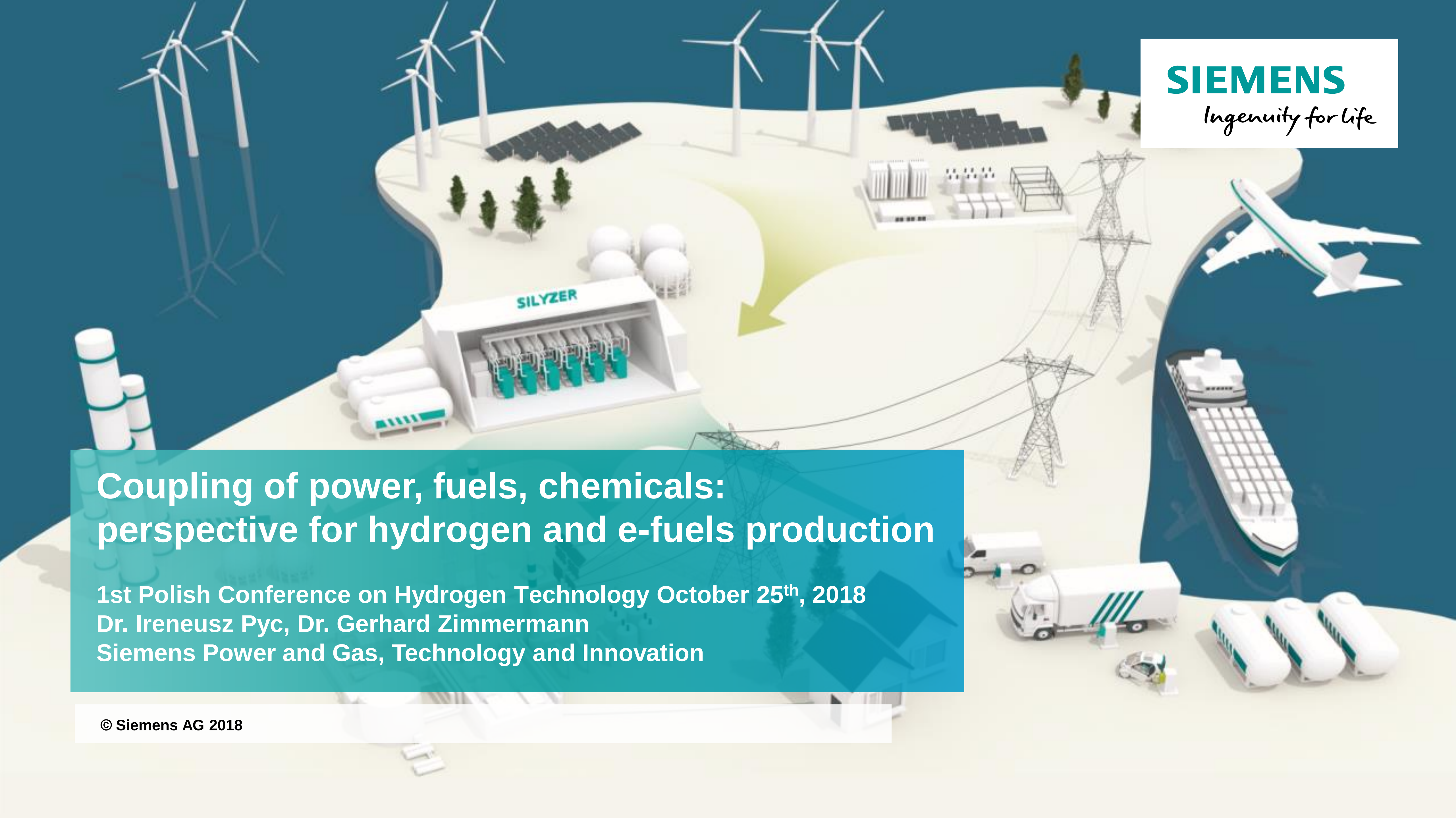

Coupling of power, fuels, chemicals: perspective for hydrogen and e-fuels production

1st Polish Conference on Hydrogen Technology October 25th, 2018

Dr. Ireneusz Pyc, Dr. Gerhard Zimmermann
Siemens Power and Gas, Technology and Innovation

De-fossilization of energy sector
Focus on power generation sector alone is not enough

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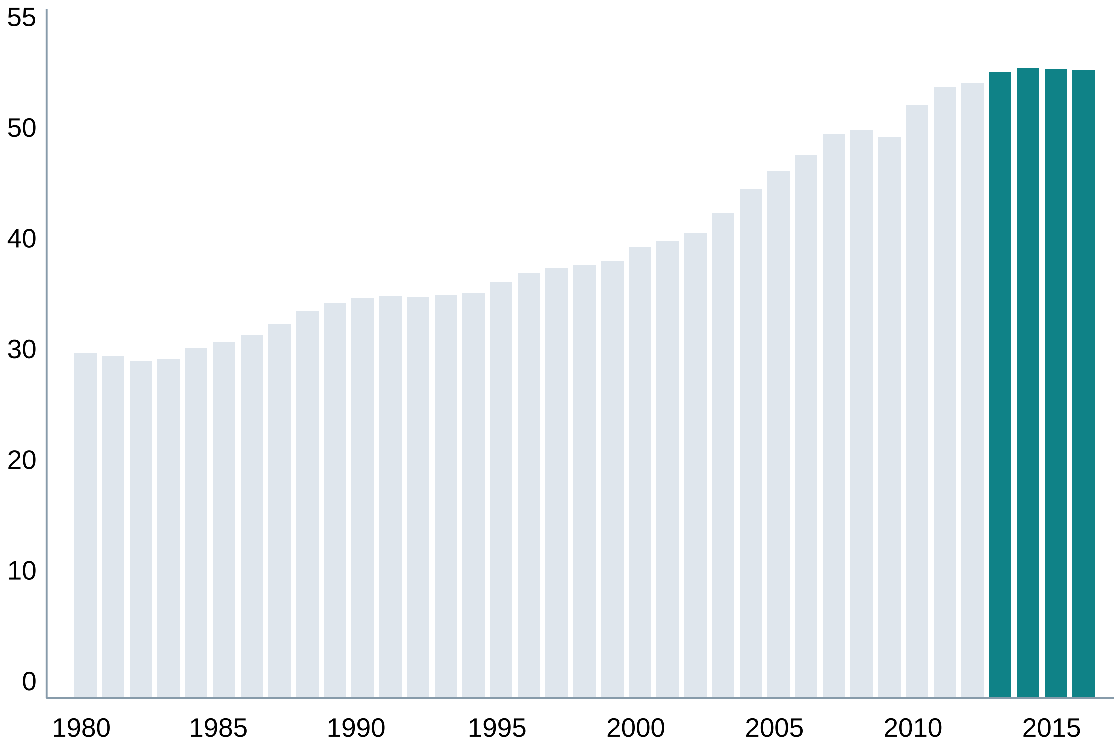
Global CO_2 (eq.) emissions 1980 – 2016
bn tons per year



Source: IEA ETP

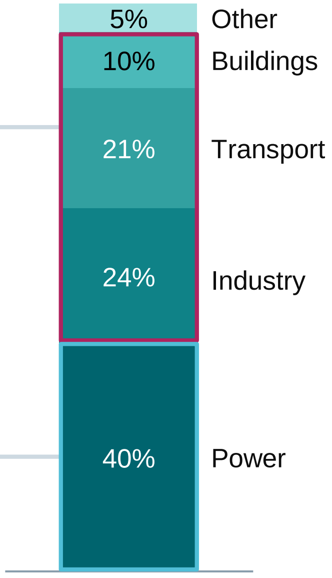
Global CO_2 emissions share by sectors

- Share on CO_2 emissions: **55%**
- Share of Renewables: **8%**

Mostly disregarded till now

- Share on CO_2 emissions: **40%**
- Share of Renewables: **22%**

Main focus so far



De-fossilization of power sector is not sufficient. Sectors such as industry, transport and buildings that account for up to 55% of total CO_2 emissions have seen only low levels of renewable penetration

Sector coupling
a key lever for energy system transformation

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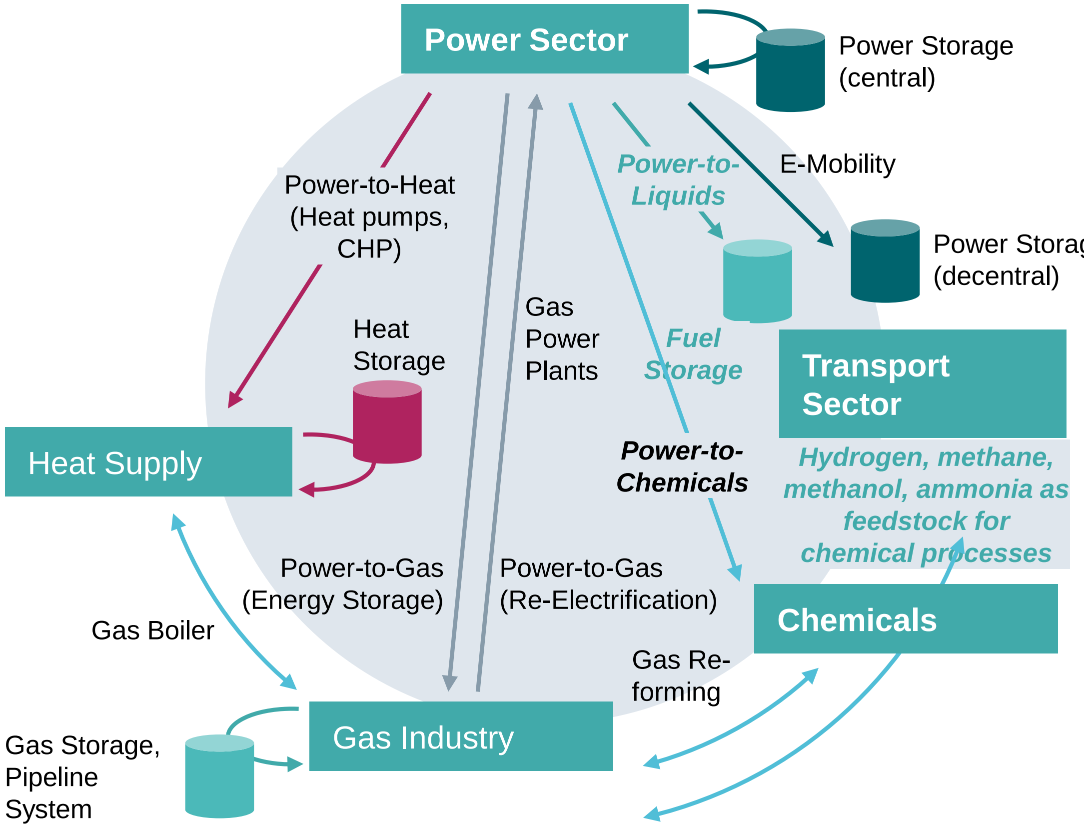
Sector Coupling – Links and Interactions



Source: Based on FENES (OTH Regensburg)

Sector Coupling

Definition

- Link between power sector and energy-consuming sectors

Value Proposition

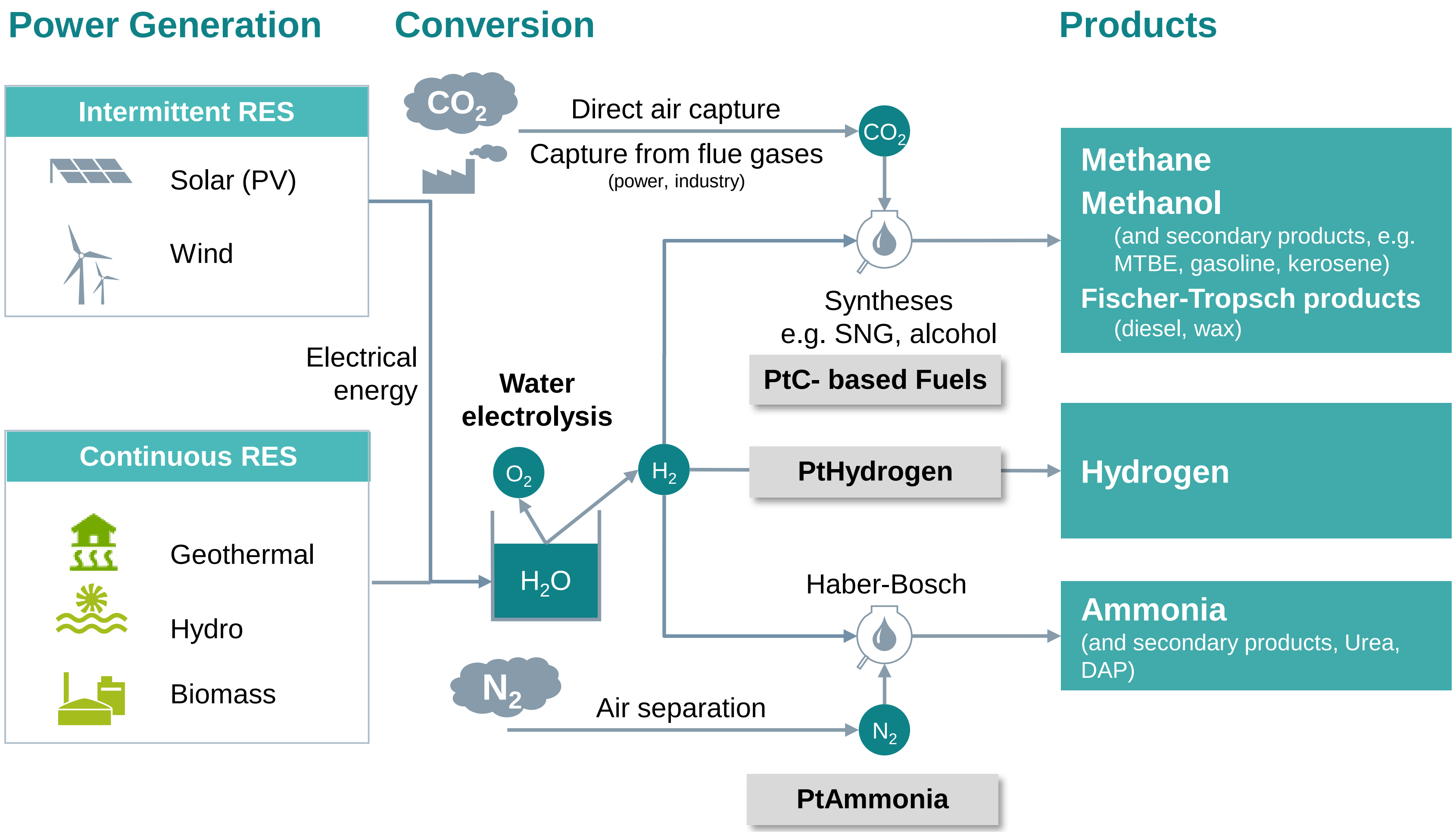
- Improvement of overall energy efficiency
- Contribution to defossilization of the energy sector
- Supports supply / load balancing (>high share of intermittent renewable generation)
- More diverse and interdependent energy supply

Drivers

- Reduction of green house gas emissions
- Reduction of energy import dependency
- Technological progress (e.g. e-mobility, battery, electrolysis)

From clean power to clean product

Hydrogen opens up multiple entries to the energy- and chemical sectors



Use- and business cases

- Carbon-neutral fuels - mobility, heat
- Chemical feedstock
- Re-electrification (long-term storage)

- Direct use for mobility (fuel cell)
- chemical feedstock (refinery), separate case, not considered
- Direct use: Re-electrification (long-term storage (turbines, engines)

- Fertilizer
- Chemical feedstock
- As carrier for hydrogen or direct use for energy

Proton Exchange Membrane (PEM) electrolysis
Key technology and efficient way to produce green hydrogen

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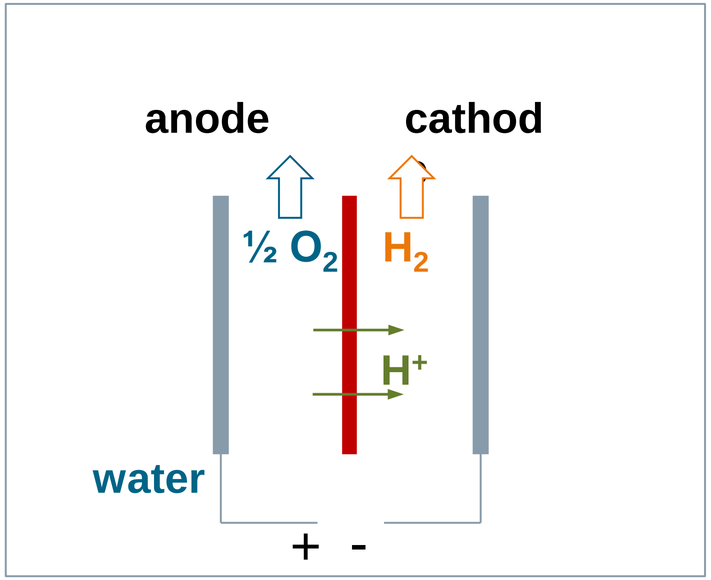
PEM principle



1973: J.H Russel released his works on PEM electrolysis

How does PEM electrolysis work ?

- Electrodes are attached on both sides of the proton exchange membrane (PEM)
- Proton exchange membrane
  - is electrolyte
  - Acts as separator to prevent mixing of the gas products

Advantages of PEM electrolysis

- Dynamic flexibility in coupling to wind-, PV- plants
  - High dynamics (ramps)
  - cold start capability with fast start-up and shut-down
- High efficiency
- High H2 - purity
- Low O&M costs
- Pressurized operation (Sylizer 200: 35 bar)
- High power density and small footprint

Silyzer 200
High-pressure efficiency in the megawatt range

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5 MW

World's largest operating PEM electrolyzer system in Hamburg, Germany

60 kWh

Specific energy consumption for 1 kg hydrogen

20 kg

Hydrogen production per hour

1.25 MW

Rated stack capacity

Silyzer 300
the next paradigm in PEM electrolysis

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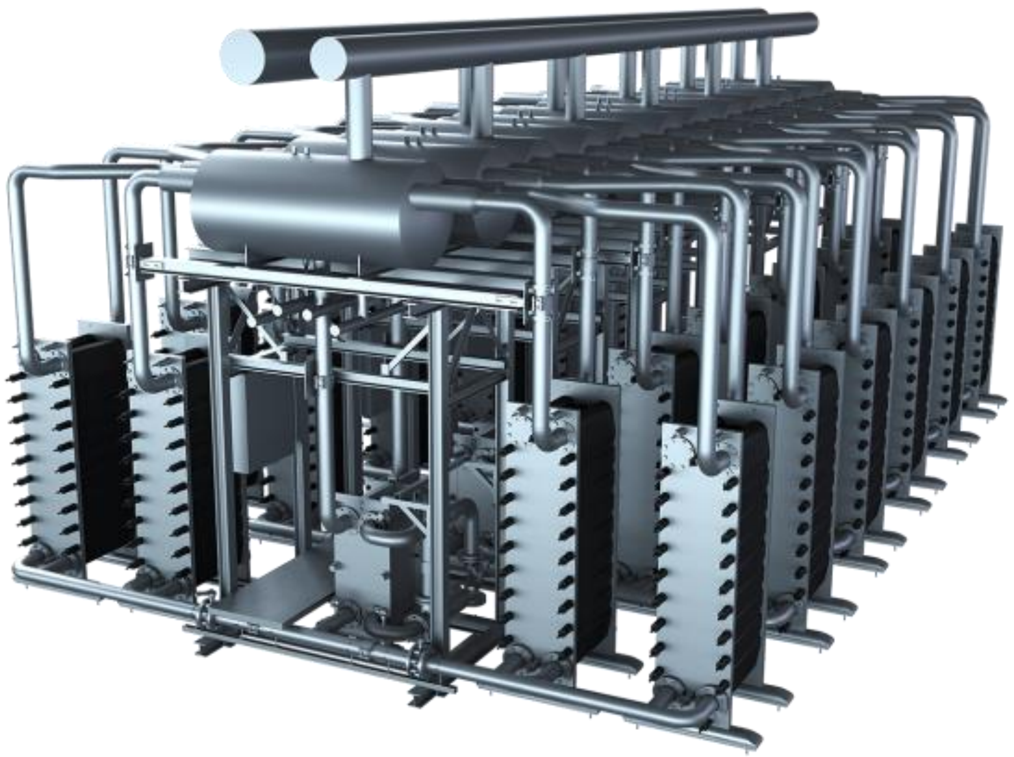
17.5 MW	per full Module Array (24 modules)
75 %	System efficiency (higher heating value)
24 modules	to build a full Module Array
340 kg	hydrogen per hour per full Module Array (24 modules)



Silyzer 300 – Module Array (24 modules)

Silyzer portfolio scales up by factor 10 every 4-5 years
driven by market demand and co-developed with our customers

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Silyzer portfolio roadmap

0,1 MW — 1 MW — 10 MW — 100 MW — 1000 MW

2011

Silyzer 100
Lab-scale demo
~4.500 op.h[1]
~150k Nm³ of H_2

2015

Silyzer 200
~24.000 op.h
~2.8 mio Nm³ of H_2

World's largest Power-to-Gas plants with PEM electrolyzers in 2015 and 2017 built by Siemens!

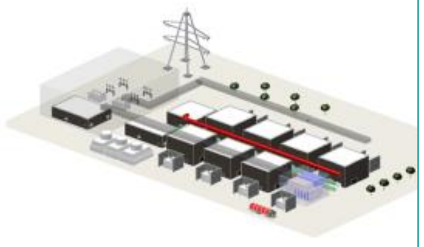
2018

Silyzer 300

Biggest PEM cell in the world built by Siemens!

2023+

Next generation
Under development



2030+

First investigations in cooperation with chemical industry

1) op.h.: operating hours

We have references for our Silyzer portfolio in all applications

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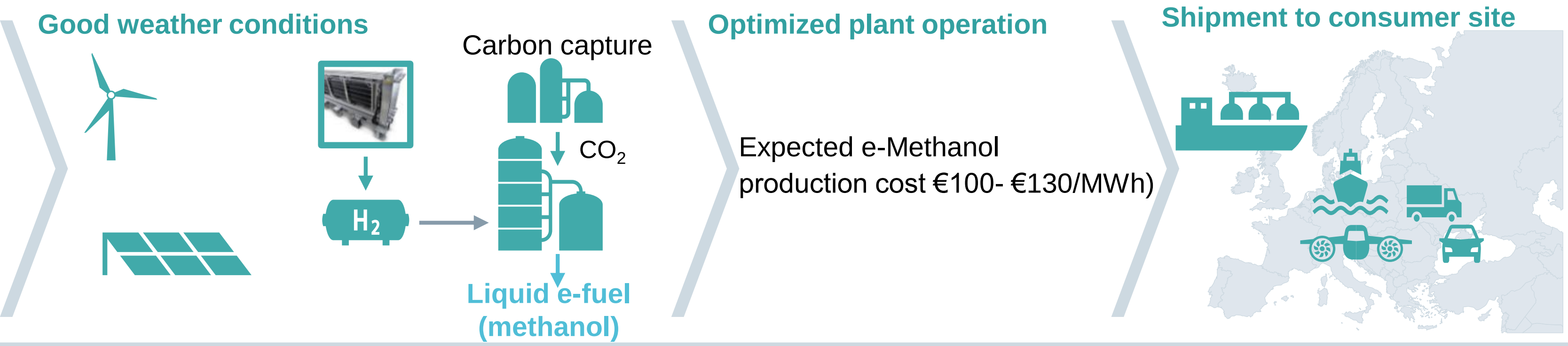
Year	Country	Project	Customer	Power demand	Product offering
2015	Switzerland	Energy System Integration Platform	Paul Scherrer Institut	100 kW / 200 kW (peak)	Container solution
2015	Germany	Argon purification/ Use of H_2 for HRS	Air Liquide, Duisburg	300 kW	Container solution
2016	Germany	Energy Lab 2.0	Karlsruhe Institute of Technology	300 kW	Container solution
2015	Germany	Energiepark Mainz	Municipality of Mainz	3.8 MW / 6 MW (peak)	Pilot Silyzer 200
2016	Germany	Wind Gas Haßfurt	Municipality of Haßfurt Greenpeace Energy	1.25 MW	Silyzer 200
2017	Germany	H&R	H&R Ölwerke Schindler GmbH	5 MW	Silyzer 200
2018	Austria	H2Future[1]	voestalpine, Verbund, Austrian Power Grid (APG)	6 MW	Pilot Silyzer 300

[1] This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735503. This Joint Undertaking receives support from the European Union‘s Horizon 2020 research and innovative program and Hydrogen Europe and NERGHY.

Going a step further: from H2 to e-fuels and chemicals
…in mobility, transportation and chemical industry

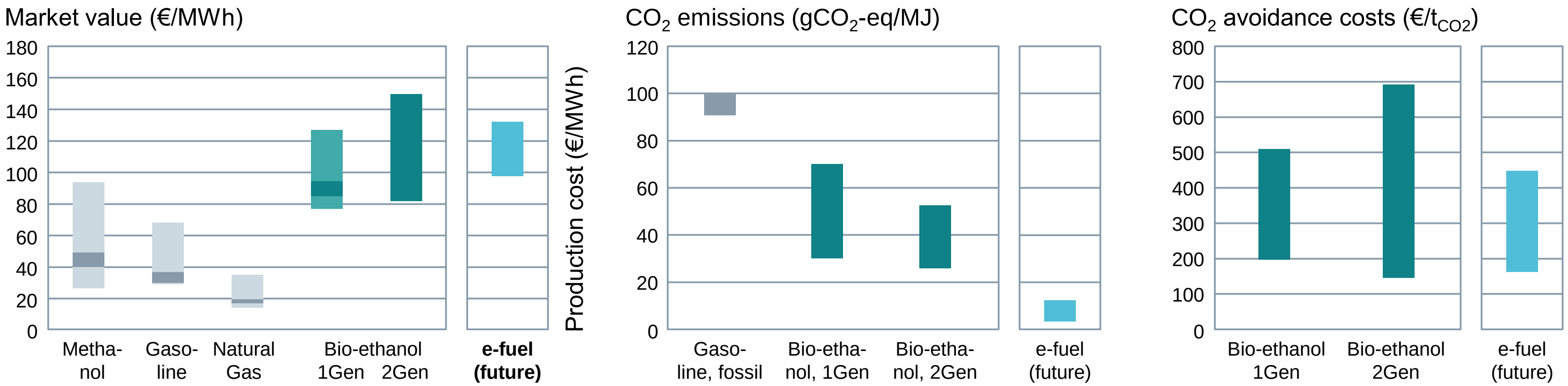
Pre-feasibility studies for e-methanol, conditions ~ 2025

- CO_2 capture
- Today to mid-term: from industrial sources
- Long-term: from the air



Economic viability

- E-fuel production cost clearly above market value of fossil fuels
- Production cost decrease due to decreasing CAPEX of renewables and electrolysis
- E-fuel with ~ 90% lower carbon footprint compared to fossil fuels
- E-fuel has the potential to outperform biofuels in terms of
  - production costs
  - CO_2 avoidance cost
  - food / fuel debate



E-fuels: comparative economics of e-methanol
are strongly related to electricity costs for hydrogen production

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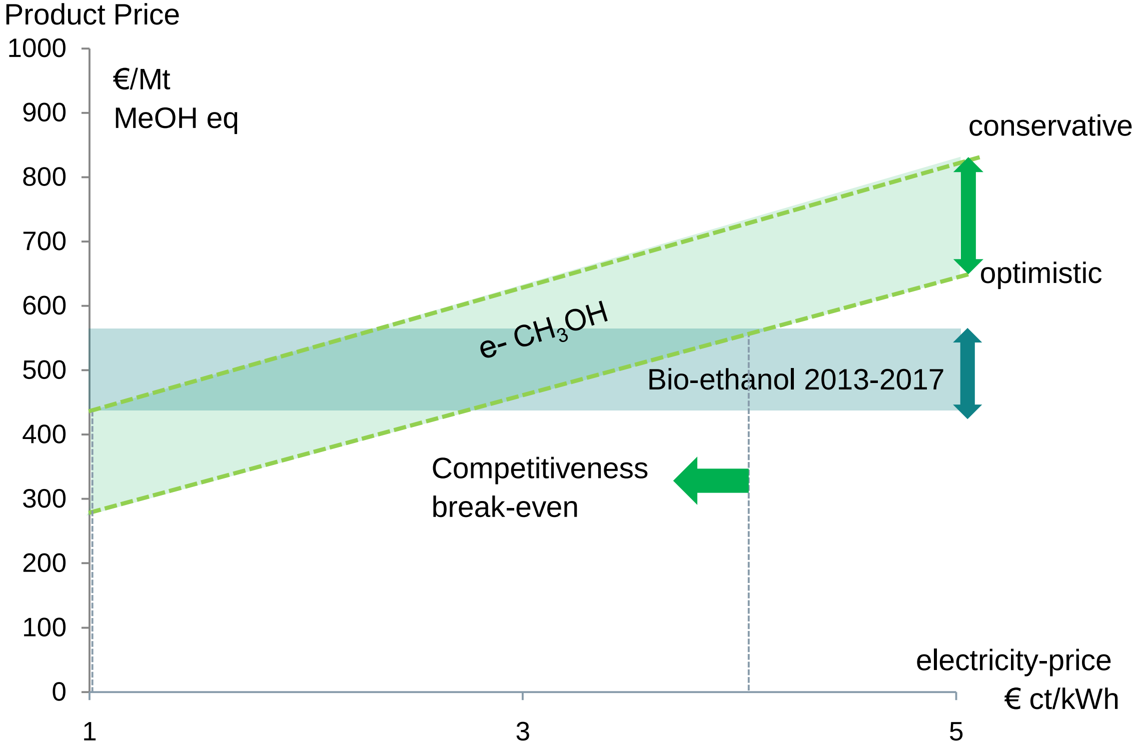
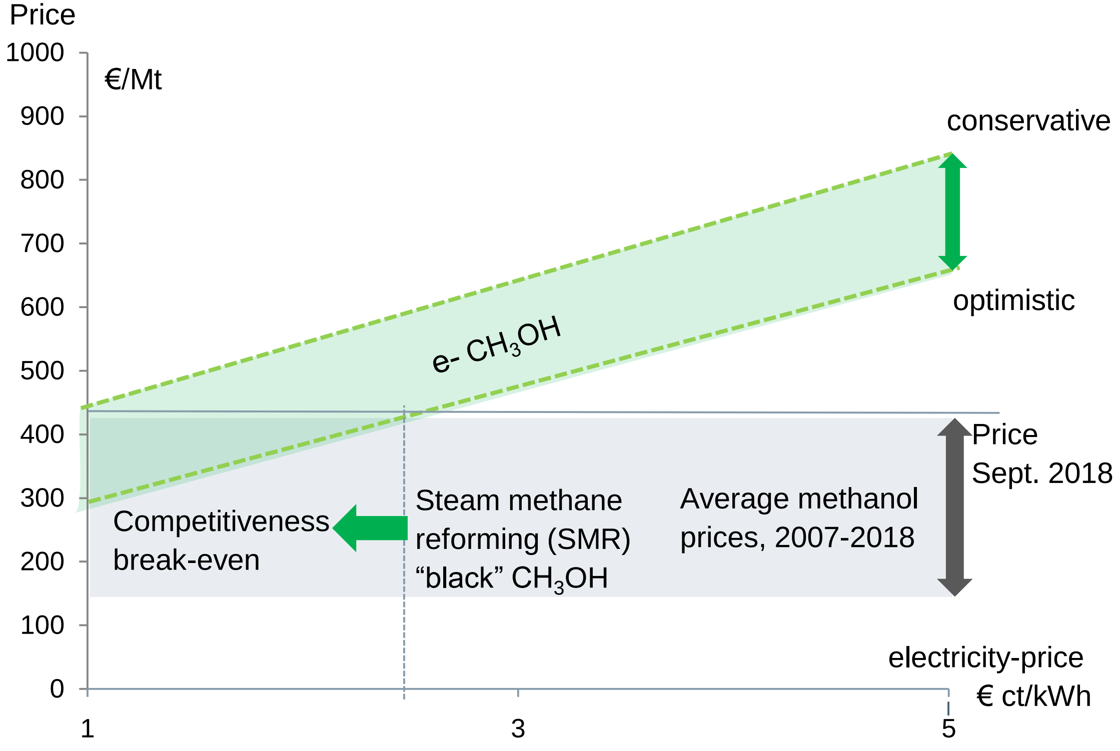
Green-methanol can compete against bio-ethanol at electricity prices less than 30-40 €/MWh



Green-methanol can compete against "black"-methanol only at extremely low electricity costs



Bio-ethanol prices: 2013-2017, Nymex, FoB

1€=1,2 $

Methanol-Prices: black (SMR) methanol : delivery to N-Europe in 2017 IHS, Oct. 2017 , Price in March 2018: Methanex, short - term price peaks excluded

Windgas Haßfurt
First power-to-gas plant in Germany in 2016

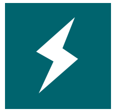
1.25 MW

rated power based on Silyzer 200

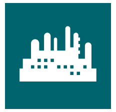
Facts & figures

- Customer: Windgas Haßfurt
- Country: Germany
- Installed: 2016
- Product: Silyzer 200

Use cases



Green hydrogen is fed into the local gas network.



Hydrogen is added to natural gas for a malthouse.

Challenge

- Installation and integration into an existing setting at Stadtwerke Haßfurt GmbH
- Supply of a complete solution (water processing, drying, storage and feeding into the gas network)
- Remote control of plants harmonized with electricity costs

Solutions

- Operation of a SILYZER 200
- Highly dynamic power consumption
- State-of-the-art process control technology based on SIMATIC PCS 7

Siemens started an engagement in e-fuels
BMWi-funded R&D project "E2Fuels“ started in Oct. 2018

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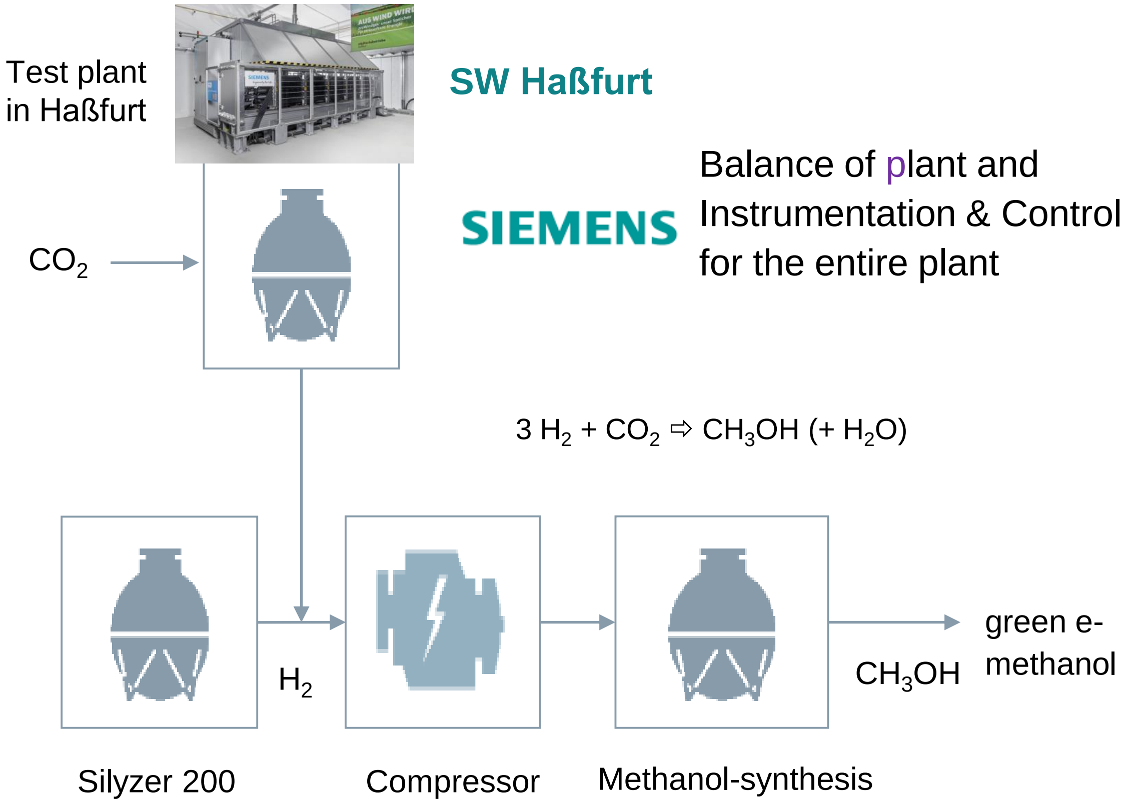
Project Structure and Partners

stadtwerk haßfurt	**SW Haßfurt**	Infrastructure site preparation
MAN	**MAN Deggendorf**	Reactor, design, erection, testing
FAU Friedrich-Alexander Universität Erlangen-Nürnberg	**FAU Erlangen**	Scientific support for innovative CO_2 based methanol synthesis
TUM Technische Universität München	**TU München**	Project coordination, system analyses,
Bundesministerium für Wirtschaft und Energie, PtJ		Funding, project coordination

Process Concept



E2Fuels: Erneuerbare Emissionsarme Kraftstoffe - Forschung zur Herstellung und Nutzung in einem sektorgekoppelten Ansatz
BWMi: Federal ministry for Economic Affairs and Energy (funding), PtJ: Projektträger Jülich (executing organization)

Summary

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1 Defossilization of energy supply is a must. Historical focus on power generation sector alone is not enough

2 Sector coupling is a key lever for energy system transformation

3 Hydrogen is one of key elements of sector coupling, it opens up multiple entries to the energy sector

4 PEM electrolysis fits to PV- and wind power use and is an efficient way to produce green hydrogen

5 PEM electrolysis scales up by factor 10 every 4 – 5 years

6 H2 based e-fuels are vital defossilization-elements for road transportation, marine and aviation

7 Comparative economics of “green”– e-methanol are related to electricity costs for hydrogen production

8 "E2Fuels" demonstration and test plant in Haßfurt is a starting point for Siemens engagement in e-fuels

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