Development of new methodologieS for InDustrial CO_2-freE steel pRoduction by electroWINning

ΣIDERWIN: A breakthrough technology to decarbonize primary steel production through direct electrification

Webinar November 24th 2021

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 768788

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WELCOME AND INTRODUCTION

José Ignacio Barbero - TECNALIA

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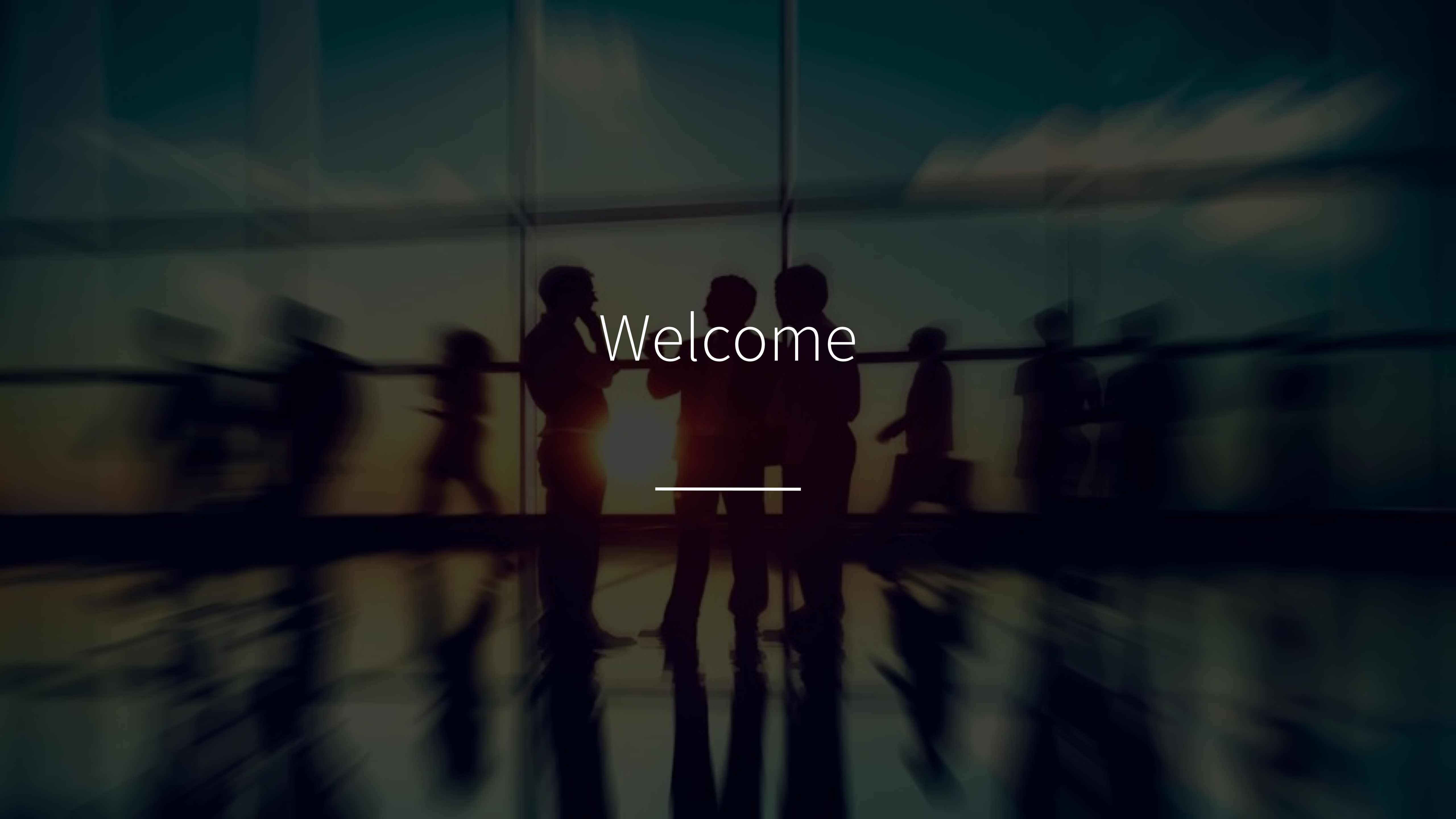
Welcome

AGENDA

Topic	Speaker
Welcome and introduction to ΣIDERWIN project	José Ignacio Barbero (TECNALIA)
The Greening of Steel? Net-Zero Steelmaking for the EU Green Deal: ΣIDERWIN	Jean-Pierre Birat (IF Steelman)
Is electrodecomposition of iron oxide a feasible reaction?	Sevasti Koutsoupa (NTUA)
Is the electrolysis of primary production scalable and industrialisable?	Cédric Flandre (John Cockerill) Thierry Conte (CFD-Numerics)
How decarbonizing primary steel production through electrolysis could play a role in the European power system?	Matthildi Apostolou (EDF) Caroline Bono (EDF)
Does ΣIDERWIN contribute genuinely to deep decarbonisation?	Anna Kounina (QUANTIS)
Final conclusions	Hervé Lavelaine (ArcelorMittal)

Introduction

INTRODUCTION

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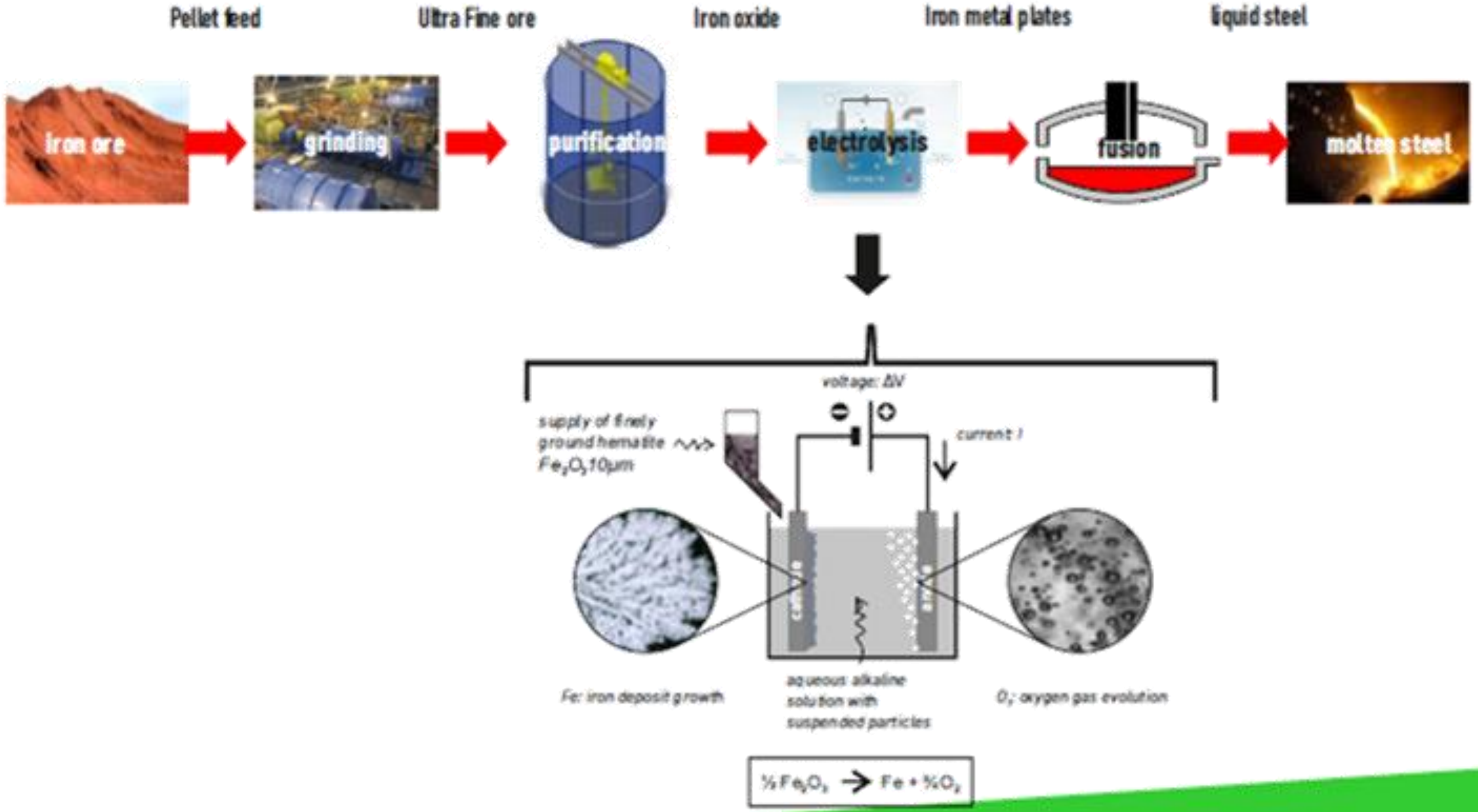
Development of new methodologieS for InDustrial CO_2-freE steel pRoduction by electroWINning

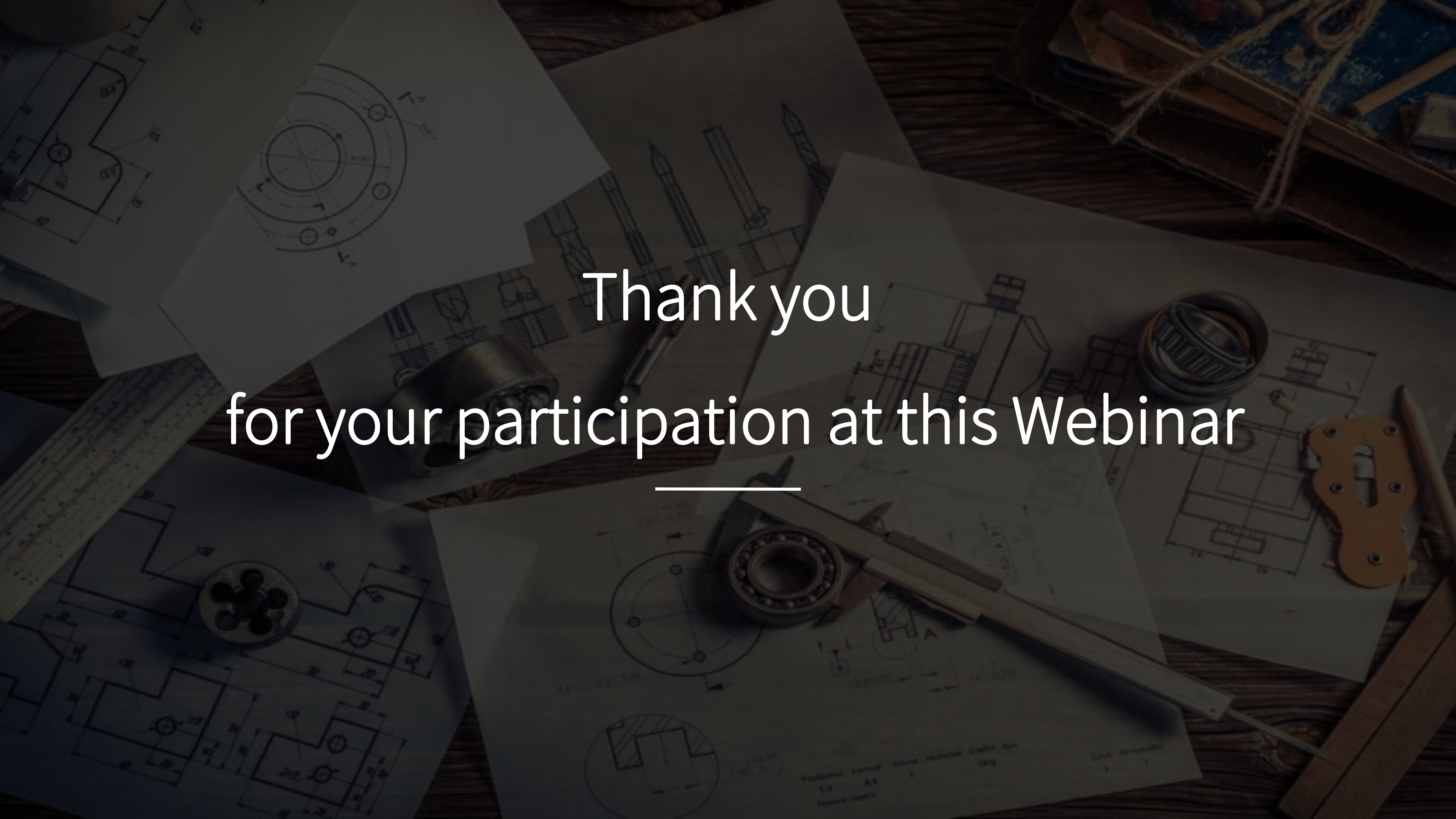
*Develop a **breakthrough innovation** compared to the actual steel production process bringing together steel making with **electrochemical process**.*

*The electrolysis process using **renewable energies** will transform any iron oxide, including those inside the by-products **from other metallurgies**, into steel plate with a **significant reduction of energy use**.*

INTRODUCTION

To develop a **breakthrough innovation**
compared to the conventional
steel production route
by electrowinning iron
from its naturally occurring oxides
at low temperature
in an aqueous based electrolyte.




Thank you
for your participation at this Webinar

Development of new methodologieS for InDustrial
CO_2-freE steel pRoduction by electrowinning

The Greening of Steel?
Net-Zero Steelmaking for the EU Green Deal: ΣIDERWIN

Jean-Pierre Birat – IF Steelman

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- Climate change and the EU Green Deal.
- Net-zero pathways (routes) for steel production.
- Two routes focus on electricity: H_2 direct reduction and electrolysis.
- Today, the webinar is focused on electrolysis, the process called ULCOWIN and then ΣIDERWIN.

Climate Change & the EU Green Deal

by 2050


A zero pollution Europe
Preserving Europe's natural capital
Transition to a Circular Economy
Sustainable Transport
European Green Deal
Farm to Fork
Achieving Climate Neutrality
Towards a Green CAP
Clean, Reliable and Affordable energy
Financing the transition
Take everyone along (Just Transition Mechanism)

Net-Zero Pathways (Routes) for Steel Production

Net-Zero Pathways for Steel Production

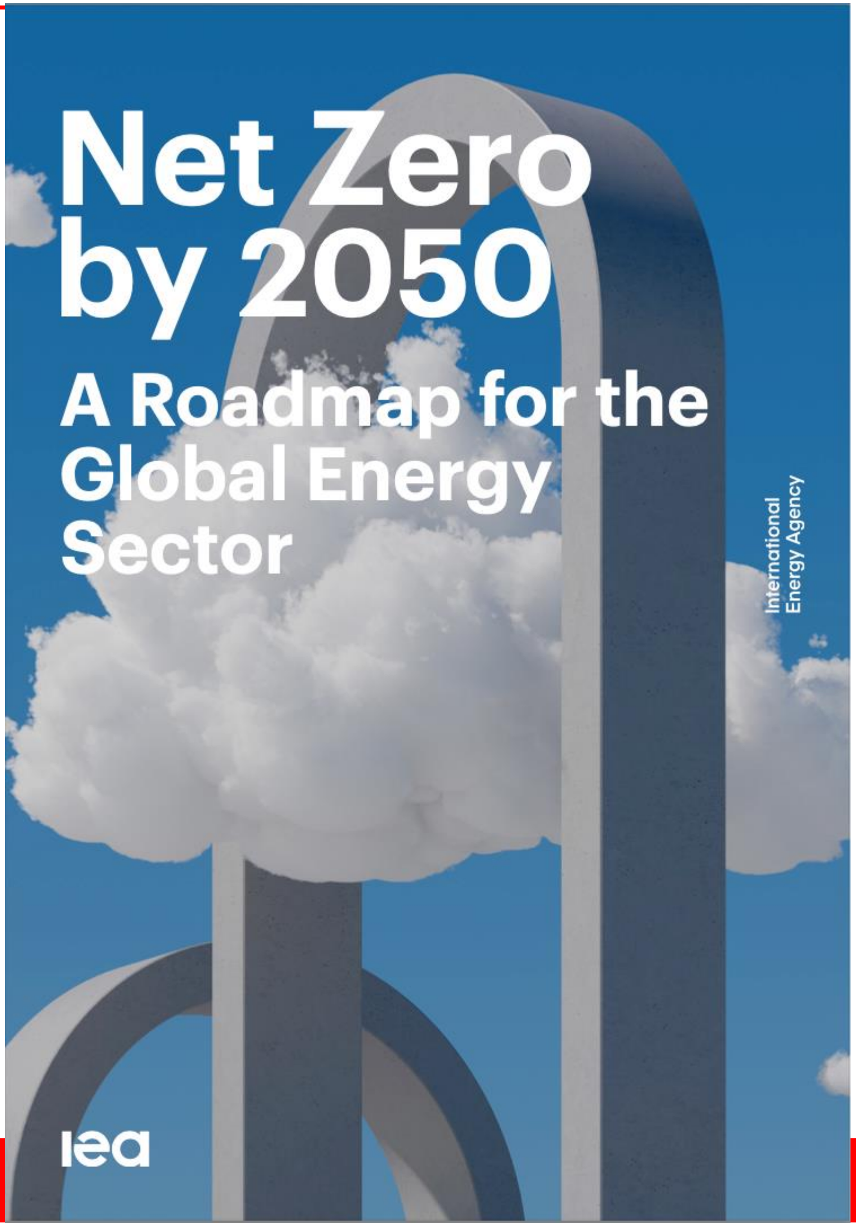
- Only the reduction part of the Integrated Mill (IM) has addressed Net-Zero "properly“.
  - Keep using carbon (coke) and capture CO_2 (CCUS).
    - Blast Furnace with CCUS (top-gas recycling or ULCOS BF, ordinary BF, top-gas recycling BF with plasma at tuyeres).
    - Smelting reduction (HISARNA).
  - Use green H_2 produced by electrolysis of water from green electricity… or NG with CCUS.
    - H_2-reduction is VERY popular these days (hype!!).
  - Use electricity directly to make iron (electrolysis).
  - Use biomass-based carbon, e.g., charcoal or biogas, or…
- The downstream part of the IM still has to address Net-Zero "properly“.
- EAF steelmill should reach (near) Net-Zero simply by using Green Electricity.

Two Routes Focus on Electricity: H_2 Direct Reduction and Electrolysis

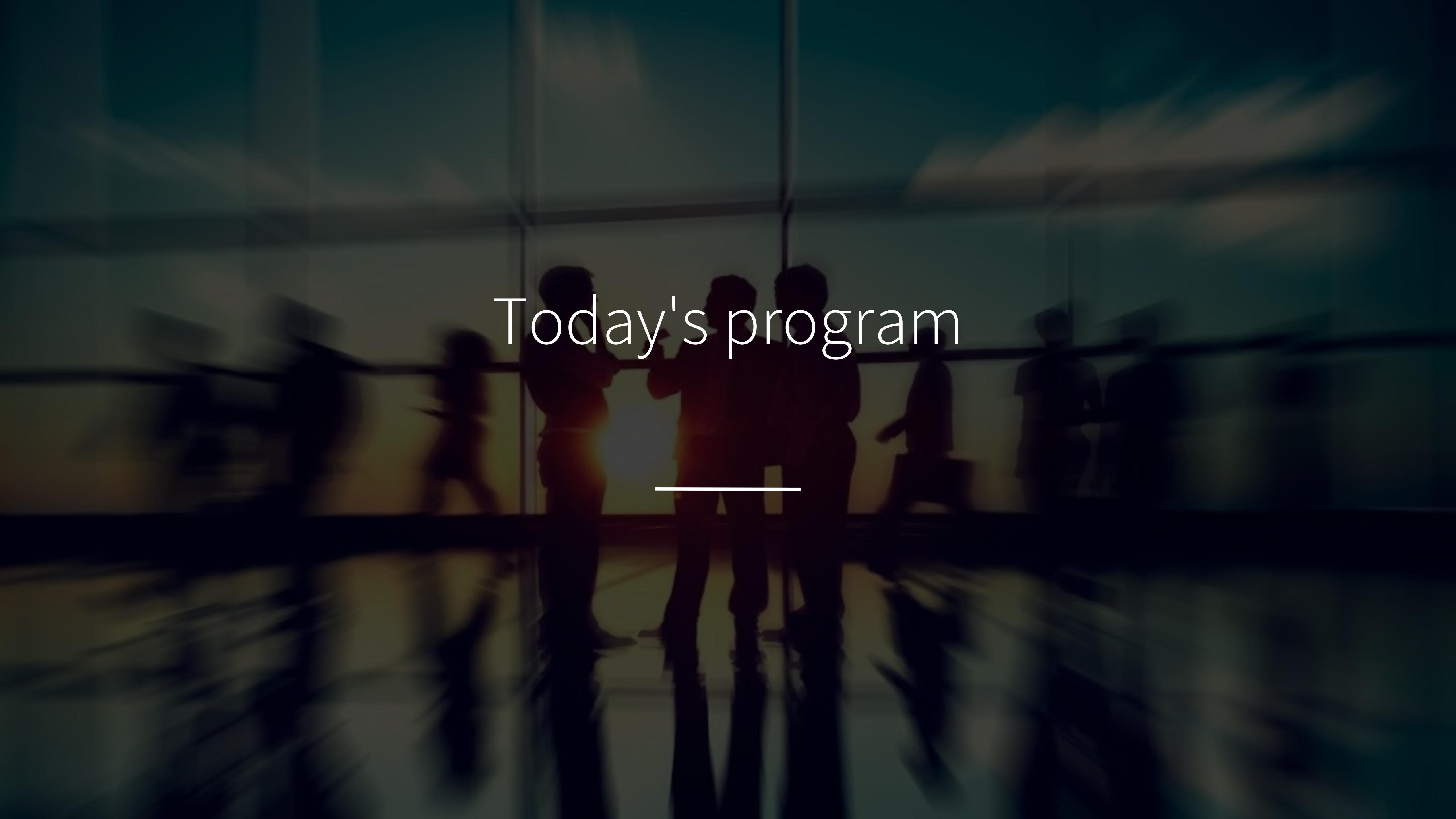
Electrification is the best way to make REN easily available

IEA study of May 2021: a world scenario to reach 1.5 °C.
In 2050:

- Energy demand 8% below today's (+ energy efficiency), GDP doubled, population + 2 G people.
- 2/3 of energy demand come from renewables (REN), i.e., wind, solar, bioenergy, geothermal and hydro. Solar becomes the largest part, increasing capacity 20 times compared to today. Wind increases capacity 11 times.
- Electricity accounts for 50% of energy use, i.e., a 2.5 times increase vs. today.
- 90% of electricity from RENs.
- All cars are electric, either batteries or fuel-cells. All buildings are at least zero-energy.
- No-fossil fuels used for sea and air transport (synfuels, ammonia, hydrogen, biofuels).



Today's program



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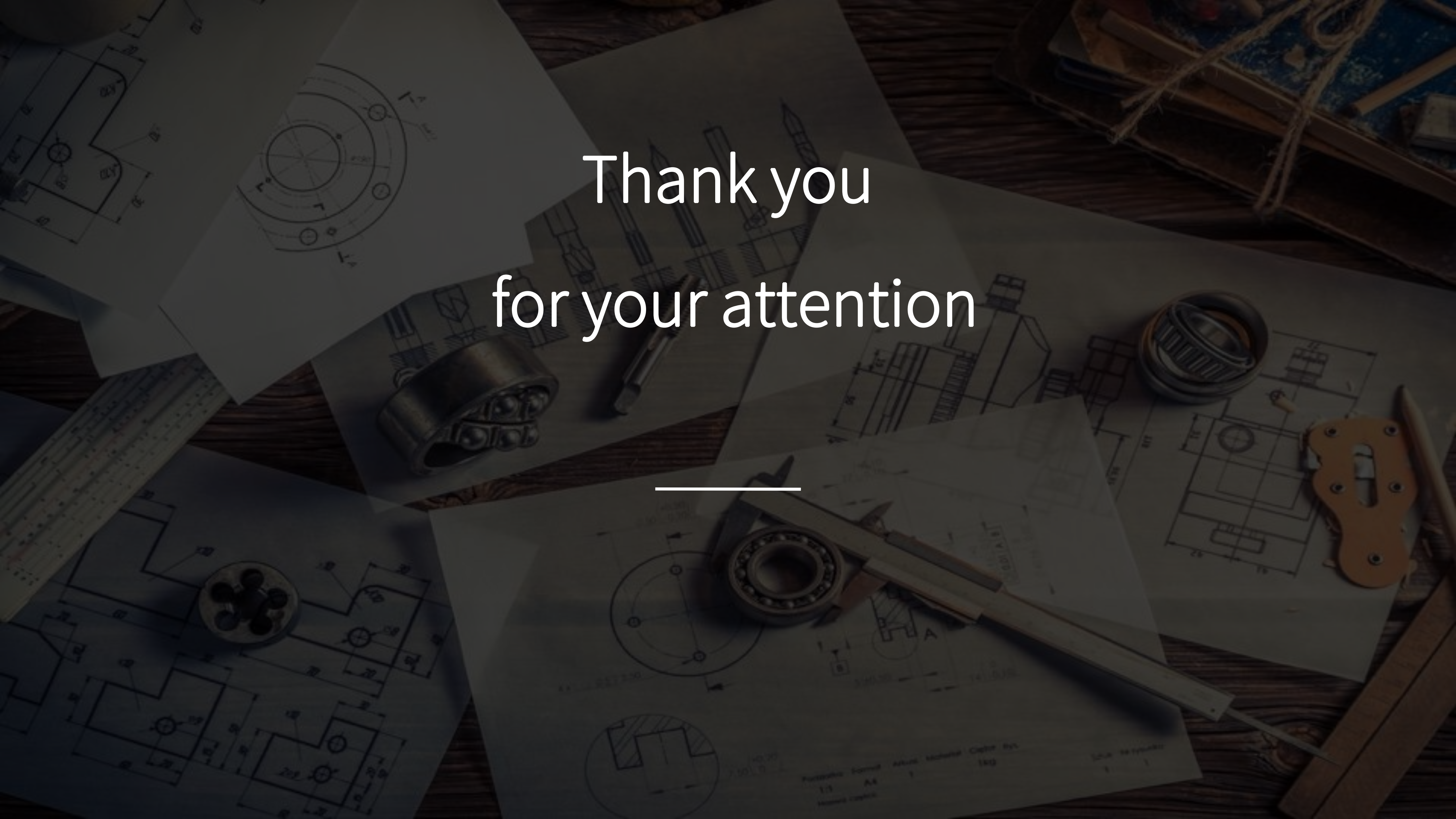
The program of the webinar was designed by Hervé Lavelaine around some provocative questions:

- Can iron really be scavenged from iron oxide (iron ore) by using electricity, i.e., by electrolysis?
- Can laboratory experiments on electrolysis of iron ore really be scaled up to industrial size?
- What role will the demand from electricity by electrolysis steelmills have with the electrical grid and the whole power system?
- Will ΣIDERWIN truly contribute to Net-Zero?


Thank you
for your attention

Development of new methodologieS for InDustrial CO_2-freE steel pRoduction by electroWINning

Is electrodecomposition of iron oxide a feasible reaction?

Sevasti Koutsoupa-NTUA

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Contents

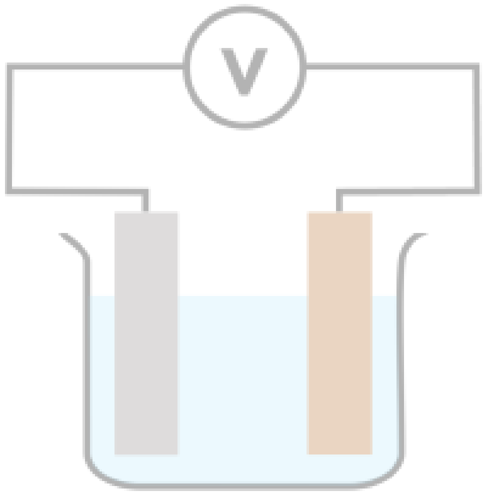
- The theory of iron oxides electrodecomposition.
- The proof of concept.
- Case of alternative raw materials.

What is electrodecompotition?

Decomposition is a type of ***chemical reaction*** *when an*
electric current *is passed through the aqueous solution of a compound.*

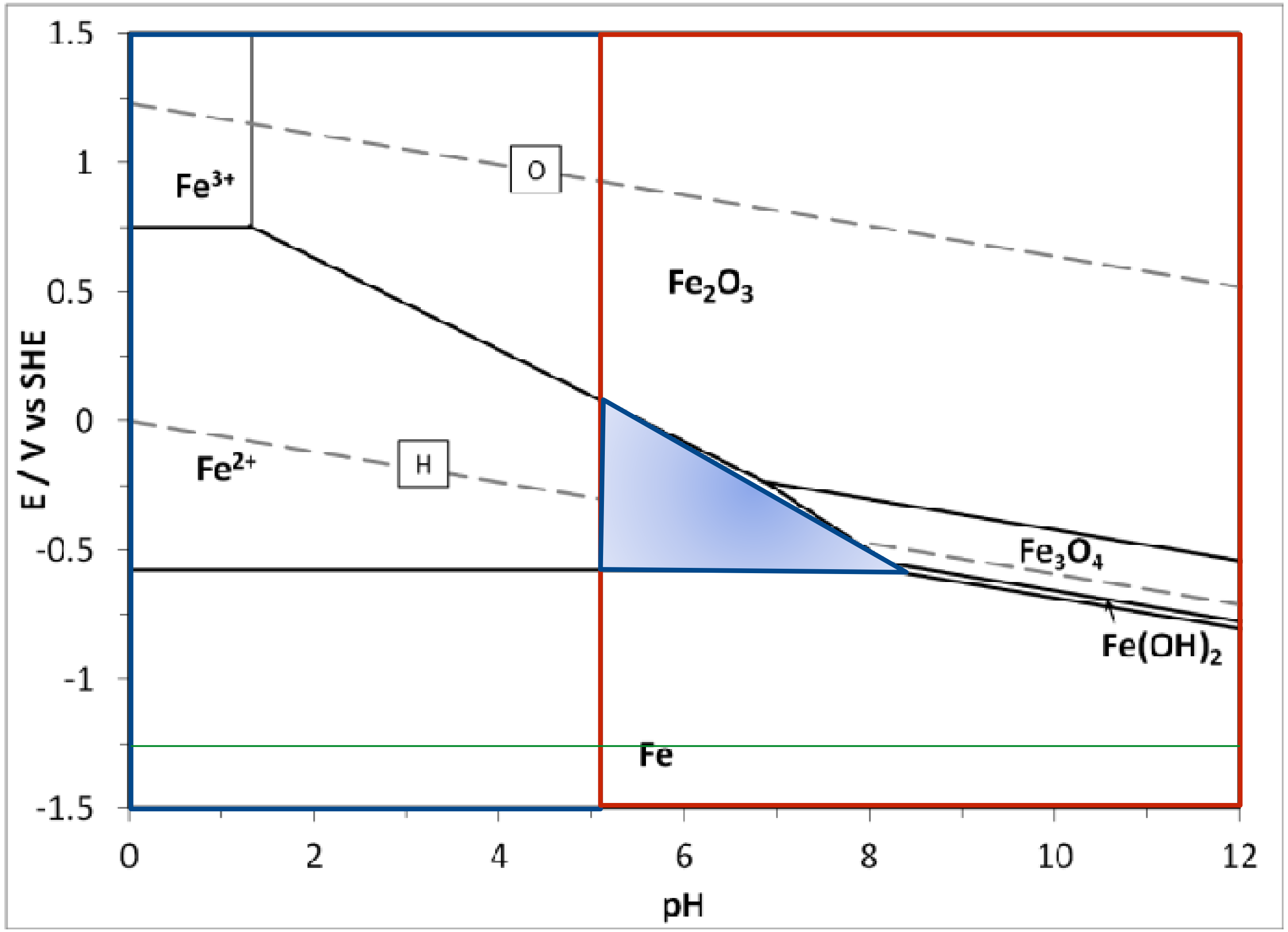
$Fe_2O_3 \rightarrow Fe^0 + O_2$ (g)

$H_2O \rightarrow H_2$ (g) $+ O_2$ (g)



But is this reaction feasible?

Theoretical background



Tanaporn Tanupabrungsun, D. Young, B. Brown, S. Nešić, 2012

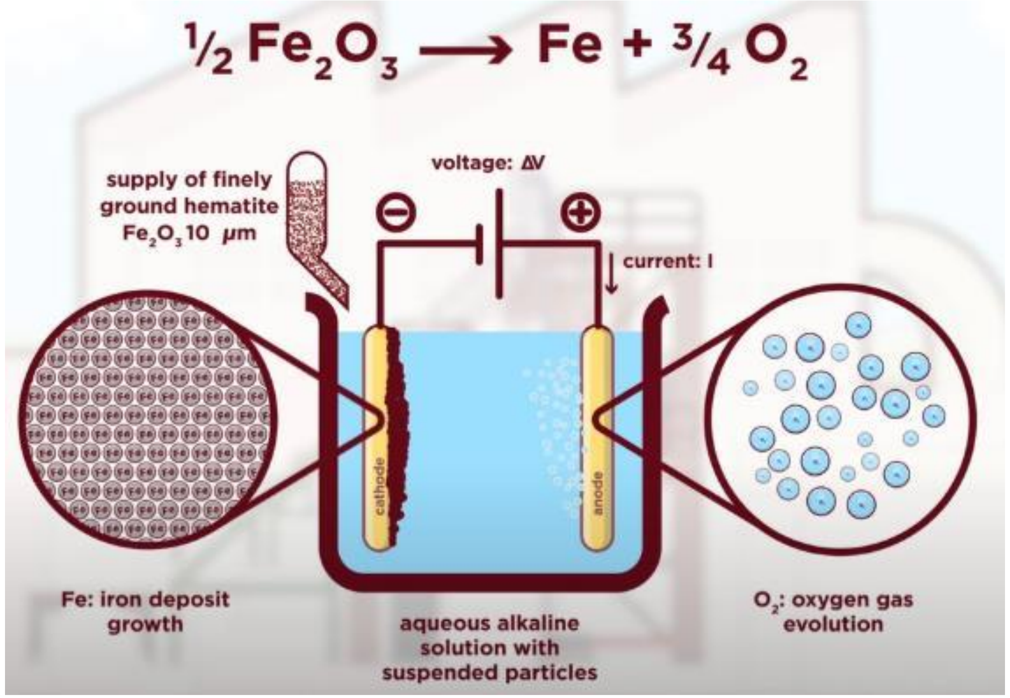
Concerning the Pourbaix diagram* iron oxide reduction is feasible under both acid and alkaline conditions.

Pourbaix diagram is* ***a plot of the equilibrium potential of electrochemical reactions against pH**. It shows how corrosion mechanisms can be examined as a function of factors such as pH, temperature and the concentrations of reacting species.*

Advantage of alkaline system;

Avoid the multivalences of iron oxides, only **Fe^{2+}** is observed.

The idea

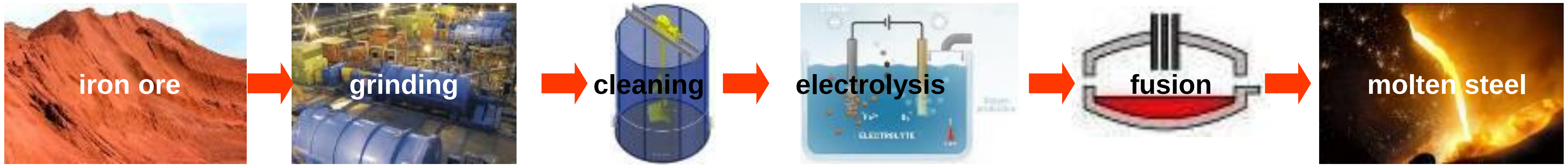


ΣIDERWIN research program used that knowledge and combined:

1. **Alkaline water electrolysis know-how.**
2. **Conventional electrowinning of metals.**

↓

Production of iron through alkaline electrolysis.



But what is really happening inside the ΣIDERWIN cell?

Overall reactions:

Cathode

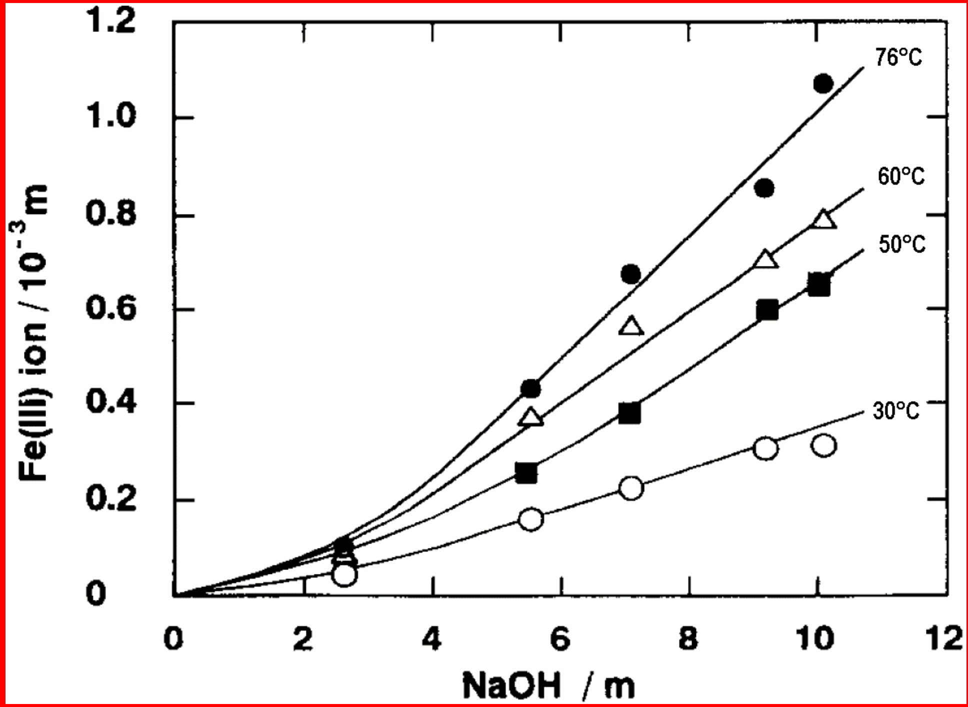
$$Fe_2O_3 + 3H_2O + 6e^- \rightarrow 2Fe + 6\ OH^-$$

Anode

$$4\ OH^- \rightarrow O_2 + 2H_2O + 4e^-$$

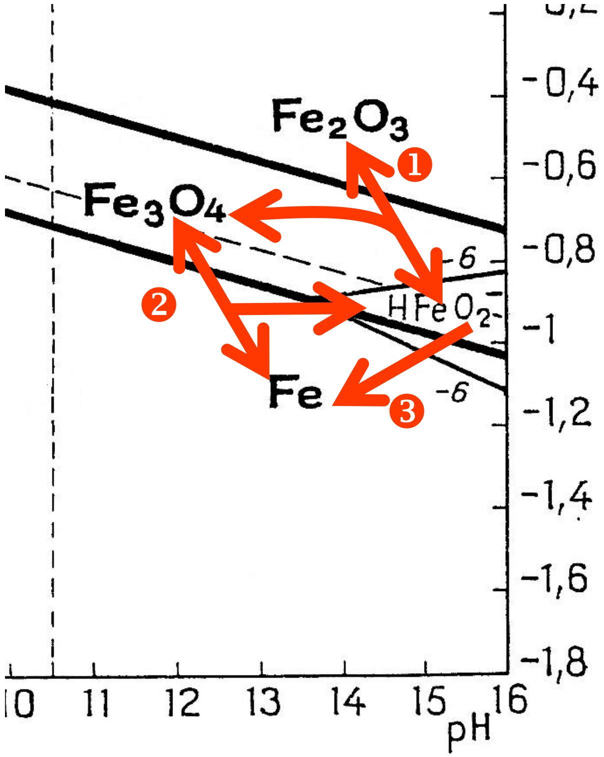
Fe_2O_3 in alkaline media shows poor dissolution at around 2×10^{-3} M in 18 M NaOH at 100 °C.

Not a typical electrodeposition process.



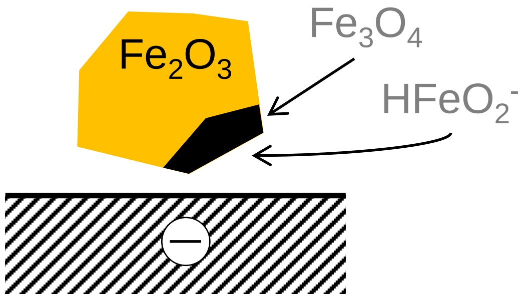
Kanji Ishikawa, Toshiaki Yoshioka, Tsugio Sato, Akitsugu Okuwaki, Solubility of hematite in LiOH, NaOH and KOH solutions, Hydrometallurgy 45 (1997) 129-135.

Mechanism of the cathodic reaction of hematite



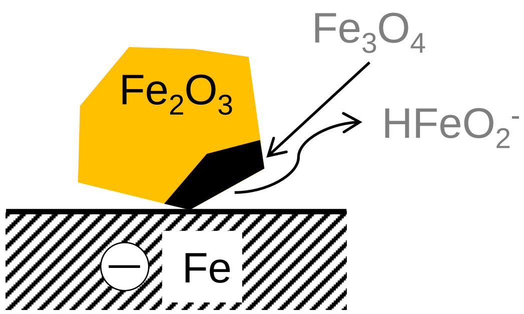
Pourbaix diagram

❶ Chemical reaction



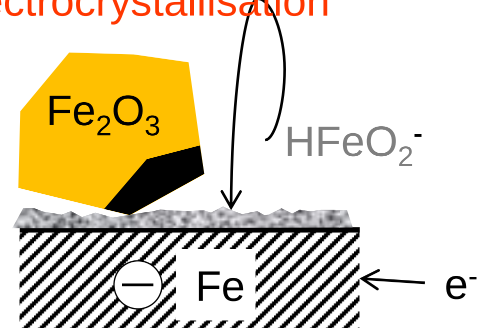
$HFeO_2^- + Fe_2O_3 \rightarrow Fe_3O_4 + OH^-$

❷ Galvanic coupling



$Fe_3O_4 + Fe + 4OH^- \rightarrow 4HFeO_2^-$

❸ Electrocrystallisation



$HFeO_2^- + H_2O + 2e^- \rightarrow Fe + 3OH^-$

	Conductivity ($S.cm^{-1}$)
Fe	$1\ 10^7$
$\alpha\ Fe_2O_3$	10^{-9}
Fe_3O_4	$2\ 10^2$

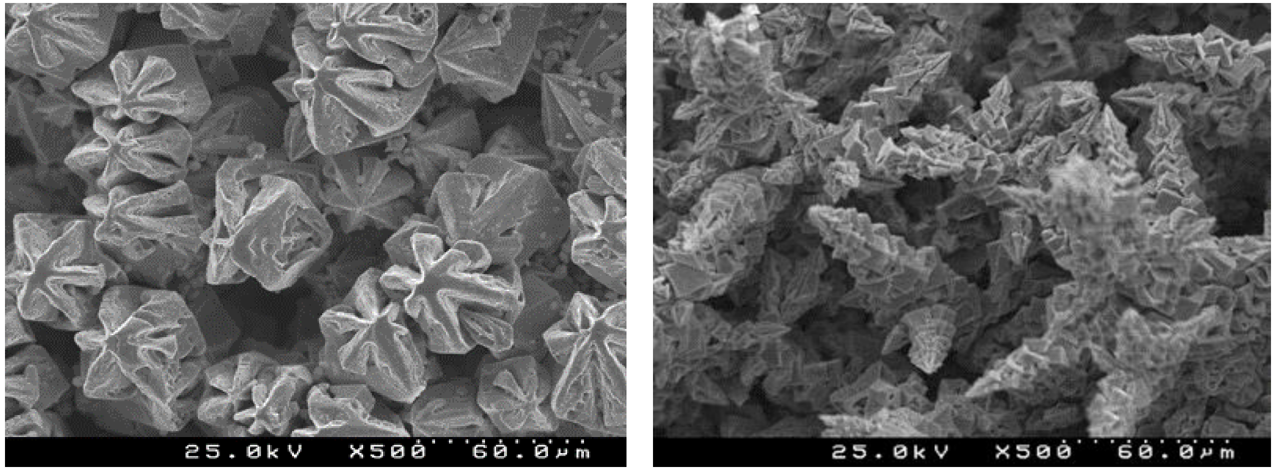
The proof of concept

$\frac{1}{2}Fe_2O_3 \rightarrow Fe + \frac{3}{4}O_2$

- Low temperature electrolysis: 110 °C.
- Conductive aqueous alkaline electrolyte medium 50 wt% NaOH - H_2O.
- Electrolysis is applied to 10 µm hematite solid particles rather than dissolved ions.

Laboratory set-up and reduced pellet at NTNU of electrolysis cell, Norway.

SEM image of iron deposit of UOA, Portugal.



- High reaction rate with current density 1000 $A \cdot m^{-2}$.
- Anodic gaseous O_2 production.
- Non-consumable anode.
- Cathodic Iron grown as solid state deposit.
- Non critical elements in electrode materials, Ni anodes.

Case of alternative raw material; BR

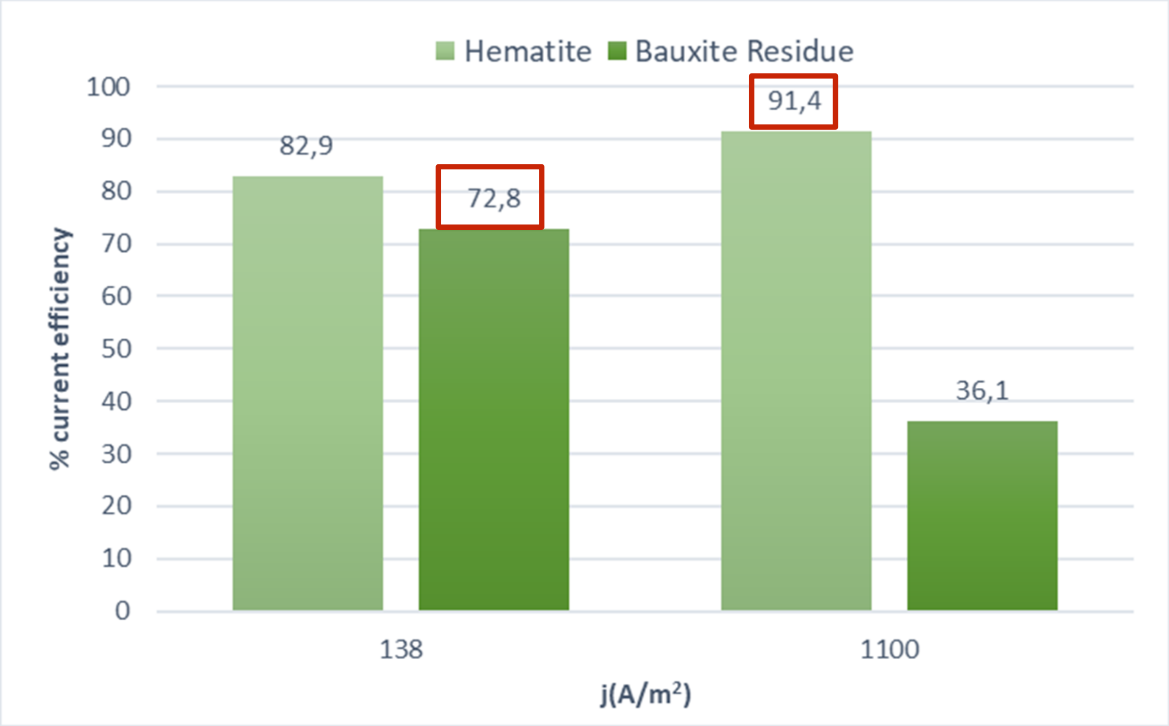
- ΣIDERWIN process has tested the alumina by-product known as Bauxite Residue.
- Bauxite Residue contains ≈40% iron oxides but the impurities it contains affect the iron oxide mechanism.

YouTube video: ΣIDERWIN Electrochemical recovery of metallic iron from bauxite residue in aqueous alkaline solution.

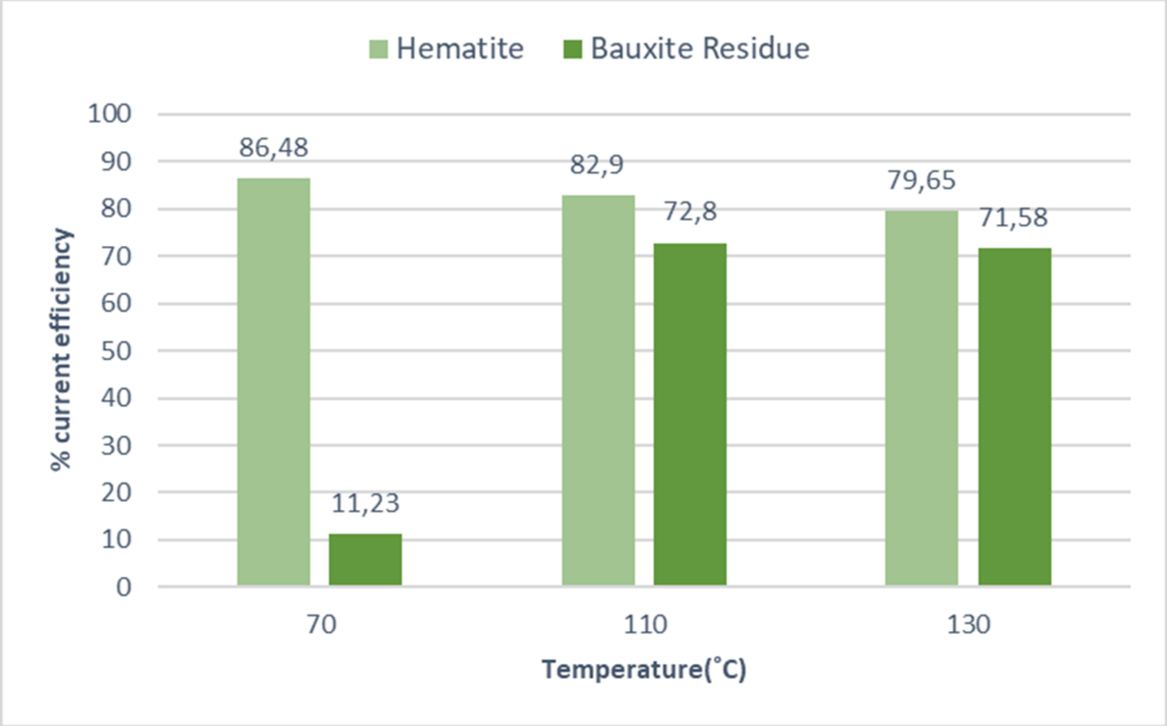
Mytilineos aluminum plant, Voiotia, Greece

Case of alternative raw material; BR

Pulp's temperature 110 °C



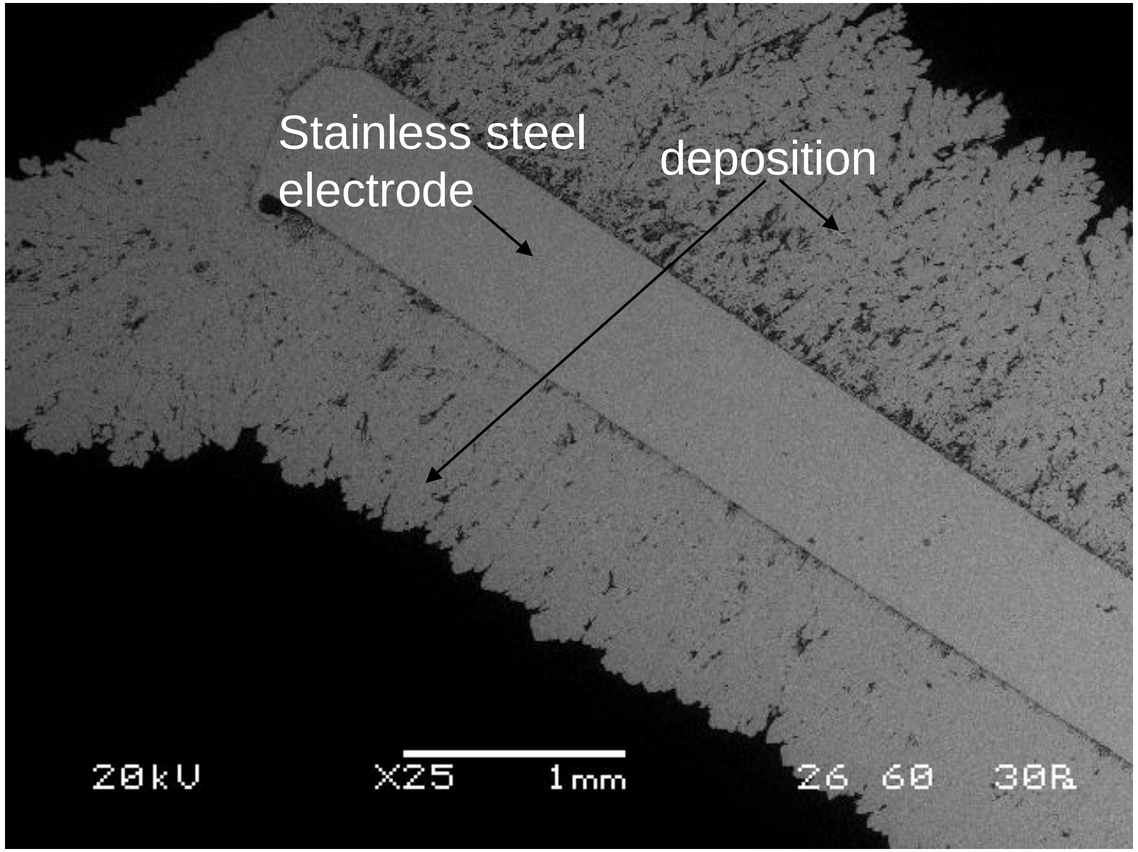
Applied current density 138 A/m^2

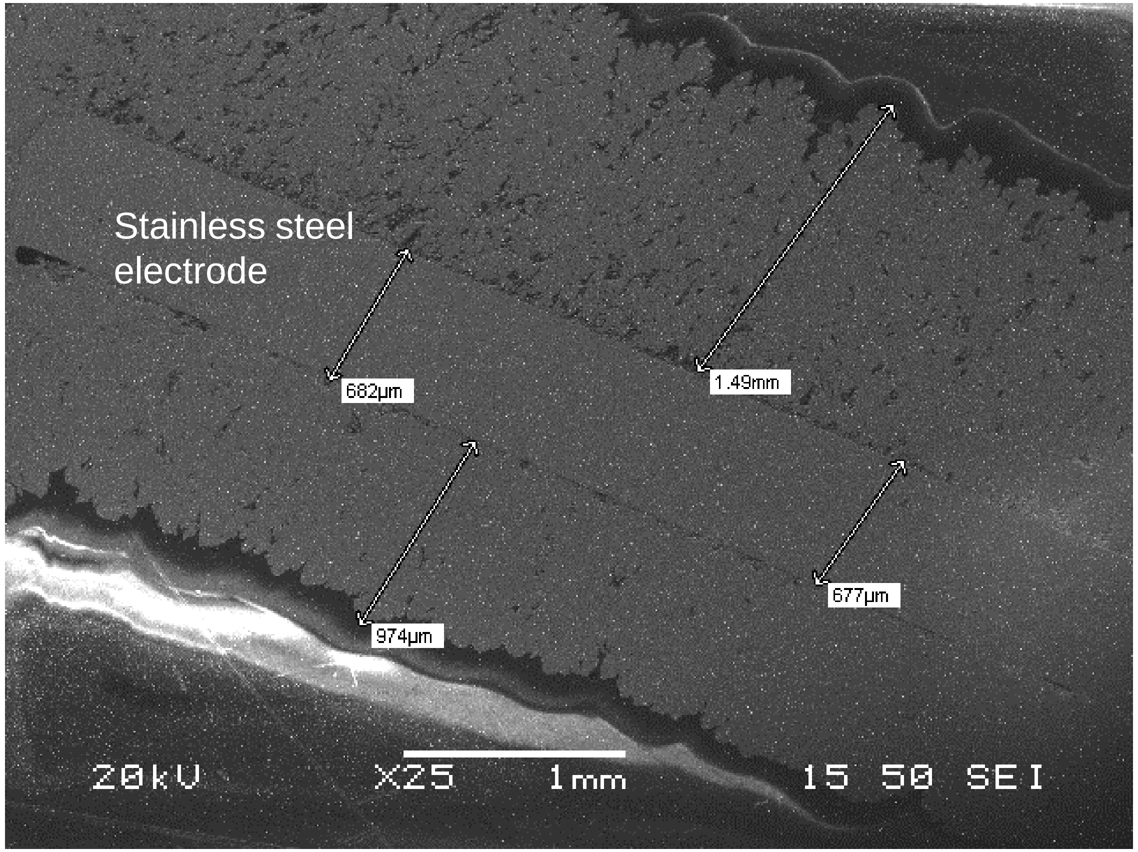


*The case of **pure raw material (Hematite)** results in a **91.8% current efficiency** and NTUA experiments with **BR** resulted to **70% current efficiency but at lower current densities than hematite.***

SEM analysis of deposited electrode-Hematite

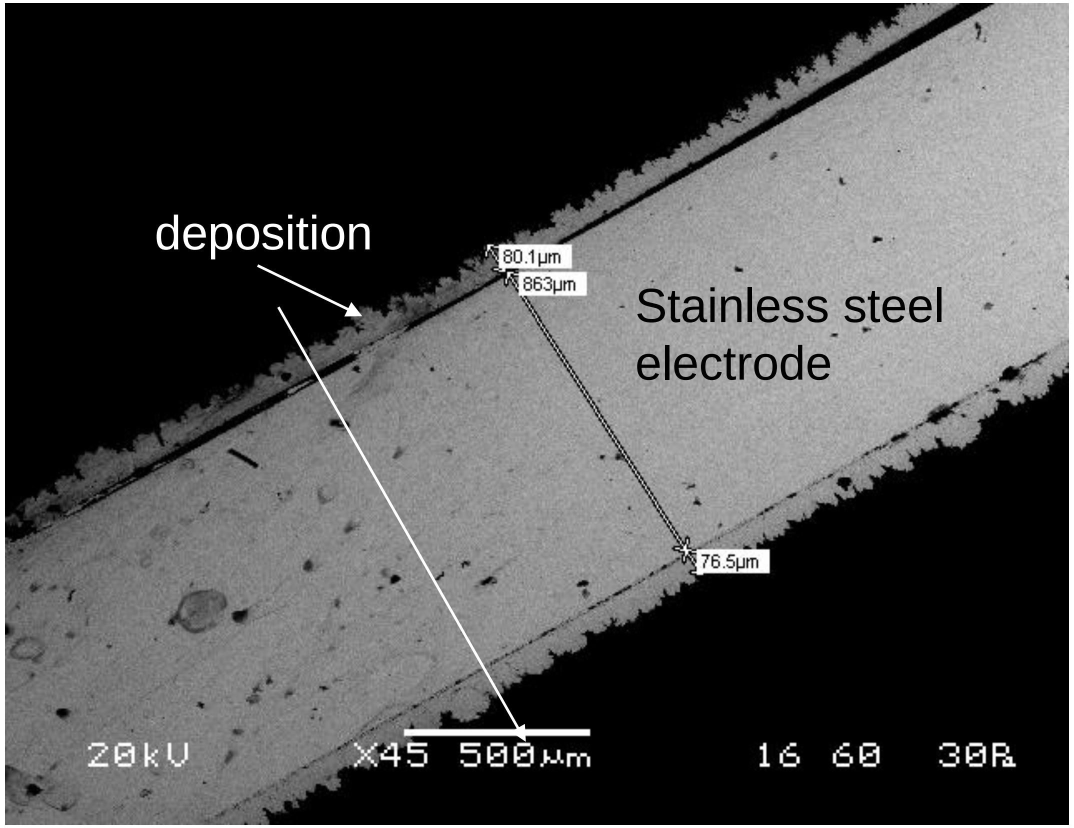
(10% w/w Hematite, 50% w/w NaOH, 24 h electrolysis, 138 A/m^2, 110 $^\circ$C)

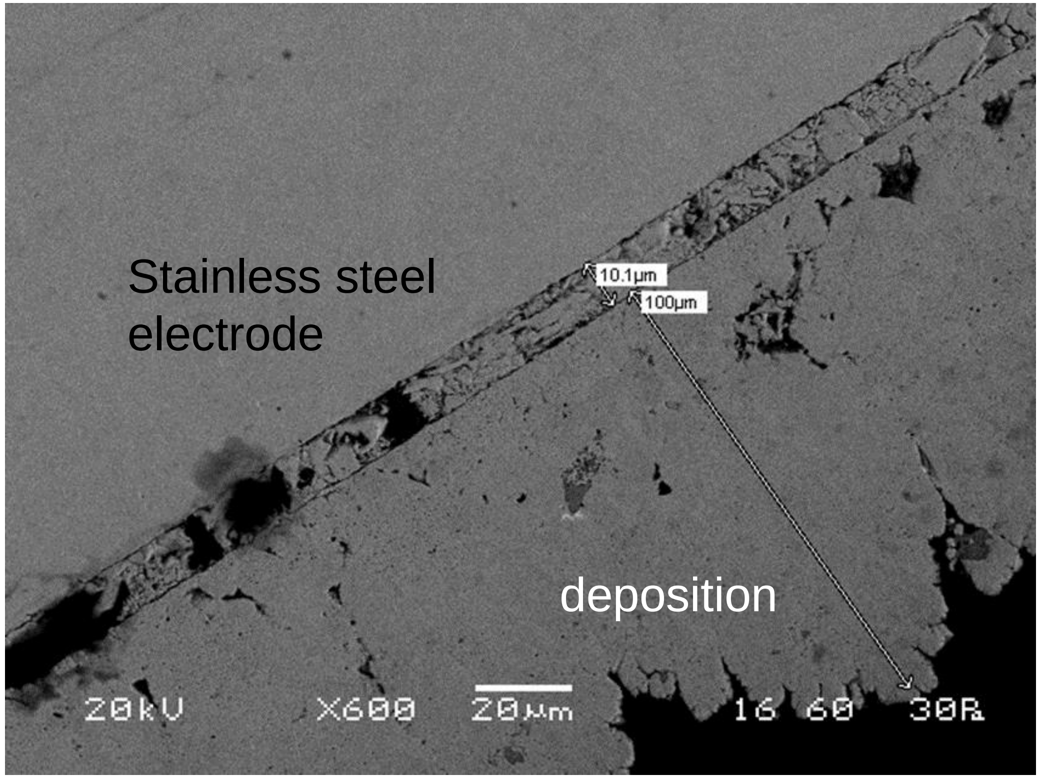




SEM analysis of deposited electrode-BR

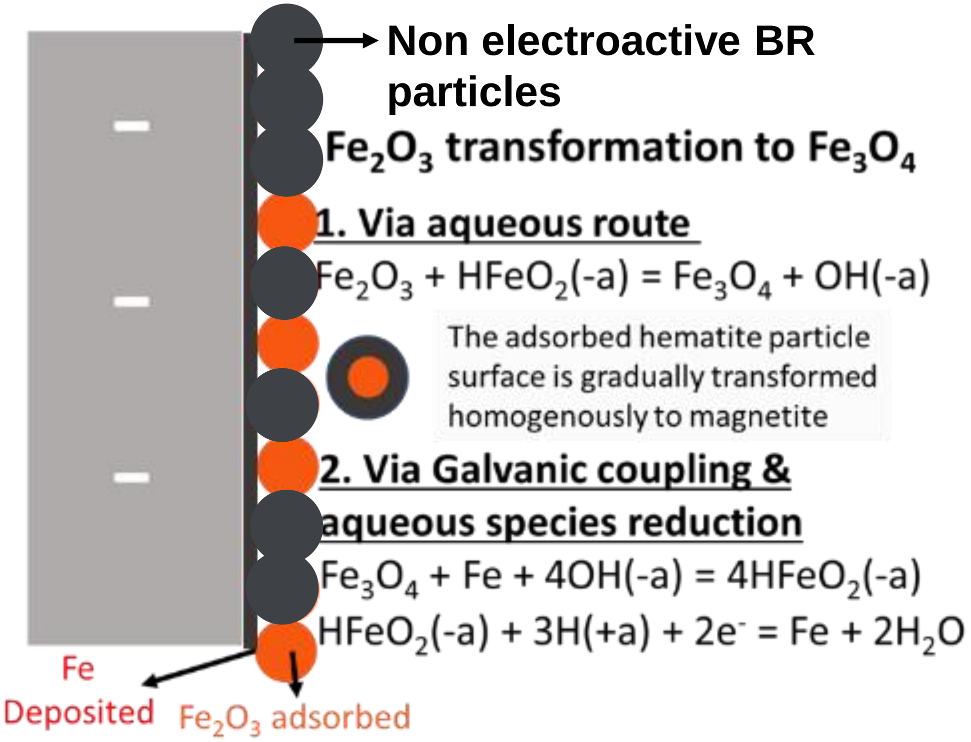
(10% w/w Bauxite Residue, 50% w/w NaOH, 24 h electrolysis, 138 A/m^2, 110 °C)



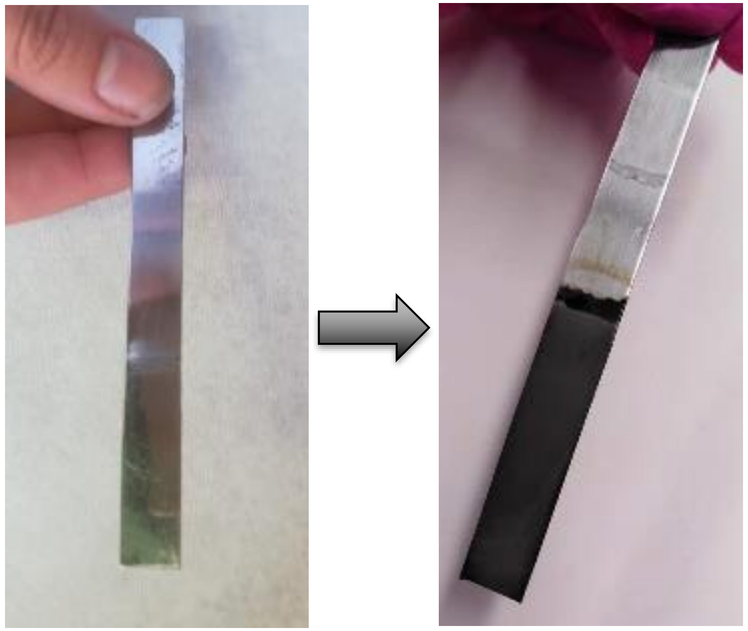


Case of alternative raw material; BR

- BR's mechanism may differ from pure iron oxide due to the non-homogeneous distribution of electroactive species.



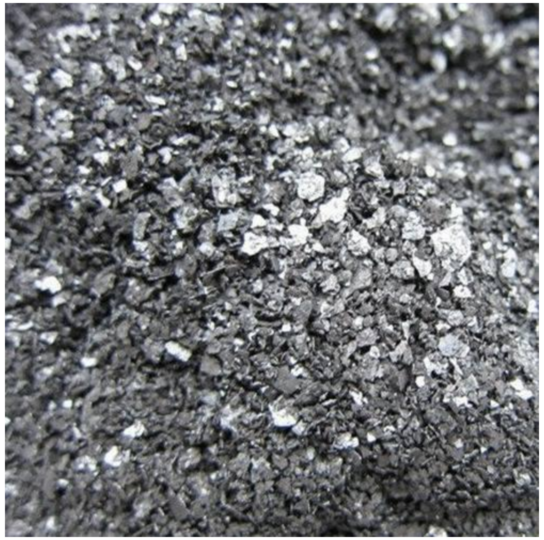
Cathode <u>before</u> and <u>after</u> of BR's electrolysis.



Case of alternative raw material; scales from steel industry

Mill scale is formed on the outer surfaces of plates, sheets or profiles when they are being produced by rolling red hot iron or steel billets in rolling mills.
Contains ***Hematite, Magnetite, Wustite and metallic iron.***

Production= 10000tn/year in Greece



Current density (A/m^2)	Efficiency (%)
138	91.88
388	97.13

Summary

- The electrowinning of ΣIDERWIN process is considered as **a solid-state electrolysis** at high alkaline solutions.

- The **alternative raw material study is under investigation** with different materials to compete as a possible feed for the electrolytic process; even though the mechanism seems to differ. The by-products use of other metallurgies could offer to the ΣIDERWIN process an extra role; the exploitation of “wastes”.

Summary

So, the **electrodecomposition of iron oxide** in alkaline enviroment and low temperature is a **feasible reaction in lab-scale** which is characterized of:

- High current density (1100 A/m^2)
- High faradaic efficiency (91.4%)
- Low temperature (110 ˚C)
- Low voltage (1.6 V)
- High energy efficiency (3.6 $MWh \cdot t^{-1}_{Fe}$)
- Explore the possibility of alternative raw materials use.

These features lead this technique to industrial scalability.

Thank you

for your attention

Questions?

Is the electrolysis of primary steel production scalable and industrialisable?

Cédric Flandre (John Cockerill)
Thierry Conte (CFD Numerics)
Webinar November 24th 2021

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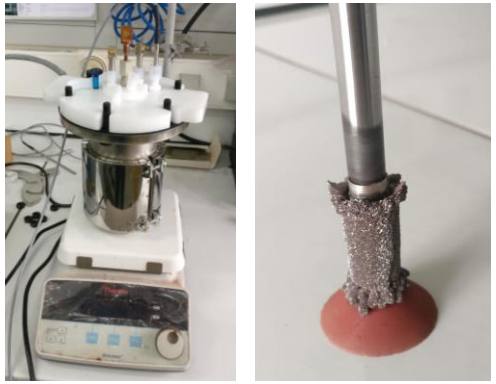
Upscaling & TRL

Technology evolution

INDUSTRIAL PLANT

- TRL-9 Maturity – Several rollouts
- TRL-8 Industrial pilot plant "flight qualified"
- TRL-7 Industrial pilot plant in operation
- TRL-6 Prototype demonstrated in relevant environment
- TRL-5 Components validated in relevant environment
- TRL-4 Components validated in laboratory
- TRL-3 Analytical and experimental proof-of -concept
- TRL-2 Technology concept/ application formulated
- TRL-1 Basic principles reported

IDEA

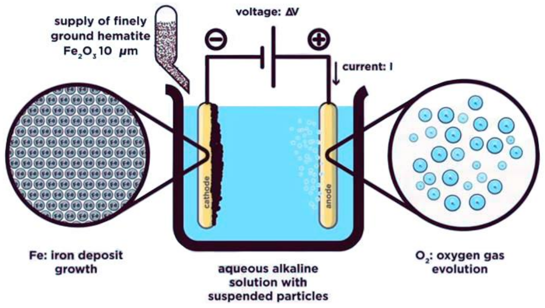

Laboratory setup


ULCOWIN

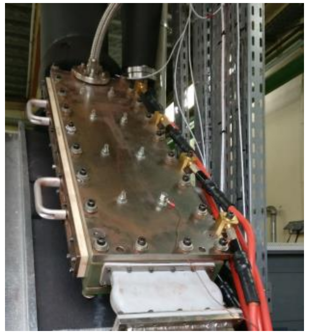

ΣIDERWIN

From a pen size cell to a large cell

$$\frac{1}{2} Fe_2O_3 \longrightarrow Fe + \frac{3}{4} O_2$$

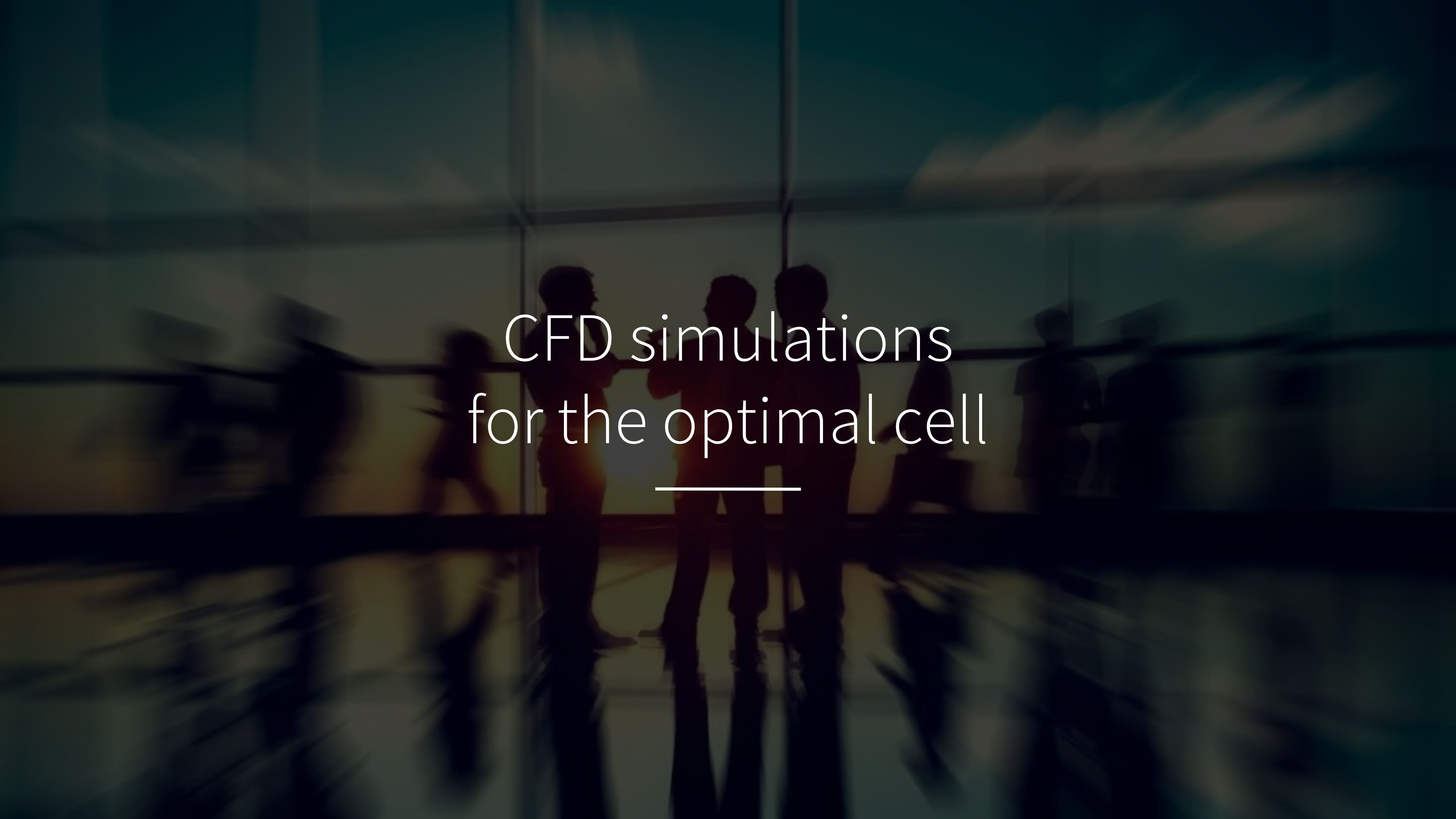


Ability to produce iron
at a lab scale < 100 g.



ULCOWIN prototype,
Iron plate up to 4 kg.

Electrowinning cell
for 100 kg iron plate production.


CFD simulations
for the optimal cell

Overview

- **Main challenge**: find the right cell design to remove the large amount of oxygen bubbles generated by the electrolysis process.
  - Potential major issue: to get oxygen accumulation in the cell leading to a drastic loss of efficiency.

- Cell design: defined using CFD simulations.
  - **CFD for Computational Fluid Dynamics.**
  - Two-phase flows modelling in the cell to understand, analyse and optimize investigated designs.

- 1st step: the CFD model has been developed and validated.
  - Objective: to establish a **relevant methodology** to calculate **two-phase flows** (electrolyte and oxygen bubbles).

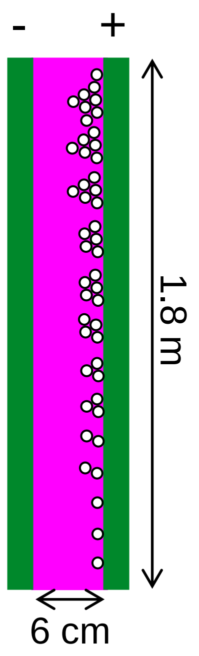
- 2nd step: CFD Models have been applied to design the cell and particularly define:
  - Cell angle to enhance the ability to drive bubbles out of the cell;
  - Anode design and implantation;
  - Degassing device to ensure a proper and smooth removal of generated oxygen bubbles;
  - Inlet distributor and outlet collector designs to reduce pressure drop and ensure a good flow uniformity;
  - Pump specification.

Oxygen bubbles management

Conventional electrowinning design is not applicable for Σiderwin cell design.

Large inter electrodes gap for bubbles and diaphragm.

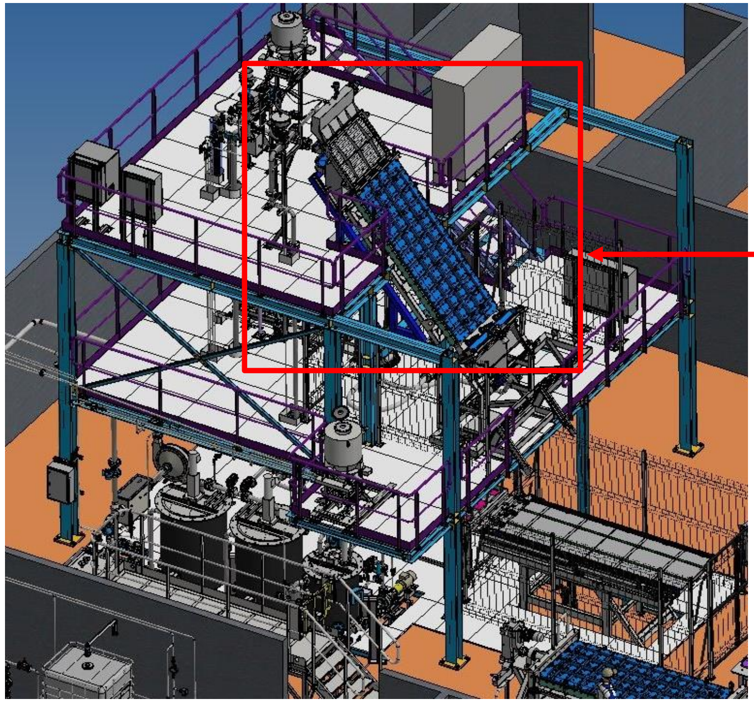
Electrode extension limited by bubble screening.



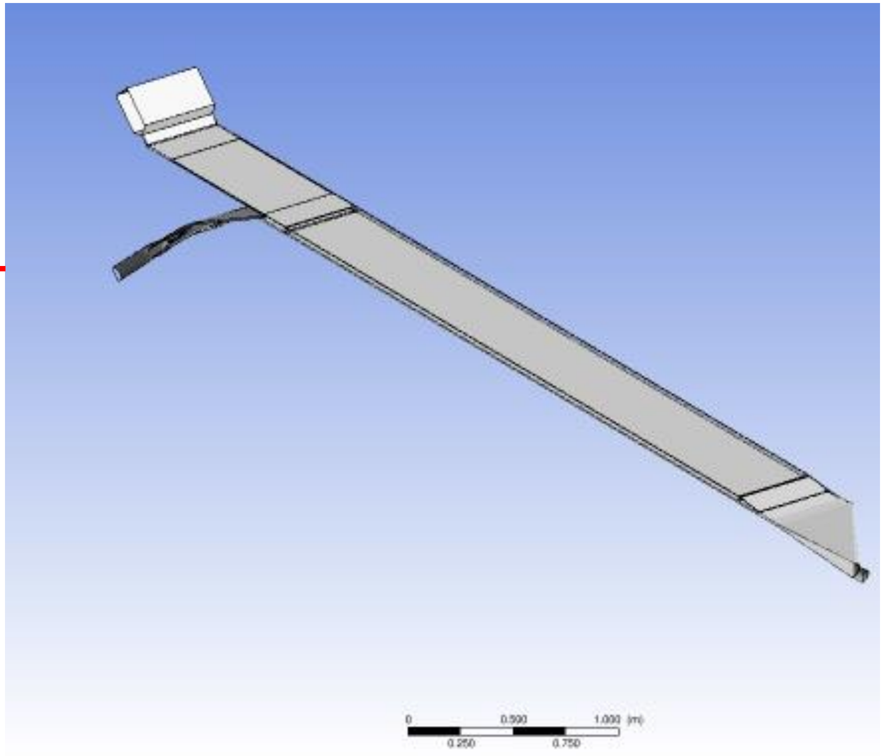
- Regarding the large amount of gas in the cell, an innovative design of the cell has to be defined to perform an efficient electrolysis process.

- The main challenges that need to be addressed:
  1) Define a cell design that allows a very short distance between anode and cathode to optimize the electrolysis efficiency.
  2) Deal with electrolyte and bubbles counterflows.
  3) Avoid bubbles accumulation in the cell especially close to the cathode and close to the anode (screening effect).
  4) Take advantage of the gas-lift effect (bubble motion gives momentum to the electrolyte that could be used).
  5) Perform an efficient gas / electrolyte separation to “send back” a pure electrolyte to the cell.

CFD models



Designed Installation

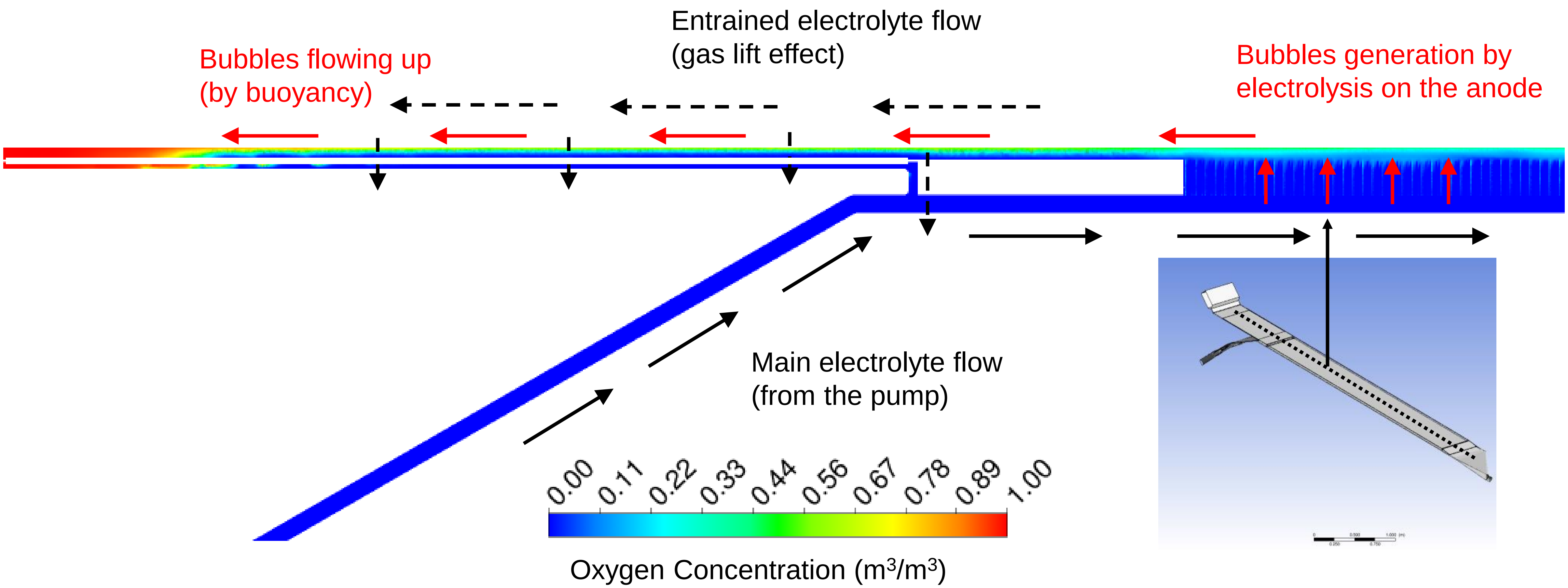


CFD models

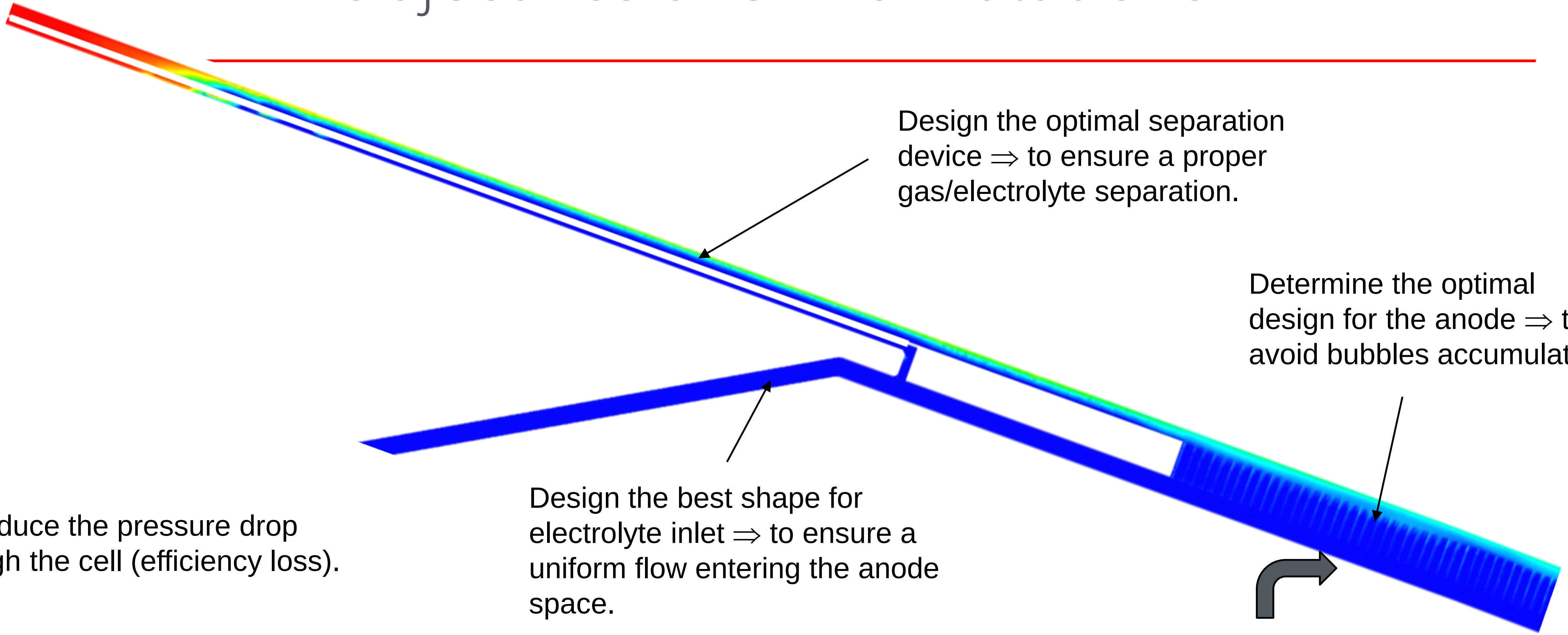
As manufactured

Flow phenomena

- Objective: define the most efficient design to drive bubbles out of the cells and drive back the entrained electrolyte to the main flow with an efficient separation.



Objectives of CFD simulations



Design the optimal separation device ⇒ to ensure a proper gas/electrolyte separation.

Determine the optimal design for the anode ⇒ to avoid bubbles accumulation.

⇒ Reduce the pressure drop through the cell (efficiency loss).

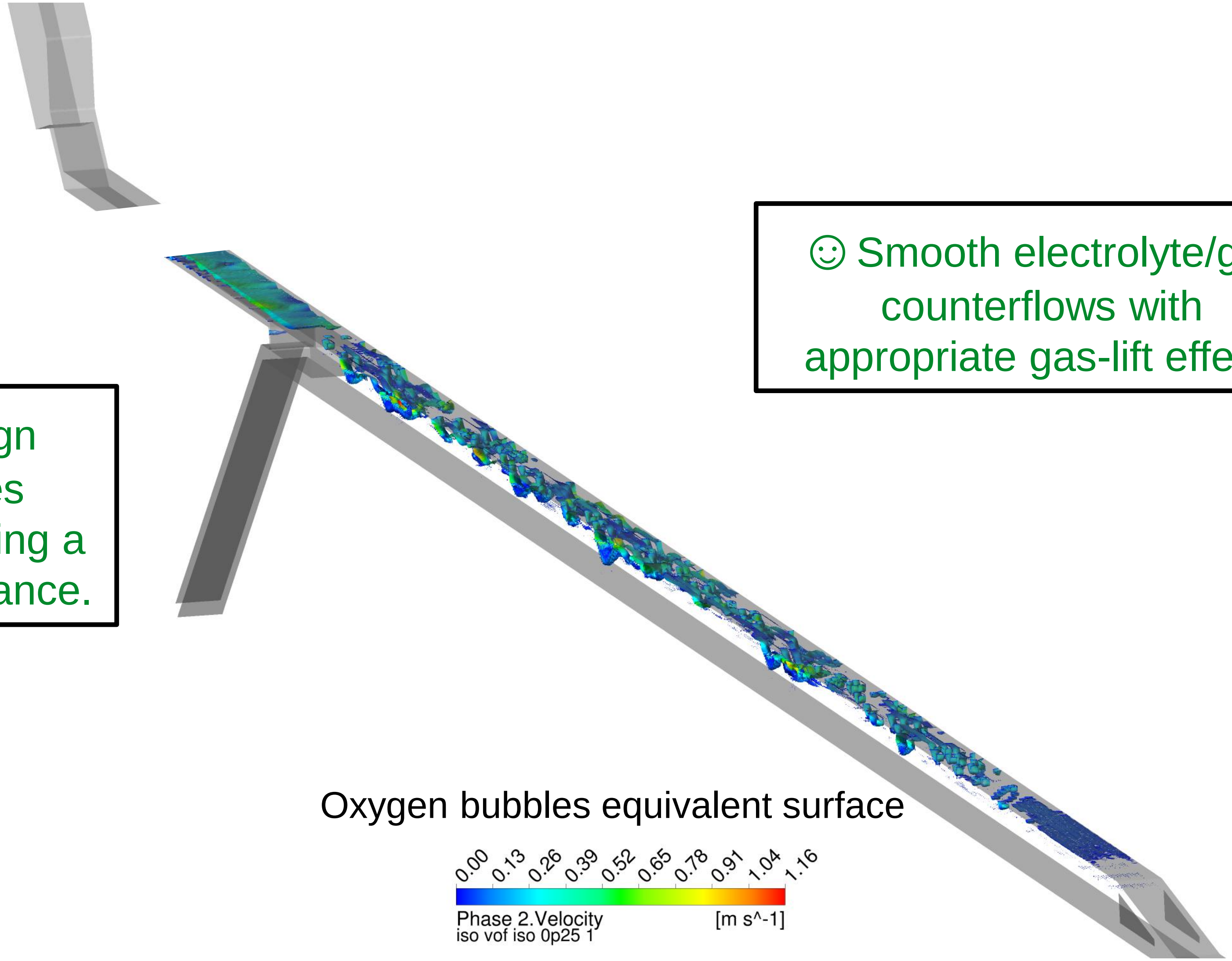
Design the best shape for electrolyte inlet ⇒ to ensure a uniform flow entering the anode space.

Determine the optimal cell angle ⇒ to control the buoyancy force and gas lift effect.

Main achievements by CFD (1)

☺ The proposed design avoids oxygen bubbles accumulation while keeping a short anode/cathode distance.

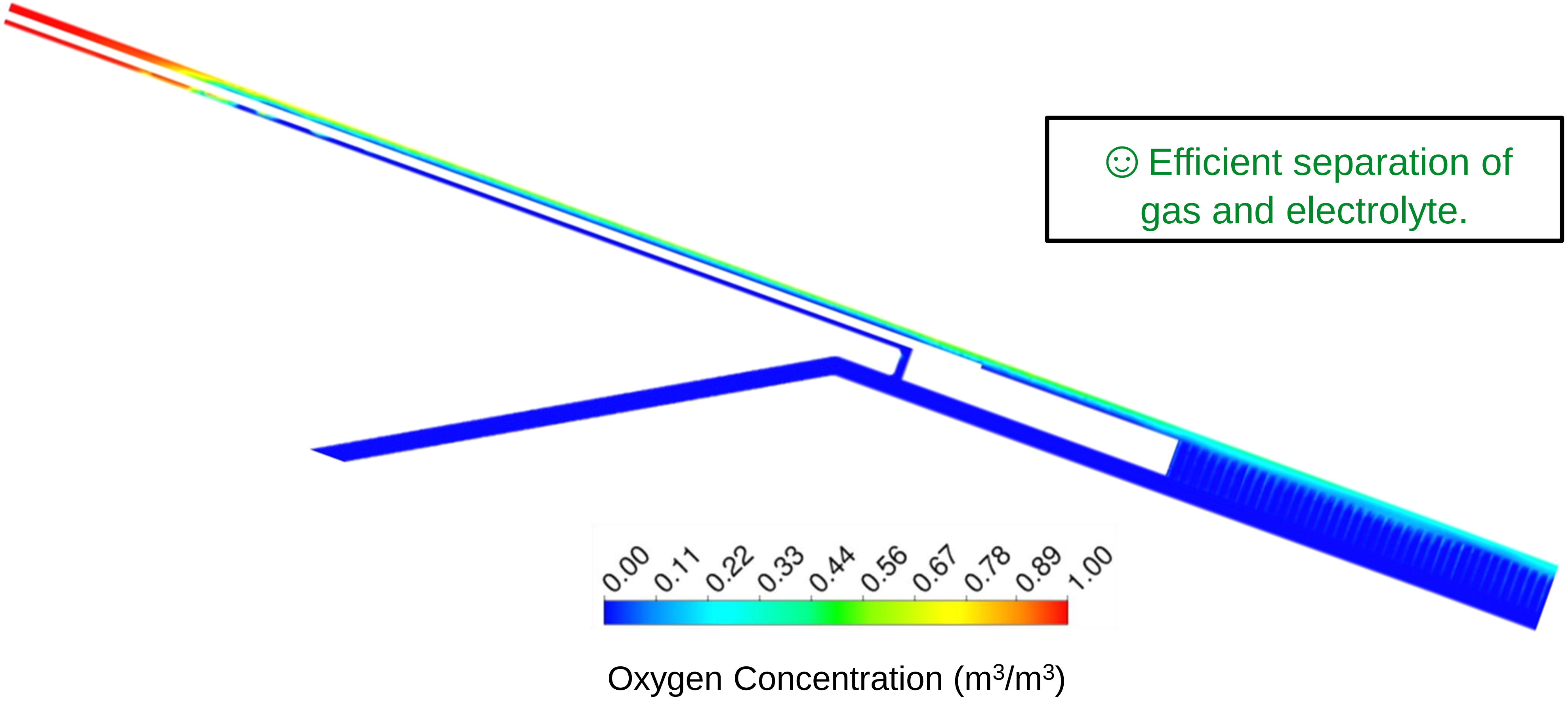
☺ Smooth electrolyte/gas counterflows with appropriate gas-lift effect.



Oxygen bubbles equivalent surface

Bubbles Velocities (m/s)

Main achievements by CFD (2)

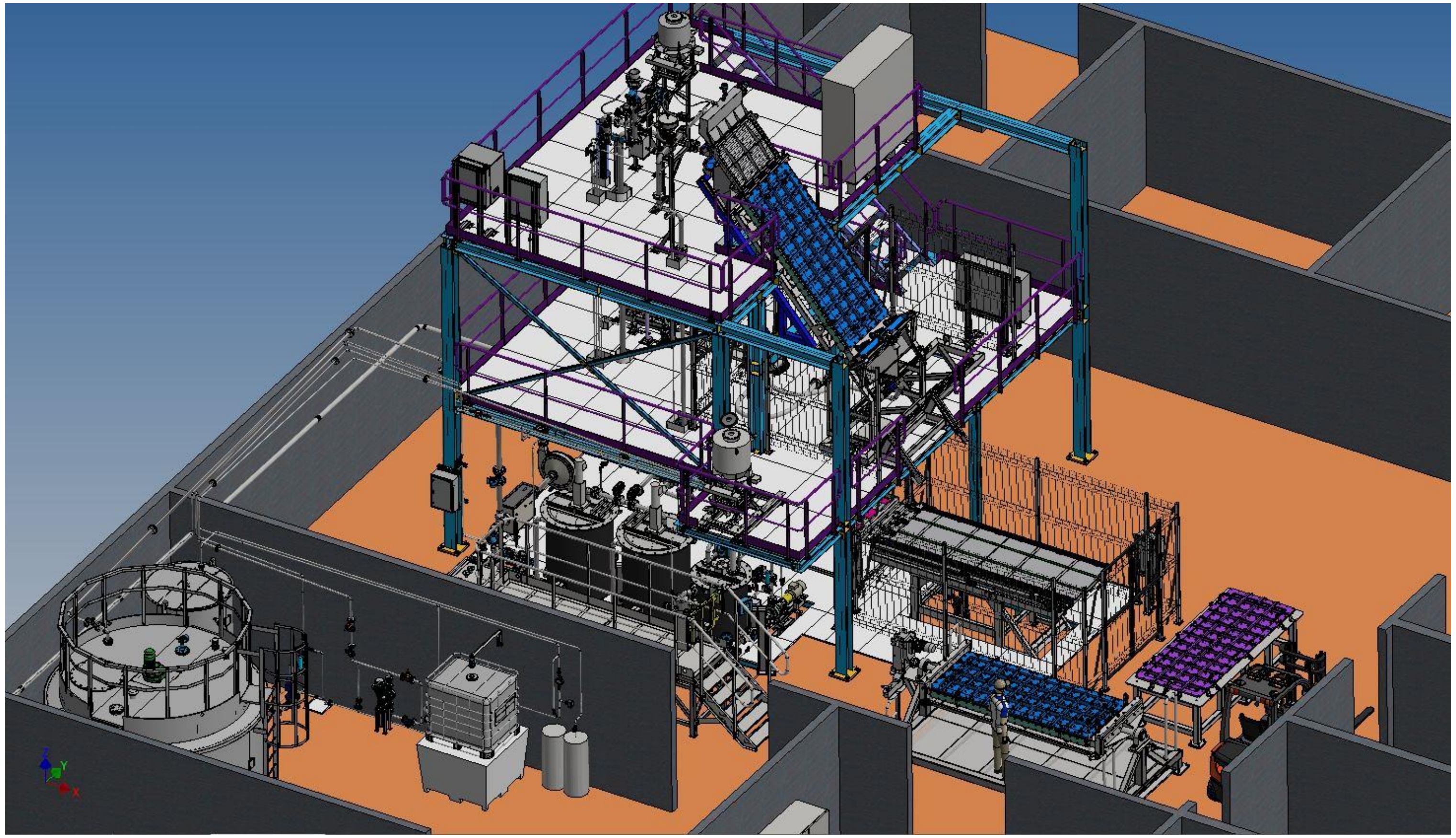


☺ Efficient separation of gas and electrolyte.

Industrialization

ΣIDERWIN – TRL6

- Design of an industrial pilot – Taking into account return of experience on previous projects / equipment.



ΣIDERWIN – TRL6

- Upscaling factor **x30.**
- Fully **automated.**
- High level of **instrumentation.**
- **Industrial** integration:
  - Continuous iron ore supply.
  - Gas collection.
  - Iron plate harvesting system.
  - Vertical extension for low footprint.

➡ **Allowing to reach TRL5.**

ΣIDERWIN – TRL6

- **Electrification of primary steel production.**
  - Flexibility toward energy input.
  - Emphasis on interruptibility.
  - Participation in demand side response (DSR).
- Possibility to enlarge **iron oxide sources.**
  - Alternative iron oxide sources (Fe-Ni slag).
  - Processing of residues from aluminium route (Bauxite Residues).
  - Fully electrified primary production, no reliance on fossil fuels.
- Radical improvement in **energy efficiency** compared to BF route, 31%, thanks to electricity.

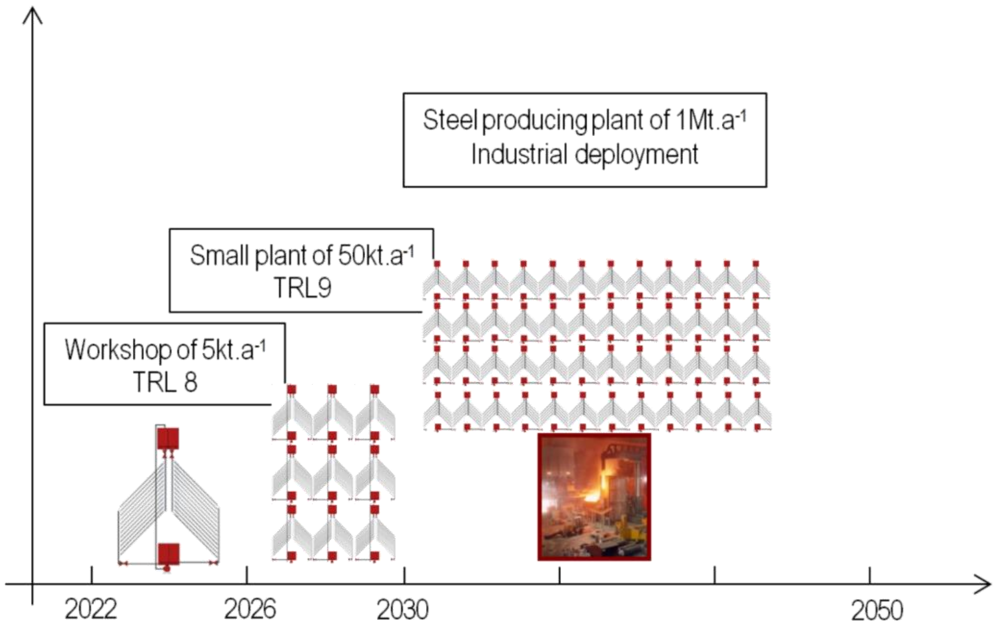
Conclusion

Σiderwin pilot → **Demonstrator** → Upscaling feasibility & Technology industrial relevance

2018	2019	2020	2021	2022
Technology review	Design	Design & Supply	Erection & Commissioning	Exploitation

After Σiderwin?

1. Further upscaling.
2. Optimization of equipment footprint.
3. Optimization of the design in regards with the optimal parameters.



Thank you

for your attention

Questions?

Development of new methodologieS for InDustrial CO_2-freE steel pRoduction by electroWINning

How decarbonizing primary steel production through electrolysis could play a role in the European power system?

Matthildi Apostolou & Caroline Bono - EDF R&D

Webinar November 24th 2021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768788

www.siderwin-spire.eu

Key idea / Challenge

Analysis of the impact of a ΣIDERWIN industrial development in the future European electricity system (time horizon 2050).

In terms of:

Energy consumption.

Costs and benefits for the power system.

Flexibility potential.

Carbon emissions reduction.

Layout and step-by-step approach

UE Reference scenario

RES chronicles

Energy and carbon intensity hypothesis

Steel industry development hypothesis

ΣIDERWIN specifications and development Hypothesis (100% 2050)

Experimental modelling of electrolysis interruption

universidade de aveiro

REFERENCE SCENARIO → ALTERNATIVE SCENARIOS → CONCLUSIONS

Reference scenario:

Consistent with EU vision of the future
Maximum industrial development of ΣIDERWIN technology.

Different scenarios:

Electricity mix
Connections capacity
CO_2 price
DSR

Balance of the European power system:

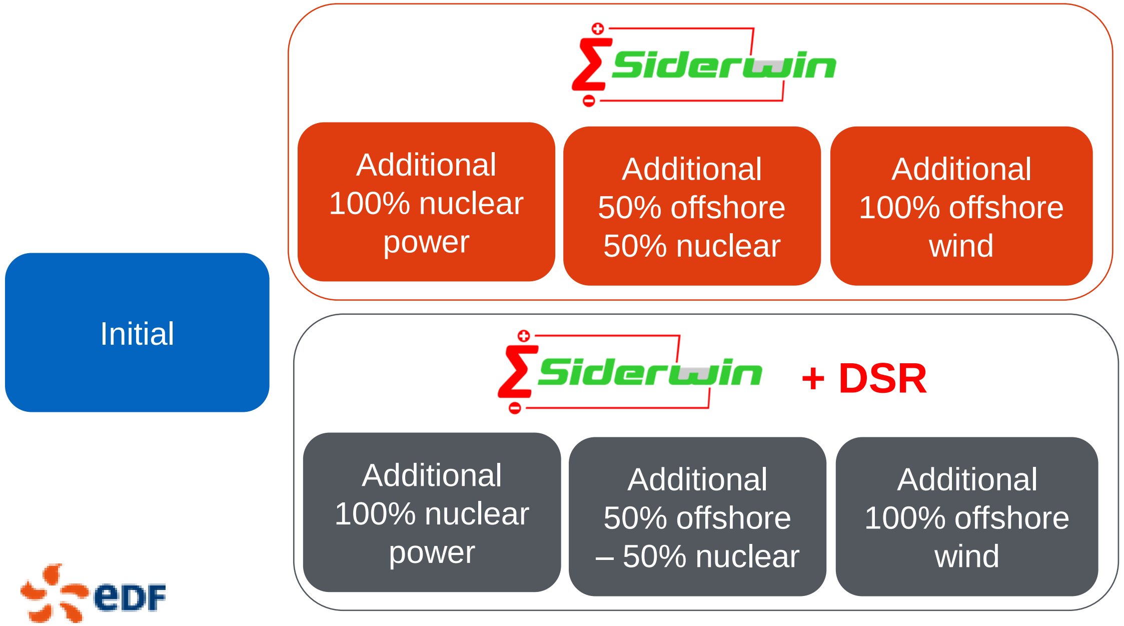
Electricity demand
CO_2 emissions
Costs
Maximum DSR potential

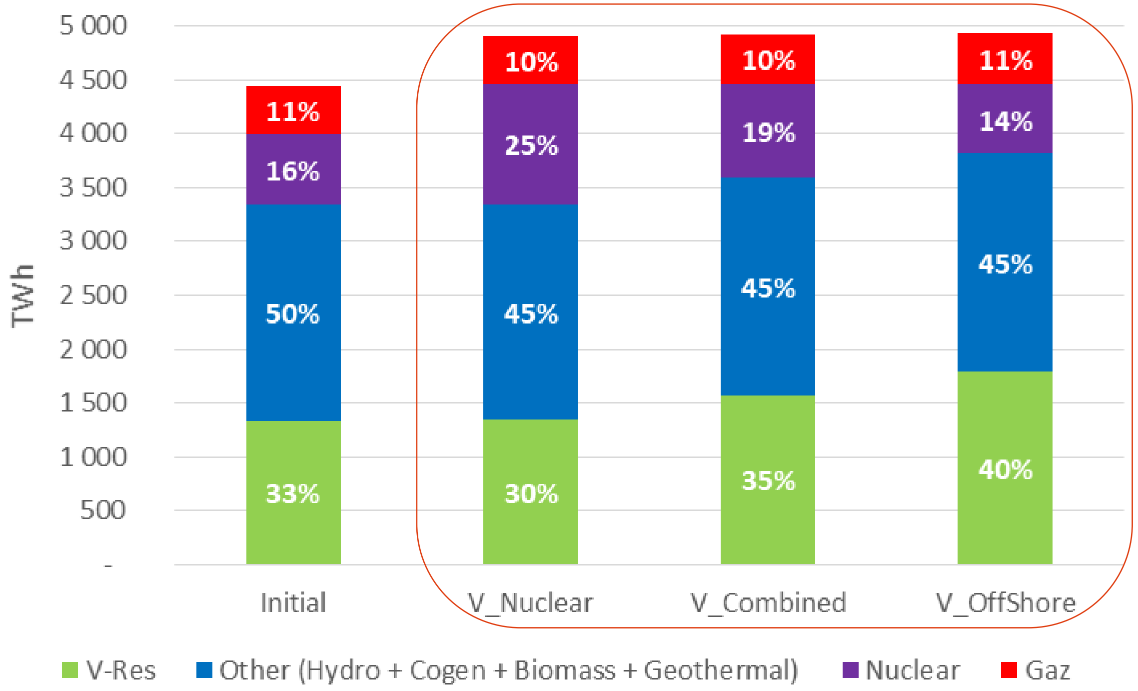
Adapting the power system model to meet additional ΣIDERWIN demand (1/3)

Additional demand of approx **471 TWh per year in 2050**

(+ 12% in average of EU electricity consumption)

Adaptation of the 2050 electricity mix for each European country (different scenarios).





Evolution of the generation mix in Europe.

Adapting the power system model to meet additional ΣIDERWIN demand (2/3)

Modeling of interconnected European power system (1)

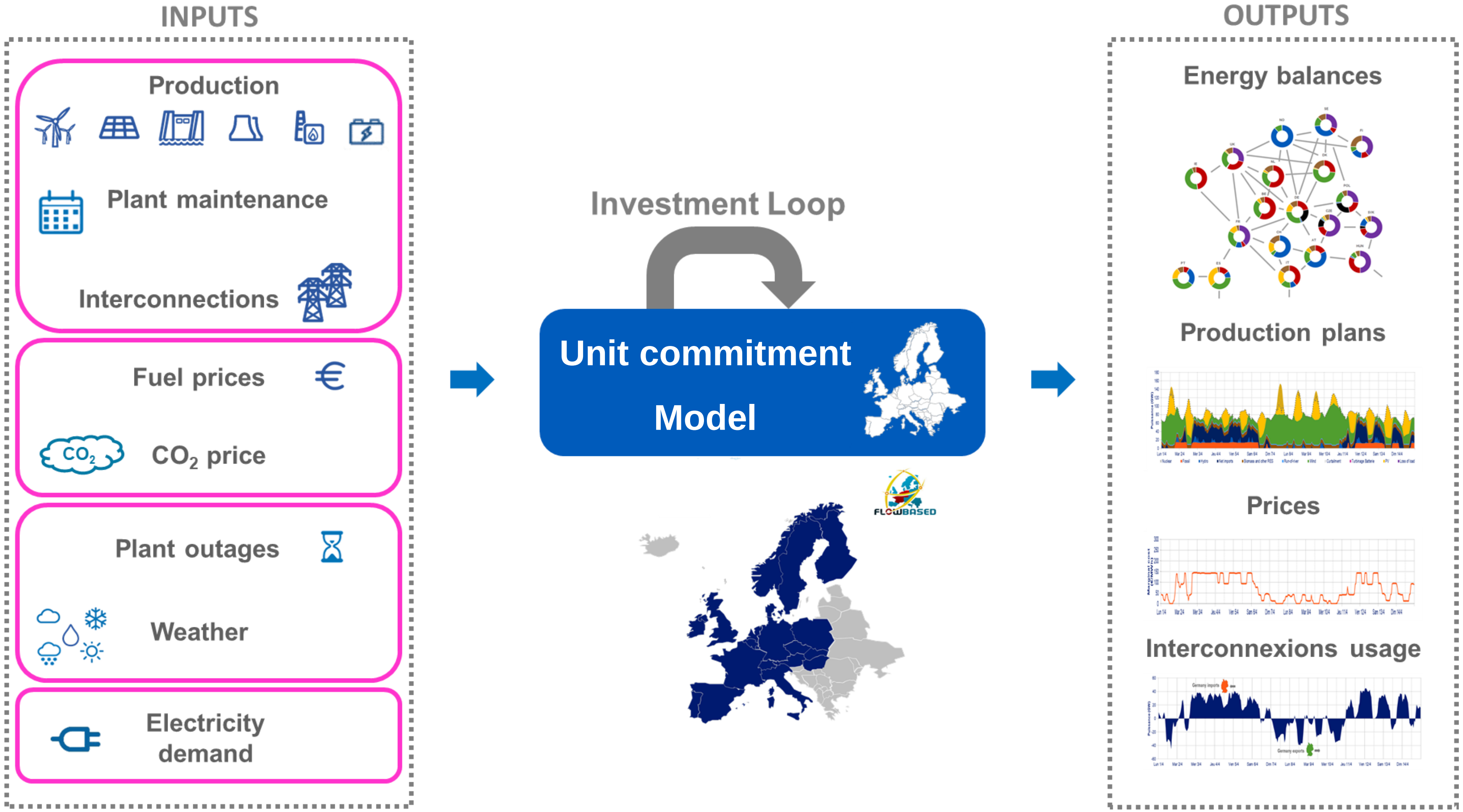
- ☑ Description of European power system
- ☑ Flexibility solutions : hydro storage, batteries…

Macroeconomic context (2)

Weather and outages uncertainties (3)

- ☑ 55 climate years

Electricity demand (4)



Adapting the power system model to meet additional ΣIDERWIN demand (3/3)

Modeling of interconnected European power system (1)

- ☑ Description of European power system
- ☑ Flexibility solutions : hydro storage, batteries…

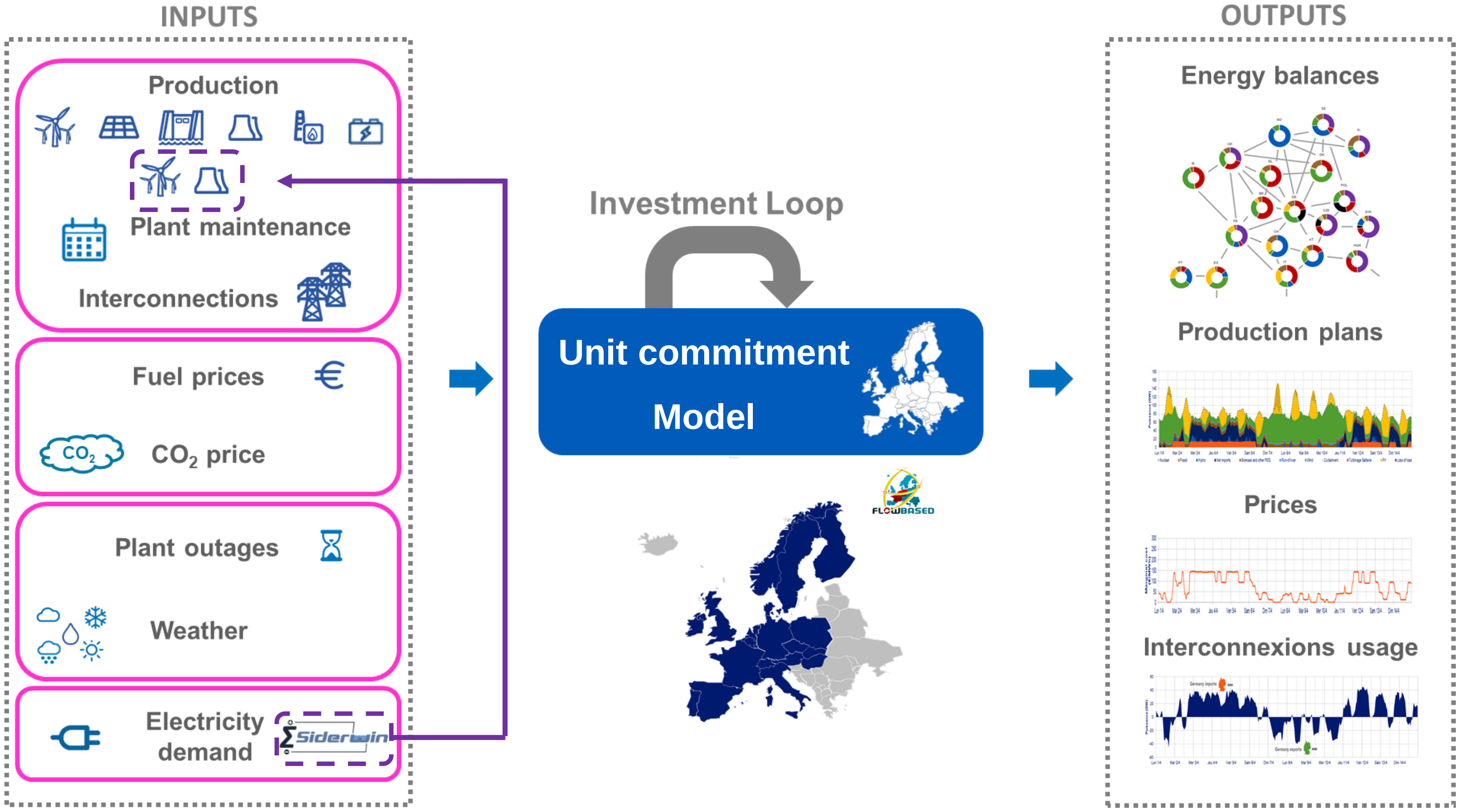
Macroeconomic context (2)

Weather and outages uncertainties (3)

- ☑ 55 climate years

Electricity demand (4)

- ☑ Demand without Siderwin
- ☑ Additional Siderwin demand

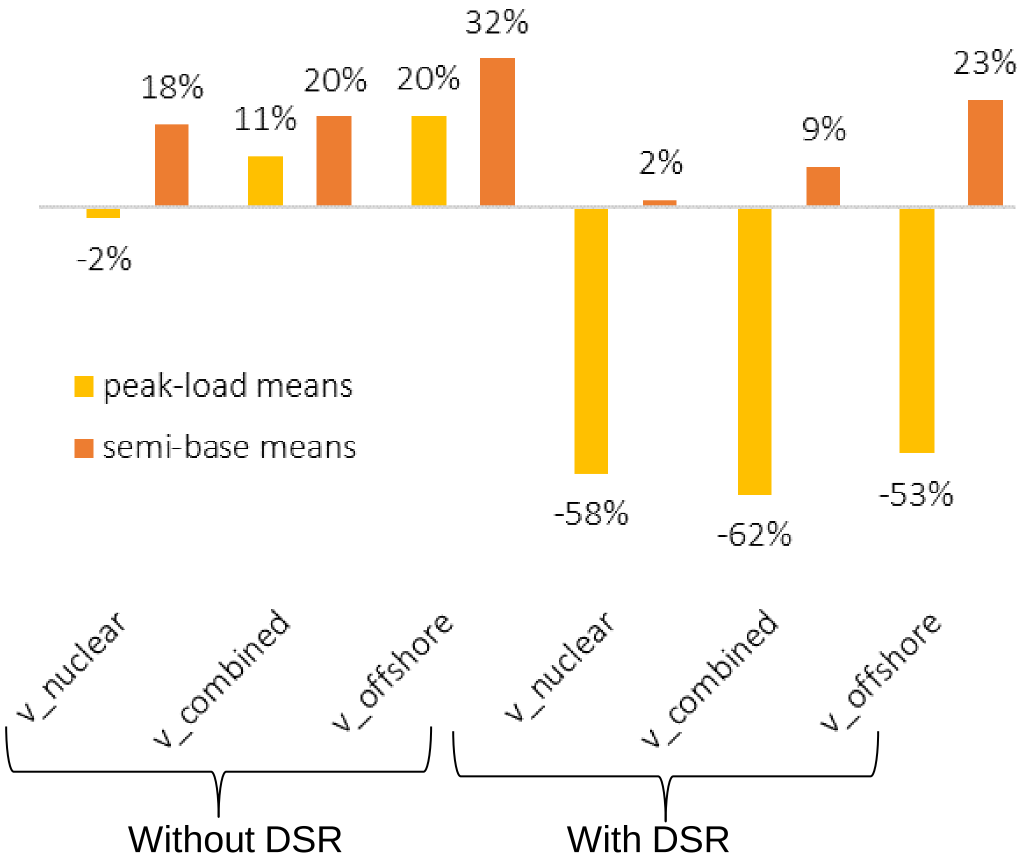


Impact on the thermal park

Thermal production ranging from -4% for the nuclear variant to +6% for the offshore variant

- Significant impact on the structure of the thermal capacities and generation: peak-load plants (OCGT*) largely disappear because they are replaced by ΣIDERWIN's DSR service.

- No negative impact on CO_2 emissions (gCO_2/kWh).

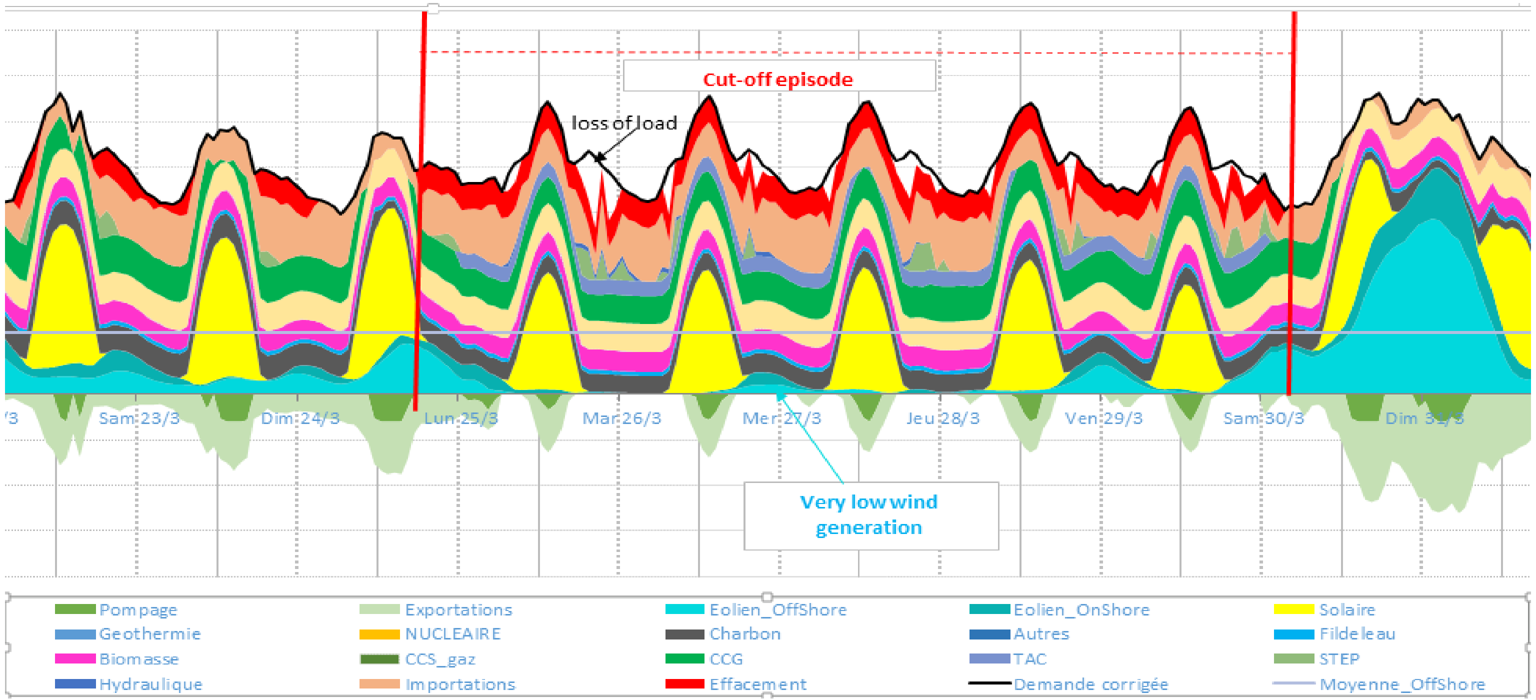


Thermal capacities variations.

*Open Cycle Gas Turbines

DSR: A real need for the power system…

Cut-off capacity of 39 GW (11 -13 TWh)



Example of flexibility: solicitation of the different generation technologies to meet demand, during a week with very low wind and high demand – Germany, Offshore Dataset.

…that finds an economic place in the contribution to the supply-demand balance

- the full cost of the system is 10 to 15% higher compared to the initial dataset.
- the short-term marginal cost is almost unaffected.
- Savings mainly related to investment costs avoided: several B€/yr for the whole of Europe.

Synthesis of results (1/2)

The deep decarbonisation of steel industry enabled by ΣIDERWIN is not jeopardized by the impact on power system.

- The European power system is able to meet the additional ΣIDERWIN demand with carbon-free means.
  - Adaptation of the 2050 electricity mix for each European country in order to meet the additional demand yielded by ΣIDERWIN's development (471 TWh per year in 2050).
  - Different scenarios have been studied in accordance with decarbonisation objectives, renewable potentials and acceptability of technologies (e.g., nuclear phase out decision).
  - Production and demand in each country are balanced.
  - Available interconnections are used when balancing supply and demand.
- Despite a strong increase in electricity demand, **the impact on CO_2 emissions of the European power system is very low** (even positive in certain scenarios) and depends on the choice of technologies used to meet the additional demand of ΣIDERWIN.
- In all scenarios, **the carbon intensity of electricity generation (g CO_2/kWh) decreases**.
- The flexibility offered by ΣIDERWIN allows for additional CO_2 savings, by replacing a large part of the peaking OCGT* plants: direct savings in thermal generation but also savings due to OCGT* plants not built.

*Open Cycle Gas Turbines

Synthesis of results (2/2)

Flexibility offered by ΣIDERWIN: A real need for the power system that finds an economic place in the contribution to the supply-demand balance.

- ΣIDERWIN should offer a **great flexibility capacity, of up to 39 GW in a European scale**, with great responsiveness and without duration or repeatability constraints.
- **This flexibility represents a real asset for the European Power System**: it could contribute to the **balance of the power system.**
  - A replacement of peak-load means (OCGT*): 80% of generation.
  - A reduction in CO_2 emissions: 6 Mt of direct CO_2 emissions avoided.
    - Not included: gains related to indirect emissions (e.g., avoiding construction of OCGTs).
  - Financial gains (mainly related to investment costs avoided): several B€/yr for the whole of Europe.

Under the assumptions of the study.

Perspectives | EDF: Flexibility assessment & tests with the pilot | eco: Flexibility market analysis

*Open Cycle Gas Turbines

Thank you

for your attention

Questions?

Development of new methodologieS for InDustrial
CO_2-freE steel pRoduction by electroWINning

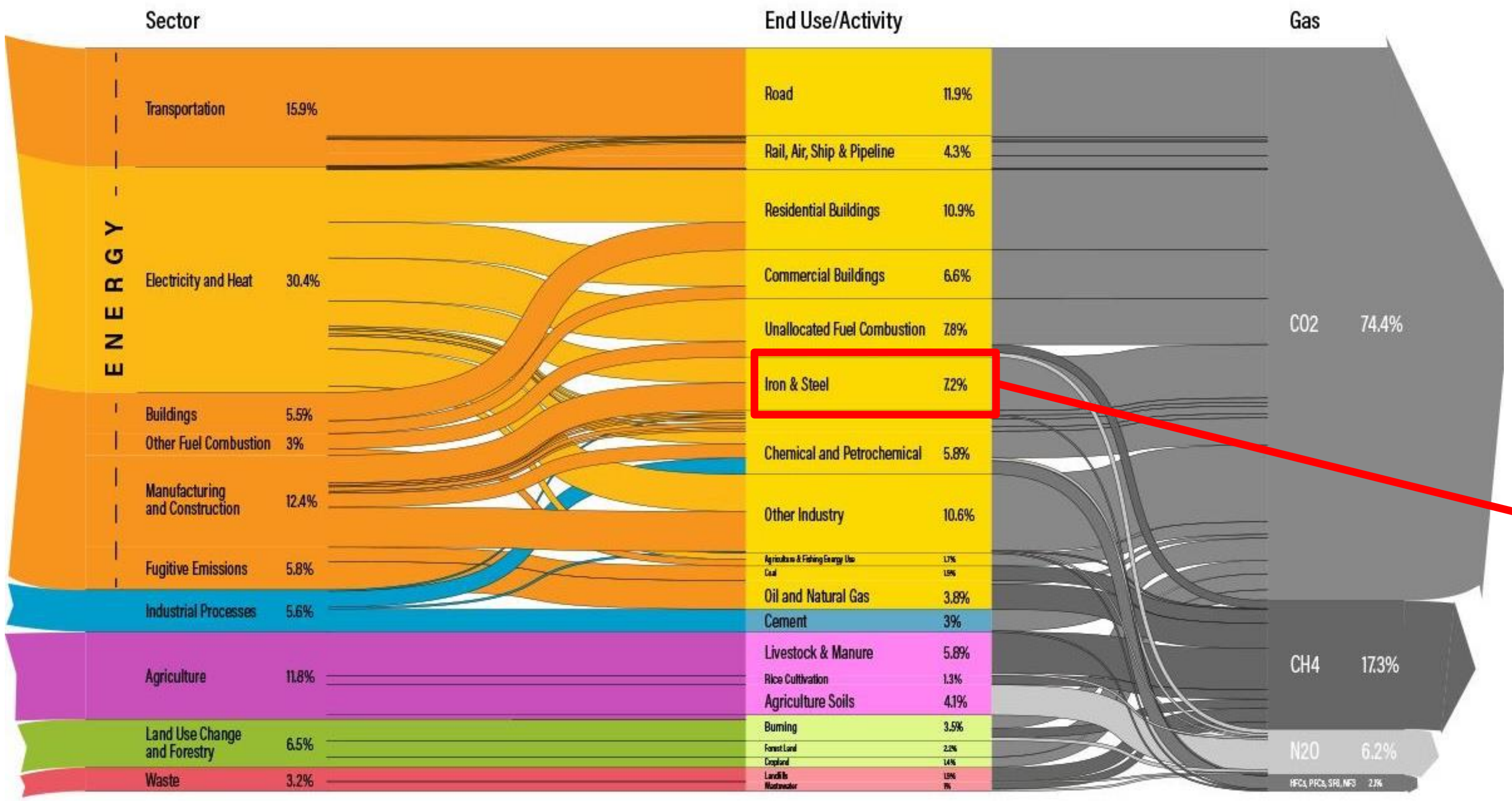
Does ΣIDERWIN contribute genuinely to deep decarbonisation?

Anna KOUNINA - Quantis
Webinar November 24th 2021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768788

Decarbonisation: a planetary journey engaging all sectors

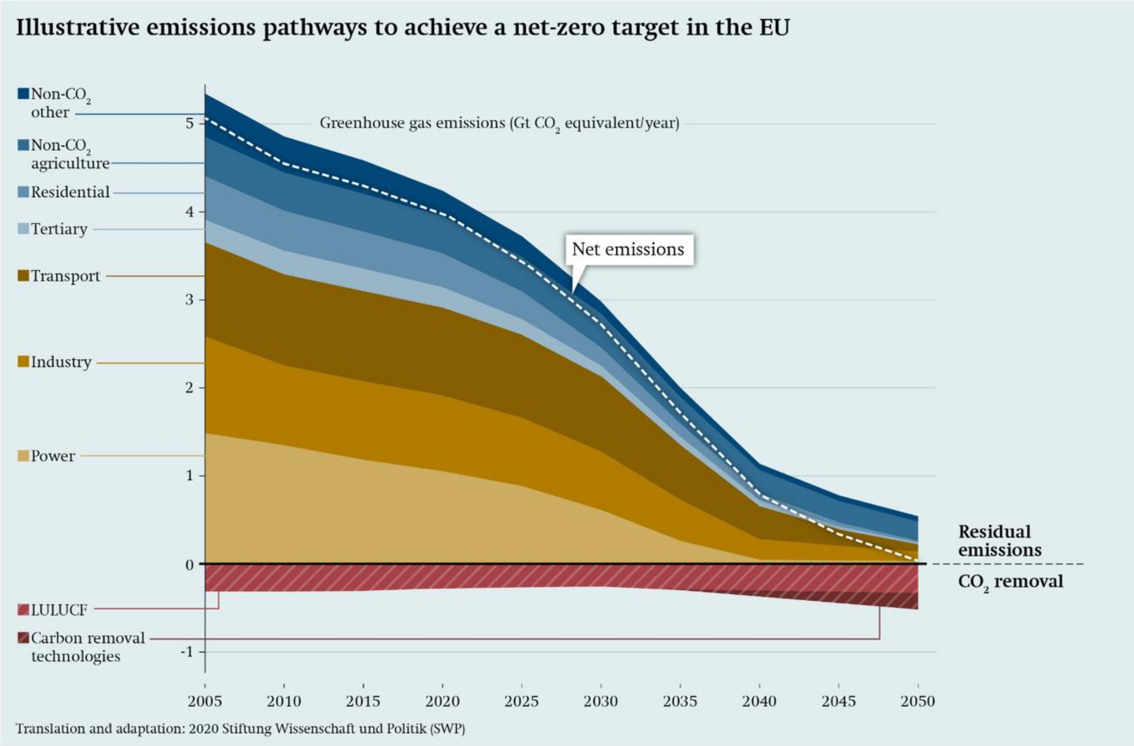
The steel industry is a major contributor of the global GHG emissions



Source: WRI, 2016

7.2%
of global emissions in 2016

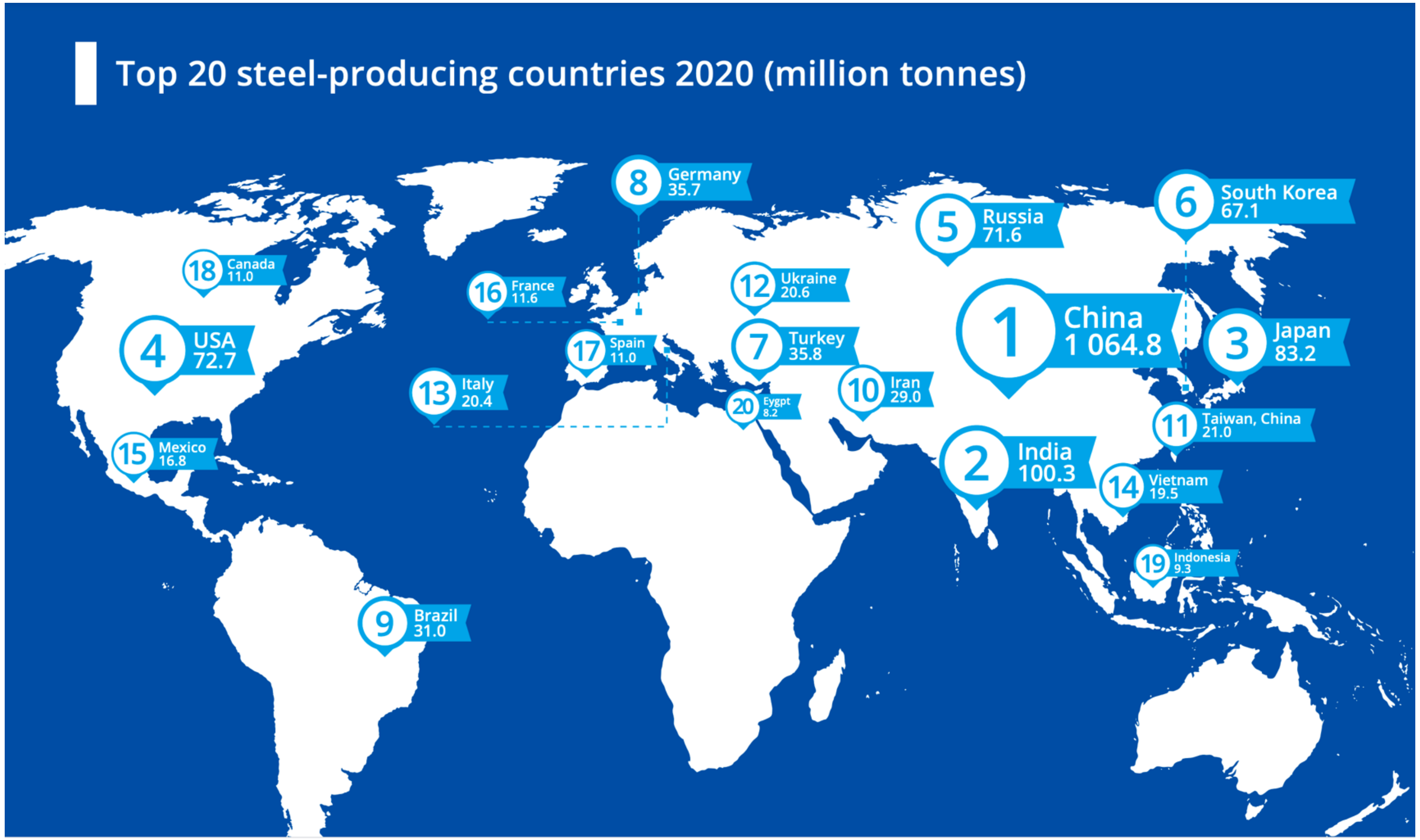
A net-zero target in the EU for all sectors



Source: World Economic Forum, adapted from the SWP, 2020

- The EU Net 0 Roadmap targets a 30% reduction in 2030 compared to 2018, and being close to neutrality by 2050.
- The steel sector has its part to play, and can follow this reduction pathway with the proper policies and technologies (EUROFER, A Green Deal on Steel).
- The European Green Deal sets the objective of creating new markets for climate neutral and circular products, such as steel, cement and basic chemicals. (European Commission, A New Industrial Strategy for Europe).

Europe can lead the way to the steel sector's decarbonisation

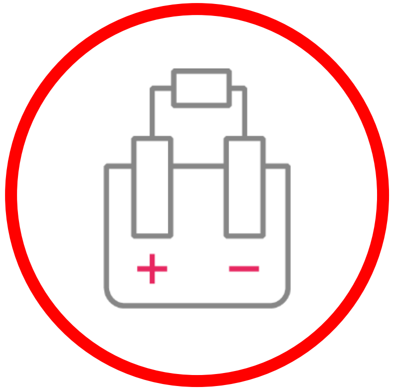


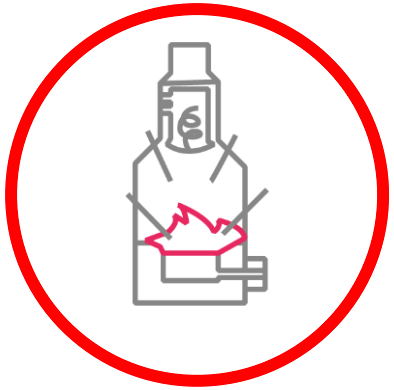
Source: Worldsteel, 2020

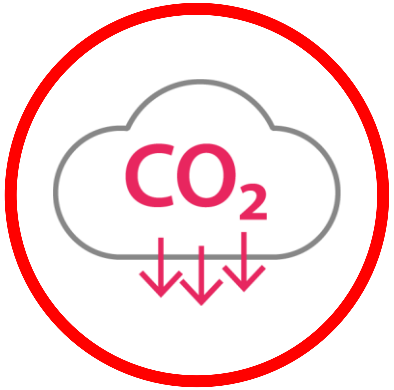
- 10% of steel is produced in Europe in 2020 – out of 1878 million tons worldwide.
- By developing innovative technologies to decarbonise its steel sector, Europe can inspire other steel-producing countries.

SIDERWIN: a decarbonisation option for the steel sector

Several pathways for decarbonizing the steel sector







↓ **Electrolysis** of Alkaline iron and smelting in electric arc furnace, or induction furnace (**ΣIDERWIN**).

↓ **Direct reduction of iron ore (DRI)** with carbon-neutral hydrogen produced from methane, and smelting in electric arc furnace.

↓ **HIsarna**® process – reduction of ore and up to 50% scrap, combined with Carbon Capture and Sequestration (CCS).

↓ **Carbon Capture and Use (CCU)** of smelting gases from integrating blast-furnace works.

Source: Agora Report, April 2021

ΣIDERWIN's key innovations

ΣIDERWIN allows decarbonisation of steel production through the following innovations:

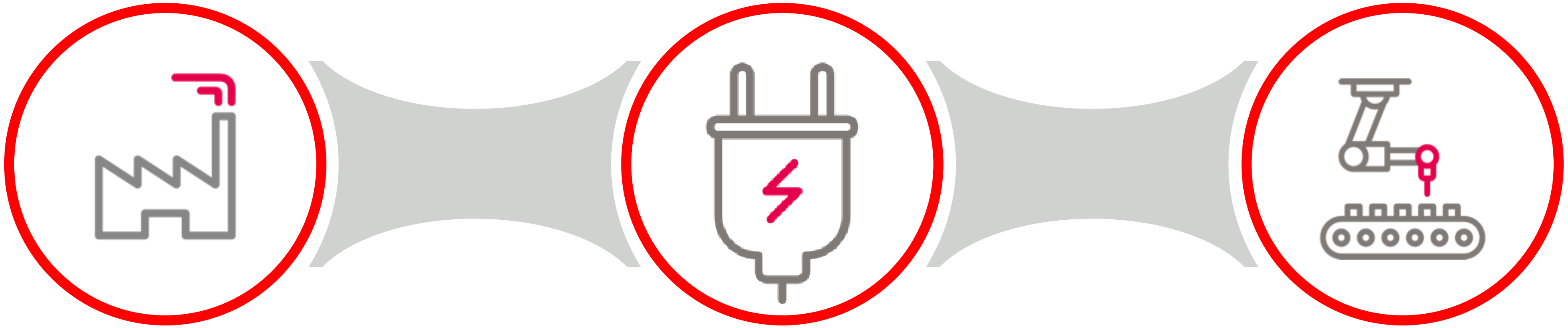
↓ **Electrolysis** process to transform iron oxide into metal thus eliminating the Blast Furnace.

↓ Use of **induction furnace** instead of Electric Arc Furnace.

↓ **Elimination** of lime plant **CO_2 emissions**, **lime and oxygen** input by electrification of the regeneration of the alkaline leaching solution and elimination of the Basic Oxygen Furnace by introduction of desulphurised and dephosphorised iron ore.

↓ Elimination of hot rolling CO_2 emissions by **substitution of natural gas** with **induction heating**.

The potential of SIDERWIN in terms of steel decarbonisation



SCOPE 1 EMISSIONS
Direct emissions

By electrifying steel production, the ΣIDERWIN technology could help reduce the <u>direct</u> emissions of the steel sectors.

SCOPE 2 EMISSIONS
From purchased power

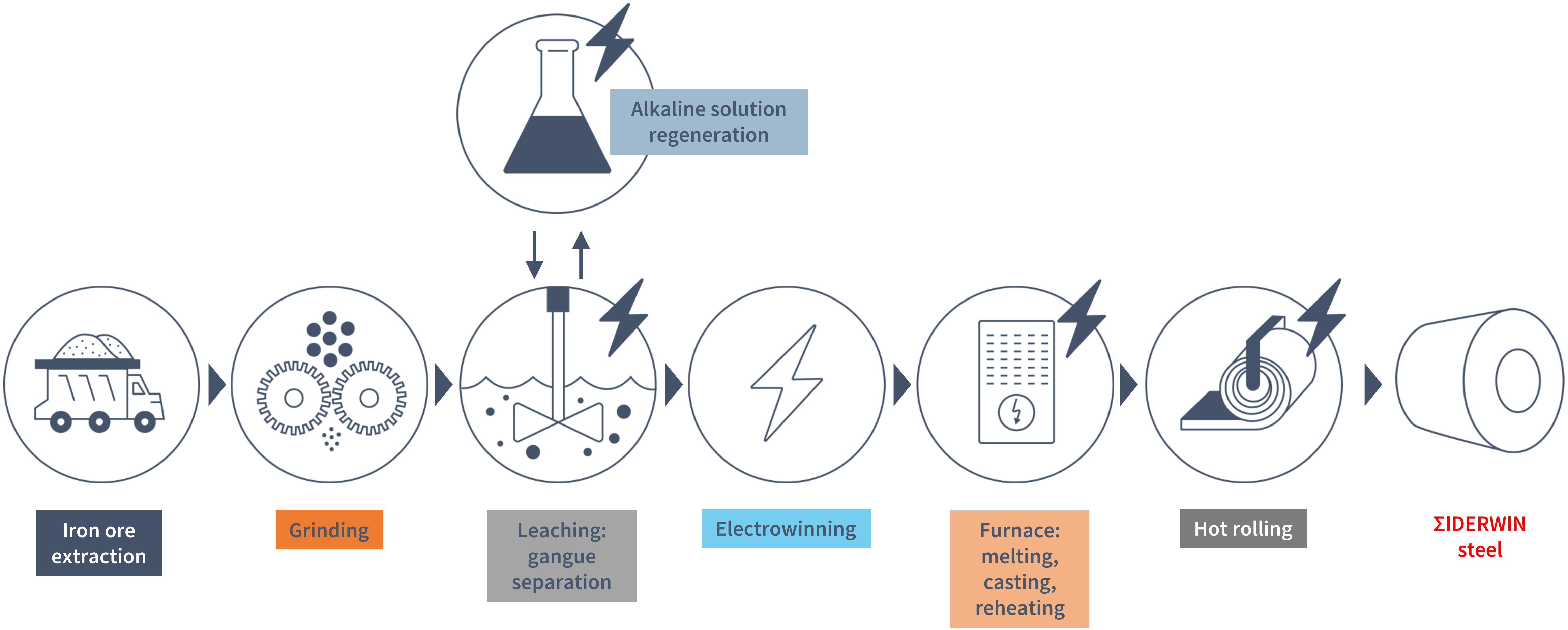
The ongoing decarbonisation of the electricity sector in Europe will drive the emissions of electrified steel production down.

SCOPE 3 EMISSIONS
From the value chain

High carbon-footprint inputs such as lime will be reduced by the ΣIDERWIN technology, reducing the emissions caused by steel's upstream value chain.

Modelling the ΣIDERWIN Technology

System boundaries: from raw materials extraction to factory gate.



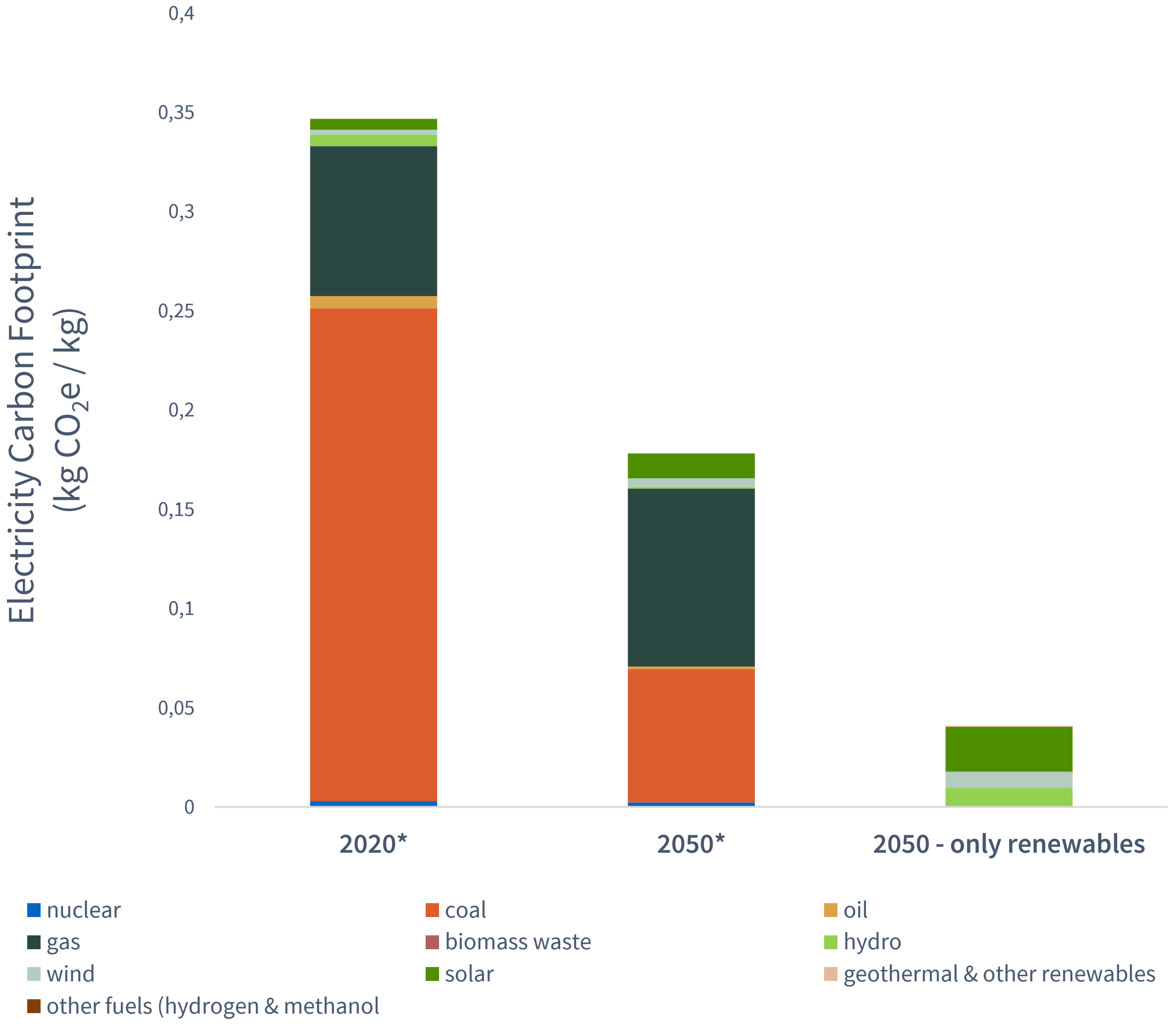
Modelling the ΣIDERWIN Technology

Data sources:

ArcelorMittal | eDF | Literature reviews | ecoinvent |

The decarbonisation potential of ΣIDERWIN

Presentation of Electricity Mix Scenarios



Several scenarios on Electricity mix were assessed to capture the potential of ΣIDERWIN:

↓ **2020*:**

an average electricity mix « as is » in Europe

↓ **2050*:**

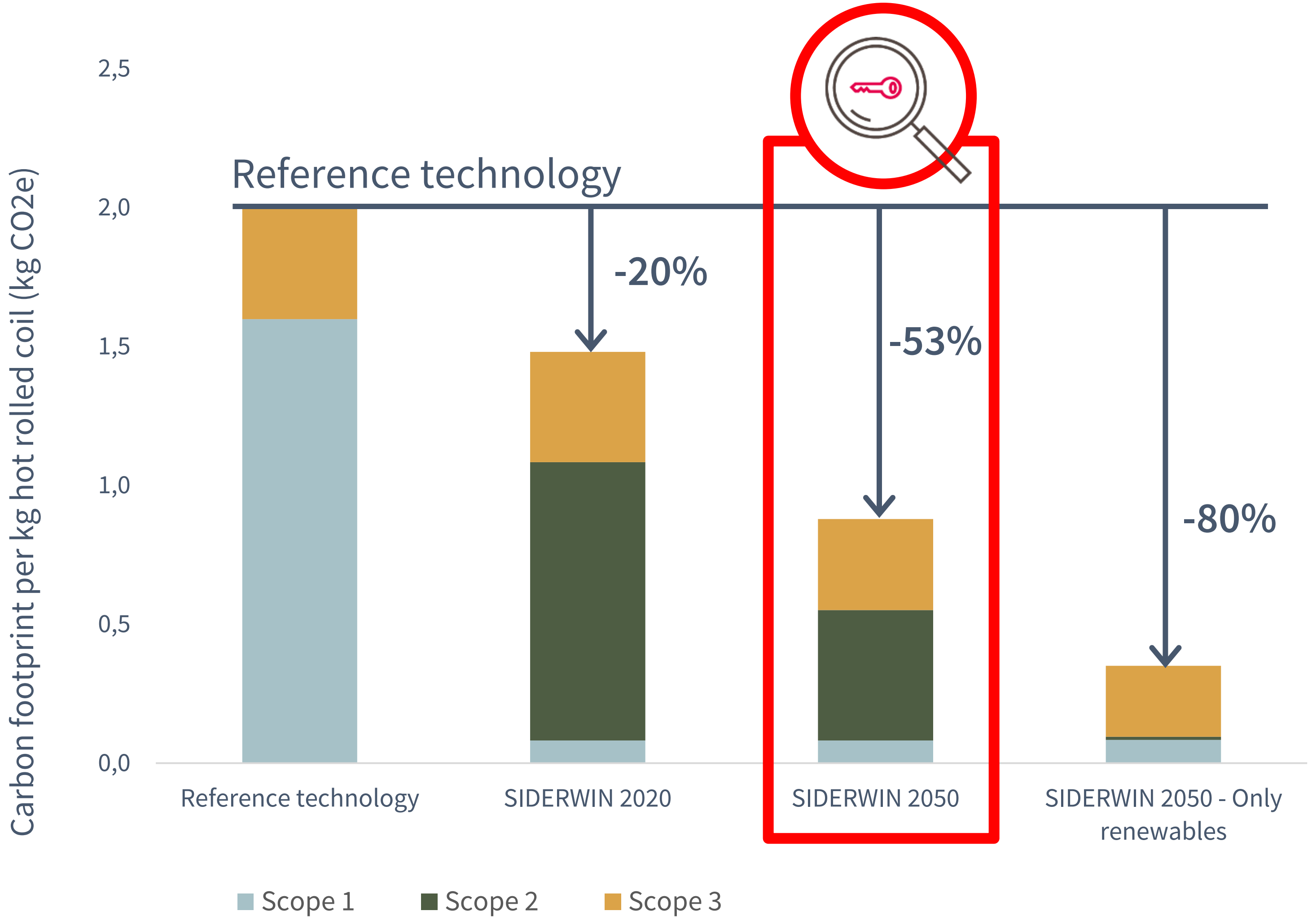
the electricity mix in 2050 according to the EU Roadmap

↓ **2050 – only renewables:**

a 100% renewable mix

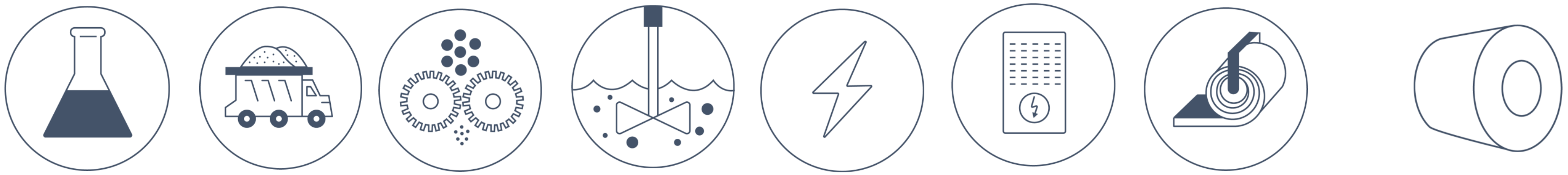
*Calculations aligned with the EU Reference scenarios 2016 report.

Carbon footprint of SIDERWIN compared to the reference technology



- Switching from the reference technology to ΣIDERWIN could allow **up to 80% reduction of footprint**.
- For the reference technology, **scope 1 emissions (direct emissions)** represent 65% of the footprint.
- For the ΣIDERWIN routes, **scope 2 emissions** represents 68% of the footprint.
- With the 2050 electricity mix, this share falls to 53% and is negligible for the renewable mix.

Carbon footprint of SIDERWIN 2050 compared to the reference technology



	Alkaline solution regeneration	Iron ore extraction	Grinding	Leaching: Gangue separation	Electrowinning	Furnace: melting, casting, reheating	Hot rolling	ΣIDERWIN steel Total (kg CO_2e / kg)
Scope 3	1%	4%	2%	4%	**48%**	**36%**	6%	**0.3**
Scope 2	0%	0%	3%	5%	**70%**	**19%**	2%	**0.5**
Scope 1	Negligible							**0.1**

The potential of SIDERWIN in terms of steel decarbonisation

UP TO 80% FOOTPRINT REDUCTION PER TON

Thanks to its innovations, the ΣIDERWIN technology could allow to reduce the footprint of steel by up to 80% per ton by 2050.

AN ASSET FOR THE EU STEEL ROADMAP

The SIDERWIN technology is thus a precious route for reducing the footprint of the steel sector and attaining its neutrality objective in 2050.

FINAL RESULTS TO COME

Further improvements of the route will be included in the final results
Other indicators will be included.

Thank you

for your attention

Questions?

Development of new methodologieS for InDustrial CO_2-freE steel pRoduction by electroWINning

Conclusions

Hervé Lavelaine – Coordinator
ArcelorMittal

Webinar November 24th 2021

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 768788

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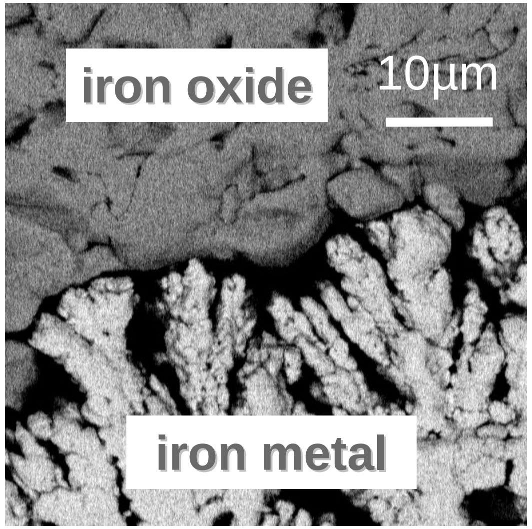
ΣIDERWIN ambitions

- An electrochemical route specific to iron element properties.

  - Science is our methodology.

  - It has identified the most opportune route to electrify primary steel production.

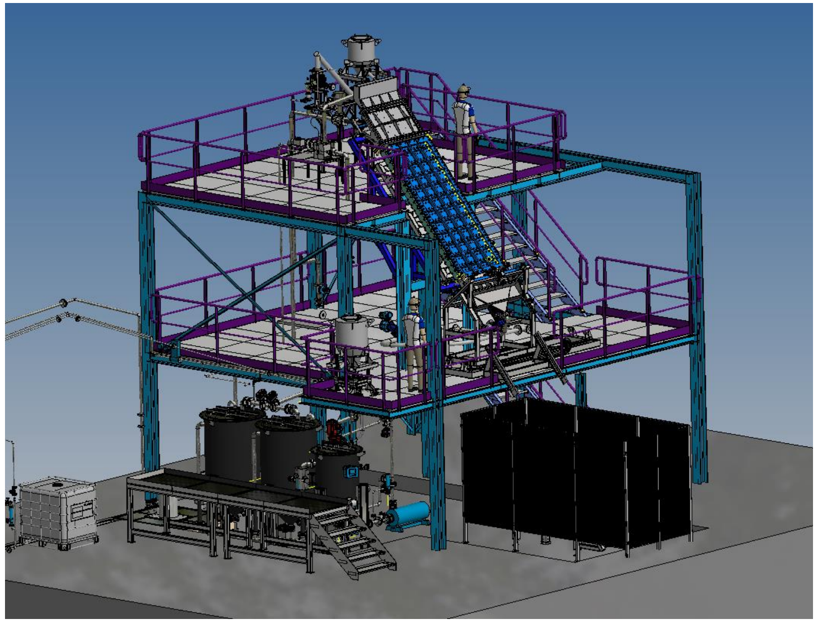


Direct transformation of iron oxide into metal.

ΣIDERWIN ambitions

- A technology scalable to industrial size for mass production of Steel.

  - Technology designed to operate readily close to physical limits thanks to simulation.
  - Technological demonstration is our methodology.



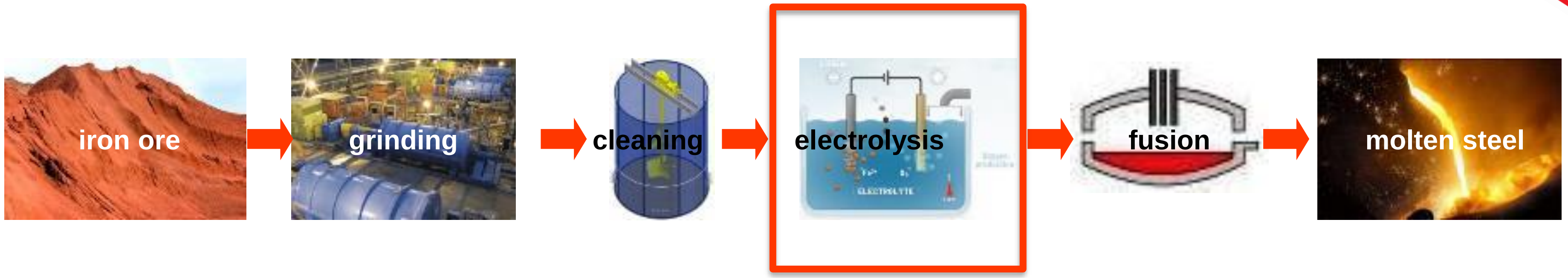
Climbing the Technical Readiness Level scale.

ΣIDERWIN ambitions

- A processing route realising full energy and environmental efficiency.

  - Electrification for physical substitution to carbon.
  - Electrification for energy efficiency and process simplification.

SMART GRID READY



Electrification of all the processing steps.

ΣIDERWIN ambitions

- A vision of future steel plants:

1. Decarbonisation imposes the reinvention of steel production.
2. Low impact activity, with lower landscape visibility, lower footprint and lower resource consumption.
3. An activity more tightly integrated in power grids, in material networks and in supply chain that contributes to the circularity of material flows.
4. An activity sensitive to energy priorities of its surrounding environment thus well adapted to European urban context.

ΣIDERWIN ambitions

- ΣIDERWIN project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 768788".

Thank you

for your attention