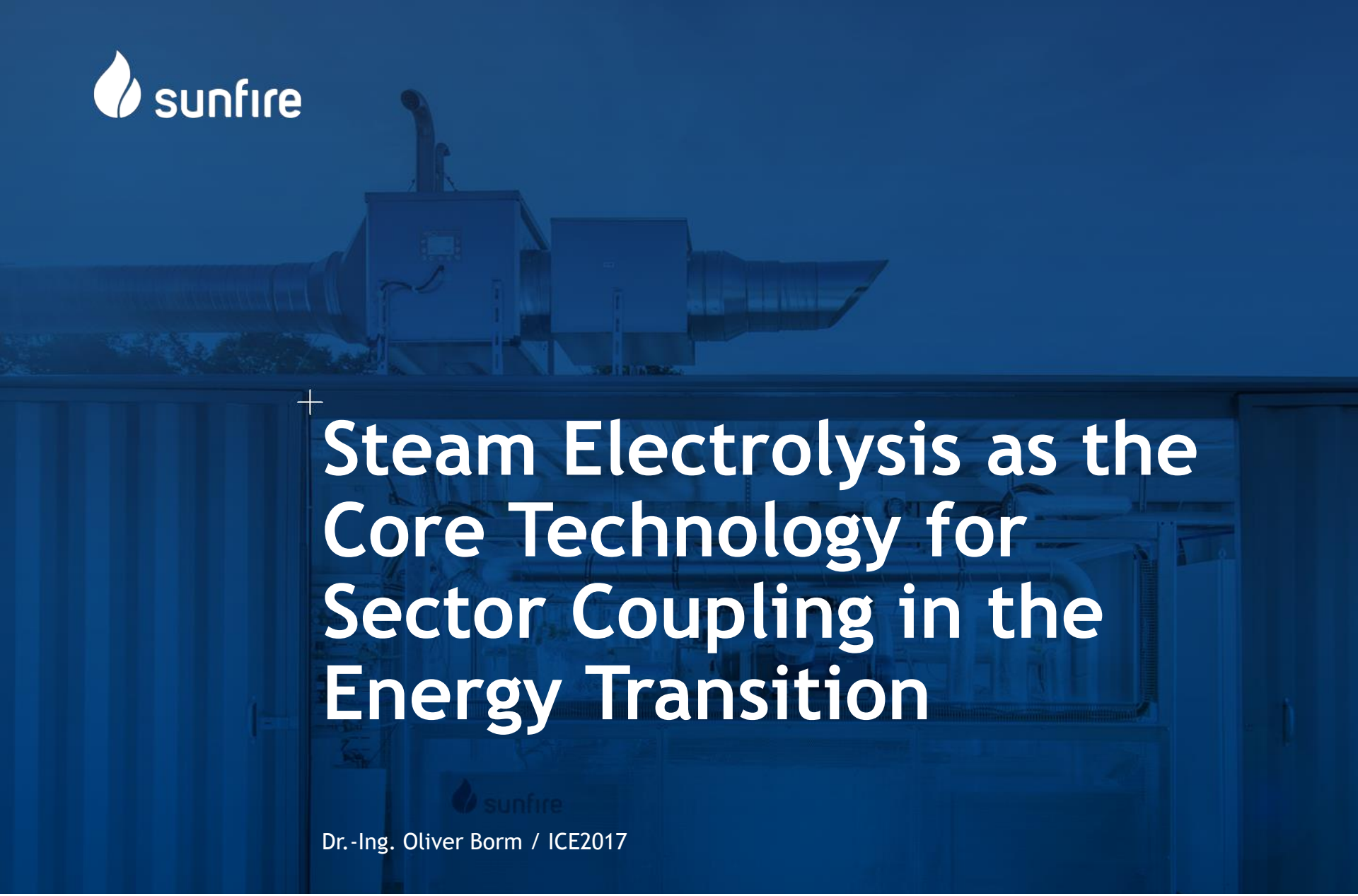


Steam Electrolysis as the Core Technology for Sector Coupling in the Energy Transition

Dr.-Ing. Oliver Borm / ICE2017

Investors

ELECTRANOVA CAPITAL

idinvest PARTNERS

INVIEIN CAPITAL CEZ GROUP

KFW

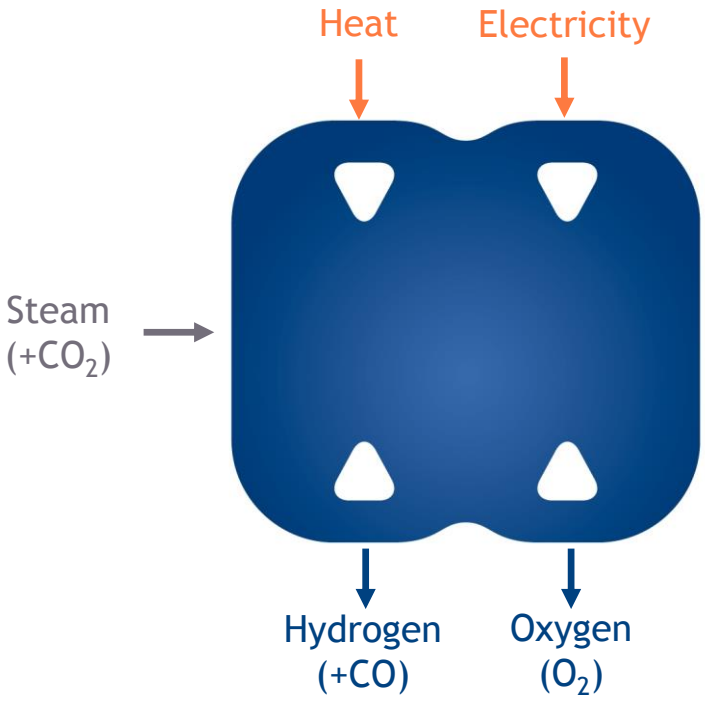
TOTAL

sunfire

Basic Information

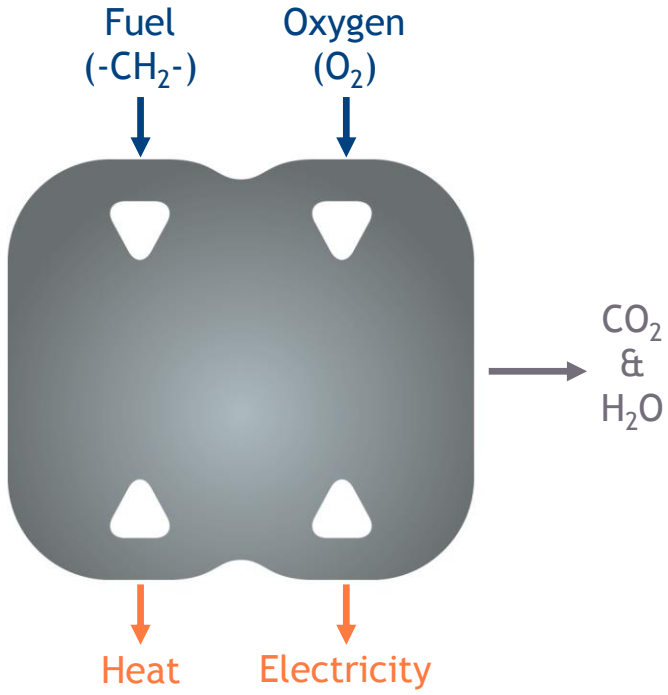
Solid Oxide Cells convert…

… electricity into **hydrogen**



Electrolysis Mode

… chemical energy into **electricity** and **heat**



Power & Heat Mode

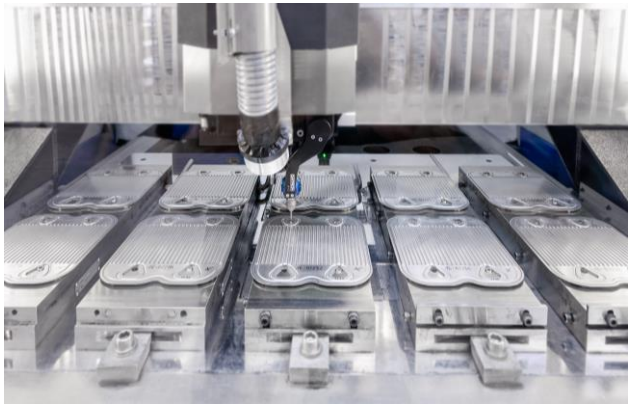
Three Core USPs

+ Highest efficiency in hydrogen production (82%$_{LHV}$ or 3.7 kWh/Nm^3) and power & heat production (35-60%$_{AC}$ and 90%$_{total}$) compared to legacy technologies such as PEM and Alkaline

+ Tolerance to carbon in electrolysis mode via co-electrolysis of CO_2 and H_2O and in fuel cell mode via internal reforming of hydrocarbons (natural gas, LPG, diesel, etc.)

+ Flexible adjustment of output from part load to full load (30%-100%) in a short timeframe

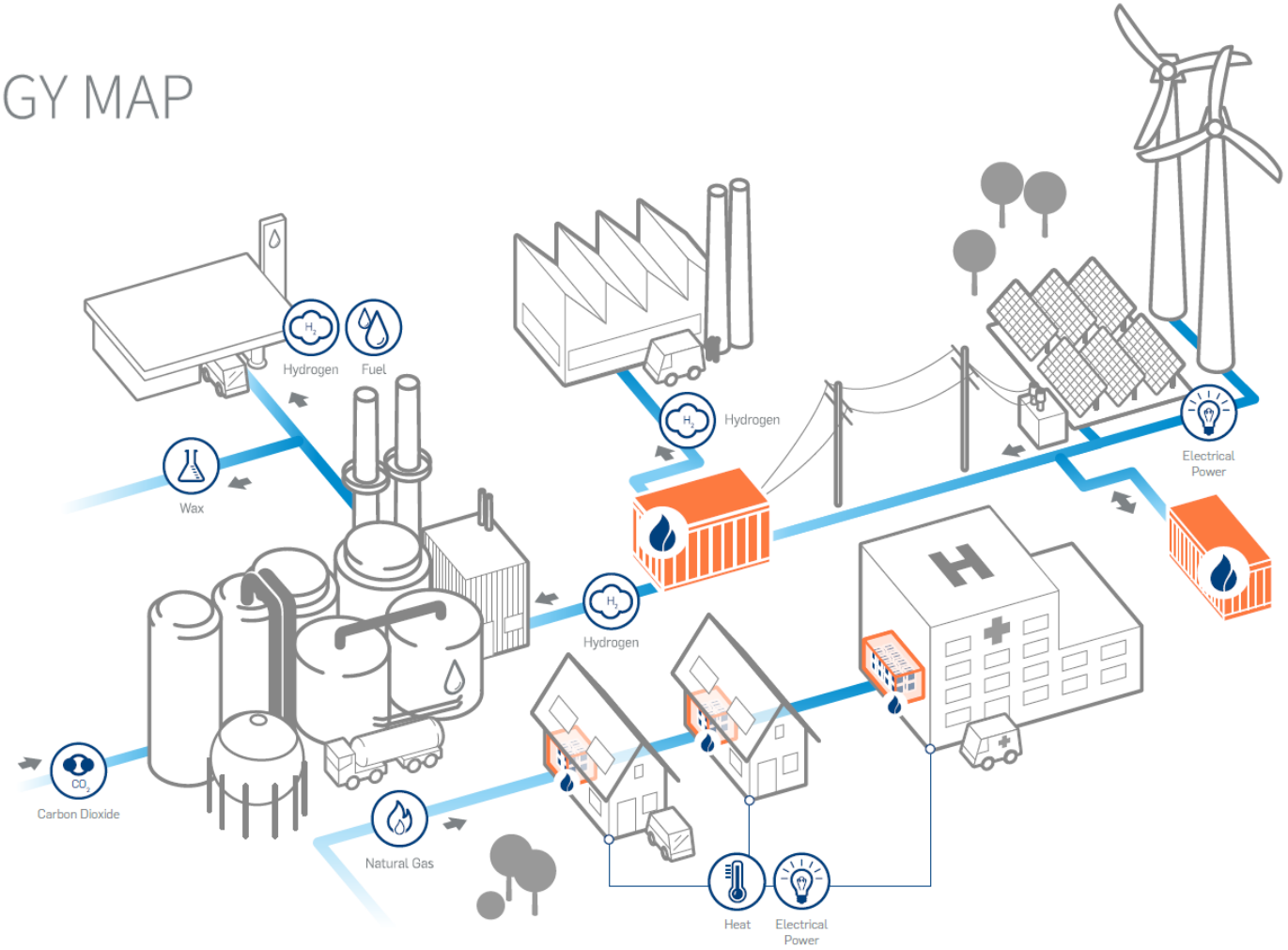
Sunfire promises low costs, high reliability and readiness to scale.



Stack Production in Dresden

System testing in Dresden

ENERGY MAP



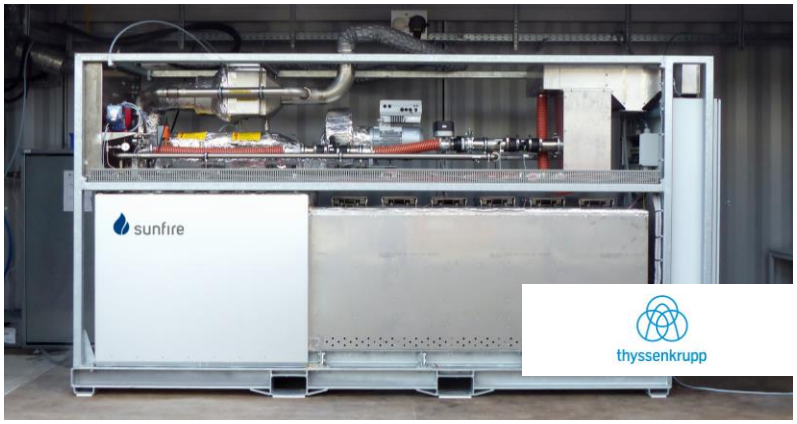
Sunfire‘s Mission

100 % “Energiewende” via sector coupling:
To bring **renewable energy everywhere** by bridging the gap between the power, mobility, chemicals and heat sectors.

One Core - Multiple Products

+ Heat and Power for Households

+ Power and Heat for Commercial Buildings



+ Power for Remote Locations

+ Fuels and Gases for Mobility + Industry

Company facts

Knowhow

- 90 Employees
- Skills in Ceramics, Stack + System Production, Engineering, Synthesis Processes, etc.

Investors

ELECTRANOVA CAPITAL
idinvest PARTNERS
INVIEIN CAPITAL CEZ GROUP
KFW
TOTAL

Patents

- 43 patent families (i.e. »process patent sunfire« WO/2008/014854)

Recognition

- EcoSummit Silver Award 2014/2015
- Cleantech 100 Company 2014/2015/2016 (only fuel cell + electrolysis company)
- Fast Company Most Innovative Company of 2016 (with Tesla and Toyota)
- German gas industry’s 2016 Innovation & Climate Protection Award

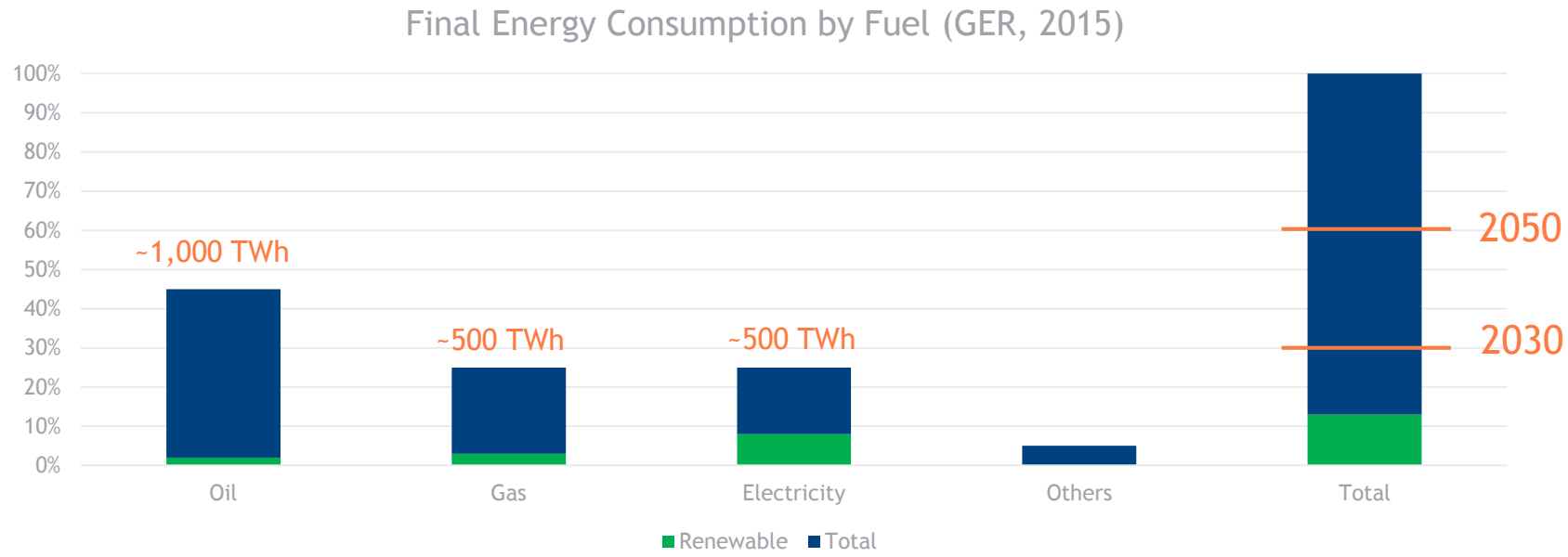
Revenues

- Multi-million Euro Revenues in Global Markets since 2011

Sectoral Integration: The Hydrogen Opportunity

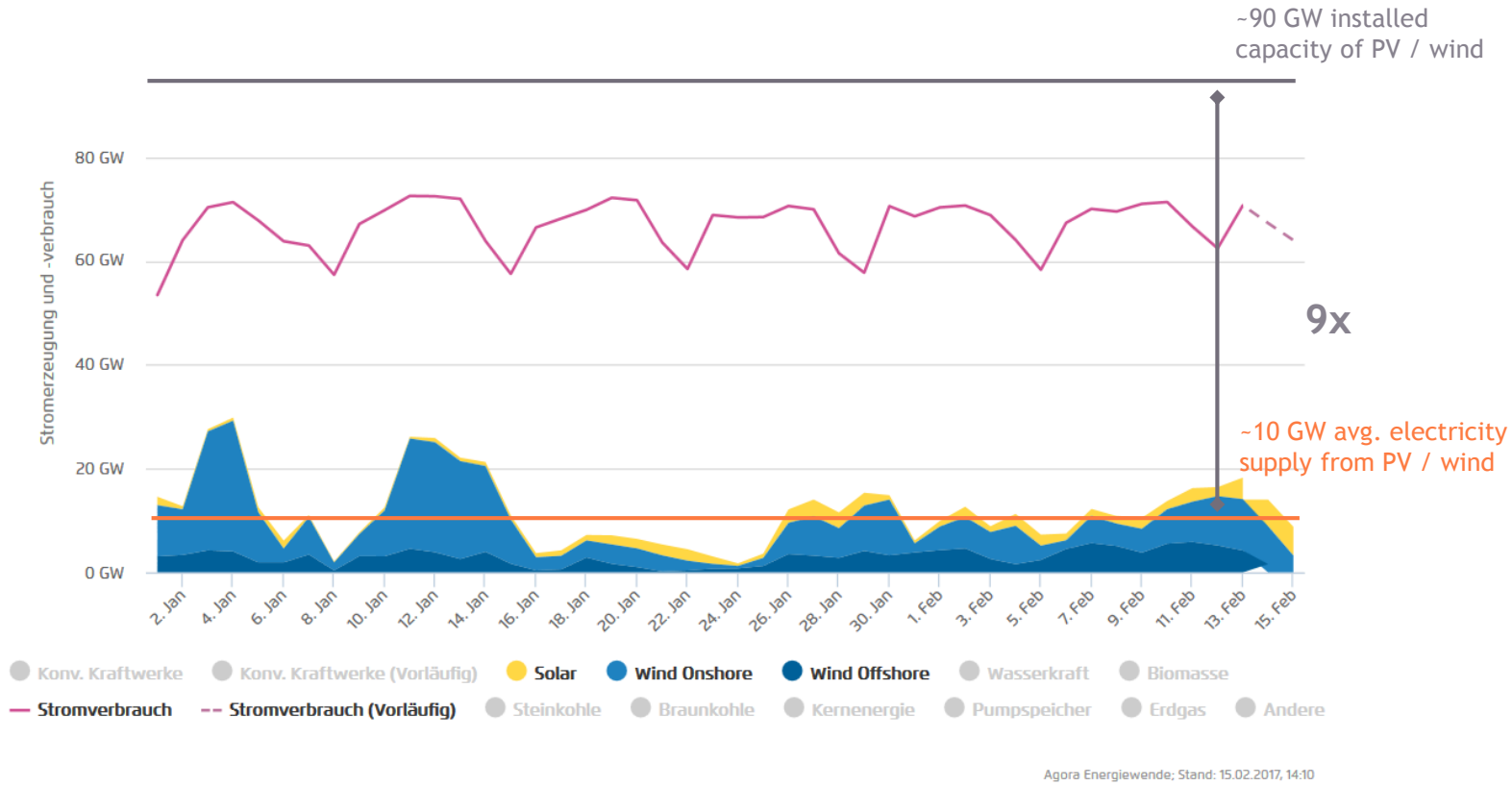
Why now?

We are lacking renewable solutions for oil and gas



- Ambitious renewable energy consumption targets: 2030 = 30% and in 2050 = 60%
- Solar and wind power are competitive with fossils, but electrical sector only 25%
- 75% of energy is used in the oil & gas sector

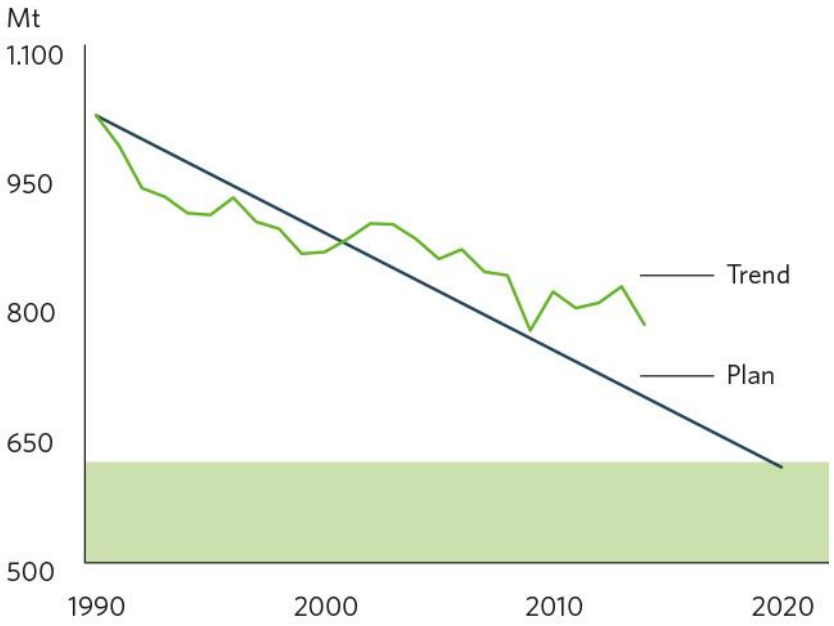
Electrification requires large overcapacities

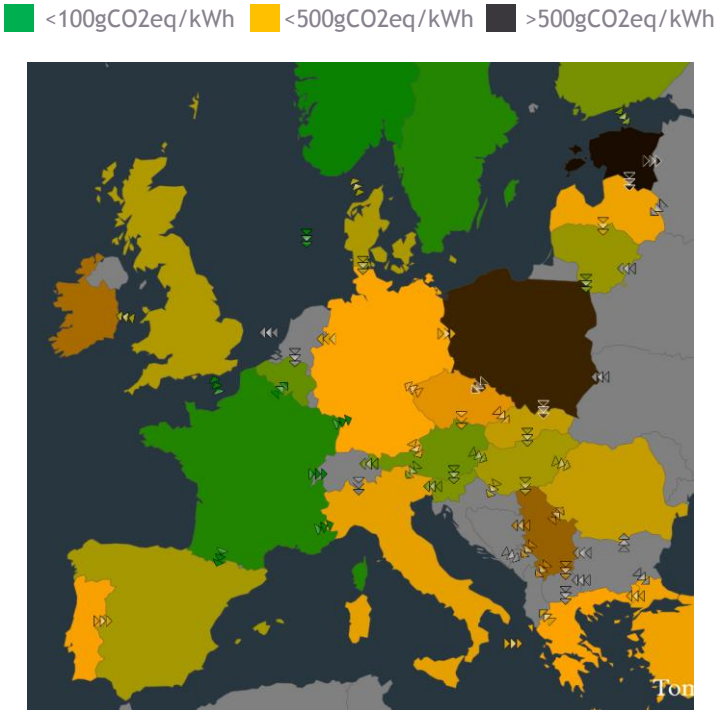


+ Solar and wind power are fluctuating and seasonal
+ A full electrification would require significant overcapacities

Source: Agora-Energiewende

W/o solutions for the o&g sector CO_2 targets will be missed

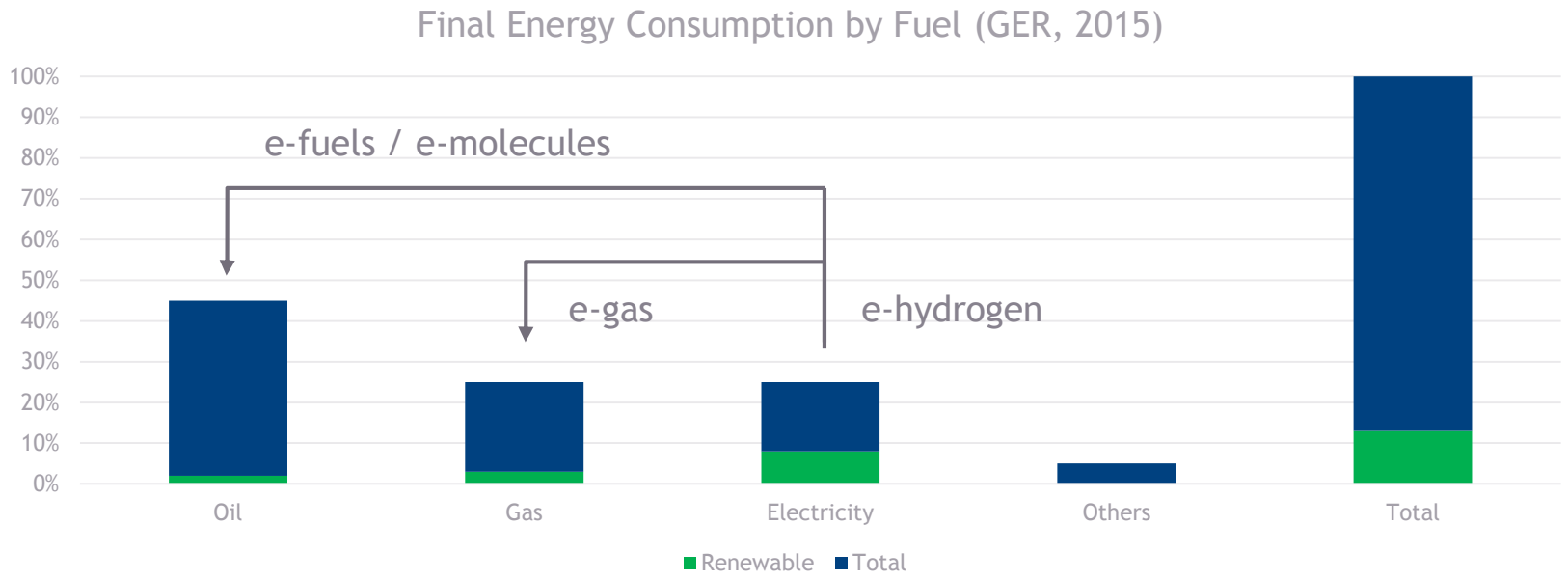




+ Germany ranks amongst most CO_2-emitting countries in Europe, despite large investments in renewable energies (>25 bn€/a)

Source: Zukunft Erdgas and www.electricitymap.org

Hydrogen is the bridge between the sectors



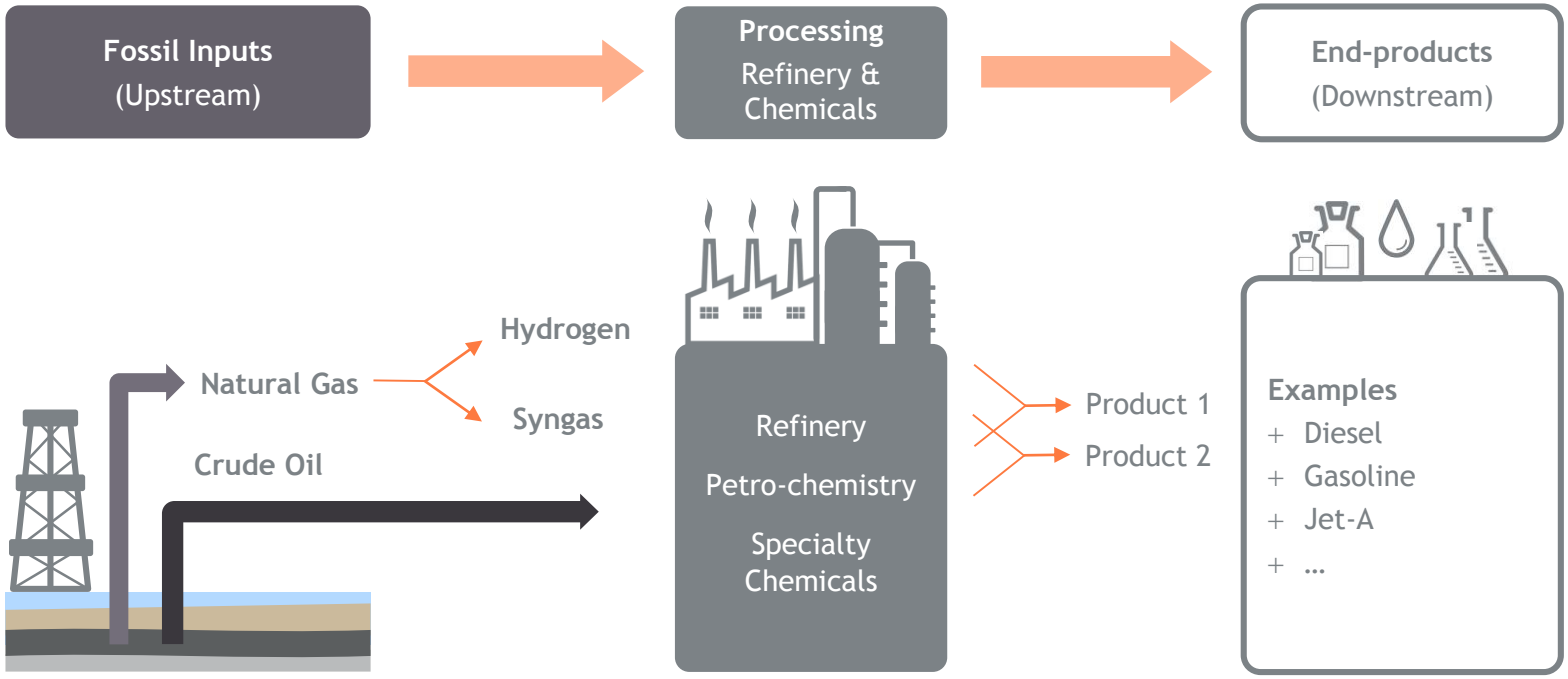
- Sectoral integration means the integration of the power sector with the oil and gas sectors via the use of hydrogen
- By purchasing renewable electricity directly from operators through Power Purchase Agreements (PPA) the share of renewable electricity production can be increased at no additional costs for the system

Sectoral Integration in practice

Where does it make most sense?

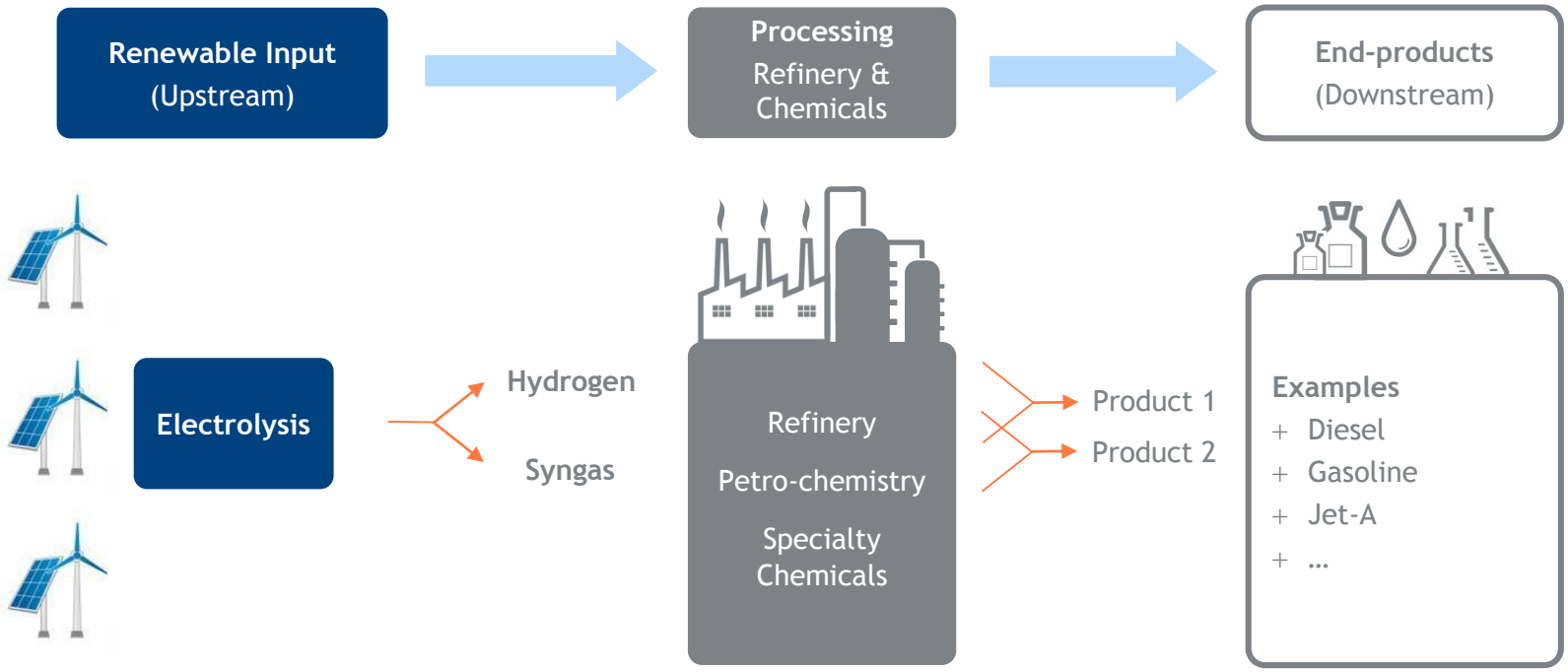
Hydrogen for refineries - the first use-case

+ Hydrogen required for the production of fuels in refineries (diesel, gasoline, etc.)
+ Only in Germany, >100.000 t/a hydrogen demand currently produced from natural gas



Hydrogen from renewable electricity to fulfill quotas

+ Fossil hydrogen can be replaced by hydrogen from renewable electricity
+ Hydrogen can already achieve “biofuel parity” → no additional costs for system
+ European market size estimated to be >10 GW of electrolysis



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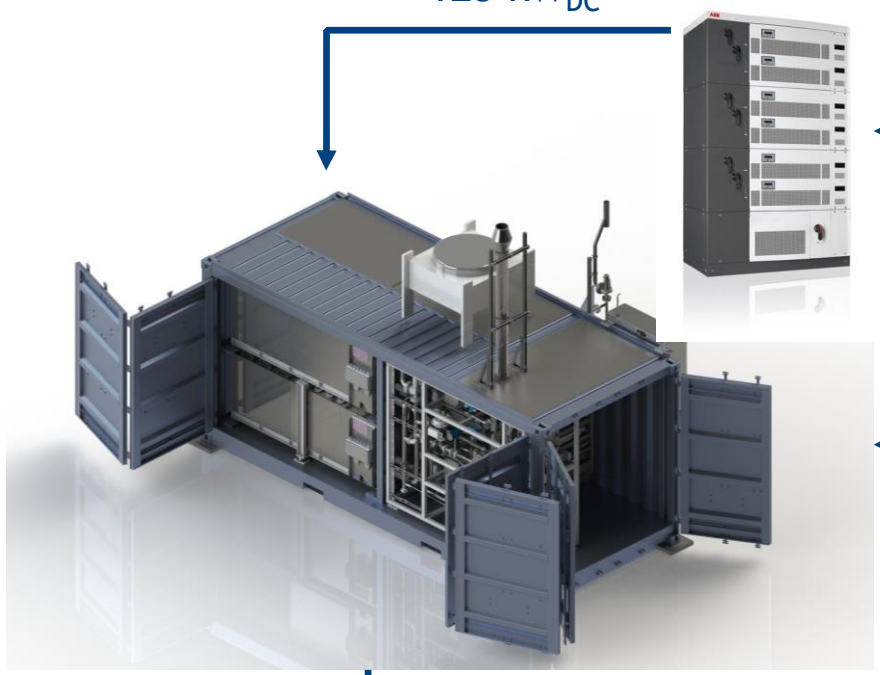
Technical Specification

Steam Electrolysis Module Performance and Interfaces

Electrical Efficiency:

Steam Electrolysis: AC → LHV 82 $\%_{LHV}$



125 kW_{DC}

132 kW_{AC}

18 kW_{AC} (BoP)

Steam 40 kg/h
@ 150°C, 3 bar(g)

H_2: 40 Nm^3/h
(3.6 kg/h; 120 kW_{LHV})

Selected Reference Projects

SALZGITTER AG
Stahl und Technologie

+ 1x 150 kW SOEC power input and 40 Nm^3/h hydrogen output
+ SOEC efficiency of >80 $\%_{LHV}$
+ Installed at an industrial steel plant
+ Meeting H_2 quality standards of steel industry

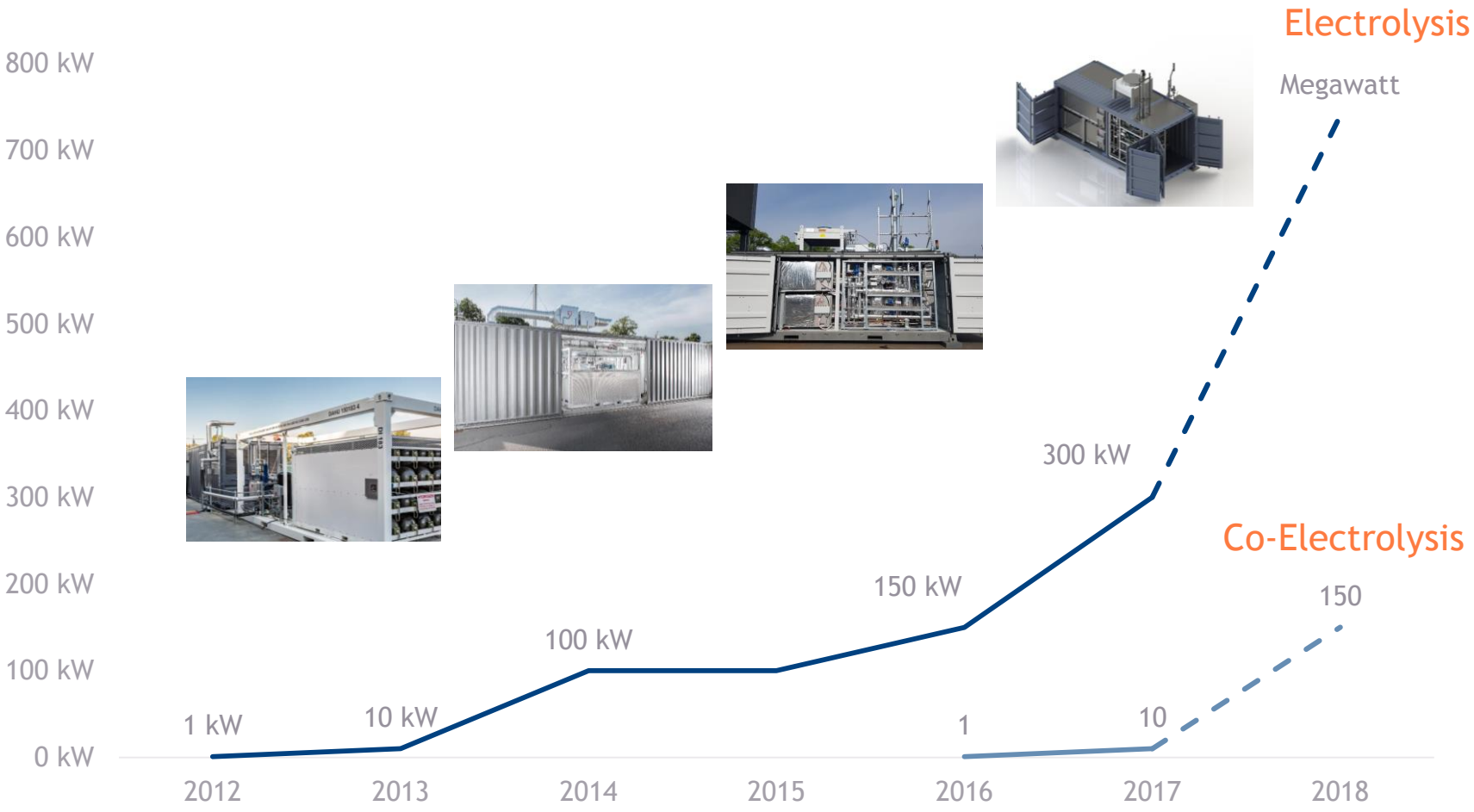
150 kW SOEC module in Salzgitter, Germany

BOEING

+ 2x 100 kW SOEC power input and 50 Nm^3/h hydrogen output
+ Reversible mode with 2x 20 kW and roundtrip efficiency of ca. 45%
+ Electricity storage for autonomous electricity supply during day and night (PV connected)

200 kW SOEC module in Los Angeles, USA

Sectorial Integration requires megawatt electrolysers



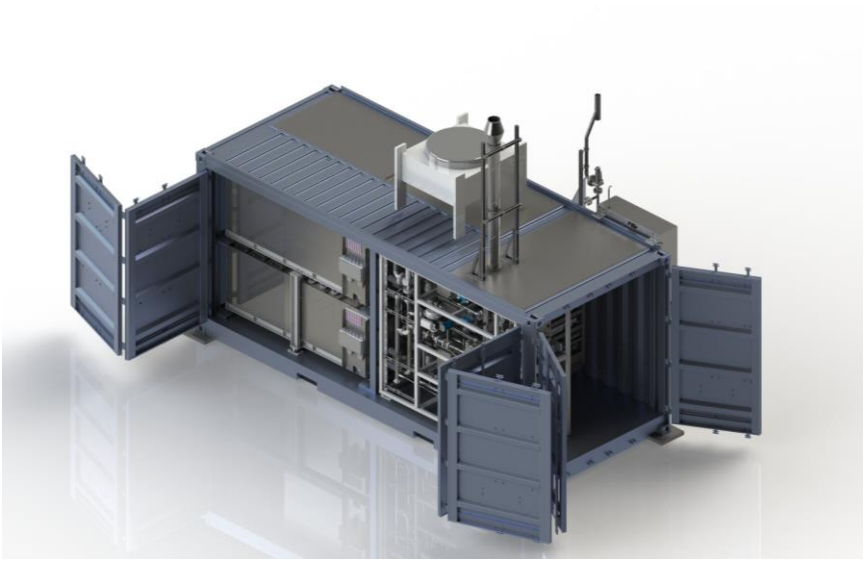
Next Generation Electrolysis

+ Modular Scaling Concept

+ SOEC Module:
  - Hydrogen output: 50 Nm^3/h
  - Electricity input: 185 kW_{AC}

+ Standard 20’ container (TEU*):
  - Up to 4 modules
  - Hydrogen output: 200 Nm^3/h
  - Electricity input: 740 kW_{AC} power

+ Hydrogen drying unit
+ Gas cooling unit



Steam Electrolysis Container (up to 4 modules) 200 Nm^3/h H_2

* TEU = Twenty Foot Equivalent Unit = 20 ft. ISO container

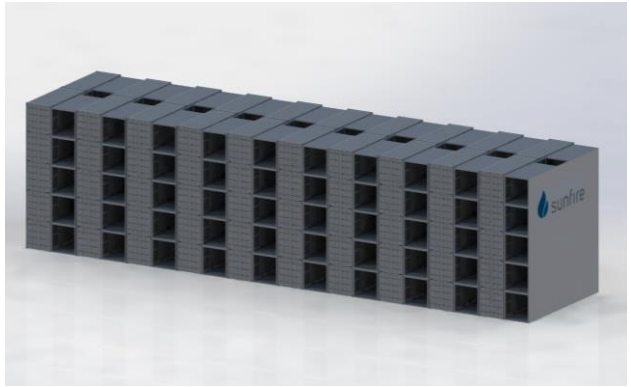
Upscaling Concept

+ SOEC Electrolysis Tower:
  - Stack up to five 20‘ container over each other for a Hydrogen output of 1,000 Nm^3/h
  - Electricity input: 3.7 MW_{AC}
  - Central Hydrogen Processing Unit
  - Footprint: 1 TEU (6.1 m x 5.0 m)

+ SOEC Electrolysis Bench:
  - Hydrogen output: 20,000 Nm^3/h
  - Electricity input: 74 MW_{AC}
  - Footprint: 2 TEU (15 m) x 10 TEU (48 m)

+ No upscaling issues due to serial production of the same reliable SOEC module
+ Incremental set-up of H_2 production capacity

1,000 Nm^3/h SOEC Electrolysis Tower



20,000 Nm^3/h SOEC Electrolysis Bench

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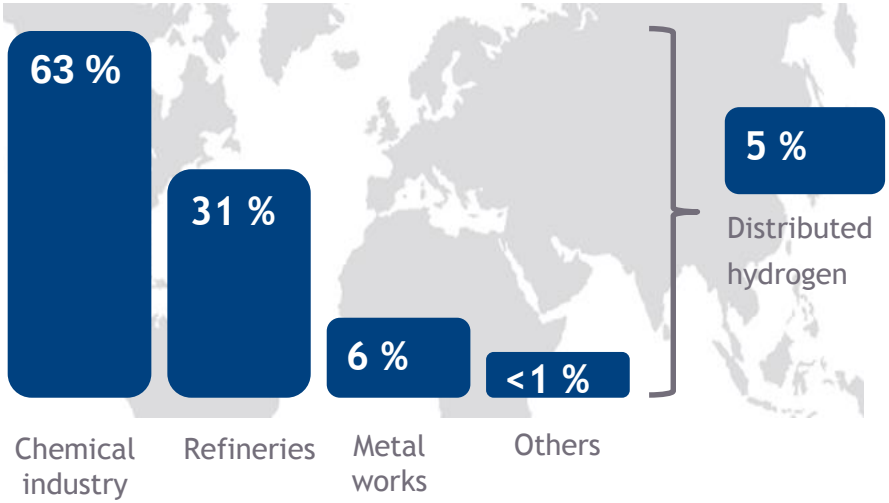
Hydrogen Market & Competition

Hydrogen Demand and Applications

- Today, fossil H2 markets in chemicals, metals and refineries
- New market potential in H_2 storage, H_2 mobility and e-fuels
- Green H_2 for Refineries and Industry threatening traditional markets of established fossil H_2 suppliers

Global Hydrogen demand
(65 Mt/a = ~2.000 TWh/a)



Electrolysis hydrogen has a significant potential in chemical industries (1200 TWh/a) and refineries (600 TWh/a).

Technologies for Renewable Hydrogen Production

2020 scenario	Efficiency in $\%_{LHV}$ (kWh/Nm^3)	Costs in €/kW (€/kW divided by η)	Advantages
Alkaline	63 (4.8)	800 (1,270)	Reliable, Robust
PEM	65 (4.7)	1,000 (1,540)	Flexible
SOEC	**82 (3.7)**	**1,500 (1,830)**	**Efficient, Reversible**

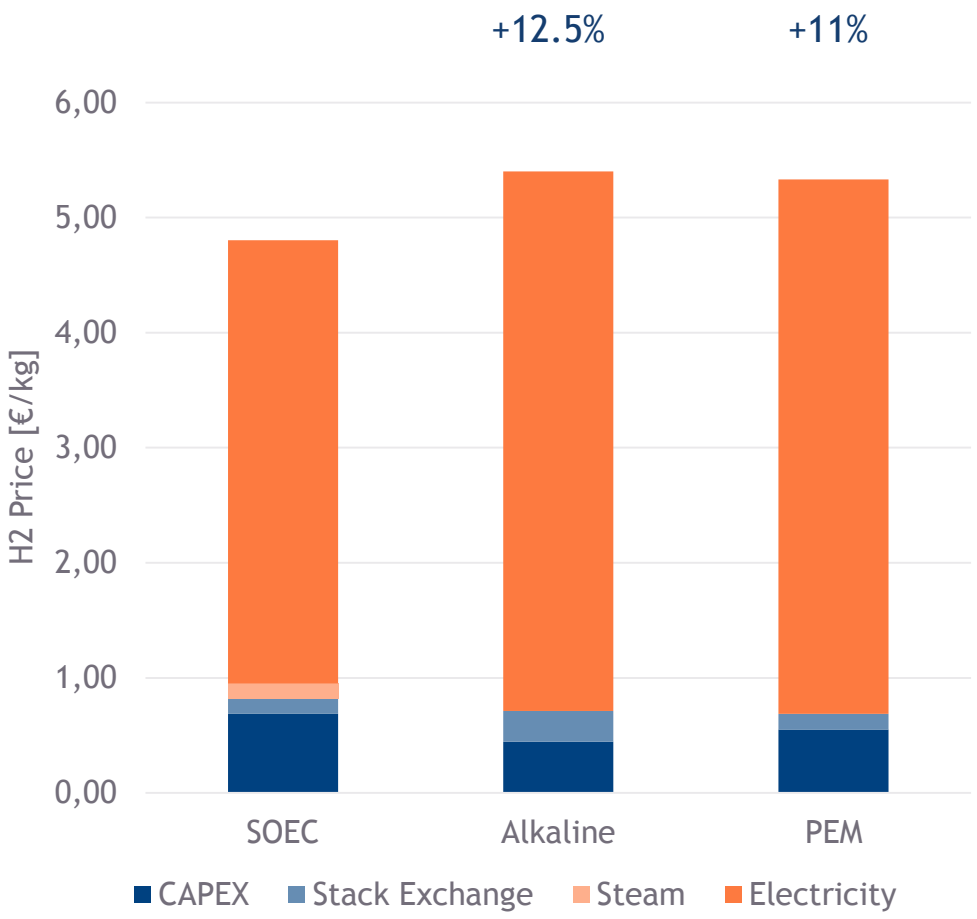
- Sunfire reaches highest efficiencies when using low-grade steam / heat
- Efficiency reduces energy costs (low OPEX) and required electrolysis capacity to produce the same hydrogen output as less efficient products (reduced CAPEX)
- This results in cost-competitive and affordable renewable hydrogen

- Additionally, Sunfire's SOEC has CO-electrolysis potential

H_2 Cost Comparison SOEC, Alkaline, PEM

Assumptions (2020 scenario):

- Electricity Costs: 80 €/MWh
- Capacity Factor: 60 % (~5,000 full load hours)
- IRR 9 %
- Sunfire electrolysis (SOEC) enables lowest costs compared to legacy technologies



THANK YOU FOR YOUR INTEREST!

ENERGY
EVERYWHERE

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