Windows to the future around Top trends in Emerging Technologies. Roadmapping exercise

December 2020

Top 20 trends in technology aiming at shaping the world in the coming decades, structured into 'Dreams' and potential 'Nightmares'

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Presentation

PREFET is a EU funded project within the European Framework Programme for Research, Technology Development and Innovation, Horizon 2020. It is focused on the detection of early-stage technology trends and their analysis. The project combines the most advanced data mining AI engines with human intelligence and crowd/expert perception tools for the implementation of responsible research and innovation and innovation capacity building. PREFET started in November 2018 and continued operating until October 2020. It was performed by a consortium of four organizations in the UK and Spain specialized in technology scouting (Linknovate), integral management of R&I projects (from idea to markets and society) (RTDI), and responsible management of research and innovation (Trilateral Research and De Montfort University) – www.prefet.eu.

The PREFET H2020 project implemented a process moving from manually identified "trend seeds" to Intelligence-Augmented desktop research supported with text-mining, data-mining and machine-learning. "**Weak signals**" were detected, and trends were "informed" (insight generation), resulting in a list of "**45 Pre-validated Trends**". These trends were mapped to UN's Sustainable Development Goals to leverage responsible research and innovation (RRI). As a result, research and innovation that are socially desirable and ethically acceptable were identified. In parallel, they were shared, using an on-line consultation process, with more than 2,000 international researchers in ICT, Health Sciences, Biotechnology and Environmental Sciences. Additional input was provided by interviews with artists, architects, and designers. A workshop focused on the exploration and prioritisation of technology trends (**Trendington**) occurred in November 2019 and resulted in a list of the "**Top 20 future and emerging trends**".

Finally, two workshops were organised with a committee of experts, in order to advance this list into a roadmap. The **"Windows to the future around Top trends in Emerging Technologies. A Roadmapping exercise**" was the main achievement of this exercise. The workshops produced spirited discussion about future and emerging trends among experts from many different fields. The participants **assessed the potential evolution of each top trend in the decades and the benefits and challenges that the trends could offer**. The main objective was to provide a concise and holistic approach (holistic in the sense of technology-based and RRI-based) to the top 20 future and emerging trends. This approach will make the trends more understandable to policymakers, the research community and society and will use metaphors ("dreams and nightmares") and futuristic scenarios as education tools.

This document presents **"Windows to the future around Top trends in Emerging Technologies. A Roadmapping exercise**" in the following order: Section 1 presents the top 20 trends of future and emerging technologies determined by PREFET and summarizes challenges and opportunities for each; Section 2 describes the methodology used in the Expert Committee workshop and results of the brainstorming roadmap exercise; Section 3 deepens the PREFET analysis of challenges and opportunities for the top 20 trends in FET and provides Roadmapping scenarios, including Clusters, Dreams & Nightmares around trends identified by PREFET; Section 4 gives a summary and final conclusions.

We want to take this opportunity to thank all contributors and supporters during this process, particularly the members of the Expert Committee, who have directly helped in the preparation of this document.

Disclaimer: During the time of this roadmapping exercise, the COVID-19 pandemic crisis was unfolding. Based on the three reasons given below, we decided not to focus on COVID-19 during the roadmapping exercise:

1. The technology foresight process contributing to the list of the top 20 trends for future and emerging technologies had already taken place before the crisis started. The roadmapping exercise was the completion of this process based on previous inputs.
2. The trends and windows on future and emerging technologies have a longer time-scope than the expected duration of the COVID-19 pandemic (the focus was on the time frame from 2025 to 2050).
3. An analysis of the contribution these trends can bring to end COVID-19 was part of a different exercise during the PREFET project.

Participants in the preparation of this roadmap

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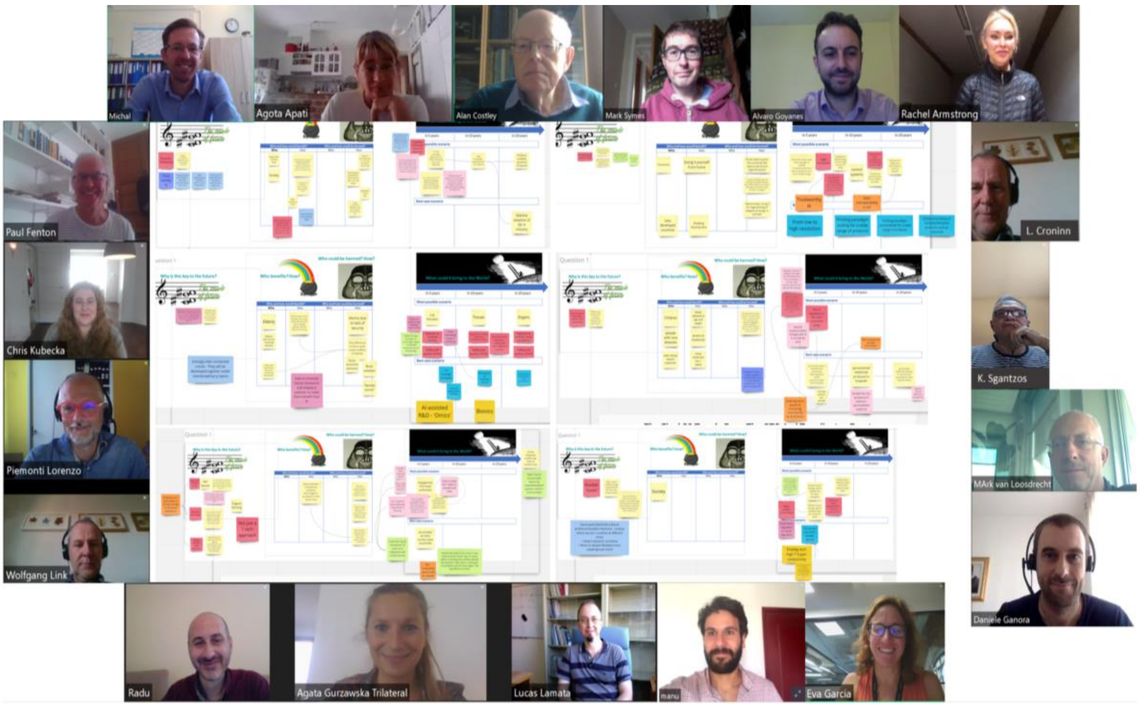

Figure 1: Participants in the preparation of this roadmap during discussion workshops.

Executive Summary

The H2020 project, PREFET, aimed at determining and analysing future and emerging technology trends with high impact potential. The project started with manually identified trends and progressed to desktop research, text and data mining and machine-learning. These efforts identified “trends” that were compared to UN’s Sustainable Development Goals (SDGSs) to leverage responsible research and innovation (RRI). Input from scientists and individuals from other fields resulted in a final list of the top 20 future and emerging trends.

Workshops and advanced discussions were used to convert the trend ideas into “roadmaps” for future research and development. The benefits and challenges of each trend were considered using a holistic approach. The objective was to make the trends more understandable to policymakers, the research community and society and to use metaphors (“dreams and nightmares”) and futuristic scenarios as education tools.

The top 20 trends were organised under three topics: 1) ICT for an interconnected society, 2) Biotechnology & health sciences and 3) Environment, energy & climate change.

- Topic 1 included Chemputing & 3D Printing Molecules, Adaptive Assurance of Autonomous Systems, Neuromorphic Computing (new types of hardware) and Biomimetic AI, Limits of Quantum Computing: Decoherence and use of Machine Learning, Ethically Trustworthy AI & Anonymous Analytics, Beyond 5G Hardware, and New Approaches to Data Interoperability in IOT.
- Topic 2 included Cognitive Augmentation & Intelligence Amplification, Regenerative medicine, Drug Discovery & Manufacturing Using AI, Bioinformatics & AI in ‘Omics’, Cellular Senescence & Life Extension and Bio Robotics/Bionics.
- Topic 3 included Energy Efficient Water Treatments, Algae and Microorganisms Against Climate Change, High Temperature Superconductivity & Twist Electronics, Self-healing batteries, Net Zero Concepts & Beyond Smart Grids, Arctic Climate Change and Zero Power Sensors & Ocean Wiring and Sensing.

Timelines, milestones and stakeholders were identified for each of these trends. Relevant opportunities for interdisciplinary research and development were identified in the form of *clusters* of selected trends. An important conclusion regarding these trends is that emerging technologies involved in their evolution have not yet reached an established dominant design phase. In addition, most of the technology will require the parallel co-evolution of several trends.

Appropriate responsible research and innovation oversight, regulation and policymaking will be essential to avoid potential misuse of the new technologies. These will require appropriate open access to ideas and inventions, socio-ethical considerations and public understanding and acceptance.

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List of acronyms/abbreviations

Abbreviation	Explanation
AI	Artificial Intelligence
EC	European Commission
ExC	Expert Committee
FET	Future and Emerging Technologies (H2020 Programme)
IA	Intelligence Augmentation
IOT	Internet of Things
ML	Machine Learning
QD	Quantum Dots
RIL	RRI Intensity Level
RRI	Responsible Research and Innovation
SDG	Sustainable Development Goal
S&T	Science & Technology

1. Top 20 trends in future and emerging technologies

One of main results from the PREFET project was a list of top 20 trends with major potential for growth and impact from 2020 to 2025 and beyond. They are considered in terms of their strength as drivers for the creation of new science-based technological horizons, as well as their potential to impact the future of humanity and all other life on Earth (Table 1).

Table 1: PREFET'S List of the top 20 trends in future and emerging technologies (link).

ICT for an interconnected society	Biotechnology & Health Sciences	Environment, Energy & Climate change
Chemputing & 3D Printing Molecules	Cognitive Augmentation & Intelligence Amplification	Energy Efficient Water Treatments
Adaptive Assurance of Autonomous Systems	Regenerative Medicine	Algae and Microorganisms Against Climate Change
Neuromorphic Computing (new types of hardware) and Biomimetic AI	Drug Discovery & Manufacture Using AI	High Temperature Superconductivity & Twist Electronics
Limits of Quantum Computing: Decoherence and use of Machine Learning	Bioinformatics & AI in 'Omics'	Self-Healing Batteries
Ethically Trustworthy AI & Anonymous Analytics	Cellular Senescence & Life Extension	Net Zero Concepts & Beyond Smart Grids
Beyond 5G Hardware	Bio Robotics/Bionics	Arctic Climate Change
New Approaches to Data Interoperability in IOT		Zero Power Sensors & Ocean Wiring and Sensing

1.1. Trend descriptions

The following tables briefly describe the evidence-based information gathered around these trends.

<table>
<tr><td>Title:</td><td colspan="2">Chemputing and 3D Printing Molecules</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">
• 3D printing reactionware and molecules refers to an automated robotic platform that can accomplish a variety of different syntheses through a chemical programming language that is able to represent chemical synthesis procedures. The automatic robotic platform is able to produce a wide variety of chemicals.
• The development of routes to digitalise synthetic and materials chemistry opens the possibility of producing chemicals and drugs from digital sources and to produce complex objects such as aircraft, vehicles, equipment in a machine from the bottom up, or with minimal human assistance.
</td><td>
• Digital programming of complex chemical and material systems: No general programming language is available for chemical operations that can direct the synthesis of organic compounds on an affordable, flexible, modular platform accessible to synthetic chemists and that could, in principle, encompass all synthetic organic chemistry.
• Currently, there is only a small database of chemicals that can be made in chemputers.
• An automated robotic platform must be able to perform all unit operations that enable it to perform a large number of synthesis protocols.
• The production of complex objects in standard platforms through digital codes entails a much more ambitious objective with many technical problems. Unlike traditional 3D printing, where parts are built in layers, the machine gives engineers the ability to build complex artefacts and some of their electronic structures quickly by controlling the chemistry at a molecular level.
</td></tr>
<tr><td>RIL[1]:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>RIL5</td><td colspan="2">
• 3- GOOD HEALTH AND WELL-BEING: Chemputing will significantly impact the availability and production cost of drugs since generic drugs will be produced locally with only a digital code. Even patented drugs can also be produced locally through licensing agreements.
• 12-RESPONSIBLE CONSUMPTION AND PRODUCTION: Ensure sustainable consumption and production patterns: Chemputing will allow the production of many goods locally and will enable a significant relocation of production closer to consumers. This will reduce the distance from production centres. International trade-related freight transport currently accounts for more than 7% of global emissions. Therefore, this technology will reduce the footprint of manufacturing activities.
• 9-INDUSTRY, INNOVATION, AND INFRASTRUCTURE: The profound dispersion of manufacturing process caused by this technology will transfer manufacturing activities from current production centres to worldwide locations, which will benefit poorer, and less industrialized, countries.
• 7-AFFORDABLE AND CLEAN ENERGY: Chemputing would have a significant impact on energy efficiency by reducing a significant percentage of freight transport.
</td></tr>
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[1] Note: Responsible Research and Innovation Intensity Level (RIL) is a method of evaluating a project and then selecting what type and how much RRI activity is feasible, appropriate and effective. PREFET applies this method to ensure that FET trends represent research and innovation that is socially desirable and ethically acceptable.

Potential futures:
• **Chemputing could revolutionise drug production** by just printing out any drug in a decentralized manner. The result would enable the production of chemical compounds locally in hospitals, research centres, or any place with access to a relatively inexpensive and automated robotic platform through just a **digital chemical code that can be published, versioned, and transferred flexibly between platforms (Dial-a-molecule)**. If this process could be automated, then much longer synthesis protocols would be accessible, with obvious benefits for drug discovery and the development of new molecular technologies. • This technology will enable rapid manufacturing processes, on demand, of even complex artefacts such as aircrafts, vehicles and computers. This could have profound implications on industry, transportation and commerce since producers may just sell a digital code and enable the object to be produced anywhere.

<table>
<tr><td>Title:</td><td colspan="2">Adaptive Assurance of Autonomous Systems</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">Great advances have been made in the last decade in constructing autonomous Cyber Physical Systems (CPS), as evidenced by the proliferation of many unmanned systems including air, ground, sea, and undersea vehicles. However, we distrust many autonomous systems. Only by making these systems safer can we expect their widespread acceptance. Historically, assurance has been attempted through design and development processes following rigorous safety standards and demonstrating compliance through system testing. However, these standards have been developed primarily for human-in-the-loop systems, and do not extend to advanced levels of autonomy. Current assurance approaches are predicated on the assumption that once the system is deployed, it does not learn and evolve.
The goal of the Assured Autonomy program is to create technology for continual assurance of Learning-Enabled, Cyber Physical Systems (LE-CPSs). Continual assurance is defined as an assurance of the safety and functional correctness of the system provided provisionally at design time, and continually monitored, updated, and evaluated at operation-time as the system and its environment evolves. An LE-CPS is defined as a system composed of one or more Learning-enabled Components (LECs). A LEC is a component whose behaviour is driven by “background knowledge” acquired and updated through a “learning process,” while operating in a dynamic and unstructured environment.</td><td>Several factors impede the deployment and adoption of Adaptive Assurance of Autonomous Systems in safety-critical applications:
Safer Autonomous Systems (SAS) involve new forms of system-safety engineering, dependability engineering, fault-tolerant and failsafe hardware/software design, model-based safety analysis, safety-assurance case development, cyber-security, as well as legal and ethical aspects.
Achieving higher levels of autonomy in uncertain, unstructured, and dynamic environments, increasingly involves data-driven machine learning techniques with many open systems science and systems engineering challenges.
Machine learning techniques used today are inherently unpredictable and lack the necessary mathematical framework to provide guarantees on correctness, while safety-critical applications that depend on safe and correct operation for mission success require predictable behaviour and strong assurance.
These systems must deal with external sensors and actuators, and they must respond in time commensurate with the activities of the system in its environment. One of the main challenges is that safety assurances, currently relying upon authority transfer from an autonomous function to a human to mitigate safety concerns, will need to address their mitigation by automation in a collaborative dynamic context.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>RIL 5</td><td colspan="2">Safer Autonomous Systems impacts at least two Sustainable Development Goals:
11 – Sustainable cities and communities: Smart cities projects aim to build more sustainable and liveable cities in a context of increasing urbanization. Smart cities will place greater reliance on autonomous systems to increase efficiency, reduce emissions, energy consumption and accidents.
12 – Responsible consumption and production: Widespread autonomous systems can help reduce human impact on the environment by reducing energy consumption. Some aspects of autonomous vehicles may deliver net energy savings, while others will increase energy consumption. It is estimated, however, that a net energy reduction of 11% to 55%, compared to the current ground-transportation conditions in the USA, could be achieved through the use of autonomous vehicles.</td></tr>
</table>

Potential futures:
• These systems will enable a level of autonomy that reduces, changes, or eliminates the role of humans. According to SAE classification, Level 5, full automation, which means that an automated system drives all the time and all aspects of the dynamic driving task into changing environmental conditions. • Recent technological advances have accelerated the development and application of increasingly autonomous (IA) systems in civil and military aviation. IA systems are expected to provide increased safety, reliability, efficiency, affordability, and previously unattainable mission capability. There is also a potential for improving safety by **removal of human errors**. • Such systems promise **a smarter and safer world**—where self-driving vehicles can reduce the number of road accidents, medical robots perform intricate surgeries, "digital" pilots participate in crew flight-operations, and Robotics and Autonomous Systems (RAS) are used for hazardous tasks and in hazardous environments.

Title: Neuromorphic Computing (new types of hardware) and Biomimetic Artificial Intelligence

Scientific or technology embryos:

Neuromorphic computing implements aspects of biological neural networks as analogy or digital copies on electronic circuits. The goal of this approach is twofold: **Offering a tool for neuroscience to understand the dynamic processes of learning and development in the brain and applying brain inspiration to generic cognitive computing.** Neuromorphic computing has the potential to create a paradigm shift in terms of energy efficiency, fault tolerance, adaptability as well as information processing capabilities. It could usher in a new class of machines capable of being "trained" to recognize patterns using fewer inputs than a digital neural network would require. One of the most appealing attributes of these neural networks is their portability to low-power neuromorphic hardware, which can be deployed in mobile devices and sensors.

- US unveils world's largest neuromorphic digital synaptic supercomputer: it is equivalent to 64 million neurons and 16 billion synapses, while only consuming 40 watts. Also, DARPA aims to create computing systems as small and efficient as the brains of insects and an AI system that can be trained on less data and operated with less energy.
- SpiNNaker is the largest neural network simulation to date, involving about 80,000 neurons connected by some 300 million synapses.
- **Others: Intel**'s Loihi, IBM

Open challenges:

- The main barrier is that we do not fully understand how the human brain works. The human brain contains a huge number of synapses, which means that they are continuously modified to acquire new information, store memories or learn new tasks. Each synapse is a complex structure in which numerous biochemical processes interact on many timescales. These structures are probably essential for learning, but we do not know why they are so complex.
- Neural networks need huge amounts of synapses and neurons to be computationally powerful. There are 100 billion neurons and 10,000 times more synapses in the human brain. If we want to build small chips with such a huge number of elements, we will need nanoneurons and nanosynapses. So, the first challenge is to imitate important functions of synapses and neurons, such as long-term memory, nonlinearity or spiking behaviour, using devices at nanoscales. We will need new physics and new materials to achieve this goal. The second challenge is wiring. The brain is like a three-dimensional wool ball with interconnected organic wires. Each neuron is connected to an average of ten thousand synapses. How can we artificially achieve such a degree of interconnection? This challenge is further complicated by our current electronics paradigm because it is largely two dimensional and composed of regular grids of wires.

RIL: RIL 2

Impacted SDGs:

Like quantum computing, Neuromorphic Computing has the potential to deliver a future solution that could be 1,000-10,000 times more efficient than current digital processing. The key advantages of neuromorphic computing compared to traditional approaches are energy efficiency, execution speed, robustness against local failures and the ability to learn. This will have a significant impact on several Sustainable Development Goals:

- **3-GOOD HEALTH AND WELL-BEING**
- **7-AFFORDABLE AND CLEAN ENERGY**
- **8-DECENT WORK AND ECONOMIC GROWTH**
- **9-INDUSTRY, INNOVATION, AND INFRASTRUCTURE**
- **11-SUSTAINABLE CITIES AND COMMUNITIES**
- **13-CLIMATE ACTION**

Potential futures:
• In the midterm, we expect neuromorphic technologies to deliver a range of applications more efficiently than conventional computers. For example, to deliver speech and image recognition capabilities in smart phones. (Currently such capabilities are available only using powerful cloud resources) • Large-scale systems may be used to **find causal relations in complex data from science, finance, business, and government**. Based on the causal relations detected such neuromorphic systems may be able to make temporal predictions on different time-scales. • In the long term, there is the prospect of using neuromorphic technology to **integrate energy-efficient intelligent cognitive functions** into a wide range of consumer and business products, from driverless cars to domestic robots.

Title:	Limits of Quantum Computing: Decoherence and use of Machine Learning

Scientific or technology embryos:	Open challenges:
Quantum computers are built on quantum physics and are able to perform computations beyond the capabilities of normal computers. However, the use of quantum states also leaves the quantum computer more vulnerable to errors. Decoherence is a major hurdle, a process in which the environment interacts with the fundamental logic unit of the quantum computer - the qubit, uncontrollably changing their quantum states and causing crashes and loss of stored information. The greatest challenge is how to reduce noise and errors on quantum computing machines. Research is currently evaluating several methods for reducing errors: • **Hardware approaches (**TOPOQDot, QII-TAQS, EDSP**)**: Conventional qubits suffer from decoherence due to the environment and the manipulation of the quantum state itself. The advent of topological quantum materials may allow the realization of qubits that are topologically protected from decoherence. • **Software approaches (**Q-CTRL, Distillation of Multi-Qubit Block Codes) to develop a set of tools that runs on quantum machines, visualises noise and decoherence and then deploys controls to "defeat" those errors. • **Hybrid concepts (**ONISQ**)**: Combine intermediate-sized quantum devices with classical computing systems to solve a particularly challenging set of problems known as combinatorial optimization.	Quantum computers are exceedingly difficult to engineer, build and program. Competing technologies and architectures are addressing these problems but no current hardware platform can maintain coherence and provide the robust error correction required for large-scale computation. A breakthrough may be many years away: • Topological insulators are the primary state of matter promising protection from loss of coherence but have not yet found application due to material quality issues. • Fault-tolerant quantum computers require a large amount of overhead. While classical computers are also affected by various sources of errors, these errors can be corrected with a modest amount of extra storage and logic. Quantum error correction schemes exist but consume such a large number of qubits (quantum bits) that relatively few qubits remain for actual computation. Each logical quantum bit (qubit) needed by a perfect quantum computer could require thousands to tens of thousands of physical qubits after being protected by codes. That reduces the size of the computing task to a tiny fraction of what could run on defect-free hardware. The root trouble is that quantum mechanics challenges our intuition. So, we struggle to determine the best algorithms for performing meaningful tasks.

RIL:	Impacted SDGs:
RIL 5	Having robust, reliable large-scale quantum computers will help solve complex real-world problems much faster than classical computers. The applications of quantum computing range from cryptography, biosciences, advanced geological exploration, retail, finances, mathematics and physics. If we get quantum technology right, the global economy will benefit. This will have a significant impact on several Sustainable Development Goals: • **3-GOOD HEALTH AND WELL-BEING** • **7-AFFORDABLE AND CLEAN ENERGY** • **8-DECENT WORK AND ECONOMIC GROWTH** • **9-INDUSTRY, INNOVATION, AND INFRASTRUCTURE** • **11-SUSTAINABLE CITIES AND COMMUNITIES** • **13-CLIMATE ACTION**

Potential futures:
• **More powerful forms of AI**: With quantum computing, we will be able to do data processing orders of magnitude more effectively than with classical computing. Quantum computing will allow comparison of more data in parallel, simultaneously, and all permutations of that data and to discover the best patterns that describe it. • **Medicine**: Quantum computing will allow modelling of complex molecular interactions at the atomic level. We will be able to model all 20,000+ proteins encoded in the human genome and start to simulate their interactions with models of existing or new drugs. • **Chemistry (and Climate Change)**: Quantum computers will allow us to unlock "simulation-driven" solutions and design new catalysts that can capture carbon from the atmosphere and turn it into new and valuable products at low cost using minimal energy. • **Material Science & Engineering**: Atomic interactions could be simulated leading to the invention of new and improved materials in shorter time cycles (as opposed to current long time cycles of materials science R&D). We may be able to discover better superconductors, better magnets and materials that will allow, for example, the development of higher energy density batteries.

Title:	Ethically trustworthy AI and anonymous analytics
Scientific or technology embryos:	**Open challenges:**
Artificial Intelligence is a disruptive technology with expected impacts rivalling those of electricity or printing. As AI technologies gain broader deployment, technical experts and policy analysts have raised concerns about unintended consequences. The use of AI to make consequential decisions about people, and replacing decisions made by humans and institutions, leads to concerns about how to ensure justice, fairness, and accountability. The use of AI to control physical-world equipment leads to concerns about safety, especially as systems are exposed to the full complexity of the human environment. At a technical level, the challenges of fairness and safety are related. In both cases, practitioners strive to prevent intentional discrimination or failure, to avoid unintended consequences, and to generate the evidence needed to give stakeholders confidence that unintended failures are unlikely. These concerns have raised a series of initiatives from both the EU and the USA to ensure that AI promotes justice and fairness, and that AI-based processes are accountable to stakeholders. In response to these concerns, these initiatives aim for greater transparency when AI tools are used for public purposes.	Computing systems programmed using Machine Learning (ML) or Deep Learning (DL) are increasingly capable of solving complex problems. Unfortunately, these systems are typically opaque and it is difficult to "look inside" and understand why they do what they do or how they work. **Opacity is the heart of the Black Box Problem—a problem with significant practical, legal, and theoretical consequences**. Legally, opacity prevents regulatory bodies from determining whether a particular system processes data are being developed and used fairly and securely. This may hinder end-users from exercising their rights under the European Union's General Data Protection Regulation. The challenge is to create a normative framework that will ensure the justice, fairness, safety and accountability of AI-based systems without hindering the potential of this technology. A problem is that many powerful AI methodologies provide valuable results in a way that it is not easily understood or interpretable. In other cases, AI-based systems can discriminate between groups even when discrimination is not intended. Several high-profile studies have demonstrated that some AI systems are inherently discriminatory.
RIL:	**Impacted SDGs:**
RIL 5	**16 – PEACE, JUSTICE AND STRONG INSTITUTIONS**: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels. The opacity of AI potentially exacerbates problems of bias, injustice and human rights abuses. Efforts to create more transparent, fair, and accountable AI technologies are aligned with UN efforts to design laws and regulations that foster more open and just societies. More countries are establishing legal and institutional frameworks to protect human rights but the widespread application of AI-based applications may hinder these efforts. **Privacy protection, non-discrimination, equality, political participation, freedom of expression and disability rights are among the human rights that may be hampered by opaque AI-based applications.**

Potential futures:

- The goal is to deploy AI systems that enhance human capabilities and empower individuals and societies and extend human intelligence rather than replace it.
- The EU has released a set of guidelines intended to ensure (1) That AI systems empower human beings, allowing them to make informed decisions and fostering their fundamental rights; (2) AI systems are resilient and secure; (3) Full respect for privacy and data protection, considering the quality and integrity of the data; (4) Transparency; (5) Diversity, non-discrimination and fairness; (6) Societal and environmental well-being; (7) Responsibility and accountability for AI systems.
- There are currently a range of initiatives at all levels (governments, businesses, ONGs, academia, International Organizations) to address political and public level regarding the increased use of algorithms and automated processing techniques and their considerable impact on the exercise of human rights." **There is an increasing awareness of the need to safeguard human rights in the area of AI. These rights focus on privacy, equality, freedom of expression and assembly**.
- Microsoft is the first major tech company to complete a Human Rights Impact Assessment (HRIA) on AI.

<table>
<tr><td>Title:</td><td colspan="2">Beyond 5G Hardware</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">5G is expected to provide new value as a basic technology supporting industry and society, along with AI and IoT, as well as further upgrading of the multimedia communication services. A new B5G paradigm is required to ensure that wireless systems can deliver the capacities that future data intensive services such as HD video streaming, augmented reality, virtual reality, and mixed reality will demand:
- The simultaneous achievement of several requirements such as ultra-high-speed, high-capacity, and low-latency connectivity.
- The pioneering of new frequency bands including terahertz frequencies.
- The expansion of communication coverage in the sky, at sea, and in space.
- The provisioning of extremely low energy and low-cost communications.
- The development of capabilities for extremely massive connectivity and sensing

• TOWS considers the infrared and visible light spectrum for future terrestrial wireless systems. Optical wireless (OW) opens new spectral bands with a bandwidth exceeding 540 THz using simple sources and detectors and can be simpler than cellular and WIFI with a significantly larger spectrum.
• CRI aims to develop a first-of-its-kind mmWave multiple-input-multiple-output (MIMO) capable network testbed. It is based on a prototype of advanced mmWave radio chips which feature unprecedented levels of integration, energy-efficiency, reconfigurability and programmability.</td><td>• Coverage extension technology including non-terrestrial network is required in order to provide services for drones, flying cars, ships, and space stations, since their service areas such as the sky, sea, and space are not fully covered by conventional cellular networks. Therefore, new network topologies and long-distance wireless transmission over several tens of kilometres is necessary.
• B5G research should address the problem of transmitting up to 1 Tbps per user. Extended spectrum towards THz will enable merging communications and new applications such as 3D imaging and sensing. However, new paradigms for transceiver architecture and computing will be needed to achieve these and innovation will be required in semiconductors, optics, and new materials.
• AI and ML will play a major role both in linkage and system-level solutions of B5G wireless networks. New access methods will be needed for massive machine-type communications. Modulation and duplexing schemes beyond Quadrature Amplitude Modulation (QAM) and Orthogonal Frequency Division Multiplexing (OFDM) must be developed.
• Security at all levels of future systems will be more critical and B5G needs a network with embedded trust. The strongest security protection may be achieved in the physical layer. B5G will accelerate the creation of data markets, and privacy protection is a key enabler for future services and applications.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>5</td><td colspan="2">• 3-GOOD HEALTH AND WELL-BEING, through wearable devices and micro- devices mounted on the human body aimed to monitor health and manage medical treatments.
• 9-INDUSTRY, INNOVATION, AND INFRASTRUCTURE, through ubiquitous communications that will enable unmanned factories, and unmanned construction sites not possible today. High-rise buildings, drones, flying cars, airplanes, and even space will be natural activity areas, and not only the ground but also on the sea, under the sea, the sky and space will be important communication areas.
• 5-GENDER EQUALITY, 8-DECENT WORK AND ECONOMIC GROWTH, 10-REDUCED INEQUALITIES, 11-SUSTAINABLE CITIES AND COMMUNITIES and 12-RESPONSIBLE CONSUMPTION AND PRODUCTION, since the world is expected to become a place where all people, information, and goods can be accessed anywhere in an ultra-real experience, and the constraints of working place and time are completely eliminated. This will eliminate the social and cultural disparities between rural and urban areas, reduce urban concentrations, promote local development and help reconcile work and family life.</td></tr>
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Potential futures:
• **Communication between humans and things**: Advanced functions of wearable devices including XR (VR, AR, MR) devices, high-definition images and holograms exceeding 8K, and new five sense communications including tactile sense will proliferate, and communications between humans and between humans and things will become ultra-real and rich (Telepresence). As a result, innovative entertainment services and enterprise services for games and sports will be developed. • **Sophistication of cyber-physical fusion**: By transmitting and processing massive data between cyberspace and physical space without delay, tighter cooperation, perhaps even fusion, between both spaces will be achieved. The cyberspace will support human thought and action in real time through wearable devices. Many things such as transportation equipment, including cars, construction machinery, machine tools, monitoring cameras and sensors will be linked in cyberspace.

<table>
<tr><td>Title:</td><td colspan="2">New approaches to data interoperability in IoT</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">Internet of Things (IoT) is predicted to connect 20.4 billion devices in 2020 and surge to 75 billion by 2025. In this connected world, machines will communicate with other machines. This will provide great opportunities and a very different way of life, with smart homes, self-driving vehicles and wearable devices. Currently, many solutions provide their own IoT infrastructure, devices, APIs, and data formats leading to interoperability issues that hinder the potential of IoT.
Big vendors like Amazon (AWS IoT), Cisco (Jasper), IBM (Watson), Apple (HomeKit), Google (Brillo), Microsoft (Azure IoT), have proliferated in the IoT market. The European project Unify-IoT, identified that there are more than 300 IoT platforms in the current market, and more to come. Each of these platforms promotes its own IoT infrastructure, proprietary protocols and interfaces, incompatible standards, formats, and semantics which create closed ecosystems (sometimes called stove pipes or silos). The necessity for these different solutions to seamlessly work together, i.e. IoT interoperability, is growing. To resolve this issue, many innovative solutions have been proposed including Adapters/gateways, Virtual networks/ overlay-based solutions, Networking technologies, Open API, Service oriented architecture (SOA), Semantic web technologies and Open standard.</td><td>Interoperability issues are the consequence of critical issues such as vendor lock-in, impossibility to develop IoT application exposing cross-platform, and/or cross-domain, difficulty in plugging non-interoperable IoT devices into different IoT platforms. These issues prevent the emergence of IoT technology on a large-scale.
The industry is attempting to address IoT interoperability challenges through standardisation. Several efforts have been made to establish standards for providing interoperability between IoT devices, networks, services and data formats owned by different providers. The European Union has funded several research projects under the H2020 program focusing on the federation of IoT platforms. However, it may be a long time before the related standards are fully agreed upon and accepted, if ever.
Many issues remain unsolved:
Even the most popular IoT platforms do not consider edge computing paradigms for speed and efficiency
The current solutions do not scale to multiple platforms with the possibility to add additional platforms when new platforms appear.
As of 2020, it is unlikely that a common set of standards will be universally accepted by academia, industry, and standardisation bodies due to misalignments in incentives.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>RIL 2</td><td colspan="2">IoT development impacts at least two Sustainable Development Goals:
11 – Sustainable cities and communities: IoT is at the core of the development of smart cities projects aimed to build more sustainable and liveable cities in the context of increasing urbanization. A smart city is an urban area that uses different types of electronic IoT sensors to collect data and then uses insights gained from that data to efficiently manage assets, resources, and services.
12 – Responsible consumption and production: Ensure sustainable consumption and production patterns. IoT can help reduce man's impact on the environment. IoT can help organizations be more sustainable by assisting in the management of water resources, the reduction of energy use, the streamlining of data collection on traffic patterns and lower gas consumption.</td></tr>
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Potential futures:
• **Enablement of marketplaces and monetization by interoperability**. An example is **BIG IoT API**, an EU funded project that addresses the interoperability gap by defining a generic, unified Web API for smart object platforms. It entails the establishment of a marketplace where platform, application, and service providers can monetize their assets. This will introduce an incentive to grant access to formerly closed systems and lower market entry barriers for developers. • **Self-evolving intelligent algorithms for facilitating data interoperability in IoT environments:** AI enables a new approach for solving the problem of IoT interoperability. IoT entails a dynamic and volatile environment with a wide diversity of data that requires a new breed of intelligent algorithms with the ability to adapt and self-learn as well as to see and analyse events at multiple levels of abstraction to gauge association and interrelationships. This research proposes three algorithmic requirements for intelligent algorithms in such IoT environments: unsupervised self-learning capability, ability to self-generate to the environment and incrementally learn with temporal changes.

<table>
<tr><td>Title:</td><td colspan="2">Cognitive Augmentation & Intelligence Amplification</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">Neurostimulation is commonly used in treating Parkinson's Disease, epilepsy, and many other neurological disorders, but these treatments require placement of electrodes inside the skull. Next-Generation Nonsurgical Neurotechnology aims to develop high-resolution, bidirectional brain-machine interfaces, enabling bidirectional recording from, and writing to, the brain. Its applications will also be useful to able-bodied people performing complex tasks, or people with a range of disabilities (neural control of prosthetic limbs and restoration of the sense of touch to the users of those limbs, relief of otherwise intractable neuropsychiatric illnesses such as depression, and improvement of memory formation and recall). These wearable interfaces could ultimately have civil and military applications such as control of active cyber defence systems and swarms of unmanned aerial vehicles, or combined with computer systems to multitask during complex activities. Several research teams are currently pursuing approaches that use optics, acoustics, and electromagnetics to record neural activity and/or send signals back to the brain at high speed and resolution. The research is focused in two directions. Teams are pursuing either completely non-invasive interfaces that are external to the body or minutely invasive interface systems that include nanotransducers that can be temporarily and nonsurgically delivered to the brain to improve signal resolution.</td><td>The brain is the most complex organ of the body and the world's most complex computational system. This makes the brain a challenge for research. The most sophisticated neural interfaces require the implantation of electrodes into the brain. Sensing and stimulating neurons at a high resolution is a challenge with implantable electrodes and attempting to replicate this performance noninvasively through the skull adds additional difficulty. Physical laws dictate that information, and hence, accuracy, will be lost in the attempt to sense or stimulate the brain from outside the head. On the other hand, non-invasive neural interfacing techniques that are applied from outside the scalp cannot provide high temporal and spatial resolution because of the dispersion of electrical signals and optical or ultrasonic waves as they propagate through the brain tissue.
Human enhancement and human-machine interaction technologies entail ethical, human rights challenges, and socio-economic impacts. These technologies offer benefits to individuals and society but they present significant ethical challenges related to human autonomy, equality, personal liberty, privacy, and accountability.
There are also significant cybersecurity issues, since these wearables provide access to the brain, they could eventually be used without the users' knowledge or permission.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>RIL 5</td><td colspan="2">3 – GOOD HEALTH AND WELL-BEING: Brain disorders are the most invalidating conditions, exceeding HIV, cancer, and heart ischemia. These conditions have significant impacts on society and public health. In addition to practical, nonclinical applications for able-bodied individuals, neural interfaces could also support research into brain function and dysfunction by providing access to neural circuits. Ultimately they could enable more precise therapeutic interventions to treat neurodegenerative disorders like epilepsy, Alzheimer's, and Parkinson's Disease, and also provide better diagnosis or localization of epilepsy, traumatic brain injuries, stroke, and other neurological diseases.
4 – QUALITY EDUCATION: Education enables upward socioeconomic mobility and is a key to escaping poverty. Neurotechnology bidirectional interfaces may help to develop solutions to enhance learning capabilities. These solutions aim to treat learning disorders, attention deficits, and poor reading skills particularly among school-age children.</td></tr>
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Potential futures:
• Hybrid Enhanced Regenerative Medicine Systems: HERMES is an innovative solution, based on intelligent biohybrids, made by the symbiotic integration of bioengineered brain tissue, neuromorphic microelectronics, and artificial intelligence, to effectively promote self-repair of dysfunctional brain circuits. • Unobtrusive Neurotechnology and Immersive Human-Computer Interface for Enhanced Learning: It is a new smart-service human-computer interface (HCI) neurotechnology platform for enhancing learning capabilities and cognitive performance. The development of unobtrusive neurotechnology addresses a critical need for practical integrated and modular brain-computer interface (BCI) solutions promoting widespread consumer and clinical use.

<table>
<tr><td>Title:</td><td colspan="2">Regenerative medicine</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">Patients needing an organ transplant currently have limited options: they must wait for a suitable donor, receive the transplant, and then spend the rest of their lives taking a cocktail of immunosuppressants. Regenerative medicine is the branch of medicine that develops methods to regrow, repair or replace damaged or diseased cells, organs, or tissues. Regenerative medicine includes the generation and use of therapeutic stem cells, tissue engineering and the production of artificial organs. Combinations of these approaches can amplify our natural healing process in the places it is needed most, or assume the function of a permanently damaged organ.
1. Tissue Engineering and Biomaterials: Tissue engineering is a strategy where biologically compatible scaffolds are implanted in the body at the site where new tissue is to be formed.
2. Cellular Therapies: Regenerative medicine also may enable the growth of tissues and organs in the laboratory and their subsequent implantation into the body. Examples include cell therapies (the injection of stem cells or progenitor cells); immunomodulation therapy (regeneration by biologically active molecules administered alone or as secretions by infused cells); and tissue engineering (transplantation of laboratory grown tissues).
3. Medical Devices and Artificial Organs: Researchers are developing and evaluating devices to supplement or replace the function of many organ systems including the heart, lung, liver, and kidney.</td><td>Regenerative medicine is progressing at an unprecedented pace but <u>many hurdles remain</u> for the clinical application of stem cell research:
• Determination of the cells that would be best for therapy: use of precursors or terminally differentiated cells.
• Understanding the important roles of the microenvironment and host tissue.
• Development of natural or man-made materials using nanotechnology to improve their surface qualities and enhance specific cell attachment and differentiation.
• Development of robust cell delivery systems.
• Evolve from the currently used laboratory practice of two-dimensional cultures to a more natural three-dimensional methodology.
• Growth factors are molecules within our body that help control stem cell function and have the potential to drive the regeneration of tissues. However, the use of growth factors in regenerative medicine has been only partially successful and controversial. Prolonged delivery helps regeneration of tissues, but collateral side effects, such as tumour formation, can be catastrophic. The safe, and economical, use of growth factors in clinical applications remains a great challenge.
• Safety issues persist (i.e. reactivation of the embryonic program and teratoma generation should be avoided). A stretch goal would be discovery of immunosuppression procedures (autologous, HLA-matched, or “safe” cells) involving one cell line suitable for all clients.
Economic factors: A major factor preventing regenerative medicine from large-scale commercialization is the cost of cells. The technology associated with regenerative medicine is very expensive. Billions of cells may be needed to construct a new piece of tissue. Tissue engineering will not become commercially viable until the cost of the raw materials decreases.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>RIL 5</td><td colspan="2">3 – GOOD HEALTH AND WELL-BEING: This research plays a key role in ensuring healthy lives and promoting well-being. Regenerative medicine aims to transform the current focus of “treatment of disease” into one that concentrates on “restoration of health”. This provides a game-changing paradigm for a wide range of many incurable diseases.</td></tr>
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Potential futures:
• Cord blood stem cells are being studied for several applications including Type 1 diabetes, cardiovascular repair, and repair of damaged brain tissue. • Helping cancer survivors restore their natural breast with resorbable implants that induce tissue regeneration. These will lead to an innovative mammary prosthesis that will be degraded over time and be replaced by the patient´s fat. • An innovative solution based on intelligent biohybrids, made by the symbiotic integration of bioengineered brain tissue, neuromorphic microelectronics, and artificial intelligence, is being developed to effectively drive self-repair of dysfunctional brain circuits. • OSTEOproSPINE is a novel bone regeneration therapy designed to guide the formation of new bone at extra-skeletal site to restore the spine's weight bearing function, reduce back pain and improve the success rate of posterolateral spinal fusion surgery. • Scientists may be soon be able to create artificial antibodies with the potential to stimulate tissue in the body to repair itself.

<table>
<tr><td>Title:</td><td colspan="2">Drug Discovery & Manufacture Using Artificial Intelligence</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">The pharmaceutical industry is facing challenges in sustaining their drug development programs because of increased R & D costs and reduced efficiency. Developing a new medicine has an estimated cost of US $2.6-billion and this cost is doubling every nine years. AI has shown promise for facilitating drug discovery by turning the drug-discovery paradigm upside down: exploring drug targets, mining drug candidates, high-throughput screening, drug design, drug synthesis, predicting drug ADMET properties, pathophysiological studies, and development of new indications using old drugs.

Benevolent Bio's AI platform is fed from data sources such as research papers, patents, clinical trials and patient records. This forms a representation of more than one billion known and inferred relationships between biological entities such as genes, symptoms, diseases, proteins, tissues, species and drugs.
Berg uses AI and ML to synthesize more than 14 trillion data points per tissue sample in just days, as it searches for differences between non-disease and disease states. The post AI algorithms then allow for insights into what is known about the biology and overlays the output onto databases that query public knowledge such as patents, publications, chemical libraries and clinical trials.
Other: MELLODDY, Open Targets Platform, Exscientia, Atomwise, Relay Therapeutics, Numerate, IBM Waston and AI Therapeutics.
</td>
<td>
Sceptics point out that some of the claims for AI-based drug development echo the excitement over computer-aided drug design, which began in the early 1980s. Although such in silico modelling techniques are important in modern drug R & D, they have not halted a decline in pharmaceutical-industry R & D productivity that dates back to the mid-1990s.
This model faces many challenges. In April 2019, IBM decided to stop developing and selling drug development tools — the Watson AI Suite, because of its poor financial performance. In addition, the current AI application is more focused on target screening and has now screened many targets through literature analysis, but confirmation of the target remains a difficult problem. Also, prediction of the drug's properties by AI is lower than that obtained through trials and analysis.
There is also a need for user-friendly interfaces to visualize complex results and facilitate data curation: MELLODDY uses interactive 3D visualisations of drug forms, products, equipment and manufacturing processes and their associated data to provide more intuitive access. Benevolent Bio produces 'knowledge graphs' to visualize relationships between the medical conditions, the genes associated with them, or the compounds that have been shown to affect them.
</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>RIL 5</td><td colspan="2">3 – GOOD HEALTH AND WELL-BEING: This research plays a key role to Ensure healthy lives and promote well-being for all. AI may usher in an era of quicker, cheaper, and more-effective drug discovery. By identifying patterns hidden in large volumes of data, AI can enhance target identification and prioritisation either by integrating and analysing data or by generating new data. It also paves the way for a precision-medicine approach, as patients are triaged, in an in-silico manner, before taking a potential drug or entering a clinical trial to determine disease treatment effectiveness.</td></tr>
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Potential futures:
• Powerful combination between AI and automation: Robot scientists using AI can test more compounds, and do so with improved accuracy and reproducibility. They are also superior at searchable record-keeping. Automation will allow transition from an augmented drug design paradigm where the design chemist makes all the decisions to an autonomous drug design paradigm, where the system can iterate through the design–make–test–analyse cycle of drug discovery without direct human intervention. • **Precision medicine**: AI-powered drug discovery efforts enable big pharma and biotechnology companies to streamline R&D efforts, including converting large patient datasets into digestible, tangible information, identifying personalized / precision medicine opportunities, or forecasting potential responses to new drugs. LifeTime aims to revolutionize healthcare by tracking the activity of our genomes in individual cells as they progress through time. The long-term vision is that LifeTime technologies will inform the physician about the molecular history of a patient's tissues, their future, and the consequences of perturbations or medical treatments. This will lead to earlier diagnosis and effective interception of disease before it become chronic or incurable. • At MIT, researchers with backgrounds in machine learning and life sciences are collaborating. They are sharing datasets and tools to develop machine learning methods that can identify novel cures for Covid-19.

<table>
<tr><td>Title:</td><td colspan="2">Bioinformatics & AI in ‘Omics’</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">Bioinformatics has led to dramatic advances in genetic studies through the application of AI to store, retrieve and analyse nucleotide and protein sequences to get an insight into life processes. Bioinformatics primarily deals with data-curation, developing tools, assisting data interpretation and analysis using web-based resources in a biologically meaningful manner. The computational expertise along with a good understating of biological processes are associated with developing appropriate algorithms for sequence comparisons, phylogenetic/evolutionary tree construction, specific pattern recognitions, sequence-structure-function elucidation, annotating sequences, deciphering metabolic pathways, gene regulation and expression and drug designing.
The science of omics has the generic goal to unravel the mystery of living systems by identifying the components of the living system and to analyse the interactions among these components which might lead to better understanding of system function.</td><td>Genomics studies require massive amounts of data. The comparison of genotypes and phenotypes will involve hundreds of millions of nucleotides. Some countries (USA, UK, China) have started to sequence the genomes of millions of citizens and at some point, they are expected to compare the sequenced genomes to respective electronic health records, and ultimately life records. These studies face the challenge of complying with data protection laws and, in the case of China, the lack of privacy protection could be a significant advantage.
The comparison of genotypes and phenotypes at a scale of hundreds of millions will require AI, big data analytic tools and algorithms beyond what we have now.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>RIL 5</td><td colspan="2">3- GOOD HEALTH AND WELL-BEING: Bioinformatics applied to genomics opens a new era of preventive and even predictive healthcare, enabling a better understanding of the molecular basis of disease: the identification of gene-based propensities to diseases as well as better identification of genetic diseases. Another area in which bioinformatics can have a significant impact is in drug discovery through identification of targets and design of therapeutic drugs.
2-ZERO HUNGER: Crop improvement through bioinformatics could reduce the general social concern over GMO crops and enable more sustainable agriculture particularly in areas of decreasing water availability. This could have a significant impact on reducing hunger and poverty, improving food security, creating employment, and building resilience to disasters and shocks.</td></tr>
</table>

Potential futures:
• We already know many diseases that are caused by single-gene mutations and simple traits like hair colour and eye colour. As we obtain the genetic sequences of billions of people, we will know more about how these sequences work. The sequences will tell us the likelihood of specific traits and disease states and let us move from precision medicine to predictive medicine, knowing precisely when and where different diseases are going to occur and preventing them from occurring. • Omics and bioinformatics are revolutionizing drug discovery by identifying potential targets of therapy and the design of therapeutic drugs. The key steps of drug discovery namely target identification, lead identification, lead optimization and pre-clinical tests needs bioinformatics intervention. • Gene-editing technologies such as Crispr-Cas9 would make it easier to repair, add, or remove genes during in-vitro gametogenesis (IVG) processes, eliminating diseases or conferring advantages that would be beneficial to both children and adults. • Genomics could also be involved in controversial gene-editing and embryo-mating to create more perfect humans. This involves leaving the area of healthcare and entering that of evolution, to determine the possible future of our species. We may be able to make genetic changes to create human beings that are better adapted to space travel and space colonization. • 'Agri-genomics' driven crop improvement is an important application of bioinformatics. Crop specific databases are being developed using whole genome sequences of important crops like rice, wheat and maize. These databases will provide enriched genomic resources for crop improvement.

Title:	Cellular senescence and life extension

Scientific or technology embryos:	Open challenges:
Cellular senescence is being studied in two areas: 1) as a mechanism that can be slowed to prevent many age-related illnesses, 2) as a mechanism that can be activated in damaged cells to weaken and destroy them: • **Senolytics, a branch of medicine that targets senescent cells,** is an area of anti-ageing medicine aiming to discover novel interventions to slow down the ageing process and simultaneously prevent diseases. Senescent cells are faulty cells that drive a number of aging co-morbidities and our eventual death. These so-called "zombie" cells linger and proliferate as we age, emitting substances that cause inflammation and turn other healthy cells senescent, ultimately leading to body-wide tissue damage. There is strong evidence that the accumulation of DNA damage and/or other cellular stressors causes cells to undergo senescence, characterized by a senescence-associated secretory phenotype (SASP), comprising pro-inflammatory cytokines, chemokines, and extracellular matrix-degrading proteins that have deleterious paracrine and systemic effects. **The Geroscience Hypothesis** is that targeting a fundamental aging mechanism such as cellular senescence, will delay, prevent, or alleviate multiple age-related disorders, including metabolic dysfunction, skeletal fragility, vascular dysfunction, frailty, cancer, and extend healthy life span. • **Senolytics can be used to help eliminate damaged cancer cells before they can spread**. Two-stage sequential drug treatments for cancer aim to first induce senescence in cancer cells and, in a second stage, use chemical compound screens to find tools to selectively kill senescent cancer cells.	The overall goal of this research is to build a firm foundation of discovery science in cellular senescence that leads to **therapeutic strategies that will slow or prevent age-associated diseases or induce senescence in targeted treatments**. There have already been successful interventions in mice. Clearing senescent cells through genetic pathways has significantly improved their health and lifespan. However, the drugs used to clear senescent cells in mouse studies are not safe treatments for humans. The main problem is the complexity of the senescence process. For a drug to be approved, it must be effective in treating a disease; however, ageing is a natural process, not a localised problem and it involves complex systemic degradation. Therefore, a major challenge is to develop greater **knowledge of the process of cellular senescence and the specific role of cellular senescence in a range of diseases** such as Metabolic Dysfunction, Skeletal Fragility, Vascular Dysfunction, Skeletal Muscle Loss and Dysfunction, osteoarthritis, memory loss, macular degeneration and cancer. The mechanisms involved in these diseases and the role played by cellular senescence are controversial issues. There is no unique and commonly accepted theory of cellular senescence. Therefore, to deliver new effective treatments, research must deliver knowledge in three fundamental areas: molecular mechanisms, cell processes and pathological disorders.

RIL:	Impacted SDGs:
RIL 5	**3 – GOOD HEALTH AND WELL-BEING**: This research plays a key role to Ensure healthy lives and promote well-being, particularly for elderly individuals. It can be instrumental in addressing one of the main health challenges today: the increase of age-related chronic diseases (obesity, diabetes, cardiovascular diseases, cancer, autoimmune diseases and Alzheimer's disease), which have traditionally been more severe in developed countries but are becoming more prevalent in developing countries as they develop and adopt "western" diets and lifestyles.

Potential futures:
• If successful, Geroscience will set the stage for pilot studies in humans using drugs that either reduce the burden of senescent cells, or modulate their inflammatory properties, to simultaneously slow or prevent multiple age-associated diseases. The objective is to develop drug treatments that can retard the aging process. • However, most scientists studying longevity are more interested with prolonging what they call "health span" than lifespan. Their focus is on helping people to age with less pain and illness and with a better quality of life. Healthcare systems currently spend more than twice as much on 65-year-olds as they do on 30-year-olds and more than five times as much on 85-year-olds. Therefore, these treatments could have a great impact on the health of the elderly and also on the sustainability of healthcare systems.

Title:	Bio Robotics/Bionics

Scientific or technology embryos:	Open challenges:
Biorobotics aims to develop biologically-inspired robots with improved and enhanced capabilities over traditional robots. It tries to use the design principles of living systems to create robots with greater mobility and flexibility than traditional robots and possess sensory abilities. **Bionics** is the integration of artificial parts into living bodies and addresses the development of prostheses and implants for body function replacement or augmentation in terms of sensory or motor performance. • RE-BIONICS aims to create novel bioelectronics devices that will mediate the rapid and facile information exchange between biology and electronics. It exploits reduction-oxidation (redox) reactions to create biohybrid circuits that interpret molecular information, compute desired outcomes, and electronically actuate cells to signal and control biological populations. • Natural BionicS aims to surgically create bio-connectors (compacted in a bio-hub) to access the spinal cord circuitries. The ultimate goal is to create a fully integrated, symbiotic replacement of human limbs with robotic parts that the user will feel and command as he would a normal part of the body. • Other: BIONIC (personalised Body Sensor Networks for Real-Time Risk Assessment), BionicVEST (For vertigo of vestibular origin), Electroceutics, or bioelectronic drugs (treating disease via control of the body's electrical signals, develop bioelectronic based therapies for non-neuronal cells).	• Bionic systems conceive and implement methodologies and technologies that provide workable solutions that make a connection between the central or peripheral nervous system and artifacts in order to fully exploit the power and sophistication of brain control. • It is crucial to consider the biocompatibility of foreign materials, toxicity, and durability. Challenges exist in the conception and development of implantable, wearable, or portable, efficient, and compact energy sources. • The design and development of machines whose functions are similar to biological creatures require the development and integration of better performing technologies, such as sensors, actuators, computation, and materials. The crux resides in comprehending the principles underlying the behaviour of living creatures to transfer these principles to the development of artifacts. • For Electroceutics, or bioelectronic drugs, microelectronic devices depend on electrons for information processing while biology depends on molecules (e.g., insulin, antibodies). New interfaces are needed that accept molecules from biology and create electrons for devices and the reverse. • Progress in this inter-science area of research is most likely to happen by increasing interaction among scientists and engineers through multidisciplinary approaches.

RIL:	Impacted SDGs:
5	**3 – GOOD HEALTH AND WELL-BEING**: This research plays a key role to ensure healthy lives and promote well-being for all ages. Missing a limb leads to impairments in the capacity to move and interact with the environment and to a substantial decrease in the quality of life. On the other hand, bionic organs may replace damaged organs widely expanding the current use of electroceutical devices (cochlear implants, retinal implants, forming a bionic eye, pacemaker for modulating heart rhythm, deep brain stimulators for treating Parkinson's and other neurological disorders)

Potential futures:
• The development of bio-hybrid computing devices that efficiently sense and process chemical information as well as operate within and control complex biological systems. This will have a profound impact in the fields of biosensor applications in areas such as biomedical diagnostics, pharmaceuticals, defense, and environmental monitoring and offer new tools to study cellular electrochemistry. • **Bionics might be used for able-bodied people**. Ottobock has produced prosthetic limbs for medical use and is now making mechanical exoskeletons for VW workers to enhance their factory performance. Bionics will reach a point where it can outperform the human body and people might be tempted to replace healthy limbs with bionic ones. The most important goal for future human health is the development of bionic organs. It is estimated that Bionic organs will be able to outperform their biological counterparts by 2030. • Biorobotics is being used to assist in actual surgeries, providing more precise and less invasive interventions. Mechatronic handheld tools allow surgeons to manipulate their hands at the macro level while affecting similar responses from a mechanical device operating at the micro level. This could even lead to "**cellular surgery**."

<table>
<tr><td>Title:</td><td colspan="2">Energy Efficient Water Treatments</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">This category comprises a set of technologies that have revolutionized treatment of water for safe drinking, and refined purification of polluted water for release or reuse – all while minimizing the energy footprint:
Microbiological processes in wastewater treatment: increasingly common wastewater treatment processes based on microorganisms that are less costly and more energy efficient than traditional methods: Anammox (to remove nitrogen from wastewater through a process that uses up to 60% less energy and 80% less organic carbon) and Nereda (based on granulation of bacteria).
Eutectic Freeze Crystallization: Water treatment processes produce aqueous waste streams with a high salt content, whose disposal is a growing concern in many parts of the world. Eutectic Freeze Crystallization is a promising low temperature desalination technique that can retrieve salt and water in pure form from the saline waste streams, at a relatively low energy cost compared to conventional evaporation-based separation processes.
Freshwater Recovery System for Hydraulic Fracturing: for extracting clean irrigation water from hydraulic fracturing wastewater using low-grade solar or industrial waste heat.</td><td>Microbiological processes in wastewater treatment: There are still challenges in the practical application of the anammox-based treatment process at full-scale. These include a longer start-up period, limited application to mainstream municipal wastewater and poor effluent water quality (*).
Eutectic Freeze Crystallisation: This technology has been known since the 1970's but it has long been considered unfeasible for industrial scale application. EFC is considered to still be in its infancy since there are various parameters that require further study. To develop a viable separation process for multi-component industrial hypersaline brines, conceptual design studies must make a detailed thermodynamic evaluation to establish which components will be crystallised, and in what quantities, under the chosen process conditions (*).
Freshwater Recovery System for Hydraulic Fracturing: The great challenge of this technology is for it to become modular, portable, scalable, and deployable at a lower cost than existing treatment systems.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>RIL 3</td><td colspan="2">6 – CLEAN WATER AND SANITATION: Fresh water is a precious resource essential to human health, food and energy security, poverty eradication and many other aspects of sustainable development. The development of more efficient and cost-effective methods for water treatment will have a great impact on some of our main challenges 1) The demand for water has outpaced population growth, and half of the world's population is already experiencing severe water scarcity for at least one month each year; 2) Most rivers in Africa, Asia and Latin America are more polluted now than they were in the 1990s.
14 – LIFE BELOW WATER: Coastal areas worldwide are affected by land-based pollutants, including sewage and nutrient runoff. This leads to coastal eutrophication, degraded water quality and the impairment of coastal marine ecosystems. Today, water quality challenges are widespread, but are most acute in some equatorial zones, especially in parts of Asia, Africa, and Central America. The development of more cost-effective methods for water treatment will benefit developing countries which lack adequate infrastructures. This will have a direct impact on the pollution of rivers and oceans.</td></tr>
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Potential futures:
The future of water treatment leads to a scenario in which the outcomes of the process not only are more energy efficient and less costly than today's treatments, but they **may become energy positive** through the production of biogas, **and economically profitable**, through the sale of valuable by-products. **The views on wastewater are changing, recognising the value of resources that were formerly considered only as pollutants**. Used waters from households and industries carry resources of quantitative interest, such as energy, nutrients, non-defined organics, salts and, of course, the water itself. In developing countries with unstable electricity supply and limited funding, this is very important. If we could build a wastewater plant that is self-sufficient in energy, that would make sewage plants feasible in many more places.

Title:	Algae and Microorganisms Against Climate Change
Scientific or technology embryos:	**Open challenges:**
Algal biomass can be converted to advanced biofuels, but development costs have prevented this from becoming a commercial reality. New approaches are more ambitious and comprehensive: 1) They aim to co-produce fuels and food at the same time from the same batch of algae to overcome current economic challenges. They explore the use of microalgae in animal feeds and directly for human nutrition. Algae-based, nutritional products and supplements such as spirulina, kelp, chlorella, astaxanthin already constitute a multimillion dollar market. Also, algae-based food products fed to poultry, livestock, and aquaculture fish, can help make industrial algae cultivation economically viable. 2) Beyond fuels, algal biopetroleum could be used for other products such as plastics that traditionally are made from fossil-based petroleum. 3) Scientists and policymakers are recognizing the urgency to remove atmospheric carbon dioxide, and microalgae are being proposed as part of the solution. Marine microalgae grow 10 to 100 times faster than the fastest-growing terrestrial plants, so their production requires only a fraction of the land a terrestrial crop needs.	• The industrial production of marine microalgae requires open-air ponds, where the algae absorb large amounts of carbon dioxide in short periods of time. But atmospheric carbon cannot diffuse rapidly enough through the pond layer where ambient air and surface water meet. New methods are being used to enhance diffusion. The algae also require large amounts of nutrients, especially phosphorus. A potential solution to algae cultivation is the development of large-scale wastewater treatment systems. • Economic viability remains a major challenge: co-production of fuels and food at the same time could overcome the economic challenges that have held this field back for decades. The food component is critically important to make algal biofuel viable. • The use of algae for biofuel and food production requires a process of selection to identify the strains most suitable for a range of co-product possibilities. Secondly, these "winners" must be grown at a large scale and the biomass passed to two distinct technologies for separating them into the component bioproducts of oil and protein. The end products obtained from the most promising pathways must be tested in field trials.
RIL:	**Impacted SDGs:**
RIL 5	• **2 – ZERO HUNGER:** Microalgae can produce enormous amounts of food, and also deliver beneficial land-use changes. There are existing projects to build large algae farms. Large-scale plants are conceivable in southern Europe and North Africa because saltwater algae thrive in sunny areas. • **7 – AFFORDABLE CLEAN ENERGY**: Microalgae could enable the production of economically viable biofuel. • **13 – CLIMATE ACTION:** To achieve climate stabilization, reducing anthropogenic emissions may be insufficient. We also need to remove carbon dioxide from the atmosphere. The industrial production of marine microalgae can help accomplish this. Algae production plants which together would cover the size of Algeria would offset all of the estimated CO_2 emissions from air transport.

Potential futures:
• Pond Technologies, Using Algae to Combat Climate Change: Pondtech design and operate scalable bioreactors that use the most abundant product -industrial greenhouse gas emissions- to cultivate algae and another valuable biomass. Emissions from industrial facilities are redirected to large tanks, called bioreactors. The emissions are moved through the algae-filled reactors where Pond's proprietary technology capitalizes on algae's natural appetite for CO_2. Conditions are optimized using lighting, sensors, and computer algorithms, maximizing algae growth and CO_2 conversion. Emissions are cleaned, oxygen is output, and algae is grown. Algae can be used to create green superfoods like chlorella and spirulina, clean feed for farm animals, natural cosmetics and food additives, and even biodegradable plastics. • How algae could sustainably reduce the carbon dioxide concentration in the atmosphere: Algae convert carbon dioxide from the atmosphere, power plants or steel processing exhaust into algae oil. In a subsequent step, this is then used to produce valuable polyacrylonitrile (PAN) fibres. Carbon fibres can replace structural steel in construction materials. Thanks to their strength, they save on cement use. Granite reinforced with carbon fibre can even be used to produce beams that have the same load-bearing strength as steel but are as lightweight as aluminium.

<table>
<tr><td>Title:</td><td colspan="2">High Temperature Superconductivity & Twist Electronics</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">Superconductivity is a phenomenon in which an electrical charge moves through a material without resistance. In theory this allows electrical energy to be transferred between two points with perfect efficiency, losing nothing to heat. Superconductors could revolutionise electrical efficiency, vastly improving power grids, high-speed data transfer, and electrical motors, to name a few potential applications. However, the problem is that they only work at very low temperatures, typically, hundreds of degrees below freezing. Many physicists believe a room-temperature superconductor could exist. Such a discovery would unleash amazing new technologies. Several unconventional or high-temperature superconductors have already been discovered but they typically require stringent conditions (i.e. extremely high pressure) that make them impractical and unaffordable.
Insulating behaviour and unconventional superconductivity in twisted bilayer graphene (TBG): A MIT team has made a giant technical leap by turning graphene into a superconductor. They achieved this feat by placing one sheet of graphene over another, rotating the other sheet to a special orientation, or ‘magic angle’, and cooling the ensemble to a fraction of a degree above absolute zero. That twist radically changed the bilayer’s properties — turning it first into an insulator and then, with the application of a stronger electric field, into a superconductor. This discovery presents new opportunities for manipulating the behaviour of 2D layered materials and ultimately achieving unprecedented control over their performance when integrated into specific functional devices.</td><td>Unconventional superconductors enable electric current to move without resistance at temperatures well above what the conventional theory of superconductivity allows. How this happens is unclear but must be clarified to realize the value of this technology. Understanding and quantitatively predicting the behaviour of condensed matter and materials is one of the great challenges of physics. Taking the high-transition-temperature superconducting cuprates as an example, despite several decades of study there is still no consensus on the mechanism of superconductivity and even the normal state from which the superconducting state arises is not fully understood.
There have been some calls for caution about TBG: In particular, superconductivity appears when the number of electrons is turned down but not when it is turned up, an asymmetry that is arguably more consistent with a conventional superconductor. In contrast to cuprates, which can be insulating at higher temperatures than those at which they superconduct, in twisted graphene the two states seem to be present in a similar temperature range. Further tests, such as determining if the superconducting state still occurs when sample vibrations are restricted, but still allow electron interactions, may help to clarify the situation.
It is still unclear whether the advantages of superconductors, such as efficiency and compactness, can outweigh the disadvantage of high cost.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>RIL 5</td><td colspan="2">7 - Affordable clean energy and 13 – Climate action: replacing conventional methods which spin turbines in magnetic fields to generate electricity, could enable greater use of highly efficient wind turbines and power plants. Also, a current that could flow forever without losing energy means transmission of power with virtually no losses in the cables. Lossless cables and high-voltage transmission across continents are key for energy systems dominated by renewable energies. A superconducting wire carrying a current that never diminishes would act as a perfect store of electrical energy.
11 – Sustainable cities and communities: With no resistance, a current could be passed through the superconducting wire and, in turn, produce magnetic fields of incredible power. This could be used to levitate trains and produce astonishing accelerations, thereby revolutionising the transport system.</td></tr>
</table>

Potential futures:
• **High Temperature Superconductivity could be the key for quantum computers** as in the two-level system required for a “qubit,” the zeros and ones are replaced by current flowing clockwise or counterclockwise in a superconductor. Quantum technology could unleash a computing power that would transform society. • **Fusion energy**: High temperature superconductors could yield faster development of nascent fusion energy which has been positioned as s carbon free alternative for energy generation. The new superconductors can be used to build magnets that produce stronger magnetic fields than previously possible. • **Topological insulators** are other materials that exhibit strange quantum behaviours. They can be considered perfect insulators for most materials but extraordinarily good conductors in a thin layer on the surface. Microsoft is betting on topological insulators as a key component in their attempt to develop a quantum computer. Topological insulators have also been considered to be potentially important components in miniaturized circuitry.

<table>
<tr><td>Title:</td><td colspan="2">Self-Healing Batteries</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">From smartphones to pacemakers and cars, batteries power much of our world and their importance continues to grow. But even as Li-ion battery technology is being recognized as a major achievement, the chemistry behind them is facing a looming challenge. Lithium-ion batteries cannot be recharged indefinitely; the materials in these batteries' electrodes expand and crack with each cycle, gradually decreasing their storage performance until they are no longer effective.

Stanford and SLAC scientists invent self-healing battery electrode: Researchers have made the first battery electrode that heals itself, opening a new and potentially commercially viable path for making the next generation of lithium ion batteries. The secret is a stretchy polymer that coats the electrode, binds it together and spontaneously heals tiny cracks that develop during battery operation. Silicon electrodes last 10 times longer when coated with the self-healing polymer, which repairs any cracks within just a few hours.
Engineers at the University of Tokyo demonstrated that if the battery is made with a model material—oxygen redox-layered oxide (Na_2RuO_3)—then something remarkable happens. Not only does the degradation from charge and discharge cycles diminish, but the layers actually self-repair. This is because the material the researchers demonstrated is held fast by a force called coulombic attraction, which is far stronger than the Van der Waals force.
Other: Self-healing liquid brings new life to battery alternative.
</td>
<td>
To fix the issues with lithium-ion batteries, battery makers commonly use nanomaterials. However, the synthesis of nanomaterials can be complex, meaning that making tons of nanomaterials at an industrial scale for battery applications can be expensive. Solutions that do not use nanomaterials, would be more feasible for large-scale applications.
This is a problem for all electrodes in high-capacity batteries since they are designed to store more energy in the negative electrodes of lithium ion batteries. One promising electrode material is silicon; it has a high capacity for soaking up lithium ions from the battery fluid, but silicon electrodes swell to three times their normal size and shrink back down again each time the battery charges and discharges. The brittle material soon cracks and falls apart.
Researchers are trying to replace the liquid electrolytes in lithium-ion batteries with solid materials such as ceramics or polymers, but many of these materials are rigid and brittle resulting in poor electrolyte-to-electrode contact and reduced conductivity. Also, high-temperature conditions inside a battery can melt most polymers.
Engineers are also looking to design rechargeable battery electrodes that can work efficiently with metal ions other than lithium. Magnesium-ion batteries are a promising alternative, but materials that can reversibly store magnesium have thus far been even more susceptible to cracking and other problems.
</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>3</td><td colspan="2">
7-AFFORDABLE AND CLEAN ENERGY and 13-CLIMATE ACTION: Increasing the energy density of batteries is of paramount importance to realise electrified transportation and to reduce dependence on fossil fuels.
11-SUSTAINABLE CITIES AND COMMUNITIES, 14- LIFE BELOW WATER, 15-LIFE ON LAND: the continuous disposal of degraded and useless batteries is a significant environmental problem since they typically are made from materials that are toxic to the environment and humans.
12- RESPONSIBLE CONSUMPTION AND PRODUCTION: The decreasing storage performance of batteries and limited useful life results in the need to replace them frequently. Also, batteries represent a considerable part of the weight of electric vehicles and devices. The demand for fresh lithium, cobalt and other necessary elements strains natural resources since lithium and cobalt are finite and extraction can lead to water pollution and other environmental problems.
</td></tr>
</table>

Potential futures:
The ultimate objective of self-healing batteries is to design a **battery that can be charged and discharged forever**. Self-healing is very important for the survival and long lifetimes of animals and plants, and the goal is to incorporate this feature into lithium ion batteries so they will have a long lifetime as well. New malleable 'electronic skin' self-healable, recyclable: University of Colorado Boulder researchers have developed a new type of malleable, self-healing and fully recyclable "electronic skin" that has applications ranging from robotics and prosthetic development to better biomedical devices. A number of different types and sizes of wearable e-skins are now being developed as researchers recognize their value in diverse medical, scientific, and engineering fields.

<table>
<tr><td>Title:</td><td colspan="2">Net Zero Concepts & Beyond Smart Grids</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">National grids worldwide are facing shrinking margins, capacity shortages and unpredictable peaks and troughs in energy supply caused by increasing levels of renewable penetration. A complex grid with diverse resources alongside fast, automated disturbance responses requires a new level of insight, without which the system can become uneconomical, unreliable, and unstable. New technologies such as machine learning and peer-to-peer cryptography can help to build new tools to share data, boost efficiency, and mitigate grid emergencies.
• Economic Data-fused Grid Edge Processor (EDGEPRO) for Future Distribution Grid Control Applications: This technology will merge advanced edge computing, data fusion and machine learning techniques for virtual metering, and a central repository for grid applications such as distributed energy resource (DER) control, and others, on one platform.
• National Infrastructure for Artificial Intelligence on the Grid is a scalable, cloud-based platform to store, process, and analyse grid sensor data. It is also the deployment of grid sensors that capture both wide-scale and localized grid behaviour, as well as the establishment of a secure data exchange mechanism.
• Secure Grid Data Exchange Using Cryptography, Peer-to-Peer Networks, and Blockchain Ledgers for sharing grid data to improve electric grid efficiency, reliability, and resiliency in a manner that preserves security and integrity.</td><td>• The extensive deployment of smart meters and sensors has flooded distribution utilities with field data. Often, the data contains errors, missing information, and outliers, and requires authentication. Different sensor networks collect data in different formats, making it cumbersome to compile, convert, and align the information. Equipment sensors and meter networks typically use different communication protocols, causing interoperability issues. As measurement points, data resolution requirements, and control actions increase, the cost of storing, processing, and computing data collected from field devices becomes prohibitively high. Consequently, data is examined only when a problem occurs. This leads to poor visibility of system operations and slow response time to faults and system anomalies.
• Recent technology advances present an opportunity to reinvent how utilities share sensitive grid infrastructure data, such as transmission maps, heat rate curves, and production schedules securely over the Internet. The lack of a simple, standard certified data sharing solution limits the electric industry's ability to enhance grid resiliency and encourages untraceable and unauthorized workarounds that increase cyber-security exposures. If energy companies made more anonymised half-hourly power data available, data scientists and engineers working on new smart grid technologies could validate new ideas quickly and cheaply.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>3</td><td colspan="2">7-AFFORDABLE AND CLEAN ENERGY and 13-CLIMATE ACTION: These projects will advance our understanding of a changing grid, allowing for greater integration of new resources like renewables and energy storage. Also, realizing data-driven applications using ML and DL to drive efficient use of grid assets will yield a corresponding decrease in emissions, primarily through more effective algorithms for integrating and operating distributed energy resources. More efficient, better managed grid systems and enhanced reliability will reduce the dependence of utilities on fossil fuels for electricity generation and reduce greenhouse gas emissions.</td></tr>
</table>

Potential futures:
• **Machine learning to help balance the grid**: The most transformative application of machine learning for grid balancing comes from unlocking and utilising flexibility in demand-side power consumption. Such algorithms can find creative ways to reschedule the power consumption of many demand and generation assets in synchrony to keep the grid in balance while helping to minimise the cost of consuming that power for energy users. • **Deployment of digital twins**: By applying self-learning techniques, artificial intelligence and machine learning, these digital power system models are adaptive and provide a virtual copy of what is happening in the physical world. Digital twin technology in the energy industry is enabling the development as well as maintenance of smart grids that are equipped with hi-tech sensors and machine learning models for enhanced performance and monitoring. Bringing the mix of cyber-physical systems, cloud computing and intelligent industrial solutions, digital twin technology is becoming the backbone for smart grid implementation, renewable energy management, better integration, and efficient transmission. Digital twin adoption for the energy sector is making it possible to establish a balance between supply and demand by enabling proactive attention to operational issues, thus, facilitating faster power restoration and outage reversal.

<table>
<tr><td>Title:</td><td colspan="2">Arctic Climate Change</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">The Arctic is extremely vulnerable to climate change and its impacts and it is now experiencing some of the most rapid and severe climate changes on Earth. Over the next 100 y, climate change is expected to accelerate and cause major physical, ecological, social, and economic changes. Changes in the Arctic climate will also affect the rest of the world through increased warming across the globe, rising sea levels, and potential alterations of oceanic processes and circulation.
• ARCTICO, Uncovering the Magnitude of Arctic Climate Change: the response in the Arctic Weather is amplified relative to the global mean. The proposed investigation seeks to constrain the magnitude of Arctic amplification by quantifying the influence of the carbonate ion concentration of sea water on the temperature signal recorded in the Arctic planktonic foraminifera Neogloboquadrina pachyderma sinistral (NPS).
• APPLICATE, Advanced Prediction in Polar regions and beyond using advanced metrics and diagnostics focusing on aspects that are known to play pivotal roles in both weather and climate prediction. These include the atmospheric boundary layer including clouds; sea ice; snow; atmosphere-sea ice-ocean coupling; and oceanic transports.
• NCoE SVALI - Stability and Variations of Arctic Land Ice: The results are based on direct field measurements and remote measurements from planes and satellites.
• Other: NCoE NORD-STAR - Nordic Strategic Adaptation Research</td><td>• A key challenge in climate change science is to provide informed constraints on the magnitude of future climate change. Uncertainties associated with such predictions remain large due to the shortness of our observational records (at best 150 years) and the absence of large climate shifts therein to serve as an analogue for future change. This is especially problematic when estimating Arctic climate change because the response in the Arctic is amplified relative to the global mean, making the Arctic the most sensitive and vulnerable environment with regards to global warming. Efforts to assess the magnitude of past (e.g. pre-industrial) climate changes using climate proxies are crucial to further our understanding of how the Arctic system will respond to continued global warming.
• The effects of a warming atmosphere on physical, chemical, biological, and human components of Arctic ecosystems are myriad, far-reaching, and accelerating, which makes it particularly challenging to understand the depth and magnitude of these changes. The warming has caused a cascade of physical changes, from direct effects such as the melting of sea-ice and sea level rise, to secondary effects such as decreased albedo (surface reflectivity) and coastal erosion, to tertiary effects such as the accelerated warming of the ocean due to feedback loops between different climate factors. Also, Arctic warming has significant impacts on biodiversity, since a great variety of animal species are in danger of losing their natural environments.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>5</td><td colspan="2">Arctic Warming and Its Consequences Have Worldwide Implications which impact several SDGs:
• 13- CLIMATE ACTION: Melting of highly reflective Arctic snow and ice reveals darker land and ocean surfaces, increasing absorption of the sun's heat and further warming the planet. Increases in glacial melt and river runoff add more freshwater to the ocean, raising the global sea level and possibly slowing the ocean circulation that brings heat from the tropics to the poles, affecting global and regional climate.
• 14-LIFE BELOW WATER, 15-LIFE ON LAND: Animal Species Diversity, Ranges, and Distribution Will Change. Reductions in sea ice will drastically shrink marine habitat for polar bears, ice-inhabiting seals, and some seabirds, pushing some species toward extinction
• 11-SUSTAINABLE CITIES AND COMMUNITIES: Many Coastal Communities and Facilities Face Increasing Exposure to Storms: Severe coastal erosion will be a growing problem as rising sea level and a reduction in sea ice allow higher waves and storm surges to reach the shore. As a consequence, Indigenous Communities Are Facing Major Negative Economic and Cultural Impacts.</td></tr>
</table>

Potential futures:
• **Build walls on seafloor to stop glacial melting**: Building walls on the seafloor may become the next frontier of climate science, as engineers seek novel ways to hold back the sea level rises predicted to result from global warming. The structures would not just be aimed at holding back the melting glaciers, but at preventing warmer water from reaching the bases of the glaciers under the sea. Glaciers melting under rising temperatures at the poles have the potential to discharge vast amounts of fresh water into the oceans, causing sea levels to rise faster than they have in recorded history.

<table>
<tr><td>Title:</td><td colspan="2">Zero Power Sensors & Ocean Wiring and Sensing</td></tr>
<tr><td colspan="2">Scientific or technology embryos:</td><td>Open challenges:</td></tr>
<tr><td colspan="2">Billions of new devices are expected to be used to make our environments smarter and more efficient. The use of copper wire networks in these sensors and the replacement of depleted batteries in wireless sensors is costly. A goal would be to eliminate batteries in wireless sensors through Energy Harvesting techniques that use an energy conversion transducer tied to an integrated rechargeable power storage device. These mini “power plants” would last the life of the wireless sensor.
• Zero-Power Wireless Chemical Sensor for Agricultural Pests and Disease Monitoring: A miniaturised, low-cost, and maintenance-free chemical sensor capable of continuously monitoring the concentration of specific volatile organic compound (VOC) vapours released from crop plants and green plants being attacked by pests or disease.
• A battery-free sensor for underwater exploration: Submerged systems using the vibration of “piezoelectric” materials to generate power and send and receive data. To investigate the largely unexplored oceans that cover 70% of the earth, researchers aim to build a submerged network of interconnected sensors that send data to the surface — an “underwater internet.”
• Zero power sensor technology: Researchers at the University of Washington have tested devices transmitting data as far as 2.8 km using RF energy harvested from WIFI networks and other reflected radio sources.</td>
<td>• Energy-autarkic sensor systems use energy from their environment for operation and data transfer. This requires both an efficient energy harvesting strategy, appropriate energy storage management and also ultra-low-power technologies for sensors, signal processing and wireless signal transfer.
• Transmitting range is critical but devices that can communicate over long distances typically consume excessive power. Low-power devices that consume microwatts of power usually have short communication ranges. The challenge is to offer both, which would be a breakthrough for different industries and applications.
• These sensors require an energy harvesting transducer that converts ambient energy to electricity. Researchers are exploring alternatives to provide zero power to sensors such as RF-energy harvesting, micromechanical photoswitches, acoustically powered underwater devices, opportunistic energy scavenging and backscatter. These all present technical challenges. The viability of each one depends on the environment where the device will operate.
• A major challenge is to make these Zero Power Sensors low-cost and maintenance-free and this is the key for their widespread use.
• A key is also to minimize power consumption through event-driven sensing capabilities in which the sensor can remain dormant, with near-zero power consumption, until awakened by an external trigger or stimulus.</td></tr>
<tr><td>RIL:</td><td colspan="2">Impacted SDGs:</td></tr>
<tr><td>3</td><td colspan="2">• 9- INDUSTRY, INNOVATION, AND INFRASTRUCTURE, 11- SUSTAINABLE CITIES AND COMMUNITIES, 12-RESPONSIBLE CONSUMPTION AND PRODUCTION: Sensors allow environmental monitoring and enable us to control many aspects of our life. Sensor networks are increasingly used in factories, industrial complexes, commercial and residential buildings, agricultural settings and urban areas. They serve to improve manufacturing efficiency, safety, reliability, automation, and security, but the problem of power consumption hinders many sensor applications.
• 3 – GOOD HEALTH AND WELL-BEING: Other potential applications are medical devices that could monitor the condition of patients.
• 13-CLIMATE ACTION, 14-LIFE BELOW WATER, 15-LIFE ON LAND: Zero power sensors might be the ultimate solution for researchers in marine biography, oceanography, soil, and wildlife monitoring and meteorology. They would be useful for anyone needing long-term, low-human-effort and widespread sensing.</td></tr>
</table>

Potential futures:
• **Applications of Zero Power Sensors go beyond our own planet.** It could be used to collect data in the recently discovered subsurface ocean on Titan, the largest moon, of Saturn. These sensors would last for long periods of time in places where it is difficult to obtain energy. Sensors that operate and communicate without the need for a battery may be especially useful for sensing in extreme environments.

2. Workshops with Expert Committee

The main aim was to keep a strong focus on the top 20 trends and the expected timeline associated with each one. At the same time conversation was kept as open as possible to allow for interconnections and multidisciplinary "ties/suggestions". Another goal was to optimise the available time and resources to deliver practical and useful output. More data could be gathered in the future with a more extensive questionnaire and deep research processes.

Within this context, the specific objectives of these workshops were:

1. Assigning a temporal variable to the trends.
2. Detecting certain milestones or breakthroughs that need to happen to take the trend to "the next level", which translates into deeper social impact or enablement of other socio-technical scenarios (e.g. combined with other trends).
3. Identifying stakeholders that could specially benefit or potentially be harmed by the topics of discussion in order to leverage ethics by design approaches during R&D initiatives within these trends.

With these objectives in mind, the following questions were introduced to the Expert Committee:

1. Why is the field/research that you are working on key to the future?

This question helped frame the potential and basic understanding of current and future implications of the topic of discussion.

2. Who would benefit, and how would they benefit, from the research? Who would be harmed, and how could be harmed, by technology development in this area?

Who would benefit and how would they benefit?		**Who would be harmed and how could they be harmed?**	
Who	**How**	**Who**	**How**

From the RRI perspective, this question was deemed to be key for a basic assessment of future implications and key-players involved in them, either as passive subjects ('benefiting from' or 'suffering from'), or as active subjects (with an active role in its development and coming to full potential in society).

3. What key capabilities do you think your technology area (trend) could offer to society if deployed with (1) current constraints; and (2) without any constraints? Note: e.g. financial and legal constraints.

Timeframe	1. With current constraints	2. Without any constraints
In 5 years		
In 10 years		
In 20 years		

The purpose of this question was to assign a clear timeline to technical, scientific, ethical, or social breakthroughs that the ExC could identify.
A secondary question that complemented this one, was "Out of all developments, which unique milestone would you select as critical for advancing the development of this topic to the next level, and when would it happen?".

Workshops were organised on August 31st, 2020 and September 4th, 2020.

3. Roadmapping scenarios: Clusters, Dreams & Nightmares

The purpose of this roadmapping exercise was to offer a vision of future and emerging technologies of greatest relevance that are inspiring, easy to understand and visual to an audience of laymen and non-scientists, yet sufficiently meaningful to be useful as an exercise of technology foresight for researchers and policymakers.

A 'roadmap' is an extended look at the future of a chosen field of inquiry derived from the collective knowledge and imagination of change-agents in that field. It portrays structural relationships among science, technology, and potential applications [2]. Science and Technology (S&T) roadmaps become an inventory of possibilities for a particular field and are used as decision aids to improve coordination of activities and resources in complex and uncertain environments. Specific uses of roadmaps include: S&T management including strategy, planning, executing, reviewing, and transitioning; Enhancing communications among researchers, technologists, industry, users, and other stakeholders; identifying gaps and opportunities in S&T programmes; and identifying future potential obstacles and risks. S&T managers also use roadmaps to help prioritize those S&T areas that have the highest potential promise.

A S&T roadmap provides a consensus view or vision of a future S&T landscape. There are many more future alternatives, however, the process of roadmapping helps narrow the field of requirements and possible solutions to those most likely to be pursued. In the case of future and emerging technologies with high-impact potential, roadmapping faces particular challenges, which are either specific to this type of technology, or are exacerbated when working around them:

1) Complexity and uncertainty.
2) Draw very long-term visions with a high degree of dreaming or imagination.
3) Face highly prevalent drivers and risks with crucial potential impact over the progression of technology.
4) Increasingly evolve from the confluence of seemingly diverse technologies.

Within this context, this roadmap is divided into three parts[3]:

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[2] Ronald N. Kostoff and Robert R. Schaller. "Science and Technology Roadmaps", IEEE Transactions on Engineering Management, Vol. 48, No. 2, May 2001.

[3] There are examples in the bibliography showing similar roadmapping exercises as, for example, The Illinois Science and Technology Roadmap, Sept. 2014, prepared in partnership with Elsevier and Ocean Tomo.

Part I: Drivers and knowledge creation in key FET

Using data from bibliographies, projects and other information sources (studied by implmenting an Intelligence Augmentation process), together with input and advice from experts, to understand the main drivers, and also the greatest risks.

Part II: Identifying high-potential technology clusters

To identify clusters that can drive technology through partnerships that cut across sectors. Technology clusters present a more granular perspective, enabling identification of emerging strengths where research activity is strong but interdisciplinay connectivity is lacking.

Part III: Harnessing roadmap technology cluster opportunities

Synthesize the opportunities and gaps into long-term visions for these technology clusters, offering a list of cross-cutting programme and policy recommendations.

Figure 2. Parts of PREFET's roadmapping exercise and summary of the methodological approach.

It was decided to address Part III in the form of "**Dreams**" (unique and ambitious visions of the new opportunities that one or several technology clusters could offer to humanity) and "**Nightmares**" (high-level visions of the main concerns about how these new technologies could be used or what they could morph into, so that they could be considered while managing R&D).

This allowed us to face specific challenges around roadmapping FET (e.g. uncertainty) and creating inspiring, easy to understand and visual future-oriented targets. This was also an effective strategy to synthesize all input from members of the ExC, who belong to interdisciplinary research fields. These dreams and nightmares act as the necessary framework to understand and provide inspiring context to the more technical and scientific-oriented 20 trends from PREFET.

3.1. Trends’ clusters

Clusters integrate technology network analysis, evaluate network strengths, and highlight R&D collaboration opportunities. Three input sources were used to define clusters of trends in PREFET’s Top list (organised by the importance of inputs):

1) “Data mining” relationships. From the AI-augmented desktop research carried out during the project, there appear to be more relationships and collaborations between the trends being clustered.

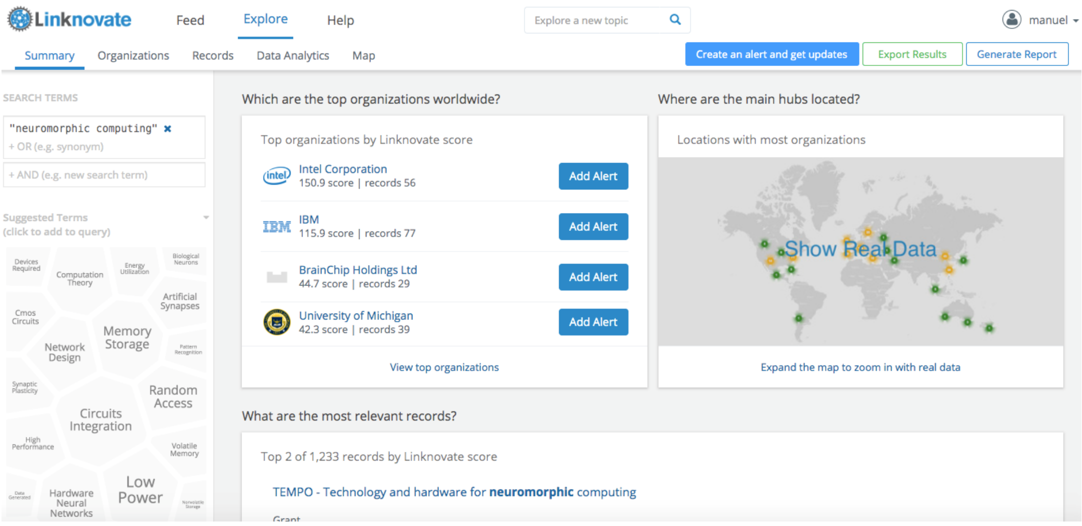


Figure 3. Example of exploratory analysis of a query, and how interrelationships among key words and players are shown, e.g. “neuromorphic computing”

2) Identification of one trend as an enabler of another trend under analysis during the workshops with members of the ExC. This occurred when members were asked about which milestone would be critical to advance a topic to the next level.

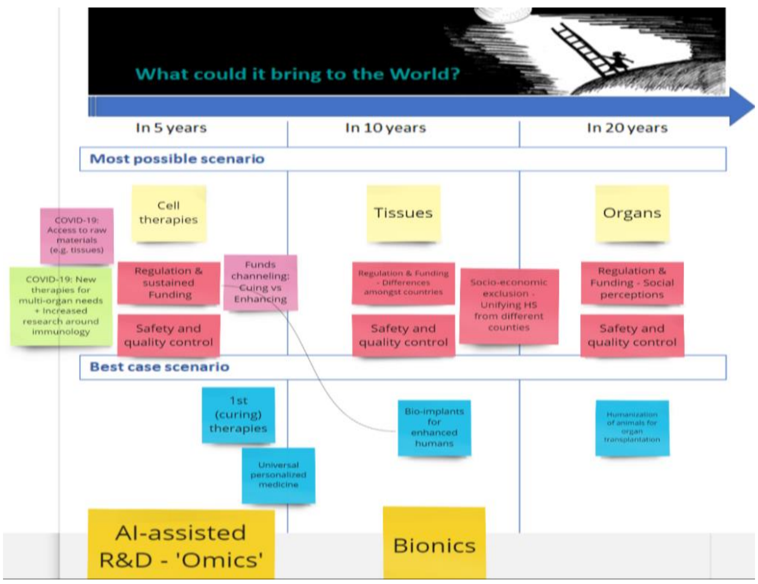


Figure 4. One example of trends identified as key enablers for the evolution of a technology during the workshops with ExC (orange Post-it notes normally at the bottom of the canvas).

3) Insights generated during the Trendington event, when experts were asked to participate in a “caravan workshop” around all trends to search for synergies among them after an exploration phase and having worked on identifying opportunities and challenges for each of them.

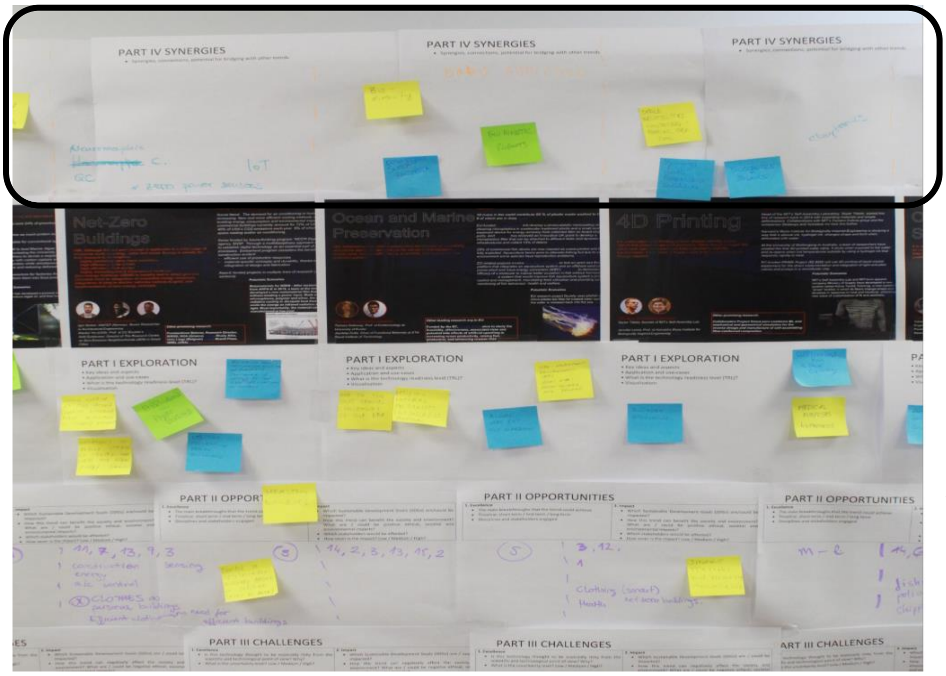


Figure 5. Exploring potential synergies among trends across areas during the Trendington event in November 2019 (top line in picture).

The following tables summarize the conclusions about clusters of trends.

Table 2: Proposed clusters around the list on top 20 trends in future and emerging technologies.

ICT for an interconnected society	• Chemputing & 3D Printing Molecules, Beyond 5G Hardware, New Approaches to Data Interoperability in IOT, New Neuromorphic Computing hardware & Biomimetic AI • Limits of Quantum Computing, Trustworthy AI, Adaptive Assurance of Autonomous Systems
Biotechnology & Health Sciences	• Regenerative medicine, Cellular Senescence & Life Extension, Cognitive Augmentation, Drug Discovery & Manufacture Using AI • Biorobotics & bionics, Bioinformatics and AI for Omics
Environment, Energy & Climate change	• Energy Efficient Water Treatments • Algae and Microorganisms Against Climate Change, Arctic Climate Change • High Temperature Superconductivity & Twist Electronics • Net Zero Concepts & Beyond Smart Grids, Zero Power Sensors & Ocean Wiring and Sensing • Self-Healing Batteries

[4] During the workshops, the three questions posed to members of the ExC (descibed in Section 2) were transformed into a graphical canvas that allowed rapporteuing results in a clearer and more participatory way (see Figure 1).

Table 3: Cross-area clusters identified from the list of the top 20 trends in future and emerging technologies.

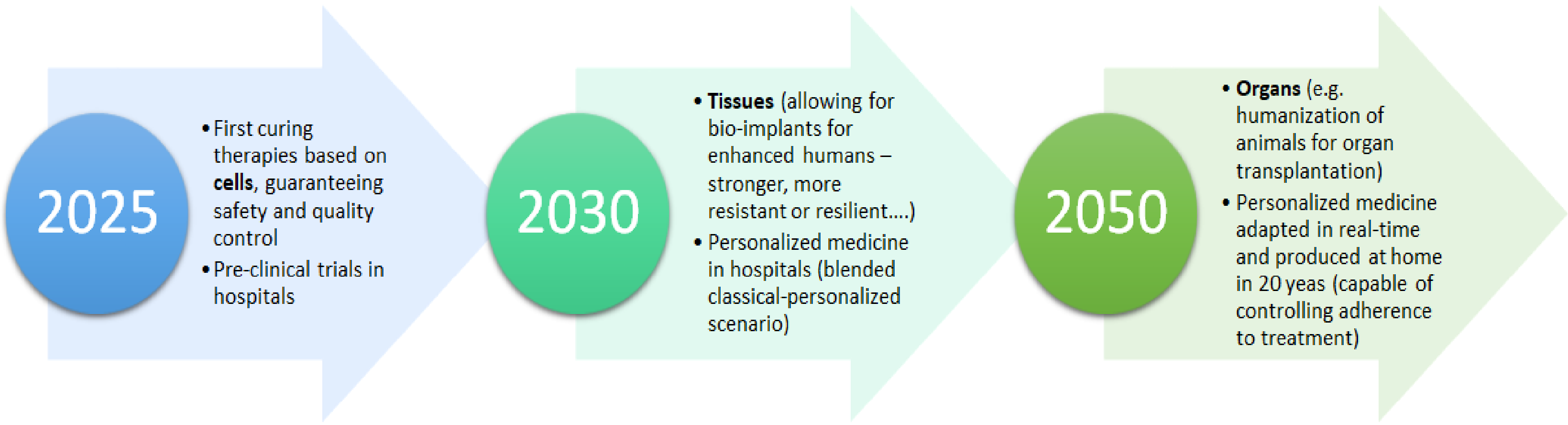
Algae and Micro-organisms Against Climate Change Biomimetic AI	Bioinformatics & AI in Genetics Anonymous Analytics Ethically Trustworthy AI	Self-Healing Batteries Bio Robotics/ Bionics	Net Zero Buildings Zero Power Sensors Neuromorphic Computing	Zero Power Sensors Bio Robotics/ Bionics Regenerative Medicine Biomimetic AI Self-Healing Batteries Beyond 5G Hardware	Cellular Senescence & Life Extension Ethically Trustworthy AI Drug Discovery & Manufacture Using AI Neuromorphic Computing

3.2. Dreams

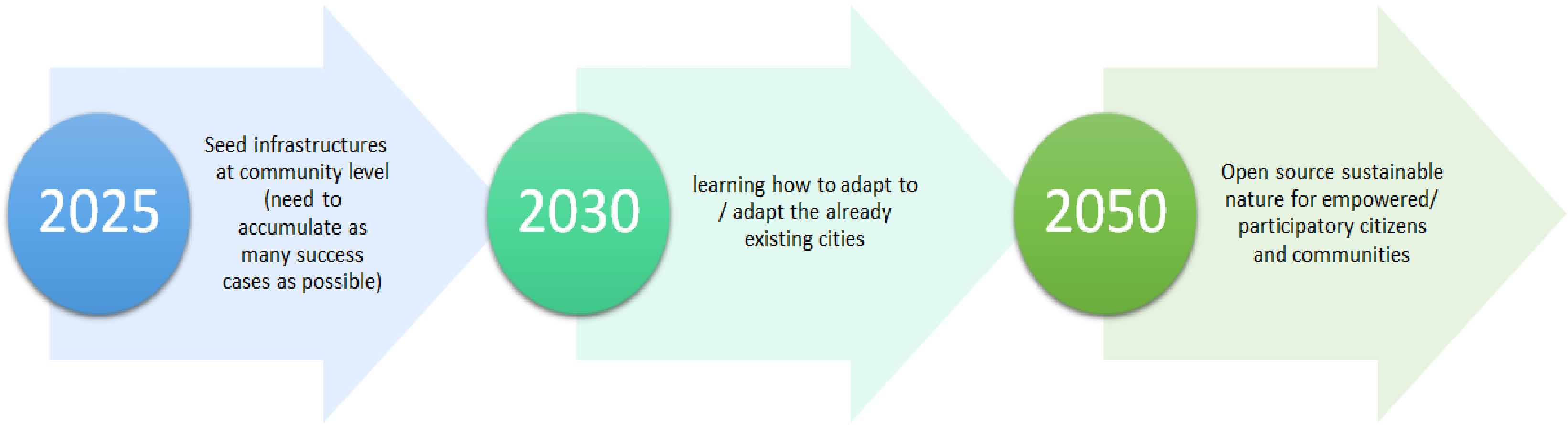
The following table shows the list of 'dreams' defined for roadmapping purposes. This list has two different parts:

1) Trends for which a timeline of milestones is foreseen (e.g. Beyond the limits of Quantum Computing), also listing the main needs to meet key milestones ahead to transform this dream into a reality (scientific and technological ones as well as societal and regulatory) (Table 4. A).
2) Trends for which more visionary scenarios have been drawn that will be possible only if several FET meet their timeline milestones and strong interdisciplinary synergies are created. The needs to transform these trends into realities have been analysed but a specific timeline of milestones cannot be prepared yet (Table 4.B).

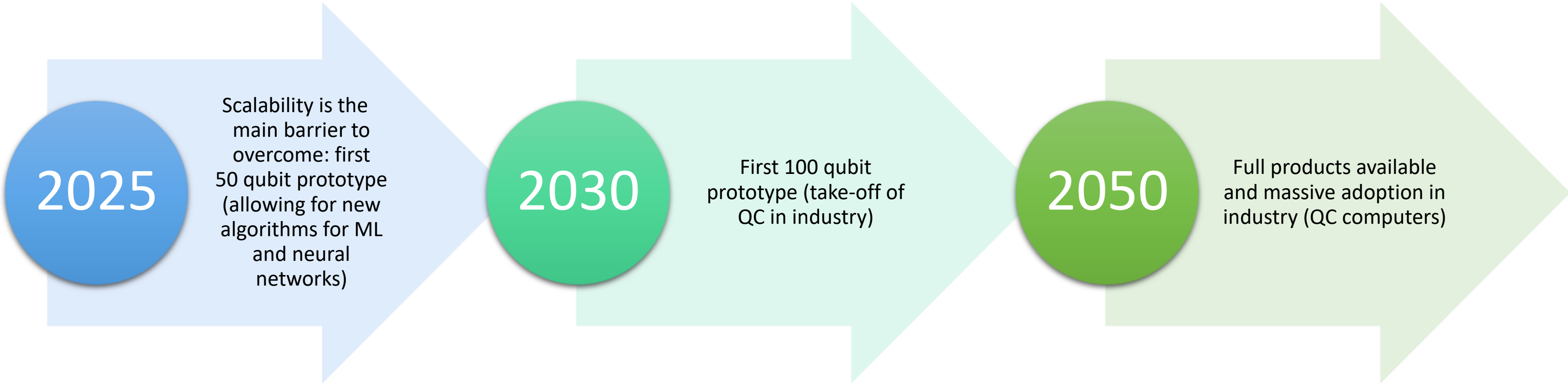
Table 4: Positive high-impact scenarios that could be made possible by top trends' clusters in future and emerging technologies.
A) Trends for which a timeline of milestones can be presented.

IMAGINE....		Associated trends' clusters	Main needs to meet key milestones ahead to transform this dream into a reality
Dream 1 **ENHANCED (SUPER) HUMANS**	Healthier humans with mental and physical capabilities today only imagined for super-heroes, such as self-healing, upgraded memory, 'forever young', with 'super' olfaction (e.g. disease) / sight / hearing (e.g. under water), … Of course, all technological breakthrough comes with risks, in this case these are mainly related to new and more extreme social disparities (see section on Nightmares).	• Regenerative medicine, Cellular Senescence & Life Extension, Cognitive Augmentation, Drug Discovery & Manufacture Using AI • Biorobotics & bionics, Bioinformatics and AI for Omics • Ethically trustworthy AI • New Neuromorphic Computing hardware & Biomimetic AI • Self-healing batteries	S&T: • Micro-transactions amongst technologies • Open, accessible, extensive DNA databases • Quantum computing OTHER: • New patient journeys and culture in health services provision • Efficient regulation
			

IMAGINE....		Associated trends' clusters	Main needs to meet key milestones ahead to transform this dream into a reality
Dream 2 **ANT-LIKE BEHAVIOR OF ALGAE (OR MICROORGANISMS) FOR SMART CITIES**	Algae and/or microorganisms making useful products by cooperative development similar to the behaviour of ants. For example: as a source of Drug Molecules, used for Healthy Ageing, in distributed/cooperative urban algae farms, becoming an increasing source of protein resources and other nutrients, biofuel, eating garbage, ... altogether at (smart) bio-homes creating "perfect" circular economy loops. In relation to the main fundamental risk related to this 'Dream', it might cause critical changes in ecosystems.	• Net Zero Concepts & Beyond Smart Grids, Zero Power Sensors & Ocean Wiring and Sensing • Algae and Microorganisms Against Climate Change, Arctic Climate Change • New Neuromorphic Computing hardware & Biomimetic AI	S&T: • Biocompatible sensors • Adapted types of precision farming OTHER: • Engagement of local authorities • Making lifestyle changes a good experience



IMAGINE....		Associated trends' clusters	Main needs to meet key milestones ahead to transform this dream into a reality
Dream 3 **QUANTUM ACCELERATION OF TECH**	Quantum Computing as an enabler of calculations and super complex and realistic accelerated parallelized simulations of chemistry, pharma, bio and other disciplines, environment, and social systems. For example, to support decision systems and simulate / control humanoids / human (or not) assisted living. In this case, the most relevant risk today is related to a potential collapse of security systems.	• Limits of Quantum Computing, Adaptive Assurance of Autonomous Systems	• Achieving scalability • Overcoming decoherence • New modelling tools • Cloud quantum computing as a service



IMAGINE....		Associated trends' clusters	Main needs to meet key milestones ahead to transform this dream into a reality
Dream 4 **DECENTRALIZED/ DEMOCRATIZED (BIO)CHEMISTRY**	100% personalized treatments adapted in real-time (e.g. blended medicines, doses, …) and rapid response systems, accessible from home by clicking a printer button (local production of complex drug solutions including formulations). Also, this will open the gateway to self-driving labs. The most relevant risk is related to the misuse/malware use of the technology (see section on Nightmares).	• Chemputing (3D Printing Molecules), Beyond 5G Hardware, New Approaches to Data Interoperability in IOT, New Neuromorphic Computing hardware & Biomimetic AI • Trustworthy AI • Regenerative medicine, Cellular Senescence & Life Extension, Cognitive Augmentation, Drug Discovery & Manufacture Using AI • Biorobotics & bionics, Bioinformatics and AI for Omics	S&T: • Sustainability and accessibility of raw materials (delivered at home) • formal architecture and models OTHER: • Legal framework & how to manage central resources and infrastructures if needed at all, as well as to manage IP when relevant

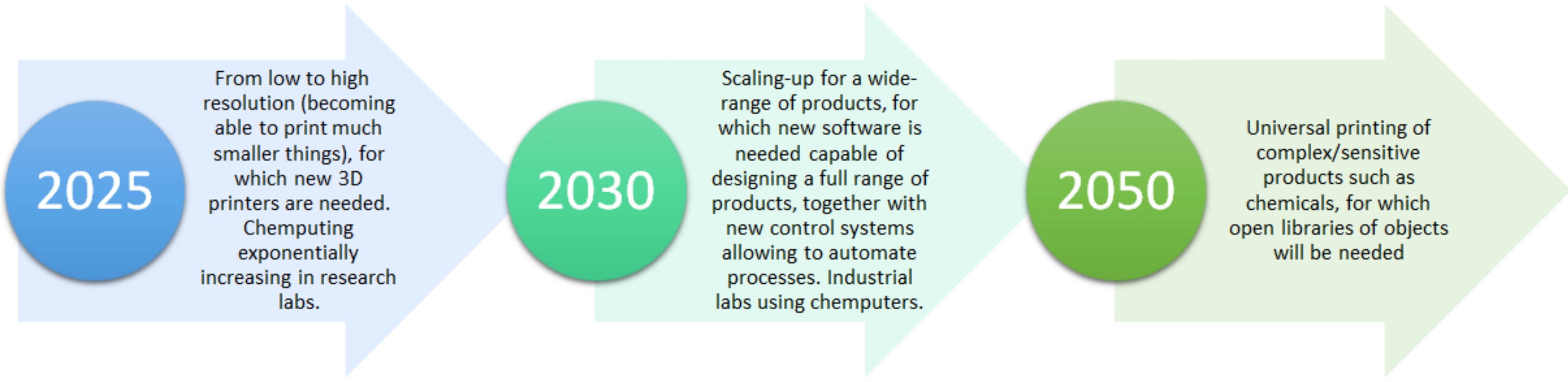


Table 4: Positive high-impact scenarios that could be made possible by top trends' clusters in future and emerging technologies. General time frame: 2050.
B) Visionary scenarios that will be possible only if several FET meet their time-bound milestones and strong interdisciplinary synergies are created.

IMAGINE....		Associated trends' clusters	Main needs to meet key milestones ahead to transform this dream into a reality
Dream 5 **SUSTAINABLE (ALMOST) NEAR-ZERO ENERGY CIVILIZATION**	The vision is for integrated systems (e.g. energy, water, and bio-systems such as microbiomes) interacting together in perfect circular loops. Also, opening the door to new ways of producing large amounts of 100% sustainable energy to 'feed' technology surrounding humans (for example, High Temperature Superconductivity & Twist Electronics could enable the vision of distributed / democratized nuclear fusion).	• Energy Efficient Water Treatment • Algae and Microorganisms Against Climate Change, Arctic Climate Change • High Temperature Superconductivity & Twist Electronics • Net Zero Concepts & Beyond Smart Grids, Zero Power Sensors & Ocean Wiring and Sensing • Adaptive Assurance of Autonomous Systems • New Neuromorphic Computing hardware & Biomimetic AI	• Equalising trade-offs between trends (i.e. water mining -extracting valuable materials from water- vs energy consumption).
Dream 6 **NEAR-ZERO ENERGY IMPACT FOR ACCELERATED TECHNOLOGY**	Related to "Sustainable near-zero energy civilization" but focuses on the concerns of several experts that some of these trends require an increase in energy consumption we are not ready to obtain without a crucial impact to the environment.	• Algae and Microorganisms Against Climate Change, Arctic Climate Change[5] • Net Zero Concepts & Beyond Smart Grids, Zero Power Sensors & Ocean Wiring and Sensing • High Temperature Superconductivity & Twist Electronics • New Neuromorphic Computing hardware & Biomimetic AI	

[5] Algae could be a way to achieve this - the other one frequently mentioned is Nuclear Fusion, part of PREFET's 45 pre-validated trends, although not prioritized in the list of top 20 FET trends.

3.3. Nightmares

Table 6 shows the main concerns about the potential impacts caused by advances in the development of the top 20 future and emerging technologies. These were expressed by members of the ExC, during online open consultation and interviews with stakeholders, and during the Trendington event.

Table 5: Potential negative scenarios that the top 20 trends in future and emerging technologies could create.

IMAGINE....		Associated trends' clusters	Main risks and needs to meet key milestones ahead to transform this into a dream
Nightmare 1 **EVIL AI**	AI controlling and dictating humans and life on Earth with no means to 'escape' from it (sometimes, not even conscious of the need to do so). AI currently exists in a specialized form. It is based on the ability of an AI agent to fulfil a specific task (e.g. predict the weather, drive a car, etc.). It is a matter of time before a set of AIs can be arranged to collaborate, to construct what we may call a "Super Intelligence" or "Artificial General Intelligence" (AGI) able to provide solutions to more complex or generalized problems. Such an entity could be used as a service to society, if it is broadly accessible, or it can be a significant adversary against humanity's goals. It is an evolutionary process that will either transform society for the better or cause its demise in the process of transformation.	• Limits of Quantum Computing, Trustworthy AI, Adaptive Assurance of Autonomous Systems • Beyond 5G Hardware, New Approaches to Data Interoperability in IOT, New Neuromorphic Computing hardware & Biomimetic AI • Biorobotics/bionics, Bioinformatics and AI for Omics	MAIN RISKS FROM THESE TRENDS: • Hacking systems that are safe today • Geo-Socio-economic exclusion. Inequality exacerbated by technology. NEEDED TO PREVENT THEM: • Ethical baseline over which AI is trained • Massive generation of accurate data • Trained new professionals • Active participation of users and citizens
Nightmare 2 **CHEMICAL AND BIO WARFARE**	Chemical weapons and vital drugs (even food) managed and used following war-like approaches (to decentralize its production, to hurt, to dominate, ...).	• Chemputing (3D Printing Molecules), Beyond 5G Hardware, New Approaches to Data Interoperability in IOT, New Neuromorphic Computing hardware & Biomimetic AI • Regenerative medicine, Cellular Senescence & Life Extension, Cognitive Augmentation, Drug Discovery & Manufacture Using AI • (Un)Trustworthy AI	MAIN RISKS FROM THESE TRENDS: • Geo-Socio-economic exclusion. Inequality exacerbated by technology. • Illegal production of sensitive products (e.g. printing weapons and drugs) NEEDED TO PREVENT THEM: • Legal framework & proper management of central resources and infrastructures if needed

IMAGINE....		Associated trends' clusters	Main risks and needs to meet key milestones ahead to transform this into a dream
Nightmare 3 **TECH-BASED SLAVERY**	Rich societies having access to "eternal welfare" and becoming super-humans, while poor societies fall behind in everything (concern expressed both during the Trendington event and workshops with experts).	• Limits of Quantum Computing, Trustworthy AI, Adaptive Assurance of Autonomous Systems, Neuromorphic Computing & Biomimetic AI • Regenerative medicine, Cellular Senescence & Life Extension, Cognitive Augmentation, Drug Discovery & Manufacture Using AI • Biorobotics & bionics, Bioinformatics and AI for Omics • Net Zero Concepts & Beyond Smart Grids, Zero Power Sensors & Ocean Wiring and Sensing	MAIN RISKS FROM THESE TRENDS: • Geo-Socio-economic exclusion. Inequality exacerbated by technology. • Brain violation, genetic racism • Anti-democratic shifts in power NEEDED TO PREVENT THEM: • Legal framework & proper management of central resources and infrastructures if needed • Avoid over-regulation on behalf of a bigger higher collective good (e.g. oversight and lack of privacy for public health), and under-regulation due to lobbies with interests in the markets enabled by these technologies

4. Conclusions and add-ons

As the roadmapping exercise concluded, we realised the value of focusing on the definition of 'Dreams' and 'Nightmares' which implies a vision-driven definition of challenges that are aligned with the nature of future and emerging technologies (FET). Starting from the list of the top 20 informed and prioritised trends for the future, most of the relevant opportunities for interdisciplinary, rich research and development were identified in the form of clusters of trends that could enable unique new horizons for science, technology, the environment and life, as well as key risks that need to be addressed in the next 5 to 30 years. These will require consideration, while managing R&D, by researchers as well as future end-users and policy-makers (Figure 6).

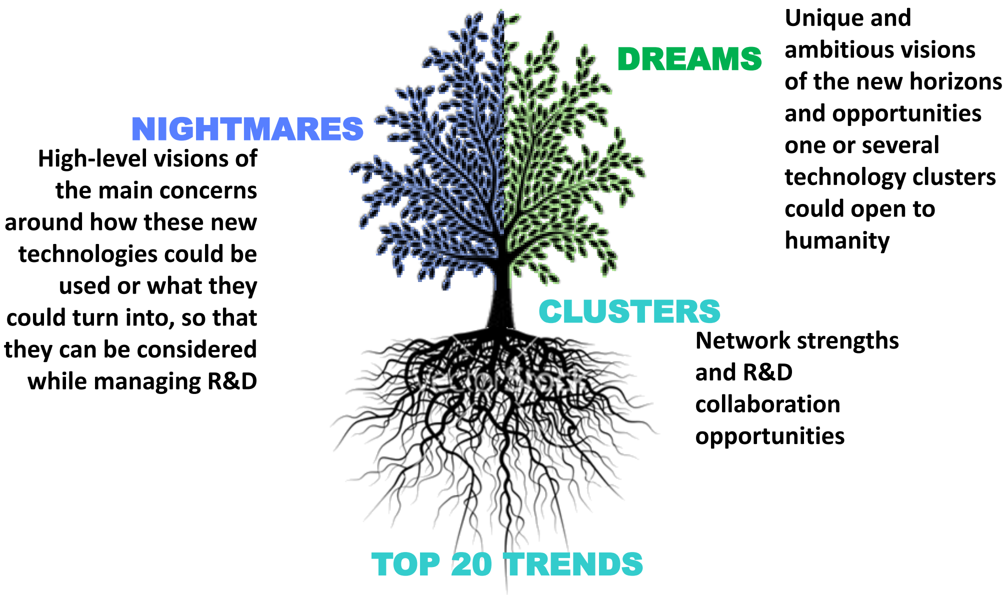


Figure 6. Graphical summary of the approach followed for the roadmapping exercise.

This **methodological approach** provides better identification of risks and drivers, as well as synergies and interdependencies among technologies. It also clarifies specific windows to the future. These windows can then be assessed in spite of the uncertainties inherent in the nature of technologies which are at their earliest stages of development, and which can have great impacts on research and at socio-economic and environmental levels. The approach also facilitates setting time milestones consistent with the evidences and information gathered around each trend and the knowledge provided by the members of the Experts Committee, and it is sufficiently ambitious to leverage progress. For these reasons, this methodology and its outcomes about the main identified FET for the period 2021-2050 have been compiled in this document under the title "**Windows to the future around Top trends in Emerging Technologies. Roadmapping exercise**".

These ***windows*** stress three main facts in relation to FET and the high-level visions around them:

1. The identified emerging technologies have not yet reached an established dominant design phase. Understanding and steering the diverse applications, the opportunities, and risks in their use, requires a collaborative effort not only in the technological communities in which they are generated, but at a broader societal level. A systematic, multi-disciplinary, multi-stakeholder and multinational coordinated approach is critical for these vision-led challenges (trends and dreams) to achieve the next level while avoiding possible risks and nightmares. Trends do not enjoy a "free lunch", whereby they can (and will) advance into clusters and address main 'Dreams' to become general time milestones from year 2025 to year 2050.
1. Windows also require the co-evolution of several trends / dreams in parallel. For this reason, new technologies also need to be resilient, meaning the aim is not to pursue an optimum, but to build a system that can work reasonably well under many different conditions. Past science and research performance is no guarantee of such future performance. Additionally, co-evolutionary advances in science and society may lead to unforeseen insights, discoveries, and urgencies that 'Nightmares' have not considered and also create competition in the fulfilments of 'Dreams' by a) disrupting status quo acceptance of limits/directions for R & I; and b) causing public investment contradictions/diversions requiring explanations of R & I trade-offs that require a more "educated/sensitised" public and commerce for acceptance.
2. Windows require long-term cycles and benefit strongly from preventing excess pressure from commercial interests. This is also a matter of keeping EU universities creative, imaginative, and competitive in the future, and highly ranked in key enabling sectors of industry and society.

Experts also stress the crucial roles to be played by regulation and policy-making. Complex systems may have many trade-offs, sometimes hidden, that threaten the overall sustainability of the final outcomes. For example, the trend "Energy Efficient Water Treatments" was not included in the 'Nightmares'. Even if energy saving measures are, in principle, always considered positive, possible "over-technologisation" of the processes may create some trade-offs, such as the use of large areas for sun-driven sludge drying reducing energy consumption but occupying otherwise fertile soil. A recent example of the importance of policy-making in this context is the policy-based incentivisation of crop production for biofuel. This policy seriously affected the availability and quality of water resources even though the idea was initially considered sustainable.

Regulation will become a driver for technology growth and will help protect trends from transforming into nightmares. However, the creation of unnecessary regulatory blocks must be prevented. This is a great challenge, since regulatory bodies will need to work using a systematic, multi-disciplinary, multi-stakeholder and multinational coordinated approach. Regulatory agencies will also need to work with researchers to understand the details and benefits of the new technology.

The importance of policymaking, steering guidelines and regulation is related to the risks associated with the potential undesirable use of FET. This highlights the relevance of responsible research and innovation (RRI) as a necessary prerequisite for developing and growing disruptive, science-based, long-term technologies. The European framework programme for research, development and innovation (R&I) identifies the following elements of RRI that are particularly relevant in the context of FET[6]:

1. Open access. Innovation is a broad term but innovation frames remain too narrow, rigid, and short-timed, based on 19th century innovation models, to address 21st century challenges and socio-economic contexts. New innovation paradigms should be explored for allowing FET to flourish at maximum potential, such as 'Open-source ideas, innovation or technologies.
2. Ethics. Whatever the technology, risks can be reduced if the system is open, in particular if the system is very complex, although an acceptable balance between openness and business and national interests can be difficult to achieve. We believe that "correction/backup mechanisms" should always be required: Rather than defining clear roadmaps with well-defined targets. It may be better to have more freedom in the proposal of technologies but to also have efficient methods to block or correct potential errors.
3. Public engagement. It is important to assure a diversity of voices for examining key innovation pathways ethically and responsibly. Processes for communicating Citizen Science value could be formulated along with FET development and these could consider fundamental questions such as: Who is it for? Who is benefiting? What economic models does it comply with? How can innovation be opened up beyond elites? How and when will the "winnings/benefits" of FET science and innovation be distributed?

The inequalities of national interests and powers will necessitate international strategies for inclusiveness to deal with these challenges as investments are made in pursuit of 'Dreams'. The Missions[7] approach designed for Horizon Europe (the European framework programme for R&I for the period 2021-2027), can in practice galvanize support for achieving objectives.

Multinational coordination must also consider the diversity between locations since the same problem may require different approaches to interdigitate with social differences/traditions. One option would be to combine top-down (coordination) and bottom-up (local actions) approaches.

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[6] "In practice, RRI will be implemented as a package that includes multi-actor and public engagement in research and innovation. This will enable easier access to scientific results, consideration of gender and ethics in the research and innovation content and process, and formal and informal science education." - https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation (we have excluded gender as this assessment was beyond the scope of the roadmapping exercise).

[7] Missions in Horizon Europe: https://ec.europa.eu/info/horizon-europe/missions-horizon-europe_en