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RESEARCH DAYS
15-16 NOVEMBER

Hydrogen Production

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Co-funded by
the European Union



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Parallel Sessions

15th November 2023

15:45-17:15



Hydrogen Production

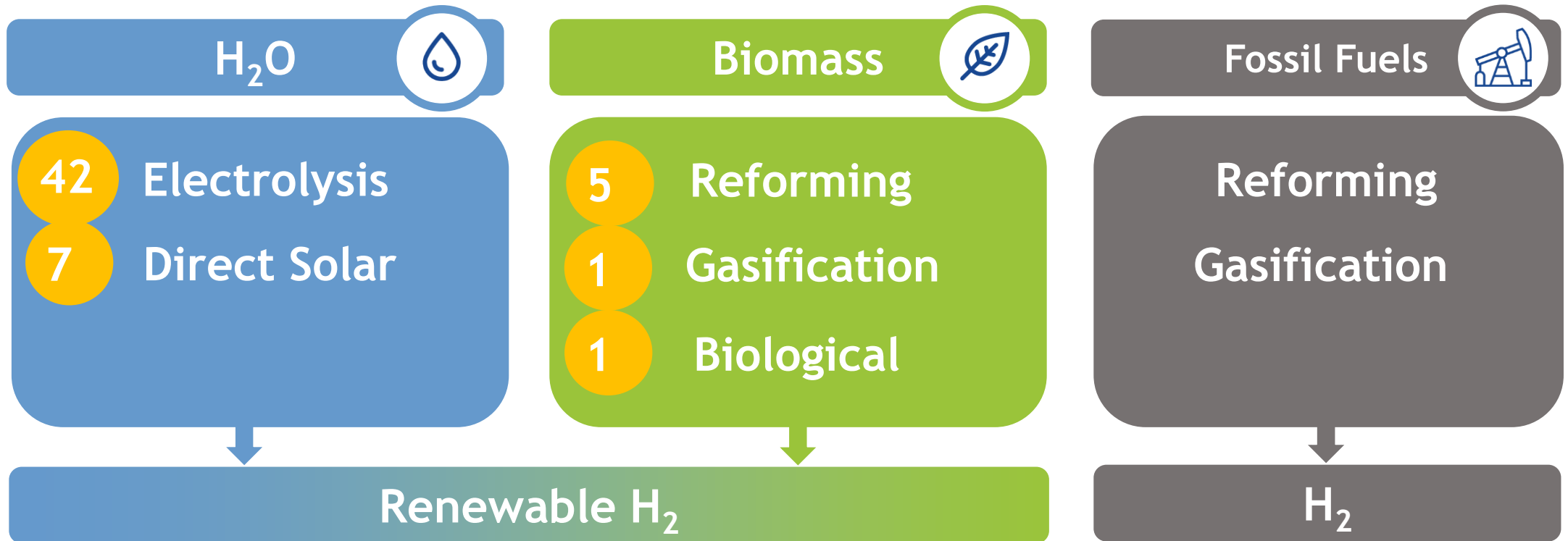


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Hydrogen Production Technical Coverage

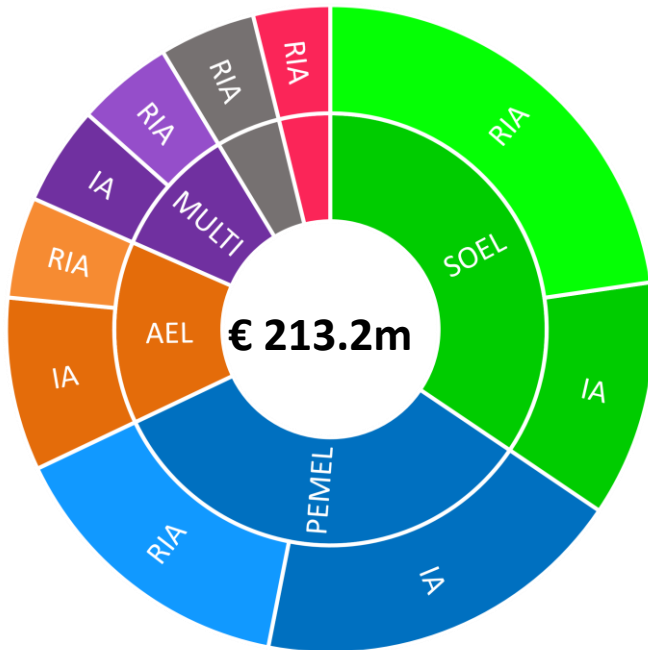
56 projects, 180 M Euro, 16.7% of Clean H₂ JU support. Only renewable H₂



Electrolysis Research and Demonstration

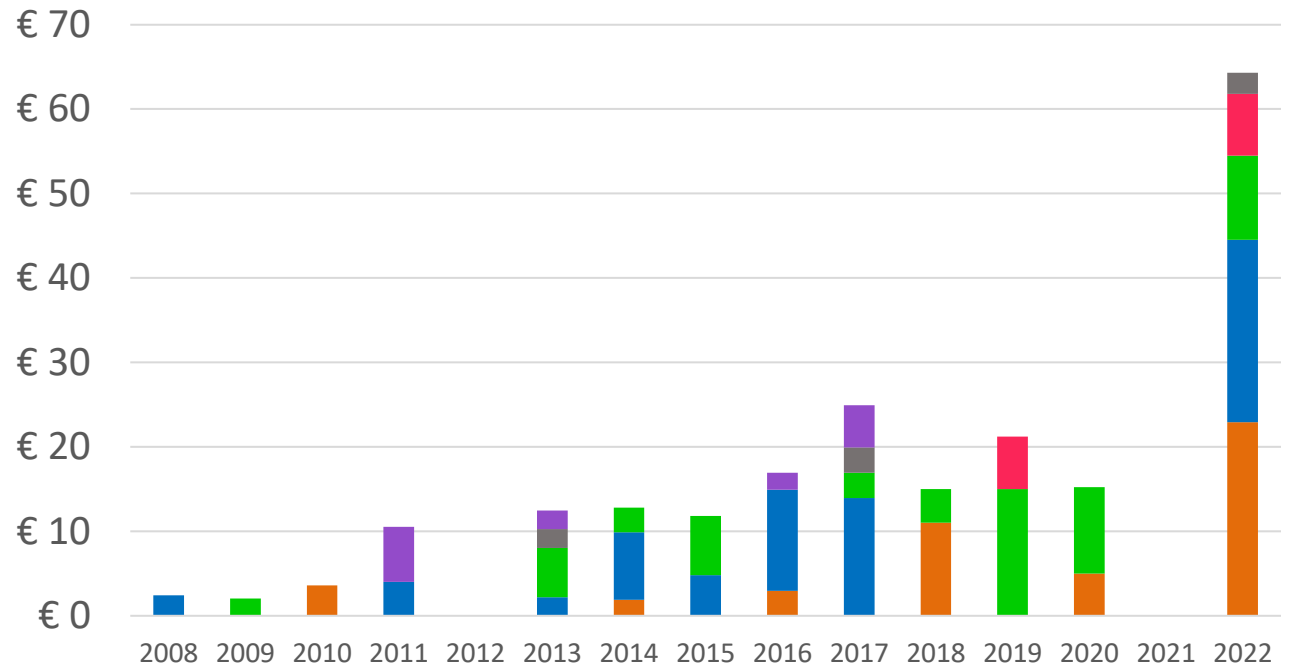
Increasing support covering all electrolyser types

Electrolysers: JU support



RIA: Research & Innovations Actions (RTD)
IA: Innovation Actions (Demo)

JU funding per electrolyser type

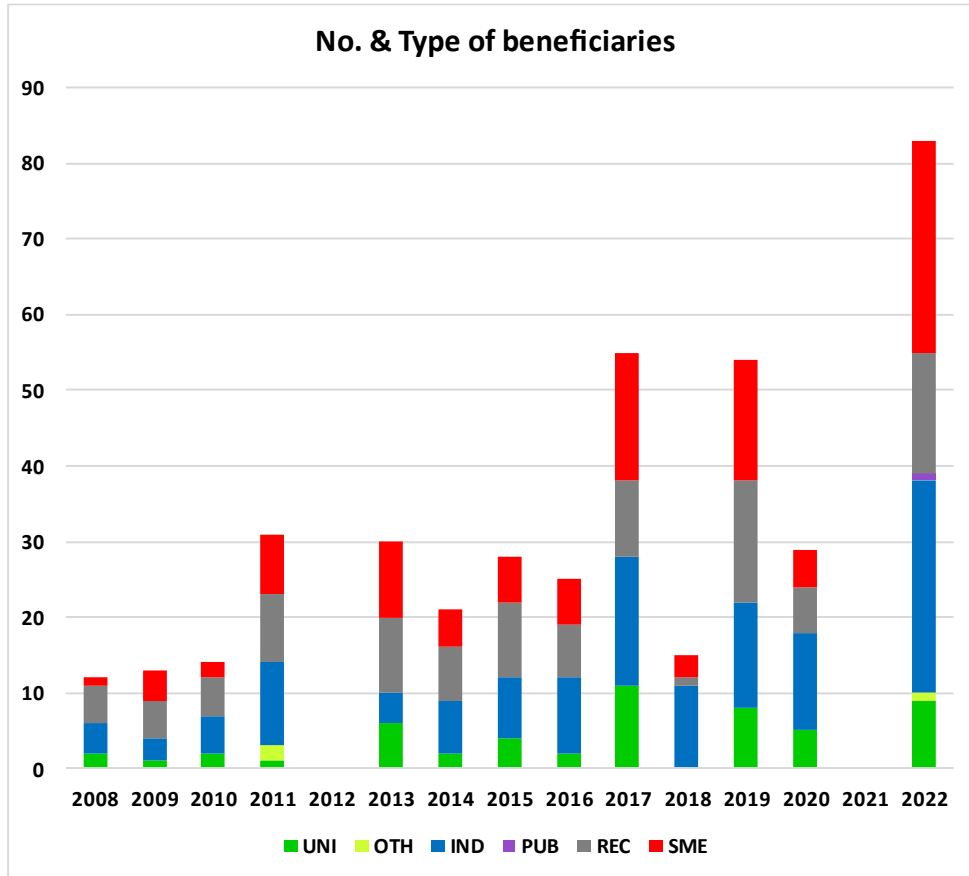


■ AEL
 ■ PEMEL
 ■ SOEL
 ■ AEMEL
 ■ PCEL
 ■ MULTI

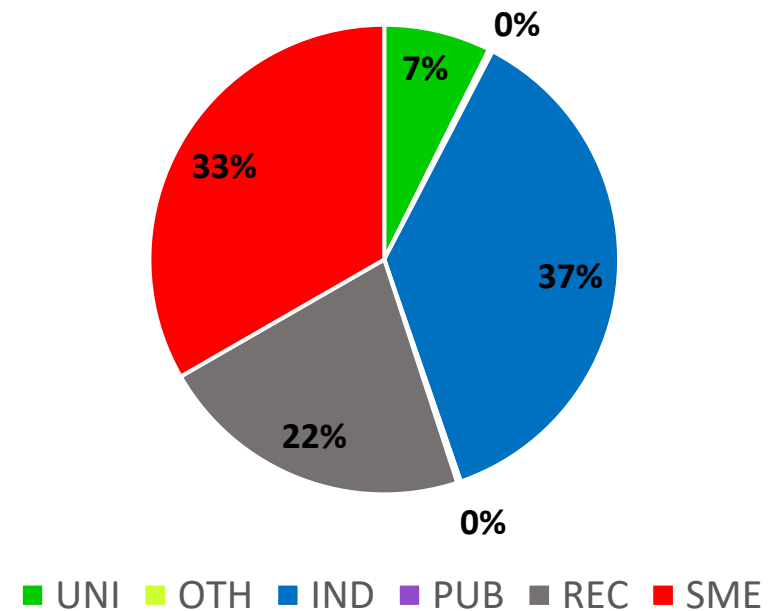
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Electrolysis Research and Demonstration

Balanced support to IND, SMEs, R&D



JU Funding per type of beneficiary



UNI: Universities, OTH: Other, IND=PRC: Private Companies
PUB: Public Authorities, REC: Research Centres
SME: Small Medium Enterprises



LT Electrolysis Demonstration projects

Large electrolyser demos up to 30MW; Stacks: PEMEL 0.5-1.25 MW; AEL 1-3MW

All facilities continue to operate after completion of each project

Project: Don Quichote
Place: Belgium
Date: 2011
Electrolyser: Hydrogenics
Funding: 5.0 m€



0.15 MW

Project: Haeolus
Place: Norway
Date: 2017
Electrolyser: Hydrogenics
Funding: 5.0 m€



2.5 MW

Project: H2future
Place: Austria
Date: 2016
Electrolyser: Siemens
Funding: 12 m€



6.0 MW

Project: Djewels
Place: The Netherlands
Date: 2018
Electrolyser: McPhy
Funding: 11 m€



20 MW

Project: Hybalance
Place: Denmark
Date: 2014
Electrolyser: Hydrogenics
Funding: 8.0 m€



1.2 MW

Project: Demo4grid
Place: Austria
Date: 2016
Electrolyser: IHT
Funding: 2.9 m€



3.2 MW

Project: Refhyne
Place: Germany
Date: 2017
Electrolyser: ITM
Funding: 10 m€



10 MW

Project: EPHYRA
Place: Greece
Date: 2023
Electrolyser: TBA
Funding: 17.7 m€



30 MW

PEMEL

AEL

LT Electrolysis Demonstration projects

EU Electrolyser industry ready to support EU H₂ policies

2016



$\eta=83\%_{\text{HHV}}$, purity 99.9%

Operating range 15-150%

Balancing services
H₂ prod costs < 25-50%



2017



In commissioning

Close cooperation of
industry with SMEs

Lack of suitable BoP

2018



Degradation @ 0.9 A/cm²

Real world market issues

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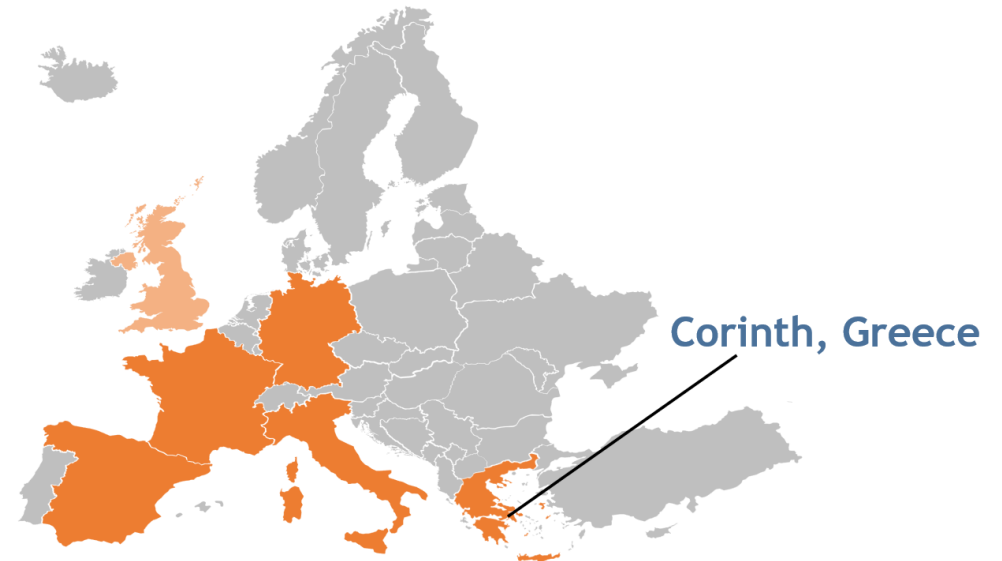
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LT Electrolysis Demonstration projects

AWP 2022 Topic 01-08: Integration of multi-MW electrolysers in industrial applications

- Project: EPHYRA
- Coordinator: MOH (GR)
- Duration: 5 years
- Project Costs = 25.4M EUR, JU contribution = 17.7M EUR.
- Project Objectives:
 - Integrate 30MW improved electrolyser in refinery
 - Industrial symbiotic approach to use O₂, use waste heat through ORC, optimise water use
 - Digital twin optimal control system
- SE EU on map of JU large demos

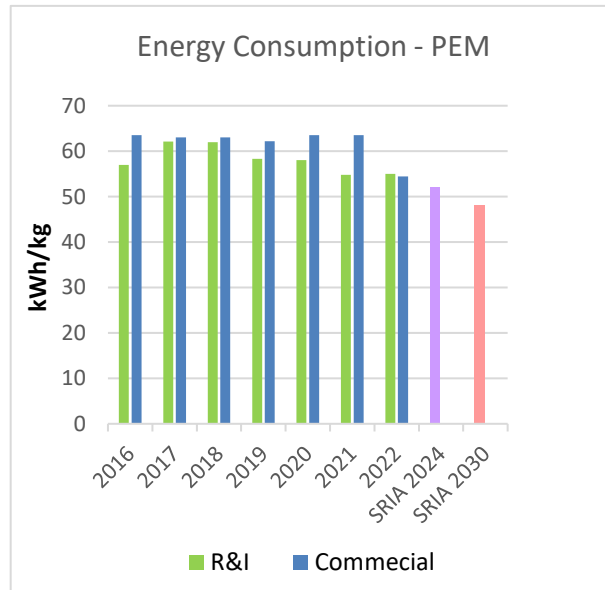
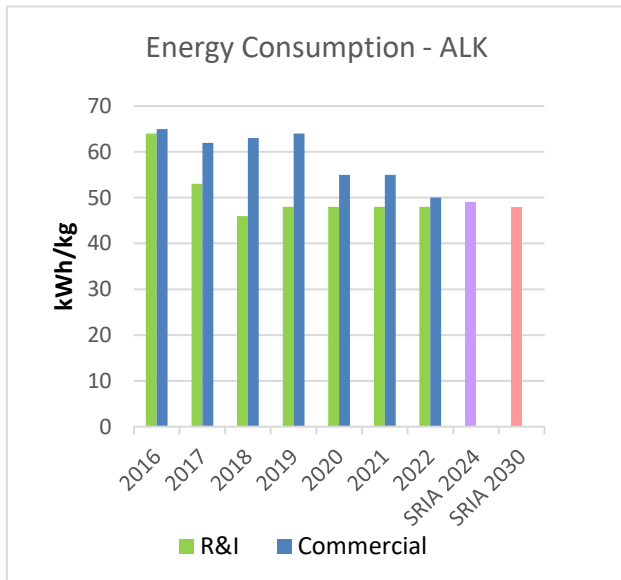


LT Electrolysis R&I projects

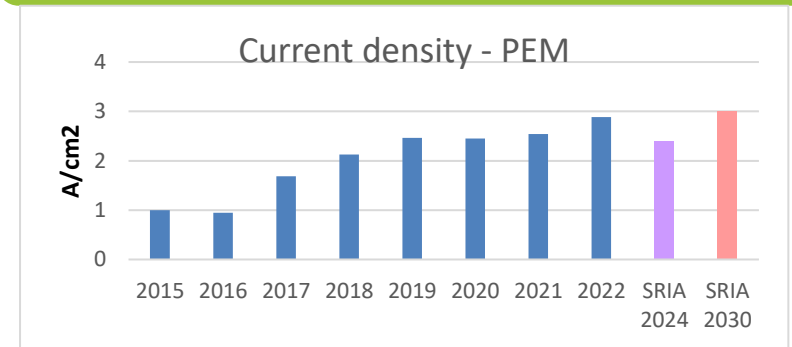
Achievement of SRIA targets safeguards Europe's leading position



Energy cons. @ system level
<55 kWh/kg



PEM Current density > 2.4 A/cm²



BoP: 4-7% of electrolyser energy consumption



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LT Electrolysis R&I projects

2019: 3x Anion Exchange Membrane electrolyser projects



2 kW AEM electrolyser

1.75V @ 1 A/cm²; 0.1M KOH

Reinforced AEMs, no CRM electrocatalysts



2 kW AEM electrolyser

1.8V @ 1 A/cm²; 0.1M KOH

P2D S/W model



2 kW AEM electrolyser,
10 bar

2V @ 1.8 A/cm²; 0.1M KOH

AEMs reinforcement
using covalent bonds



Non-PGM catalysts
Reinf membranes

1.8V/cell @ 1 A/cm²
< 50mV/kh

Performance of parts
could not be
achieved @ stack

AEMEL Testing
protocols &
AEMEL hub

2022: 2x Anion Exchange Membrane electrolyser projects

HERAQLES: improve manufacturing processes for 25kW AEMEL - 500 cm² cells, 50 bar, 1A/cm²
HYScale: scaling up cells and testing a 100kW AEMEL - 400 cm² cells, 15 bar, 2A/cm²

LT Electrolysis projects - Going off-shore

New electrolyser OEMs / players to JU frameworks

2020: OYSTER project



Marinisation of 3MW
AEL - Stiesdal (DK)

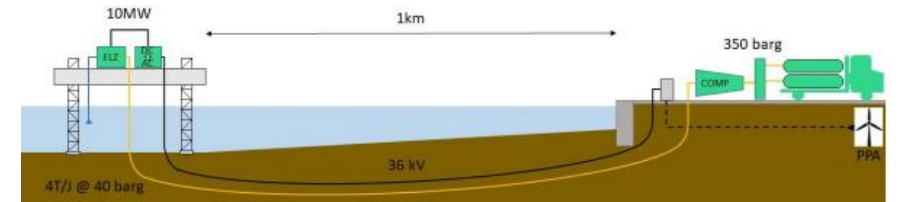
Near-shore operation

Zeeland (NL)

Integrated
desalination



2022: HOPE project



Marinisation of 10MW PEMEL
- Frames Energy / Plug (NL)

Off-shore operation

Oostende (B)

Recycled barge



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the European Union

LT Electrolysis projects - Latest projects

Revisiting AEL but also going “disruptive”

2022



Advanced AEL, 80 bar, 120°C, 50kW stack validation

PEACE

Advanced AEL, 90 bar 2-stage pressurisation, 50kW stack



Advanced PEM, 200 bar, 50kW stack

2023 - Currently in GAP

TRL 2-4, novel concepts, disruptive designs for next generation LT electrolyzers

HT Electrolysis Demonstration projects

HTEs finding their place in the industrial courtyards, facilitating strategic partnerships

2018

PAUL WURTH BECOMES NEW LEAD INVESTOR AND TECHNOLOGY PARTNER OF SUNFIRE



GrInHy2.0
Green Industrial Hydrogen

2019



MULTIPLHY

NESTE INVESTS IN SUNFIRE

2015



Salzgitter Iron and Steel Works
150kW

GrInHy
Green Industrial Hydrogen

Salzgitter Iron and Steel Works
720kW - 200 Nm³/h - η 84.6% ✓
Availability 84% ⚠️
Valuable open access data 👍

Rotterdam Neste Biorefinery
2.4MW in commissioning

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HT Electrolysis R&I projects

Higher efficiencies, improved durability, innovative concepts

2017



- >5,600 h of testing
- Degradation of 1.2% / 1,000h @ 0.6 A/cm²

2022

PRESHYOUS, HYP3D, OUTFOX, PilotSOEL

- 5 bar; 0.85 A/cm²
- Improved manufacturing
- Intermediate temperatures

2018



PCE, tubular cells, 10kW
10 bar, 600°C



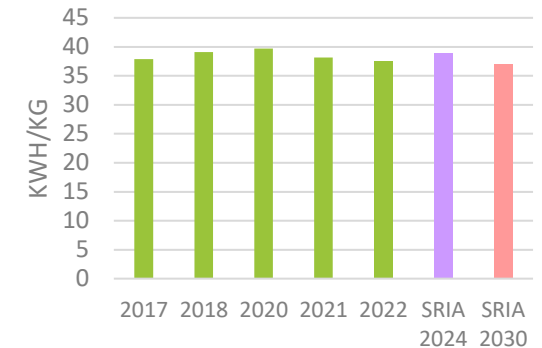
- SEU tested for 500h @ 10bar
- 2 racks of 16 SEUs tested @ 3 and 7 bar
- Faradaic efficiency of 61%

2022

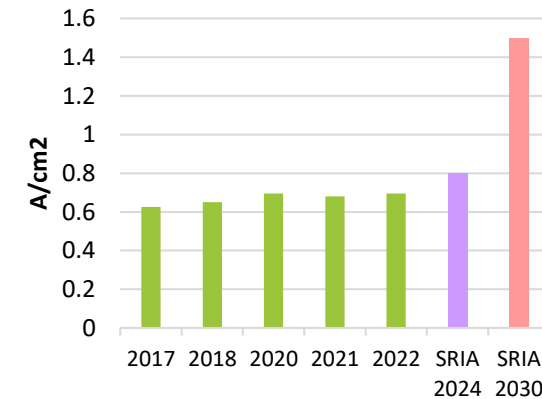
PROTOSTACK

- 5kW stack to be tested @ 30 bar
- To be validated for 2,000h

Electricity Consumption - SOEL



Current density - SOEL



Degradation: 0.37%/1,000
Availability: 93.7%

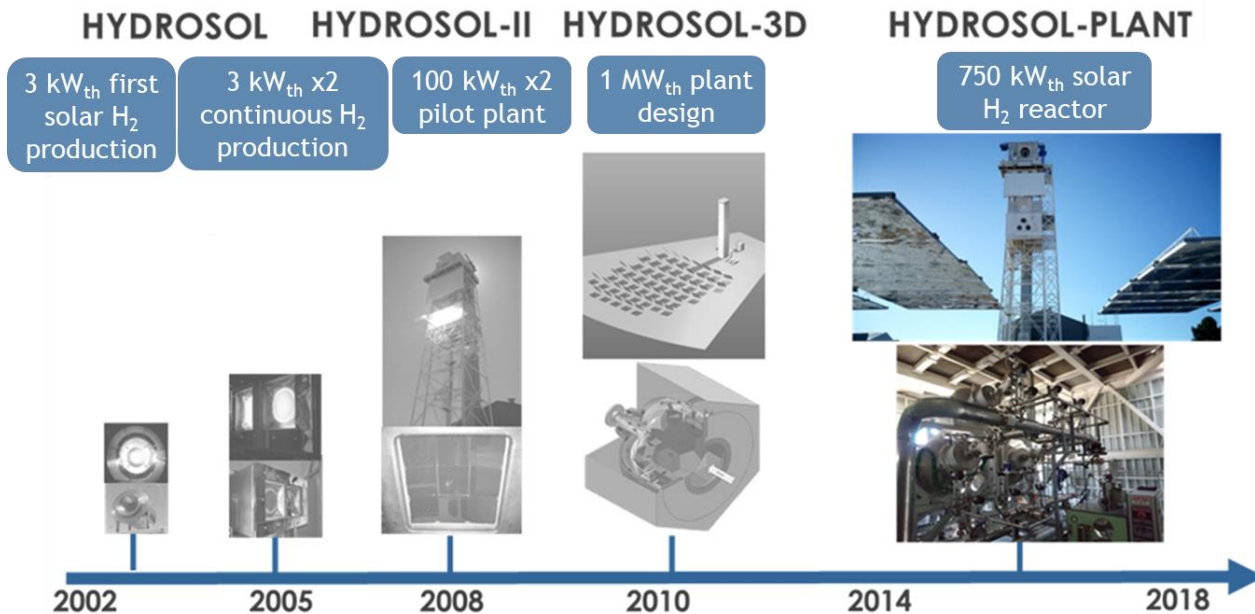


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HT Direct production of H₂ from sunlight

Large improvement of redox thermochemical cycles for water dissociation using concentrated solar-thermal power

Previous HYDROSOL-projects



- Production of stable NiFe₂O₄ lattice structures - 150 cycles
- Heat recovery of high temp heat >60%
Scaling up & Stability of reactor
- Demonstration of efficiency >5% in the field tests of the 750 kW_{th} plant



HT Direct production of H₂ from sunlight

Efficient water splitting via a flexible solar-powered Hybrid thermochemical-Sulphur dioxide depolarized Electrolysis Cycle

2013

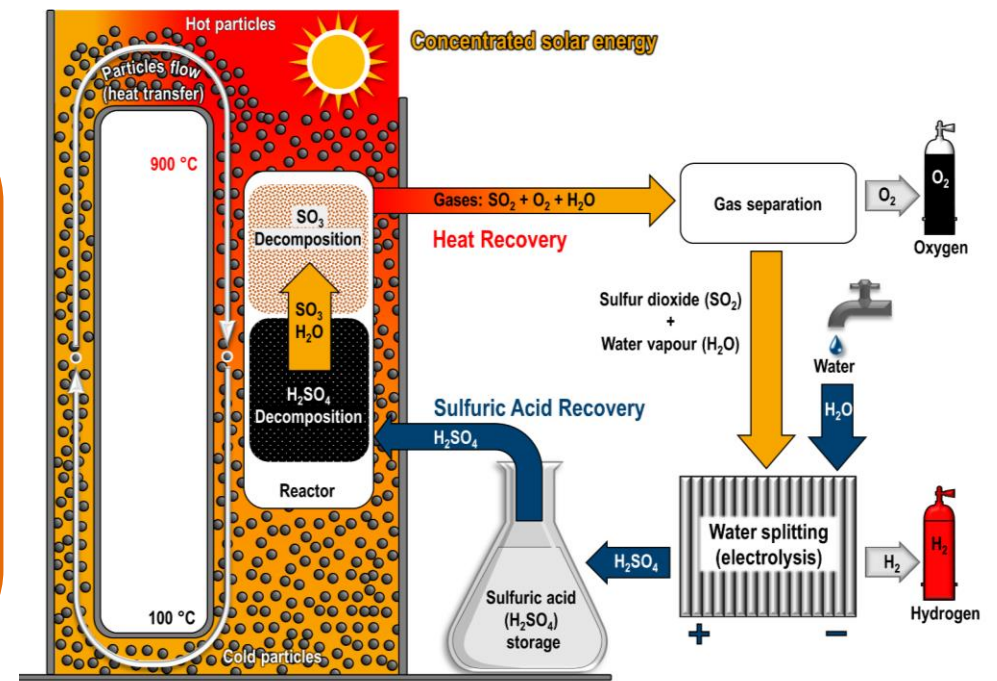


2022



Targets of HySelect:

- 750kW_{th} centrifugal particle receiver using a hot particles storage system
- a 250kW_{th} SAD-STS*¹ and a 100kW_e SDE*² into a pilot plant
- testing period 6 months in a large-scale solar tower
- solar-to-fuel energy conversion efficiency of >10 % (HHV)
- >0.75 kg/year per m² land area used



*1 sulphuric acid decomposition-Sulphur trioxide splitting

*2 sulphur dioxide depolarized electrolyzer

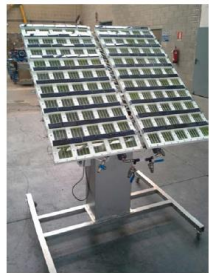
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LT Direct production of H₂ from sunlight

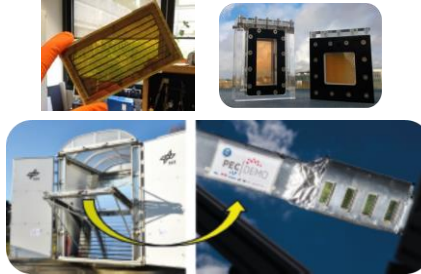
Scale-up and outdoor demonstration of a photo-electrochemical (PEC) system @ 10 m² and a photo-catalytic system @ 0.5 m²



- 1.6 m² irradiated surface (η=3 % STH)



- Hybrid PEC-EV
- η =9 % STH
- 4x50 cm²



- PV-electrolyser concept
- 10 m² prototype
- η =9 % STH
- LCOH = 4 - 10 €/kg



Demonstration of 10 m² direct coupled PV-EC*¹ device



Efficiency record of 14 % for SHJ*² PV-PEM electrolyser



6 €/kg achievable with integrated PV-EC approach



Constraints in scaling-up an integrated PV-EC device



2023

Photo-catalytic project in GAP

- STH % > 5%
- >500 h
- 500 cm²

*1 PV-electrochemical
*2 Silicon Hetero junction



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Biomass gasifiers & reactors; Biogas reformers

Singular projects on biomass; Recent emphasis on raw biogas compact reformers

 Dry biomass: H₂ <5 €/kg from biomass gasification 

2012





UnifHy 1MW_{th}
plant - 500kg/d

2023

Project in GAP

- 3MW_{th}
- 95kg H₂/h
- LCOH <2.2€/kg

 Biogas without CO₂ prior removal 

 100kg/day H₂  Conversion $\eta = 71.5%$ 

2015



2017



NEXT STEPS

PEMEL: Possible ban on PFAS should receive timely and appropriate attention - Strategic Research Challenge

R&I on BoP

Sea water electrolyzers - attention to water usage

All KPIs to be met at the same time

HT electrolyzers: focus on durability and pressurised operation in both SOEL and PCEL

Solar to H₂ still to reach efficiency targets

H₂ from bio-sources: thermolysis of biogas for production of H₂ and carbon black

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