ENERGY STORAGE
INTRODUCTION TO TWO POWER-TO-X TECHNOLOGIES

FREE ONLINE WEBINAR June 20, 11:00 - 12:00

RECYCALYSE | DARE2X

European Union's Horizon 2020 research and innovation programme fund the project **RECYCALYSE** under grant agreement No 953073, **DARE2X** has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101083905.

WEBINAR AGENDA

11:00 – 11:05	1	**WELCOME AND INTRODUCTION** P. Morales Moya | SUSTAINABLE INNOVATIONS
11:05 – 11:15	2	**INTRODUCING THE ENERGY STORAGE AND POWER2X CONCEPT** C. Kallesøe | DTI / RECYCALYSE Coordinator
11:15 – 11:35	3	**THE SOLUTION BEHIND RECYCALYSE** S. Pitscheider | DTI Researcher
11:35 – 11:55	4	**THE SOLUTION BEHIND DARE2X** C. Mølleskov| DTI / DARE2X Coordinator
11:55 – 12:00	5	**Q&A, MENTIMETER SESSION** P. Morales Moya| SUSTAINABLE INNOVATIONS

RECYCALYSE - DARE2X

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 861960

WEBINAR NOTICES

This session is being recorded

Please, make sure your microphone is muted

Use the chat function to enter your questions

This is an interactive session, please, participate on menti.com

WEBINAR SPEAKERS

Pablo Morales Moya
SUSTAINABLE INNOVATIONS

Christian Kallesøe
DANISH TECHNOLOGICAL INSTITUTE

Simon Pitscheider
DANISH TECHNOLOGICAL INSTITUTE

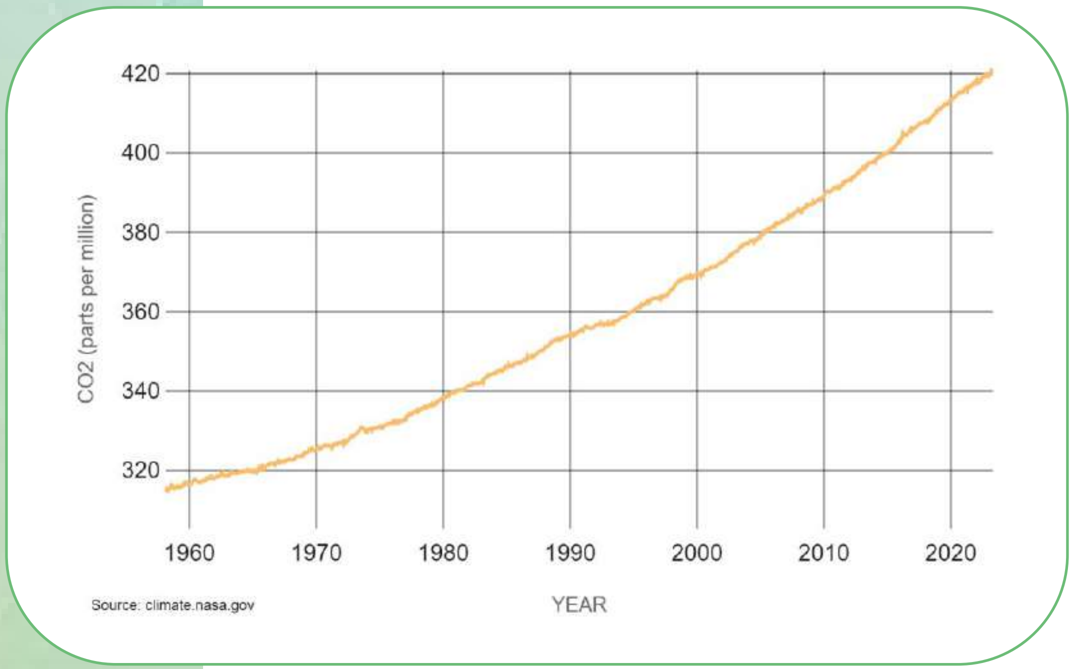
Christoffer Mølleskov
DANISH TECHNOLOGICAL INSTITUTE

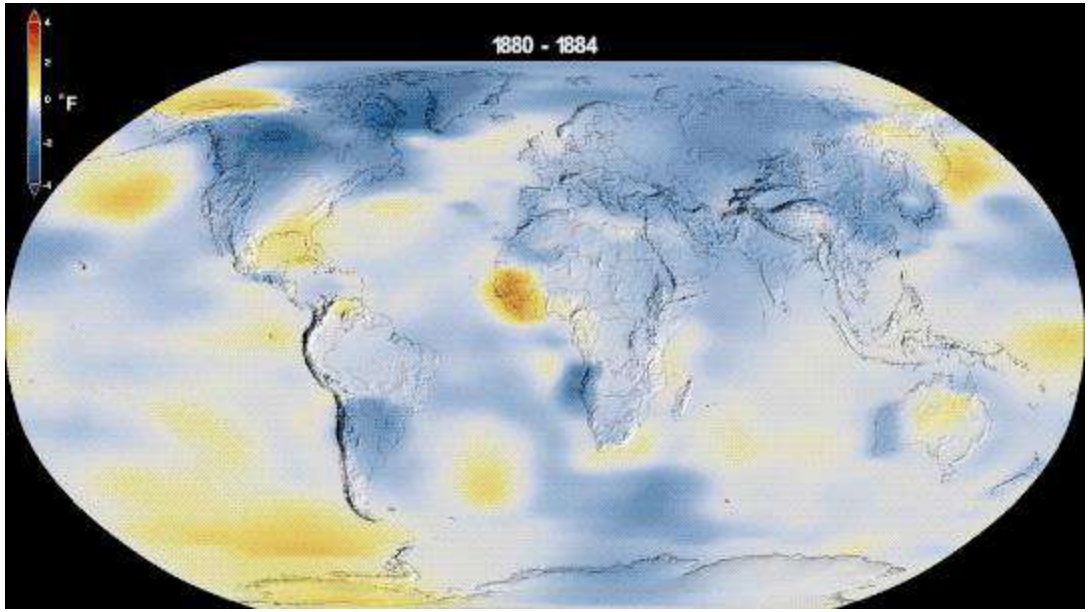
2

INTRODUCING THE ENERGY STORAGE AND POWER2X CONCEPT

Christian Kallesøe

CURRENT WORLD SITUATION

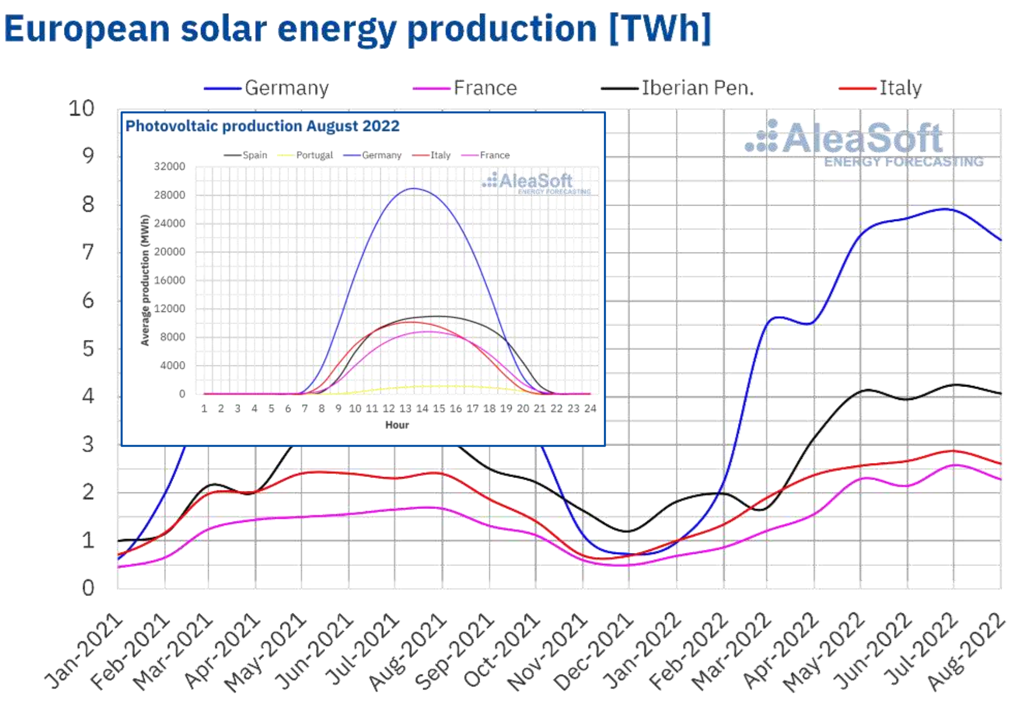


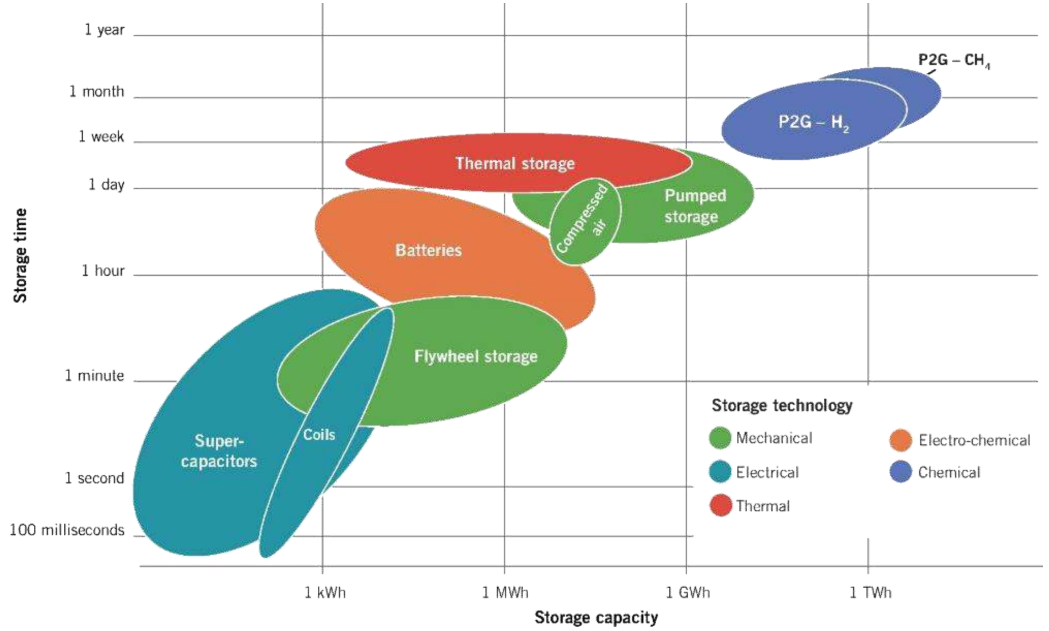


- There is a correlation of the ammount of CO_2 in the atmosphere and the rise in temperature.
- The Paris Agreement looks to stop the temperature rise by 1.5^{o} C.

Source: https://climate.nasa.gov/

ENERGY STORAGE

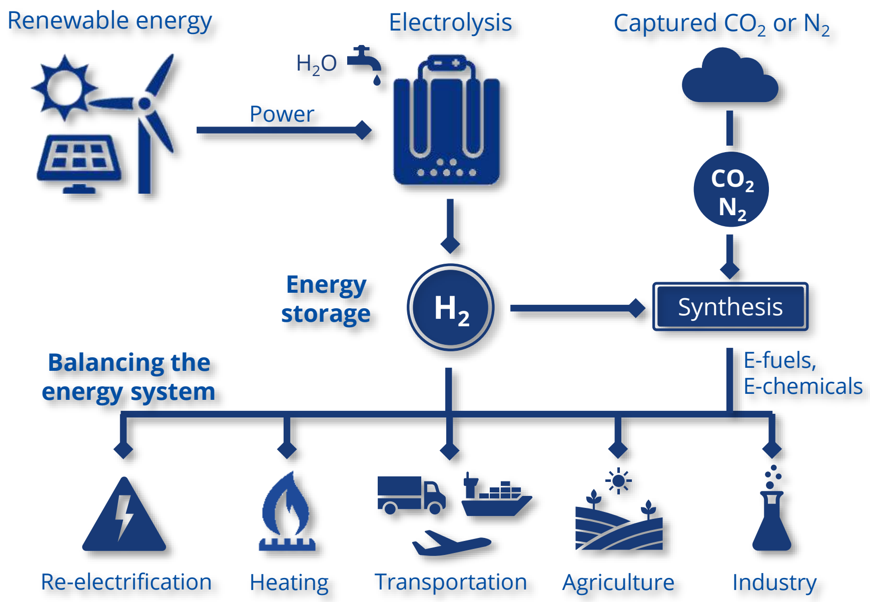


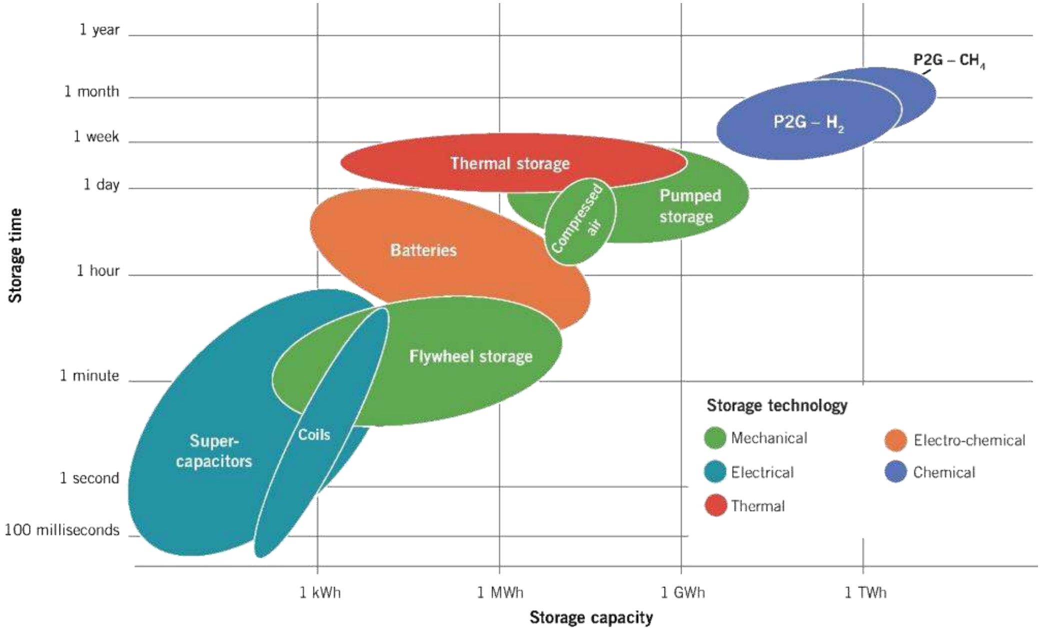


Intermittent electricity production requires energy storage

Laiminger et al. 2020

POWER-TO-X



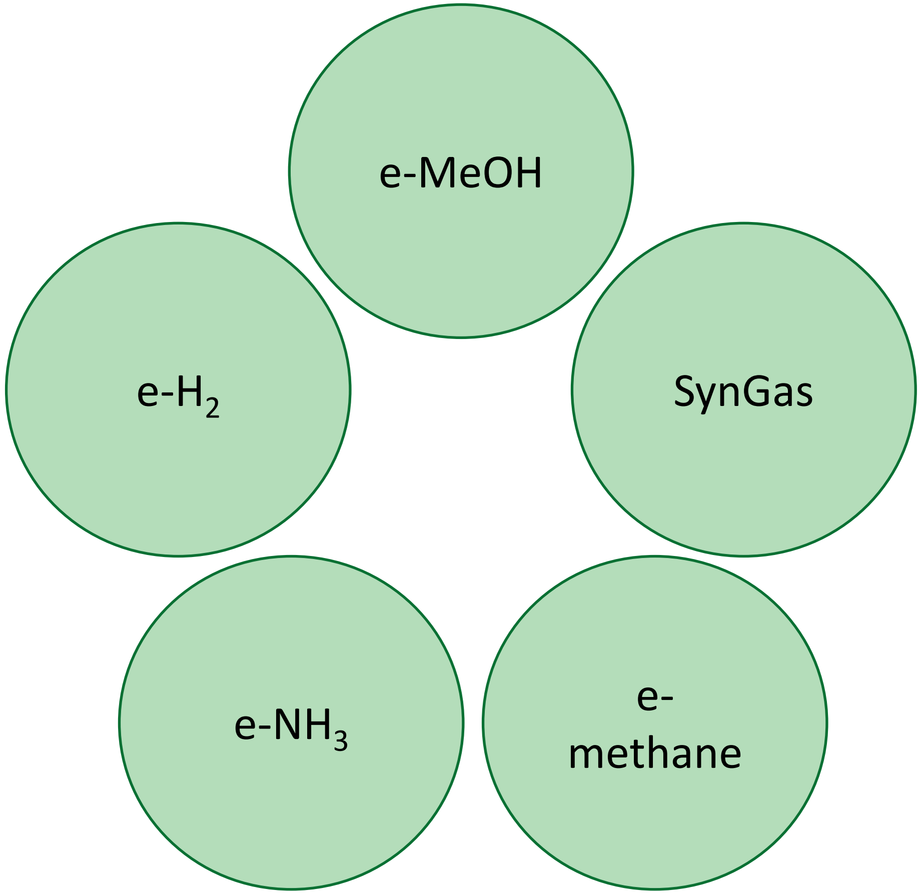


Power2X are the reaction pathways that use renewable energy to make e-fuels and e- chemicals that can be used in different applications. These e-fuels can have even higher energy density.

Adapted from: https://www.ramboll.com/da-dk/net-zero-explorers/power-to-x-explained

Laiminger et al. 2020

MOST COMMON CHEMICAL INTERMEDIATES AND FUELS



- By adding CO2 to e-H2, e-fuels such as e-diesel, e-methanol, e-kerosene, e-dimethylates (E-DME), and e-methane can be produced.
- By adding nitrogen to e-H2, you can produce green ammonia (e-ammonia)
- These e-fuels can have very high energy densities.

CURRENT APLICATIONS

e-H_2

- H2 is an important green fuel.
- Can be used in fuel cells, however its low volumetric enegy density limits its use as a fuel.
- To overcome storing problems it can be directly converted.

e-MeOH

- MeOH can be used as fuel for heavy mediums of transportation.
- Gasoline motors can be easily converted to run on e-MeOH.
- Easier to produce than e.g. e-diesel or aviation fuel.

SynGas

- Syngas is a precursor to chemicals, heavy duty fuels and aviation fuel.

CURRENT APLICATIONS

e-methane

- e-CH_4 can be used to produce other chemicals
- e-CH_4 can be an alternative to biogas

e-NH_3

- >1 % of the world's total carbon emissions comes from the production of ammonia.
- Ammonia is the most important fertilizer in the world.
- e-ammonia is thought to be the green fuel of the future of big shipping.

THE BIG PICTURE

3

THE SOLUTION BEHIND RECYCALYSE

Simon Pitscheider

Webinar

Energy Storage: Introduction to Two Power-to-X Technologies

20 June 2023

+ RECYCALYSE -

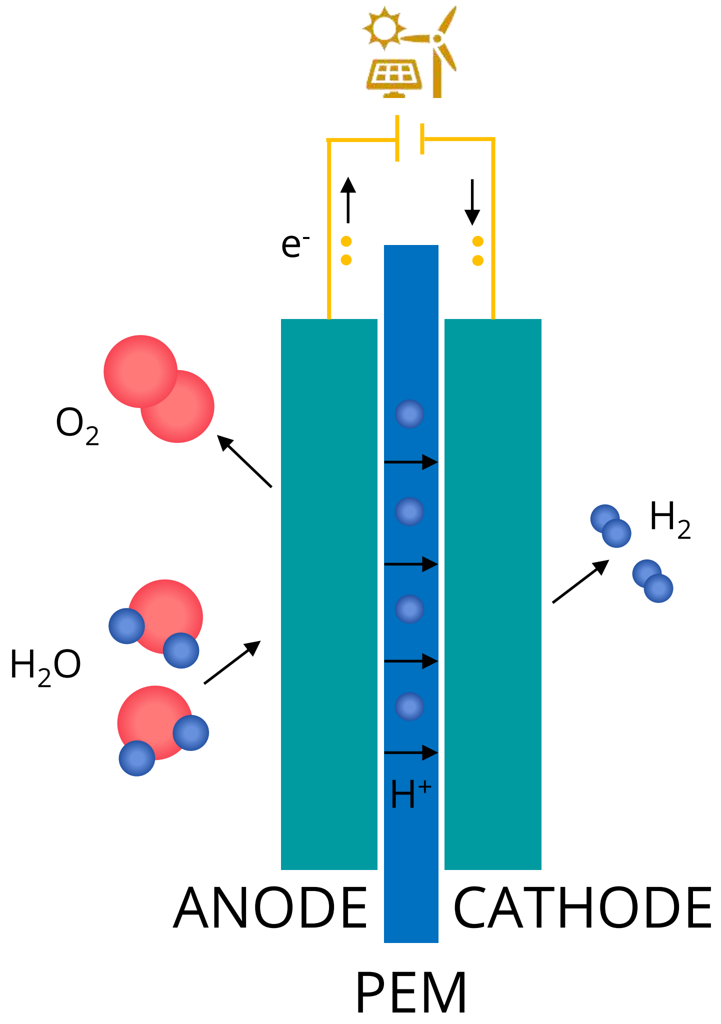
New sustainable and recyclable catalytic materials for proton exchange membrane electrolysers

Electrolysis

Proton exchange membrane	Alkaline	Solid oxide

PEM advantages

- Dynamic operation ability
    - Fast dynamic response times
- High efficiencies
    - Can operate at high current densities
    - Reduced operational costs
- High pressure operation ability
- Very high gas purities
- Uses clean water only (safe)



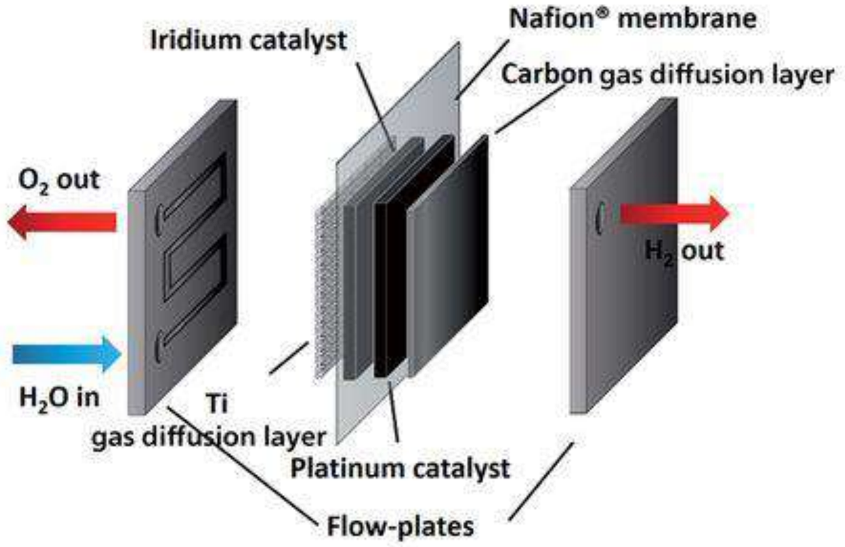
PEM electrolysis

Critical raw materials

- Anode: Iridium & ruthenium extremely low volume elements
  - High capital costs
  - Production rates: Ir: 9 tons/year, Ru: 12 tons/year
  - Huge amount of CO2 emissions during their mining (mined outside EU)

Metal	CO_2 footprint (kg CO_2-eq/ kg metal)
Ruthenium	2,110
Iridium	8,860
Nickel	6.5
Manganese	1.0
Copper	2.8
Titanium	8.1

Nuss & Eckelman, *PLoS ONE, 2014*



Cronin et al., *Energy Environ. Sci., 2014*

OBJECTIVES

RECYCALYSE will mainly focus on two objectives:

1. Develop and manufacture highly active sustainable oxygen evolution catalysts that will reduce or eliminate the use of Critical Raw Materials, thus decreasing CO_2 emissions and reducing cost.

2. Establish a recycling scheme for proton exchange membrane electrolysers catalysts, electrodes and overall systems. By implementing the recovered elements in the new developed catalysts, dependence on materials import in Europe is reduced or avoided, thus reaching a full circular economy.

GOAL

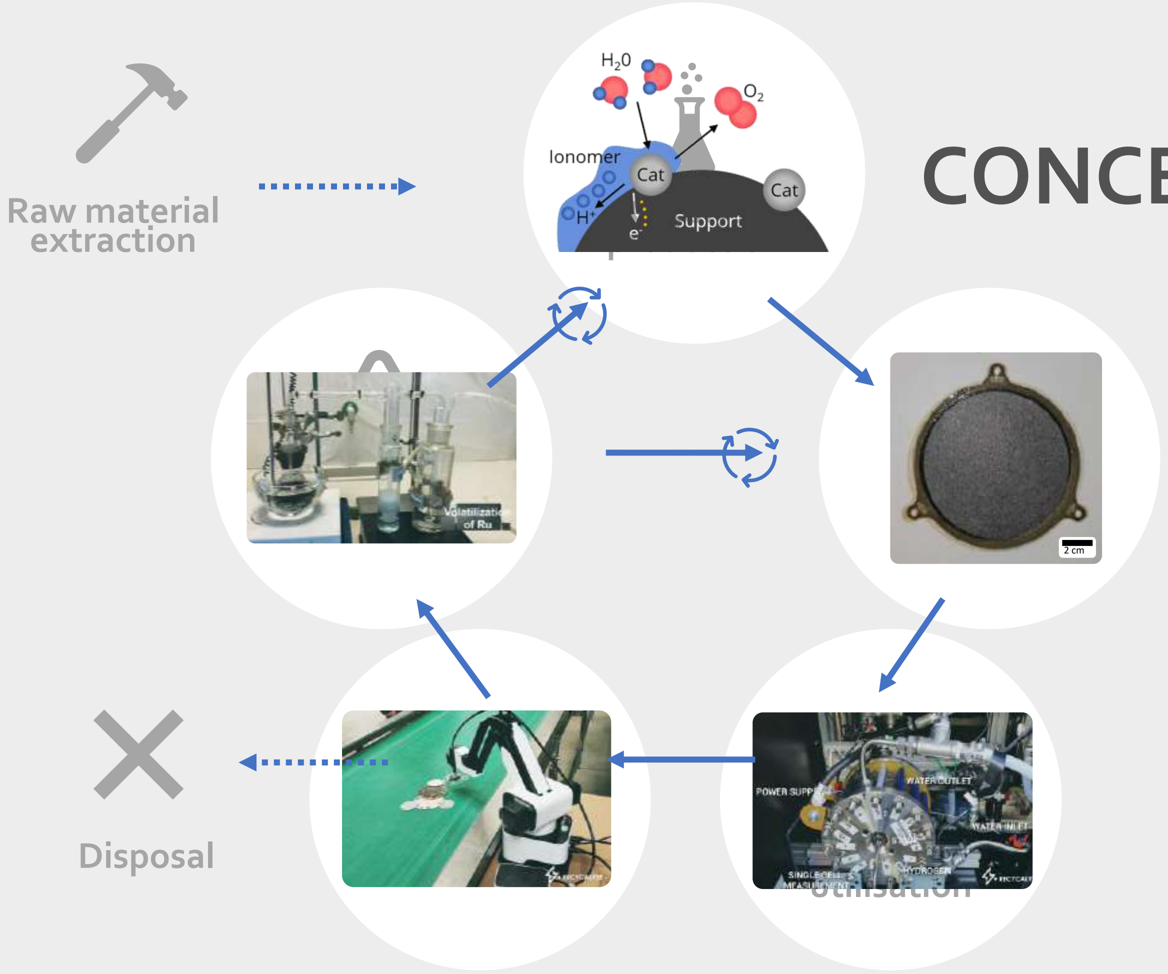
Overcome the main existing barriers for PEM electrolysers to penetrate the market, namely the **price**, **accessibility** and **performance** of electrocatalytic materials.

EXPECTED RESULTS

1. New stable catalysts materials with improved activity (supported $Ir_xRu_yO_z$ catalysts) and reduced CRM content (supported catalysts alloyed with earth abundant elements as well as CRM-free catalysts)
2. Efficient catalysts manufacturing processes
3. Scalable recycling processes for CRM, and other elements contained in the catalysts, e.g. Ni, Mn and Cu
4. Recycling of the spent MEAs utilising reactivation processes
5. Recycling strategies focused on the overall PEMEC system
6. A circular economy reached by reusing the recycled materials to prepare fresh catalyst and the reactivated MEAs

RECYCALYSE

CONCEPT



This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N. 861960

Catalyst materials

High performing catalytic sites

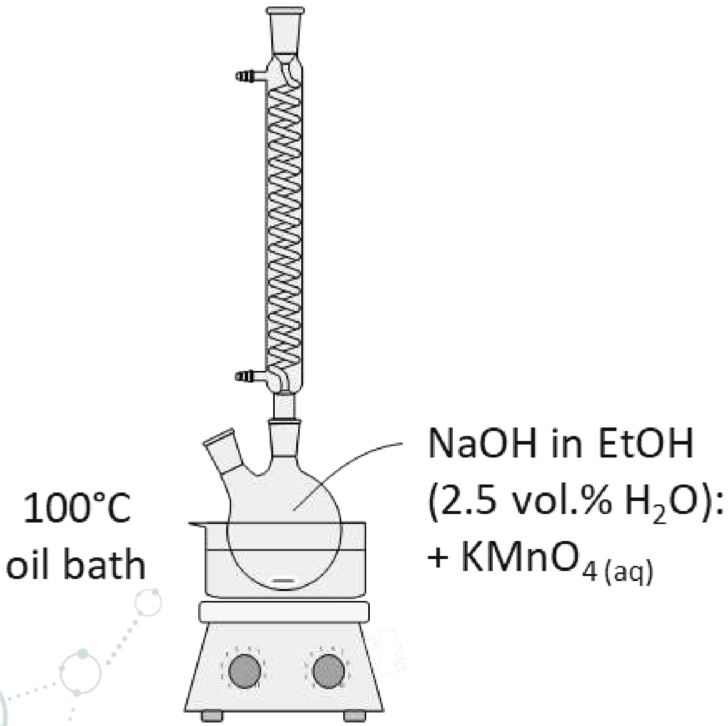
New catalyst support

Combined catalyst upscaling and fabrication

CRM free catalyst synthesis

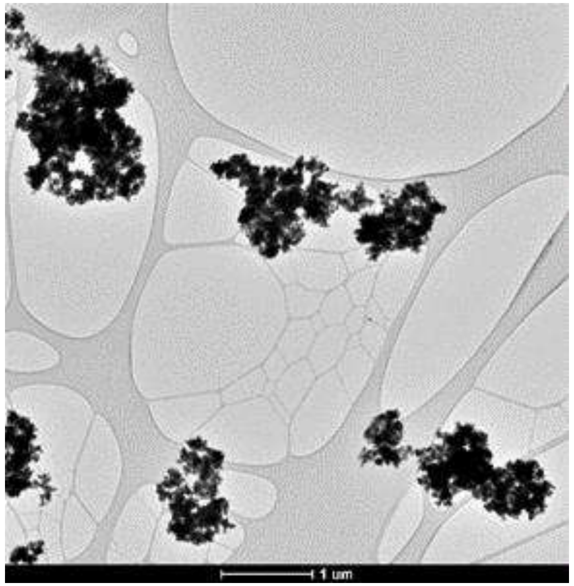
Mn_yO_x, $M_zMn_yO_x$ (M = Au, Ag) and composites of $Au_zMn_yO_x$

1. Synthesis MnO_x



2. $M_zMn_yO_x$ (M = Au, Ag) preparation
   - Au or $AgNO_3$ (+ $NaBH_4$) reduction in presence of MnO_x

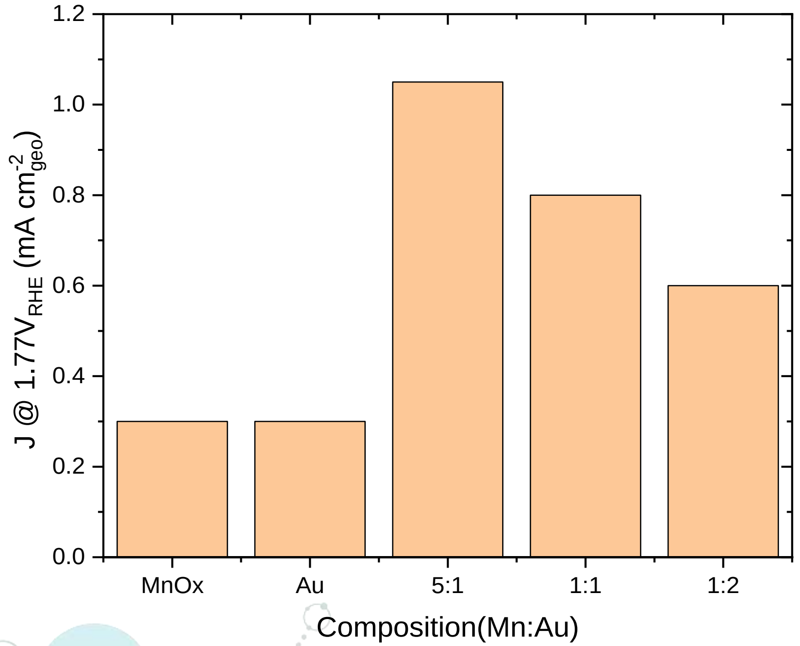
3. Composite $Au_zMn_yO_x$ (M = Au, Ag)
   - Deposition of Au NPs onto MnO_x (stirring overnight)



CRM free catalyst – MnOx + NW Au

Performance vs Composition

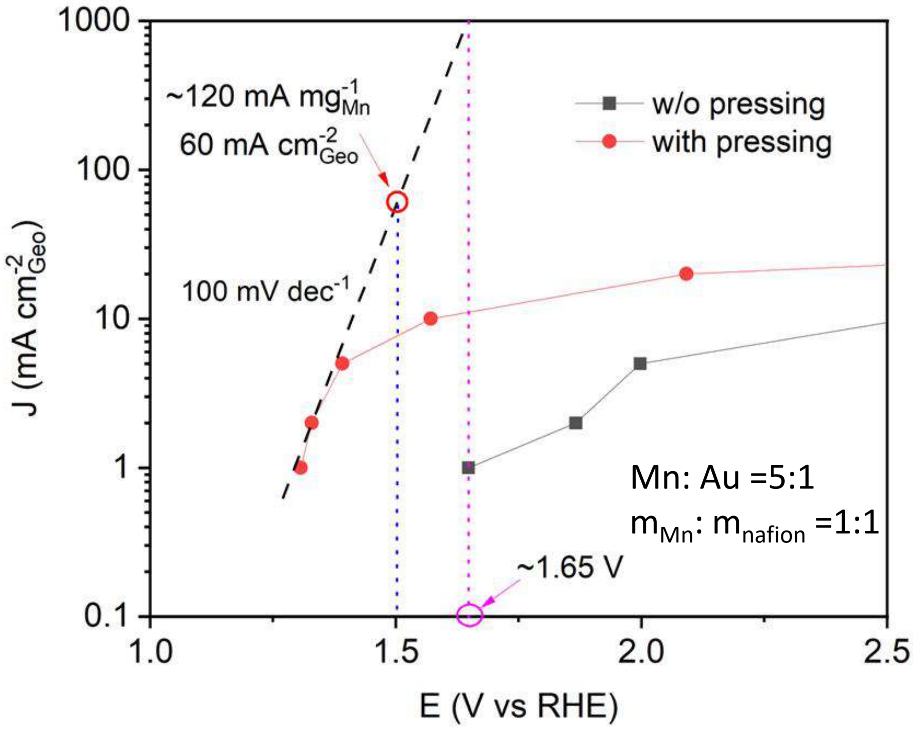
- H-Cell
- 0.1M $HClO_4$
- Loading: 482µg/cm2
- CVs: 1.1 - 2.0, 2mV/s

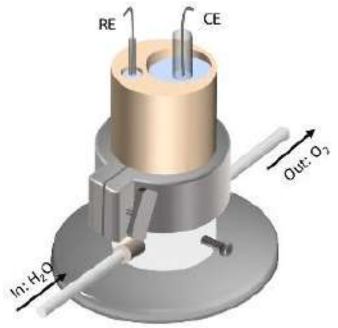


Composite (5 Mn: 1 Au) performs the best

Performance

OER measurements in GDE





With catalyst layer optimization more performance can be expected.

Catalyst layer prepared by spray serves as WE
4 M HClO4 serves as electrolyte
Current control mode

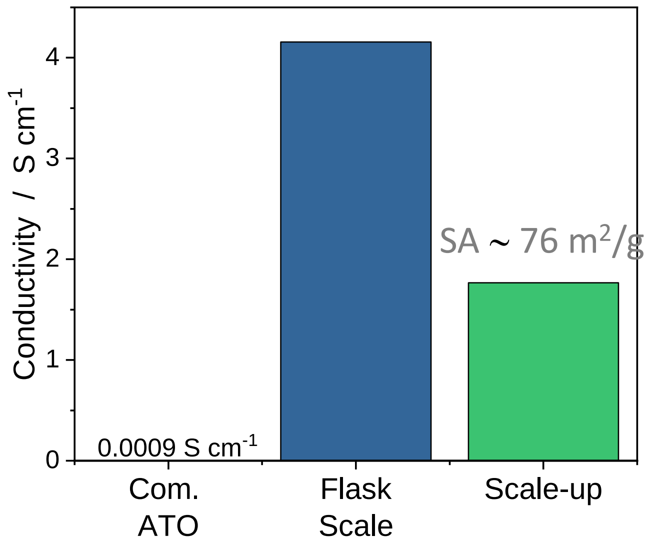
Catalyst support

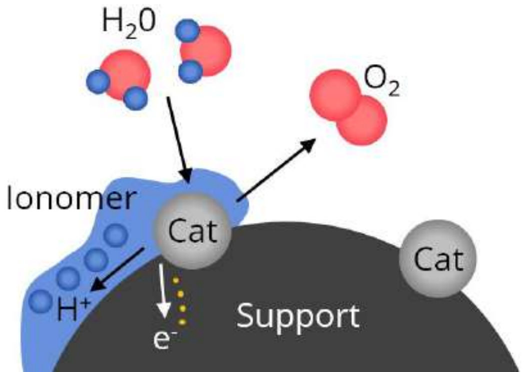
Demands:

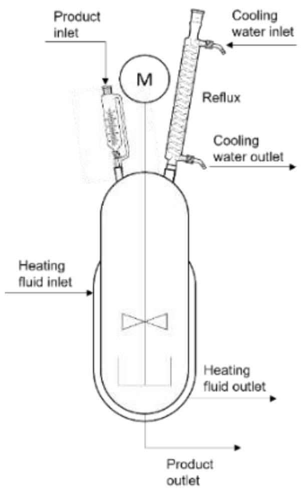
- High surface area, high conductivity, high electrochemical stability
- Most promising in terms of processability, reproducibility, easy to scale-up, meeting demands → ATO

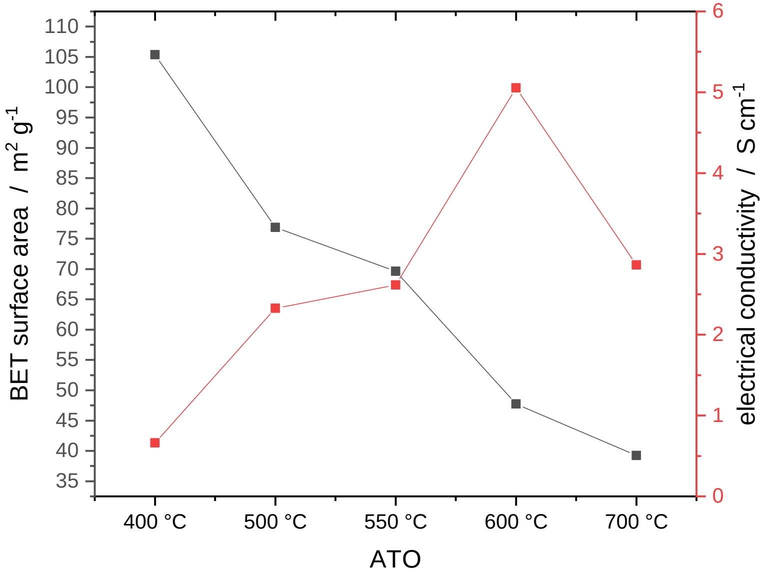
Results:

- Synthesized ATO has by a factor of 10^4 higher conductivities
- Conductivity of Flask Scale and Scale-up at the same order of magnitude
- Difference might be linked to porosity of material







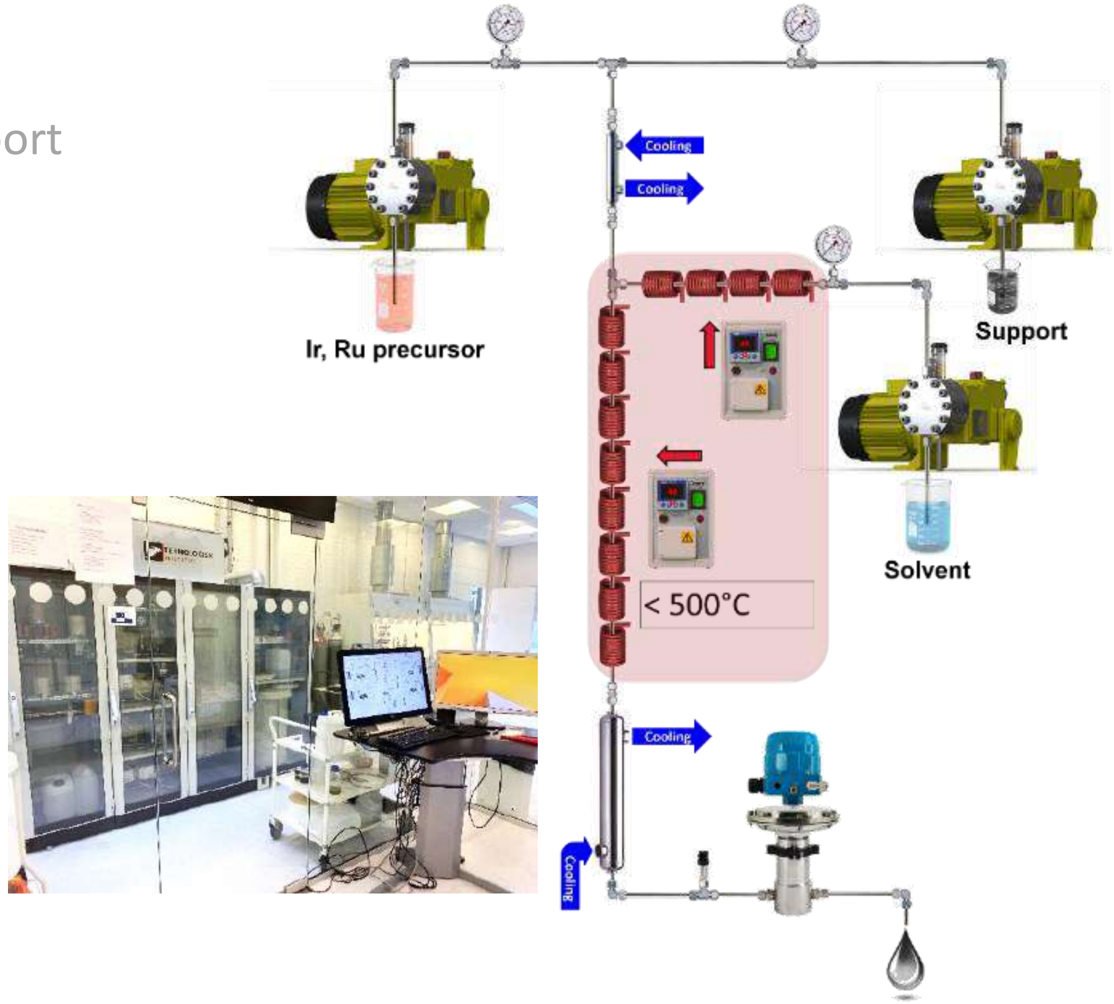


Combined catalyst structure

Hydrothermal flow synthesis of catalyst materials

- Combined Ir-alloy and support
- Upscaling challenge: Homogeneous IrRu distribution on support
- 15-20 g produced for stack

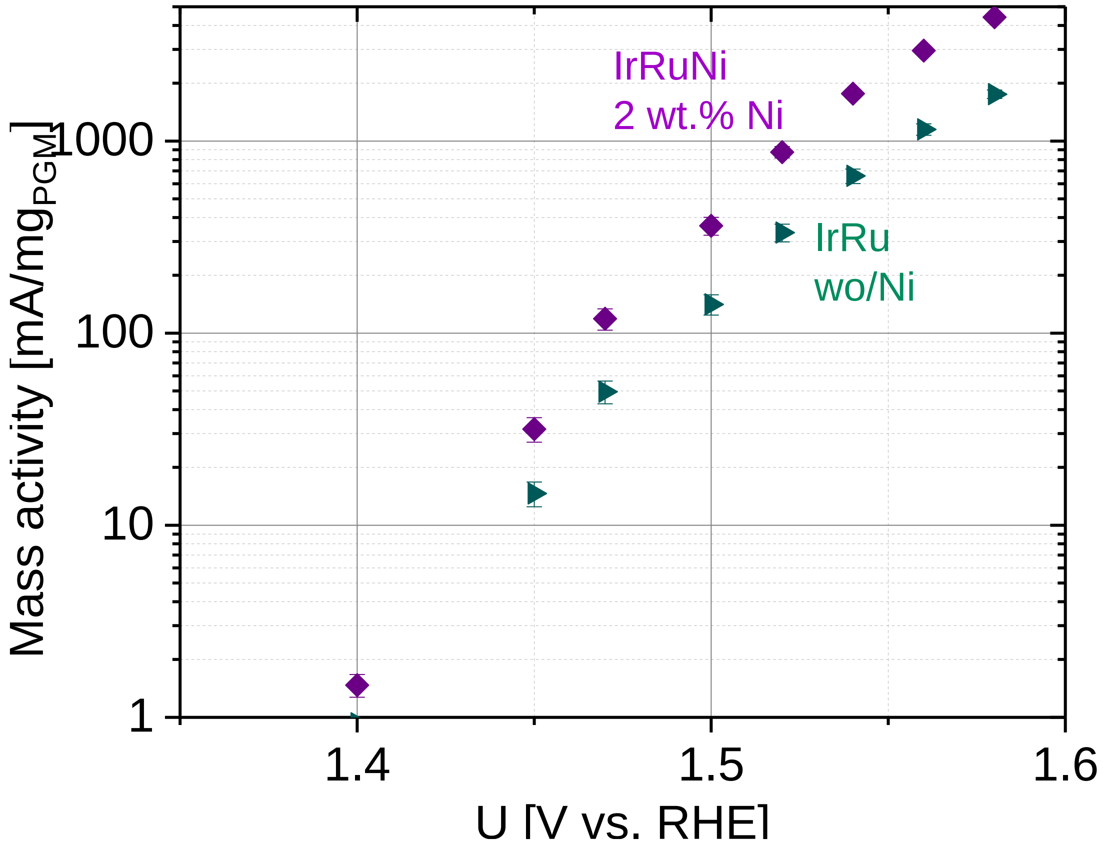
- Precursor and support solutions are pressurised to 300 bar at fixed flow rate
- Cold precursor solutions mixed with hot solvent and instantaneously reaches 250-300 °C
- Warmed solution continues through heated section
- Solution is cooled to room temperature
- Solution exits reactor through a pressure relieve valve



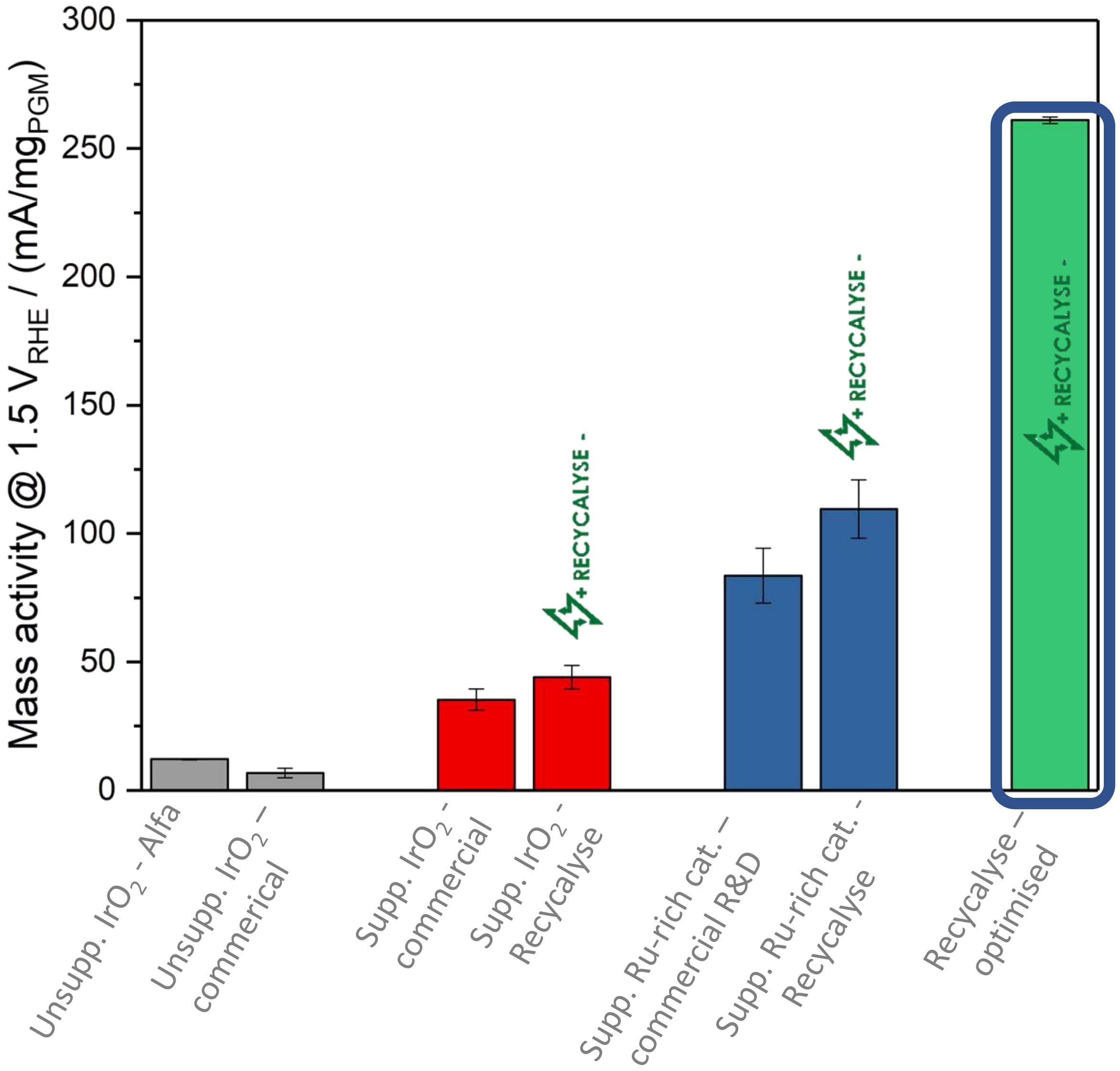
Combined catalyst and fabrication

Improving the catalyst activity by having Ni present in the synthesis

- Literature suggests that Ni can promote the formation of the Hollandite structure in IrO_2
- Adding controlled amounts of Ni during the synthesis showed substantial improvement of the catalyst activity
- Analysis using synchrotron-based PDF showed that we likely get a semi-amorphous structure with mixed Rutile and Hollandite structure



Combined catalyst upscaling and fabrication



Formulation passed on for stack production

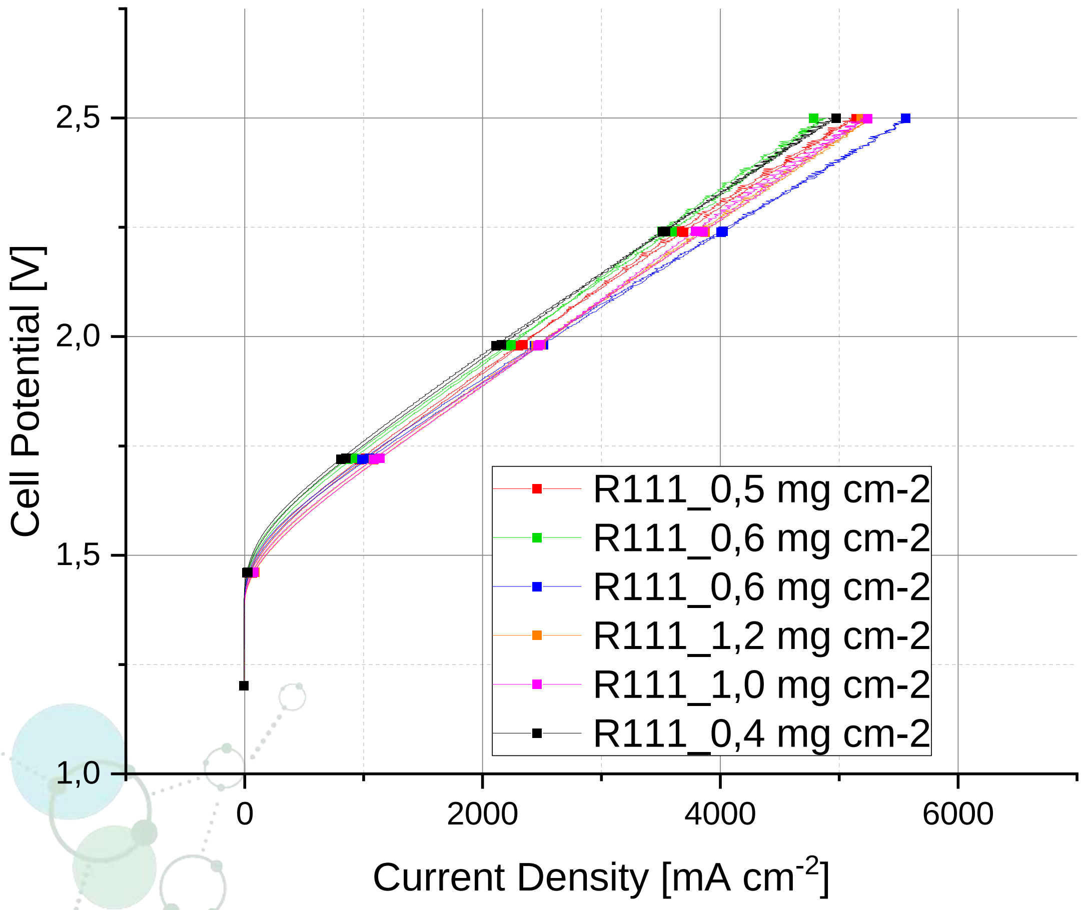
Electrodes and electrolyser

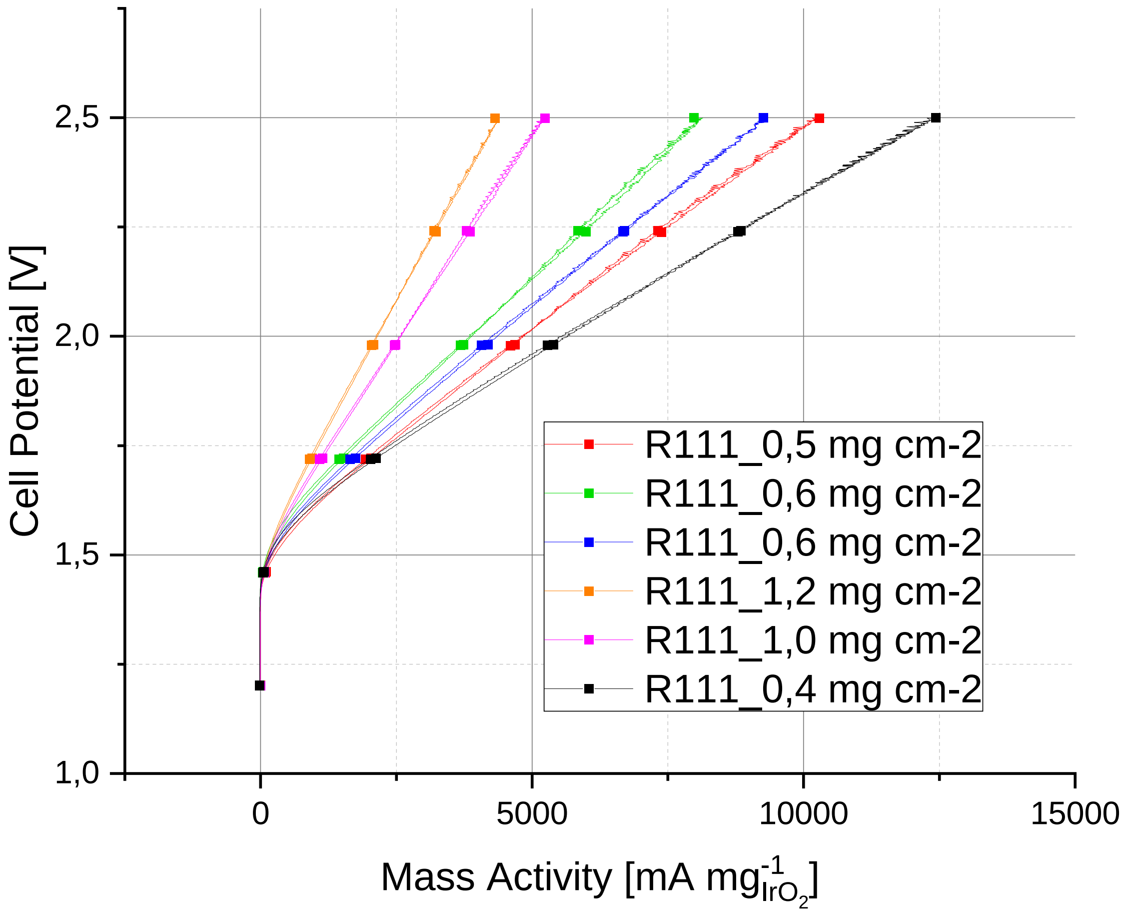
Electrodes and single cells

Electrolyser system

Electrodes and single cells

Catalyst investigation: Optimal Catalyst Loading? → Current Density vs. Mass Activity

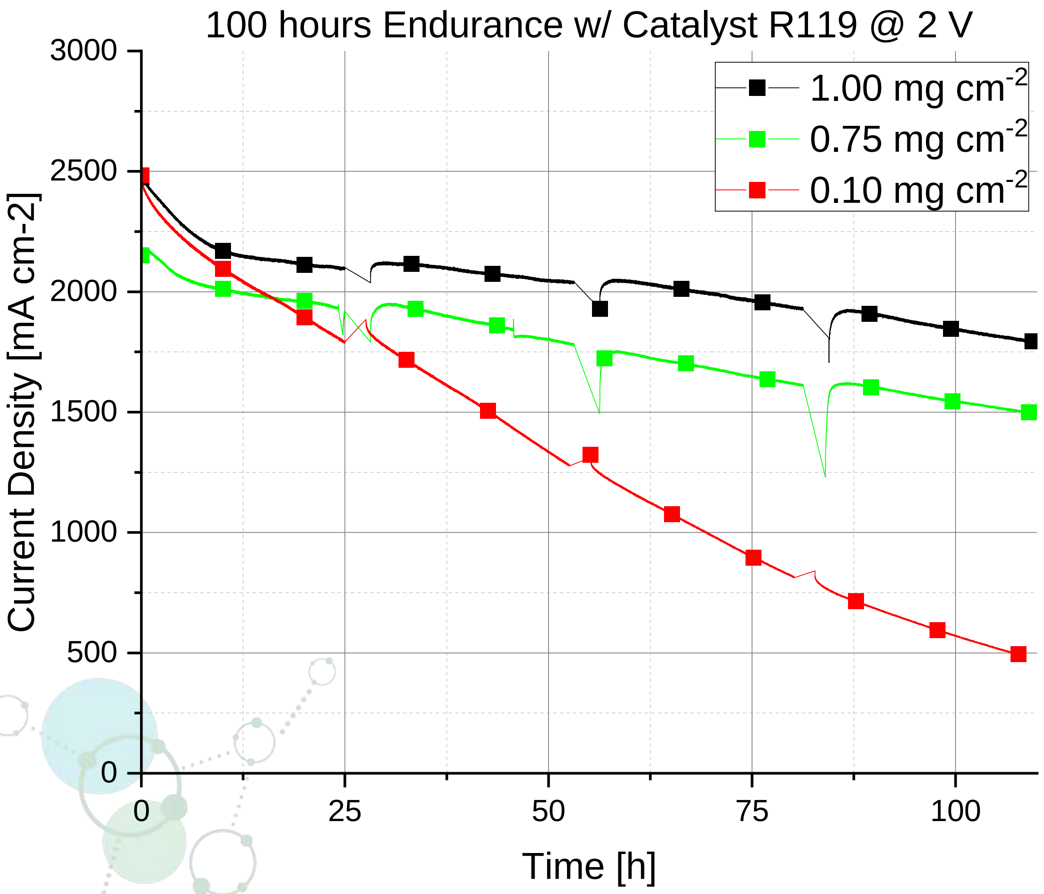


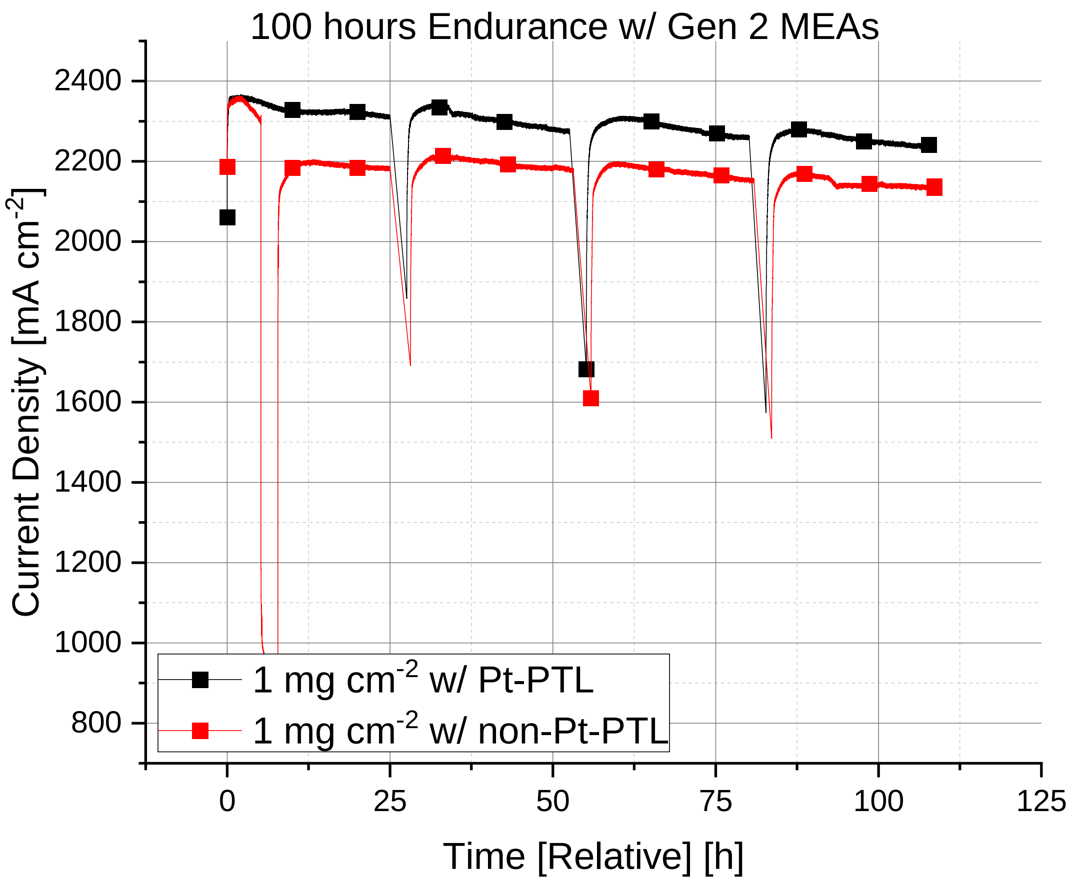


Electrodes and single cells

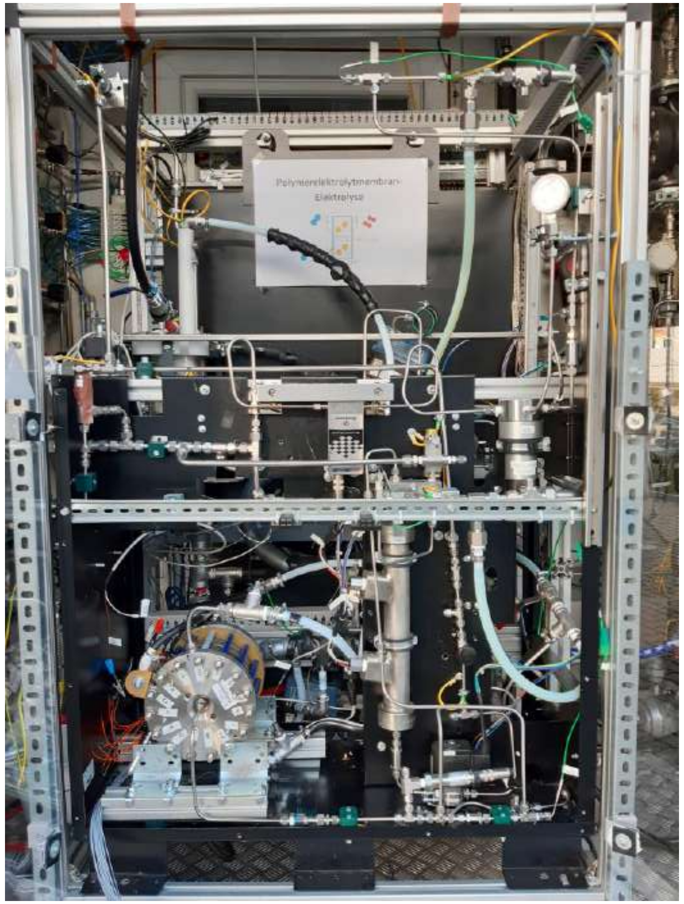
RECYCALYSE

MEA Degradation: MEA Configuration vs. Operation for 100+ hours





Testing of the stack

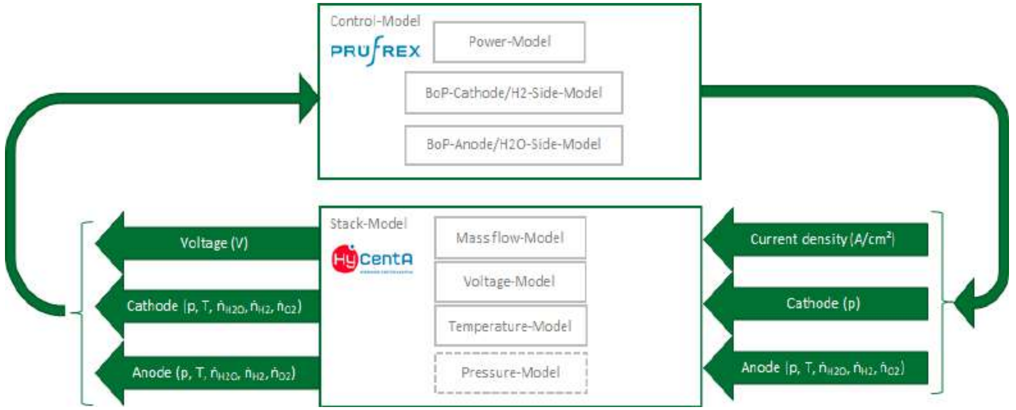


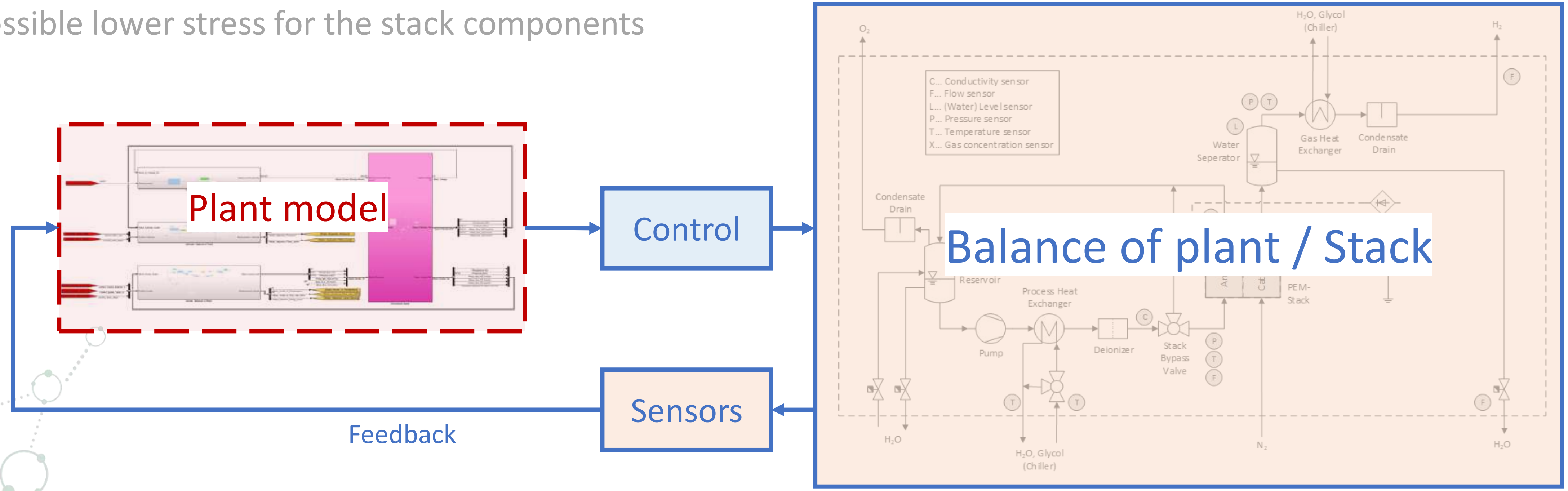
Electrolyser system

Model based control

Benefits of model-based control

- System simulation with reduced amount of sensors
- Higher control quality
- Possible lower stress for the stack components



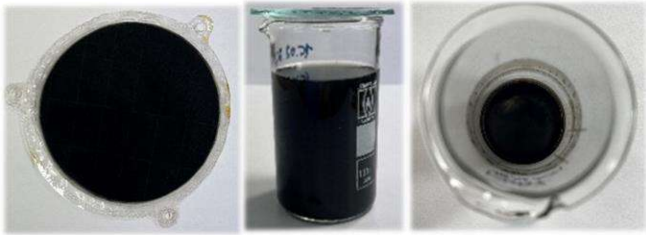


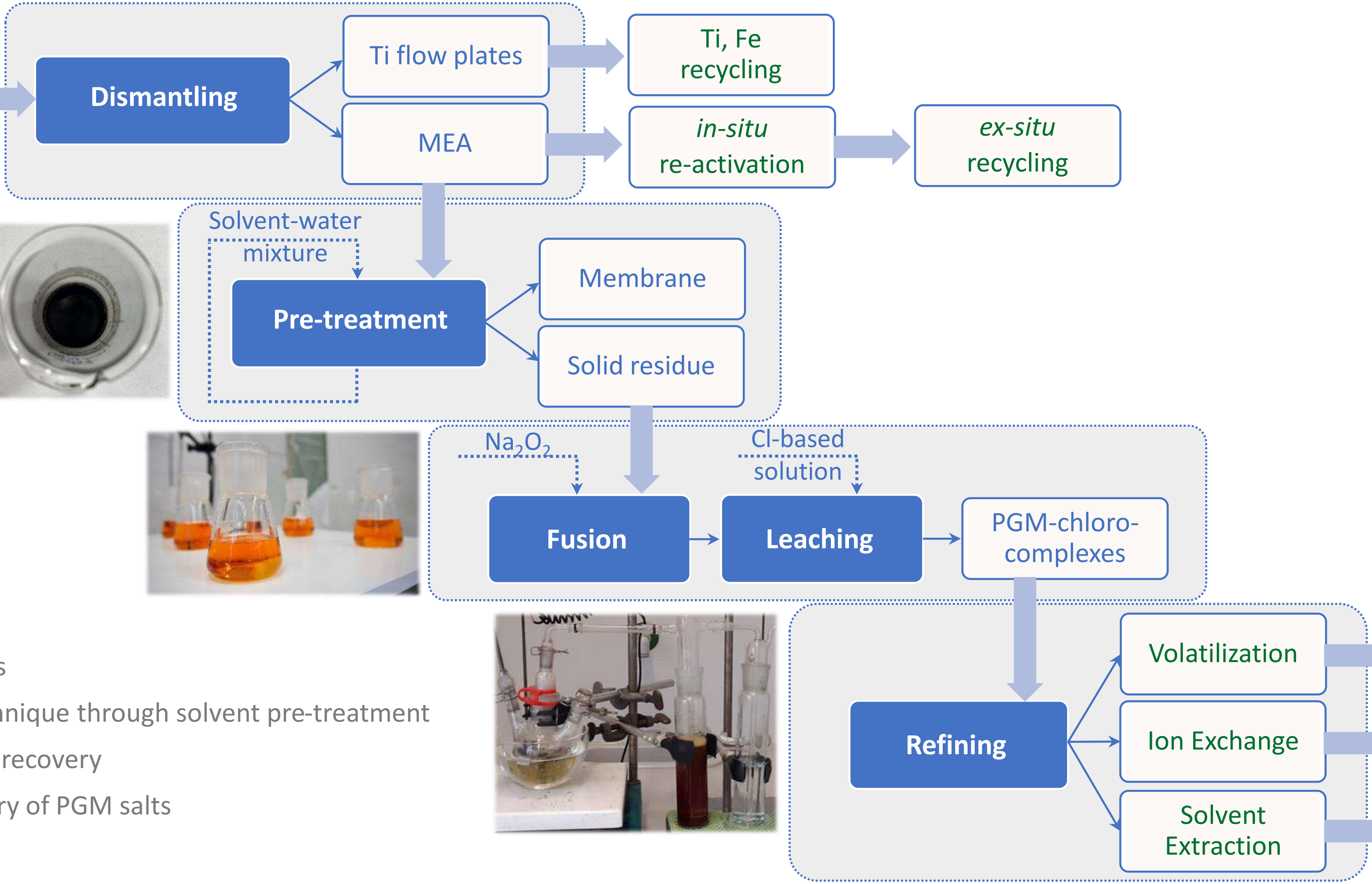
Circular economy

Materials recycling

Sustainability

Material recycling of PEMEC system



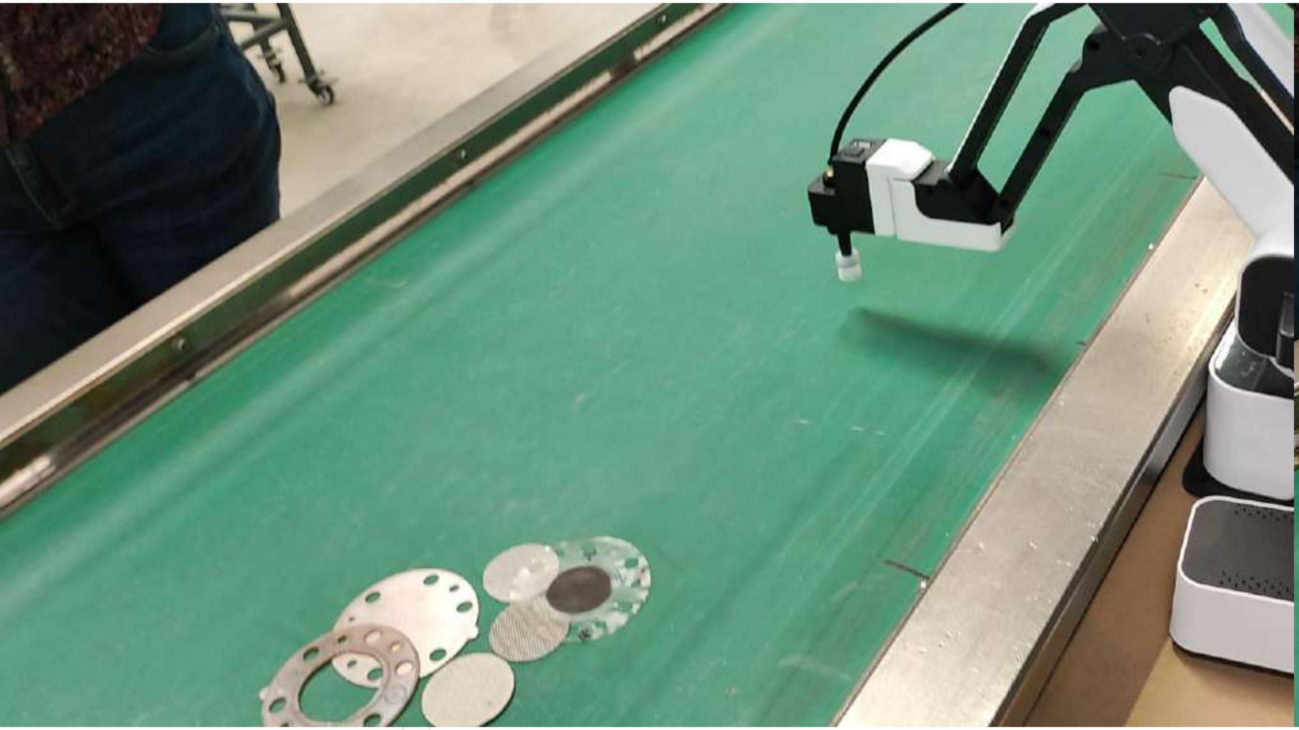


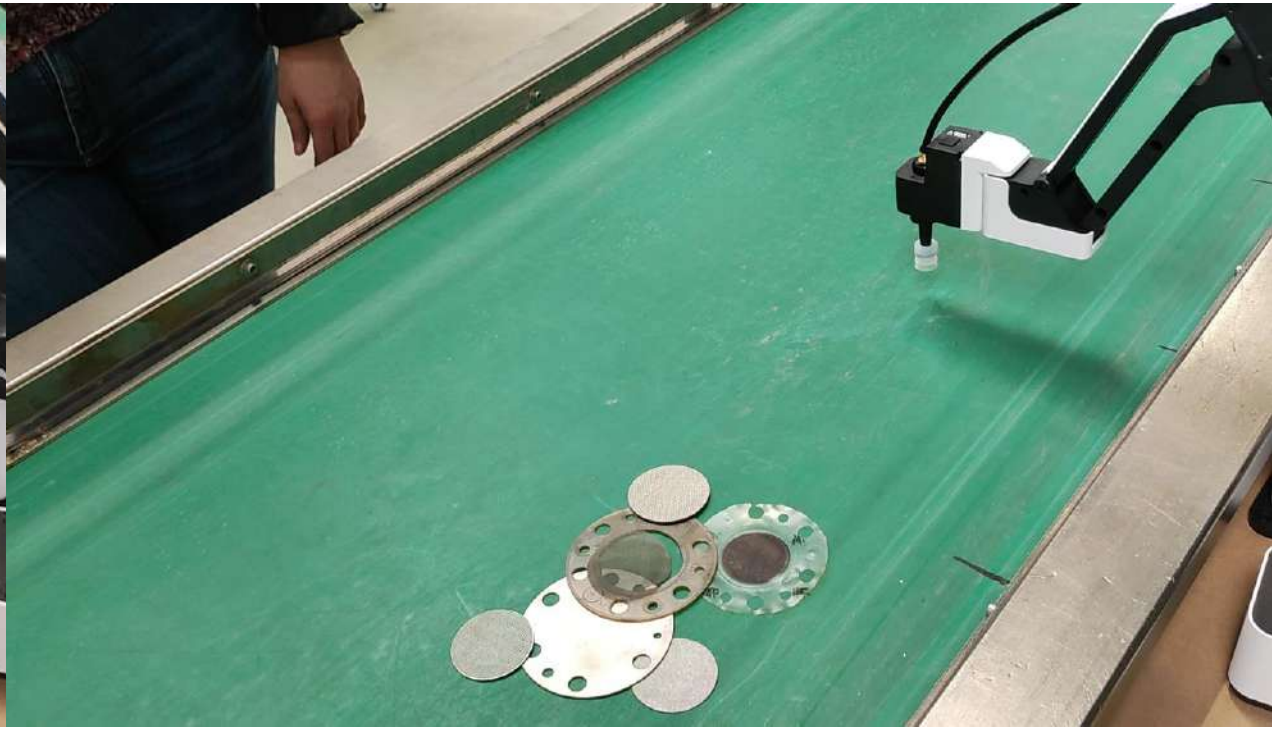
Current progress

- Automated MEA pick-up process
- Efficient catalyst separation technique through solvent pre-treatment
- Novel distillation process for Ru recovery
- Selective separation and recovery of PGM salts

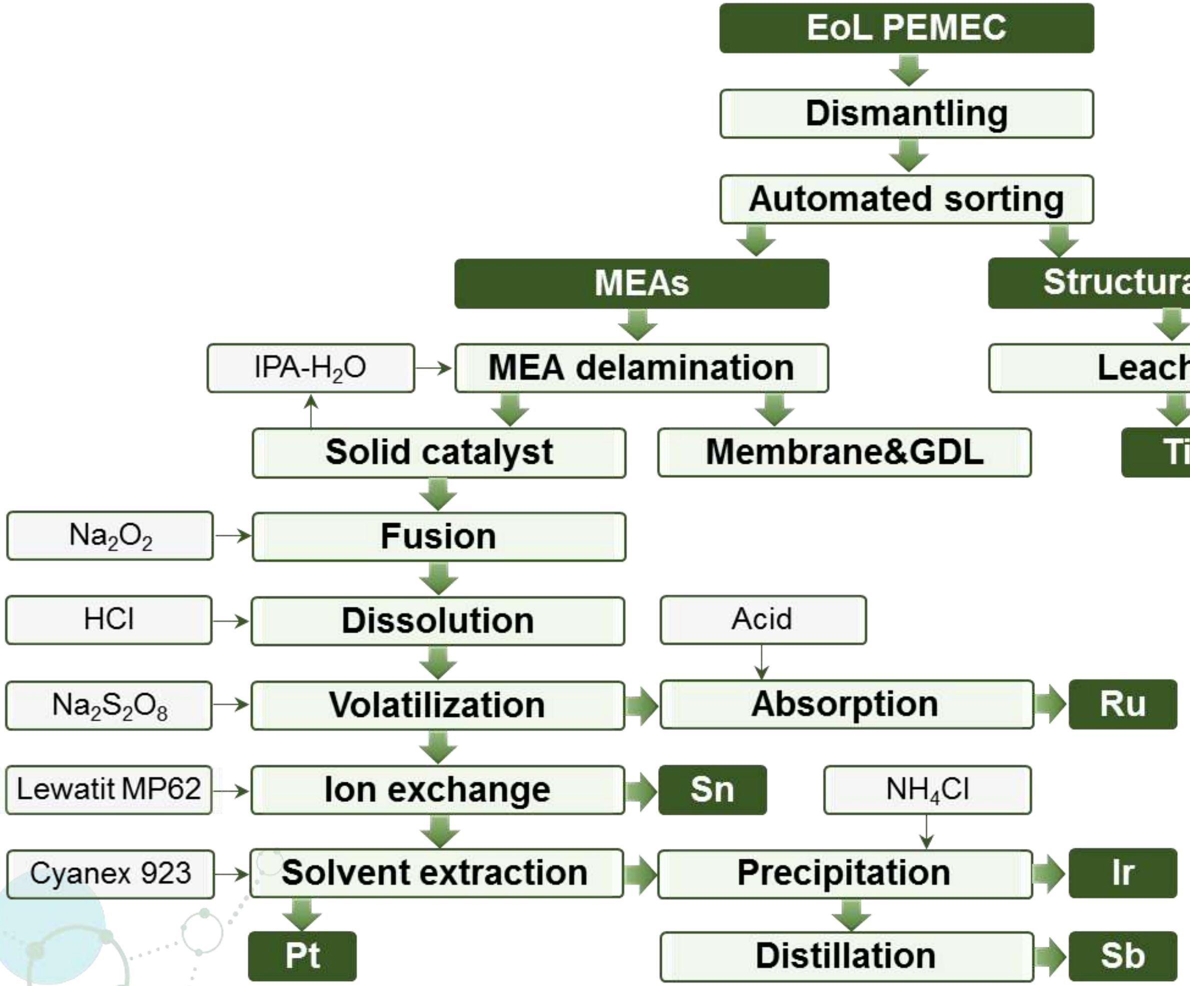
Material recycling of PEMEC system

Recycling of the whole PEMEC system [ACC]





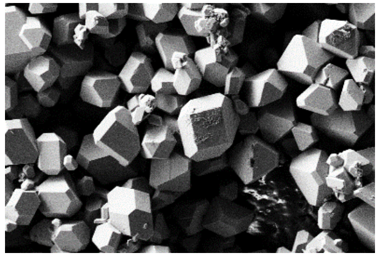
Developed recycling scheme



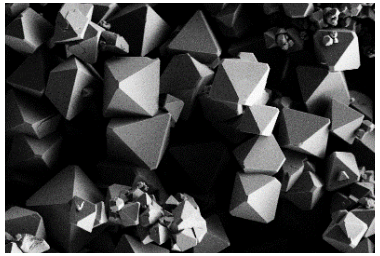
In progress

- Establish the recovery path for Sb/Sn salts
- Test the whole scheme with the spent stack

SEM-images (x5.000)



$(NH_4)_2PtCl_6$



$(NH_4)_2IrCl_6$

$(NH_4)_2RuCl_6$

Outlook

Goal: Overcome the main existing barriers for PEM electrolysers

- Non-CRM catalyst is a challenge but has potential
- Support usage with great potential for reducing CRM
- Non-CRM alloying with IrRu shows great potential
- Second generation stack being assembled for system implementation and demonstration
- Recycling scheme established for all critical raw materials
- Use of recycled materials in progress

4

THE SOLUTION BEHIND DARE2X

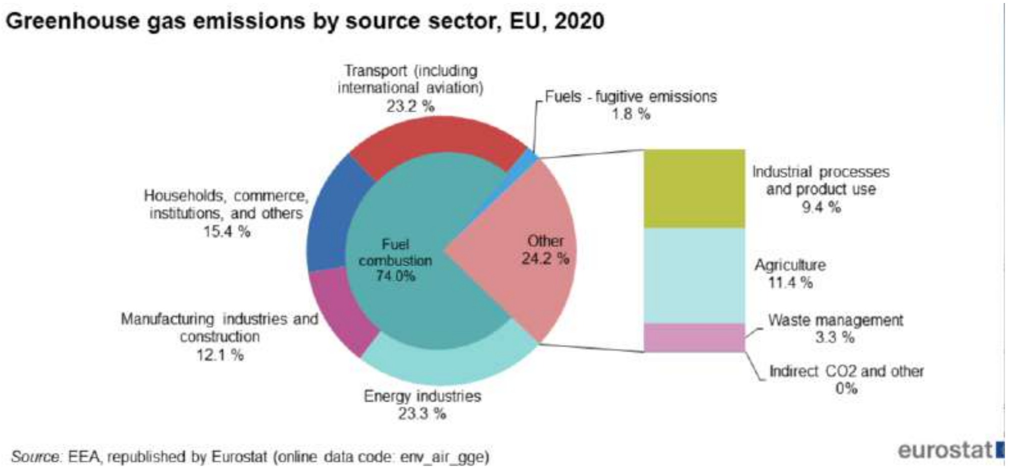
C. Mølleskov | DTI / DARE2X Coordinator

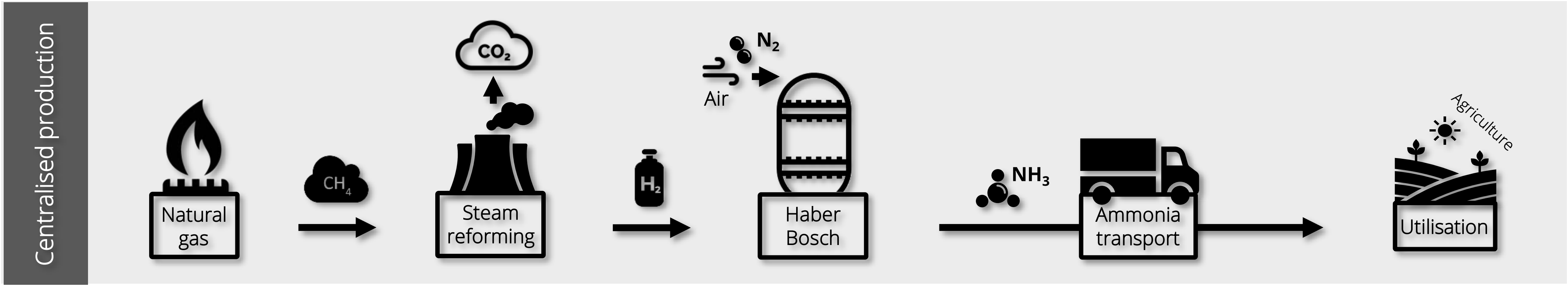
The Haber Bosch process – Grey Ammonia

Temperature: 400-500 ^oC

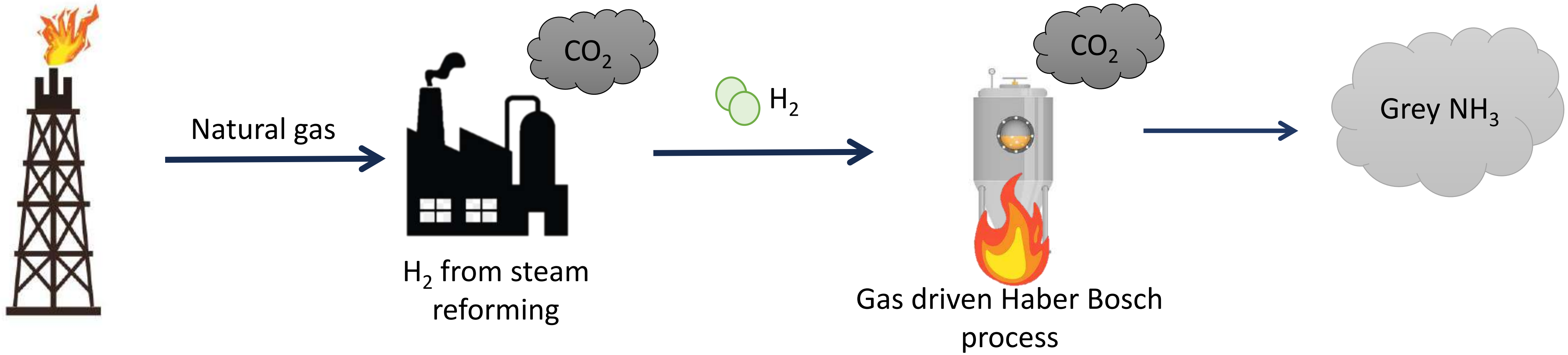
Pressure: 100-300 bar

CO_2 emitted: 1% of the global CO_2 emissions.

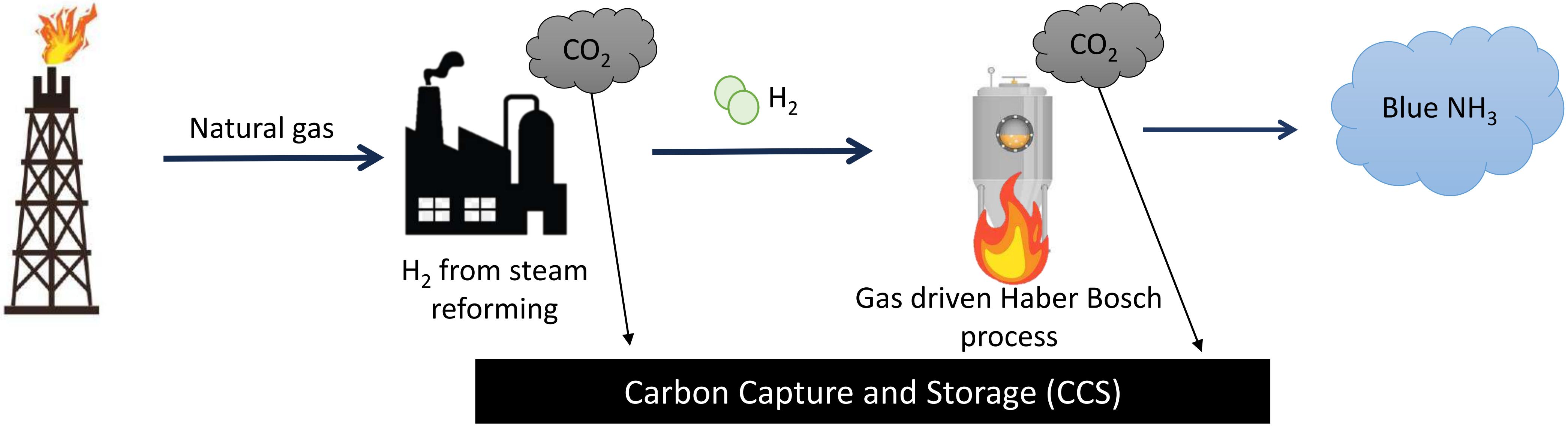




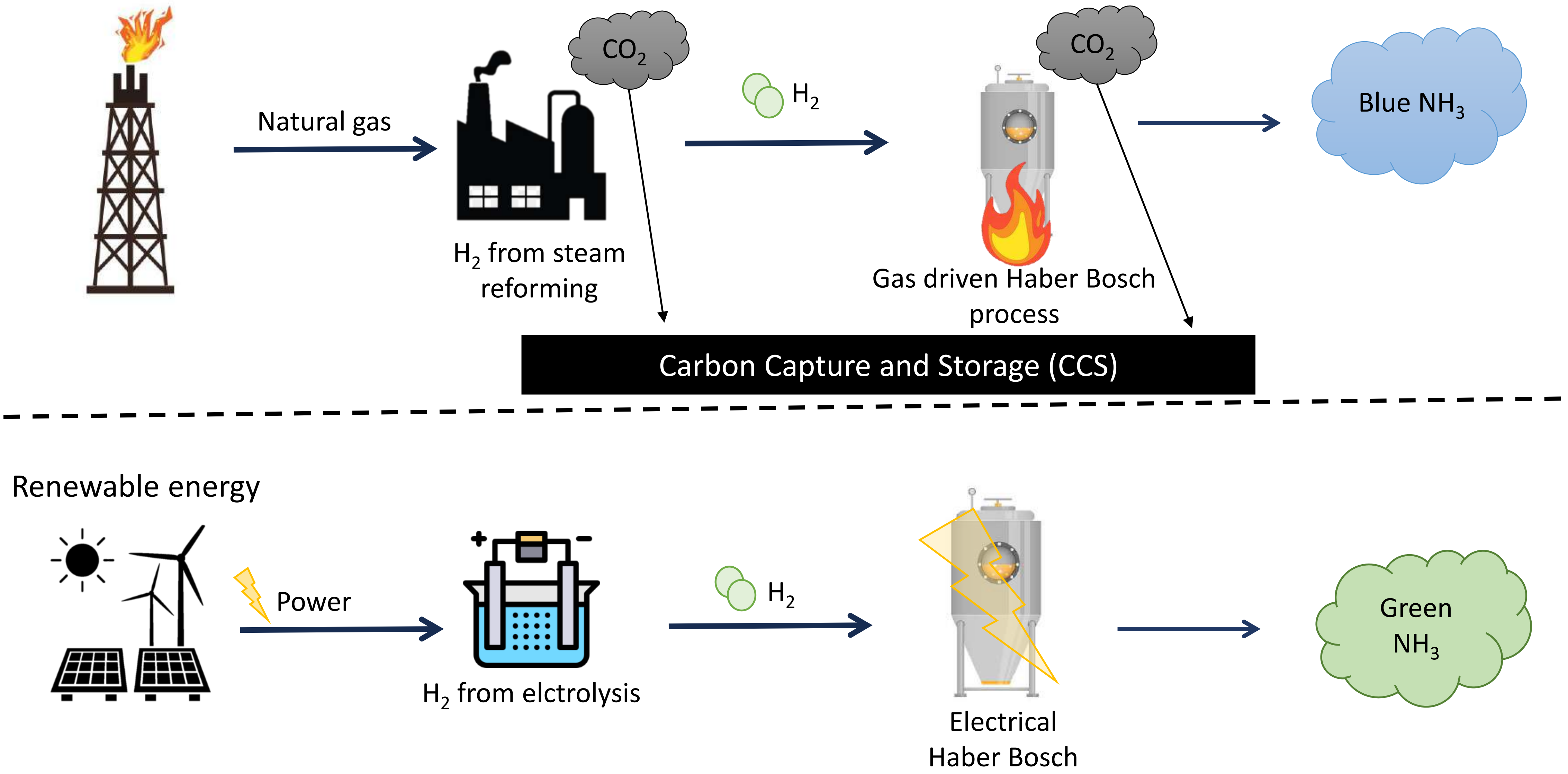
Green vs. Blue vs. Grey Ammonia



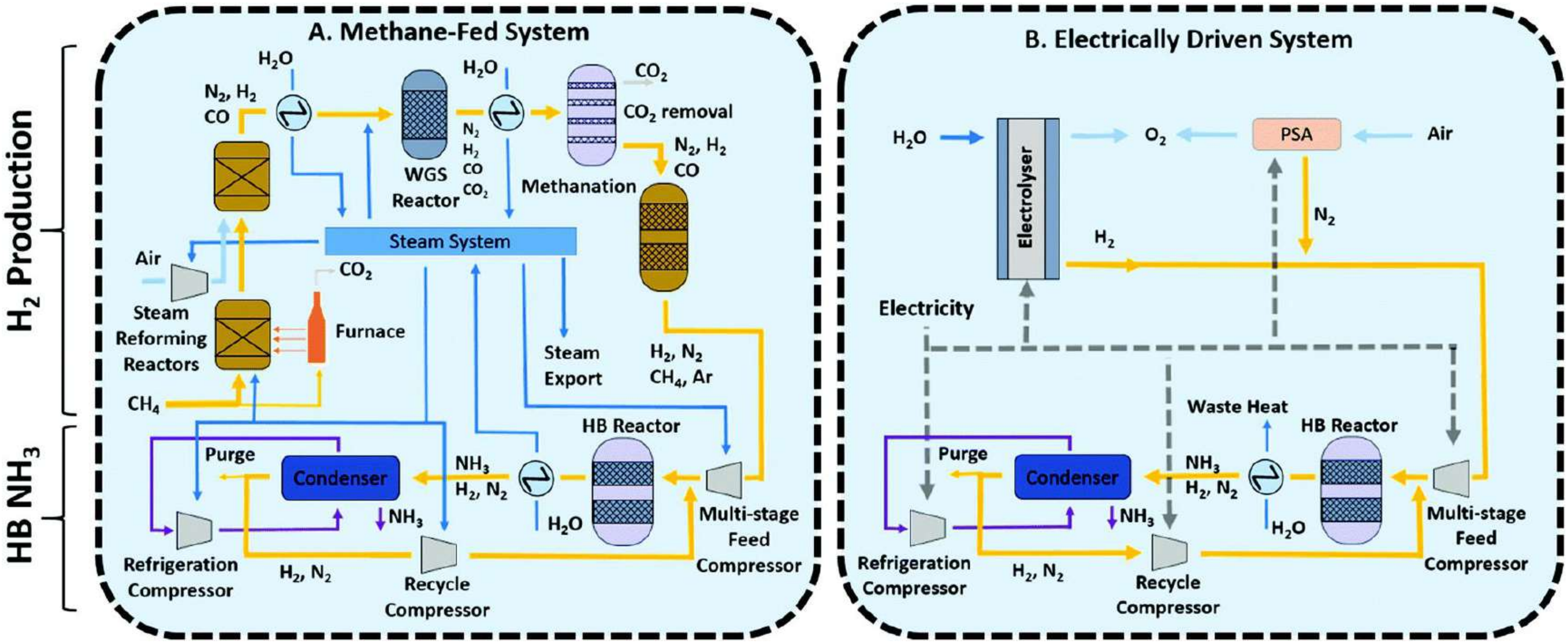
Green vs. Blue vs. Grey Ammonia



Green vs. Blue vs. Grey Ammonia

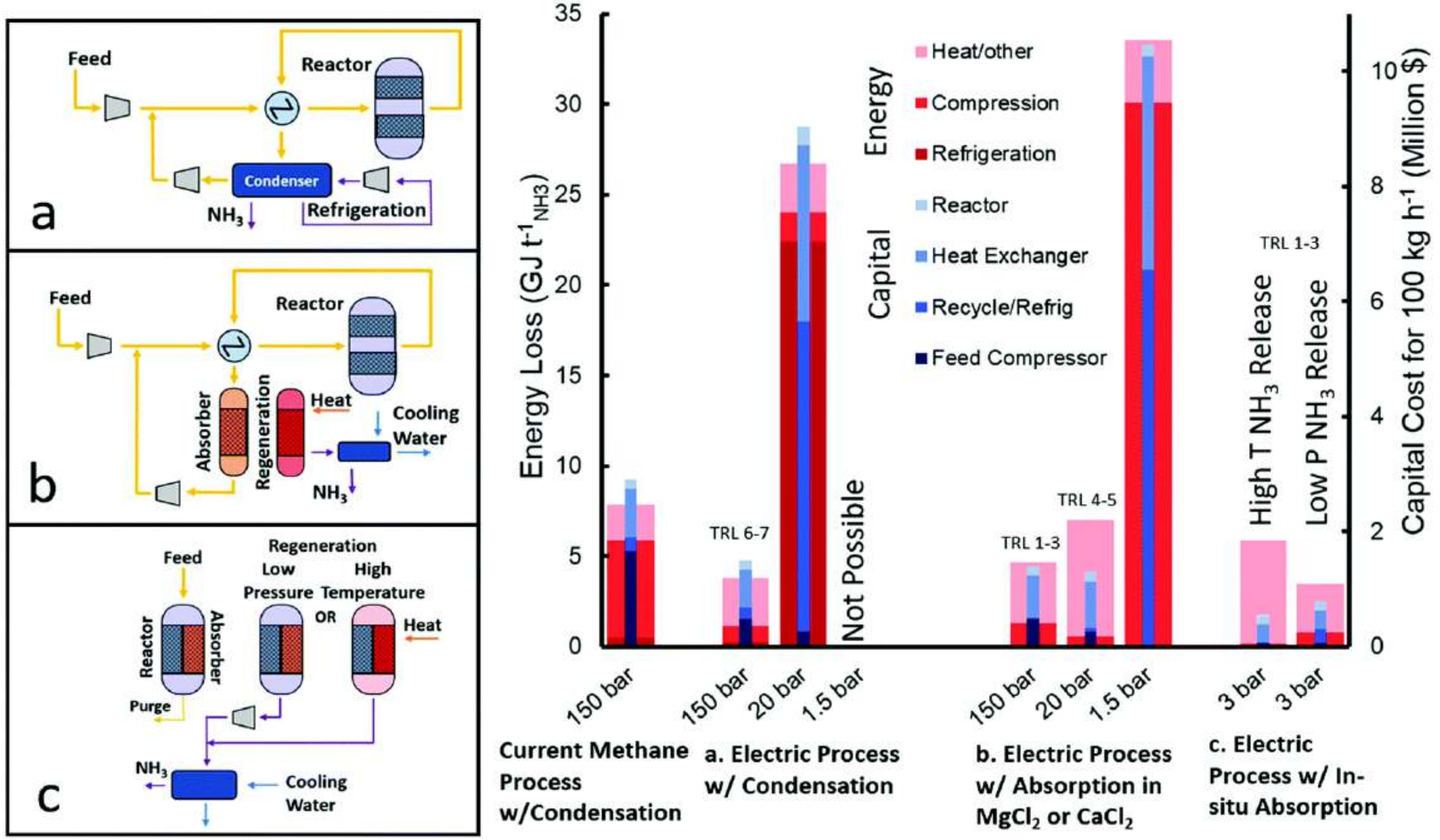


Methane vs Electrical NH3 Synthesis



Smith, C., Hill, A. K., & Torrente-Murciano, L. (2020). Current and future role of Haber-Bosch ammonia in a carbon-free energy landscape. Energy and Environmental Science, 13(2), 331–344. https://doi.org/10.1039/c9ee02873k

Efficiencies & Economics of NH3 Synthesis



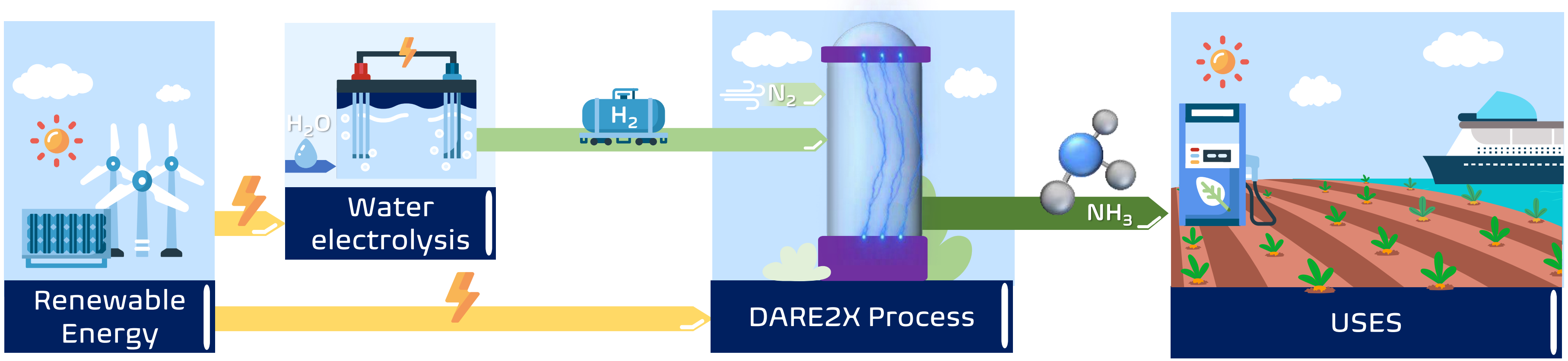
Smith, C., Hill, A. K., & Torrente-Murciano, L. (2020). Current and future role of Haber-Bosch ammonia in a carbon-free energy landscape. Energy and Environmental Science, 13(2), 331–344. https://doi.org/10.1039/c9ee02873k

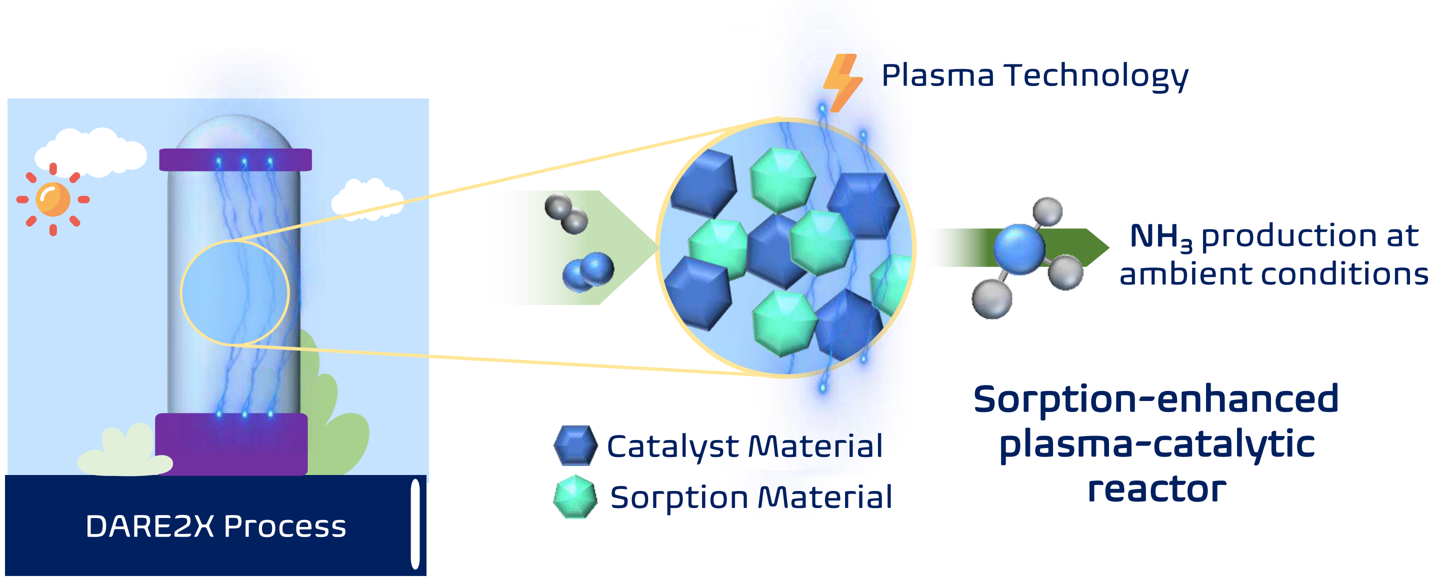
State of the art for alternatives – Green Ammonia

Ammonia production technologies	TRL
Electric HB with alkaline electrolysis	8-9
Electric HB with high pressure PEM electrolysis	6-7
Electric HB with SO electrolysis	3-5
Electrochemical	1-3
Electric low-pressure HB with absorption	4-5
Electric low-pressure HB with *in-situ* absorption	1-3
Non-thermal plasma	1-3
Others (photocatalytic, metallocomplexes, biological)	1-3

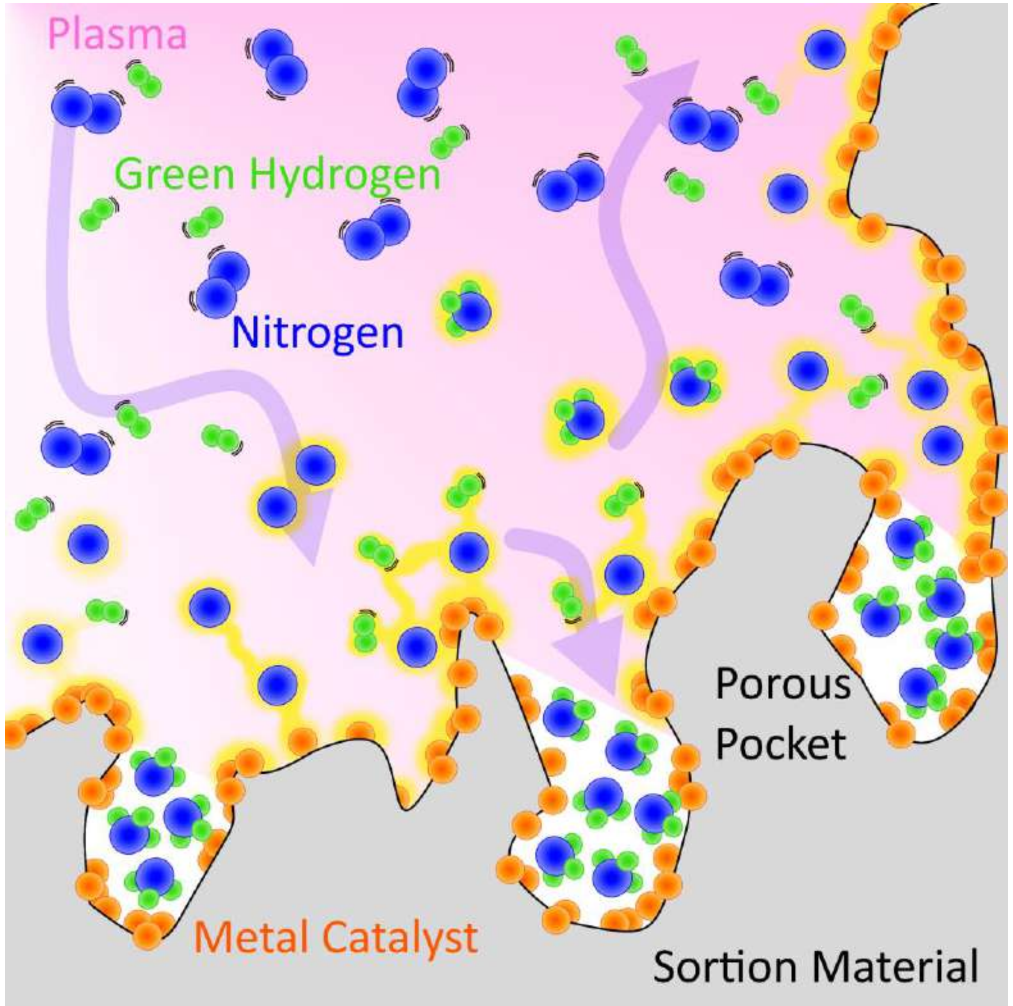
Smith, C., Hill, A. K., & Torrente-Murciano, L. (2020). Current and future role of Haber-Bosch ammonia in a carbon-free energy landscape. Energy and Environmental Science, 13(2), 331–344. https://doi.org/10.1039/c9ee02873k

DARE2X Concept





Activation of N_2 by plasma



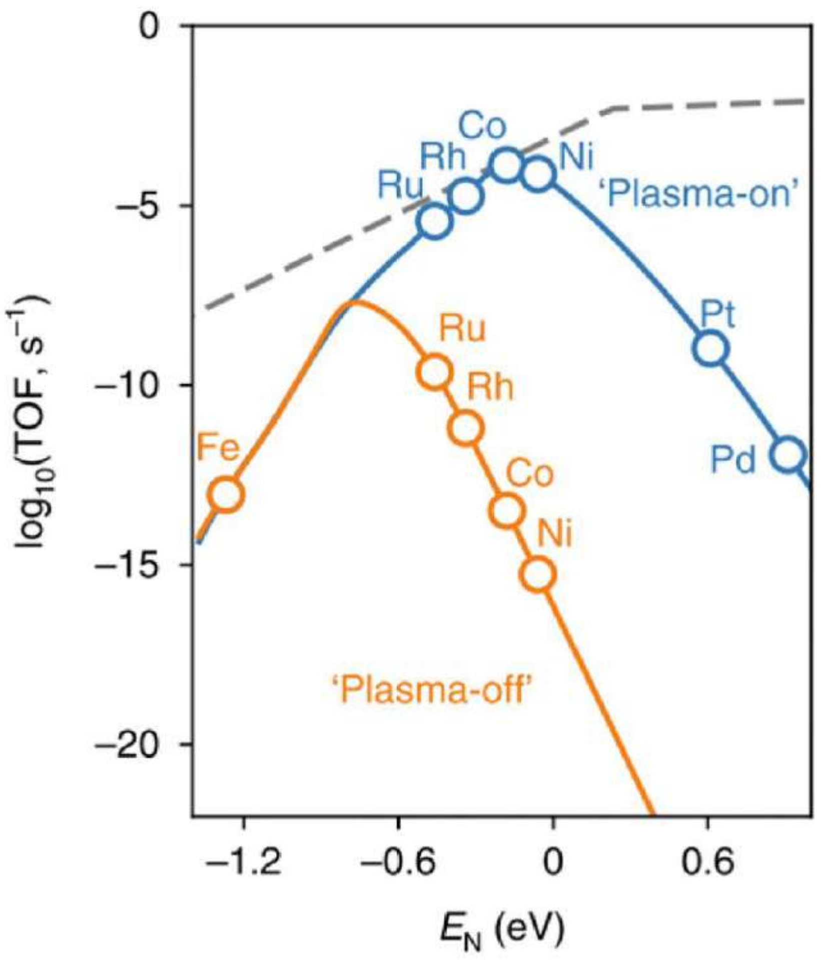
Advantages:

- Plasma reactor operating at ambient temperature and pressure.
- Formation of N and H radicals – easy reaction.
- Dynamic operation

Disadvantages:

- Ammonia decomposition in plasma
- Energy efficiency

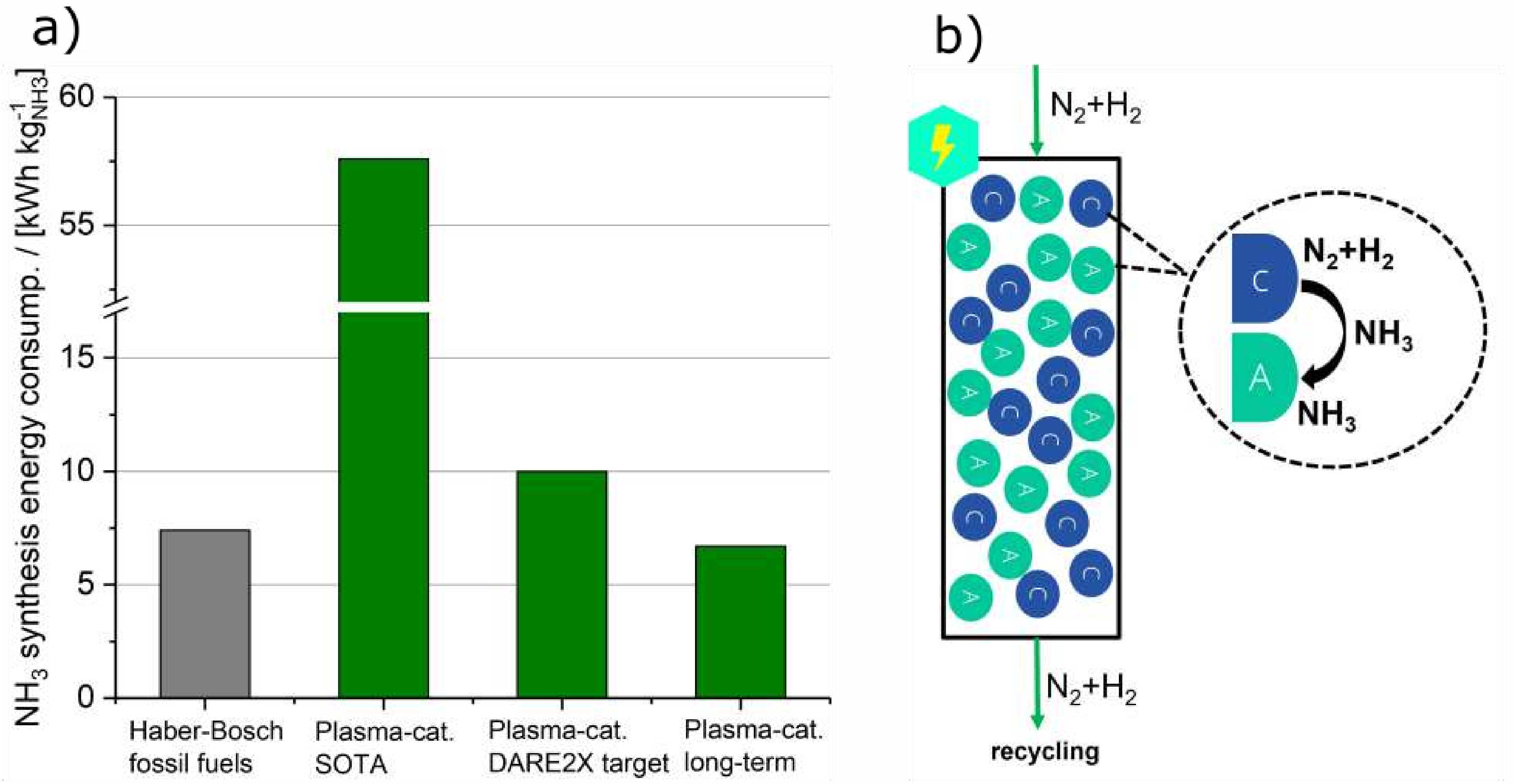
Catalyst materials characteristics



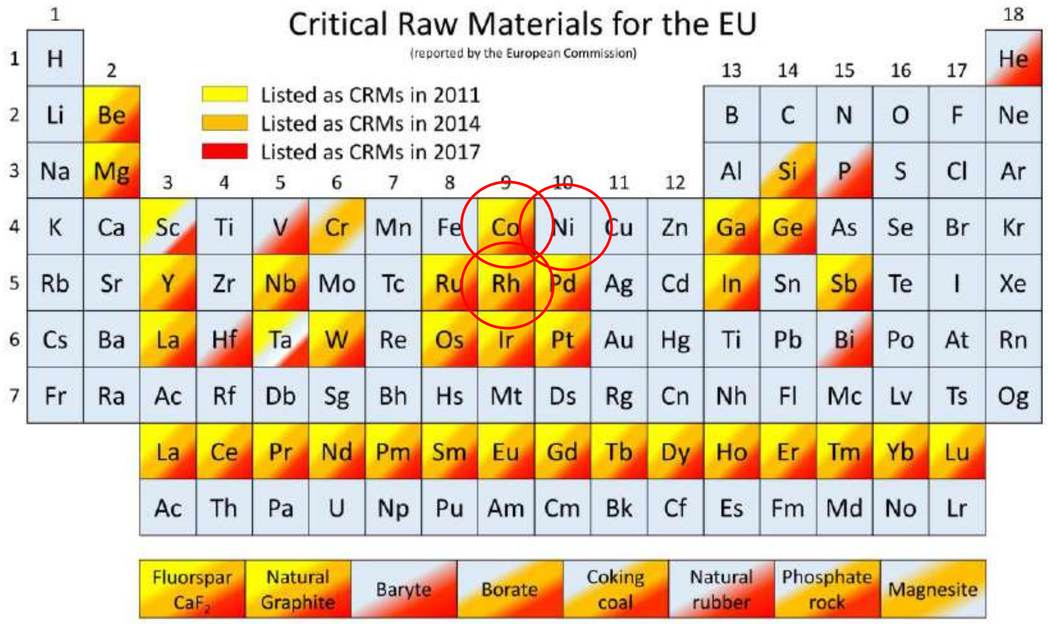
- Plasma-on changes the optimum catalyst (shift the volcano).
- We focus on modelling the best catalysts for the reaction.
- The most interesting metals for the reaction based on literature are:
    - Co
    - Ni
    - Rh

Mehta et al, *Nature Catalysis* **2020**, 1(4), 269-275; DOI: 10.1038/s41929-018-0045-1

Efficiency of plasma process



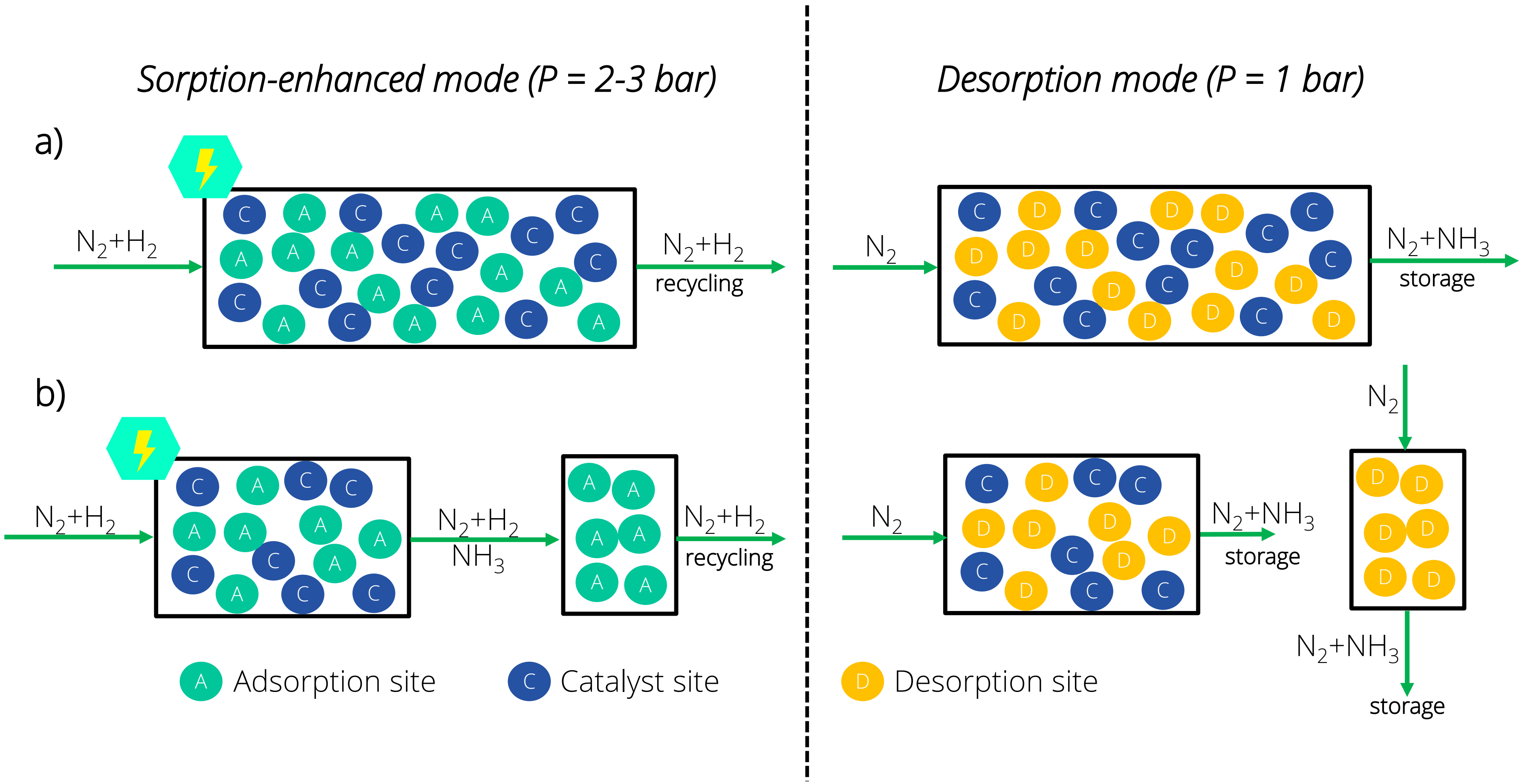
Catalyst materials characteristics



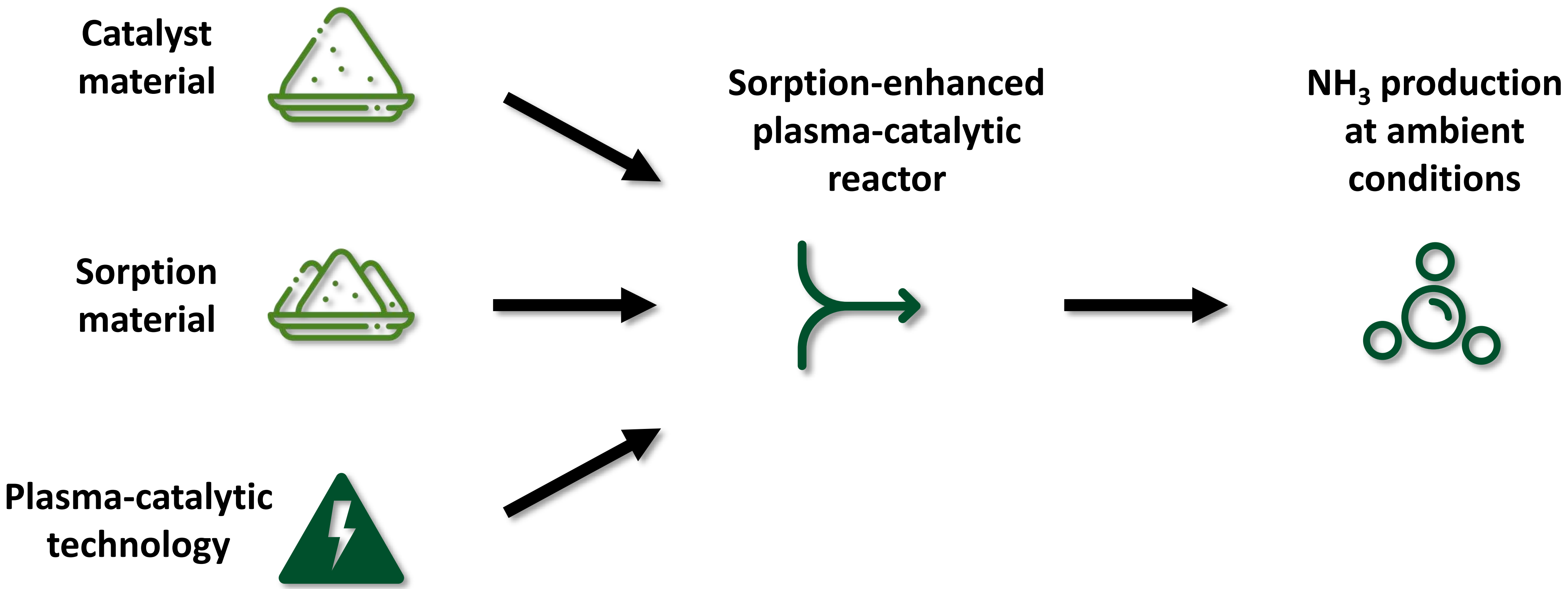
Rizzo, A.; Goel, S.; Grilli, M.L.; Iglesias, R.; Jaworska, L.; Lapkovskis, V.; Novak, P.; Postolnyi, B.O.; Valerini, D. The Critical Raw Materials in Cutting Tools for Machining Applications: A Review. *Materials* **2020**, 13, 1377. https://doi.org/10.3390/ma13061377

- We will reduce the amount of CRM used by working with nanoparticles.
- We will include in our research alloying and promotors species.

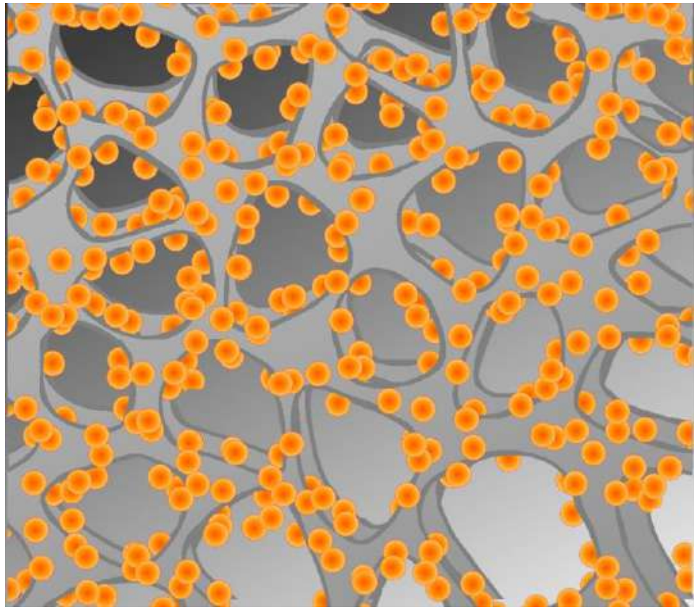
Operation strategy



Our Strategy

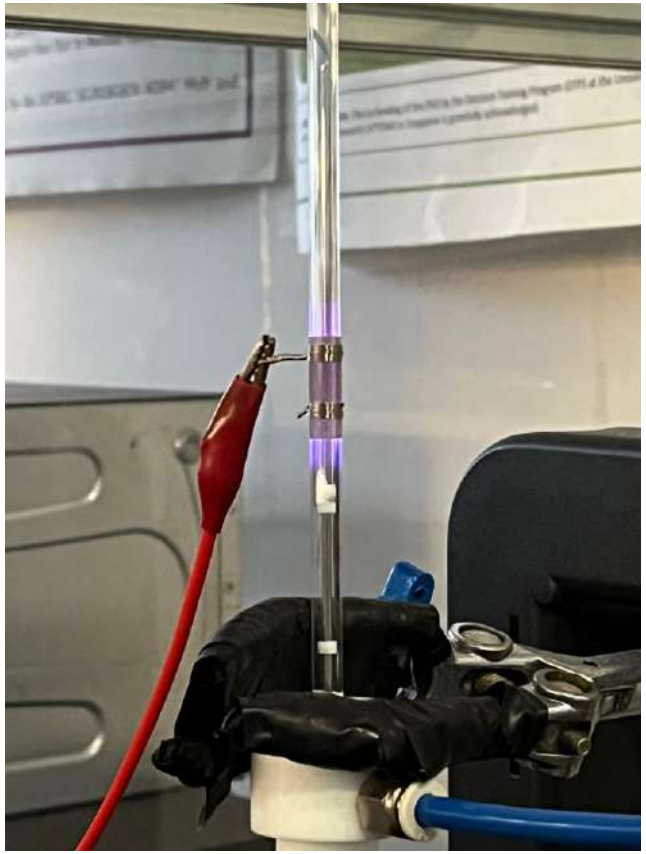


Sorption Material role



- The sorption material will adsorb and desorb the NH_3 produced.
- The sorption materials investigates are zeolites.
- The zeolites will allow to enhance the collection of $NH_{3.}$

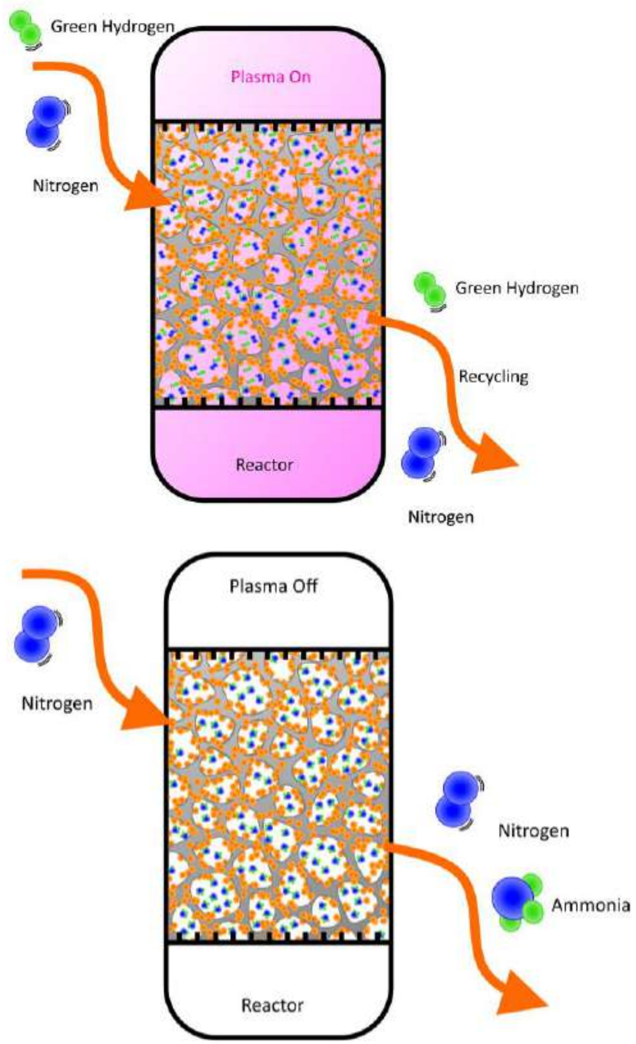
Reactor design



- Electric discharges can activate the N_2 molecule.
- Low pressure reactor (1-3 bar).
- Room-temperature operation.
- Low-cost materials
- Multiscale modelling will allow for a more efficient conversion

Take home messages

- DARE2X solution one of the pathways towards decarbonising ammonia production in EU.
- The decentralized process of ammonia production can be a game changer for the fertiliser industry and a future green fuel.
- Our strategy includes the combination of a metal catalyst, sorption material and plasma catalytic technology.
- DARE2X focus on increasing energy efficiency of the plasma catalytic approach to compete with the centralised Haber Bosch process.



The consortium

DANISH TECHNOLOGICAL INSTITUTE

Coordination, catalyst development and integration of technology.

UNIVERSITY OF LIVERPOOL

Plasma-catalytic reactor development and integration of technology.

Hulteberg CHEMISTRY & ENGINEERING

Sorption material development and integration of technology.

NATIONAL INSTITUTE OF CHEMISTRY

Catalytic material screening.

LOMARTOV [Applied Innovation Engineering]

Techno-economic feasibility study.

ENSO ENVIRONMENTAL SOLUTIONS

LCA and LCC development.

5

MENTIMETER, Q&A

Pablo Morales | SUSTAINABLE INNOVATIONS

5

MENTIMETER, Q&A

Pablo Morales | SUSTAINABLE INNOVATIONS

https://www.menti.com/ale5ksg7m1q4

Mentimeter

WHAT COUNTRY ARE YOU FROM?

17

Mentimeter

WHAT INUDSTRY DO YOU WORK FOR?

18

Mentimeter

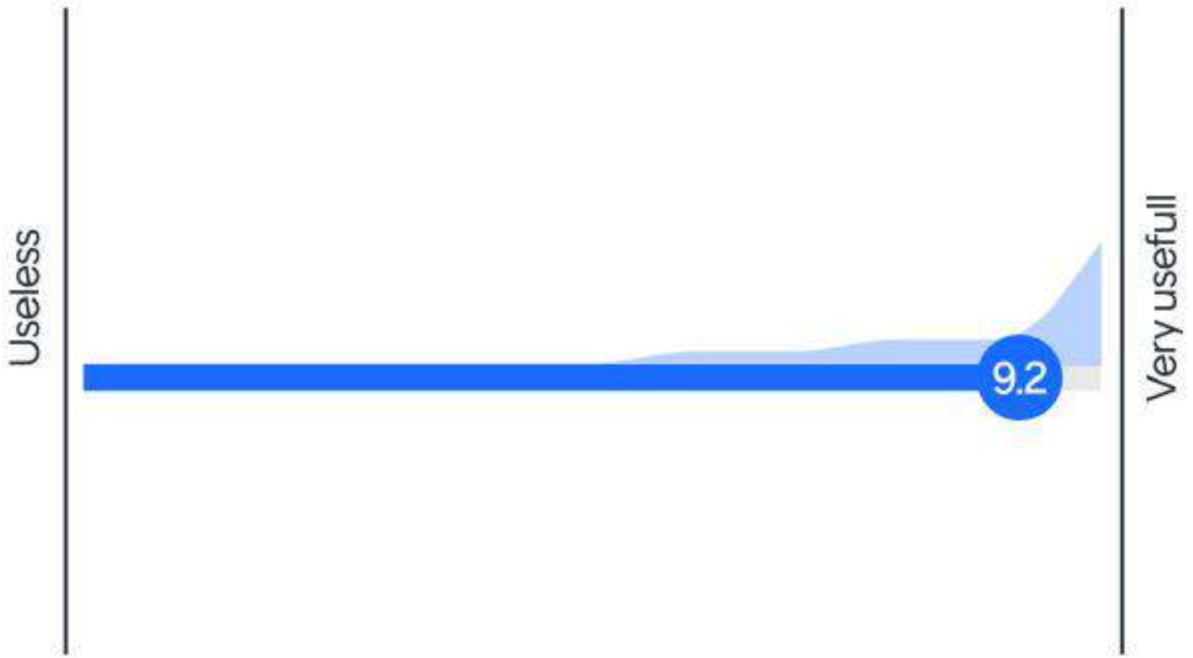
WHICH TECHNOLOGY DO YOU WORK WITH?

solarphotovoltaics
surface catalysis
alkaline electrolysis
ammonia production
catalyst
catalysis
fuel cells
metallurgy
ammonia
soec
non-thermal plasma
pemec
water electrolysis
h2 production
photocatalysis
maintenance
electrochemistry
electrolysis
catalyst development

16

Mentimeter

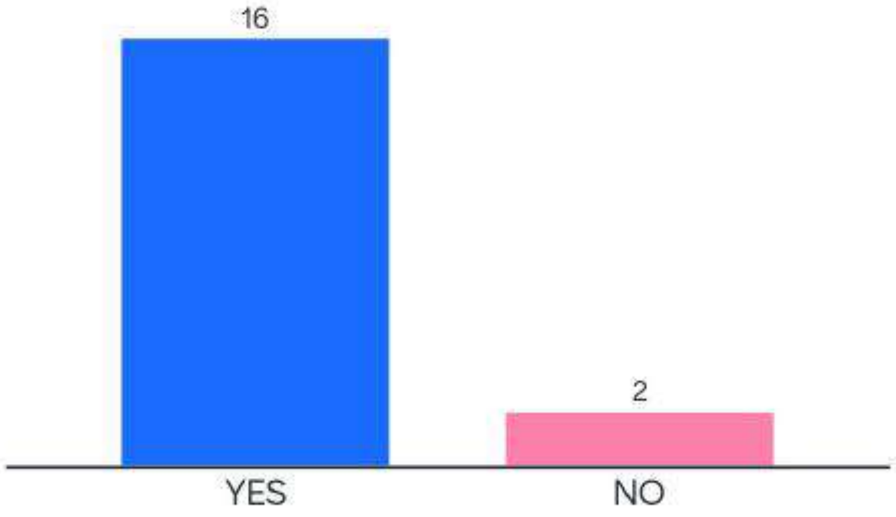
How useful did you find the content and the talk's ideas?



16

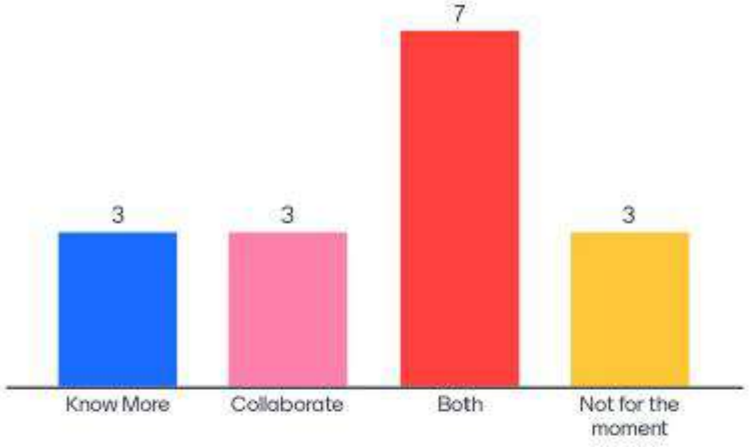
Mentimeter

Are you likely to use this information in your future work or studies?



18

Would you be interested to know or collaborate more about the RECYCALYSE and DARE2X project?



Mentimeter

16

THANK YOU

RECYCALYSE -

DARE2X

WWW.RECYCALYSE.EU

info@recycalyse.eu

@RECYCALYSE

WWW.DARE2X.EU

DARE2X @DARE2X_EU