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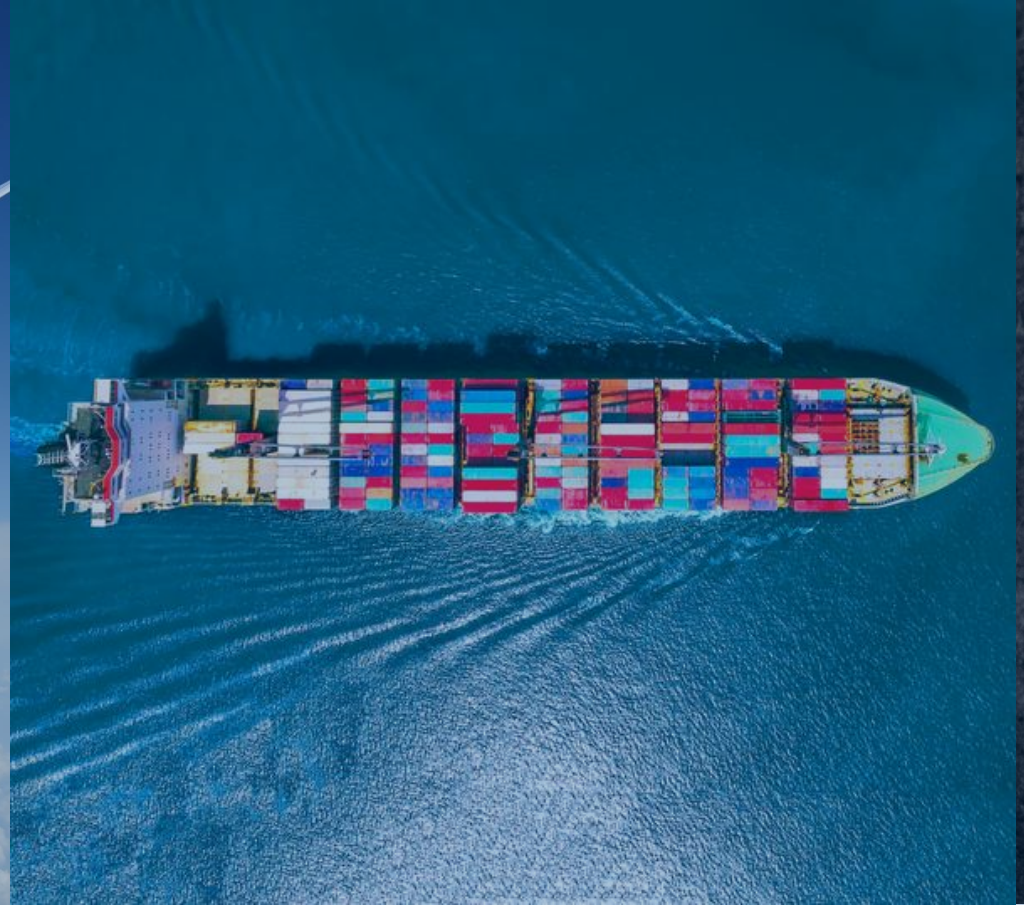
COMMERCIALIZING SYNTHETIC FUELS

Development of Co-Electrolysis for Power-to-Liquids

20-10-2019 Nils Aldag, Managing Director









F.Jarabica / Shutterstock.com

What do commercial planes, container ships and cosmetics have in common?



They all use large amounts of crude oil – the “black gold” that our economies depend on.





Renewables have become competitive, but they cannot power planes, ships and chemicals directly.





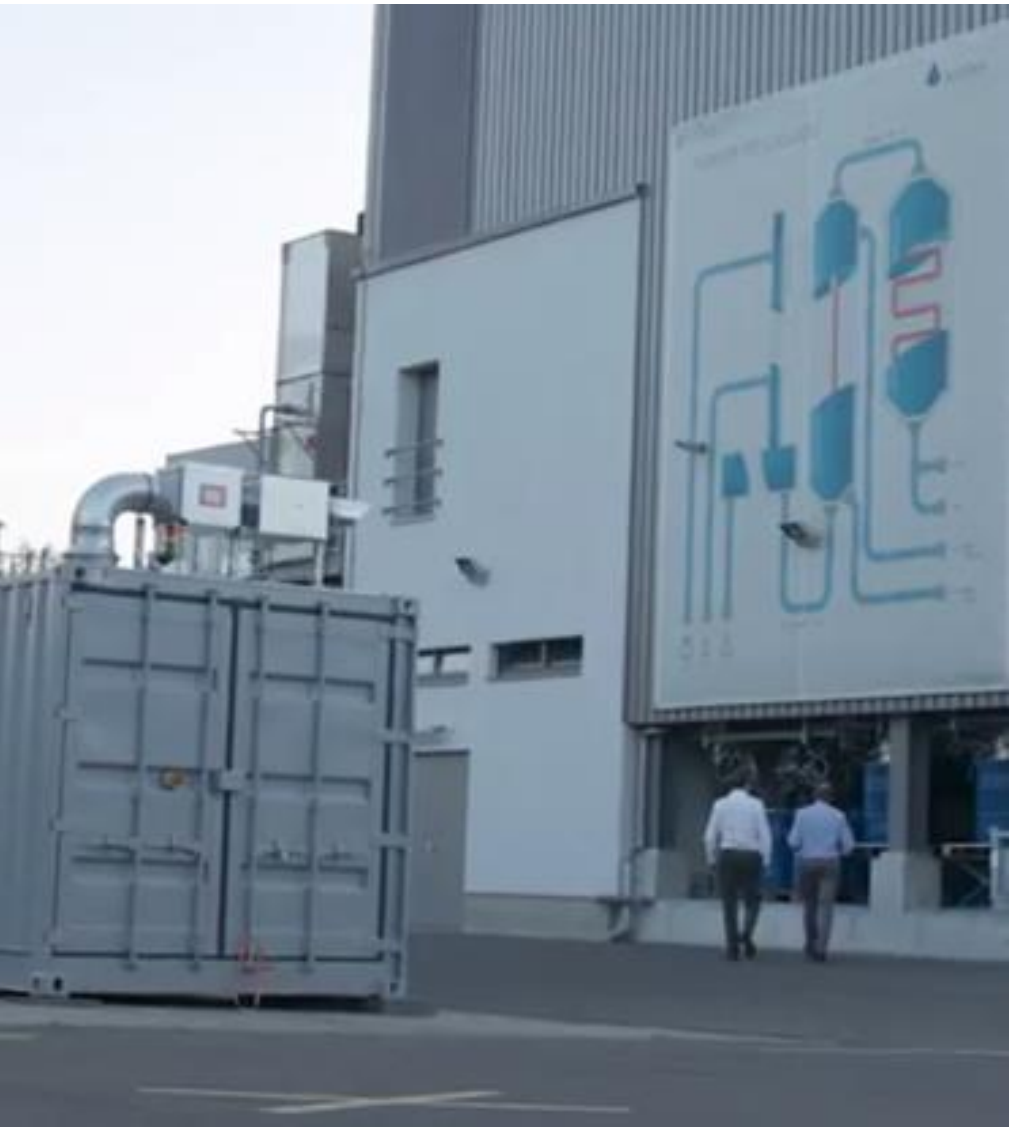


Sunfire is the pioneer in the conversion of renewable electricity and CO_2 into E-Fuels.

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LEADER IN FUELS MADE FROM ELECTRICITY





Sunfire Power-to-Liquids Demonstration Plant

LEADER IN FUELS MADE FROM ELECTRICITY

- Sunfire is a leading provider of Power-to-X plants for the production of electricity-based fuels and gases
- 160 people in Dresden and Neubrandenburg
- Raised 58 M€ venture capital from strategic investors and private equity (e.g. SMS group and TOTAL)
- Current production capacity of 20 MW/a to be increased to 200 MW/a at existing location
- 165 global patents protecting Sunfire technology

SUNFIRE ELECTROLYSIS PRODUCTS

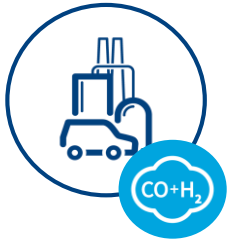


Sunfire-HyLink 200

Renewable hydrogen - up to 730 kW per system / 200 Nm^3 H_2 per hour. The world's most energy efficient electrolysers, with a system power consumption of down to 3.7 kWh/Nm^3 H_2.



Sunfire-HyLink in Action



Sunfire-SynLink 200

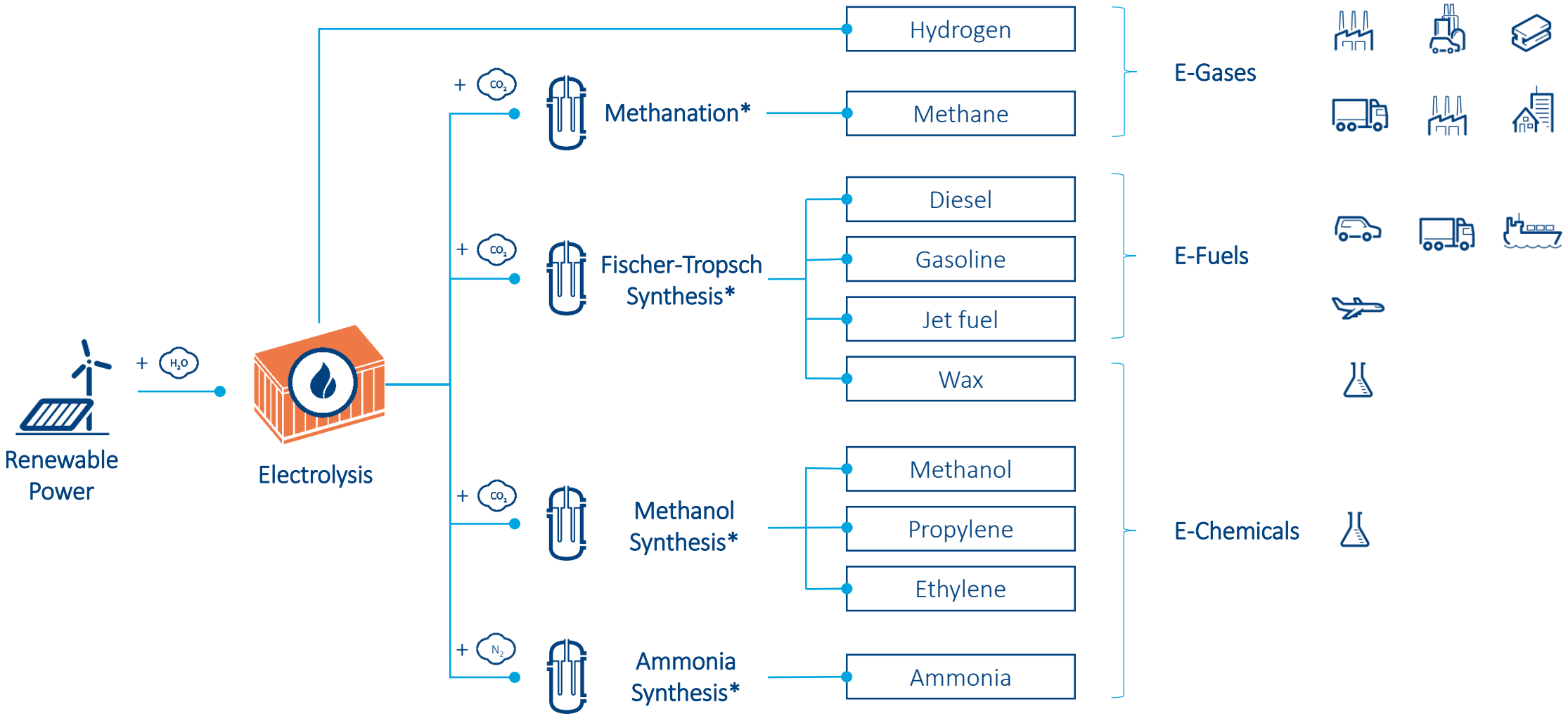
Renewable syngas - up to 790 kW per system / 200 Nm^3 syngas per hour. The world's only electrolysis technology capable of producing syngas directly from H_2O and CO_2.

Highest conversion efficiencies for lowest total costs!



Sunfire-SynLink in Action

POWER-TO-X PRODUCTION PATHWAYS



* Source: dena, Heutige Einsatzgebiete für Power Fuels, 08/2018

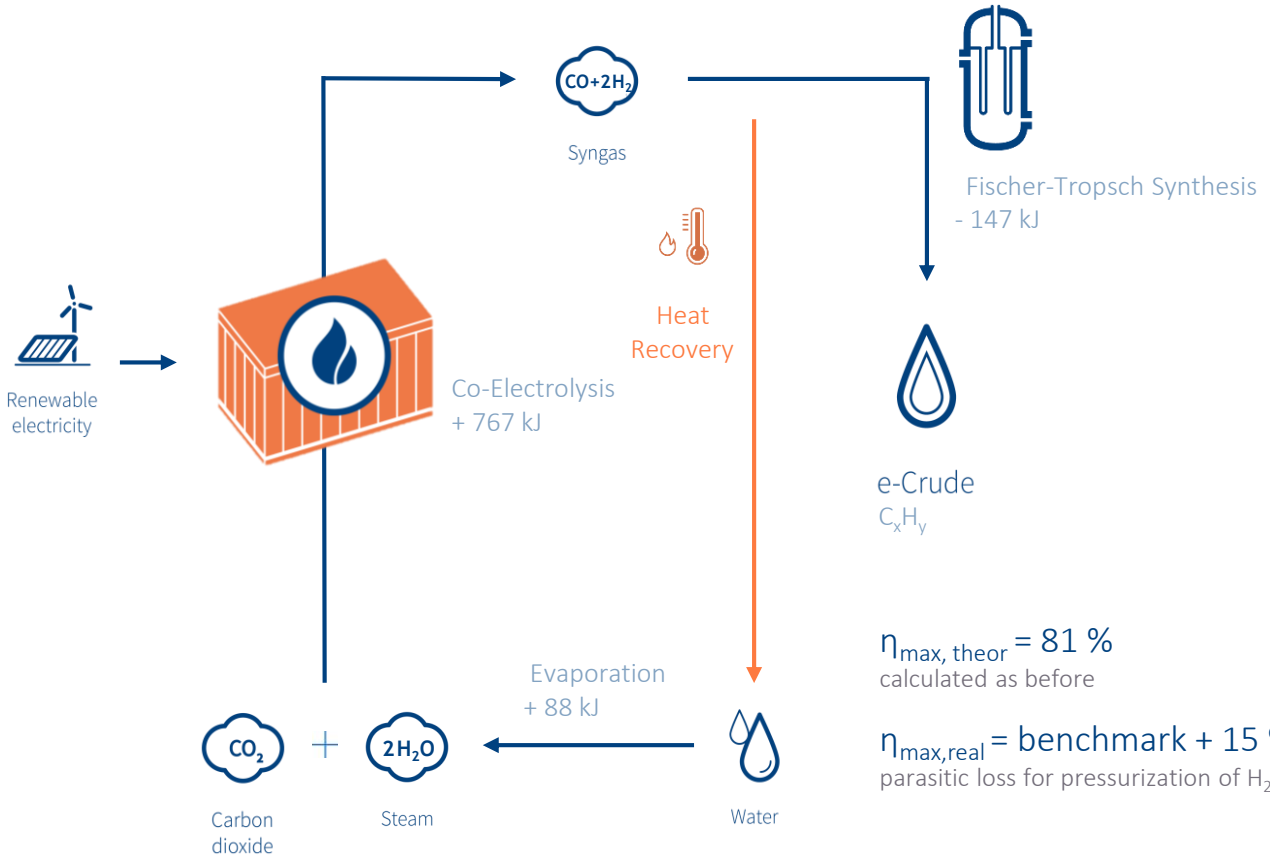
FUTURE MARKETS

Transport (aviation, maritime and existing fleets)	**Steel**	**Chemicals** (Methanol, Syngas, Ammonia)
Replace fossil fuels (diesel, gasoline and jet fuel) and fossil hydrogen (from SMR)	Replace coal based iron by renewable Hot Briquetted Iron (HBI)	Replace SMR based hydrogen and syngas for methanol and other chemical molecules
Germany, EU, USA	Germany, EU	Germany
Renewable Energy Directive Additional political support necessary	Requires an ETS price of > 50 €/t CO_2	Political support necessary Currently no policy in place
2030: 8 – 10 GW (3.5 - 6 % of German market)	2030: 40 GW (8 MtH_2/a) 2050: 240 – 360 GW (47–67 MtH_2/a)	2030: tbd

THE SUNFIRE PROCESS WITH SYNLINK



CO-ELECTROLYSIS + SYNTHESIS



Higher efficiency due to process integration and shift from catalytic to electro-chemical conversion

$\eta_{max,\ theor}$ = 81 %
calculated as before

$\eta_{max,real}$ = benchmark + 15 % points
parasitic loss for pressurization of H_2 is included

All values refer to energy conversion necessary for the production of 1 kmol of -CxHy- hydrocarbons

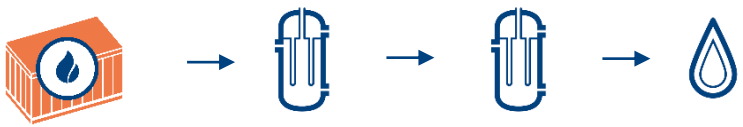
P2L TECHNOLOGY COMPARISON

Water-Electrolysis + RWGS + Synthesis



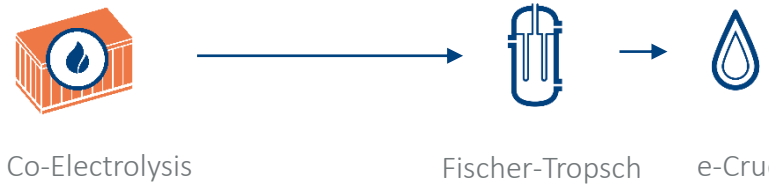
- 3-step process
- Reverse Water-Gas-Shift (RWGS) necessary (900 – 1,000 °C)
- Efficiency: $\eta_{max, real}$ = 40 - 48 % ($_{theor}$ = 69 %)

Steam-Electrolysis + RWGS + Synthesis



- 3-step process with heat recuperation
- Reverse Water-Gas-Shift (RWGS)necessary (900 – 1,000 °C)
- Efficiency: $\eta_{max, real}$ = 50 - 58 % ($_{theor}$ = 81 %)

Co-Electrolysis + Synthesis

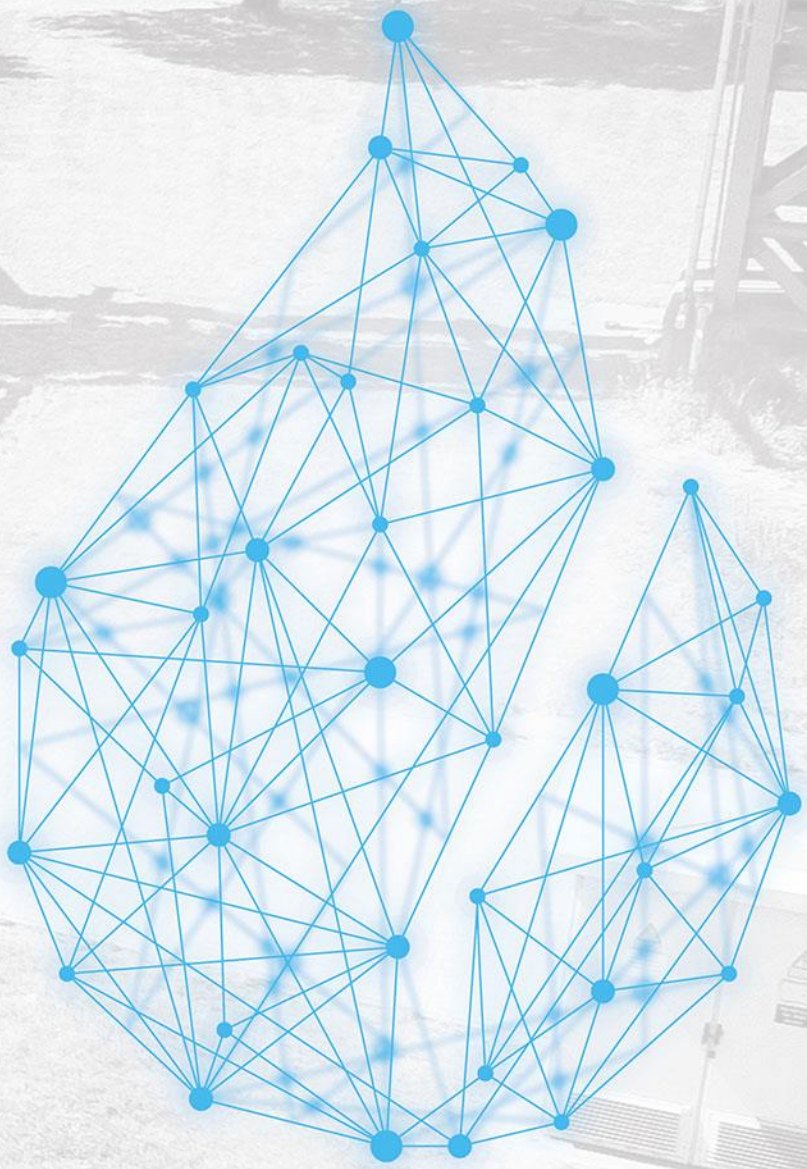


- 2-step process with heat recuperation (= less CAPEX)
- No Reverse Water-Gas-Shift (RWGS) necessary
- Efficiency: $\eta_{max, real}$ = 55 - 63 % ($_{theor}$ = 81 %)

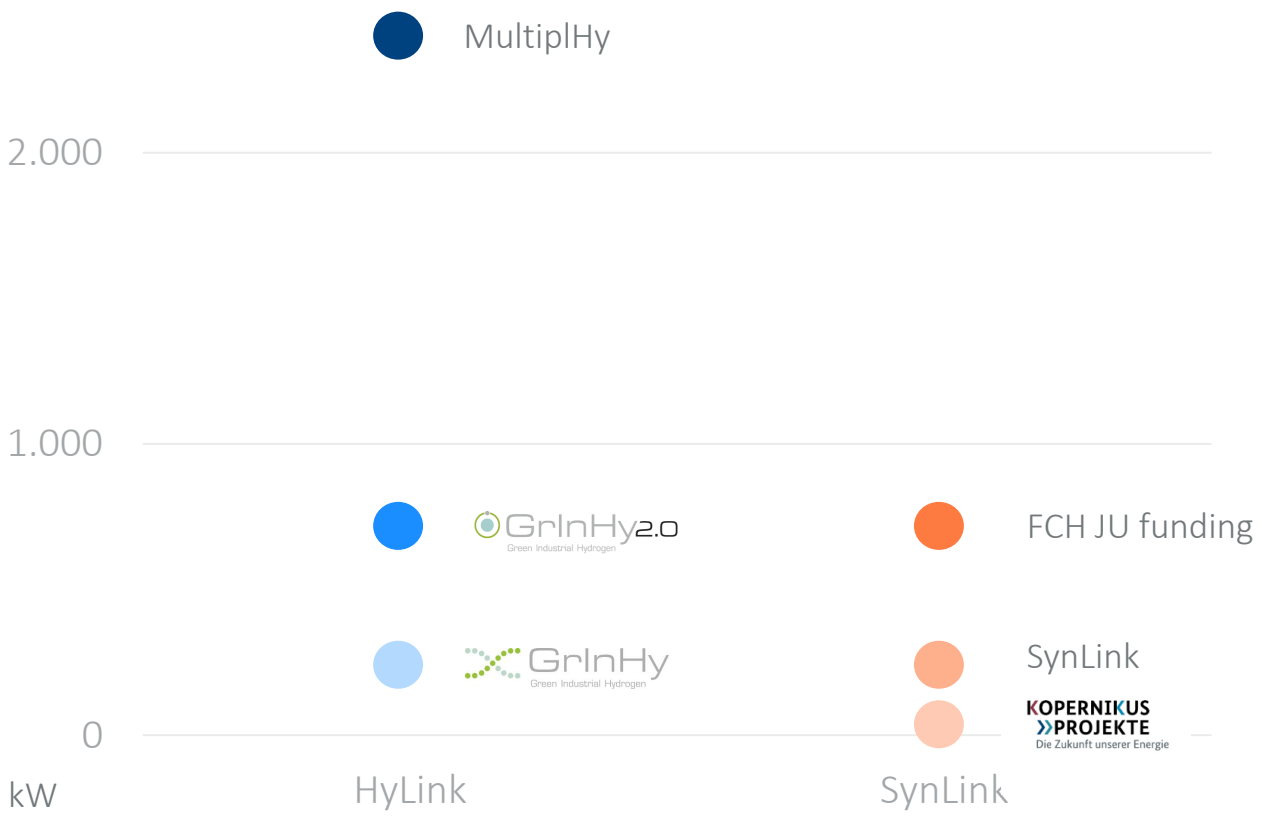
All values refer to energy conversion necessary for the production of 1 kmol of -CxHy- hydrocarbons

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PRODUCT DEVELOPMENT



R&D PROJECT MAP SUNFIRE



GrInHy 1.0 (running)
150 kW – 40 Nm3/h hydrogen production
Long-term testing

GrInHy 2.0 (running)
750 kW – 200 Nm3/h hydrogen production
Cost reduction; long-term testing

MultiplHy (granted, in preparation)
2.500 kW – 650 Nm3/h hydrogen production
Cost reduction; long-term testing

Kopernikus 1.0 (running)
10 kW – syngas production
Coupling with Fischer-Tropsch

SynLink project (running)
150 kW – 37 Nm3/h syngas production
Coupling with methanol synthesis

FCH-JU project (in application)
750 kW – ca. 200 Nm3/h syngas production

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Development of industrial scale SOEC

These projects have received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700300 and No 826350.

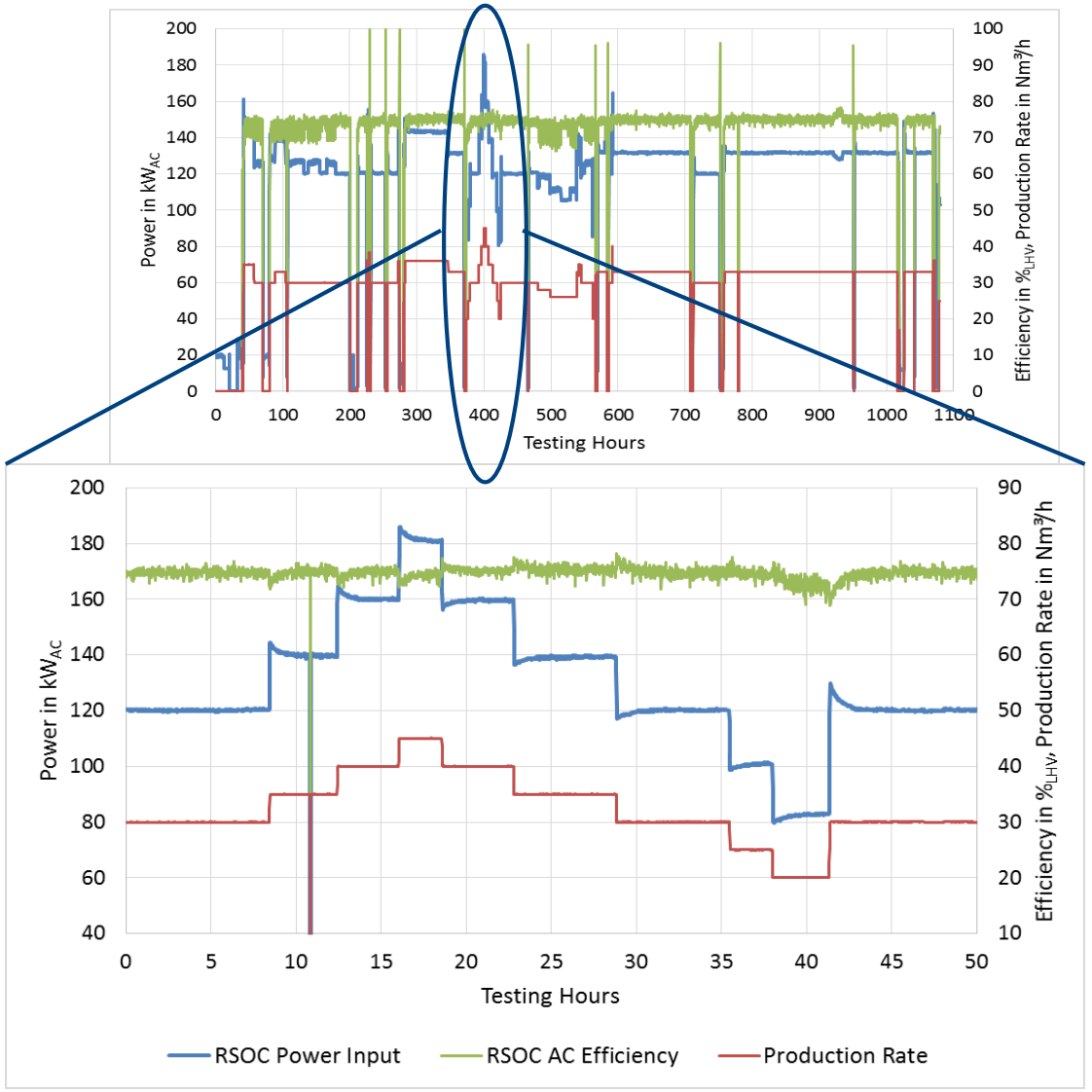
GrInHy
Green Industrial Hydrogen

GrInHy2.0
Green Industrial Hydrogen

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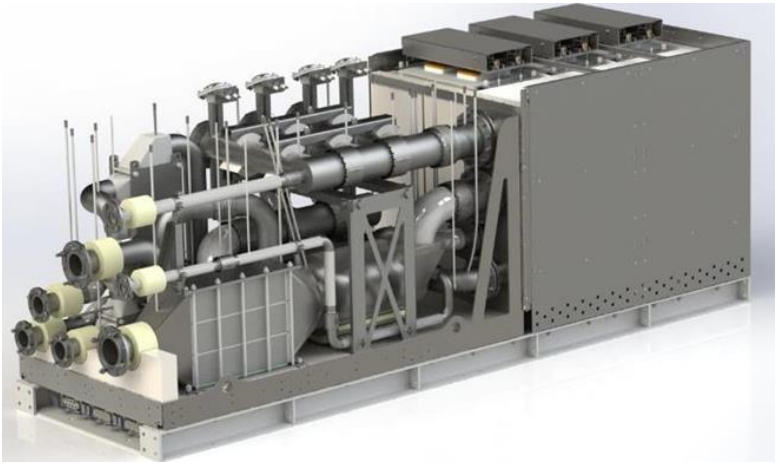
HYLINK OPERATING RESULTS

- 13,000 h operation, about 120,000 Nm^3 H_2 produced → Long-term target 50,000 h
- 20 thermo-cycles and a few hundred load cycles, no safety related incidents
- Low degradation 25 $m\Omega cm^2/kh$ ≈ 0.8 %/kh voltage degradation
- Load variation between 50 % (20 Nm^3/h, 80 kW_{AC}) and 113 % (45 Nm^3/h, 180 kW_{AC}) at nearly constant efficiency

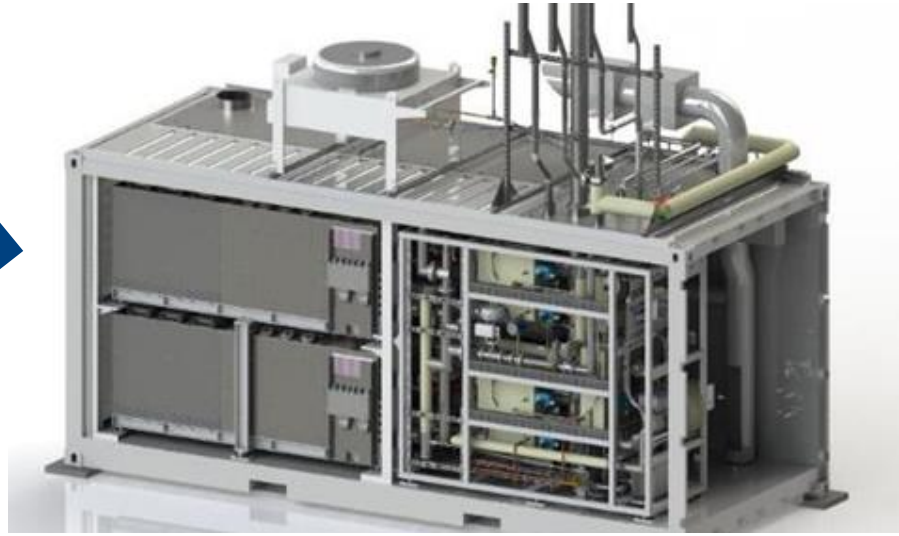


SUNFIRE-HYLINK GEN.0

- 40 Nm^3/h production rate in 20‘ container
- Complex system design
- Costs > 5,000 €/kW_{el}
- Current long-term tests based on this design. Product generation not in production anymore.



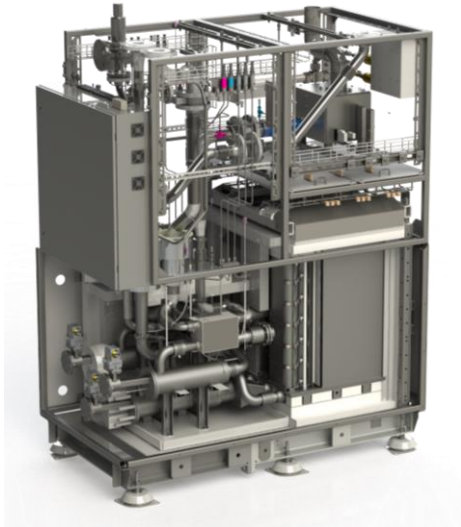
Electrolysis module with 1x 24 stacks



Electrolysis system with 2x 24 stacks (20 Ft container)

SUNFIRE-HYLINK GEN.1

- 200 Nm^3/h production rate in 40‘ container
- Significantly improved footprint
- Approx. 50% cost reduction
- Simplified design
- Design successfully validated internally and currently implemented into customer projects



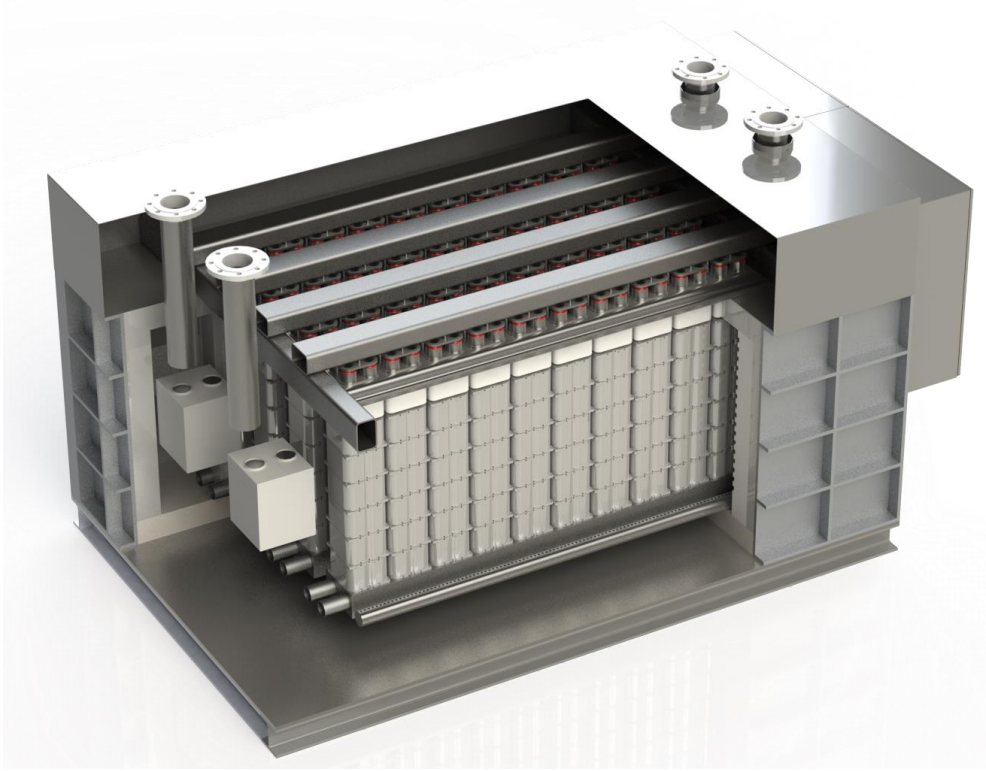
Electrolysis module with 1x 36 stacks



Electrolysis system with 8x 36 stacks (40 Ft container)

SUNFIRE-HYLINK GEN.3

- 350 Nm^3/h production rate not containerized anymore
- Significantly improved footprint
- > 50% cost reduction
- Hotbox and coldbox component integrated into stack unit
- Design currently under development.



Electrolysis system with 1x 240 stacks (no container)



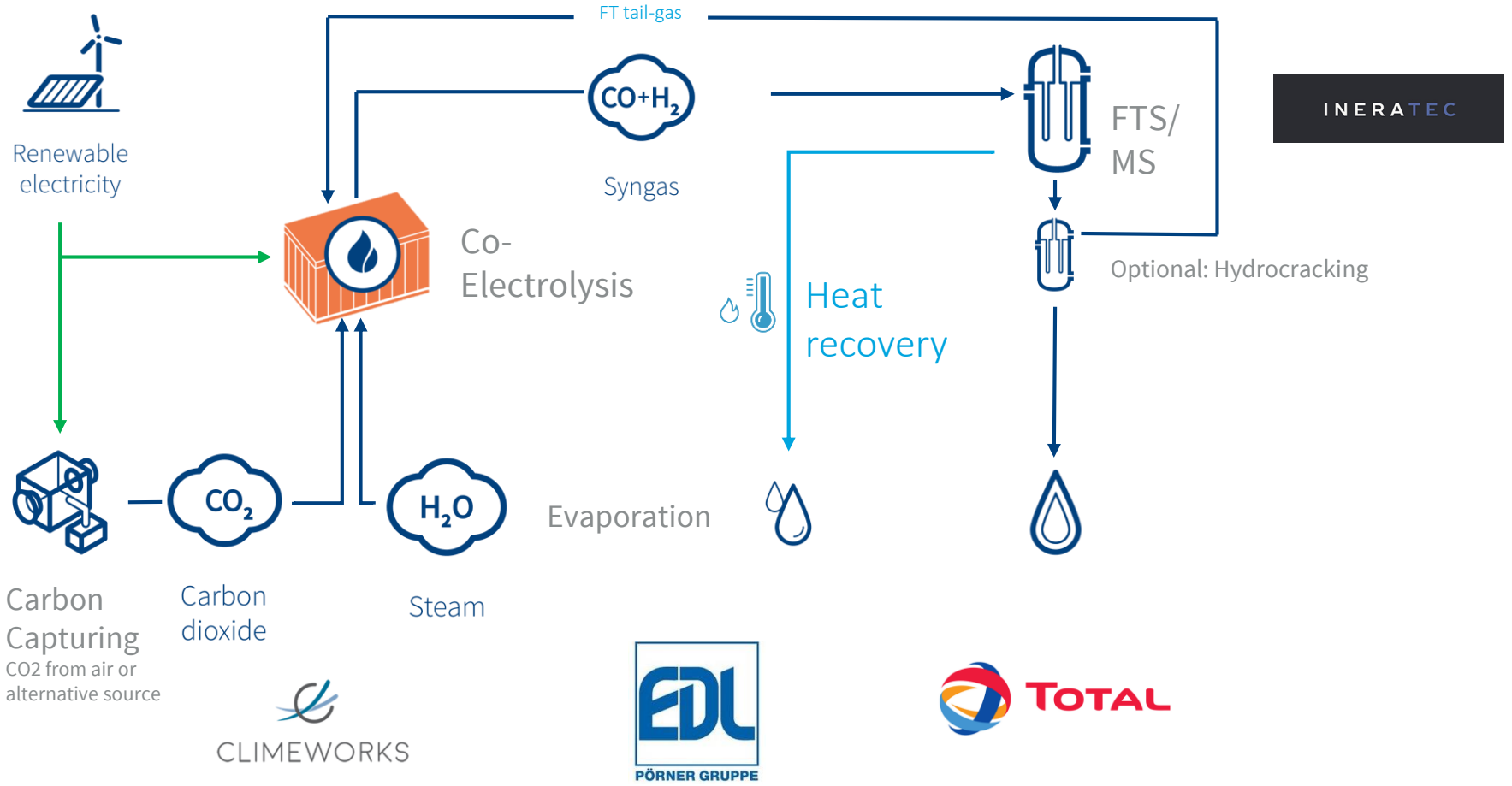
Development of an integrated P2L plant

KOPERNIKUS PROJEKTE
Die Zukunft unserer Energie

Bundesministerium für Bildung und Forschung

Federal Ministry for Economic Affairs and Energy

Development of an integrated P2L plant



Fraunhofer CBP

Fraunhofer IMWS

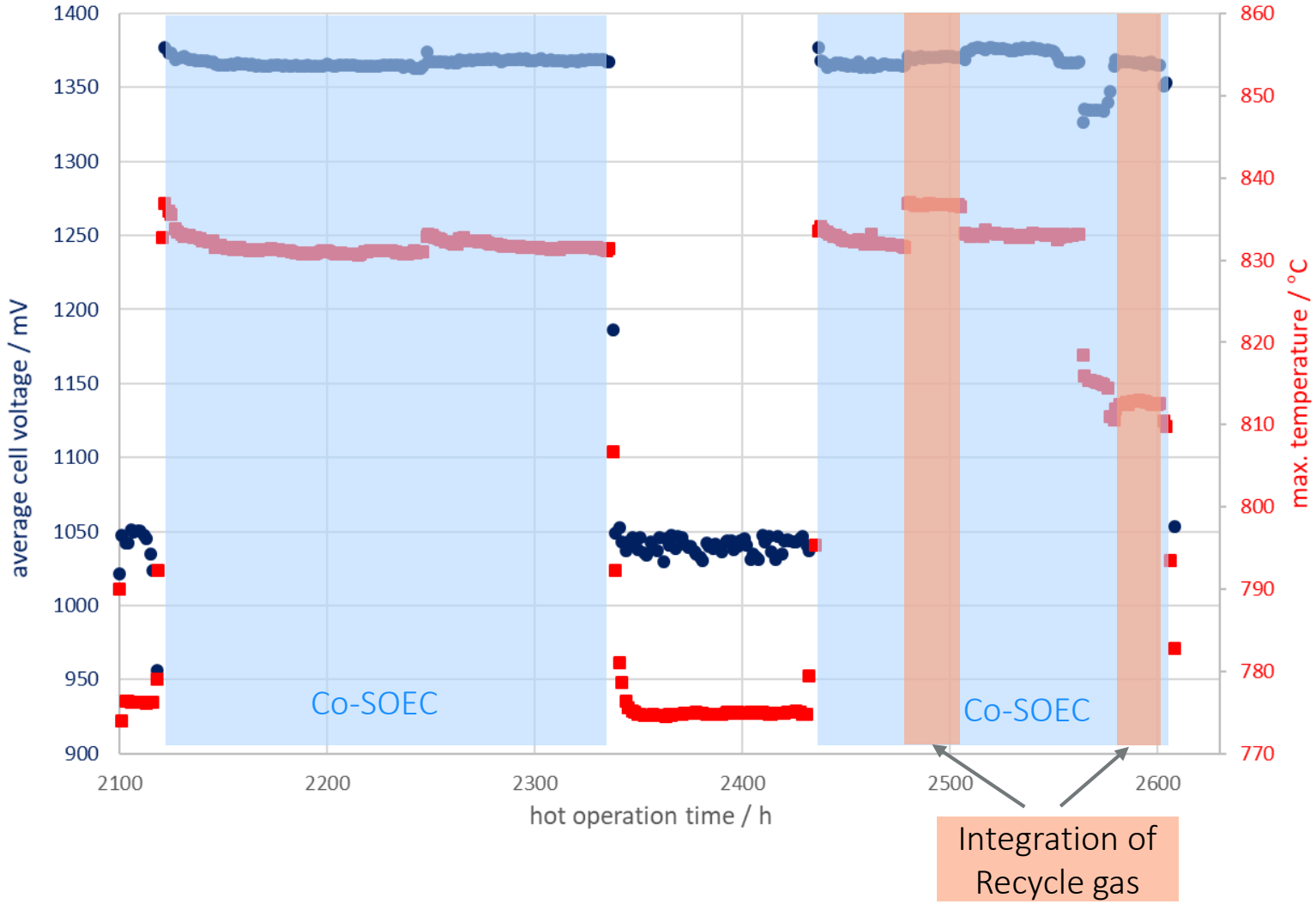
Fraunhofer IKTS

DLR

EIFER

SYNLINK + SYNTHESIS OPERATING RESULTS

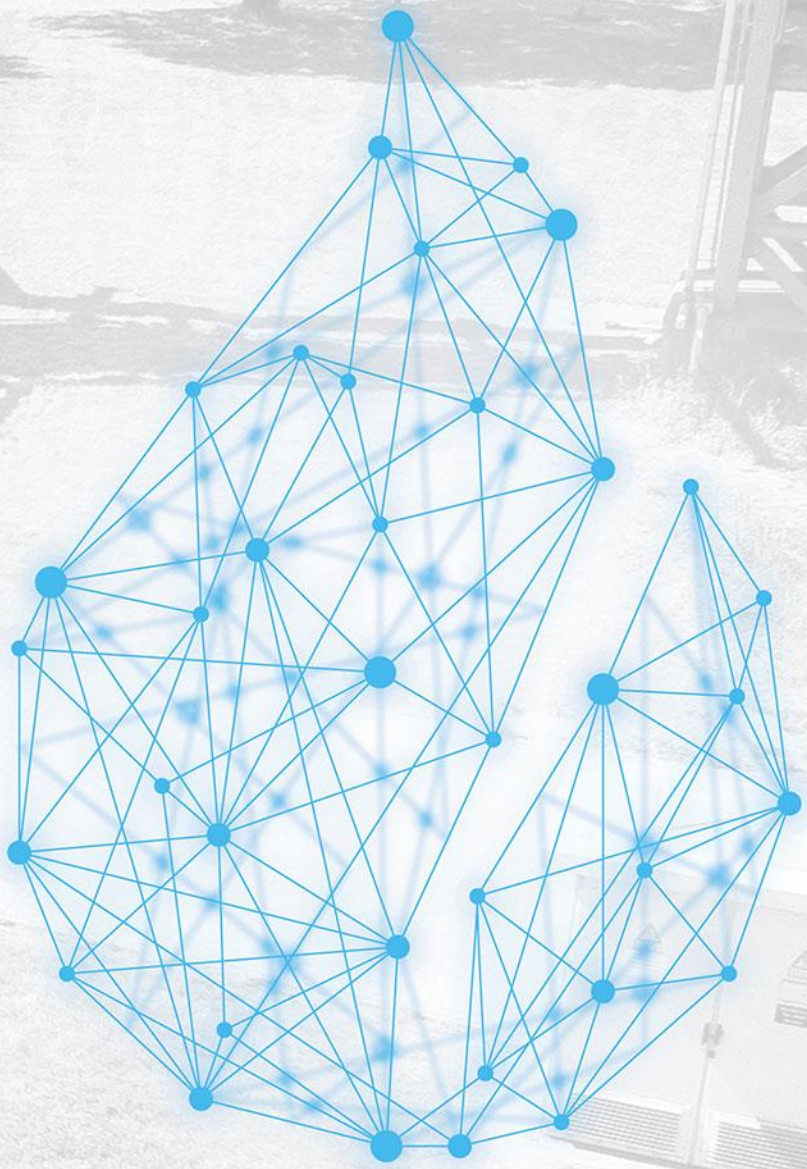
- Successful stable operation of P2L plant with co-electrolysis producing FT-product
- Successful system operation of > 2,600 h
- No higher degradation compared to H_2O-SOEC
- Integration and reforming of recycle gas from FTS



RESEARCH REQUIREMENTS

- Generate long-term real time load operation experience of new system generations in industrial practice
- Reduce degradation of stacks and systems through use of improved materials and appropriate operational modes
- Reduce costs through integration of more stacks per unit and a better integration of balance-of-plant components
- Improve integration of all process steps (DAC, co-electrolysis, synthesis, recuperation) to increase process efficiency

NEXT STEPS TO COMMERCIALIZATION



NORSK E-FUEL PROJECT POTENTIAL

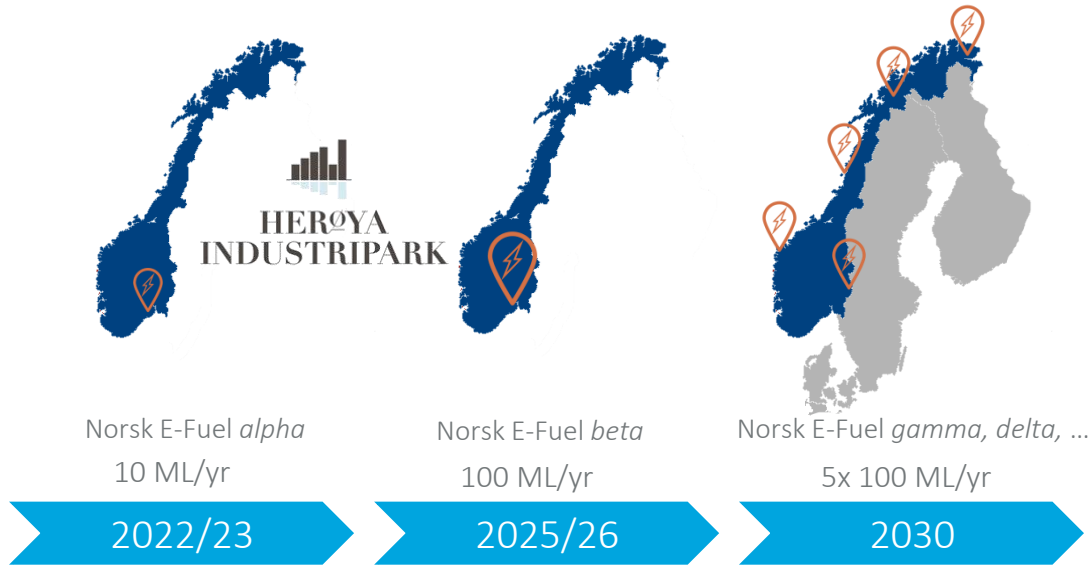
- From Norway for Europe!

norsk e-fuel

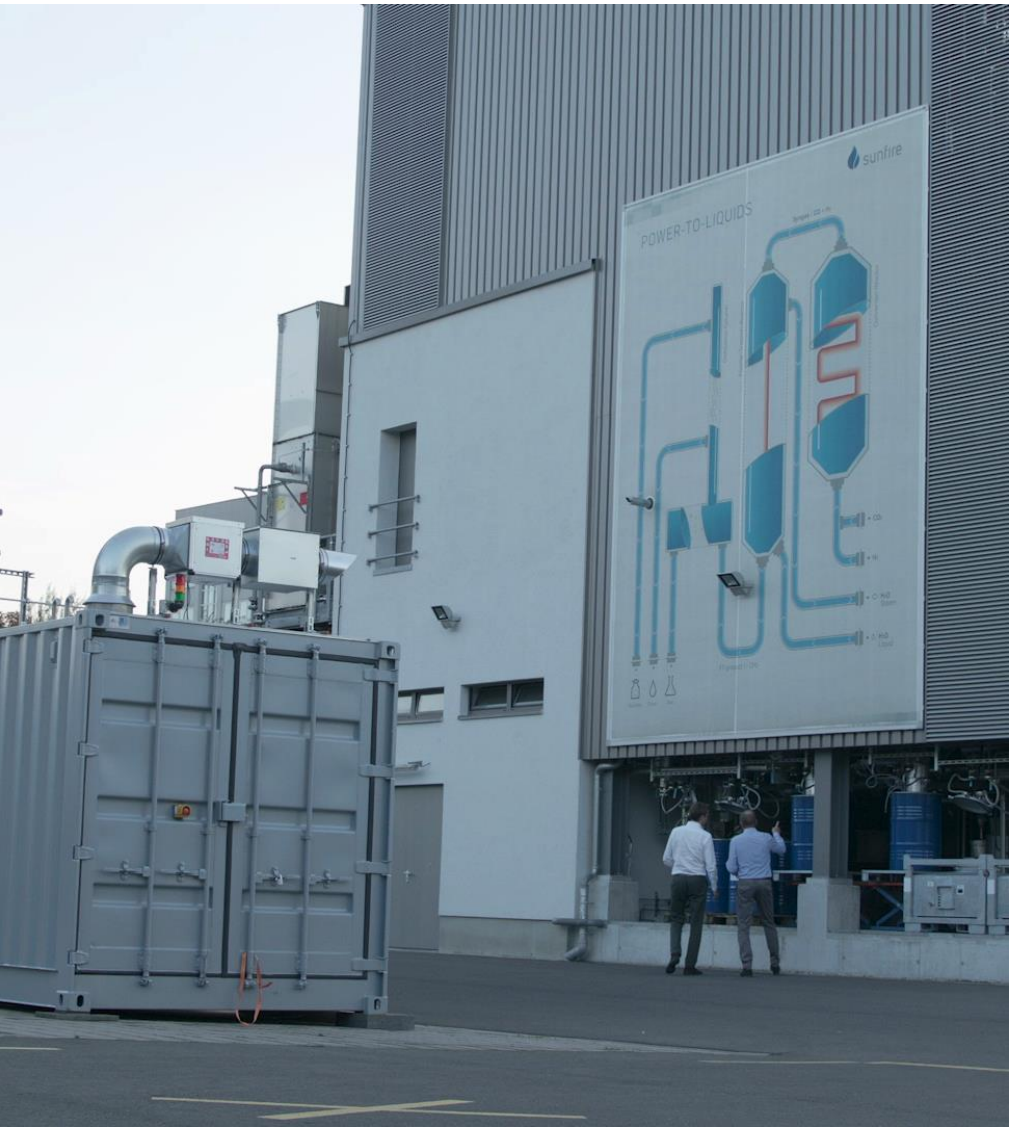
- Together with a strong consortium, Sunfire will develop the first commercial P2L plant by 2022

- Herøya industrial park offers unique advantages:
  - Low electricity prices (3.5 ct€/kWh)
  - Continuous power supply (> 8,000 h/a)

- Widespread market potential with 5-10 further potential projects in Norway



	Unit	Norsk e-Fuel *alpha*	Norsk e-Fuel *beta*
Output	Tons/a	8,000	80,000
CAPEX	M€	80	450
Installed Capacaity	MW	25	200
Targeted costs	€/Liter	< 2,00	<1,60



Sunfire P2L plant in Dresden, Germany

PROJECT STATUS

norsk e-fuel

- ✓ Norwegian development company “Norsk E-Fuels SA” founded
- ✓ Location for first installation in negotiation / alternative location available
- ✓ CO_2 and power sources available
- ✓ Equity investment secured from Norsk E-Fuels shareholders, a Norwegian bank and 2 refineries
- ✓ Guarantee from EPC partner for turnkey ready plant
- ✓ Two refineries for product upgrading and marketing
- ✓ Offtake agreements in the range of 3-4 €/liter

VIELEN DANK

Nils Aldag
Managing Director & Co-Founder

Sunfire GmbH · Gasanstaltstraße 2
01237 Dresden · Germany
www.sunfire.de

