PRODUCTION OF RENEWABLE HYDROGEN AND SYNGAS VIA HIGH-TEMPERATURE ELECTROLYSIS

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Heat-to-Fuel interfaces to advanced Power-to-Gas and Power-to-Liquids Technologies (e-fuels), 2021-03-08/09

AGENDA

1 SUNFIRE INTRODUCTION

2 SOEC ELECTROLYSER TECHNOLOGY

3 MARKETS AND APPLICATIONS

4 TECHNOLOGY DEMONSTRATION

5 SUMMARY AND OUTLOOK

AT A GLANCE

Sunfire is a leading electrolysis company.

Sunfire at a glance

- Established in 2010, Sunfire is a **leading electrolysis company**.
- Sunfire offers both **pressure alkaline (AEL) and solid oxide (SOEC) electrolyzers**, providing a unique product portfolio suitable for every hydrogen application.
- Fewer than ten credible electrolysis companies face a politically set EU **green hydrogen market of EUR 18 bn** until 2030; Sunfire is one of them.
- Green hydrogen from electrolysis is a **once-in-a-generation opportunity**.

Key facts

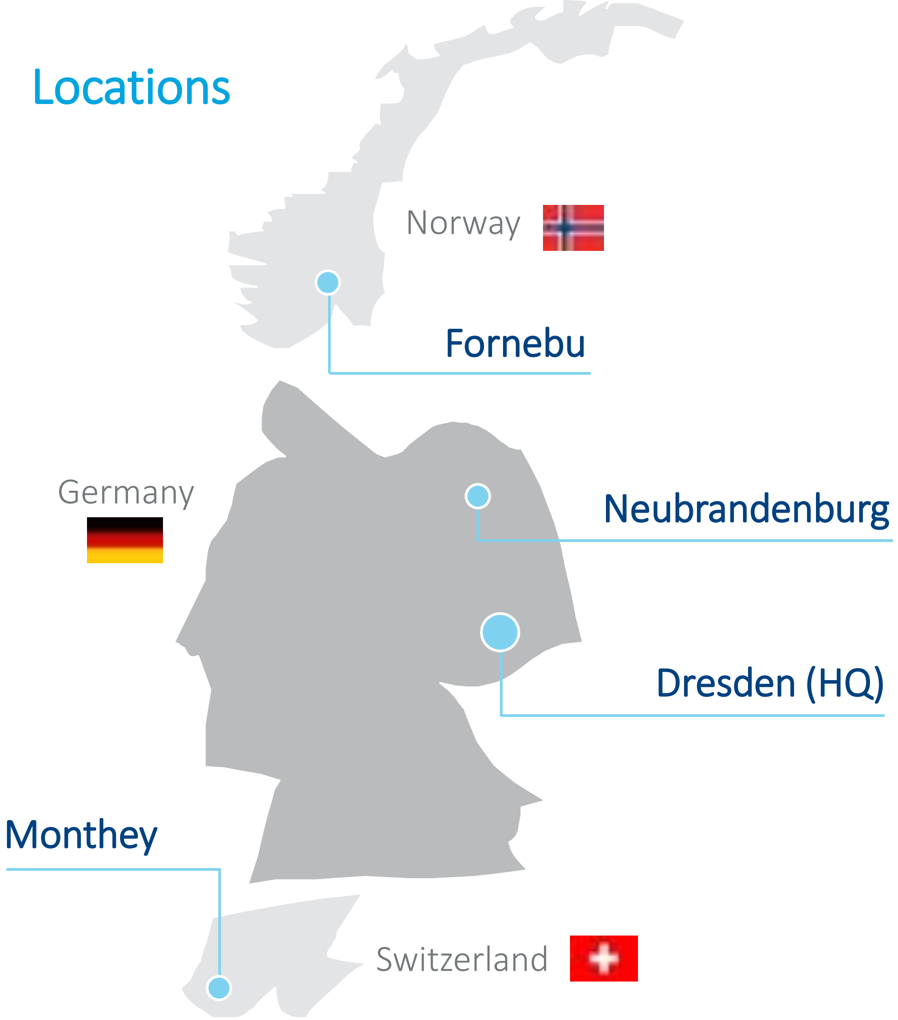
> EUR 100 million
Funding

> 250
Employees

>20
Industrial projects

500 MW / 200 MW p.a.
2025 production AEL / SOEC

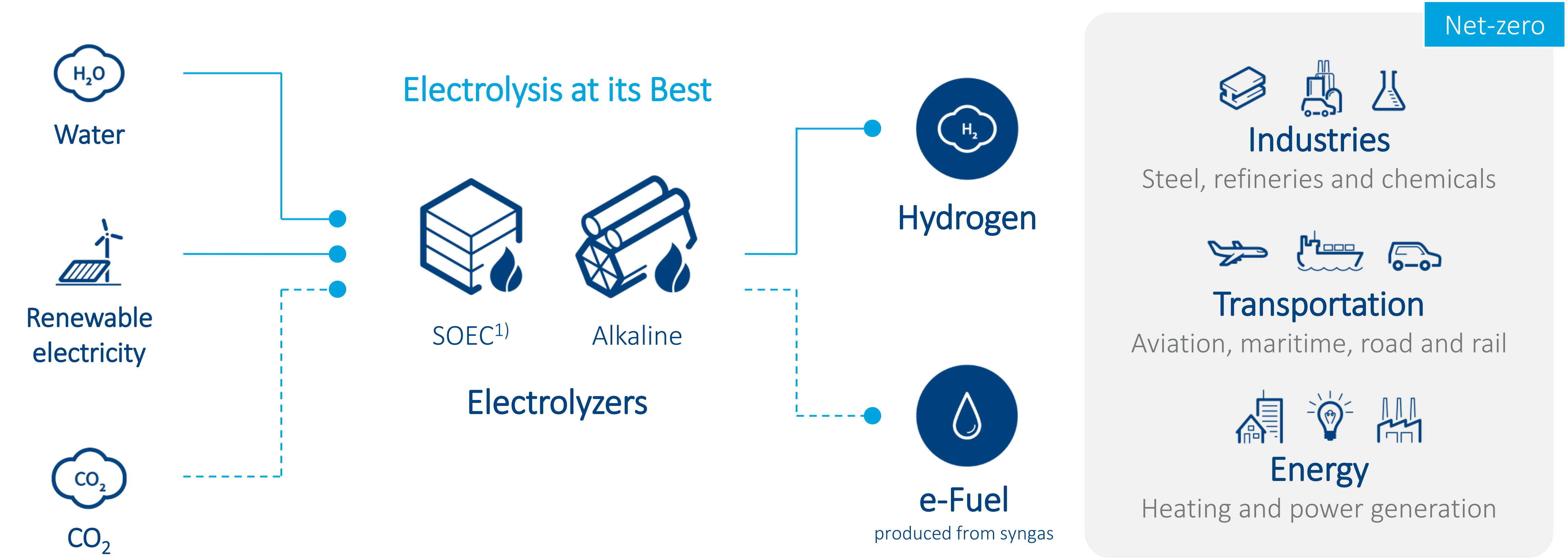
Locations



OUR MISSION

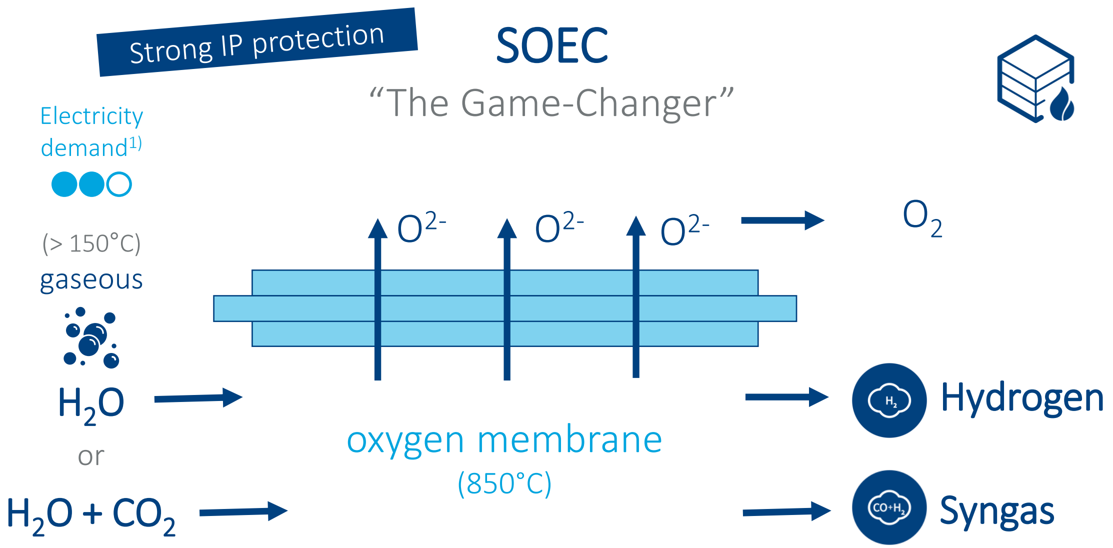
We provide superior electrolysis solutions to produce renewable hydrogen and e-Fuel

Sunfire electrolyzers convert renewable electricity into **renewable hydrogen** and **e-Fuel,** enabling a carbon-neutral **industry, mobility and energy sector**.



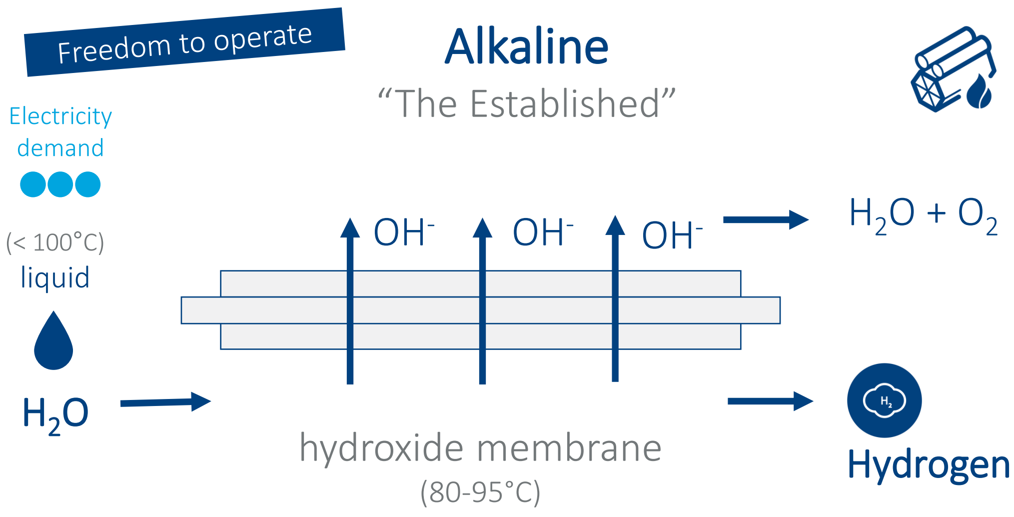
1) Solid oxide electrolysis cells

SOEC and Alkaline each have individual strengths that are valued by customers



Core Advantages

- Highest conversion efficiency ($84\%_{\text{LHV to AC}}$)[2]
- Industrial off-heat integration via steam provision
- CO_2 reduction capability



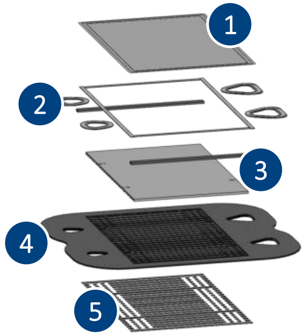
Core Advantages

- Proven technology (> 20 years)
- Competitive price (650 EUR/kW_{AC})
- Pressurized hydrogen production (30 bar)

1) External vaporization lowers energy demand by 16% while better kinetics allows additional efficiency increase. In total, SOEC provides > 20% more hydrogen or syngas output per kWh_{el}
2) Referring to overall system efficiency given steam @ 150°C and atmospheric hydrogen pressure

Stacks are integrated into modules which are integrated into electrolyzer systems

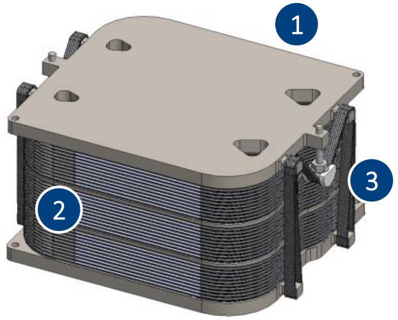
Cell
0.125 kW



1. Membrane electrode assembly
2. Glass sealing
3. Nickel foam
4. Sheet metal cassette
5. Cathode contact

x 30

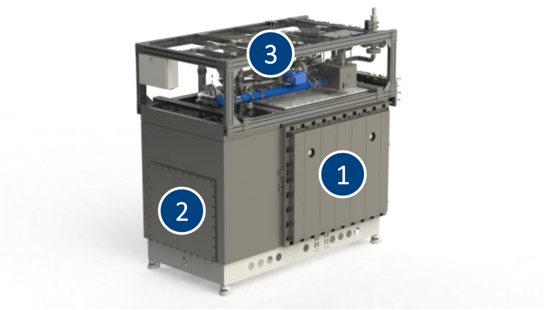
Stack
3.7 kW



1. End plates
2. Cells
3. Stack tensioning

x 60

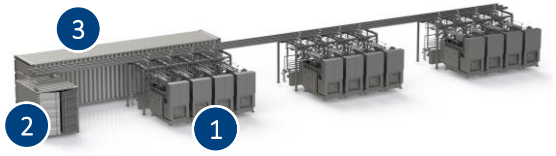
Module
225 kW



1. Stack unit
2. Gas processing unit (GPU)
3. Supply and discharge unit (SDU)

x 12

System
2.7 MW



1. Block (= 4 modules)
2. Fluid interface unit (FIU)
3. Power electronics

Generation 0	Generation 1	Generation 2	Generation 3	
2014-2017	2017-2020	2021-2024	from 2025 onwards	…

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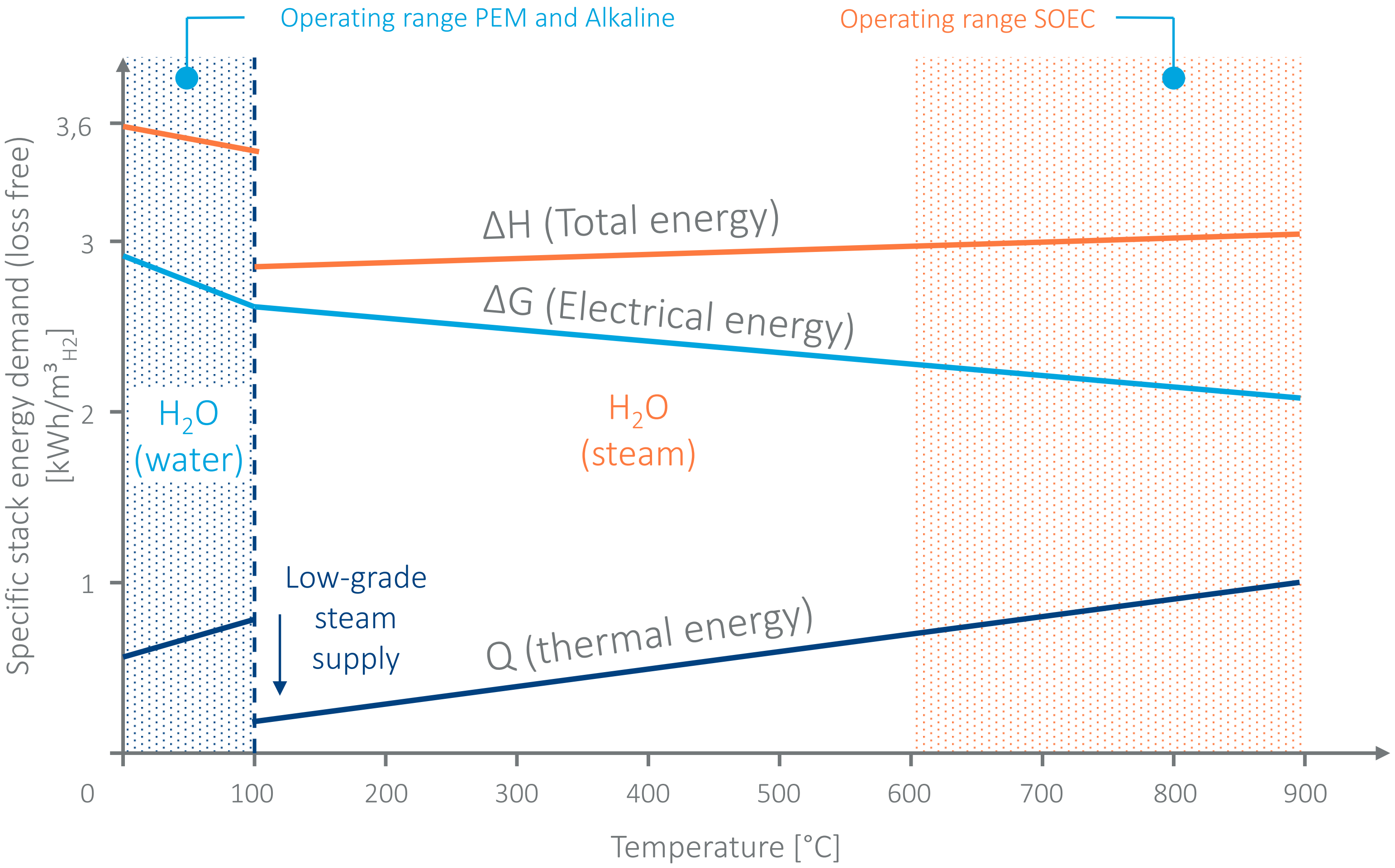
SOEC outperforms low-temperature electrolysis technologies



- Due to the dissociation of steam, SOECs require less energy compared to liquid water
- SOEC has a theoretical minimum stack efficiency advantage of 16 % assuming optimal low-temperature conversion
- One-third of the total energy comes from heat → SOECs require less renewable electricity
- Compared to state-of-the-art low temperature electrolysis, SOECs achieve a 30 % higher conversion efficiency on a system level

Hydrogen and syngas production

HyLink

Renewable hydrogen
as feedstock for industries

Use of steam where waste heat is available → Ideal for coupling with exothermic synthesis processes

Conversion efficiency[1)]: **> 84 %$_{\text{LHV to AC}}$**
Hydrogen output: **750 Nm³/h (12 modules)**
Power consumption: **3.6 kWh/Nm³**
Hydrogen quality: **> 99.99 Vol.-%**

Applications

sunfire

Electrolyser
Generation 2

SynLink

Clean syngas as feedstock
for green hydrocarbon products

Direct conversion of CO_2 and H_2O to syngas in one single process step is unique to SOEC.

Conversion efficiency[1)]: **> 82 %$_{\text{LHV to AC}}$**
Syngas output: **750 Nm³/h**
Power consumption: **3.85 kWh/Nm³**
Syngas (H_2 / CO) ratio: **1.5 … 3.5**

Applications

1) Referring to overall system efficiency given steam @ 150 °C

Technology status and targets

Efficiency[1)]	2020	2025	2030
HyLink	84 %	86 %	88 %
SynLink	82 %	84 %	86 %
Durability			
Stack lifetime	40,000 h	60,000 h	75,000 h
Degradation	20 mΩcm^2 / kh	8 mΩcm^2 / kh	7 mΩcm^2 / kh
Levelized cost of hydrogen[2)]	EUR 5.00 / kg_{H2}	EUR 2.30 / kg_{H2}	EUR 2.00 / kg_{H2}

1) Lower heating value to alternating current
2) Assuming electricity costs of EUR 35 / MWh

HyLink efficiency & power consumption:
88 %$_{LHV,AC}$ → 104%$_{HHV, AC}$ → 3.4 kWh/Nm^3 → 38 kWh/kg

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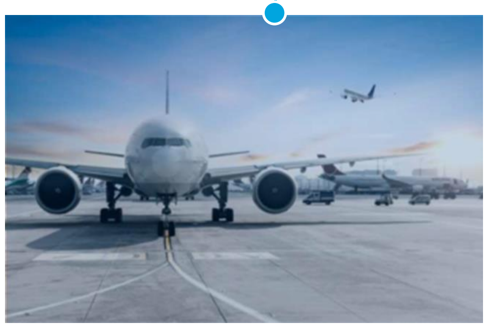
Sunfire target markets

40 GW EU electrolyzer demand until 2030

6 GW e-Fuel | 4 GW Steel | 4 GW Refineries

e-Fuel



Revenue potential[1)]
EUR 2,700 m

- **SynLink:** Proprietary Co-Electrolysis achieves superior efficiency and lowest e-Fuel costs
- **Renewable Fuel Partnership:** Strategic bond with Neste, largest renewable fuel producer
- **e-Fuel:** Production at spots with low electric costs and high RES share
- Paving the path to **renewable aviation and maritime transports**

Steel

Revenue potential[1)]
EUR 850 m

- **HyLink:** Electrolyzer achieves superior efficiency and lowest H_2 costs in the market
- **Steel EPC Partnership:** Strategic alliance with SMS group – the world's leading steel EPC
- Steel industry is among the largest contributors of greenhouse gas emissions – 7-9% of total emissions
- **Direct Reduced Iron (DRI)** saves up to 95% of CO_2 emissions

Refineries

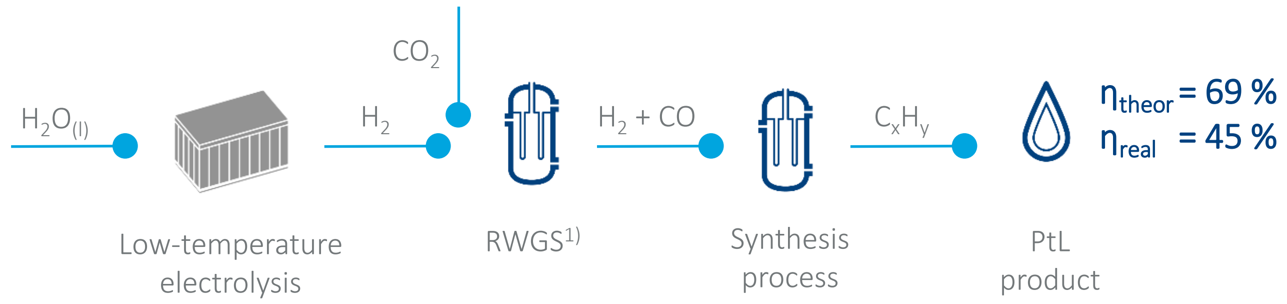
Revenue potential[1)]
EUR 850 m

- **HyLink:** Electrolyser achieves superior efficiency and lowest H_2 costs in the market
- Refineries need to fully decarbonize their value chain until 2050.
- As per **RED II**, fuel suppliers need to reach an average share of **renewables of 14 % in 2030**
- Substituting fossil-based with renewable **hydrogen** is a low-cost way to increase the share of renewables in transportation.

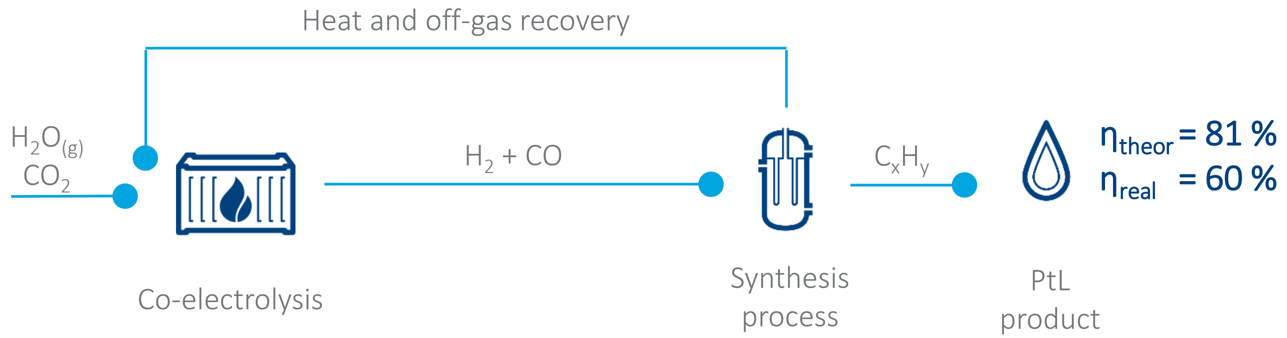
1) Cumulated revenues 2020-2030

Co-electrolysis: High-efficient Power-to-Liquid applications

Legacy PtL technology



Sunfire PtL technology



- Legacy Power-to-Liquid (PtL) technologies require 3-step process including a CAPEX-intensive and inefficient Reverse-Water-Gas-Shift (RWGS) reactor.
- Sunfire's Co-Electrolysis technology results in a 2-step-process with lower CAPEX investments.
- 30 % higher efficiency due to fewer process steps and heat integration from downstream exothermic synthesis process (e.g. Fischer-Tropsch)

Norsk e-Fuel

25 MW alpha → 200 MW beta → x 5 → 1 GW (total)

1) Reverse-Water-Gas-Shift reaction is required in order to generate carbon monoxide (CO)

AGENDA

GrInHy2.0
Green Industrial Hydrogen

#1 GrInHy: Production of renewable hydrogen for green steel-making

Objective	Supply of 100 tons of renewable hydrogen for green steel making.
Technology	150 kW Sunfire HyLink (2016) and 720 kW Sunfire HyLink Gen. 1 (2020)
CAPEX	Total budget EUR 4.5 million (2016) and EUR 6 million (2020); Sunfire budget EUR 2 million (2016) and EUR 3 million (2020)
Achievements	15,000 hours operating period, efficiency of up to 82 % proven in GrInHy1
Upscaling	Salzgitter Steel works has a strategic commitment to achieve zero-carbon steelmaking by 2050 (project name "SALCOS").

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

SALZGITTER FLACHSTAHL
A Member of the Salzgitter Group

cea

PAUL WURTH
SMS group

sunfire

tenova

Timeline

2016	2017	2018	2020
1st FCHJU funding granted	Start of operation 150 kW HyLink	2nd FCHJU funding granted	Start of operation 730 kW HyLink

GrInHy
Green Industrial Hydrogen

#1 GrInHy: Production of renewable hydrogen for green steel-making

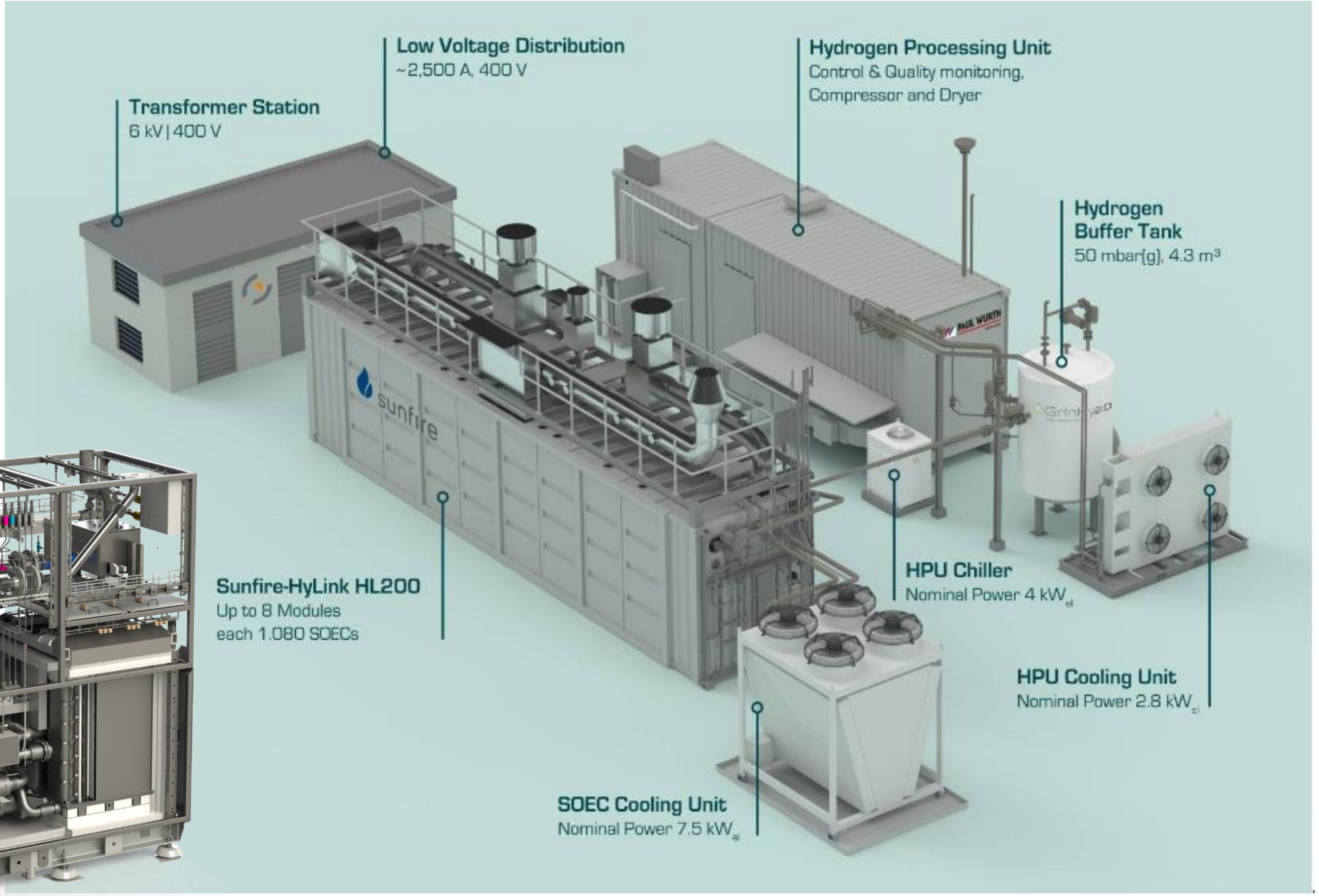
- GrInHy1.0 - Reversible SOC system with 3 operation modes
  - electrolysis for hydrogen production and downstream injection in pipeline
  - hydrogen fuel cell for power production
  - natural gas fuel cell for power production

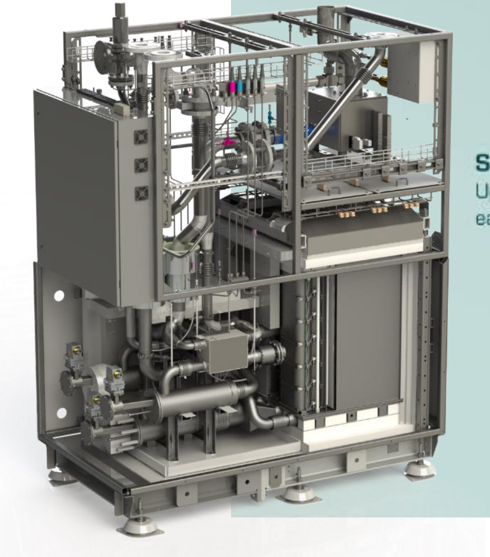
- Technical specification

Operation Mode	SOEC mode	H2-SOFC mode	NG-SOFC mode
rSOC AC Power	143 kW	30 kW	25 kW
HPU AC Power	12 kW	-	-
Hydrogen Production	40 Nm³/h	-	-
Dynamic Range	50…125 %	30…100 %	30…100 %
rSOC AC Efficiency	84 $\%_{LHV}$	47 $\%_{LHV}$	50 $\%_{LHV}$

TECHNOLOGY DEMONSTRATION

#1 GrInHy: Production of renewable hydrogen for green steel-making





Objectives of GrInHy2.0

- Electrolyser scale-up to 720 kW$_{el,AC}$
- Hydrogen production 200 Nm³/h (18 kg/h) → up to 37 Nm³/h per module
- Efficiency 84 %$_{el,LHV}$ (< 40 kWh$_{el,AC}$/kg)
- Operating times (target):
  - > 15 000 h system
  - > 20 000 h stack

#2 MULTIPLHY: Renewable hydrogen for a refinery

MULTIPLHY

- **Objective** — Supply of 960 tons of renewable hydrogen to a biofuel refinery
- **Technology** — 2.5 MW Sunfire HyLink Gen. 2
- **CAPEX** — Total budget EUR 10 million, Sunfire EUR 6 milli
- **Targets**
- **Ups**

11:20 Session: Demonstration projects

Tuesday, the 9th of March 2021

Multimegawatt high-temperature electrolyser to generate green hydrogen for production of high-quality biofuels

Julie Mougin, Head of Hydrogen Technologies Laboratory, CEA

NESTE · sunfire · ENGIE · cea · PAUL WURTH SMS group

Timeline

2019	2020	2021	2022
FCHJU funding granted	Official project start	Start of erection	Start of production

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Summary

- SOEC Electrolysis achieves an up to 20% higher efficiency compared to LTE technologies if steam is available → ideal partner to all integrated synthesis processes
- Technology is ready for deployment in large scale, although there are still challenges due to missing long-term experiences
- Hydrogen for refineries offers an immediate CO_2-reduction potential via blend in existing vehicle fleet
- Capability of Co-Electrolysis paves the path to competitive e-Fuels in the transport sector
- Direct Reduced Iron (DRI) process using green hydrogen allows a nearly complete decarbonization of the iron and steel industry

Acknowledgement

The SOC development activities received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 826350 (GrInHy2.0) and No 875123 (MULTIPLHY).
The JU receives support from the European Union's Horizon 2020 research.

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RENEWABLES EVERYWHERE

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