wind. S. Baumann (Jülich): There is no conflict between the two approaches, as there will never be too much electricity for the foreseeable time horizon. J. Kargul (Warsaw): the key is in the dichotomy direct and indirect power generation. A. Magnuson (UU): our roadmap refers to renewable electricity and artificial photosynthesis, therefore we do not exclude wind. We can also stress that wind+electrolysis is an available technology, it can be our starting point for a new energy market. H. Bercegol (CEA): We could also emphasise that our approach intends to maximise the photon conversion. E. Simon (Siemens): In some regions there is a lot of wind and not so much sun, the implementation routes should then consider the geographical hot spots for each type of renewable. Other comments of W. Leitner referred to centralised vs. decentralised and biomass: we will adopt a decentralised approach and not include biomass in the roadmap.

Midterm review – session 2 – Prof. Geert-Jan Kramer (Utrecht University), see Annex 3.

Prof. Gert Jan Kramer commends the effort of the SUNRISE team to create a roadmap for solar fuels and chemicals, as this is a critical topic for the coming decades. Aware of the intention to merge with Energy-X, he thinks synergy can lead to a stronger impact, allowing to build on the strengths of both communities and remove the existing overlap. However, there seems to be an excessive optimism on the speed of progressing through the TRL towards commercial maturity. About a 100 billion $ are needed to get to the bottom line of a new energy technology and 1.000 billion $ for it to achieve "materiality[2]. It is useful to consider the year 2000 as reference year, as the past two decades are characterised by a fantastic pace of change. Clean tech is now a 300 billion $ industry, but there is still significantly untapped potential to scale up this market to a trillion $.

Regarding the shift to market, the estimated affordable cost is 200 $ per barrel of solar fuel, as shown in a recent paper from Joule[3]. The SUNRISE roadmap targets the production of fuels from solar energy alone. The challenge is to realistically estimate the timeline needed to scale up this technology, which is ultimately based on the "artificial leaf" concept. At the same time, there are technologies like electrolysis that are already available for the production of "solar fuels".

Questions from G. J. Kramer for the SUNRISE consortium:

1. **Will SUNRISE be developing a new technology platform? Or will you be feeding into existing technology platforms?** Recommendation: the latter, however the roadmap seems to be written as if for the former. This needs to be clarified in order to build the most suitable consortium for a future large-scale research programme on solar fuels. The notable exception is Direct Atmospheric Carbon Capture (DACC), for which a TRL jump from 1-2 to 5-7 in 10 years seems unrealistic in the opinion of G. J. Kramer[4].

C. Faber (UCL): yes, we will develop a new technology platform, this was the purpose of the flagship initiative. Our approach was inspired from the Quantum technology platform, which also deals with a large spectrum of TRL levels. Reaction G. J. Kramer: You are framing this programme in the landscape of the EU projects, whereas I framed my question from a business perspective. Your intention then relies on the support of the industry to reach the higher TRL levels you are envisioning. There is then a significant risk of overpromising. As technology agnostic, nothing is more frustrating than seeing change around the corner and still not happening. It is important to inform the policy makers that we have the technology to make significant progress in the coming decades. Looking at the numbers from electrolysis section, 1.000 euro/kW is mentioned, but this might not be attractive for industry (which is already at 250 euro/kW). If you are aiming for a completely new technology platform, you need to consider the technology trends and the likely situation in 10 years from now.

H. de Groot (UL): It will be indeed critical to produce solar fuels at an affordable cost (as indicated by our industrial partners). Prof. John Mathews looked at the energy transition from China, which exceeds the most optimistic predictions[5]. Reaction G. J. Kramer: there has been progress on new technologies which in some cases overtook the old ones. However, the price must be affordable.

L. Hammarström (UU): Our roadmap was based on a timeline of 10 years and a funding of 1 billion euro. Perhaps we need to move away from these boundaries and focus on realistic time and budget scales.

2. **How do you plan to handle within a single programme, technology development at such different TRL levels?**

H. Bercegol (CEA): Should DACC be a new technology platform, and how would you see it developing within SUNRISE? A. G. J. Kramer: I am insufficiently aware of the boundary conditions in the EU funding landscape. However, the DACC is the truly open challenge, where breakthroughs are needed. This only justifies the emergence of a new technology platform, whereas the others can be fed into existing technology platforms.

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[2] G.J. Kramer and M. Haigh, "No quick switch to low-carbon energy", Nature volume 462, pages 568–569 (2009).
[3] Kraan et al., "An Energy Transition That Relies Only on Technology Leads to a Bet on Solar Fuels", Joule (2019), https://doi.org/10.1016/j.joule.2019.07.029.
[4] Nevertheless, the Swiss company Climeworks has already reached demonstration level (TRL 6), with several plants already operational. This technology has the potential to reach commercial application within the next 10 years.
[5] John Mathews, "Global Green Shift: Where Ceres meets Gaia", 2017.

Reactions industrial representatives: Dr. E. Simon (Siemens): Once the technology reaches efficiency levels comparable with existing ones, it will become an interesting investment. Then, once technology reaches higher TRL, the industry can definitely take over. Dr. L. Baraton (Engie): We can invest in electrolysis to produce hydrogen, and this can kick-start the development of artificial photosynthesis.

3. **Which synergies do you see?**

H. de Groot (UL): We are committed to merging with Energy-X. SUNRISE is transitioning from an initial club of enthusiasts into an inclusive community, where economic and social sciences are also represented.

Session with Mission Innovation IC5: SUNRISE roadmap review and feedback

The IC5 members were given access to the draft of the Roadmap document, and following a plenary session, the group split up in breakout sessions to prepare recommendations for improving the roadmap.

Carina Faber - Presentation SUNRISE Roadmap (see Annex 4).

Some background was given on how the SUNRISE Vision and Priority Research Directions have been defined. As a logical next step, the SUNRISE Roadmap will provide a guideline on *how* to reach the Vision goals when starting from the current state.

As a starting point, major milestones have been defined for the three classes of SUNRISE products, *i.e.* hydrogen, ammonia and carbon-based chemicals & jet fuels. The milestones are defined for 2025 – 2030 – 2050. Secondly, major technological targets related to the major milestones have been defined. A number of Key Enabling Technologies needed to accomplish the milestones have been listed and will need to be further developed within SUNRISE. Further information is found in Carina's presentation in the appendix.

Next, the group split in three break-out sessions and collect input to revise the milestones and the technical appendices to the draft Roadmap.

Plenary Questions and Feedback

Question Prof. Roel van der Krol (Helmholtz): One of the Roadmap scenarios refers to "less energy use by 2050", which is unrealistic. Although future process efficiencies will be higher and at the same time people consume less (at least in Europe), you need to avoid the impression that a lower energy consumption is needed to reach the SUNRISE goals. This should be rephrased in the Roadmap. Laura Lopez (ICIQ) answered that the roadmap did not develop scenarios, but that the mentioned scenario stems from the EC's 2050 long-term strategy and that she will add more information about this scenario through a footnote in the roadmap.

Question Dr. Peter Vach (BMBF): When reading the document, one could get the impression that SUNRISE is building an entirely new platform to reach a carbon-free future. Huub de Groot replies that we should indeed be careful how to profile ourselves. This is in line with Geert-Jan Kramer's remark; "don't try to cover it all".

Question Prof. James Durrant (Imperial College): Should we pay more attention to transportation of solar fuels between different global regions, for instance from sunnier to less sunnier areas? Hervé Bercegol replies that this aspect has not been included in the Roadmap because radiation differences are typically not that large, for instance 'only' a factor of two between South and North Europe. Huub adds that we should aim at local production in highly efficient economic areas. China has attempted land grabbing in Africa but eventually decided to focus on its own territory. Roel v.d. Krol does not agree. A factor two is a significant difference and therefore transportation of solar fuels should be taken in account. As an example, the EC is currently looking into options for hydrogen production in North-Africa. Huub de Groot (UL) questions if North-African countries are willing to support this. Artur Braun (EMPA) would expect such countries to be happy to get involved. The consortium will further explore opportunities for solar fuel production on other continents. If possible, SUNRISE could make stronger links to existing, smaller, European consortia already working on similar topics. Huub agrees that these groups should be included in further consultations.

Dr. Ann Magnuson (UU) comments that sustainability goals have not been clearly described in the Roadmap (to be reviewed). Dr. Nicola Armaroli (CNR): Overall, it is difficult to get highly accurate numbers on e.g. electrification, hydrogen use, etc. to enable a precise comparison between, for instance, specific regions and the entire globe.

Dr. Peter Vach (BMBF): The 2050 goals in the Roadmap seem to be less ambitious compared with other documents. For instance, if in 2050 a few thousand households will be equipped with SUNRISE technology, politicians will not be impressed. Huub replies that these numbers apply for low TRL technologies developed in Approach 2 and 3. They will be part of the end game, but high TRL technologies described Approach 1 will be deployed on a much larger scale. Peter Vach replies that although we need to be realistic, we do need to communicate very clearly that SUNRISE will contribute to the Energy Transition. The consortium will therefore perform a critical review of target numbers mentioned in the Roadmap.

Breakout sessions followed, on specific chemical targets in SUNRISE roadmap, with the goal to collect 10 concrete recommendations on each topic listed below for revisions of the Roadmap.

1. Hydrogen: short presentation by Prof. Leif Hammarström (UU), see Annex 5.

Discussion: Roel v.d. Krol advises that the goals should be in the triangle Efficiency-Stability-Upscaling. Leif Hammarström agrees that we should describe the goals in these areas. The, goals must be both realistic and ambitious. The Roadmap milestones should be once more reviewed against the SUNRISE Vision. The target price of 4 €/kg might be too high, as others already mention lower prices. Carina Faber (UCL) states this is just a rough estimate. Engie and Siemens agreed to the number, but the range is very broad; a footnote should be added to the Roadmap for clarification. The condition "product stability >1 year" may be confusing and should also be reviewed.

2. Ammonia: short presentation by Dr. Vincent Artero (CEA), see Annex 6.

Discussion: Additional LCA input is needed – action from Stefano Cucurachi (UL)

3. Carbon-based chemicals and (jet) fuels: short presentation by Dr. Hervé Bercegol (CEA), see Annex 7.

Discussion: Need more consistency on units used in the Roadmap; the goals must be expressed in units that are understandable for policy makers and chemical industry.

4. General context, governance, lobbying: short presentation by Dr. Frédéric Chandezon, see Annex 8.

Discussion: The dissemination of the roadmap should be discussed during the next MB meeting (scheduled on November 7th, 2019). By that time, all suggested changes will be implemented, so that the roadmap could be shared with the supporters the following week. Consultations can be done via the website. National "Roadmap dissemination events" need to be organized on short term. The executive summary will be distributed to the EC through Philippe Schild.

3. Conclusions

The overall conclusion was that SUNRISE undertook a very important, pioneering task, with the future challenge of getting industrial and political support to reposition the European economy on a circular trajectory. SUNRISE not only addressed the European level, but through cooperation with the Mission Innovation IC5 "Converting sunlight", took the initiative to drive global roadmapping efforts for artificial photosynthesis.

The partnership with Energy-X was seen as a crucial step to engage all stakeholders of the solar-to-products community in generating a future large-scale research initiative that would cover the full spectrum of the technology readiness levels.

The support of the industry will be paramount to materialise the transition to a solar-based economy by 2050. The consortium should seek ways to engage with the industry along the entire value chain. At the end of the SUNRISE CSA, the Roadmap will be presented to the EC and will provide input to the Calls in Horizon Europe, as well as lay the foundations of an institutionalized partnership as of 2024. We will need to perform an effective lobbying on both national and European levels, in order to ensure the implementation of the Roadmap by means of funded research projects.

Annexes

1. **Written evaluation input from Prof. dr. W. Leitner, Max-Planck Institute for Chemical Energy Conversion**
2. **Presentation for the Mid-term Evaluation session by Prof. dr. W. Leitner, Max-Planck Institute for Chemical Energy Conversion**
3. **Presentation for the Mid-term Evaluation session by Prof. dr. G.-J. Kramer, Utrecht University**
4. **Presentation on SUNRISE Roadmap by Dr. C. Faber, Université Catholique de Louvain**
5. **Short presentation on the Hydrogen section of the Roadmap by Prof. Leif Hammarström, Uppsala University**
6. **Short presentation on the Ammonia section of the Roadmap by Dr. Vincent Artero, CEA**
7. **Short presentation on the Carbon-based chemicals and (jet) fuels section of the Roadmap by Dr. Hervé Bercegol, CEA**
8. **Short presentation on the general context, governance and lobbying by Dr. Frédéric Chandezon, CEA**

MAX-PLANCK-INSTITUT FÜR CHEMISCHE ENERGIEKONVERSION

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The SUNRISE Consortium
c/o Iulia Degeratu
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Van der Burghweg 1
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The Netherlands

Mülheim an der Ruhr, der 1. November 2019

Mid-term review;

Dear Ms Degeratu:

With E-Mail from September 13, you have requested an assessment of the activities of the SUNRISE consortium with respect to the deliverables for the mid-term assessment. I am very happy to follow this request as I have been very impressed by the initiative and its development in the recent months. In particular, I will focus my assessment on the Roadmap Document (D1.2), the "Consolidated Vision" (deliverable D1.1), and the first outline for governance, in the form of a Joint Partnership Proposal on Fossil-Free Industry, proposed jointly with Energy-X. I consider these deliverables the central outcome and action plan for the future development of SUNRISE.

With kind regards,

(Prof. Dr. Walter Leitner)

General:

The SUNRISE consortium was formed as a Coordination & Support Action (CSA) to identify research needs and innovation targets to facilitate the transition to a circular economy and a carbon-neutral society. The ultimate goal is a sustainable CO_2 cycle, where the concentration in the atmosphere is decreased and then maintained at a level compatible with climate stability and sustainable use of natural resources and land. Towards this vision, SUNRISE aims at competitive production pathways to hydrogen, ammonia and light carbon-bearing molecules from atmospheric water, nitrogen and carbon dioxide. A major focus lies on technology concepts often referred to as "artificial photosynthesis". On a short term, this can be achieved by utilization of hydrogen produced from non-fossil resources exploiting renewable energy via photovoltaics and electrochemical processes. On a longer term, the development of photoelectrochemical, biological and biohybrid systems is envisaged in SUNRISE. An associated important strategic development is the transition from a centralized production to a more decentralized approach favouring the development of a circular economy at a local scale. With this approach, SUNRISE aims to contribute to a fully CO_2-free electricity system, a CO_2-neutral circular economy, net climate neutral mobility for people and goods as well as affordable negative emissions technologies at a significant scale.

A major deliverable for the first period was the generation of a SUNRISE Roadmap to define technology options and strategic action points (D1.2) for the "Consolidated Vision" (deliverable D1.1). Furthermore, a first outline for governance, in the form of a Joint Partnership Proposal on Fossil-Free Industry, proposed jointly with Energy-X was also to be delivered. The present assessment will focus on these three deliverables as they represent the core for all other actions and milestones of the CSA.

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Consolidated Vision:

The consolidated vision reflected in the Executive Summary of the Roadmap and highlighted above has been derived from consultations with various stakeholders and intensive internal discussions. It provides a bold and ambitious target of crucial importance to a sustainable future in Europe. It is highly appreciated that science and innovation are clearly aimed at the three dimensions of sustainability, ecological welfare, economic benefits, and societal needs. To engage the scientific community, industrial stakeholders, and NGOs in this process arriving at a common vision is a major achievement.

Roadmap:

In the draft of the Roadmap, the overarching goals are translated into “technological approaches”, “technology milestones”. For the latter, “technology targets” are discussed in detail. Again, the input of the scientific community was gathered extensively through consultation and workshops. In particular, this comprises the SUNRISE stakeholder event with more than 170 participants held June 17.-18 2019 at Brussels. This was followed by a three days (17.-19. July 2019) roadmapping workshop of the project team in the EERA premises in Brussels. The results of these workshops, as outlined in detail in the Roadmap and the Technical Annex, were discussed intensively with the Energy-X consortium, and the initiatives jointly engaged in an open forum at the EuropaCat conference in August in Aachen, attracting some 350 participants.

In its draft version of September 2019, the SUNRISE Roadmap has identified three major technological approaches (TA) defined as:

TA-1: Electrochemical conversion with solar power

TA-2: Direct conversion via photoelectrochemical cells

TA-3: Direct conversion via biological and biohybrid systems

An increasing level of integration between energy harvest and (bio-)chemical conversion is inherent in this list. For the energy harvest, direct use of sunlight, largely via photovoltaics and related technologies is envisaged, inspired by the concept of "artificial photosynthesis".

Based on this concept, "technology milestones (TM)" are defined that translate roughly into the potential for implementation of the three approaches in specifically targeted applications. These milestones are:

- TM-1: Sustainable hydrogen production
- TM-2: Sustainable ammonia production
- TM-3: Sustainable carbon capture
- TM-4: Sustainable production of commodity chemicals and (jet) fuels
- TM-5: Long-lasting carbon-based materials

Each "technology milestone" is broken down further into "technology targets", for which timelines, technology readiness level (TRL, current and target), and action points for research and development are presented.

The five "technology milestones" are clearly addressing major challenges and crucial pillars to reach the SUNRISE vision. They are central elements in the transition towards a defossilized industrial future. The direct connection to the three major "technological approaches" remains at this stage somewhat less obvious, however. In particular TM-3 "Sustainable carbon capture" will not be influenced significantly by progress in the three TAs.

Furthermore, the upfront definition of photovoltaics as the direct exploitation of sunlight inherently defines concrete system boundaries for the implementation strategies in the TM applications. While this may well be necessary to provide a common framework within the consortium actions, it needs to be assessed more clearly on a systems level. This seems in particular relevant in view of the goal to provide decentralised, regional solutions. While direct use of sunlight may be the preferred option in parts of Europe that have major influx

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form direct solar power, other parts that are rich in wind, geothermal or even bio-based energy sources may benefit more from other technologies to harvest the primary energy. It is currently not yet obvious from the roadmap, whether SUNRISE proposes the approach to utilize photovoltaics as ultimate and single entry point universally or under a defined set of boundary conditions.

Joint Partnership Proposal on Fossil-Free Industry:

The documents for the mid-term review contain also an outline for a partnership with the working title "**Fossil Free Industry: Fossil-free Fuels, Chemicals and Materials for a Circular Economy"**. The concept results from the intensive interaction between the two CSAs "SUNRISE" and "ENERGY-X". Both initiatives share the common goal to provide technological solutions for the *grand challenges* originating from the re-design of the energy/chemistry-nexus and thus turn them into *major opportunities* for European societies.

The consolidated vision of SUNRISE is reflected perfectly in the short description of the proposed partnership. While there are of course differences between the technological approaches and detailed technology targets between the two CSAs, they are complementary and in many ways synergistic, rather than competing. With the urgent need to develop disruptive technologies from concepts to full scale in a very challenging short timeframe, the joint discussion is therefore evaluated extremely positive.

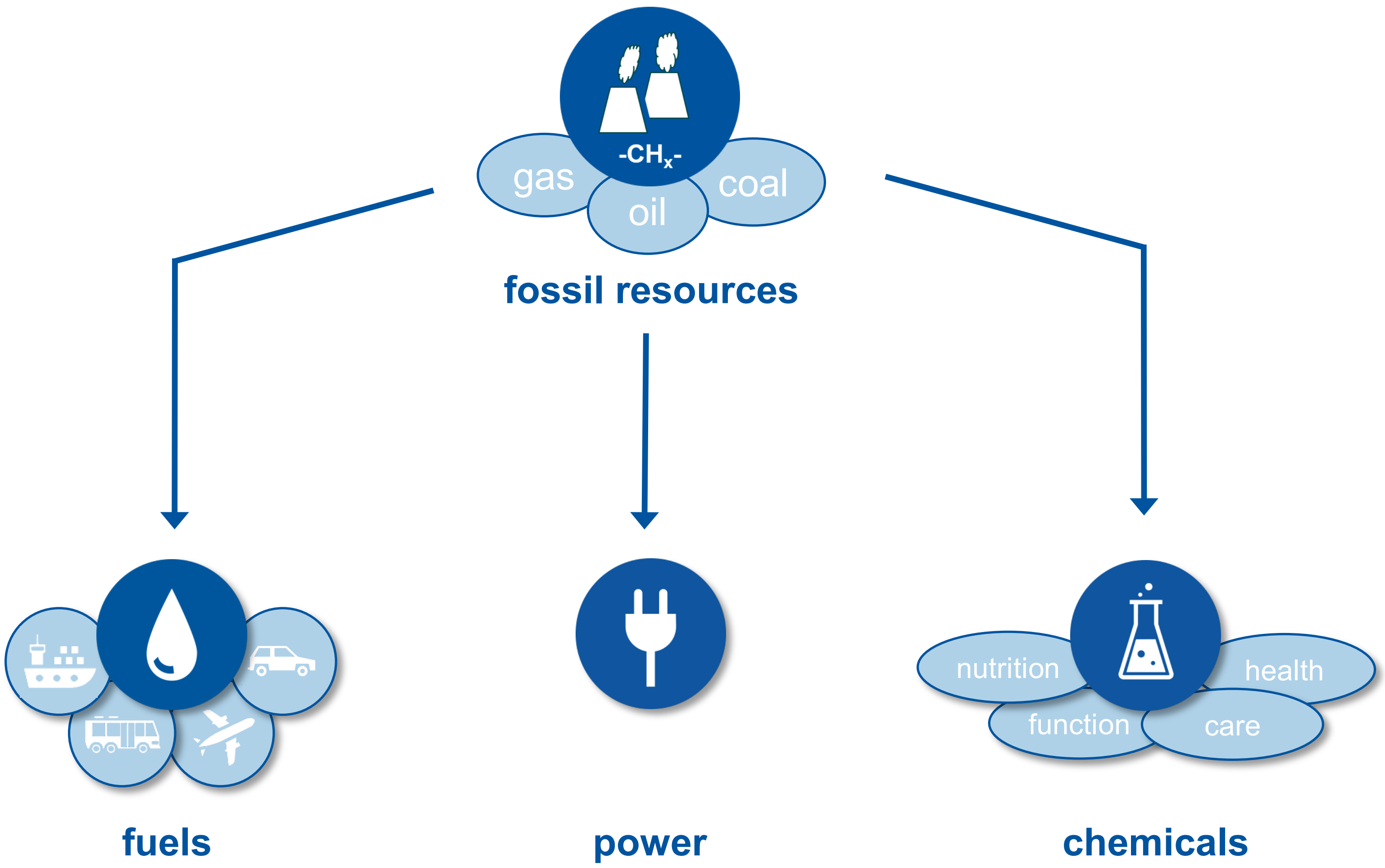
Among the achievements of both CSAs in the initial phase, three main aspects are particularly impressive: mobilisation of scientific creativity, participation of global industrial players along the value chains, and engagement of societal stakeholders through NGOs. The SUNRISE consortium is strongly encouraged to continue in direction of the joint partnership.

SUNRISE Midterm Review

Walter Leitner

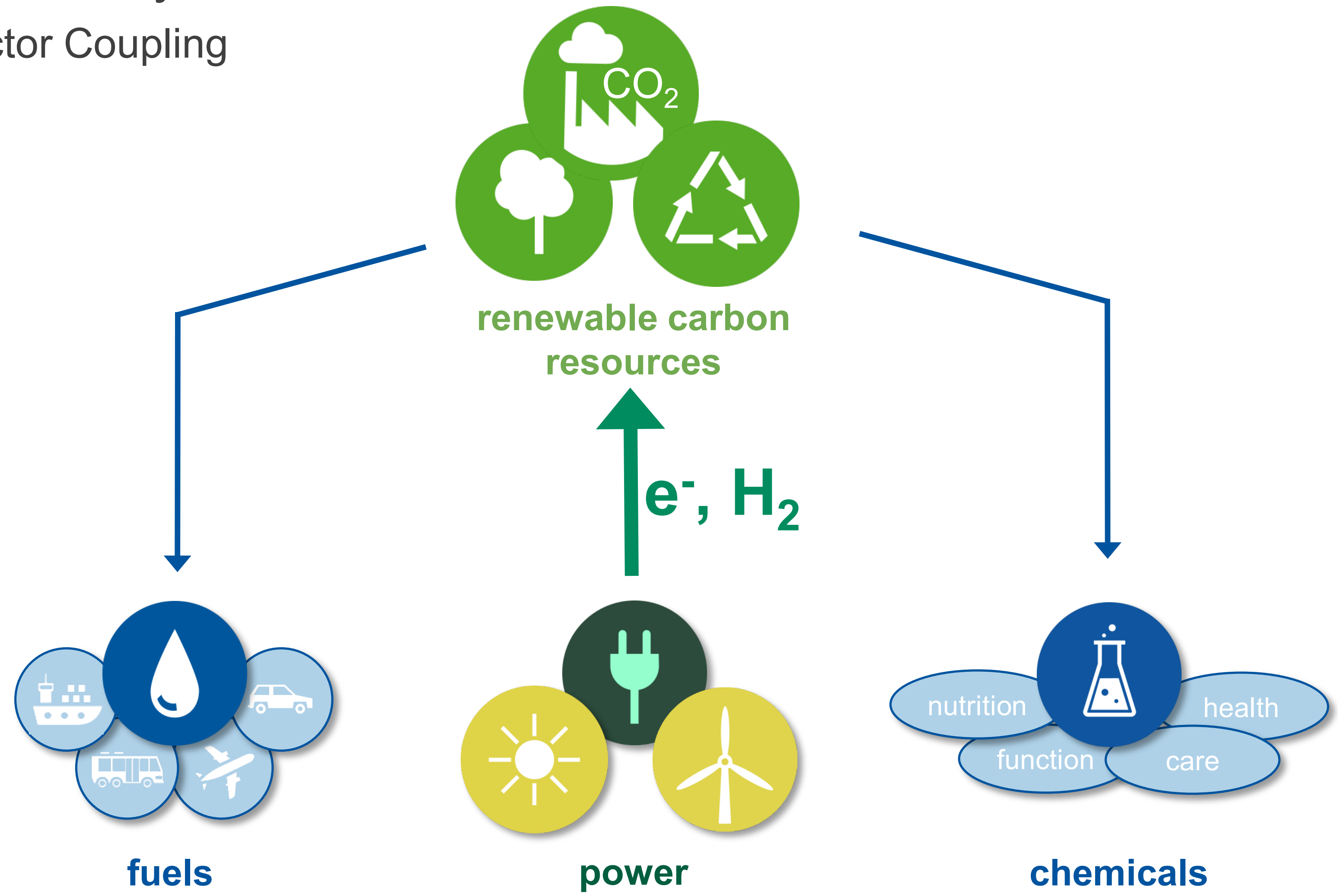
Video Conference
October 10, 2019

The “Fossil Age”



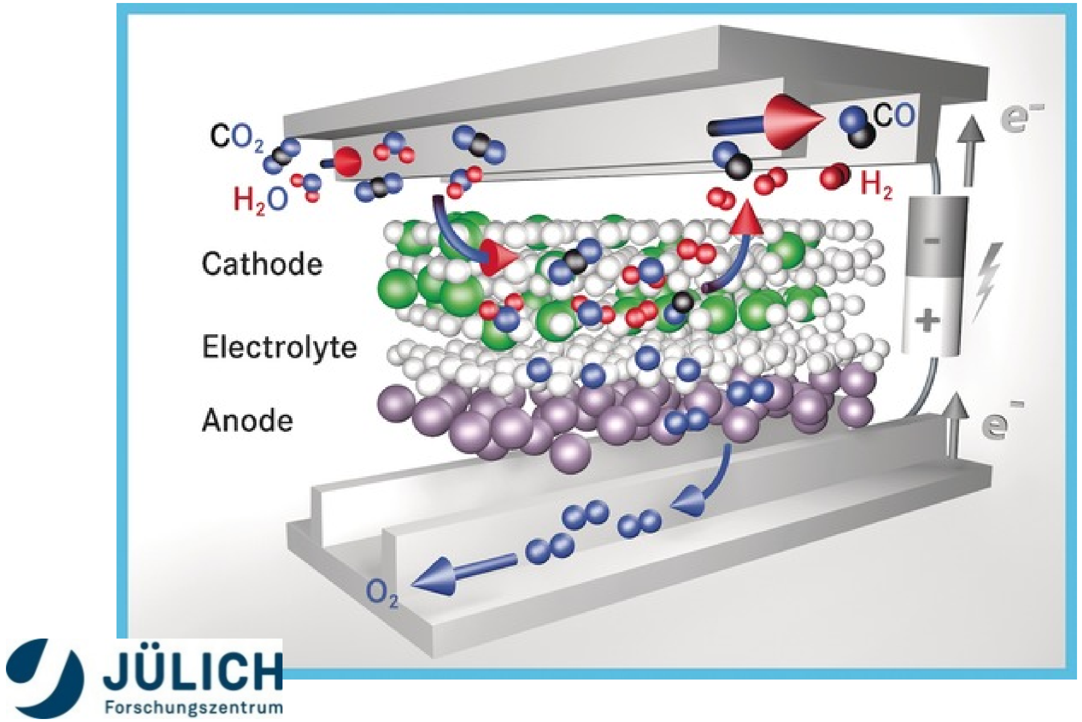
Closing the Carbon Cycle

Power-To-X and Sector Coupling



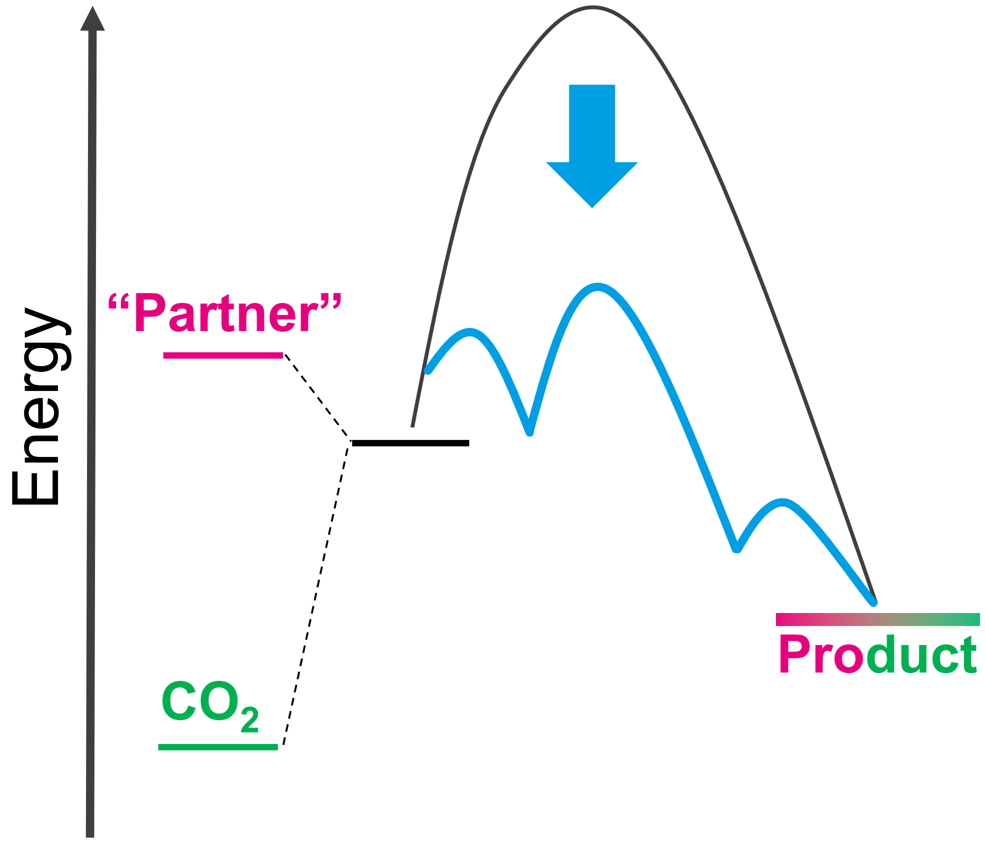
“Power-to-X”: The Challenges

Electrolysis



L.G.J. de Haart, R.-A. Eichel, et al. *Angew. Chem. Int. Ed.* **2017**, 56, 5402 –5406.

Catalysis



J. Klankermayer, W. Leitner, et al., *Angew. Chem. Int. Ed.* **2016**, 55, 7296 –7343.

A. Bardow, W. Leitner, et al., *Chem. Rev*. **2018**, 118, 434–504.

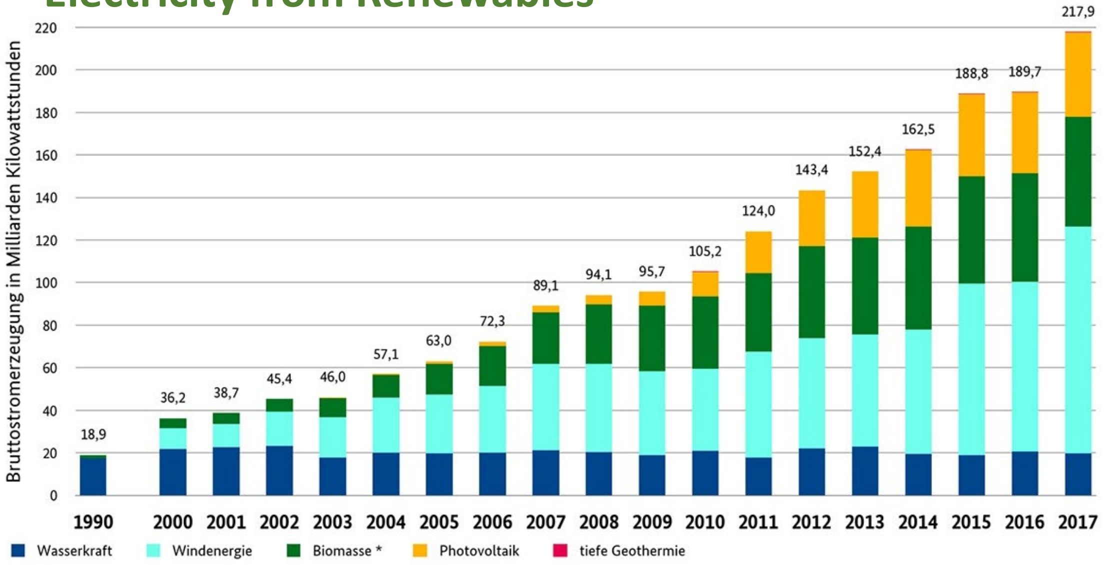
„Energiewende“ oder „Stromwende“?

- **Electricity, 2018:**
  647 TWh @ 38% renewable [1]

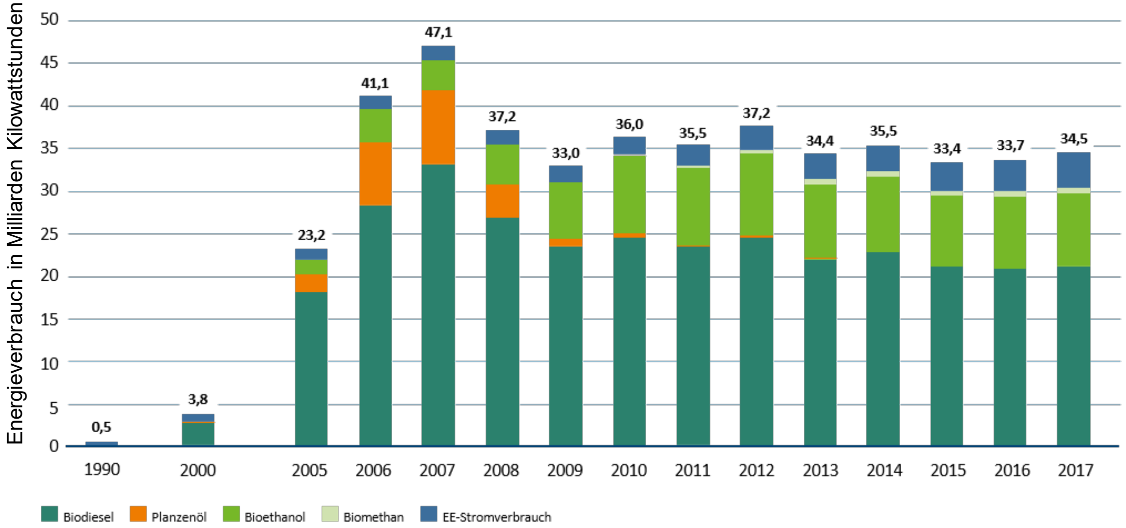
- **Mobility & Transport, 2017:**
  663 TWh @ 5% renewable [2]

- **Chemical Industry, 2016:**
  20 Mio t raw materials @ 13% renewable [3]

Electricity from Renewables



Mobility with Renewables

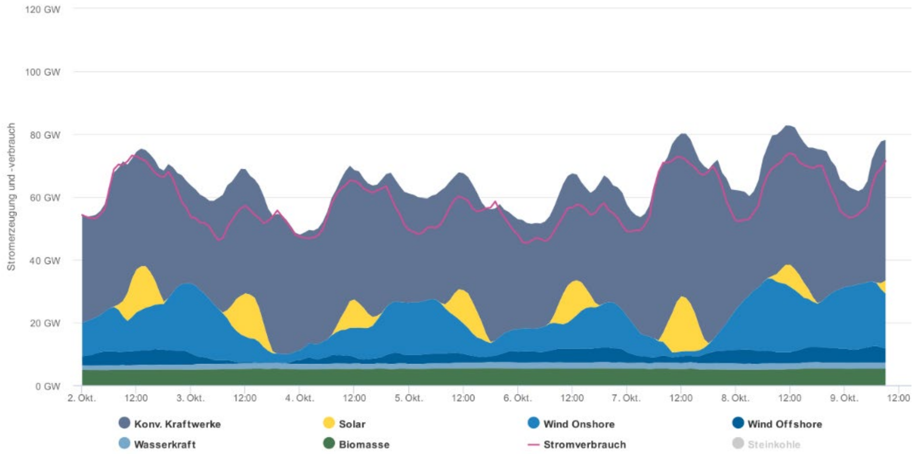


1) Bundesumweltamt
2) Bundesministerium für Wirtschaft und Energie, „Erneuerbare Energie in Zahlen“
3) VCI, Daten und Fakten, 2017.

„Import“ of Energy will remain essential for the Mobility Sector

„Überschussstrom“

Fluctuating Supply and Demand



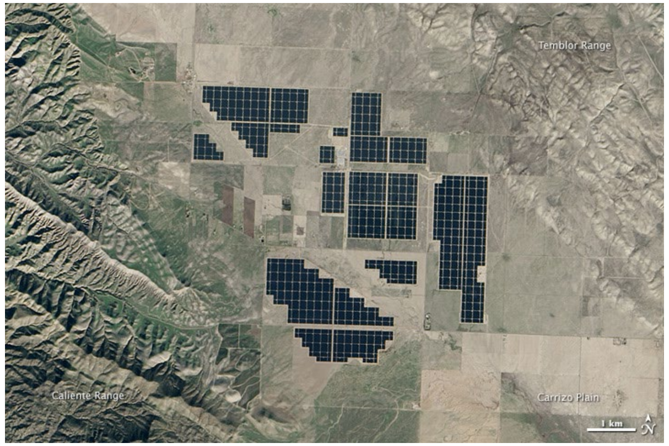
25 TWh (2030)
→ ca. 1 Mio t fuel

„Sweet Spots“

alpha ventus
North Sea (near Borkum)

0,24 TWh (60 MW rated capacity)
→ ca. 10.000 t fuel

Topaz Solar Farm
California/USA



1 TWh (550 MW rated capacity)
→ ca. 40.000 t fuel

Some data for Germany

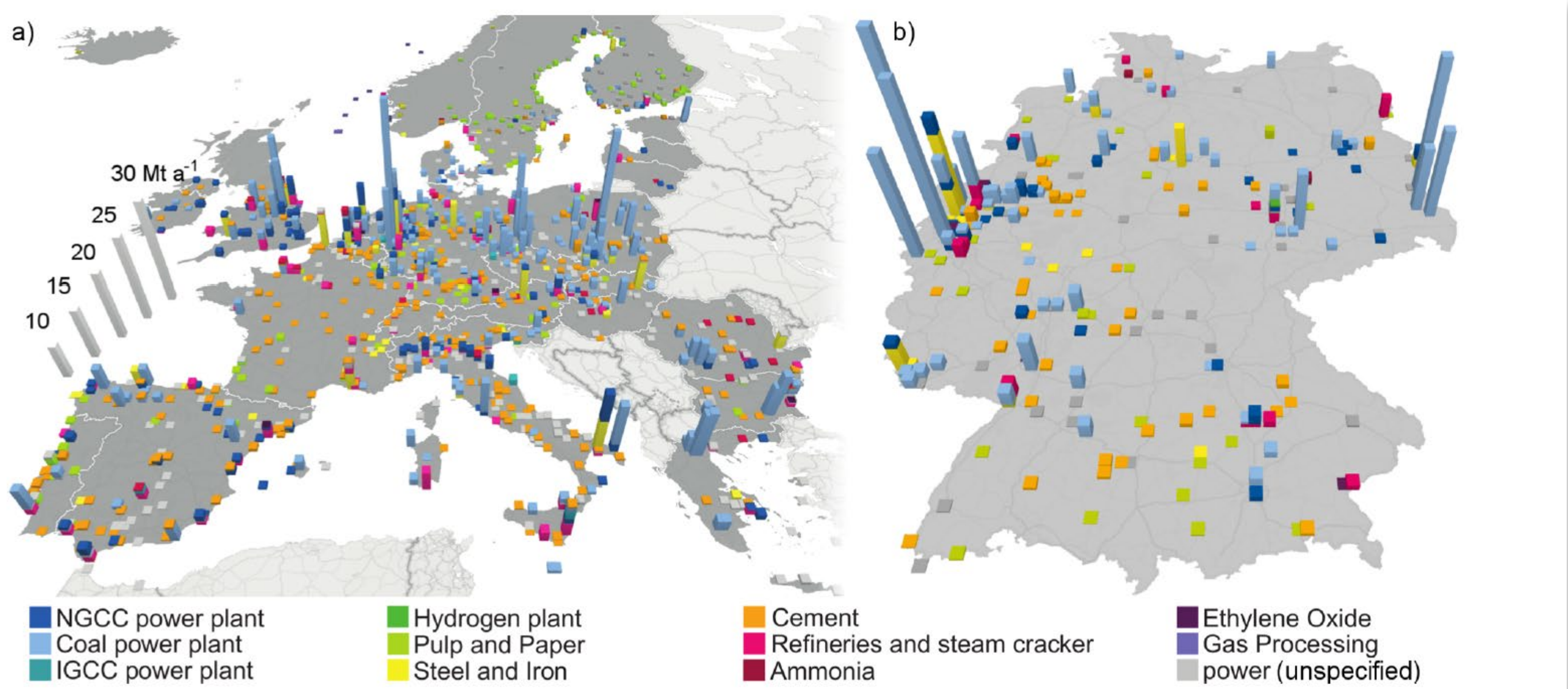


Figure 2. Distribution of CO_2 point sources (>0.1 Mt a^{-1}) in 2011 in a) Europe and b) Germany as exemplary country. The CO_2 emissions map has been created using the PowerMap Preview Plugin for Microsoft Excel 2013.[59] Color online.

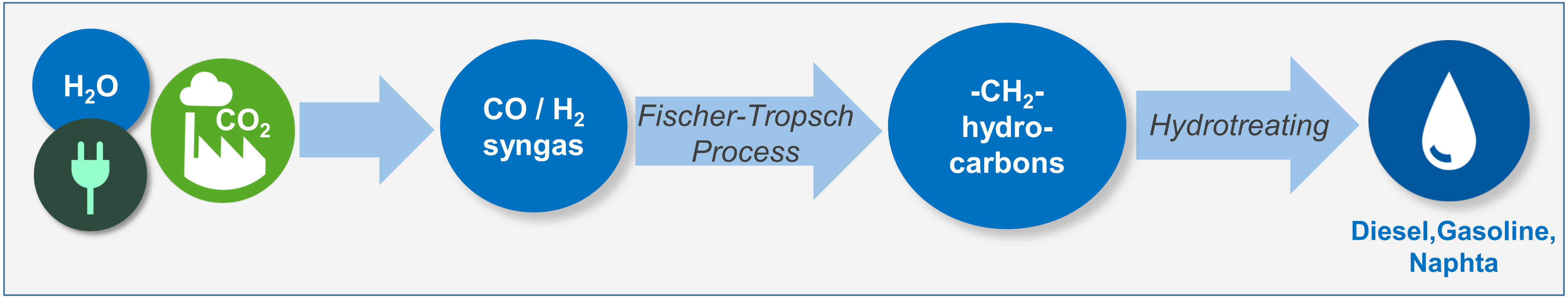
Challenges and opportunities for sector coupling

- ⇨ **Dynamic deployment of cost-effective renewable electricity, but energy will remain a valuable resource**
- ⇨ **The chemical value chain may be "de-fossilized", but cannot be "de-carbonized"**
- ⇨ **Carbon resources will be abundantly available also in post-fossil energy scenarios, but sources are distributed and diverse**
- ⇨ **"Harvesting" renewable energy in chemicals and fuels requires fundamental research and innovation in catalysis**

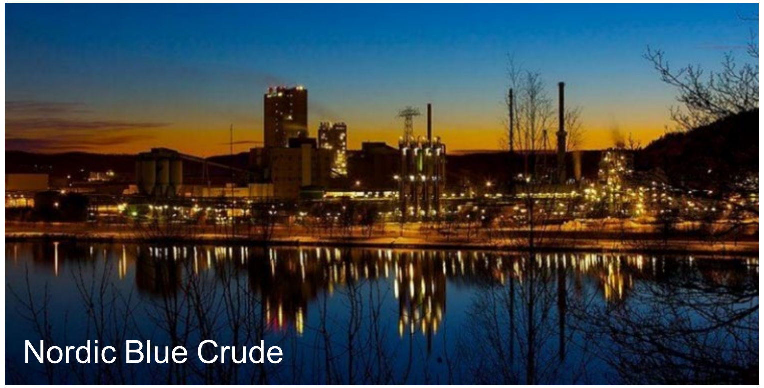
"Power-to-Liquid"


F. Fischer


H.Tropsch



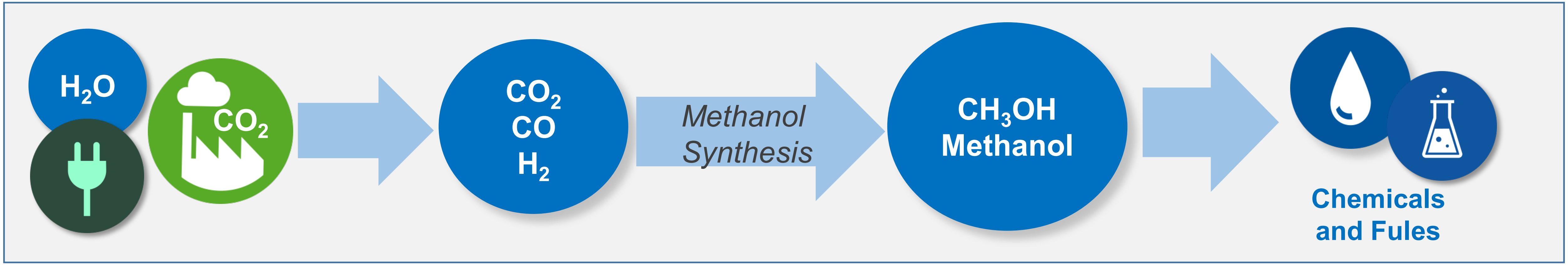
INERATEC; Karlsruhe, Germany
Decentralized module



Nordic Blue; Herøya, Norway
from 2020: 10 Mio L a^{-1}

Oryx; Qatar
since 2006: 1800 Mio L a^{-1}

„Power-to-Methanol“

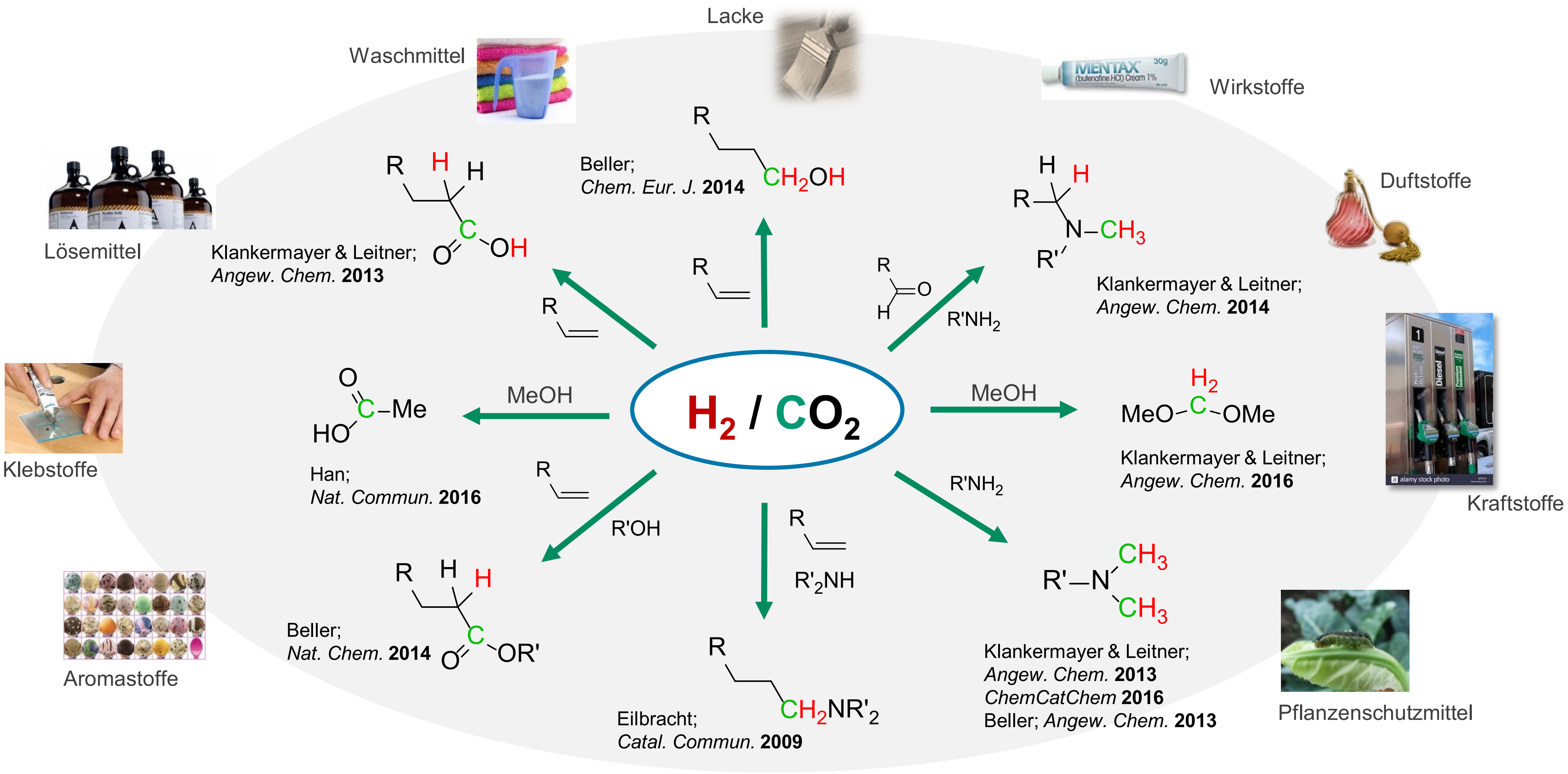


Carbon2Chem
ThyssenKrupp Stahlwerk Duisburg
2020, 27 t a^{-1}

Carbon Recyling International
Stravensgi, Island, since 2016, 4 kt a^{-1}
China: 2021, 100 kt a^{-1}

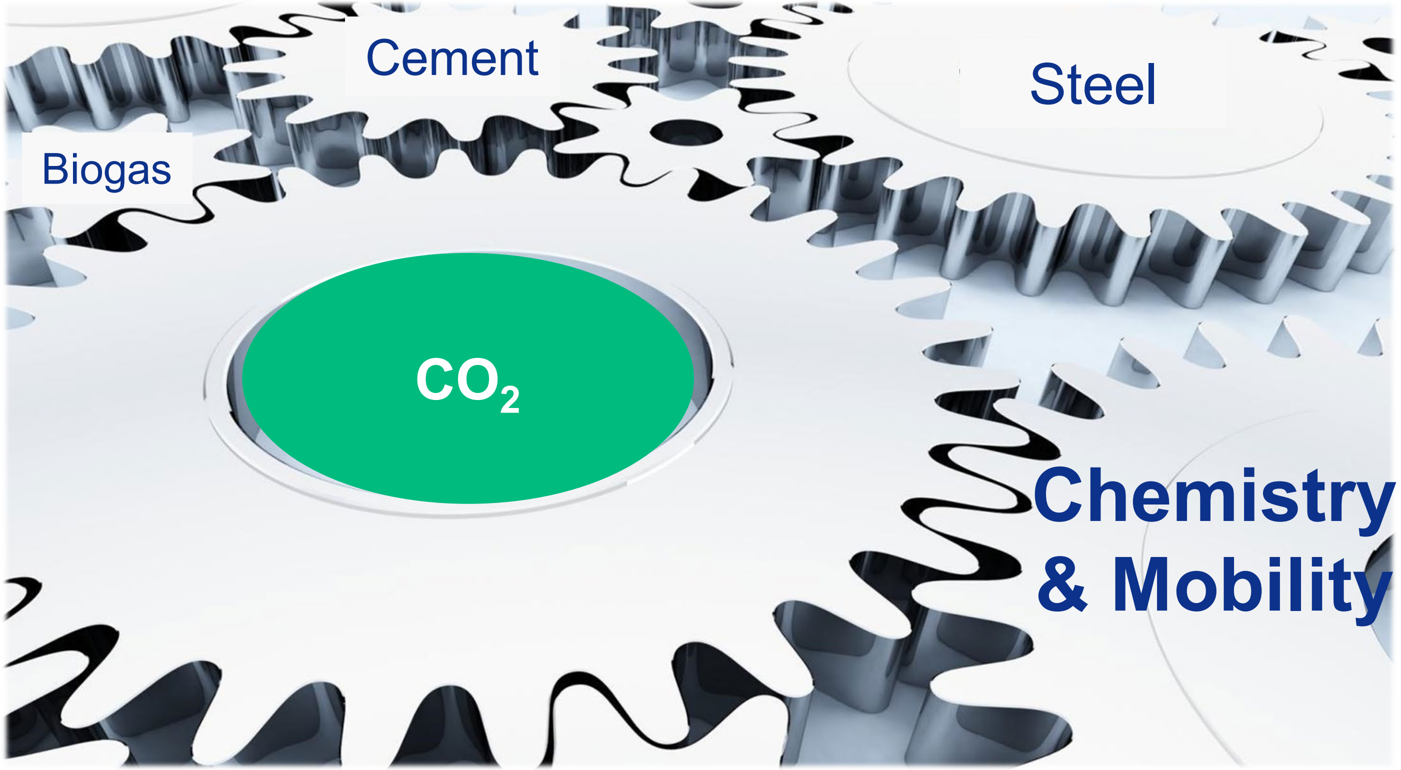
Lurgi MegaMethanol Technology
1 MT a^{-1}

Green Chemistry with CO_2/H_2



J. Klankermayer, W. Leitner, *Science* **2015**, 350, 629-630.

„Power-To-X:“ CO_2 Enables Sector Coupling



KOPERNIKUS PROJEKTE
P2X
Die Zukunft unserer Energie

Carbon2Chem®

Carbon4PUR

Bundesministerium für Bildung und Forschung

A. Bardow, W. Leitner, et al., *Chem. Rev.* **2018**, 118, 434–504.

P2X: Roadmap Prozess

Zivilgesellschaftlicher Beirat

BUND
Bund für Umwelt und Naturschutz Deutschland
FRIENDS OF THE EARTH GERMANY

DGMK

DVGW

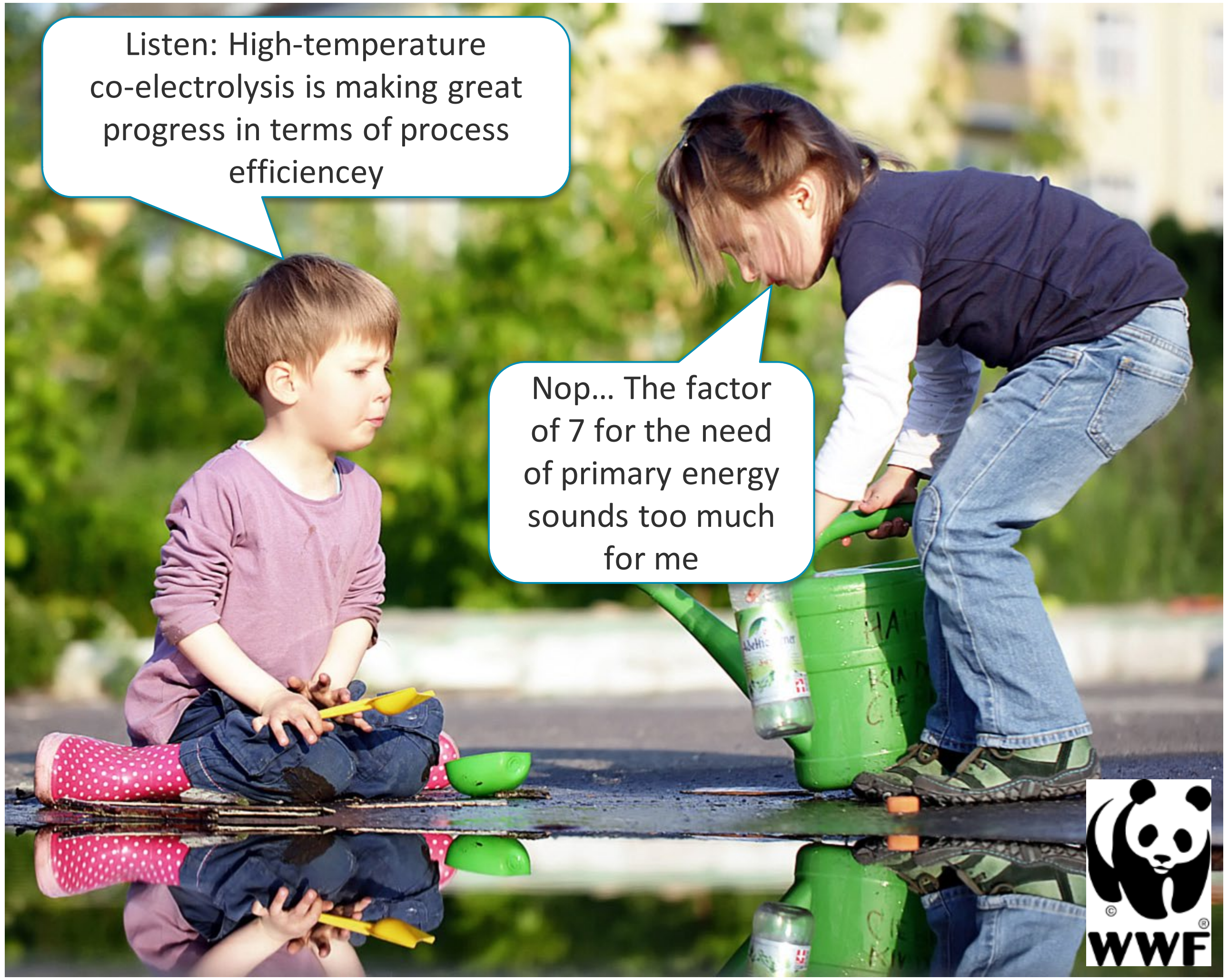
IG BCE Industriegewerkschaft Bergbau, Chemie, Energie

IRR Innovationsregion Rheinisches Revier GmbH

VCI

WWF

VDMA



Universiteit Utrecht

Copernicus Institute of Sustainable Development

To note: this is the SUN

Sol Iustitia Illustra Nos

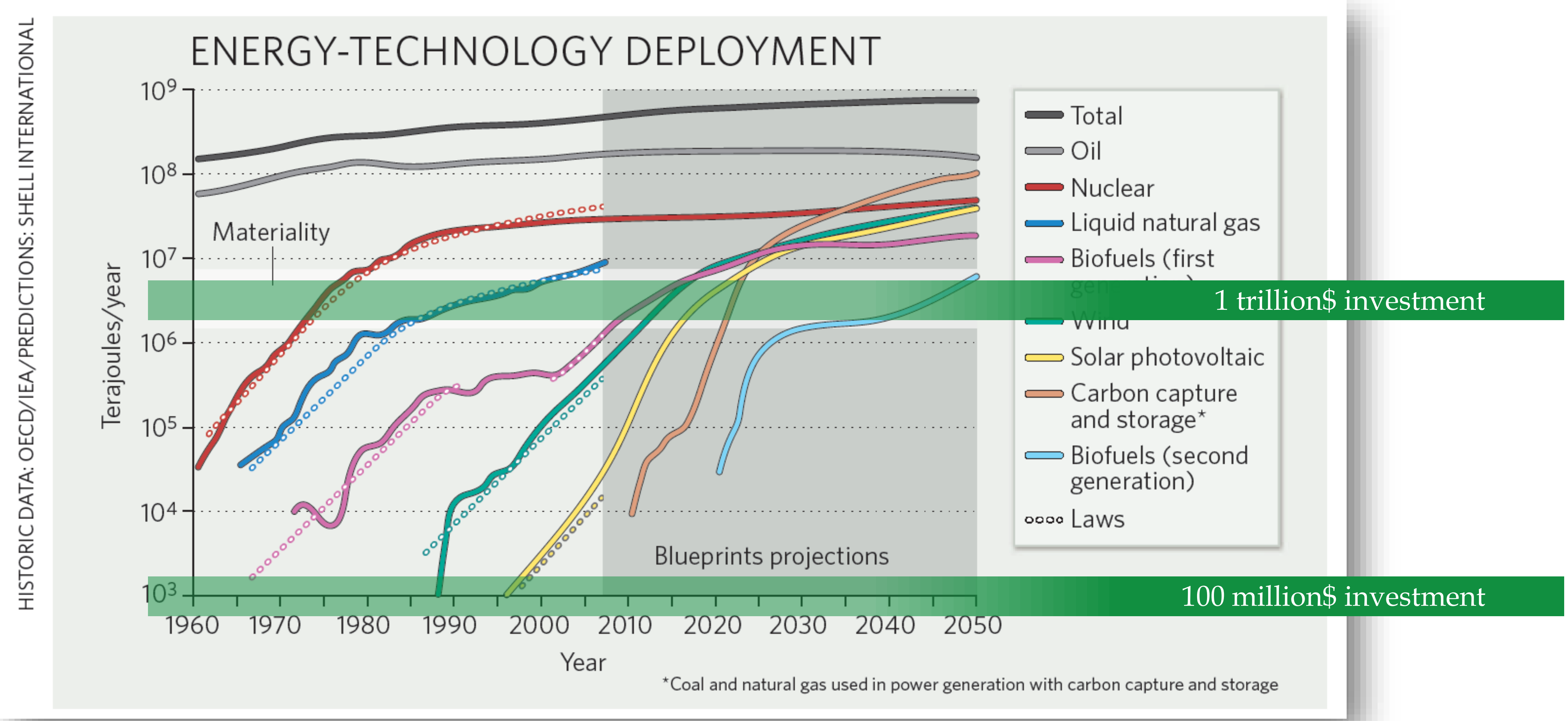
SUNRISE review – framing thoughts

Prof. dr. Gert Jan Kramer

10 October 2019

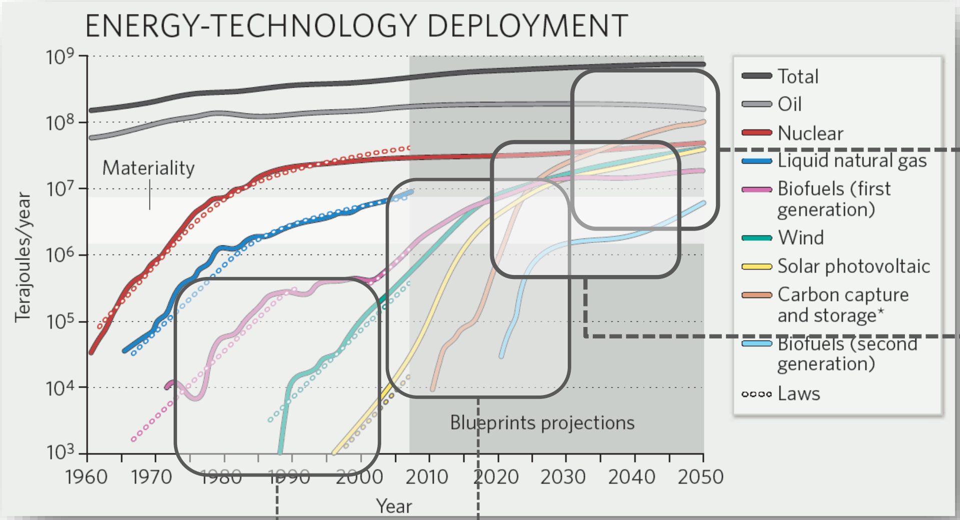
Universiteit Utrecht

The Big Picture (i)



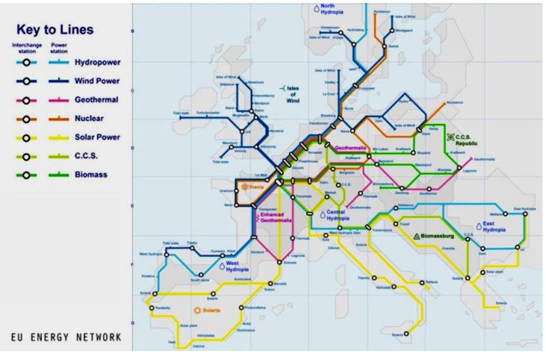
Universiteit Utrecht

The Big Picture (i)



Dealing with fuels and irreplaceable carbon

Post 2025 – Making the RE *system* work



1970s to 2000 – Creating the Technologies

Ca. 2000 to 2030 – Technolog

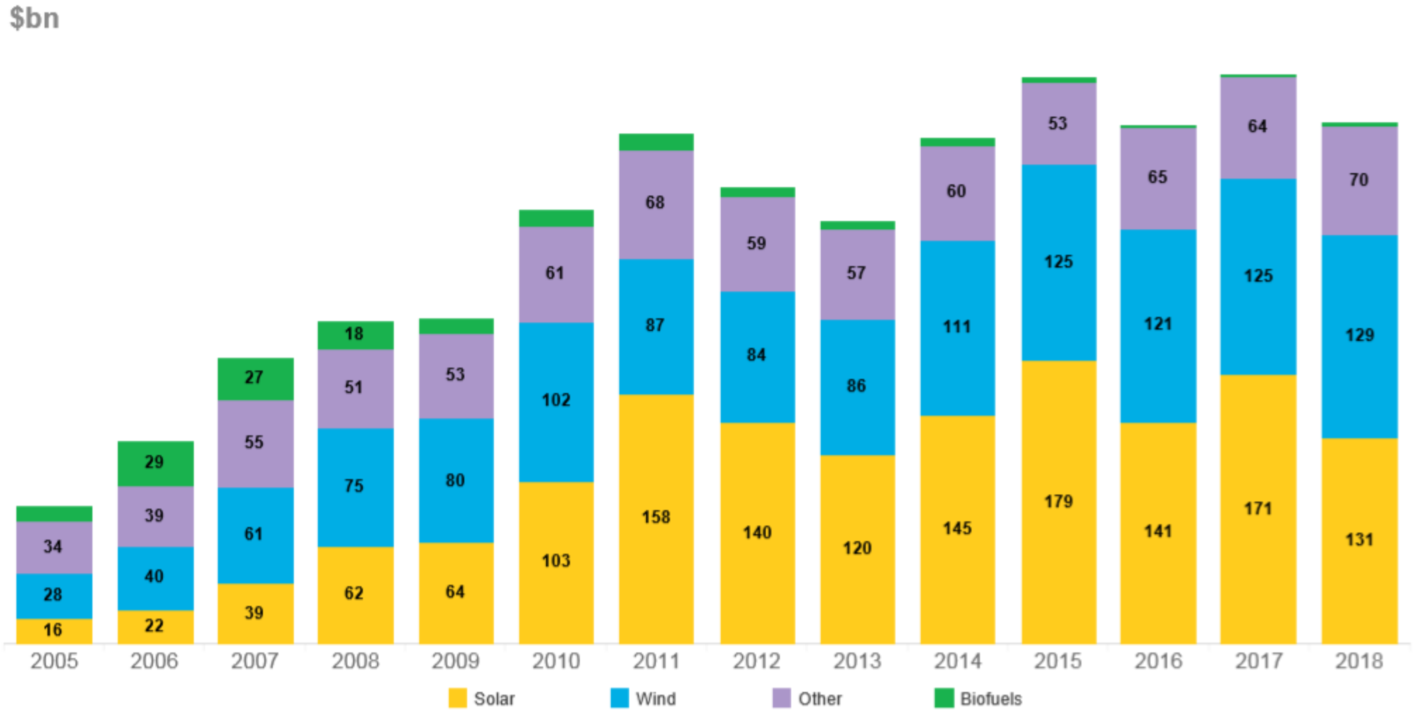
Based on G.J. Kramer and M. Haigh, *No Quick Switch to Low Carbon Energy*, Nature, **462**, 568 (2009)

Clean Tech is a 300 billion $ industry

SUNRISE Roadmap, p. 7:

"Technologies for the transition to a low-emission society are not available on a large scale today."

That's not true



Bloomberg New Energy Finance, *Clean Energy Investment Trends, 2018* (2019)

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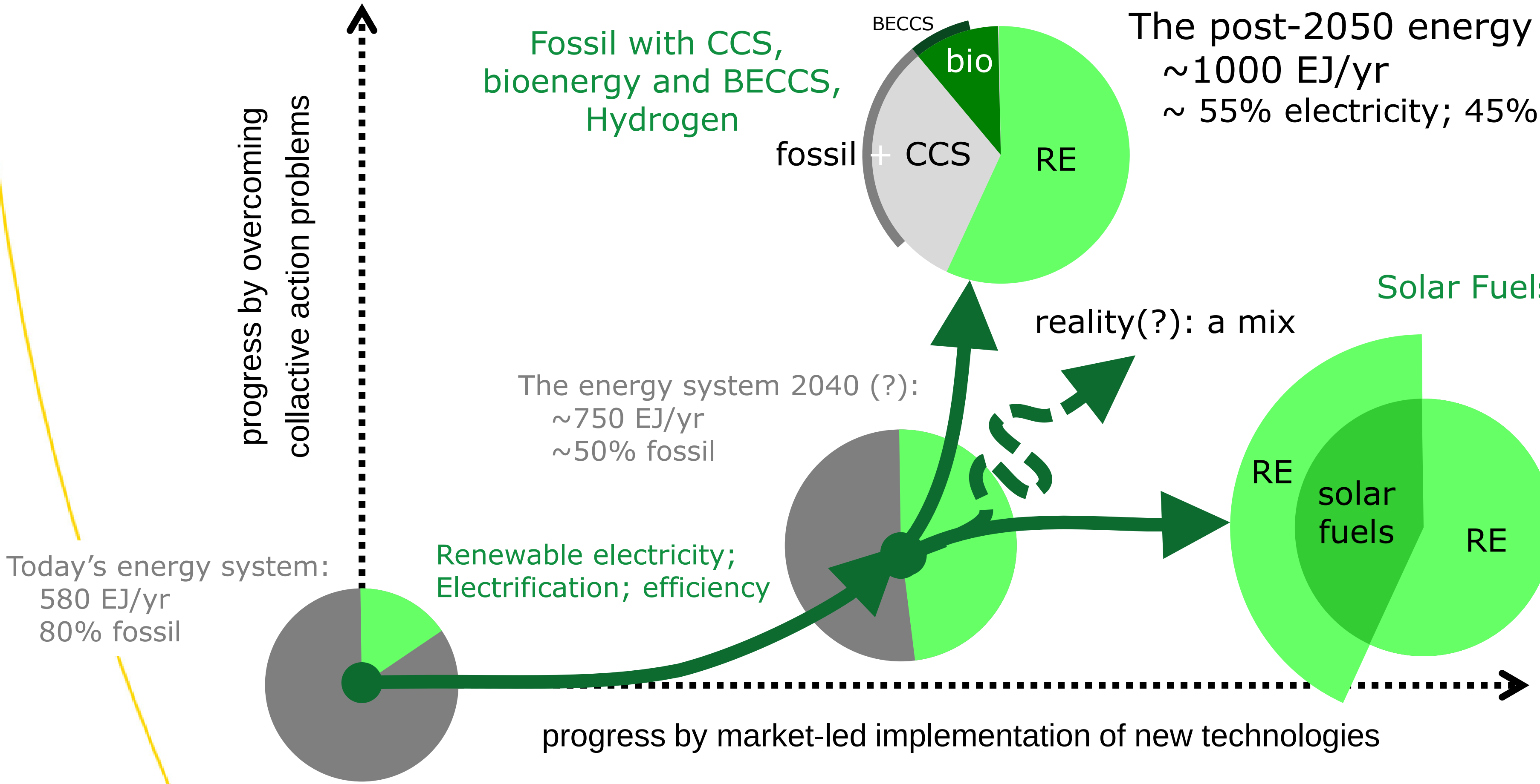
The Choice on Carbon Management and Future Fuels



Kraan, Kramer, Haigh and Laurens, *An Energy Transition that Relies only on Technology leads to a Bet on Solar Fuels*, Joule **3**, 1-4 (Oct, 16, 2019)

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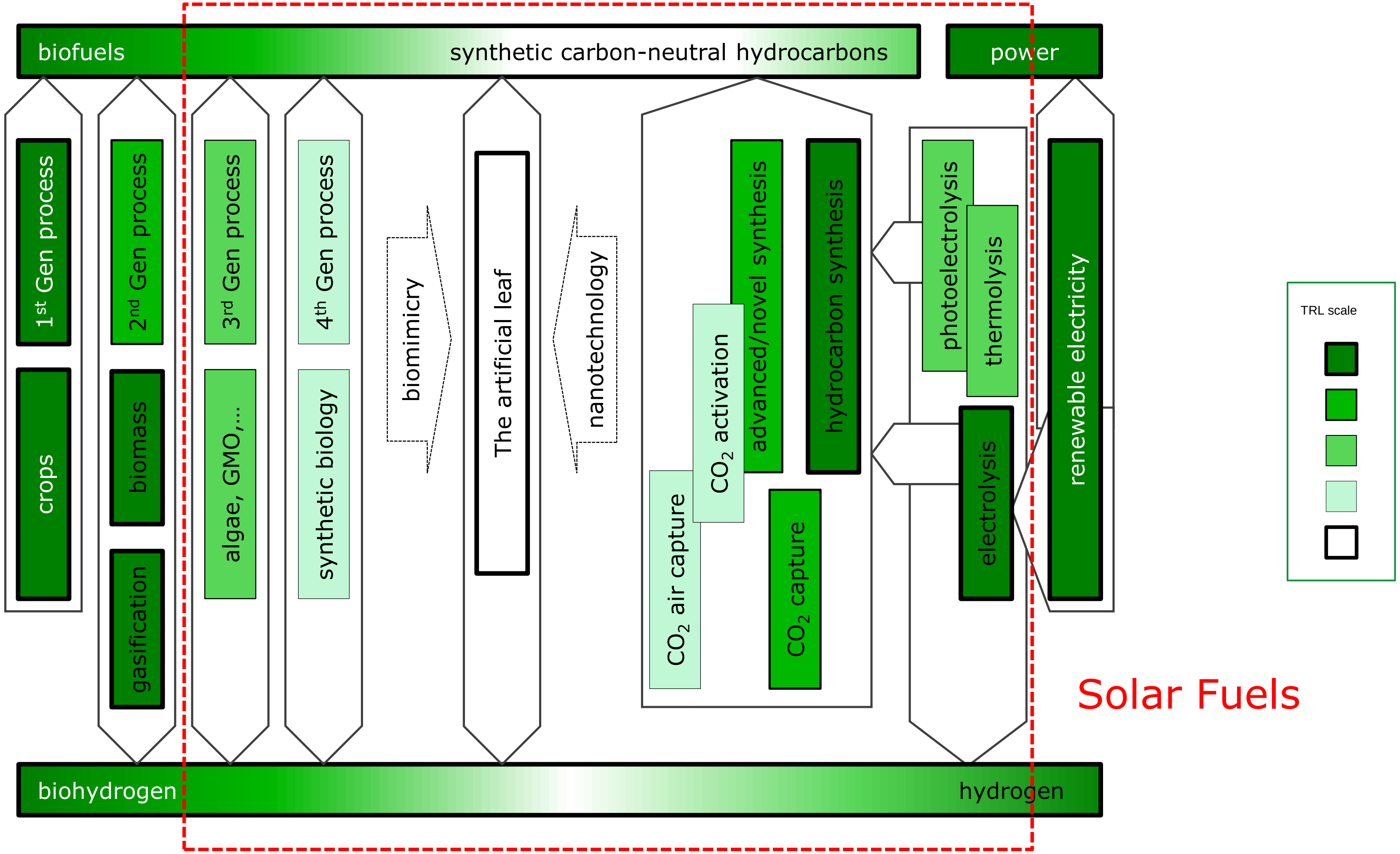
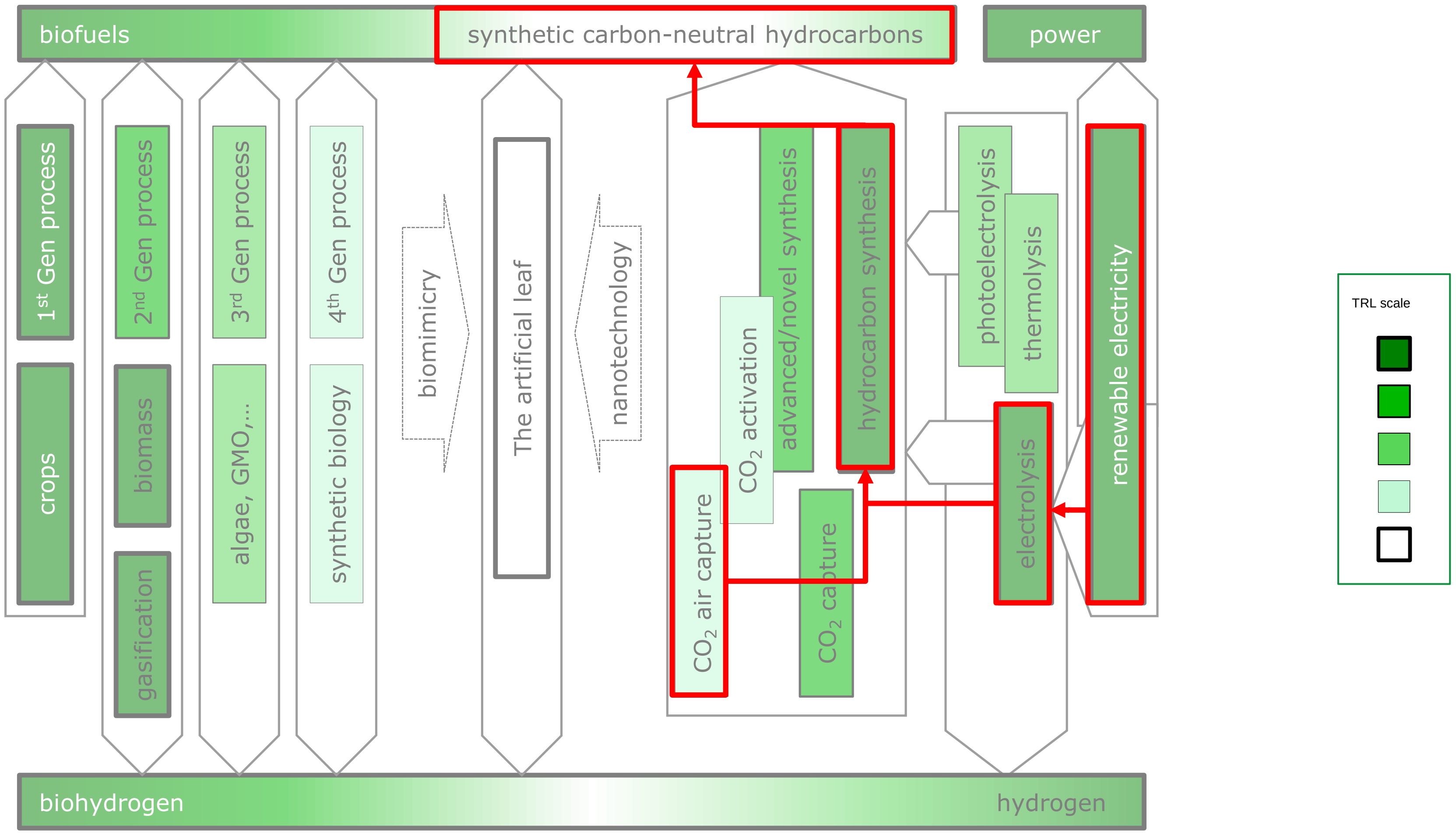
The competitive landscape of 'solar fuels'



R. Purchase et al, *Semi-Synthetic Responsive Matrices for Artificial Photosynthesis*, in *Bioinspired Chemistry* (2019)

The benchmark



R. Purchase et al, *Semi-Synthetic Responsive Matrices for Artificial Photosynthesis*, in *Bioinspired Chemistry* (2019)

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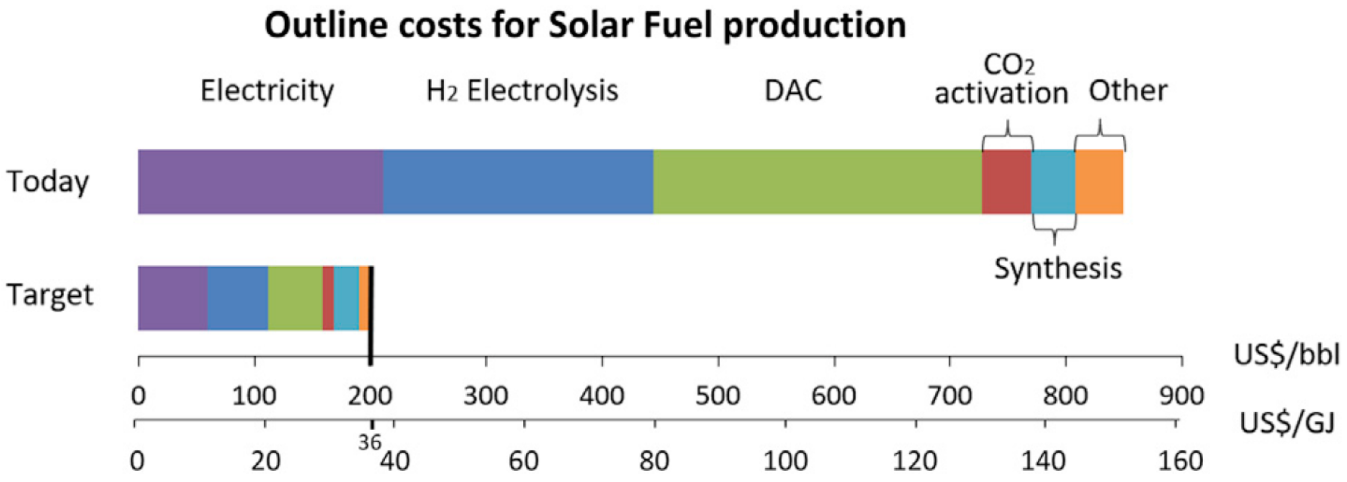
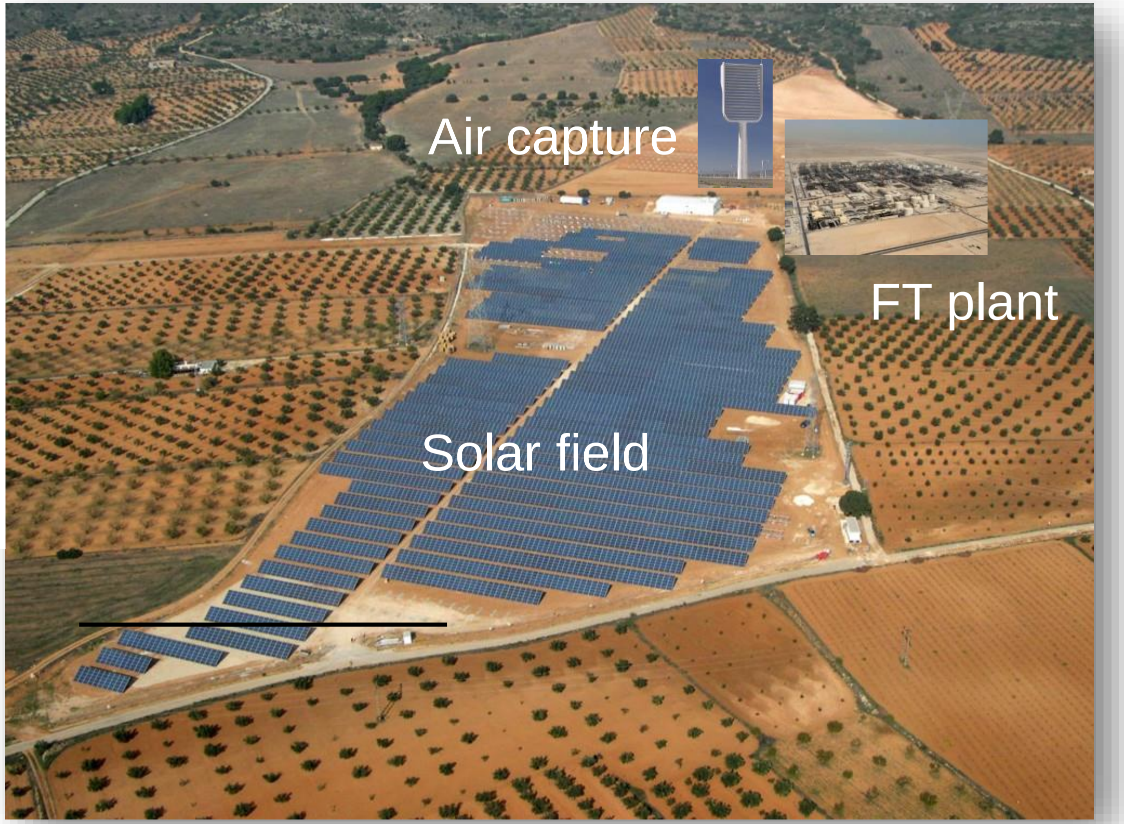
Synthetic Solar Fuels: back-of-the-envelope cost





200 $/barrel – affordable?

Kraan, Kramer, Haigh and Laurens, *An Energy Transition that Relies only on Technology leads to a Bet on Solar Fuels*, Joule **3**, 1-4 (Oct, 16, 2019)

My Bottom-line Questions to SUNRISE

Will you be developing a new technology 'platform'?
Or will you be feeding into existing technology platforms?

I think it is (and should be) often the latter, but the roadmap seems to be written as if it is the former.

(Clarity on this is critical when shaping the consortium.)

The notable exception is Direct Atmospheric CO_2 Capture & Conversion (DACC).

(A TRL jump from 1-2 to 5-7 in 10 years seems unrealistic)

How do you plan to handle within one Programme technology development at such different TRL levels?

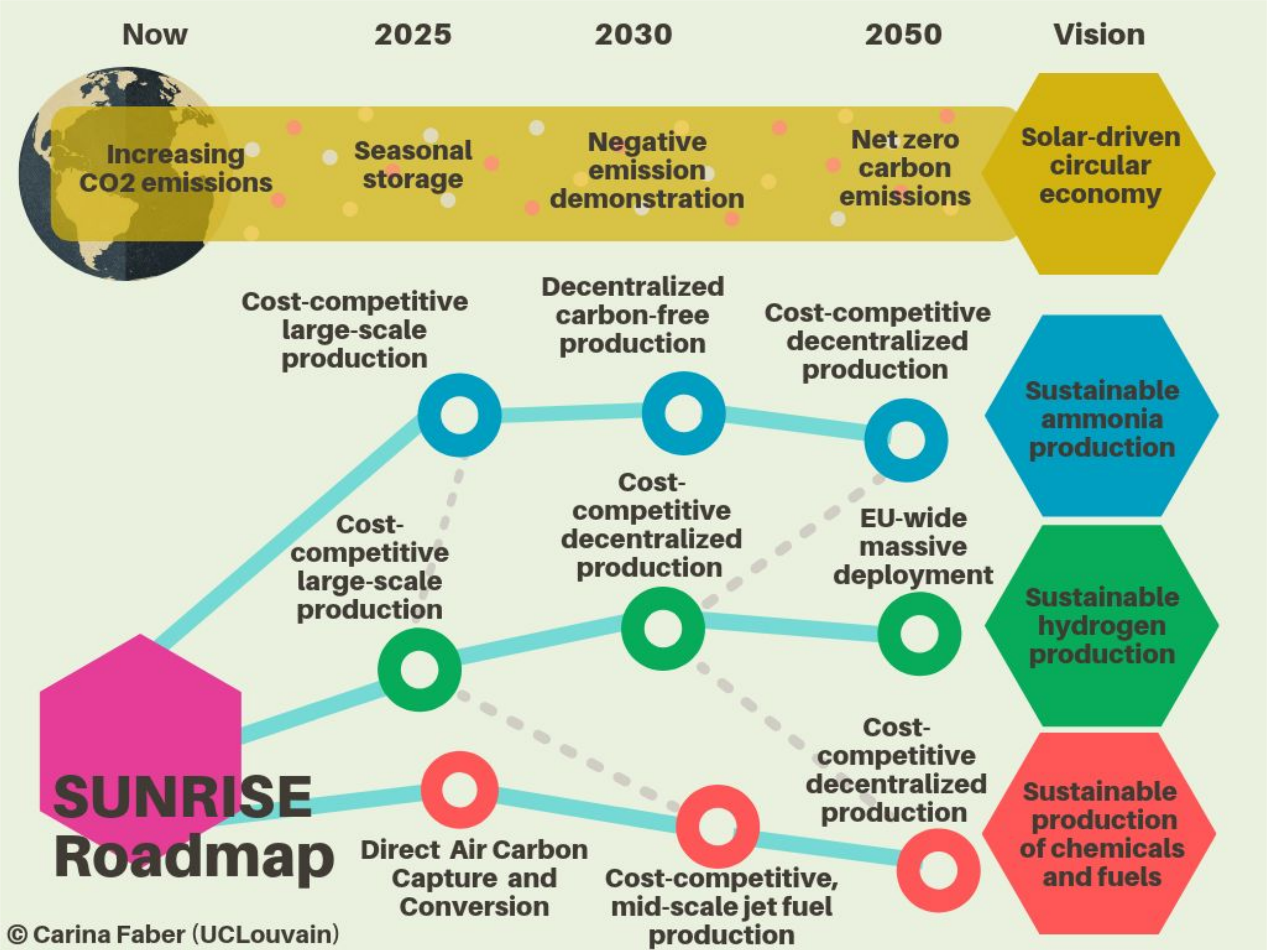
What synergies do you see?

SUNRISE

Solar energy for a circular economy
Technological Roadmap

Draft

Carina Faber | Université Catholique de Louvain, Belgium
carina.faber@uclouvain.be


Now
2025
2030
2050
Vision
Increasing CO2 emissions
Seasonal storage
Negative emission demonstration
Net zero carbon emissions
Solar-driven circular economy
Cost-competitive large-scale production
Decentralized carbon-free production
Cost-competitive decentralized production
Sustainable ammonia production
Cost-competitive large-scale production
Cost-competitive decentralized production
EU-wide massive deployment
Sustainable hydrogen production
Cost-competitive decentralized production
Sustainable production of chemicals and fuels
SUNRISE Roadmap
Direct Air Carbon Capture and Conversion
Cost-competitive, mid-scale jet fuel production
© Carina Faber (UCLouvain)

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Context: What does the world look like today?

- A roadmap is **not an abstract object** standing on its own: its purpose comes with its **actual implementation and the solution it brings to real-world challenges**
- It is crucial to **analyze the specific context** in which it will have to persist;
- Even though it is a **technology roadmap**, **strongly dependent on non-technological enablers such as financing mechanisms, political support and social commitment**
- Some of the trends will accelerate the development of the proposed solar-driven SUNRISE technologies, others will hamper them.
- The latter have to be anticipated and, if possible, circumvented.

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Context: What does the world look like today?

What are today's drivers? And Challenges?

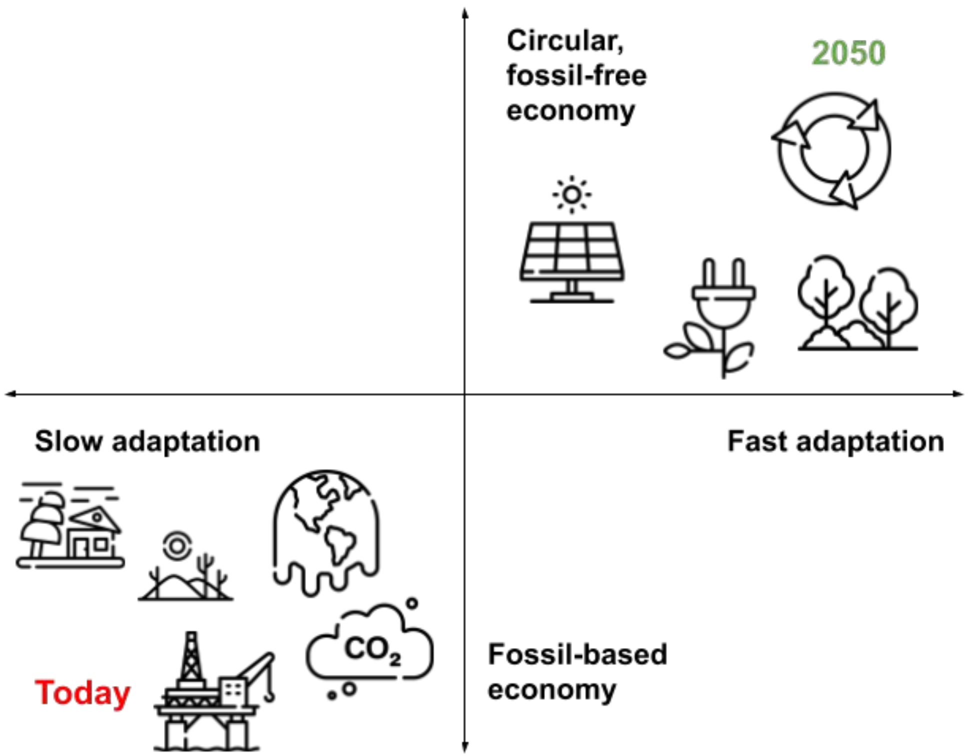
Ecological drivers

- Today's **energy production system strongly depends on fossil-based energy sources and raw materials**
- Their intensive use over the last decades not only depleted the Earth's reservoirs, but also caused a **significant increase of the carbon dioxide concentration** in the atmosphere
- Latest reports point out the **tremendous consequences** of the ongoing warming on ecosystems, resources and accordingly society in general
- In EU, **energy and transport sectors** generate the major part of GHG emissions (54% and 24% in 2016)
- **Chemical industry**, one of the largest industrial GHG emitters in Europe

Already in 2050, burning of fossil fuels should no longer be the rule but the exception in technologically well-developed countries

Technologies for the transition to a low-emission society not available on a large-scale today.

Scenarios: What will the world look like in 2050?



Scenarios: What will the world look like in 2050?

- SUNRISE envisions the **sustainable production of chemicals and fuels using solar energy and raw materials abundantly available in the atmosphere**
- Due to high number of considered products (ranging from hydrogen to jet fuel) and broad scope of proposed technologies with different degrees of maturity, **beyond the scope of this roadmap to model future scenarios based on current data**
- Future needs of chemicals and fuels estimated by analyzing different scenarios described in the current literature:

  → **"2050 long-term strategy climate-neutral Europe" (EC 2018)**

  →**Recent reports of the International Panel on Climate Change**

  These scenarios set frame for the goals to be achieved by the proposed technologies.

Scenarios: What will the world look like in 2050?

2050 long-term strategy climate-neutral Europe

- confirms Europe's commitment as a leader in global climate action
- presents a vision for **achieving net-zero greenhouse gas emissions by 2050**
- **socially fair transition**
- **Decoupling economic growth from depletion of natural resources**
- Eight economy-wide scenarios, divided in three different categories depending on their levels of emission reductions (from 80% to 100%)
- The scenarios cover the potential range of required reductions for the EU to contribute its share to the Paris Agreement's temperature objectives ("*well below 2° C"* and "*1.5°C temperature change")*.

IPCC Special Report Global Warming of 1.5ºC

- discusses impacts of global warming of 1.5 ºC above pre-industrial levels and four illustrative global model greenhouse gas emission pathways
- In pathways for limiting global warming to 1.5ºC, CO_2 emissions are reduced globally to net zero around 2050
- All pathways examined use Carbon Dioxide Removal (CDR), but in different amounts

Scenarios: What will the world look like in 2050?

Implications for SUNRISE

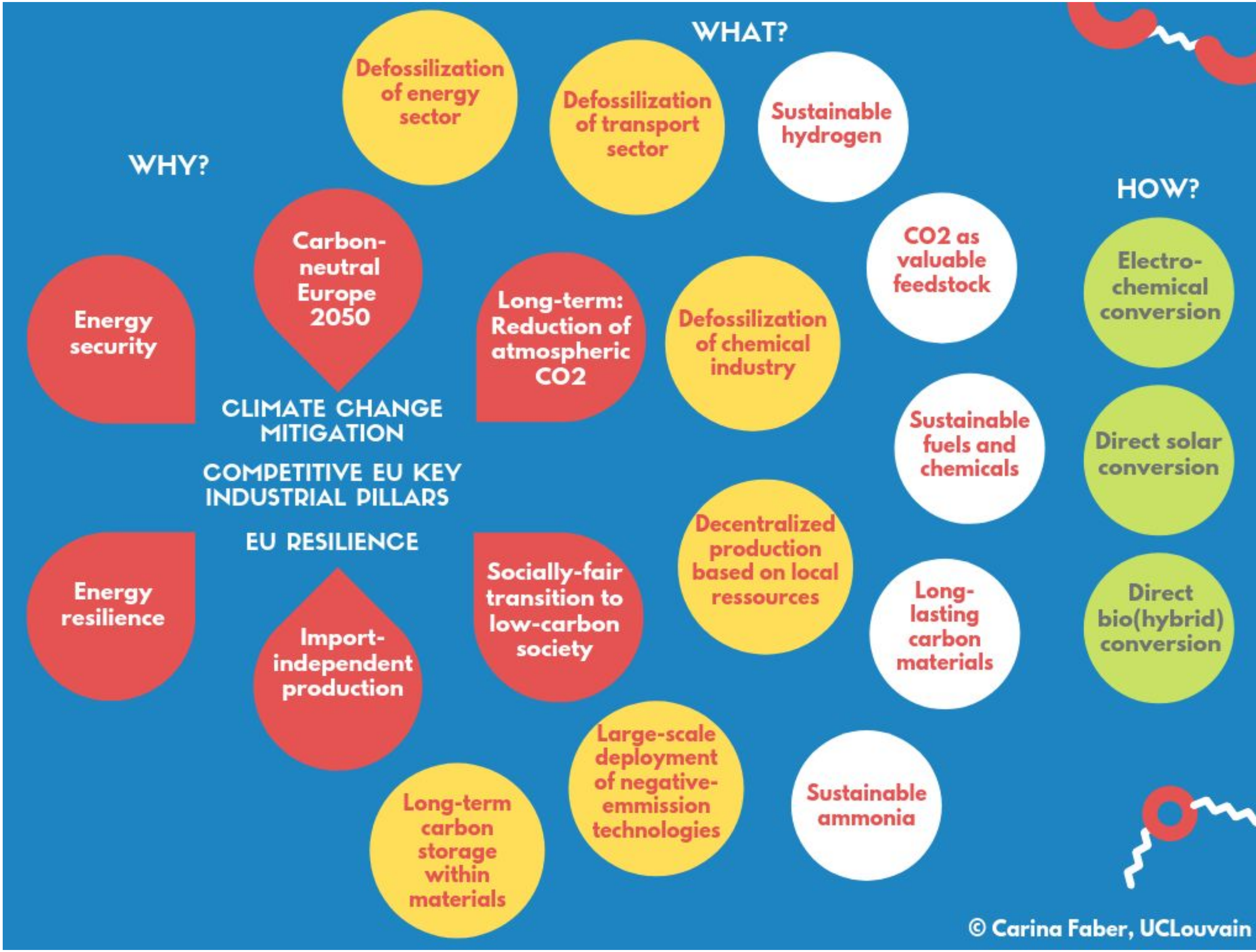
- **energy system transition is underway**
- highest ambition level can only be achieved if all mitigation options are exploited: **electrification, hydrogen, bio-based feedstocks and substitution**
- **SUNRISE technologies with low technological readiness are not included** in the described scenarios, but their great impact (projected as 2 TW for Europe alone), will determine the electricity demand and the decentralization for industry decarbonization
- some scenarios, such as the fourth illustrative pathway in the IPCC report mentioned above, **largely rely on the deployment of a BECCS model**, where biomass becomes an important energy carrier. For this pathway, the needed land area for bioenergy is expected to amount to 7.2 million km^2, globally, by 2050: **land use, biodiversity!**

The development of technologies included in the SUNRISE portfolio alleviate the needs for land use, water and nutrients consumption, since they are based on decoupling of economic growth from depletion of resources, while high solar-to-fuel yields are targeted

Vision: How to get the future we want?

The vision of SUNRISE is to enable a circular economy of renewable fuels and chemicals on a global scale using abundant molecules as feedstocks (*e.g.* water, carbon dioxide, nitrogen) and, in the long term, sunlight as the sole energy source.

- SUNRISE wants to develop **artificial photosynthesis technologies in a broad sense**
- aiming at **solar-to-products yields tenfold to hundredfold higher than current biomass practice**
- Using the **smallest possible land area** is a key objective in order to propose technologies compatible with other essential goals (sustainable food production system, preservation of biodiversity)
- based on ubiquitous resources - thus enabling a **purely decentralized and import-independent production system**
- SUNRISE will create **substantial added value for all European countries** by providing **tailored solutions** for each European region to achieve the **best utilization of solar irradiance and site-specific resources**


WHY?
WHAT?
HOW?
Defossilization of energy sector
Defossilization of transport sector
Sustainable hydrogen
Carbon-neutral Europe 2050
Energy security
Long-term: Reduction of atmospheric CO2
Defossilization of chemical industry
CO2 as valuable feedstock
Electro-chemical conversion
CLIMATE CHANGE MITIGATION
COMPETITIVE EU KEY INDUSTRIAL PILLARS
EU RESILIENCE
Sustainable fuels and chemicals
Direct solar conversion
Energy resilience
Import-independent production
Socially-fair transition to low-carbon society
Decentralized production based on local ressources
Long-lasting carbon materials
Direct bio(hybrid) conversion
Long-term carbon storage within materials
Large-scale deployment of negative-emmission technologies
Sustainable ammonia
© Carina Faber, UCLouvain

Vision: How to get the future we want?

The **sustainable large-scale production of solar fuels and chemicals** is key to enable the SUNRISE vision. It is based on both **point and distributed sources of carbon dioxide**, the **ultimate goal being the extraction of carbon dioxide from the atmosphere and its long-term storage in long-lasting carbon materials.**

- Given the vast variety of possible solar fuels and chemicals, SUNRISE has to limit its efforts to special classes of products to **ensure efficiency of a joint large-scale research effort**
- **fuels and chemical commodities**, which are needed and produced in **large volumes** today (millions of tons per year or more on a global scale) and sold at a **small price** (range of 1€ per liter)
- market is a major **challenge, calling for very efficient, simplified and durable processes**
- Ubiquitous low-energy species extracted from environment and upgraded with abundant renewables
- High-value molecules (*e.g.* pharmaceuticals) are low volume markets; exception: fuels, fatty acids, biodegradable plastics

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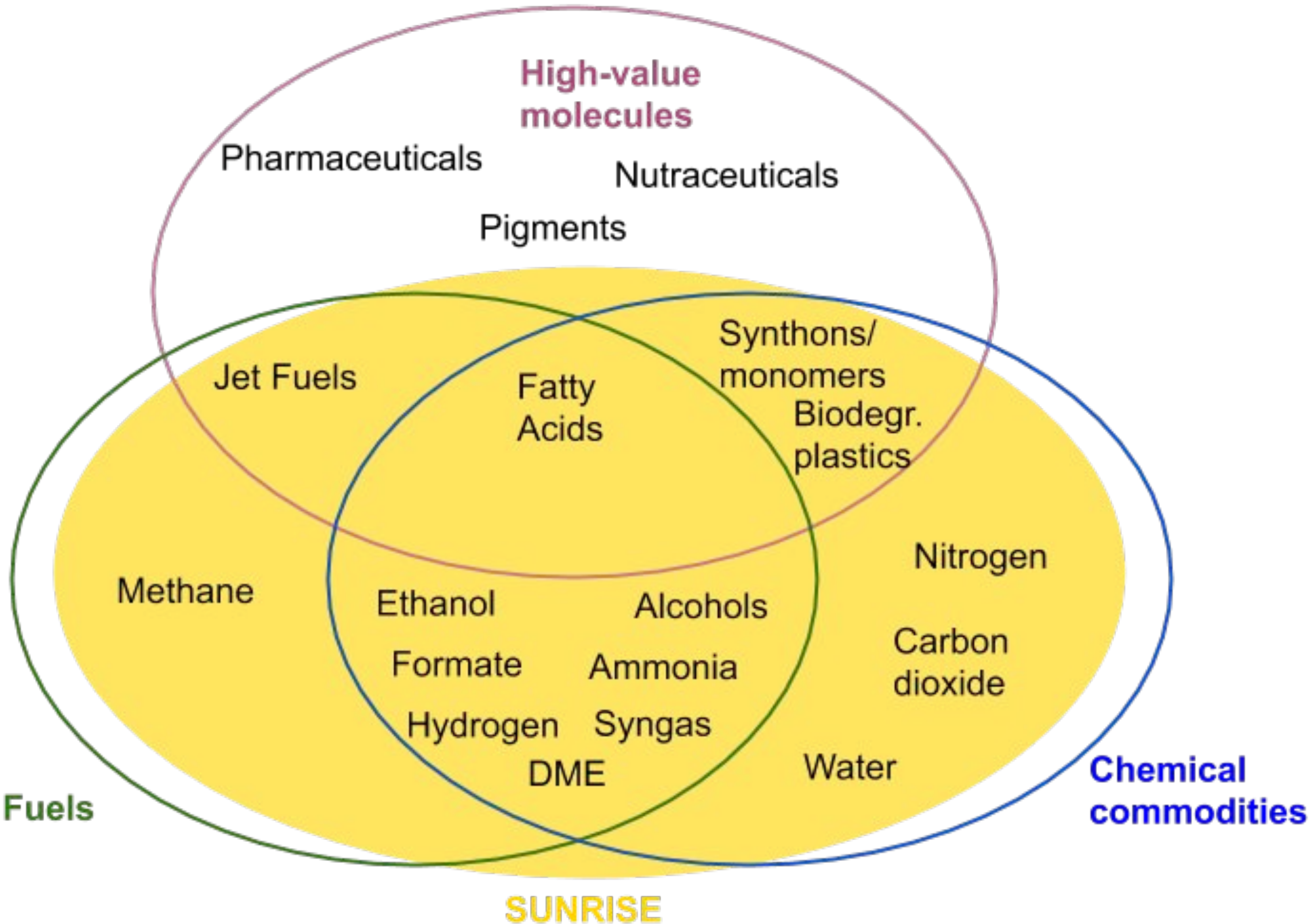
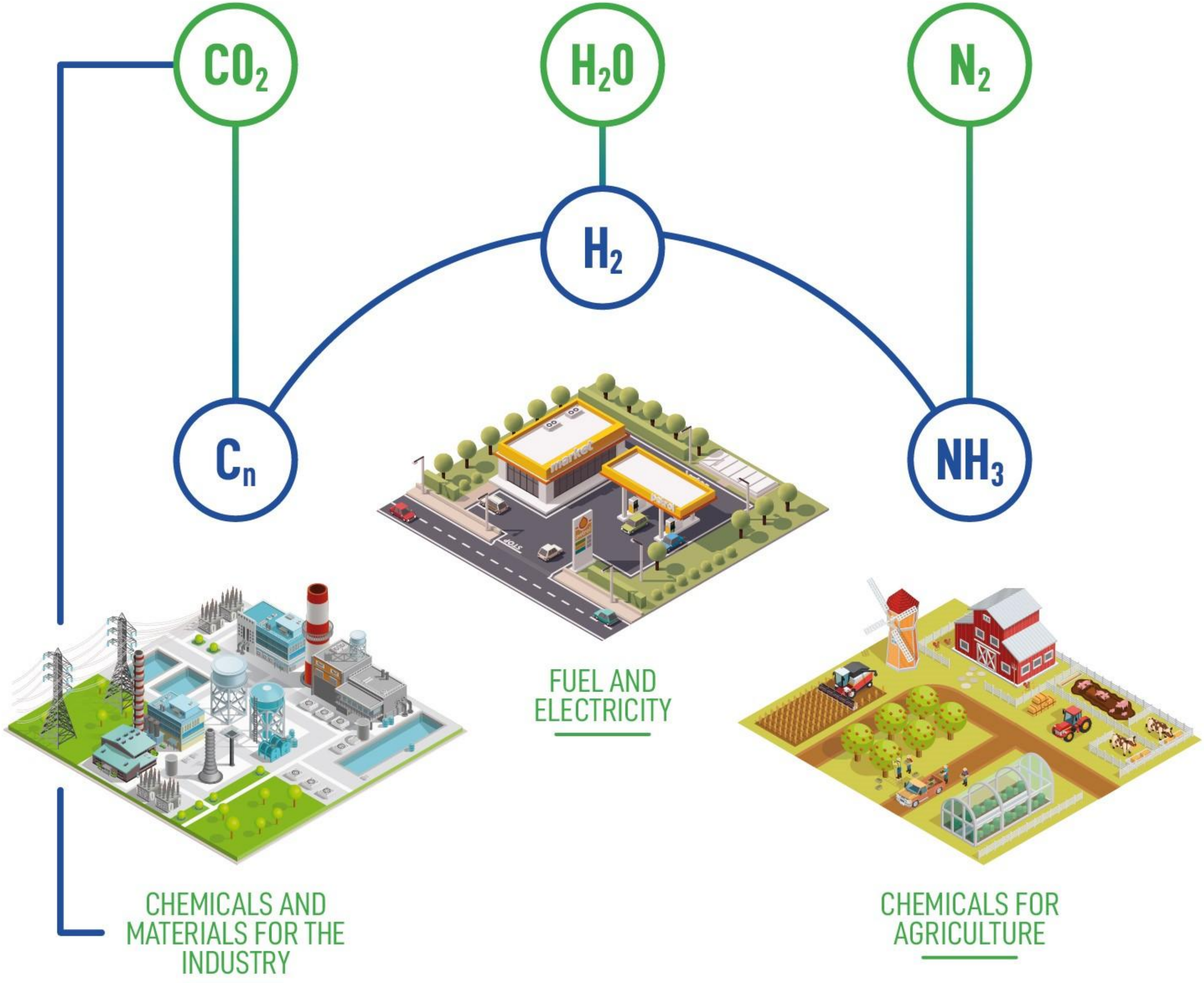


Key molecules considered in SUNRISE are highlighted in the yellow oval area, comprising fuels and chemical commodities, but not high-value molecules per se.

The SUNRISE roadmap is structured around the products we can provide to society, not the technologies.



Vision: How to get the future we want?

Example: Hydrogen

- highly important energy vector
- Especially wrt transport sector, already well-covered topic: existing European large-scale structures such as the **private public partnership *Fuel Cells and Hydrogen Joint Undertaking (FCH JU)*** and their recently released *Hydrogen Europe Roadmap*
- **Sustainable, large-scale hydrogen production is central to the SUNRISE vision**
- Hydrogen represents an **enabling molecule** in the production of ammonia and carbon-based fuels and chemicals
- not only electricity-based hydrogen technologies with a high technology-readiness-level (TRL) are considered; less mature methods based on the direct conversion of sunlight to hydrogen have a prominent place
- **A significant increase of the solar-to-hydrogen yield, high demands on sustainability and circularity in the systems and an economically-viable production of solar hydrogen are key drivers.**

SUNRISE Roadmap: how to go from the current state to the vision?

SUNRISE Roadmap: how to go from the current state to the vision?

SUNRISE: Solar energy for a circular economy

Vision

The sustainable production of fuels and commodity chemicals at affordable costs of materials and Earth surface using solar energy

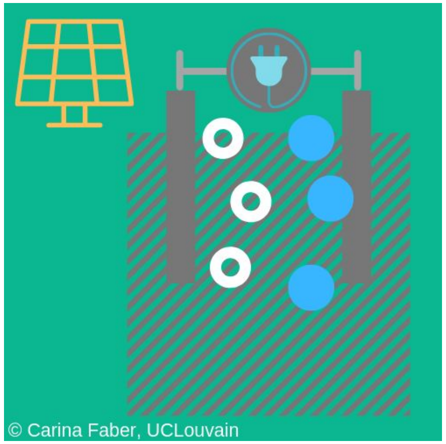
Three main technological approaches

→ mimick natural photosynthesis to **store solar energy** in chemical compounds

→ energy from light, water and carbon dioxide transformed into **solar fuels** (hydrogen and carbon-based fuels)

→ multitude of different technologies, three main areas: **solar-driven electrochemical conversion, photo(electro)chemical** and **biological/bio-hybrid approaches**

SUNRISE Roadmap: how to go from the current state to the vision?

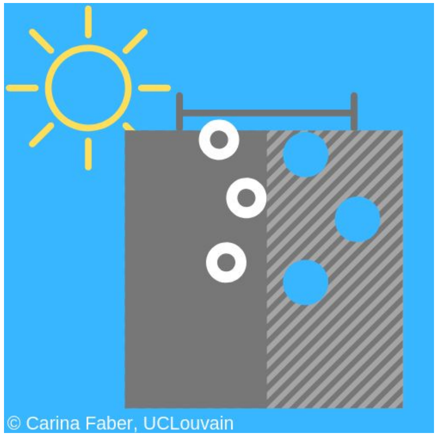


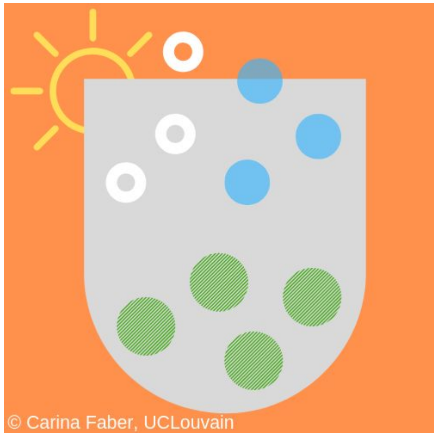
Electrochemical conversion with solar power

Direct conversion via photo(electro)chemical systems

combine everything necessary to go directly from sunlight to the final chemical product

includes biomolecular systems: biological molecules extracted from living cells wired to inorganic components





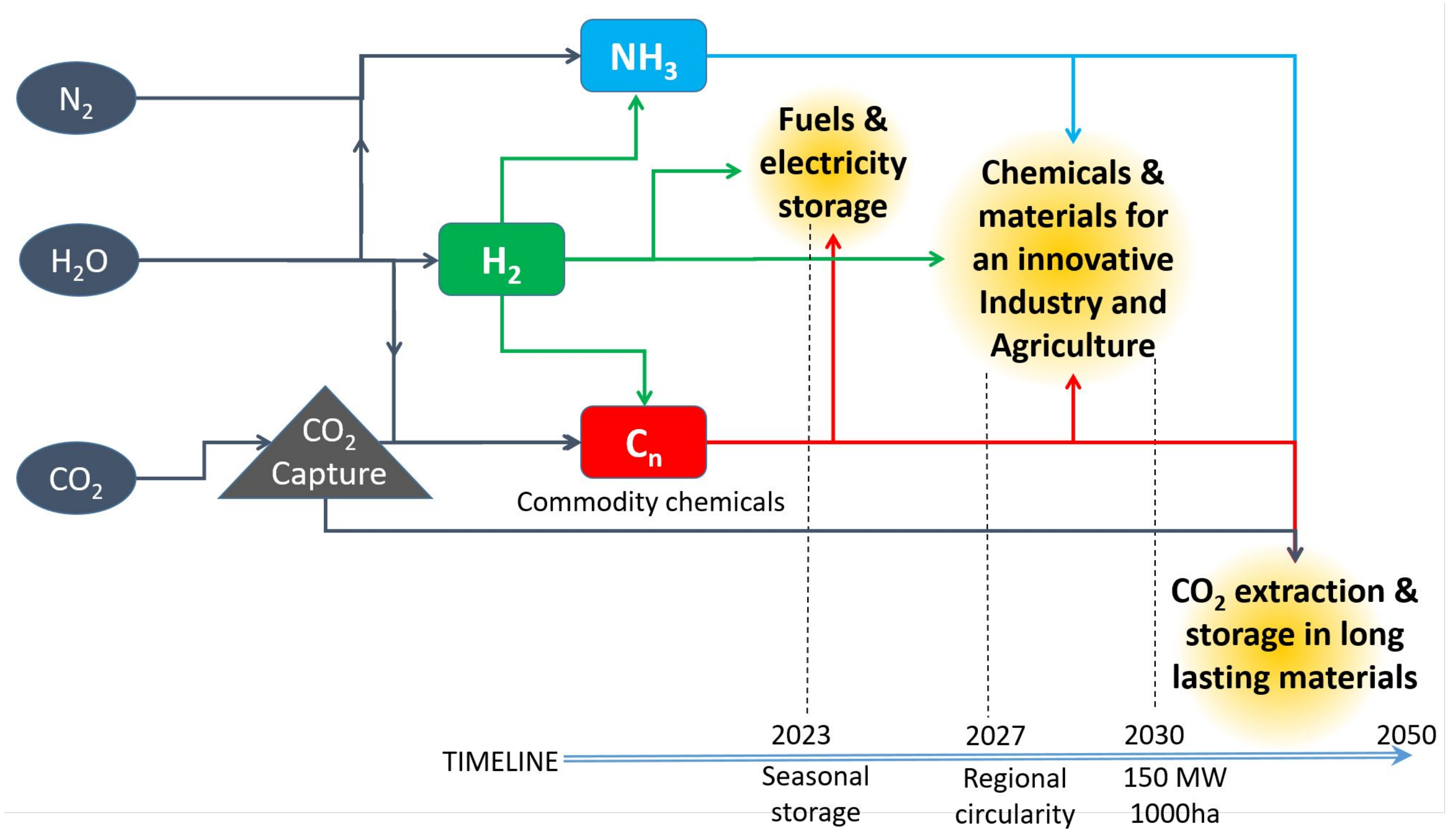
Direct conversion via photo(electro)chemical systems

living photosynthetic cell factories

includes biohybrid systems: living microbes wired to inorganic components

SUNRISE Roadmap: how to go from the current state to the vision?

Technological milestones to be achieved

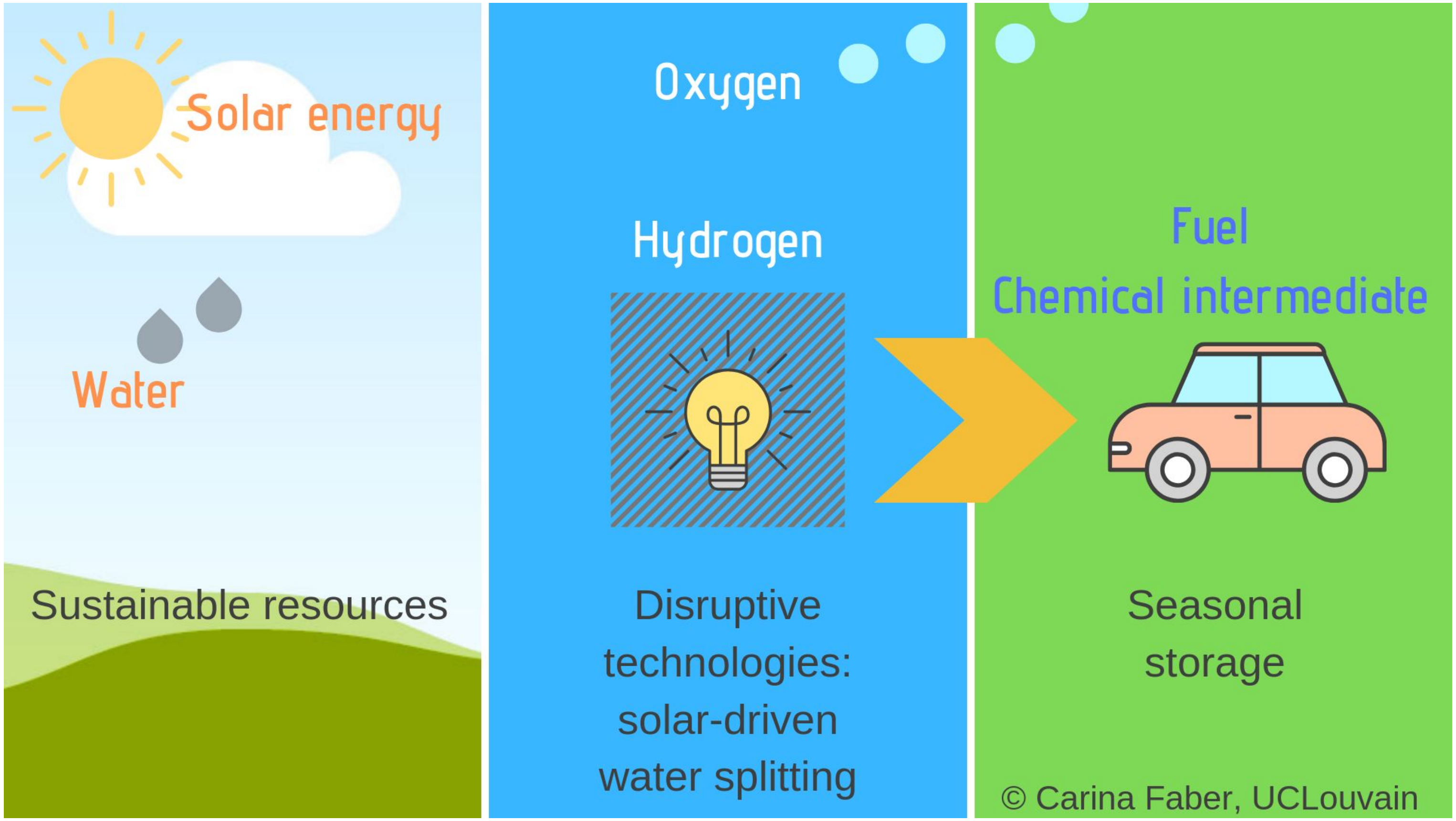


- Carbon, hydrogen, oxygen and nitrogen are the main atomic building blocks
- Molecular hydrogen, H_2 are key in the reduction of carbon dioxide and nitrogen

SUNRISE Roadmap: how to go from the current state to the vision?

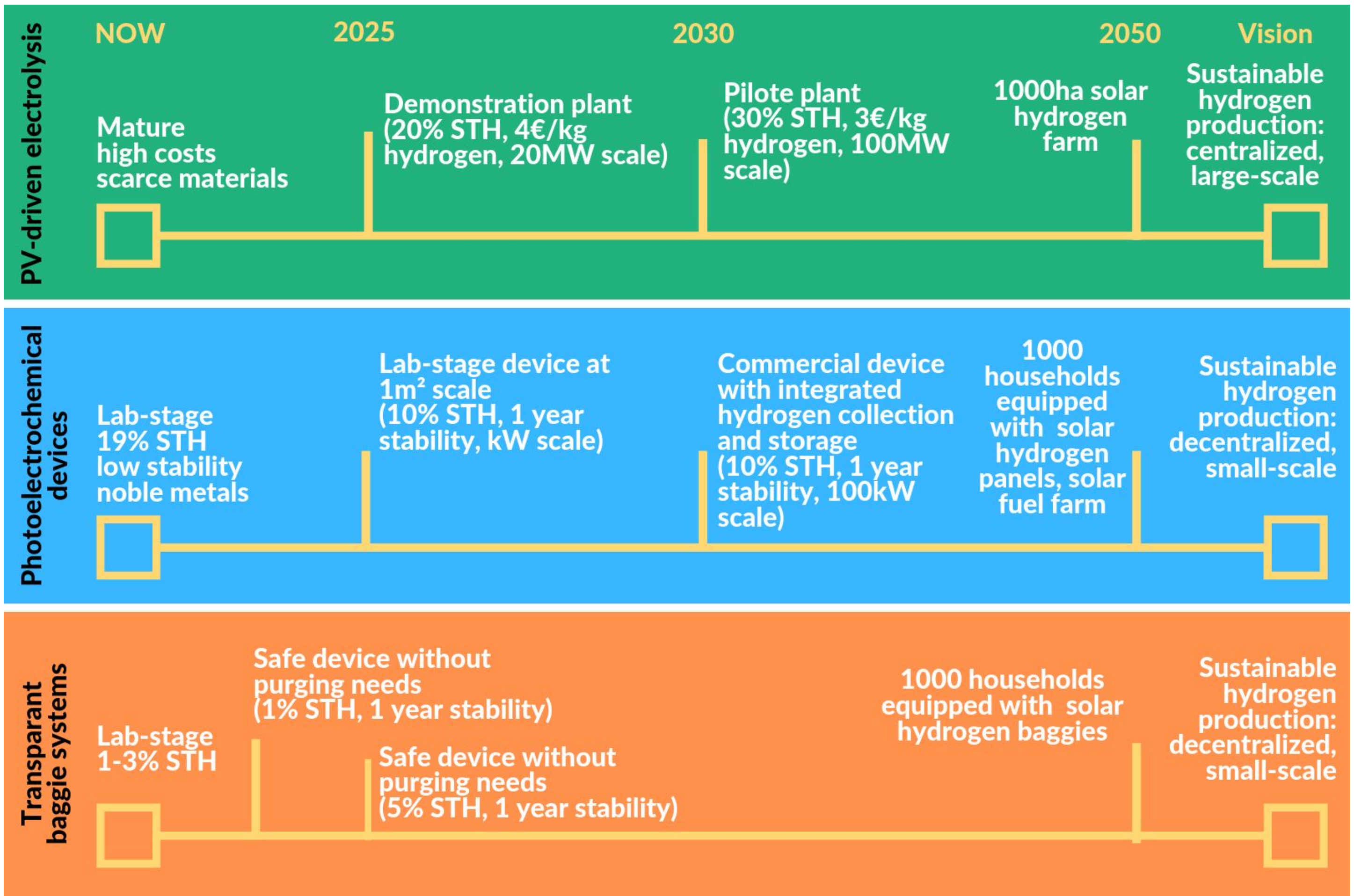
Sustainable Hydrogen production

The SUNRISE vision is to produce green hydrogen in a fully sustainable way, exclusively using solar energy and abundantly available materials and resources



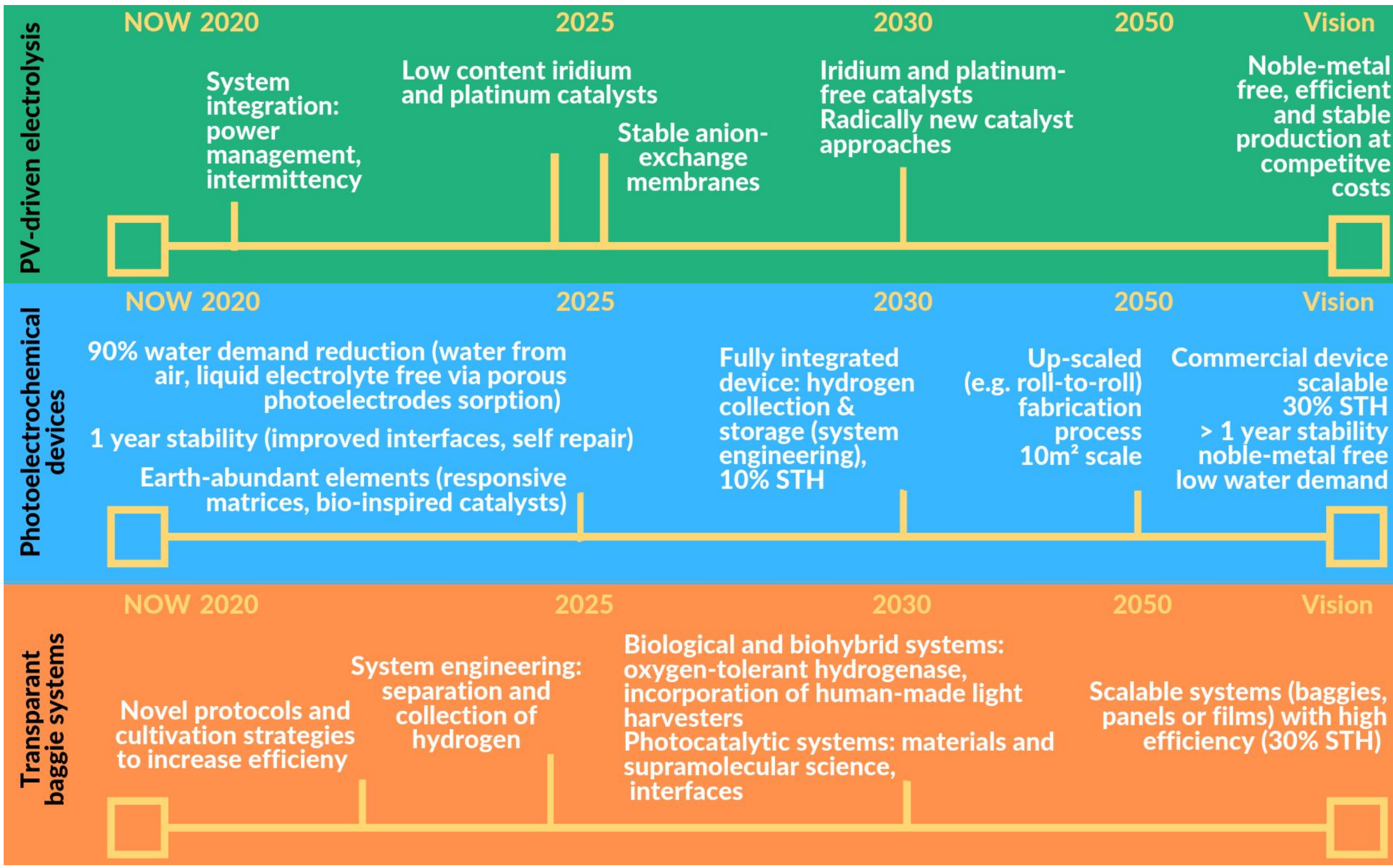
SUNRISE Roadmap: how to go from the current state to the vision?

Major milestones



SUNRISE Roadmap: how to go from the current state to the vision?

Major technological targets



SUNRISE key enabling technologies

The future deployment of SUNRISE technologies at scale, providing net global GHG reductions, necessitates enabling resources, technologies and analyses.

Upscaling, *i.e.* bringing novel technological solutions from the lab to a global industrial scale, is a significant challenge for mature SUNRISE technologies. The overall sustainability, the availability of needed resources on a large scale and economic viability have to be ensured.

Novel materials will allow cost-competitive, efficient and durable solutions across the three proposed technological SUNRISE approaches.

Product separation, *i.e.* the conversion of a mixture of chemical substances into distinct products, is a crucial step once the desired solar fuel or chemical is produced by the artificial photosynthesis device; in most of today's devices product separation, purification and collection represent one of the major bottlenecks due to the energy consumed for production and operation.

The SUNRISE tool-box comprises **computational materials modelling, quantitative sustainability assessment, synthetic biology and emerging concepts**.

Needed resources beyond the scope of SUNRISE

Social and environmental impact

Land use and freshwater demand

The deployment of any new technology should carefully consider the additional land use and freshwater demands in this context.

Impact of SUNRISE technology on the environmental resources

	Today global production [a] [Mt / y]	Production potential [b] [tons ha^{-1} y^{-1}]	Land use [km^2]	Freshwater use [c] [Mt / y]
Hydrogen	70	52 - 130	13 500 - 5 400	630
Formic Acid	< 1	1 182 - 2 956	8 - 3	< 0.5
Formaldehyde	52	386 - 964	1 350 - 540	30
Methanol	75	274 - 686	2 700 - 1 100	85
Ethanol	95	197 - 494	4 800 - 1 900	110
Ammonia	176	308 - 772	5 700 - 2 300	280

Technical Appendix: technologies and milestones
on the “call level” of future work programmes

Sustainable hydrogen production

1. Large-Scale hydrogen production using PEM electrolysis
2. Hydrogen-production using photoelectrochemical cell devices

   ...

Sustainable ammonia production

1. Renewable Haber-Bosch process
2. Electrochemical ammonia synthesis

   ...

Sustainable carbon-based chemicals and (jet)fuel production

1. Dark electrochemical reduction of CO_2 to C1/C2/C3 products
2. Electrochemical production of hydrocarbon fuels

   ...

Carbon capture technologies

1. Amine-based carbon capture
2. Low-Temperature Direct Air Capture

   ...

Enabling technologies

   ...

A great team work with excellent researchers from all-over Europe:

Yagut Allahverdiyeva-Rinne (University of Turku), Vincent Artero (CEA), Laurent Baraton (Engie), Andrea Barbieri (CNR), Hervé Bercegol (CEA), Maximilian Fleischer (Siemens), Han Huynhthi (Engie), Joanna Kargul (Warsaw University), Hélène Lepaumier (Engie), Laura Lopez (ICIQ), Ann Magnuson (Uppsala University), Arne Roth (Fraunhofer)

SUNRISE Roadmap: Next steps

A roadmap takes its only purpose from being implemented!

Content:

- **revise milestones, extend technical appendix forms, etc.**

  → this afternoon: split into discussion groups (H2, NH3, carbon-based fuels, technical appendix)

- **extend to international level (tomorrow)**

Lobbying:

- **decide for publication state**
- **disseminate draft roadmap to national and European contacts, colleagues**
- **present roadmap to EC (*e.g.* lunchtime meeting DG energy)**

  → this afternoon: group discussing about possible strategies

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www.sunriseaction.eu

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carina.faber@uclouvain.be

Recommendations

- Couple to use/cleaning of less-clean water? (connect to SDG ”clean water”)
- State that this is a tech development, not a business case development map (we don’t point out where businesses can be made).
- Point out knowledge transfer between the different approaches and targets (*e.g.* H_2 vs CO_2)
- Explain how targets on efficiency and scale have been set.
- IPCEI on Hydrogen. Check their goals for large scale projects (100 MW to several GW before 2028).
- Write that SUNRISE will analyse all technologies with respect to scalability, sustainability, environmental footprint.
  Add to the schemes goals in terms of scalability and sustainability (replace IrOx with earth abundant, etc.).
- P 31: 4 Euro/kg in 2025 is probably too high (Milestone in Scheme).
- P31 should not goals rather be “X% of EU fuel provided by solar H2”, that specifying the size of one plant?
- P31 it looks like PEC can never be large scale, but only decentralized – is this intentional?
- References to how projected costs have been calculated.
- Note on the use of units (kg^{-1}, kWh^{-1} etc.) + how STH efficiencies were calculated.
- P. 32 add to key enabling technologies: “cat + membranes that can operate at different conditions (pH, waste water...)”
- Are “visions for 2050” aligned with those from the vision document – check!
- P. 34: The scheme looks wrong. “Now” looks like “Goals”, while >1 year stability may be 2025-2030, but finally must be >10 years

Recommendations

- P 21 Clarify that it is **production** of H2 is the focus.
- Couple to use/cleaning of less-clean water? (connect to SDG ”clean water”)
- References to how projected costs have been calculated.
- Note on the use of units (kg^{-1}, kWh^{-1} etc.) + how STH efficiencies were calculated.
- State that this is a tech development, not a business case development map. (we don’t point out where businesses can be made).
- Point out knowledge transfer between the different approaches and targets (*e.g.* H_2 vs CO_2)
- Explain how targets on efficiency and scale have been set.
- IPCEI on Hydrogen. Check their goals for large scale projects (100 MW to several GW before 2028).
- Write that SUNRISE will analyse all technologies with respect to scalability, sustainability, environmental footprint.
- P 31 ff: add to the schemes goals in terms of scalability and sustainability (replace IrOx with earth abundant, etc.)
- P 31: 4 Euro/kg in 2025 is probably too high (Milestone in Scheme). The cost estimates in the test below lack references.
- P. 31: clarify in the text that the milestone 2025 is not just for SOE. In addition, ion exchange electrolyzers should be mentioned (“ENAPTER” – company that started).
- P31 should not goals rather be “X% of EU fuel provided by solar H2”, that specifying the size of one plant?
- P31 it looks like PEC can never be large scale, but only decentralized – is this intentional?

Moderator: **MI IC5/ Sunrise roadmapping workshop : Break-out session Ammonia**

Vincent Artero (CEA)
Participants:
Roel van de Krol (HZB)
Tony Vlcek (Heyrovsky Institute)
Rita Toth (EMPA)
Medhi Jafarian (Univ Adelaide)

Recommendations:

1. Consider NH_3 as a energy (H_2) carrier/fuels? (add a arrow to fuels and electricity in scheme page 29
2. Concerns about safety?
3. Photocatalytic N_2 fixation (including molecular systems) should be included, with same caution as for electrocatalytic systems. Relevant in the N_2 + water production scheme (right on the scheme p 37)
4. Introduce explicitely SOE for NH_3 production (https://arpa-e.energy.gov/?q=slick-sheet-project/solid-state-alkaline-electrolyzer-ammonia-synthesis).
5. The sentence « catalysis research with ab-initio modelling and high-throughput screening, in-operando analytical tools, multi-scale modelling, systems engineering, life-cycle cost Analysis » is also valid for electro and photo(electro)chemical N_2 fixation
6. N_2 capture, concentration and separation from O_2 in matrices deposited on (photo)electrodes or photocatalysts.
7. Develop biohybrid systems (see Nocera PNAS 2017)
8. Life-cycle & environmental footprint (indicated in the enabler box) should be developed in the text

Solar Energy for a Circular Economy

- A Coordination and Support Action (CSA) -

Meeting between SUNRISE and Mission Innovation IC5

Breakout session : Carbon-based molecules

James, Arne, Hélène, Hervé, Huub, Julio, Nicola, Thomas, Winfried

www.sunriseaction.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 816336

10 recommendations

1. Bioeconomy should be mentioned
   a) Synergies on CO_2 reduction.
   b) Link with 200 platform chemicals of biomass (photo)conversion
   c) Mention existing pathways of production
2. Express goals in units understandable by policy makers, and adapted to the chemical industry (compared to volume of chemical products)
   a) Products not specified
   b) Find data
3. Why not limit to H_2 + thermochemical processes ?
   a) Like Dan Nocera suggested to us in June
   b) Present TRL= 6 (not 4, correction needed).
   c) Include solar thermochemical as solar-assisted thermochemical conversion.
   d) Also addition of H_2 (from renewables) to improve thermochemical system.
   e) Put this story first, before electroreduction of CO_2
4. Justification of CO_2 electroreduction vs High Temp steps could be improved and detailed
   a) Selectivity, not well defined, not enough focused onto.
5. Advantages and disadvantages of high or low current densities : avoid contradiction and paradoxes
   a. Relate electrodruction of CO_2 to concentrated sources;

6. Energy-efficiency of product purification
7. Need of a section on catalysis: there we need energy-X.
    a) Low current density catalysis. Catalysis for PEC should be highlighted in the main document (supposing it is enough described in the Appendix).
8. PEC for CO_2
    a) TRL = 1-3 (NOT 3-4)
    b) Decentralized AND CO are not compatible. Focus on a realistic product for decentralized deployment (= at the level of users)
    c) Blue graphic on p. 51 should have more technical details
9. biocatalytic
    a) "Novel strategies to avoid contaminations of production cells from foreign strains" should be solved before pilot stage (by 2025)
10. Availability of CO_2 questionable – even though abundance is certain
    a) What is the thermodynamic limit of CO_2 capture?
    b) System thinking, as in section 10 of Energy-X Research Needs

Thank You

“The worls has enough for everyone’s need…. but not enough for everyone’s greed."

Mahatma Gandhi

Topics discussed

- Suggestions for contents, context, scenarios, vision
- Suggestions for impact towards the community, EC and members states (Lobbying)
- Members of the group:
- Joanna Kargul, Yagut Allahverdiyeva, Amelia Ochoa, Stefan Baumann, Laura Lopez, Philippe Schild, Carina Faber, Frédéric Chandezon (moderator)

Contents, context, scenarios, vision

- The roadmapping team should reconsider the thermochemical processes to be integrated (or not) in the roadmap and/or a how document

  → Stefan leader

- Context:

  → Add footnotes for clarification for energy consumption

  → Specify in the introduction that we analyzed scenarios and not made ours

General impact

- Get official version of the roadmap ready with green light of the SUNRISE management board to disseminate it
- Making awareness of this roadmap at different levels: community (to strengthen it), the MS, EC and beyond

Impact towards the community

- Inform via the newsletter the supporters that the roadmap is available and what feedback is expected from them
  - → Roadmap is available for download on web page
  - → Technical appendix downloadable (≈ 170 pages) and is splitted in sections so that supporters can download the section they are most interested in
  - → Feedback needed not on the wording but on the how documents: specifications, milestones, mapping the gaps in the how documents (mapping and gapping

Impact towards the member states

- Public dissemination of the roadmap (executive summary) in national roadmap dedicated events
- Organize ASAP roadmap-events targetting high level, policy makers, representatives of industry and national funding agencies, media
  - Coordinated meetings with a standardized communication material (presentation)
  - SUNRISE national nodes should convey the message at those events

Remark: a roadmap event is not a “standard” stakeholder workshop

Impact towards the EC

Remark: we are not yet that visible at the european level !

- Executive summary of the roadmap can be distributed by the commission
- Roadmap events lunches with representatives of different DGs (separate events à priori)

Impact beyond EC

- Mission innovation is the right frame for that !
- An alternative is to make contact with IC via colleagues from SUNRISE and ENERGY-X having contacts

Solar Energy for a Circular Economy

Deliverable D5.2
Symposium

WP5. Management

Lead Beneficiary: UL – Leiden University
Delivery date: 31 January 2020
Dissemination level: Public
Version: v1.0

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V 0.5	31/03/2020	Joanna Kargul (UW)	Corrections/revisions
V 1.0	31/03/2020	Huub de Groot (LU)	Corrections/revisions

Contents

1. Executive summary

This document, D5.2 Symposium Report, is a deliverable of the SUNRISE CSA, which is funded by the European Union's H2020 Programme under Grant Agreement No. 816336.

On February 3rd – 7th, 2020, a series of meetings were organized in Brussels by the SUNRISE consortium, partly in collaboration with Energy-X and the Representation of the State of Hessen to the EU. The week started on February 3rd – 4th with a closed consortium meeting at EERA to finalize the work on the SUNRISE deliverables. On February 5th – 6th, the formal kick-off of SUNERGY took place, the follow-up initiative of the CSAs SUNRISE and Energy-X. At this event over 100 stakeholders of both CSAs gathered for a series of public sessions on February 5th and 6th following a high-level lunch event at the European Parliament on February 5th and ending February 6th noon. February 6th pm and 7th am were spent on public SUNRISE meetings at EERA to collect input for the SUNRISE blueprint, deliverable D1.3.

During the sessions on February 3rd – 4th, the SUNRISE deliverables were reviewed by the consortium as well as the planning of remaining efforts needed to conclude pending deliverables. The discussion was documented and the outcome is presented in this document. The public SUNRISE sessions on February 6th pm and 7th am were used to discuss the programming of future consortia and investment scenarios to realize (parts of) the SUNRISE roadmap. This discussion is also presented in this document.

During the public kick-off meetings on February 5th – 6th, the CSAs SUNRISE and ENERGY-X presented their achievements throughout the past year, and proposed their joint vision on providing sustainable and competitive alternatives to fossil fuels by 2050. Keynote speakers like Peter Dröll (Director Prosperity, Directorate General Research & Innovation) highlighted the strong support of the European institutions towards R&I to achieve the ambitions of the European Green Deal. The session on February 6th am was focused on upcoming funding opportunities and recently awarded projects relevant for SUNERGY.

The public meetings brought together a broad representation of academia, policy, and industrial actors together with NGOs, consumer associations, citizens, students, and press correspondents to mobilize the critical mass needed to implement the future large-scale research initiative SUNERGY.

2. Agenda of the meetings

A. SUNRISE Final Consortium Meetings

Session 1: Deliverables

Monday, 3 February 2020

13:30 – 13:45 Opening words by Huub de Groot (LU, SUNRISE CSA coordinator)**.**

13:45 – 15:45 Deliverables WP 1 Strategy and structuring
D1.1 Consolidated vision (Nicola Armaroli, CNR)
D1.2 Roadmap (Hervé Bercegol, CEA)
D1.3 Blueprint (Ann Magnuson, UU)
Revision, integration (all)

15:45 – 16:00 *Coffee break*

16:00 – 17.00 WP 2: Innovation and Exploitation (I)
D2.1 Innovation process (Arne Roth, Fraunhofer)
D2.2 Innovation structure (Peter Ellis, Johnson Matthey)

17:00 End of Day 1

Tuesday, 4 February 2020

9:00 – 10:45 WP 2: Innovation and Exploitation (II)
D2.3 Innovation and exploitation plan (Max Fleischer, Siemens)
Revision, integration (all)

10:45 – 11:00 *Coffee break*

11:00 – 12:00 WP 3: Dissemination, Communication and Education
D3.1 Dissemination Plan
D3.2 Website & App
D3.3 Resources
D3.4 Data Management Plan
Revision, integration (all)

12:00 – 13:00 *Lunch*

13:00 – 14:00 D4.1 Governance Plan (Frédéric Chandezon, CEA)
Discussion next steps, all

14:00 – 14:15 *Coffee break*

14:15 – 17:00 D4.2 Terms of Reference (Max Fleischer, Siemens)
Revision, integration with D1.3 Blueprint (all)

17:00 End of the meeting

Session 2: Programming future consortia

Thursday, 6 February 2020 PM, 13.00 - 17.00

Blueprint - 100% scenario.

Aim: Collect input from SUNRISE consortium members and invited Energy-X stakeholders on the structuring of future research calls and investment needs to fulfil the entire SUNRISE Roadmap by 2030.

Friday, 7 February 2020 PM, 9.00 - 13.00

Blueprint – "compromise" scenario

Aim: Collect input from SUNRISE consortium members and invited Energy-X stakeholders on the structuring of future research calls and investment needs to fulfil prioritized parts of the SUNRISE Roadmap by 2030.

B. Public meetings / SUNERGY kick-off

Part 1 : SUN-ERGY policy lunch event at the European Parliament

'Decarbonising Europe: How large-scale R&I initiatives on fossil-free fuels and chemicals can contribute to the European Green Deal'

5 February 13.00 – 14.30
European Parliament I Brussels (by invitation only), Moderator: Joanna Kargul, University of Warsaw, SUNERGY Executive Board

13.00 – 13.10	Opening statements - Morten Helveg Petersen, MEP, Denmark
13.10 – 13.40	Keynote: Helene Chraye and Mark van Stiphout, the European Commission
13.40 – 13.55	SUNERGY, the way forward - Bert Weckhuysen, SUNERGY coordinator, Utrecht University
13.55 – 14.10	The industry perspective - Maximilian Fleischer, Chair SUNERGY Industrial Board, Siemens AG
14.10 – 14.25	Questions from the audience
14.25 – 14.30	Closing remarks - Morten Helveg Petersen, MEP, Denmark

Part 2: SUNERGY public kick-off event

'Fossil-free fuels and chemicals for a climate-neutral Europe'

February 5, 16.00 – 18.00
TownHall Europe, Square de Meeus, Brussels

15.30 – 16.00 Registration and coffee
16.00 – 16.10 Welcome (Bert Weckhuysen, SUNERGY coordinator, Utrecht University)
16.10 – 16.30 SUNERGY (Frédéric Chandezon, SUNERGY deputy coordinator, CEA)
16.30 – 17.00 Perspective from industry (Jan Mertens, ENGIE)
17.00 – 17.30 Perspective from European Commission (Peter Dröll, Director Prosperity, DG RTD)
17.30 – 17.55 Q&A
17.55 – 18.00 Wrap-up
18.00 – 20.00 Networking reception

February 6, 9.00 – 14.00
The Representation of the State of Hessen to the EU, Brussels, 21 Rue Montoyer, Brussels

9.00 – 9.30 Registration and coffee
9.30 – 9.40 Opening Address (Johannes Bade, Head of Unit Higher Education, Research and the Arts, Representation of the State of Hessen to the EU)
9.40 – 10.00 SUN-ERGY Vision (Bert Weckhuysen, SUNERGY coordinator, Utrecht University)
10.00 – 11.00 SUN-ERGY Implementation approach
- Ramp-up phase leading to a large-scale initiative (Gabriele Centi, ERIC)
- Starting point of implementation: key elements of SUNRISE and ENERGY-X roadmaps (Hervé Bercegol, CEA)
- Q&A

11.00 – 11.30 Coffee Break
11.30 – 11.50 Presentation Photo-contest winner (Amedeo Agosti, University of Bologna)
11.50 – 13.00 Short presentations by recently awarded projects in the area followed by a round table discussion (Moderator: Joanna Kargul, Warsaw University):

- CE-NMBP-25-2019: Photocatalytic synthesis, awarded project 'DistributEd Chemicals And fuels production from CO_2 in photoelectrocatalytic Devices' (Siglinda Perathoner, ERIC)
- LC-SC3-RES-29-2019: Converting Sunlight to storable chemical energy, awarded project 'Novel photo-assisted systems for direct Solar-driven redUctioN of CO_2 to energy rich CHEMicals' (Huub de Groot, Leiden University)
- ITN-2019: Awarded project 'Training the next generation of scientists in solar chemicals for a sustainable Europe by hybrid molecule/semiconductor devices' (Pau Farràs, NUI Galway)
- ITN-2016: Awarded project 'Electrochemical Conversion of Renewable Electricity into Fuels and Chemicals' (Petr Krtil, J. Heyrovsky Institute of Physical Chemistry)

- LC-SC3-CC-1-2018: Social Sciences and Humanities (SSH) aspects of the Clean-Energy Transition, awarded project 'COllective action Models for Energy Transition and Social Innovation' (Merce Almuni, VITO-Energyville)

13.00 – 14.00 Lunch

3. Minutes of the meetings

PART 1: Minutes consortium meetings

Dates: 3-4/02/2020

Location: EERA, Brussels

SUNRISE Final Consortium Meeting

Minutes

Session 1: Deliverables

Monday, 3 February 2020

Opening words by Huub de Groot (LU, SUNRISE CSA coordinator)

Huub de Groot/ UL congratulates the consortium for the autonomous attitude in organizing the work and delivering the results. *Huub* informs the consortium about an open session for an amendment to the Grant Agreement, including a two-month-extension to SUNRISE. *Frédéric Chandezon (CEA)* thinks the extension offers some flexibility but should not delay in working on the future initiative SUNERGY. All agree the work should continue as planned, following the original schedule. The due dates of the three deliverables are shifted to 30 April 2020: D2.3 the fully developed innovation and exploitation plan, D4.2 terms of reference, and D5.3 the final report.

One of the key outputs of SUNRISE is the roadmap. A scientific narrative would be needed for the industrial companies to consider investing. During the sessions on Thursday and Friday, we will also look at the investment scenarios that can cover (parts of) the roadmap. Investing in low TRL can only be justified for technologies with a very high market potential, which is the case of the SUNRISE technologies. *Huub* reminds the consortium that at the DG ENER meeting on 24 October 2019, EC officials suggested the consortium to come up with two investment scenarios: a compromise scenario covering priorities of the Roadmap – and a full-scale scenario, covering the entire roadmap.

Announcement Max Fleischer: Siemens Energy has been created under the Siemens holding, Max is now part of this new company. Due to complex and lengthy formalities to change the representation in SUNRISE, it was decided that Max, together with Thomas Soller will continue to work on SUNRISE.

<u>Deliverables WP 1 Strategy and structuring</u>

D1.2 Roadmap (Hervé Bercegol, CEA)

The work on the Roadmap finished last November. Since then, corrections and comments were received from various partners (CEA, Empa, Helmholtz, Leiden University, Siemens Netherlands and Turku University) and the supporters community (among others Climeworks TU Delft, TNO, TU Berlin, Univ. of Paris). The main document was corrected and the appendices were changed/expanded.

The Roadmap includes three approaches with very different maturity levels, which posed challenges in terms of alignment. Some of the Roadmap goals are included in the manifesto. The goals, as presented in the manifesto, are discussed further.

Discussion:

- The goal for **2025** is to make (liquid) fuel from CO_2 and sunlight on a house roof. This goal appears realistic and there is no efficiency target associated to it.
- **2030**: run a mid-sized airport (Copenhagen) and its flights entirely fossil-free. There seem to be on-going discussions in Energy-X between DTU and the Copenhagen airport. **Action point Frédéric/CEA:** ask Energy-X about the status of the discussions.
  Huub/UL: There are similar on-going discussions in The Netherlands, at Schiphol, with TU Delft. The impetus to bring this technology to maturity is very strong, 2025 may be even more realistic. *Joanna Kargul (UW):* There are existing private partnerships in place, *e.g.* airport of Rotterdam aiming at a consumption of 1000 L renewable jet fuel/day by 2021.
- **2050:** use artificial photosynthesis and renewable energy to produce carbon-neutral fuels and chemicals across Europe. *Hervé* shows a calculation for the production of Jet fuels with PV + electrolysis, assuming: CO_2 capture at 9 GJ/t CO_2. At a solar-to-electric efficiency of 15% (conservative figure for today) and electric-to-fuel efficiency of 40%, CO_2 capture eats up 1/5 of the harvested solar energy, giving a final total yield of 5% Solar-to-fuel. The efficiency of CO_2 capture must increase in parallel with the improvement of conversion processes. If electric-to-fuel efficiency reaches 55% in 2030, with PV panels delivering 30% Solar-to-electric, an energy consumption of CO_2 capture decreased to 5 GJ/t CO_2 would keep its energy demand below 1/5 of the total (then the solar-to-fuel efficiency would eventually reach 14%. *Huub/UL* criticizes this methodology, because efficiencies are misleading and photon-to-product yields are the correct approach to avoid beginners' mistakes with ergodicity. Moreover, according to *Huub*, incremental approaches are not sufficiently disruptive for a flagship or similar large-scale initiative. For formic acid, the inappropriate approach leads to assumed (fixed) efficiencies that are 40% solar (PV) to electric and 64% electric-to-product (25% solar-to-product) and 5 GJ/t CO_2 captured. Huub observes that this implies connecting two Carnot cycles, which is what SUNRISE aims to avoid. In the end what makes the difference is the rate at which the conversion takes place. At thermodynamic equilibrium there is no conversion of CO_2 and no concentration energy required. The higher the rate, the more free energy will be needed for the concentration of CO_2. A slower process over a large area (via decentralized devices) thus offers a more favourable balance between energy stored and energy wasted than the current processes with electric concentration to high density, albeit at a higher materials cost. Avoiding two

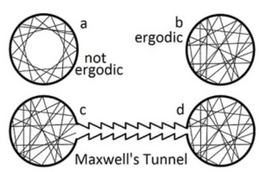

Figure 1. In ergodic systems the time average is the same as the spatial average and energy is required (selfassembly, adsorption, condensation) to localize particles in space. Also it is impossible to catch particles like in a fly catcher, without an energy gradient, and the faster particles are catched (stored), the more free energy is required and the more entropy is produced. Figure from https://en.wikipedia.org/wiki/Ergodic_hypothesis

separate Carnot stages would require a new class of materials that can act as both absorber and catalyst. *Max/Siemens* agrees the currently available way to convert solar to products with PV – electric concentration – Electrolysis – Thermocatalysis is doable albeit very limited in energetic conversion efficiency (due to the need for high CO_2 concentration as well), whereas the new approaches looking at the direct solar-to-product conversion promise more efficient conversion, by circumventing some Carnot limits with nonadiabatic strategies that allow for intermediate steps with near-unity yield at very low energy loss.

Frédéric reminds the consortium that the SUNRISE roadmap was highly praised by the EC officials, as well as by the Energy-X representatives. The future SUNERGY roadmap should follow a similar approach and format.

D1.3 Blueprint (Leif Hammarström, UU)

Leif presents the draft Blueprint document (also on the *Plaza under Library→ Deliverables → D.1.3 Blueprint*).

Action all partners: review the document, especially on the competences listed – and complete if necessary.

Huub: There are also scientific "trends", such as in the case for Electrochemistry. To avoid over- or underrepresentation for a specific competence, we should refer to the European competitive edge and mention the most representative organizations. **Action Stefan/Helmholtz**, to review the list together with Leif and make it open for further inclusion.

Suggestions from partners:

- Refer to EIT InnoEnergy
- Mention ESFRI = European Strategy Forum on Research Infrastructures, (https://www.esfri.eu/).
- ICIQ and ISE-Fraunhofer should also be mentioned, as test centers on solar fuels,
- Investigate if EERA or AMPEA have an overview of all relevant infrastructures for solar fuels **Action Frédéric/CEA and Anita/EERA** to investigate.
- Policy-making and legislative aspects. The challenge is to mobilize the investors and governments (via *e.g.* Green bonds) – **action Huub/UL** to provide text input.

Remark *Max/Siemens*: the document looks rather conservative. We may need to mention the more progressive, emerging competences that are needed for the development of slow, low-concentration processes for C capture, to overcome the thermodynamic limits. *Huub/UL* agrees we need to refer to the competences needed to develop materials that can capture CO_2 from atmosphere and catalyze its conversion directly → **Action Huub/UL** to provide input to Leif (and Ann Magnuson) on far-reaching competences for direct C capture and conversion.

On the same line: some wording is rather soft, such as the evaluation of a possibility to set-up a strategic advisory board. **Action Frédéric/CEA** to strengthen the wording of this paragraph.

Section 5 (currently "Business models") could be renamed "Investment scenarios". According to Huub, the idea of this section is to provide a short narrative for the investors, highlighting the main scientific hurdles, where they are positioned in the roadmap in terms of TRL and timelines, as well as the associated investment needs. To progress on this, we will need the input of **Peter Ellis/JM** and **Philippe Jacques/EMIRI** during the workshops on 6-7/02/20.

Other comments:

- The pictures in section 5 were taken from the Roadmap, but lack a timeline axis, this must be put back. **Action Huub** to provide a text on the innovation pipeline.
- *Hervé/CEA* observes that also in case of bio (algae) conversion, half of the energy is used by the microorganisms, so that must also be accounted for. *Leif/UU*: if the CO_2 concentration is not limiting concentrating CO_2 by microorganism is basically cost-free.[1]

D1.1 Consolidated vision (Nicola Armaroli, CNR)

The vision of SUNRISE has not changed since the beginning of the project. The three targets of SUNRISE are: 1. Solar fuels (H_2, ethanol); 2. Solar chemicals (*e.g.* N-based fertilizers) and 3. Removing and recycling CO_2 from the atmosphere (long-term, 2050).

Nicola expresses concern that the direct conversion is now out of the text of the large-scale IA call. Frédéric mentions an RIA call, open for the entire spectrum of SUNRISE technologies (to be discussed in the WP 4 Governance session).

WP 2: Innovation and Exploitation (I)

D2.1 Innovation process (Arne Roth, Fraunhofer)

Transition to a circular economy is beyond the normal commercial context. Challenges:

- Long (> 10 years) innovation cycles in the chemical industry
- High investments required
- Renewables are generally more costly than fossil-based technologies
- High risks

A SUNRISE Innovation process (SIP) was designed to provide a framework that could maximize the prospects of solar-to-products technologies – in the form of "valleys" (following the model of the Silicon valley) as local nodes to support innovation and foster a business-friendly environment. The innovation team must be part of the governance structure. The Innovation process includes: idea generation, evaluation & selection, experimentation, commercialization, and implementation. The last step is often the most challenging, as it requires the highest investment (*e.g.* to build pilot plants) and lengthy timelines. Next steps:

- Creation of a SIP team
- Selection of topics/content of webinars/forums
- Selection of SUNRISE nodes
- Information flow and IP matters (D2.2. and D2.3)

D2.2 Innovation structure (Arne Roth on behalf of Peter Ellis, JM)

[1] If CO_2 concentration is slow, its costs are low, but it is not cost free, unless ergodicity is broken by e.g. selfassembly, adsorption or condensation, in which case one has to pay for it at a later stage.

The current status: IPR guidelines were drafted, consistent with the practices used in H2020. The benefits of information sharing must be balanced with the needs to generate commercial partnerships.

The deliverable D2.2 is an interim report leading to D2.3, and is currently available in a draft form. A working meeting follows on Wednesday 5/02, with all involved partners, to refine and consolidate the document.

An open innovation structure implies that IP is shared by all members of the consortium. *Huub/UL* proposes a step-wise methodology to share IP with the priority to the consortium members, by allowing private partners to buy IP within a project, where after it is offered to other projects and then to the outside world. According to Peter (JM) this would lead to highly constrained grant agreements, which is, according to industry, probably not worth the trouble. Huub emphasizes that we may nevertheless transfer from an economy of scale IP model with highly protected synergistic patent portfolios to a farming IP model with extensive licensing. To allow for this, IP should be transferred to distributors licenses. Those are not necessarily in the project (RIA or IA) that generated the IP.

Several challenges were identified for the exploitation. The innovation protocols change during product lifecycles, from low to high TRLs. In terms of science-to-business exploitation, no one-size fits all requirements for business, this depends on the market.

Discussion:

Thomas Soller/Siemens suggests to address the product development cycle too. Arne agrees, Thomas will be involved in the workshop planned on Wed 5/02.

Green bonds: not yet addressed in the innovation deliverables (D2.2 mentions de-risking). *Hervé*: even when the technology progresses to high TRL, you need basic science to optimize the devices. Special mechanisms must be created in order to allow for systematic innovation. Arne agrees, but thinks this is already addressed in the document.

IA (Innovation Action) call: Frédéric reminds the partners that the IA call and other calls to be released are still competitive calls, and other consortia can also apply.

Frédéric indicates that SUNERGY has to be an umbrella to share results (also failures, as pointed out by *Hervé*), and provide a good forum to advance the field. Agreements among different projects might be made.

Finally, *Huub* acknowledges the contributions of all attendees and closes the session. Anita gives indications for dinner.

End of day 1.

Tuesday, 4 February 2020

WP 2: Innovation and Exploitation (II)

D2.3 Innovation and exploitation plan (Thomas Soller, Siemens)

Thomas Soller presents the plans for the writing of the deliverable D2.3. Exploitation depends on regulatory and market boundary conditions. There are three main scenarios for market deployment, debated at the 13th Forum Energiewende, 20 January 2020:[2]

- “Modern jazz” Market developing freely and the most efficient solution naturally emerges;

[2] Background document on the Plaza, under Meetings → 2020 → Consortium_3-4Feb20_Bruss.

- "Unfinished symphony" – when policy or legislations guide the market development through economic incentives;
- "Hard rock scenario" – green technologies driven by individual state policies (not preferred).

Siemens was encouraged by the German policy makers to define a scenario for green energy technology development, choosing between the two considered scenarios (the first two above). This approach may also be useful for SUNRISE.

According to these scenarios, global energy emissions are estimated by the World Energy Council to lead to a global temperature increase with *ca* 2,5 °C, unfinished symphony: 2-2,3 °C, whereas the last scenario can lead to a temperature increase of more than 3 °C.

Discussion:

Huub/UL suggests to start from the SUNRISE vision and assess which scenario can lead to a certain percent of circularity. We need to look at the opportunities offered by the European context: cities as support for the deployment of new technologies, availability and willingness to pay for it with the European citizens.

Frédéric/CEA: it seems we favour a small-scale approach for circularity when you consider cities.

Leif/UU: We are living in a globalized world, any exchange at regional levels is in fact global, we cannot neglect exchanges with other regions. Defining local circularity can only be done in a global context.

Huub/UL: we need to decouple economic growth from the use of resources. The DG ENER representatives asked us to propose scenarios for our technology and insisted to refer to the current policy documents, such as the SET Plan. Nevertheless, the views of the World Energy Council are more inclusive and representative, as compared to *e.g.* the International Energy Agency (IEA) that may be considered biased towards the oil industry (*Nicola/CNR* agrees). *Max/Siemens*: indeed, the discussion with the representatives of the World Energy Council was meant to provide us with an open perspective free from individual national interests.

Frédéric/CEA: Since we are compelled to come up with a governance scheme with strong industrial participation, the instruments need to be properly structured: we are doing this in consultation with Energy-X.

Huub/UL: exploration puts a limit on how fast fossil resources can be exploited. We are proposing a paradigm shift, from exploration to manufacturing change, and PV was the first technology to achieve this. Energy transitions are assumed to take 30 years. If we manage to circumvent the thermodynamical limits of the current state of the art practices in CO_2 conversion and find a way to manufacture devices to directly absorb and convert CO_2 to products, we can significantly accelerate the energy transition.

Further, Thomas presents an overview of the IP-related concepts addressed in D2.2 and the need to work them out in D2.3. For example:

- The IP Management Committee (IPMC) may need further detailing.
- Defining IPR building blocks for the SUNRISE consortium may need to refine the ownership strategies for joint results, set-up joint ownership rules according to state-of-the art models such as DESCA, MCARD etc.
- Define the role of the consortium in the alignment of various IP strategies and facilitation of innovation exchange among projects. Should this be part of the Governance?

Discussion:

Max/Siemens: Who will pay for the investment related to maintaining the relevant patents? We can propose a structural instrument, such as a European patent pool or database that can maintain EU patents relevant to the circular economy. This can be funded with EC support for the first period, before generating benefits (via licensing) to self-sustain itself. *Artur Braun/Empa:* This may entail changing IP protection legislation. *Hervé/CEA:* Patent laws should however not hinder the development of green technologies. *Huub/UL*: the research organizations developing the technologies take on the patenting cost for the first stage, and sell the patents to the interested industrial parties. A revolving fund can ensure the mechanism to commercialize the technologies. We may also define procedures to screen the publications for IP by the Partnership, in an open innovation ecosystem. However, this may make small companies reluctant to participate. The complexity of joint ownership situations may slow down the cooperation within the Partnership (remark *Leif/UU*).

Action point: Max/Siemens and Huub/UL to discuss with the EC officials (such as Philippe Schild) possible options to ensure long-term funding for SUNRISE innovations.

Finally, effective exploitation strategies are discussed. The failure to commercialize technology ventures is largely related to a poor understanding of the market. We may need to:

- Define a baseline/metrics for all projects;
- Clarify and visualize the link between technology and product development, including involved stakeholders (from TRL 1 to 9), according to different market scenarios. These scenarios however do not account for disruptive developments.

Joanna/UW proposes to look at very disruptive examples, such as Apple. We can definitely capitalize on the societal need to address climate change and secure a future for the future generation. This need was less prevalent 10 years ago, now the momentum is there, and time can favor a disruptive approach. Comment *Artur/Empa*: but what about the others who have never made it?

Huub/UL: the energy market is very large, and the level of investments there are far beyond our comprehension. Scientific advisory board member Dan Nocera from Harvard suggested that private stakeholders in those sectors we are aiming to provide substitute technologies for will continuously inquire about the market potential of the SUNRISE technologies as their principle due diligence process, to decide if they should step in at low TRL levels in what may convert their existing infrastructure and business models to adopt with disruptive technologies:

- Replacement of fossil fuels;
- Replacement of fossil-based chemicals;
- Manufacturing equipment (refineries etc.).

Huub/UL: Assuming a hypothetical budget of 1 B€ and two major demonstrator targets such as the high TRL airport and the lower TRL roof, also assuming redundancy (several projects working on the same goal), one can define the needs for a number of RIA and IA addressing the targets, aligned across TRLs within the considered budget boundaries. Our challenge is to present a credible plan to achieve it.

Philippe Jacques (EMIRI): It may be interesting to have a discussion with EIT InnoEnergy, which is coaching project teams in order to build their business case, in such a way that details can be worked out later, at the project level.

WP 3: Dissemination, Communication and Education (Laura Lopez, ICIQ)

D3.1 Dissemination Plan

The project has reached a large number of supporters. The SUNRISE community (including newsletter subscribers and social media followers) counts 2.125 members. However, reaching further the general public and the policy makers remains challenging.

The main dissemination and communication tools were deployed with the involvement of the consortium partners.

Communication highlights for the last months include: Lunch meeting at DG ENER (24 October 2019), Public poll for the SUNERGY name, the national stakeholder meetings, participation stand at the SET Plan conference and COP 25, SUNERGY photo contest and SUNERGY kick-off meeting.

D3.2 Website & App

The SUNRISE website is the main online tool for communication, supplemented by social media channels. A test app version was developed by Tobias Gärtner for scientific information exchange. However, this tool may need to be re-purposed.

Next actions, discussion:

Laura mentions that there will be efforts to maintain the communication on SUNRISE, however the extent of that depends on the resources allocated. A new budget must be drafted to cover the follow-up communication and dissemination actions, related to SUNERGY (discussion on-going with Energy-X, Bert Weckhuysen). *Frédéric* indicates that funding may come via a new CSA, however plans are currently unclear.

Web traffic: 1600 average monthly sessions, of 5 pages and 4 minutes/session, on average. Events such as the participation to COP25 led to a significant increase of visits on the website. Visits come primarily from the US, France and Germany. There is also intense activity from the US on twitter. There is an issue with Facebook: first, it requires payment. Also, after a few months of running, the SUNRISE page was labeled as a page with socially-relevant (politically sensitive) content, which subjects it to content reviews and censorship. Based on the current discussions on the dissemination and communication plan, focusing on Instagram for SUNERGY instead of Facebook appears the best option. The SUNERGY Instagram account is already open, as it was used for the photo contest.

D3.3 Resources

Communications resources were developed to support the dissemination efforts: mugs, posters, roll-ups, leaflets, infographics and videos.

D3.4 Data Management Plan

A Data Management Plan was drafted, describing the SUNRISE strategy and practices regarding the open access to scientific publications etc. The project outputs (project reports and publications, dissemination and outreach materials, deliverables) will all be made publicly available on the public repository ZENODO, in line with the Open access dissemination strategy.

Next actions:

- Set main objectives and actions for the Dissemination and Communication plan;
- Update the SUNRISE app with recent publications and make a final survey on its future development among consortium members;
- Upload all output materials to Plaza and ZENODO;

- Facts and figures infographics;
- Digital story: a wrap-up about the full project.

Action Laura to follow-up with the consortium.

WP 4 Governance

Anita Schneider/EERA presented a briefing for the policy-makers, based on the manifesto, to be printed out and distributed to the participants from the EP event on February 5th.

D4.1 Governance Plan (Frédéric Chandezon, CEA)

Frédéric/CEA presents "the path to SUNERGY", the succession of steps and events leading up to the merging of the two CSA initiatives. The present governance structure of the SUNERGY initiative involves a Scientific Executive Board and an Industrial Board (under definition and chaired by Maximilian Fleischer from Siemens), supported by ICIQ, EERA and DTU. There is no Strategic Advisory Board in SUNERGY.

Comments partners:

- *Artur Braun/Empa:* There was a lack of democratic vote and selection for example when assigning members to Boards.
- *Philippe Jacques/EMIRI*: It only makes sense to discuss the organization once funding is guaranteed.

The D4.1 document presents a scenario, a timeline and an organizational structure of a SUNERGY European large-scale research and innovation initiative. Main developments are presented:

- A key document was "Orientations towards the first Strategic Plan for Horizon Europe". In this document, only the old flagships are acknowledged. At page 22, it is stated: *"Preparatory actions supported under the FET Flagships part of Horizon 2020 will also e.g. inform the work on missions, co-funded/co-programmed partnerships and regular calls for proposals"*. The reference to co-funded partnerships may be related to the Clean Energy Transition (CET).
- Five missions were launched for Horizon Europe. While not ignoring them, *Frédéric/CEA* thinks we should not target missions, the way they are supposed to operate is not clear either. Getting involved in the current missions as they are defined can lead to fragmentation. *Huub* mentions there is a large budget associated to missions. *Philippe Jacques/EMIRI* shares *Frédéric's* opinion, it seems missions will likely act as "debating clubs". Nevertheless, should there be a call for new missions, SUNERGY will submit a proposal.
- A joint (SUNRISE & Energy-X) proposition for a Partnership (*FCM: Fossil Free Fuels, Chemicals and Materials for a Circular Economy*) was submitted to the various rounds of consultations on Partnerships, and raised awareness among the national and European stakeholders. Although dismissed for 2020, there is the possibility for a Partnership as of 2024. The three forms of partnerships (co-programmed, co-funded or institutionalized) are presented, with their particular features. Co-programmed and institutionalized partnerships allow public-private partnerships. Institutionalized partnerships receive budget from the European Commission, who commissions the decision-making to the partnership consortium, whereas co-programmed partnerships work with the mandated representatives of the consortium to decide on the priorities for the open calls.

Institutionalized partnerships are not very flexible instruments adapted for established communities and with legally binding agreements. Revising roadmap and objectives and entering new partners is thus quite difficult and requires amendments. According to *Frédéric*, a co-programmed partnership (such as the current contractual Public-Private Partnerships, cPPPs, *e.g.* SPIRE) seems to be the most suitable option for SUNERGY. There are some changes in Horizon Europe with respect to the organization of the cPPPs. Comment *Philippe Jacques*: the co-funded partnerships allow for additional budget from the Member States. *Huub* points out the difficulty of obtaining commitment from Industry and the Member States. SUNRISE has promised a credible path towards getting this commitment. *Frédéric* indicates that it is possible to have both industry and MS in a co-programmed partnership but following information obtained by *Philippe Jacques* from EC contacts, it is not yet clear how at the moment.

The plan proposed by the Governance team:

- Short-term (February – December 2020): coordination and community building; implement the blueprint and prepare the ramp-up phase
- "Ramp-up" phase (2021 – end 2023): roadmapping, monitoring, implement the SUNERGY roadmap
- Long-term (as of 2024): co-programmed public-private partnership

Discussion:

- *Stefan/FZJ* mentions that sources from the German NCP indicate that a second round of partnerships cannot be taken for granted. The willingness to fully reopen the procedure seems to be limited. Therefore, the future proposal needs to be extremely convincing.
- *Artur/Empa* expresses concern that the supporters cannot understand the governance mechanisms They need clear topic areas to work on. To achieve critical mass, *Leif/UU* points out the importance of providing coordinated inputs to the EC (at MS levels, but also with AMPEA, Mission Innovation).
- *Huub/UL* urges the current SUNRISE consortium not to underestimate the importance of producing a high-level output, with funding from the on-going SUNRISE CSA. It is very important to proactively promote topics into the EU-launched calls.
- *Joanna/UW* stresses that the consortium must become active in formulating the calls not only giving feedback to the content of calls. *Frédéric/CEA* suggests organizing writing clubs (also joint with Energy-X) **– action Frédéric**.
- *Philippe Jacques/EMIRI:* The goals for 2030 are supposed to be realized by the industrial community, however the governance structure proposed seems to be driven by the research community. In order to obtain commitment from the EC, the governance structure should allow for industrial participation.

A <u>governance structure is proposed for the "ramp-up" phase of SUNERGY</u>, aligning coordination via CSA, ERA-NET and implementation (RIA, IA, including a large IA project).

- *Huub/UL*: An ERA-NET may be a step backwards, as it leads to fragmentation. *Laura* shares this opinion. The idea about incorporating running projects in the emerging SUNERGY initiative (as per suggestion *Laurent Baraton/ Engie*) prompts Huub with the idea of a scheme evaluating the outputs of running EU-funded projects (on a voluntary basis), as a way of claiming authority in the field with a self-invented Quality and Impact Assurance structure. EU can demand the newly-funded projects to enter a cooperation agreement, as is done already with *e.g.* Batteries.

- *Frédéric/CEA:* Although some things seemed to have been decided before we had the chance to act (such as the first round of partnerships), the EC is in the process of shaping Horizon Europe, so opportunities may arise even before 2024. *Philippe Jacques/EMIRI:* there are discussions on the Batteries partnership (decided two years ago), already for more than one year, to define the priorities.
- *Leif/UU*: We should then align the targets for SUNERGY so that they are in line with the start of Partnership of 2024, for example amend the dates in the Manifesto to "start+1 year", +5 years, +10 years.
- *Hervé/CEA*: Apart from the dichotomy between the compromise scenario and the "all-in/all-out" scenario, there may also be an opportunistic/realistic scenario. Although the compromise scenario is largely based on the plans for the second round of partnerships, there may be new opportunities offered by the Green Deal, targeting 2030, which is unlikely to be postponed.
- *Nicola/CNR*: We were not successful so far with the Partnerships and Missions. Perhaps we are missing a more direct path towards securing a large-scale initiative. *Stefan/FZJ:* The Flagships stemmed from DG Connect because this is how it has been developed at the EC level, diverting budgets originally devoted for IT-related topics to energy and other topics.
- *Huub/UL:* the EC operates via the member states, there is no decision made in Brussels. To succeed, we must make our plan and using the instruments available at EU level.
- *Hervé/CEA*: asks what are the right actions to take to engage with politicians? *Huub/UL*: come up with a full-throttle scenario that makes sense and present to politicians. We should also have a compromise scenario, and make clear why the better plan is the preferred one. *Frédéric/CEA*: we must also align our goals with Energy-X, to be one voice towards the European decision-makers.

A follow-up CSA "Breakthrough zero-emissions energy generation for full decarbonization" was proposed in the FET programme on Dec. 19/Jan. 20, coupled to a RIA topic.

According to *Frédéric/CEA*, the CSA was dropped by the EC, where the final answer from DG Connect was that they cannot support the CSA initiative, motivating that one CSA cannot receive special treatment over the others selected at the same call for new FET Flagships. Nevertheless, the RIA plan is still valid, for low-TRL technologies (budget for three projects, at 4-4,5 Meuro/project). The call will be published in March, and close on June 23rd, most likely single-stage. *Huub/UL* advises to organize joint consortia with Energy-X.

Action point Frédéric/CEA and Laura/ICIQ: circulate information about the coming RIA call among the supporters community.

Another CSA topic was discussed by Energy-X with DG RTD, "Creation of an innovation community for solar fuels and chemicals". Status to be checked with Gabriele Centi (Energy-X), **Action point Frédéric/CEA**.

Discussion:

- *Max/Siemens* suggests to label upcoming initiatives "SUNERGY", this may increase visibility and increase chances of success (assuming excellent proposals are submitted).
- *Philippe Jacques/EMIRI* informs the consortium that 1 Billion euro will be allocated to 8-12 calls (IA) under H2020, closing June.[3] This is the case for the IA call under discussion with Energy-X.
- An action point **Frédéric/CEA** is to investigate other opportunities from the Green Deal.

Innovation Action call for a Large-scale initiative:

The tentative call deadline is on August 2020, TRL 4-7. The topic needs final approval from Member States via NMBP/Strategic Programme Committee.

- *Max/Siemens*: these calls are targeting device demonstration at several tons/year. Very interesting for Siemens, Shell, Total. Nevertheless, the funding effort is very significant (10-30 Meuro per proposal).
- *Huub/UL*: an IA call is appropriate for current technologies, mainly those coming out of Energy-X. The direct conversion technologies would benefit from a series of RIA calls. On direct conversion, the algae conversion would be suitable for upscaling.

There was a request from Energy-X to assign a member from SUNRISE to the writing team for this IA call. The name of Vincent *Artero/CEA* was proposed. Leif Hammarström and Ann Magnuson/UU were considered, they declined. **All agree that Vincent Artero (CEA) should be included in this team**.

Stefan/FZJ: perhaps we can consider platform-like calls with smaller-scale projects on lower TRL technologies, addressing topics aligned with the core IA topics and giving the opportunity to utilize the large scale infrastructure built by the IA-demonstrator (*e.g.* testing a bench-top pilot at the demo-site).

Nicola/CNR: As per info from Gabriele Centi, there will be a single IA call, large (100 Million euro) and it is considered that some of this budget is dedicated to low-TRL research. Nevertheless, there will not be multiple calls. The call is indeed oriented towards large industrial demonstrators.

Next Governance event: meeting on SUNERGY Governance, on 19 February, from 10.30-16.00, at DECHEMA (Governance leader in Energy-X) - in Frankfurt. The participation of representative Energy-X members is again uncertain, this remains a challenge.

D4.2 Terms of Reference (Max Fleischer, Siemens)

<u>Why does the industry need an orchestrated R&D initiative?</u>

There is an overall agreement that the Energy System is going to change. Cooperation will emerge form traditionally separated sectors, towards a cyclic energy and carbon system. Opportunities:

- Unprecedented markets for industries (already showed for PV and wind)
- Industry needs an orchestrated link with academia

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[3] This refers to the special Green Deal call. According to the latest information (February 2020) the due date will be shifted to early 2021, but the call will still be part of the H2020 framework.

- The European industry should lead on the manufacturing of the components and assembly of the systems.

Max shows a comparison to the US initiative JCAP, funded by the Department of Energy. The focus of JCAP is the direct conversion. JCAP is organized with a governance board (nine persons with management functions, from the participating institutions), a scientific advisory board (seven persons from non-contributing academic institutions + one industrial partner) and a strategic advisory board (eight persons from renowned institutions, not necessarily scientists). Max joined the strategic advisory board, which only gives advice to the scientific board. The structure of JCAP provided inspiration in the set-up of the Industrial Board of SUNERGY.

General tasks of the Industrial Board:

- Align the R&D programme with the industrial/economic needs on short- and long-term;
- Give credibility to the SUNERGY initiative, and mobilize industrial participation;
- Generate proposals for implementation.

The industrial board will work on market needs and forecasts, in order to steer scientific developments. It will also provide inputs on pricing for synthetic molecules, expected quantities and economic needs (CAPEX, OPEX, efficiencies). It will also work with the investors on making the output of the research bankable. Also proposed: reviewing the content of the proposed research projects, from the market perspective (time to market and acceptance). *Frédéric/CEA* thinks such a review function should rather take place upstream, at call level.

The composition of the Industrial Board (chaired by Max Fleischer, Chief expert energy at **Siemens Energy**) is also presented. The following are considered as members (the confirmed ones in bold letters): Covestro, VICAT, **Haldor Topsee** (from the Energy-X network), **Engie**, **CO_2 Value**, EMIRI (from SUNRISE). Other propositions: petrochemical company (Total, Shell, Repsol). **DECHEMA**, SMEs such as Ineratec, Avantium or Photanol.

- Proposed by partners (*Joanna/UW* and *Yagut*/*Turku*): Nestle.
- Proposed by *Philippe Jacques*/*EMIRI*: identify and involve companies from Eastern European countries.
- Other propositions: Austrian oil company OMV, ArcelorMittal.

Action partners: propose companies and send contacts to Max.

End of the meeting

PART 2: Minutes Blueprint meetings

SUNRISE Blueprint Meetings

Minutes

Sessions:	Feb. 6 - 15:00 – 18:00:	“Full Scenario”
	Feb. 7 - 9:30 – 12:30:	“Compromise Scenario”

Participants:

Huub de Groot (UL, chair) (both days)
Harald Kerp (M2i, minutes) (both days)
Vincent Artero (CEA) (Feb. 6, first hour)
Frédéric Chandezon (CEA) (both days)
Hervé Bercegol (CEA) (both days)
Max Fleischer (Siemens) (both days)
Hélène Lepaumier (Engie) (both days)
Peter Ellis (Johnson Matthey) (Feb. 6, first hour)
Artur Braun (EMPA) (Feb. 6 + Feb. 7, first hour)
Joanna Kargul (UW) (both days)
Matthias Meier (FZ) (both days)
Stefan Baumann (FZ) (both days)
Laura Lopez (ICIQ) (Feb. 7)
Julio Lloret (ICIQ) (both days)
Fernando Fresno (IMDEA) (both days)
Henrik Koch (NTNU) (both days)
Nicola Armaroli (CNR) (both days)
Yagut Allahverdiyeva-Rinne (UTU) (both days)
Arne Roth (Fraunh) (both days)
Walter Leitner (Max Planck) (Feb. 7)
Alexis Bazzanella (DECHEMA) (Feb. 7)

Introduction and background - Huub de Groot (LU, SUNRISE CSA coordinator)

Some background is provided on the exercise that is needed to complete the SUNRISE Blueprint document, deliverable 1.3, with investment scenarios. The idea of this section is to provide a short narrative for the private investors, highlighting the main scientific hurdles and technological challenges, where they are positioned in the roadmap in terms of TRL and timelines, as well as the associated investment needs, both public and private. To progress on this, we will need the input of Siemens, Johnson Matthey, Engie, EMIRI, and possibly from selected Energy-X partners who were also invited for the workshop.

The D 1.3 draft document contains a table with an overview of the SUNRISE technologies and TRL goals for 2030, that can be used to collect input on the investment needs and that can serve as a starting point for the session of today. We basically need estimate ranges for both public and private investments needed to push SUNRISE technologies to the targeted TRL levels. The table also includes a preliminary list of companies associated with the different technologies copied from the Technical Appendices of the Roadmap.

Huub proposes the following work flow:

1. For each SUNRISE technology, the number of IA and RIA proposals are estimated needed to reach the targeted TRL goals.

2. Three types of calls will be considered, taking into account the following tentative budgets:
   - Large IA call: 100 M€
   - IA demonstrator: 10 M€
   - RIA call: 5 M€
3. For each call the percentage of private and public contributions are estimated, leading to total financial ranges for private and public contributions.
4. Additional costs, such as external infrastructural costs and overall management costs, as well as additional funding resources, e.g. the European innovation fund coming from the carbon tax 2020-2030, are also taken into account.
5. Industry indicates the prioritizing criteria, e.g. by outlining the most promising (clusters of) technologies that can be brought to the market by 2030.

The result is a “full scenario” needed to realize the full SUNRISE Vision and “compromise scenario” to realize prioritized parts of the SUNRISE roadmap.

During the sessions, the blueprint D 1.3 draft text was used as a living document in which the earlier mentioned table was continuously updated while important comments were added into the text for elaboration afterwards. Apart from the various comments added to this document a selection of additional remarks, taken from the discussions, are listed below.

February 6 – “Full scenario” session – additional comments:

- Table 1a-1b: Max (Siemens) comments that 4000t of hydrogen supply (for an airport) is a huge quantity given the low mass density. Huub (UL) replies that according to Gabriele Centi, the current focus for the prospective IA is on methanol. Max indicates that first RIA’s are needed for the feasibility, as part of, or followed by an IA.
- Table 1c: ExxonMobil appears to be pushing these ‘green convertors’. Advice is to start again with RIA’s for feasibility, followed by an IA.
- General comment/question by Huub: Shouldn’t we have multiple IA’s in parallel to have various technology options to choose from? The problem arises that probably there aren’t enough EU companies for separate IA’s. Max replies that within the IA’s there should be room for multiple technologies in parallel. Huub agrees that risk mitigation should be within the IA’s. In addition, having parallel tracks provides optimal cross-fertilization for maximum synergy benefits, and delivers de facto an open innovation environment with respect to founding and transferring IP.

  Max provides an example that in a power-to-ethanol demonstrator plant it is possible to exchange different electrolyzers. In addition, one should aim for ‘distributed demos’, *e.g.* plants distributed over countries with low/high solar irradiation intensity.

- Table 4a: The question is asked if new fuel components will encounter issues with regards to the certification of jet fuels, that are very strict? Arne Roth (Fraunhofer) replies that there are standard specs in place for synthetic jet fuel components. The certification process takes many years and costs a couple of M€.
- Table 4b: A couple of demos are already out in the field. However, since these are relatively small-scale, we will aim for "upscaler demo plants".
- General comment by Huub: In this exercise we develop a "call scheme" over the course of 10 years. We will not add a detailed timeline, we will just show the number of calls needed to reach the SUNRISE goals and identify critical paths to demonstrate the value chain source to final product as the single prioritizing criterion in three priority research directions as indicated below.
- After submitting our blueprint as part of a comprehensive design and description (a.k.a. business plan) the process will be 'out of our hands'. Next steps will be that DG Connect will review the outcome and engage in rounds of consultations with EU member states.
- Regarding CO_2, Hervé notes that negative emissions technologies are not detailed in the roadmap. Their importance is stated, technical possibilities are discussed, mainly related to construction materials, but we lacked expert views to back-up a technological timeline. However this theme is high on the agenda of CO_2 value Europe.

  Max states that CO_2 taxes will have an effect on fossil fuel prices.
- Central management of the projects will need to be steered by a CSA: Assuming a total project portfolio of 1 B€, 1% (10 M€) is assumed to be sufficient to run the CSA (1 M€/year).
- For regional SUNRISE valleys, it is proposed that they could line up with hydrogen valleys. Pillar 3 in Horizon Europe, "Innovative Europe", could be sourced for the demonstrators when they end successfully. This will be equity financed, *i.e.* not in our budget. In this case, central management will move out as they will operate on their own, central management will only monitor.
- Arne (Fraunhofer) states that an independent group of experts might be needed that accompany, support and connect individual projects with respect to their techno-economic (TEA) and environmental (LCA) assessments. These studies are usually very different and consequently not consistent/comparable. There should be an independent group making sure that methods pursued in TEA/LCA are to a certain extent consistent. Huub refers to our mid-term review and QIA processes, which however do not fully cover the effort proposed here.
- The session is closed with the remark that the full list of calls discussed today corresponds to the "full scenario" for a large-scale research initiative under HE, *i.e.* equivalent to a "full Flagship" under H2020.

February 7 – "Compromise scenario" session – additional comments:

- The session starts with the observation that under HE “private investments” not only contain corporate investments but also investments made by financial institutions in the various member states, like BlackRock.
- Walter Leitner (Max Planck) states that we need to make a distinction between ‘small demonstrators’ (*i.e.* working devices in operating conditions) and ‘full demonstrators’ (*i.e.* large pilot plants), the latter being far more important for companies.
- Laura Lopez (ICIQ) comments that in IA calls companies costs are not fully reimbursed (only up to 70%) which means that actual corporate costs are higher. This has to be taken into account when making the split between private and public investments.
- Leitner comments on CO_2 capture: This is already being done at large scale. We should team up with ongoing efforts and focus on *e.g.* capture + integrated conversion, as proposed in the roadmap.
- Overall the discussion focused on the structuring of the IA / RIA / demonstrator calls, how the technology pipelines feed into the pilot scale demonstrators that are foreseen, and the prioritization of technologies as demanded by industry (see D 1.3 document).
- Since a significant part of the work is focusing on high TRL, we expect to get access to another billion in pillar 3. Hélène Lepaumier (Engie) remarks that we should try to access in addition to the innovation fund related to public money coming from the ETS and carbon tax 2020-2030. However, it must be noted that SUNRISE / SUNERGY will only control specific technology developments, such as PEC, and the rest we feed into.

As an end note: As mentioned before the overall plans are being elaborated in a structured way in the draft blueprint document (D 1.3) on the SUNRISE Plaza. The current version of the table and tentative textual notes as drafted during the work sessions are given at the following pages.

SUNRISE technology	Current TRL	TRL target 2030	Companies involved	Private investments (estimate)	Public investments (estimate)	Comments
1. Sustainable hydrogen production						
1a. PV-driven electrolysis of water	4-6	9	Siemens (DE) Nel (N) ITM (UK) Hydrogenics (US, BE) Areva H2Gen (F) Air Liquide (F)	40% C FI p.m.	30% EU 30% MS	IA Demo 2
1b. Photoelectrochemical devices	2-4	5-8	Engie (F) Siemens (DE) SABIC (NL)	20% IA	100% RIA (MS) 80%IA (MS) 100% DD	RIA IA Distributed demo
Transparent baggie systems (microorganisms and photocatalytic systems)	3-4	6-8		40% IA	100% RIA+D 60% IA	RIA lab demo (g/ng)IA
2. Sustainable ammonia production						
2a. Low-emission Haber-Bosch	5-6	9	Yara (N) Casale (CH) Thyssenkrupp (DE) Haldor Topsøes (DK) Siemens (DE)	40%	30% EU 30% MS	IA demo
2b. Electrochemical and plasma-assisted ammonia synthesis	1-2	4-5	n.a.		100% RIA (MS) 100% DP (MS)	2 RIA 1 Demo project
2c. Photoelectrochemical devices	1-2	4-5	n.a.		100% RIA (MS) 100% DP	2 RIA 1 Demoproject
Microorganisms for direct fertilizer production	1-2	4-6			100% RIA (MS) 100% DP	2 RIA 1 Demoproject
3. Sustainable carbon capture						
3a. CO_2 capture from concentrated sources (concentrate on local value creation) co-adaptation of capture and catalytic conversion into long term storage of Carbon/CO_2, targeting Negative Emissions	6-7	9	ENGIE (F) (orchestrate) Gas for Climate consortium[4] Fluor (VS) Mitsubishi (J) Siemens (DE) Aker solutions (N) Shell (NL) Solvay (BE) MTR (US) RWE (DE) BASF (DE) LINDE Engineering (IRL-DE-US) LafargeHolcim (F, CH)	30% IA cluster Pipeline will feed into larger DEMOs	70% cluster	IA Demo upscaling link to 4.1 and 4.2 TEAM up with Separate Big 300 ME demo in pillar 3
3b. Direct CO_2 Capture from the atmosphere	6	8-9	Climeworks (CH) Antecy (NL) Global Thermostat (US) Carbon Engineering (Canada) Ineratec (DE)	30% IA cluster Pipeline will feed into ongoing large demo	70% IA cluster	IA including RIA and Demo (Don't forget low exergy energy) link to 4.1 and 4.2 Don't forget negative emission (1MW scale)
Direct Atmospheric CO_2 Capture & Conversion including PEC	1-2	5-7		40% IA	100% (MS) 30% IA 30% MS IA	10 RIA 3 Demoproject g/ng IA

[4] https://gasforclimate2050.eu/gas-for-climate

						(don't forget low exergy energy)
4. Sustainable production of commodity chemicals and (jet) fuels						
4a-1. Electrochemical water splitting and thermocatalytic conversion of CO_2	6	9	Airline Global Alliance Powerfuels Aireg (DE) Sunfire (DE) Ineratec (DE) Velocys (US) BASF (DE) Casale (CH) Total (F) Synhelion (CH) Toyota (J, BE) Abengoa (ES) Brightsource (Isr) Helpe (Gr)	30%	70%	2 IA clusters FT and methanol) feeding into Demo plant
4a-2. Direct electroreduction of CO_2	3	6			100% (MS)	4-5 RIA feeding into 2 demo
4b. Direct solar-thermochemical conversion of water and CO_2	4-5	6		40% IA	100% (MS) RIA 30% EU IA 30% MS IA	RIA demo g/ng IA upscaler demo plant
4c. Biocatalytic production of carbon-based solar fuels and chemicals	1-6	4-9	Photanol (NL) Ecoduna (AU) Synthetic Genomics (US) Euglena (J) Total (F) Neste (FI)	40% IA	100% RIA (MS) 100% RIA (MS) 30% EU (IA) 30% MS(IA)	8 RIA and 3 demo and 1 small IA Demo plant 100 kt/yr

The demonstrators should all contribute to the decoupling of economic growth from utilization of resources.
All the high efficiency effort should aim for low investment cost and halving the product price compared to fossil resources

IA calls will need very strict programming criteria, RIA are open calls

Another billion in pillar 3, and in addition from the innovation fund (public money coming from the carbon tax 2020-2030), for the highest TRL:
Several pipelines feed into pilot scale production of Jet fuel, 300-500 million revolving fund with airlines
Several pipelines feed into pilot scale production for CO_2 capture from concentrated sources, and CO_2 from the atmospheric capture

Why is this good for Europe/the best for Europe

- Decarbonization of the energy sector paves the way for the other sectors (the supply side argument)
- Why us: we are broad, application oriented, try to develop technology, and we have vertical integration, science - technology - industry over the entire knowledge chain
- Many national projects, now it is time to go European and broaden from photovoltaics (and wind)
- If we don't follow this pathway for defossilization we will lose the primary industry in Europe in what is by far the biggest market
- Priority: demonstrate the value chain source to final product (prioritizing criterion)
- By providing a new paradigm we create room for interpretation for other scientific disciplines and for socio-economic stakeholders

Priority: demonstrate the value chain source to final product (prioritizing criterion)

- Combine water electrolysis with CO_2 capture, this gives the fully integrated value chain.
- Does integration of steps gives better processes (efficiency selectivity/purity, concentration) over the value chain (PV+electrolysis vs PEC vs molecular vs biological)?
- How do we get all the hydrogen to decarbonize - existing - value chains (parliament)

Define groups (Frédéric, with mutual triggering)

Call on house roof (decentralized)
Call on centralized

The tentative budgets for the hree types of calls considered are:

- Large IA call: 100 M€
- IA demonstrator: 10 M€
- RIA call: 5 M€

Management: central management/governance/programming/monitoring takes 1% -> CSA

Sunrise valleys: makers join hydrogen valleys, Pillar 3 for the demonstrators when they end successfully. This will be equity financed, not in the budget, central management will move out, they will operate on their own, central management will monitor

Infrastructures: Research infrastructure costs can be charged to projects.

Specification and testing: Bids are called for from centers that will be qualified to do this. Budget: 1M€/yr , 10 M€ total for 1-3 centers associated with PV centers or hydrogen valleys depending on the costs.

Quantitative sustainability analysis is mandatory for every project with go/nogo decisions from the QIA team and program board

Dissemination is in every project, in addition there is global dissemination at the partnership level with the management

Education is part of the central CSA.

Annexes

1. **Invitation for the SUN-ERGY policy lunch event**
2. **Invitation for the SUNERGY public kick-off event**
3. **Press release SUNERGY Kick-off**
4. **Briefing for politicians**

Annex 1: Invitation for the SUN-ERGY policy lunch event

ENERGY-X
Sunrise

SUN-ERGY KICK-OFF EVENT. FOSSIL-FREE FUELS AND CHEMICALS FOR A CLIMATE-NEUTRAL EUROPE

5 February 2020 | European Parliament, Brussels
13.00 – 14.30

Dear

You are invited to contribute in person to a high-level lunch discussion on how large-scale, integrated R&I initiatives in the area of fossil-free fuels and chemicals can contribute to meeting the targets of the Paris Agreement and the ambitions of the European Green Deal.

The event will be held at the European Parliament on 5 February 2020, from 13.00 to 14.30 and will be hosted by Mr. Morten Helveg Petersen, MEP (Denmark). The debate is organized at the initiative of the two European flagship initiatives on energy, SUNRISE and ENERGY-X, which propose clear technological pathways to decarbonize the European industry and society over the next 30 years. SUNRISE and ENERGY-X started under Horizon2020 and have joined forces to prepare a large-scale research and innovation initiative in Horizon Europe, that will complement the scope of existing European partnerships and enable the full decoupling of economic growth from the utilization of resources. Whereas current public-private partnerships all focus on improvements downstream, with limited impact, SUN-ERGY proposes high impact technologies that address the initial stages of the light-to-products and fuel conversion from atmospheric CO2 at high yield.

The aim of the event is to facilitate the debate between high-level stakeholders on the **focus and timing of the future large-scale initiative in the field of fossil-free fuels and chemicals**. The discussion comes at a time when greater attention to climate and energy issues and ongoing developments at European level (including on Horizon Europe and the Clean Planet for All strategy) offer the right framework for action and a great opportunity to join efforts towards reversing climate change.

We would be very honoured to have you as a speaker, considering your key involvement the European Green Deal. The event is by invitation only, with high-level speakers like yourself, from the European Parliament, European Commission, and the European flagship consortia SUNRISE and ENERGY-X.

We sincerely hope that you will accept our invitation. We will follow-up with your office in the coming days – in the meantime, we remain at your disposal for additional information.

Yours sincerely,

Prof. Jens Nørskov, Technical University of Denmark
Coordinator of ENERGY-X

Prof. Huub de Groot, Leiden University
Coordinator of SUNRISE

Prof. Bert Weckhuysen, Utrecht University
Coordinator of SUN-ERGY

Dr. Frédéric Chandezon, CEA Deputy
Coordinator of SUN-ERGY

SUNRISE (https://sunriseaction.com) and **ENERGY-X** (www.energy-x.eu) are two ongoing Horizon 2020 projects (FET Flagship CSA, research area Energy, Environment and Climate Change) selected to prepare a large-scale initiative in the field of fossil-free fuels and chemicals over the course of one year (March 2019 - February 2020). The two projects **will pursue their roadmap actions until February 2020, when they will merge into the SUN-ERGY initiative.**

Annex 2: Invitation for the SUN-ERGY public kick-off event

Sunrise

ENERGY X

Update #1
January 21, 2020

SUN-ERGY Kick-off event

February 5, 2020 | Brussels (TownHall, Square de Meeus)
16.00 – 18.00, followed by a reception
February 6, 2020 | Brussels (The Representation of the State of Hessen to the EU, 21 Rue Montoyer)
9.00 – 13.00

Dear Friend,

We would like to invite you to the **kick-off of SUN-ERGY**, a large-scale, integrated R&I initiative in the area of fossil-free fuels and chemicals. SUN-ERGY stems from two European flagship initiatives on Energy, **SUNRISE** and **ENERGY-X**, which will end in February 2020. They have joined forces to launch SUN-ERGY, a large-scale research initiative in Horizon Europe, that will complement the scope of existing European partnerships and enable the full decoupling of economic growth from the utilization of fossil resources.

During this event, the CSAs SUNRISE and ENERGY-X will present their achievements, and propose their joint vision on decarbonizing the European industry and society over the next 30 years. This initiative comes at a time when greater attention to climate and energy issues and ongoing developments at European level (including on *Horizon Europe* and the *Clean Planet for All* strategy) offer the right framework for action and a great opportunity to join efforts towards reversing climate change.

The kick-off event is organized in two sessions: an afternoon session on 5 February 2020, from 16.00 to 18.00, followed by a reception, and a morning session on 6 February 2020, from 9.00 to 13.00.

You are kindly asked to **confirm your attendance before January 28th and register at this link**. An early registration is very much appreciated, in the view of event logistics.

Yours sincerely,

Prof. Jens Nørskov, Technical University of Denmark
Coordinator of ENERGY-X

Prof. Bert Weckhuysen, Utrecht University
SUN-ERGY coordinator

Prof. Huub de Groot, Leiden University
Coordinator of SUNRISE

Dr. Frédéric Chandezon, CEA
SUN-ERGY deputy coordinator

With the friendly support of the Representation of the State of Hessen to the EU

SUNRISE and **ENERGY-X** are two ongoing Horizon 2020 CSAs (*Call FETFLAG-01-2018, research area Energy, Environment and Climate Change)* selected to prepare a large-scale initiative in the field of fossil-free fuels and chemicals *over the course of one year (March 2019 - February 2020). The two projects* **will pursue their roadmap actions until February 2020, when they will merge into the SUN-ERGY initiative.**

If you need further information send us an email to
contact@sunriseaction.eu & **contact@energy-x.eu**

www.sunriseaction.eu & **www.energy-x.eu** are shaped by

SUNRISE Grant agreement No. 816336

ENERGY-X Grant agreement No. 820444

Annex 3: Press release SUNERGY Kick-off

Kick-off of the SUNERGY initiative

Over 100 stakeholders of the Coordination and Support Actions (CSAs) SUNRISE and ENERGY-X gathered on February 5-6, 2020 in Brussels for the kick-off meeting of SUNERGY, a large-scale research and innovation (R&I) initiative in the area of fossil-free fuels and chemicals. Renewable energy experts from academia, industry and policy addressed the current opportunities and challenges towards decarbonizing the European industry and society over the next 30 years.

The launch event was organized in two sessions: a high-level lunch discussion at the European Parliament (EP) on February 5, and a public two-day conference. The TownHall Europe hosted the afternoon session on February 5, while the morning session on February 6 was hosted by the Representation of the State of Hessen to the EU.

Large-scale R&I initiatives to decarbonize Europe

MEP Morten Helveg Petersen hosted the high-level lunch discussion at the EP. Representatives from both initiatives debated on how large-scale R&I initiatives in the area of fossil-free fuels and chemicals can contribute to meeting the targets of the Paris Agreement. Keynote speakers were Cristian Silviu Bușoi (ITRE Committee Chair), Hélène Chraye (Directorate Clean Planet of Directorate General Research & Innovation), Mark van Stiphout (Directorate General Energy), Bert Weckhuysen (SUNERGY coordinator), and Maximillian Fleischer (Siemens).

SUNERGY coordinator Bert Weckhuysen: The SUNERGY initiative comes at a time when greater attention to climate and energy issues and on-going developments at European level offer the right framework for action and a great opportunity to join efforts towards reversing climate change.

A common vision to close the carbon and nitrogen cycles

During the public kick-off meeting, the CSAs SUNRISE and ENERGY-X presented their achievements throughout the past year, and proposed their joint vision on providing sustainable and competitive alternatives to fossil fuels by 2050. Keynote speakers like Peter Dröll (Director Prosperity, Directorate General Research & Innovation) highlighted the strong support of the European institutions towards R&I to achieve the ambitions of the European Green Deal.

SUNERGY deputy coordinator Frédéric Chandezon: This kick-off meeting has served as a key step towards unifying the SUNRISE and ENERGY-X research communities and defining directions for large-scale initiatives within the new European R&I framework Horizon Europe.

Background

SUNRISE and ENERGY-X are two out of the six CSA projects that were selected for the Horizon 2020 call "FETFLAG-01-2018" within the research area of Energy, Environment and Climate Change. Both initiatives received €1 million from the European Commission to develop a detailed proposal for a large-scale research initiative during one year, from March 2019 to February 2020.

Both SUNRISE and ENERGY-X aim to develop sustainable approaches for the storage of renewable energy (solar and wind) through its conversion to fuels and commodity chemicals using abundant molecules such as carbon dioxide, water and nitrogen. The two projects bring together 30 committed organisations, backed by an initial supporting community of approx. 300 stakeholders from academia, industry, and society.

Media contacts:

SUNRISE Communication Team
contact@sunriseaction.eu
www.sunriseaction.eu

ENERGY-X Communication Team
contact@energy-x.eu
www.energy-x.eu

Annex 4: Briefing for politicians (next pages)

renewable fuel
and chemicals from
the air we breathe

SUN
ERGY

WE WILL TRANSFORM

RAW MATERIALS THAT ARE ABUNDANTLY AVAILABLE IN THE ATMOSPHERE

(water, carbon dioxide, nitrogen) into green fuels and chemicals. The process takes its energy directly from renewable sources, avoiding the drawbacks of current biofuels. It will increase the yield per hectare by at least ten times compared to biofuels, at half the price of fossil fuel.

THIS TECHNOLOGY

USES RENEWABLE ENERGY TO REPLACE FOSSIL RESOURCES,

eliminates net CO_2 emissions, closes the carbon and nitrogen cycles locally and regionally, and feeds carbon into long-lasting materials.

THE GLOBAL ECOLOGICAL TRANSITION

THAT WE ENVISAGE WILL TAKE AT LEAST 30 YEARS.

But 10 years will be enough to kickstart key technologies, and to turn the most advanced existing technologies into attractive commercial activities.

vision

2025

make fuel from CO_2 and sunlight on a house roof

2030

run an airport and its flights, entirely fossil-free

2050

use artificial photosynthesis and renewable energy to produce carbon-neutral fuels and chemicals across Europe

who we are

SUNERGY

Is a large community of scientists, engineers, world-leading multinational companies, innovative small and medium-sized enterprises, national and regional governments, civil society organisations and local authorities.

To date, more than

300

companies and organisations have signed up to our initiative.

Our supporters come from

25

countries across Europe and beyond, including the United States, Africa and Australia.

SUNERGY

unites and builds on two initiatives funded under

horizon 2020

SUNRISE and **ENERGY-X**. They were selected by the European Commission to prepare for FET Flagship status, a billion-euro programme which identifies "visionary, science-driven, large-scale research initiatives addressing grand scientific and technological challenges".

our approach

SUNERGY

Is a game-changing, large-scale initiative to turn CO_2 and other atmospheric gases into fuels, fertilisers, plastics, pharmaceuticals and building materials with minimal land use.
The process uses energy from renewable sources and can take advantage of existing infrastructure.

Existing European partnerships focus on reducing the carbon footprint of 'downstream' activities, where products are produced and distributed.
By contrast, SUNERGY's pipeline of high-impact technologies will transform the supply side, harnessing renewable energy to convert CO_2 and other gases to fuels and chemicals at high efficiency.

This is a bold and ambitious response to the huge challenge of climate change. But we know that our linear economic model is unsustainable. So just fixing the existing system on the demand side is not enough.

By closing the loop from a linear to a circular economy, Europe can decouple economic growth from resource consumption by 2050 - and become independent of fossil fuel imports which currently cost us hundreds of billions of euros every year.

1. SUNERGY will power the European Green Deal

By 2050, we will create carbon-neutral fuels and chemicals using abundant natural resources, decoupling Europe's reliance on rapidly-depleting fossil fuels.

Beyond that, they address three further priorities of the von der Leyen Commission:

2. SUNERGY will help build an economy that works for people

By 2050, we will produce sustainable fuels and chemicals that are affordable for everyone, creating millions of jobs and saving hundreds of billions of euros on imports of oil and natural gas.

3. SUNERGY will support the European way of life

By 2050, we will power an uncompromising high-energy-intensity society, where economic growth and prosperity are decoupled from the consumption of finite natural resources.

4. SUNERGY will promote a stronger Europe in the world

By 2050, we will decrease Europe's dependency on oil and gas imports with new global leadership in an arena of high-impact, game-changing technology.

milestones

2025

make fuel from CO_2 and sunlight on a house roof

Plants use sunlight to convert ambient CO_2 into carbohydrates. By 2025, we will mimic this process in the laboratory at high efficiency, aiming for a much greater sunlight-to-CO_2 yield.
This technology will allow European citizens to manufacture high-purity fuels and chemicals on demand, to any desired concentration, at an affordable cost, on their own house roof, farm or private garden.

2030

run an airport and its flights, entirely fossil-free

Around 30 million passengers travel through a mid-sized airport like Copenhagen each year, burning some 2 billion litres of aviation fuel. By 2030, we will completely replace the energy and fuel consumption of an airport like this, using electricity from renewable sources to power high-yield CO_2 conversion. This large-scale proof-of-concept will provide a blueprint for others to follow.

2050

use artificial photosynthesis and renewable energy to produce carbon-neutral fuels and chemicals across Europe

Building on high-yield artificial photosynthesis and the efficient conversion of CO_2 and nitrogen with renewable energy, by 2050 we will provide access to scalable and affordable green fuels and chemicals across Europe. This will play a major role in eliminating the continent's unabated carbon emissions, displacing imported fossil fuels with a market potential of 250 billion euros per year and establishing Europe as the world's first carbon-neutral continent.

the science of SUNERGY: a work in progress

The scale of
the challenge sets out to transform the EU's energy, transport and chemical industries. These industries are crucial to Europe's growth, competitiveness and quality of life - and their decarbonisation is a key element of the transition to a carbon-neutral Europe.

In 2017, the energy and transport sectors were jointly responsible for nearly 80% of Europe's greenhouse gas emissions, while the chemicals industry is entirely dependent on fossil-based raw materials and energy carriers. To make the clean energy transition a reality, growth must be decoupled from environmental pollution and the consumption of finite resources.

Over the last decade, much progress has been made in electricity production. New technologies and lower costs mean that wind and solar energy are now an established worldwide alternative to fossil fuels. But for transport and heating, fossil fuels are still an unmatched energy source with a huge existing infrastructure.

Battery technologies are part of the solution. But batteries alone cannot meet our needs, especially when it comes to air travel and long-distance haulage.

the answer: synthetic fuels and chemicals

To address these challenges, we need to create synthetic fuels and chemicals that allow us to store energy in chemical bonds. New forms of fuel will allow Europe to overcome seasonal variations in renewable electricity supply, and to transmit large quantities of energy over long distances. With the highest energy density of all energy storage media, synthetic fuels can store large amounts of energy cheaply over long periods of time. They also fit into our vast existing fuel infrastructure, originally built for the storage, transmission and use of fossil fuels.

The direct supply of energy-rich chemicals, from carbon feedstock for the chemical industry to nitrogen fertilizers for the supply of our food is an important step on the way to displacing fossil fuels by sustainable alternatives.

To address these challenges, we need to create synthetic fuels that allow us to store energy in chemical bonds. New forms of fuel will allow Europe to overcome seasonal variations in renewable electricity supply, and to transmit large quantities of energy over long distances. With the highest energy density of all energy storage media, synthetic fuels can store large amounts of energy cheaply over long periods of time. They also fit into our vast existing fuel infrastructure, originally built for the storage, transmission and use of fossil fuels.

At the same time, we will meet aspects of the European Green Deal towards decarbonising the chemical industry. Energy-rich synthetic chemicals will use air as a source of carbon and nitrogen, and the process of creating them will be powered by renewable energy, either using synthetic hydrogen fuels or from sustainable sources such as solar and wind power.

THE RIGHT AMOUNT OF ENERGY...
Different industries require different energy concentrations. Synthetic fuels can be manufactured to meet their exact needs.

...AT THE RIGHT TIME...
Synthetic fuels and chemicals allow energy to be stored and handled for use on different timescales: overnight, for a few days, for a season, or for many years.

...AT THE RIGHT LOCATION...
Decentralised manufacturing in a circular economy requires different forms of energy in smaller amounts at specific locations.

...IN THE RIGHT FORM...
Synthetic fuels convert and store energy to the exact form in which it will be used, avoiding complex and inefficient multi-step conversions.

...AT THE BEST EFFICIENCY AND HIGHEST YIELD...
High efficiency is key. For artificial photosynthesis using sunlight, we target photon-to-product yields of at least 70%.

...WITH EFFICIENT MATERIALS ON DEMAND...
Synthetic fuels use materials efficiently and therefore minimise the costs of extraction, storage and transport, especially when it comes to materials that are rare in the earth's crust.

...AND AT THE BEST PRICE!
The latest developments in artificial photosynthesis will allow us to reach 70% photon-to-product yields. At this level, less than 3% of the surface of Europe could provide all fuels and chemicals we need - less than half of the area currently devoted to housing, transport and commerce - vastly reducing conversion and distribution costs.

where next?

to make SUNERGY a reality Europe needs:

strong political and scientific/ technological leadership:

to coordinate a complex undertaking across many borders and among many partners.

a sophisticated organisational framework:

to successfully bring together many different sectors, disciplines, levels of governance, levels of technology maturity, funding schemes and national interests.

a clear long-term strategy:

to take on and overcome technological and societal challenges.

multiple, semi-independent, parallel development routes:

to provide additional assurance of success given the early stage of development of some technologies.

substantial public finance:

to de-risk investment, kickstart the most promising technologies and allow rapid scaling-up.

commitment from private investors:

to ensure buy-in and match public funding with the support of major international players

European partnerships - as they exist already today and in their future shape under Horizon Europe - are designed specifically to enable large-scale, transformative projects such as these. Indeed, several partnerships currently being discussed by the European Commission and member states address themes that are also central to **SUNERGY**. This is proof of the relevance the European decision-makers and industry assign to them. However, these current partnerships focus on downstream conversion technology. A partnership that unlocks the benefits of upstream technologies, settled in existing urban zones by developing existing infrastructure, is an indispensable complement to these.

unlocking the renewable energy future

SUNRISE
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ENERGY-X
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Be a change maker & Join our community!

@sunriseaction

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SUNRISE - Solar Energy for a Circular Economy

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