Hydrogen & e-fuels
energy systems, technology, and projects

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Agenda

Watch where the money goes and why!

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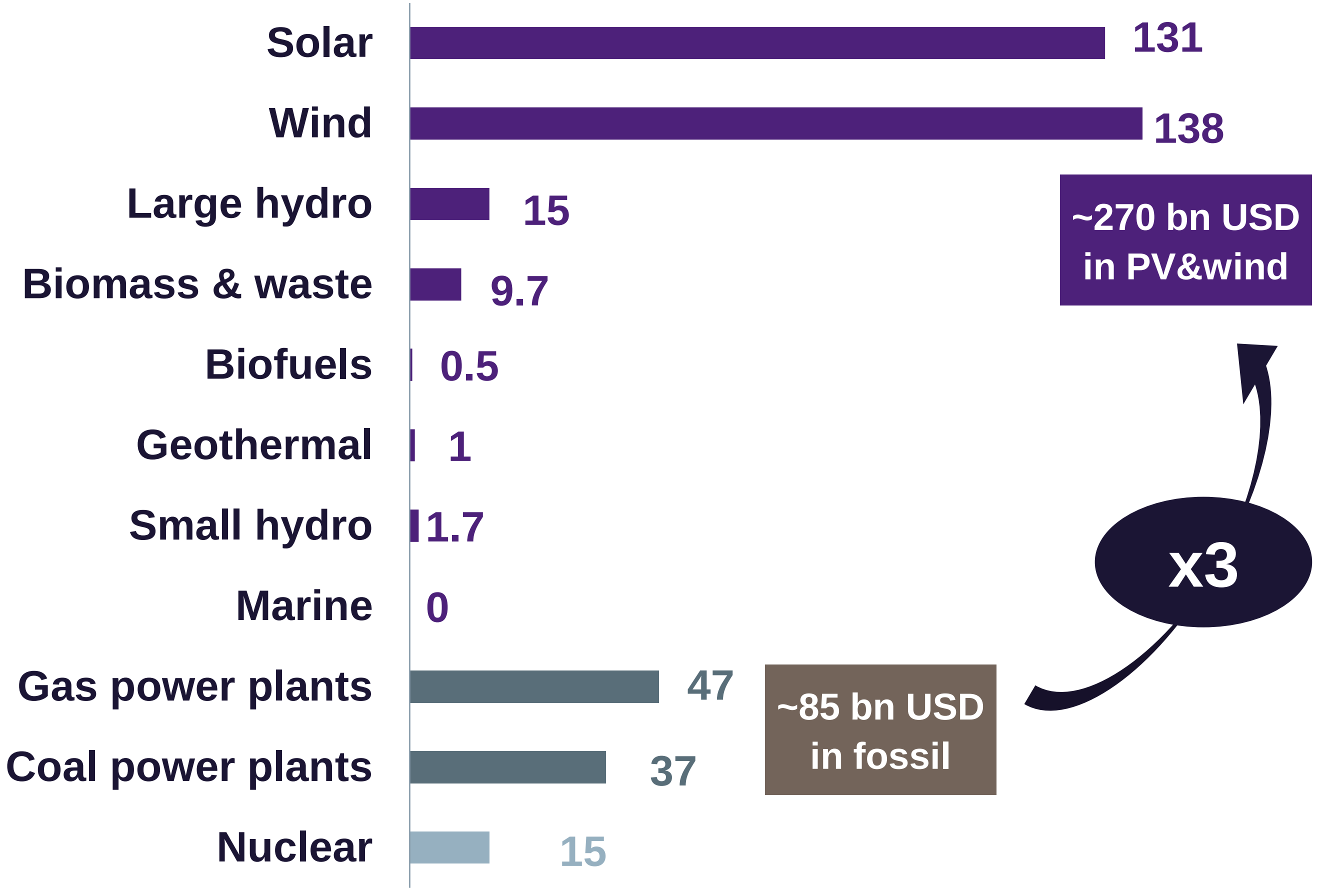
Global new investment in energy in 2019, billion USD



Source: FS-UNEP, UN, BloombergNEF (2020) - New investment volume adjusts for re-invested equity. Total values include estimates for undisclosed deals.

Exemplary auction results (2017-2019)

Brazil: $1.7 ct/kWh
Chile: $3.4 ct/kWh
Canada: $3.0 ct/kWh
Mexico: $1.9 ct/kWh

UK: $5.1 ct/kWh
France: $5.0 ct/kWh
Germany: $3.2 ct/kWh

Portugal: $2.3 ct/kWh
Chile: $3.4 ct/kWh
Dubai: $1.7 ct/kWh
Mexico: $2.1 ct/kWh

Source: IRENA (2019) Renewable energy auctions: Status and trends beyond price; Martin et al. (2020) Renewable Energy Auction Prices: Near Subsidy-Free?

Weighted-average auction/PPA learning curve trends indicate further significant cost decrease of renewable generation

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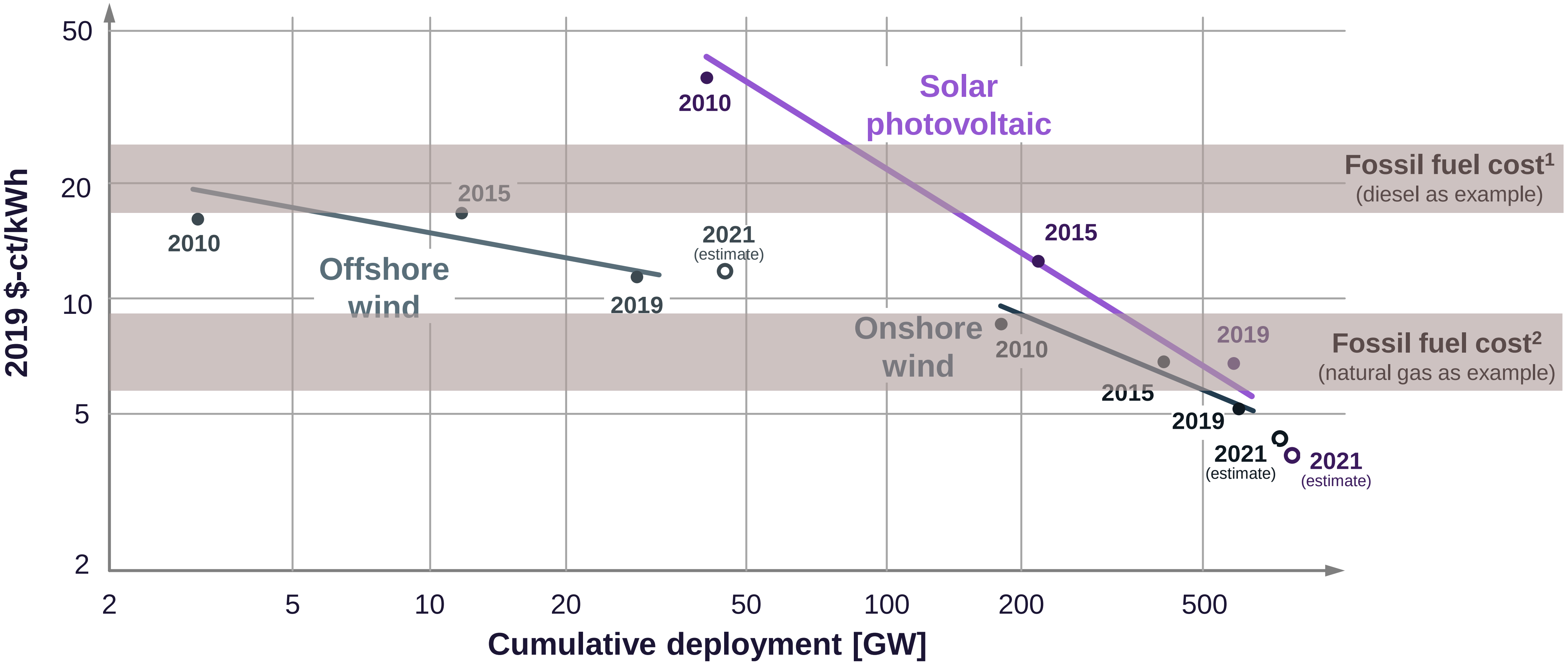

Diagram according to: IRENA (2020) Renewable power generation costs in 2019, International Renewable Energy Agency, Abu Dhabi – note: LCOE/auction price data for utility-scale projects

1 Assumed diesel cost of 1 EUR/l and conversion efficiency of 40% | 2 Industrial natural gas price of 3.1 ct/kWh (EU-27, ec.Europa.eu/Eurostat) w/ conversion efficiency of 40% and 60% USD/EUR = 1.15

The integration of renewable power generation is a challenge!
Case study Germany

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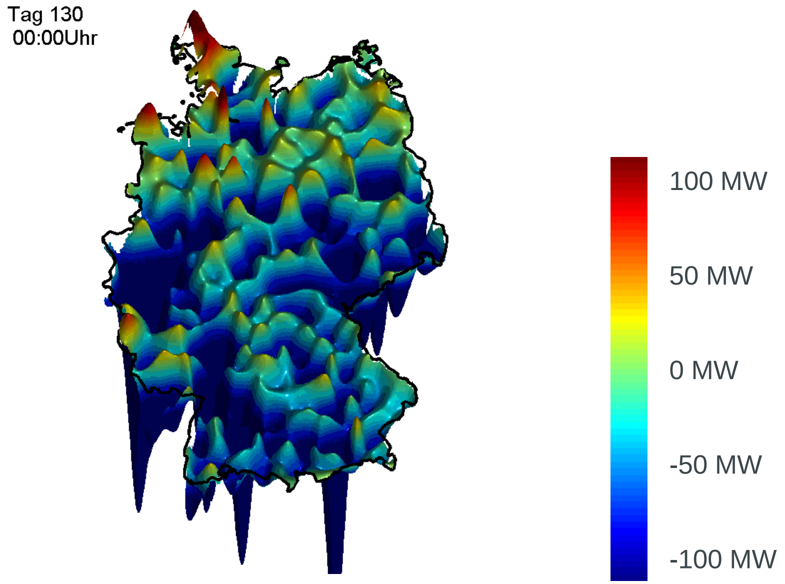
40% share of renewables

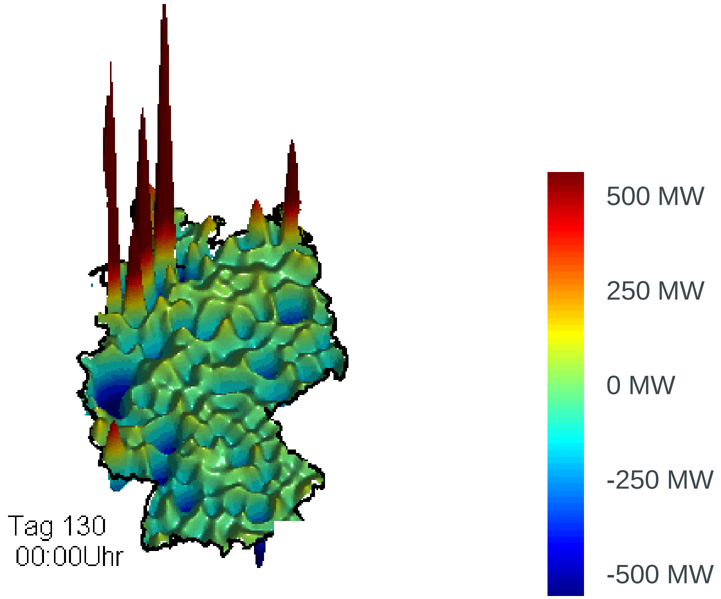


~Today

© IFHT

80% share of renewables

Future scenario



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Past
Production follows consumption

Today
Consumption/production mismatch

Future
Production decoupled from consumption

Source: German Power Network Development Plan

Sector coupling enables decarbonization, system stability and balancing of renewable energy generation & demand

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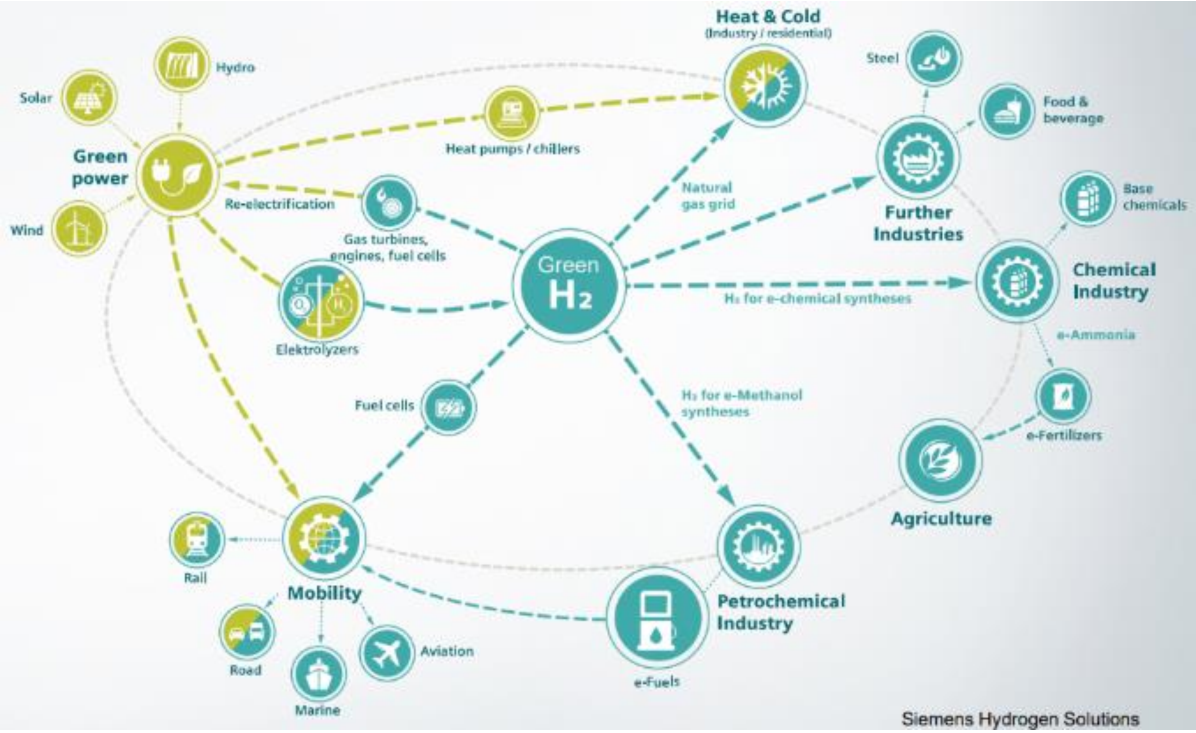
Examples for direct electrification in the transportation sector

Hydrogen as example for indirect electrification



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1 Energy Systems: Transition and Outlook

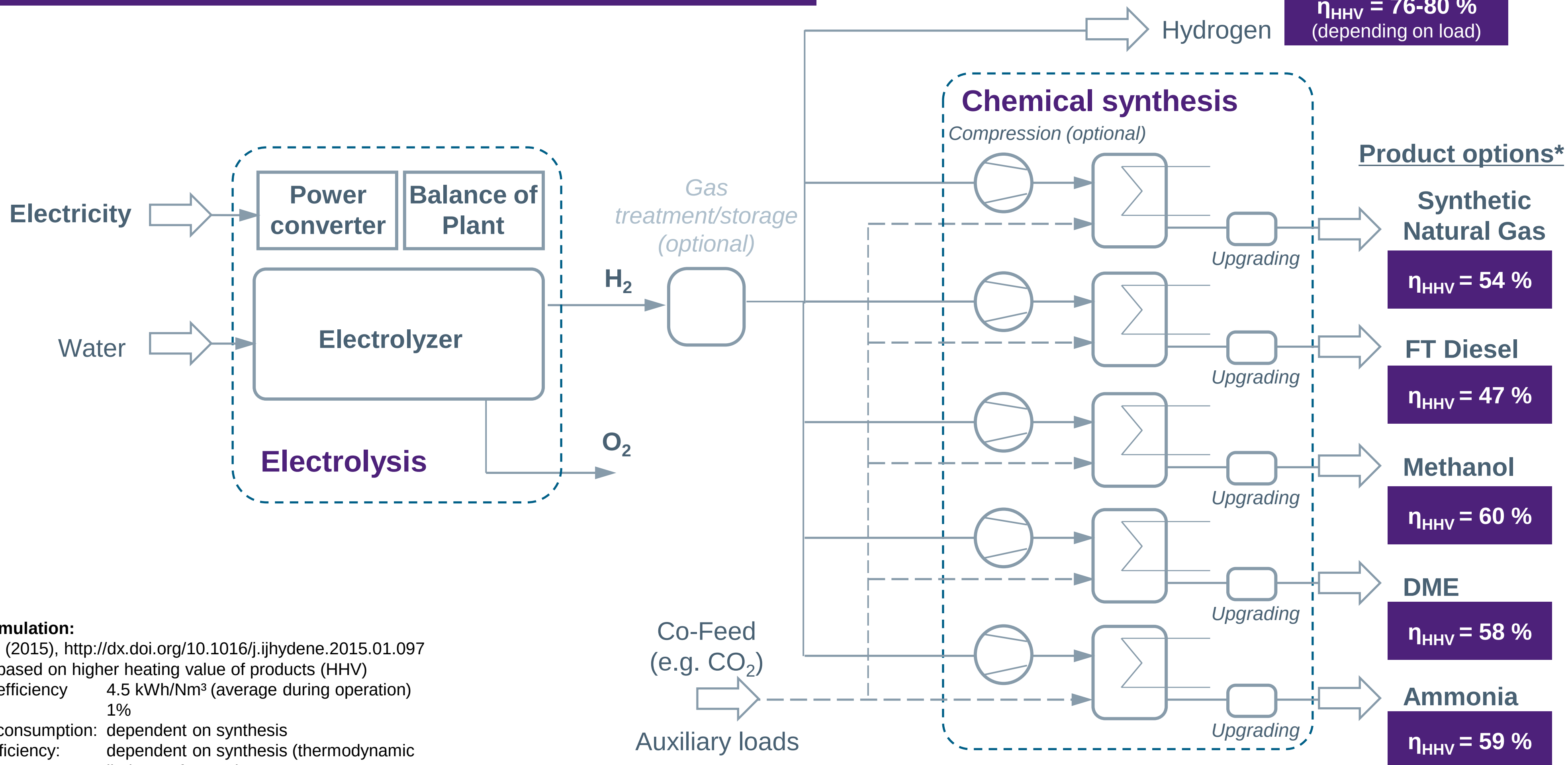
2 **Hydrogen and efuels for Sector Coupling**

3 Key element: Electrolysis

4 Implementation: Haru Oni

Overall process efficiency decreases when hydrogen is further converted in downstream synthesis plants

Realistic process efficiency considering economic perspective



***Process simulation:**

Tremel et al. (2015), http://dx.doi.org/10.1016/j.ijhydene.2015.01.097

Efficiencies based on higher heating value of products (HHV)

Electrolysis efficiency	4.5 kWh/Nm³ (average during operation)
H2 loss:	1%
Aux. power consumption:	dependent on synthesis
Synthesis efficiency:	dependent on synthesis (thermodynamic limit as reference)

Conversion of hydrogen enables better fit to existing infrastructure and widens the application fields

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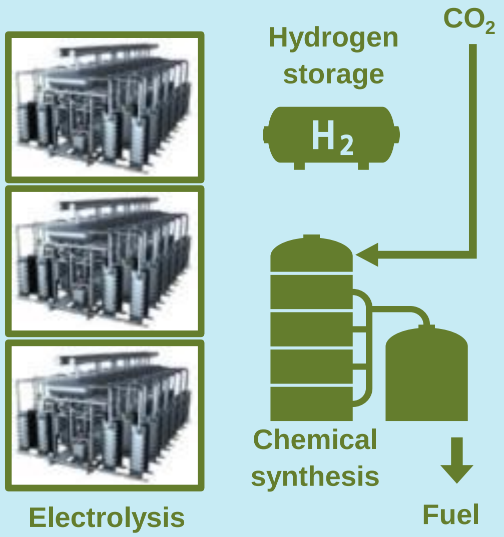
Renewables (on-grid / off-grid)

200 MW wind farm
800 GWh_{el}

Power-to-Fuel Plant



400 GWh Green Fuel

Liquid fuel infrastructure

400 GWh fuel

Air traffic

~12 mil. km air mileage
fleet with 8 planes

OR

Road transport

~130 mil. km road mileage
fleet with 1500 trucks

OR

Heating

35,000 flats in existing buildings
(150 kWh/m²/a, 80 m²)

South Australia with good wind and solar conditions as an example for Power-to-Fuel system layout and operation

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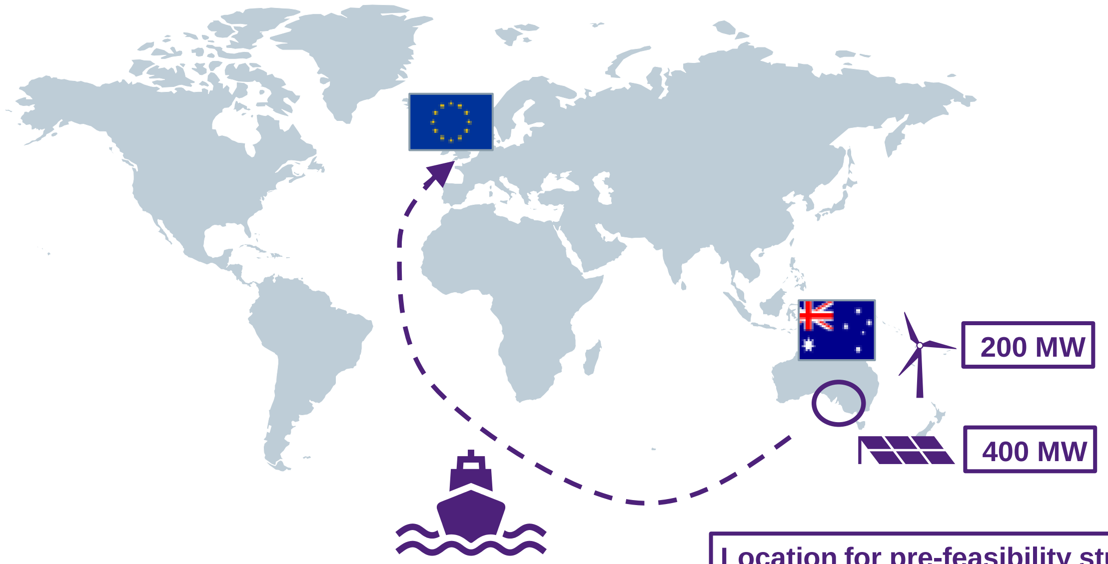
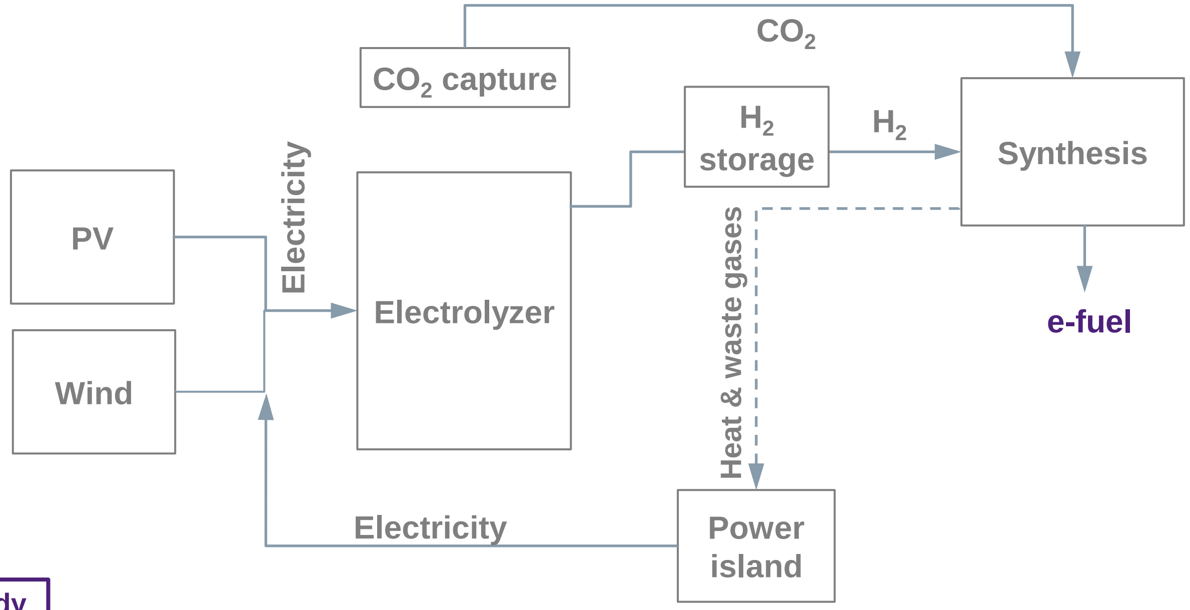
Case Study: Power-to-Fuel plant in Australia in the next 5-10 years



Location for pre-feasibility study
- South Australia
- Good solar conditions: 1680 FLH
- Good wind conditions: 3500 FLH



PV & wind in South Australia: low costs are enabled by curtailment, intermittent operation, and moderate capacity factors

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Power-to-Fuel plants around the world – optimized for future boundary conditions (2025/2030)

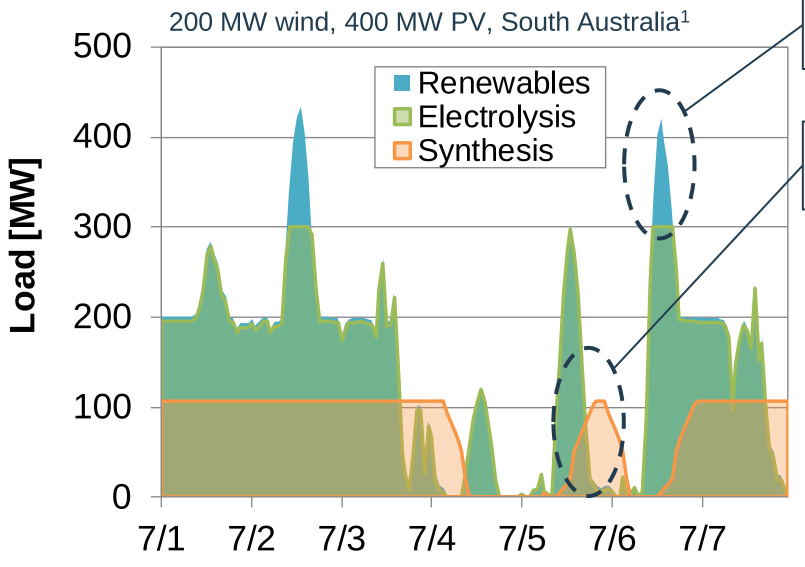
Input parameters

- ✓ Renewable generation profiles
- ✓ Technical parameters (e.g. efficiency, aux. loads)
- ✓ Technical limitations (e.g. max. ramp rates)
- ✓ Specific investment cost of components
- ✓ Specific O&M
- ✓ Financing conditions

>30 plant or site specific parameters

Power-to-Fuel plant optimization

Optimization target: lowest production cost



Optimization results		Efficiency as target
Plant investment	**~960 EUR/(MWh p.a.)**	+25%
P2X efficiency	**η=45%** (LHV basis)	+13 p.points
Production cost	**1.0 EUR/l** (gasoline eq.)	+25%

Future techno-economic parameters, e.g. Renewables[2]: 400 EUR/kW (PV), 900 EUR/kW (wind) | Electrolysis[3]: 500 EUR/kW, 4.5 kWh/Nm³ | Hydrogen storage[4]: 286 EUR/kg | Chemical synthesis[5]: 450 EUR/kW_{HHV} | CO2 capture from flue gas[6]: 50 EUR/t | WACC: 7-8%; lifetime: 20-25 years

1 Synthetic generation profiles based on weather data | 2 400 EUR/kW and 900 EUR/kW are ca. 50% lower than today's lowest prices given by IRENA (2017) | 3 Future parameters (2025/30) according to E4Tech (2013) | 4 Kruck et al. (2015) HyUnder project | 5 Tremel et al. (2015) | 6 Rubin et al. (2015)

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The efficiency of an electrolyzer depends on current density and therefore on design and operation strategy

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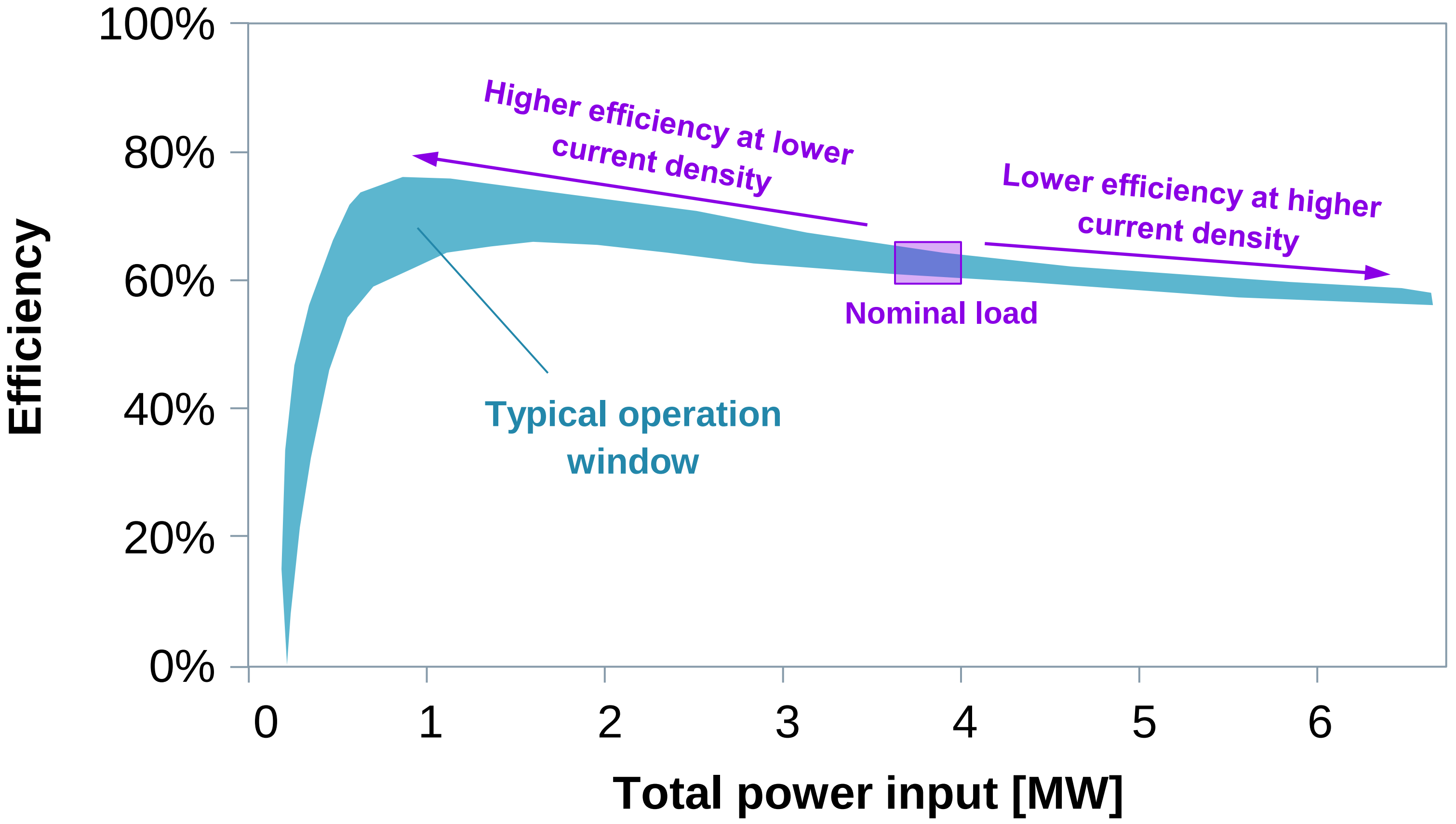
Efficiency (incl. BoP and compression) and load of the SILYZER 200 plant in Energiepark Mainz



Source: Kopp et al. (2017) - "Energiepark Mainz: Technical and economic analysis of the worldwide largest Power-to-Gas plant with PEM electrolysis

Silyzer 300 – Full Module Array
The next paradigm in PEM electrolysis

Silyzer 300 – full module array (24 modules)…

… and detailed picture of 6 modules

17.5 MW
power demand

> 76.0 %
system efficiency

24 modules
to build a full module array

335 kg
hydrogen per hour

Electrolysis portfolio scales up by factor 10 every 4 – 5 years

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Siemens Energy portfolio roadmap

0.1 MW — **1 MW** — **10 MW** — **100 MW** — **1,000 MW**

2011

Silyzer 100
Lab scale demo
~4,500 OH[1],
~150k Nm^3 of H_2

2015

Silyzer 200
~86,500 OH[1]
~7.3 m Nm^3 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+

Chemical synthesis plants are already in the 1-10 GW range

1 Operating Hours; Data OH & Nm^3 as of Dec 2019

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How to harvest one of the best wind locations worldwide?

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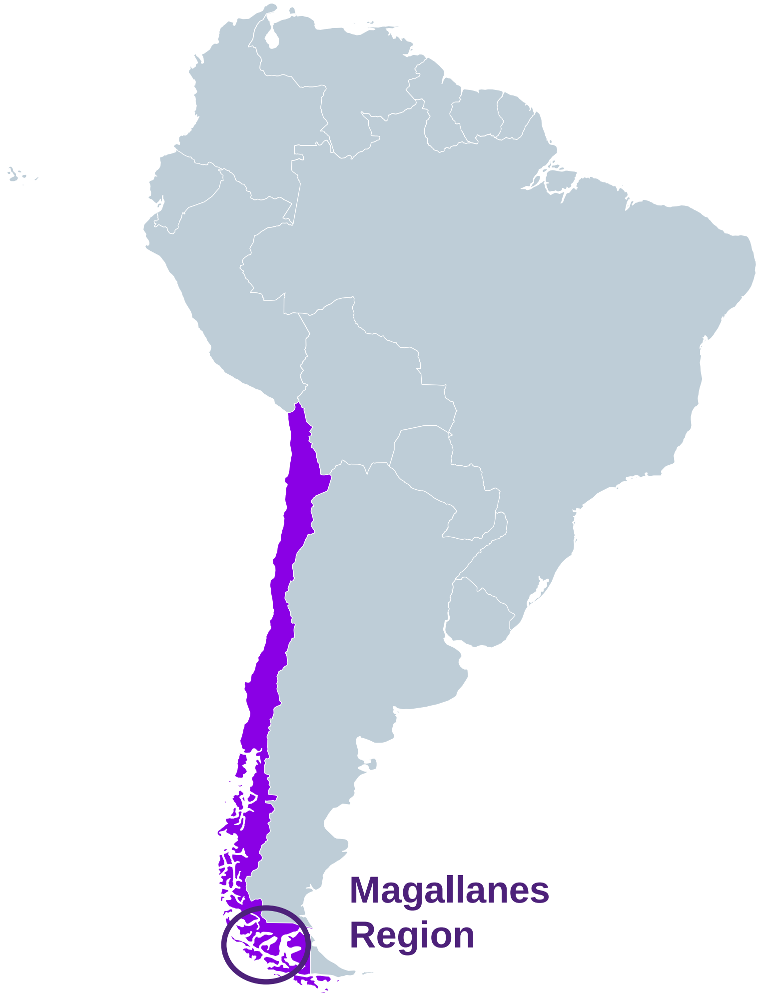

1 Fraunhofer IEE – Windmonitor: ca. 1800 FLH in 2018

Project Haru Oni in Chile: the full value chain from wind energy to green methanol & gasoline

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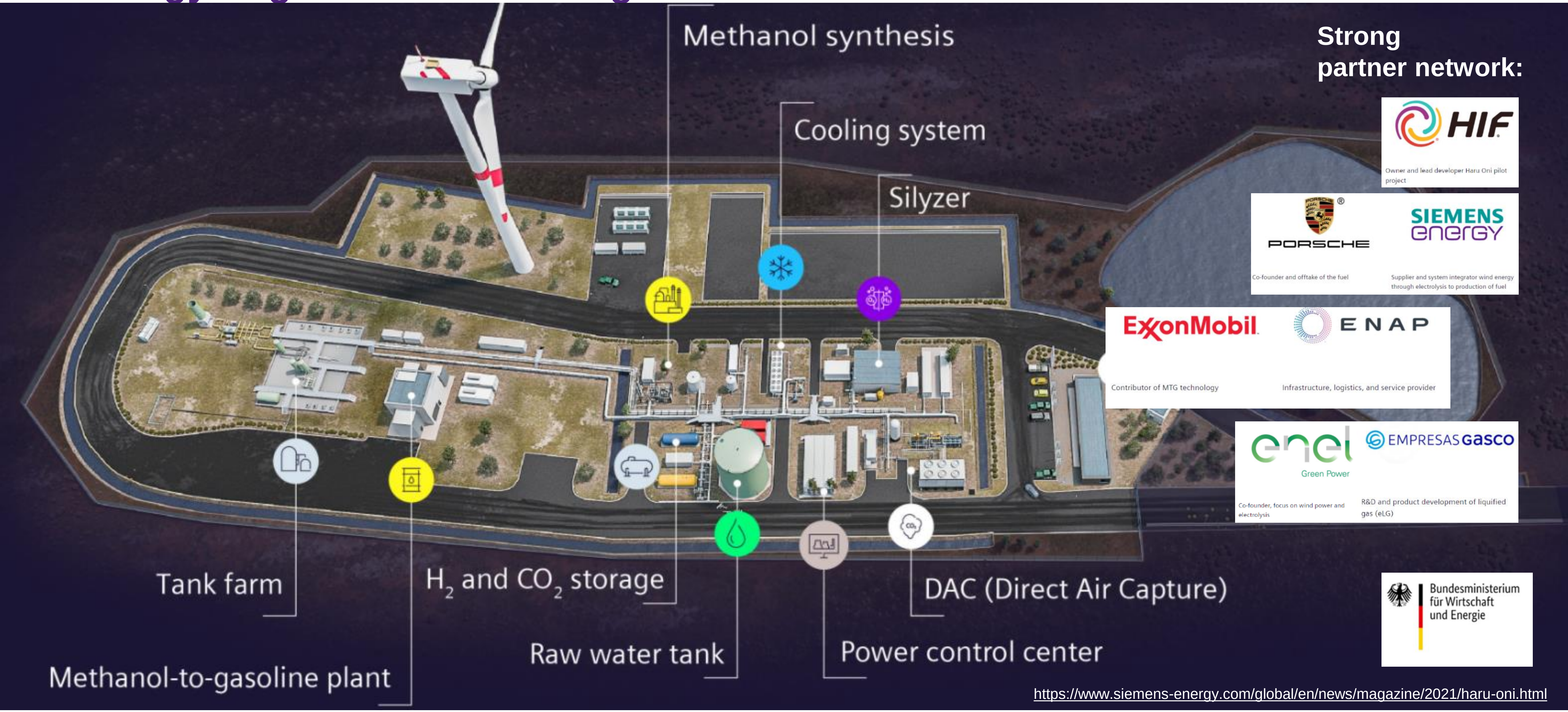


https://www.siemens-energy.com/global/en/news/magazine/2021/haru-oni.html

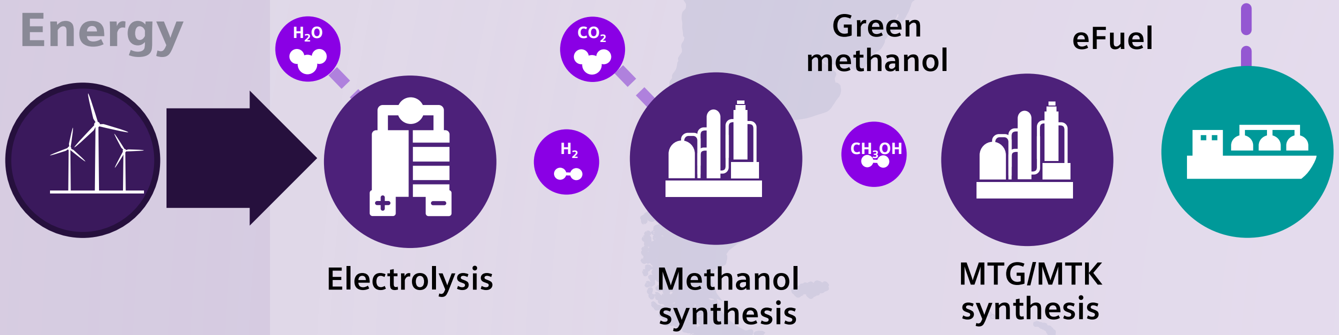
Project Haru Oni: area allows for significant scale and impact

Market

	Target applications	Wind power installation	Electrolysis capacity	CO_2 savings (ton per year)
Pilot phase until 2022	▪ e-fuel for Porsche cars	3.4 MW	1.25 MW	~900
1st phase until 2024	▪ e-fuel (road) ▪ e-kerosene (aviation) ▪ e-methanol (ship)	280 MW	175 MW	~0.15 million
2nd phase until 2026	▪ e-fuel (road) ▪ e-kerosene (aviation) ▪ e-methanol (ship)	**~2.5 GW**	**~2 GW**	**~1.7 million**

Wind Energy

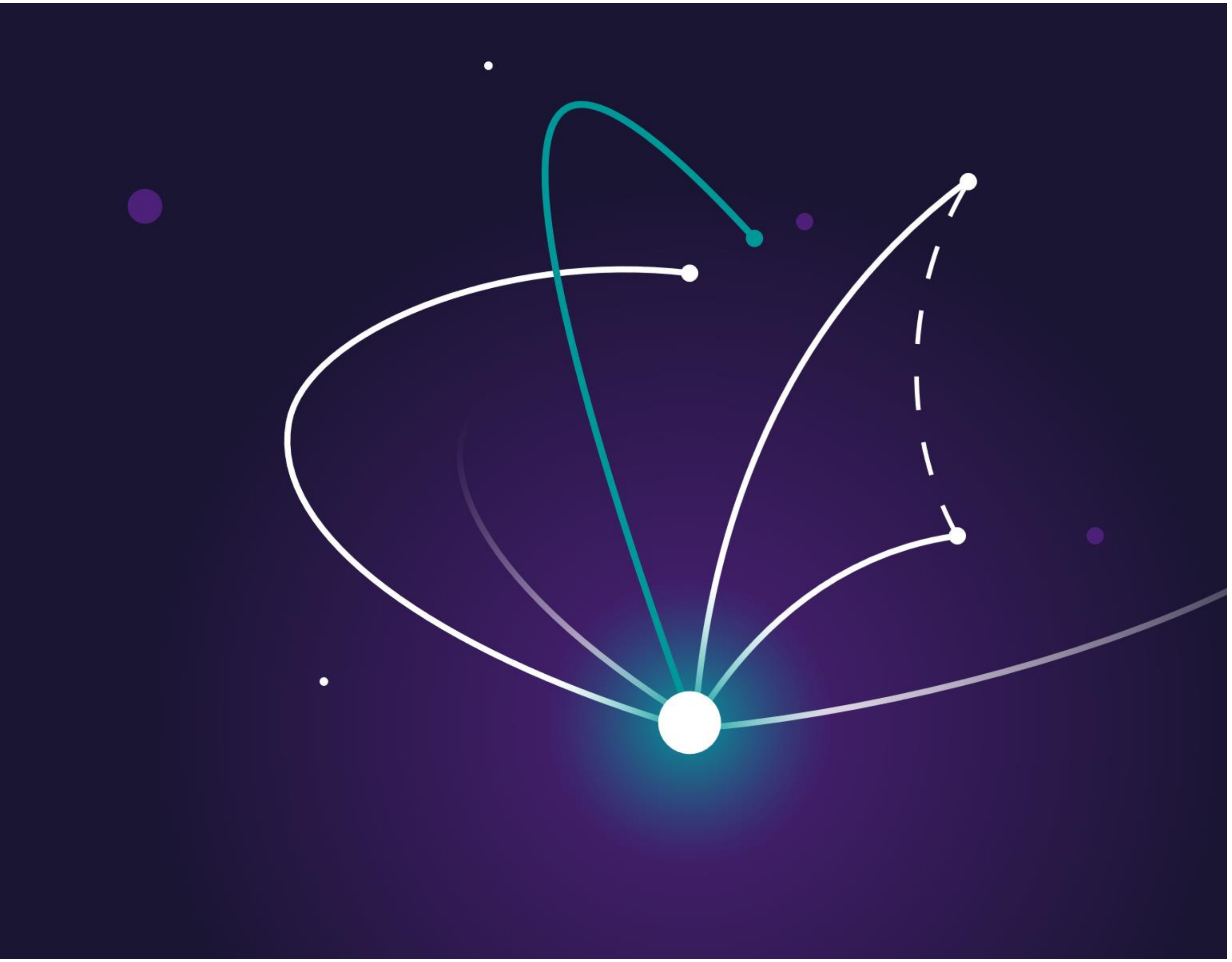
POWER TO LIQUID



Sep 10, 2021
Construction begins on world's first integrated commercial plant

https://www.siemens-energy.com/global/en/news/magazine/2021/haru-oni.html

Thank you for your kind attention!



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