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Liquid Hydrocarbons

Electrofuel / e-Fuel Production Pathways and Costs

10-09-2018

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Investors

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KFW

TOTAL

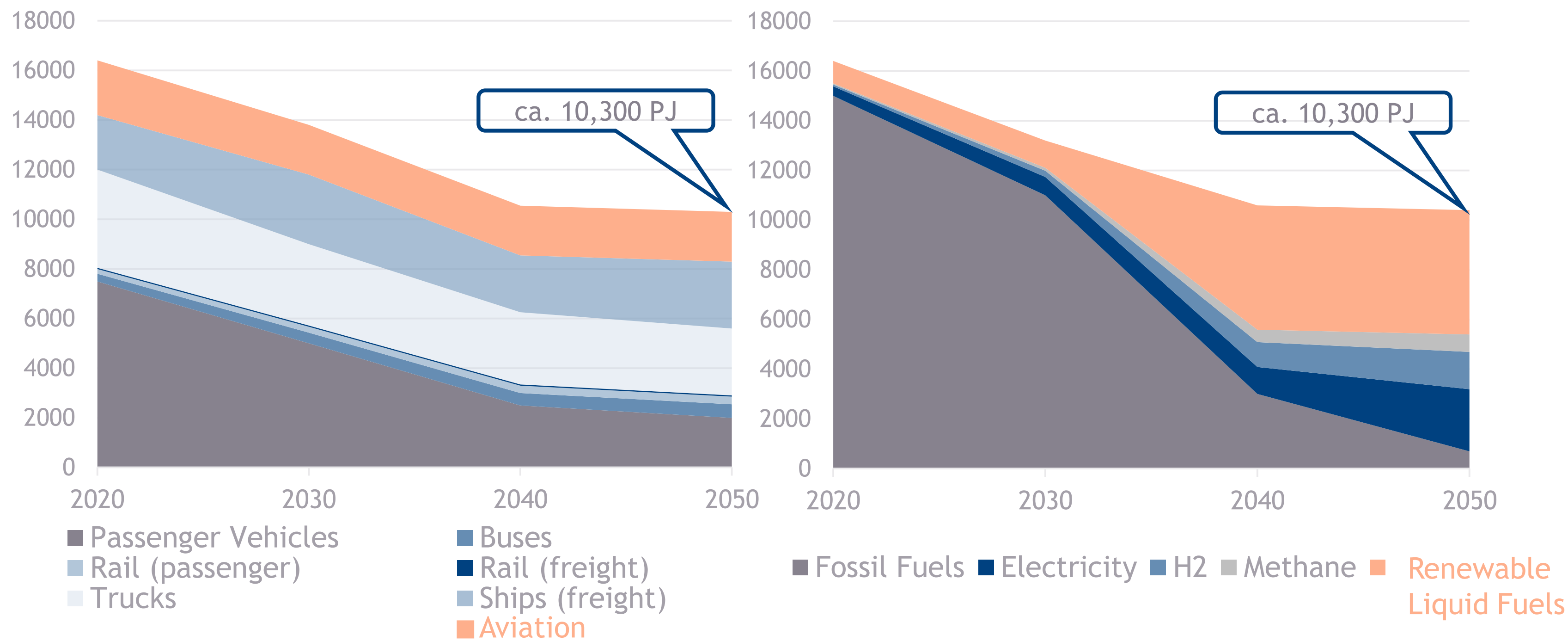
Key Assumptions

- Chapter 1 (Potential): e-Fuels are a necessity to reach long term goals decarbonization goals as set during COP 21.
- Chapter 2 (Technology): The e-Fuels technology is ready for deployment and requires almost no adaptation of infrastructure.
- Chapter 3 (Costs): e-Fuels can already be economically competitive with renewable fuel solutions (=bio-parity). Fossil parity is expected by 2050 latest.

Market Potential

e-Fuel: A Necessity for Transport to Tackle Climate Change

Anticipated primary-energy consumption of the EU transport sector

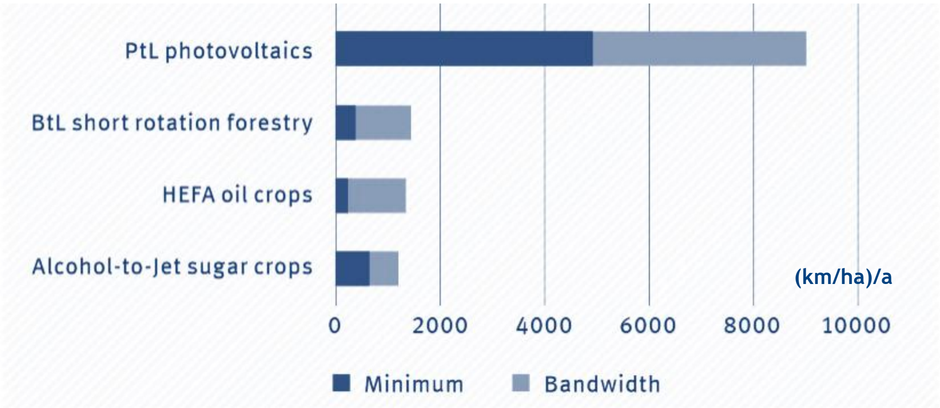


+ To achieve CO_2 reduction targets, fossil fuels need to be phased out
+ Hard-to-electrify sector will make up 50 % or 5,000 PJ in 2050
+ >300 GW of e-Fuels needed in 2050 (>10 GW/a from now)

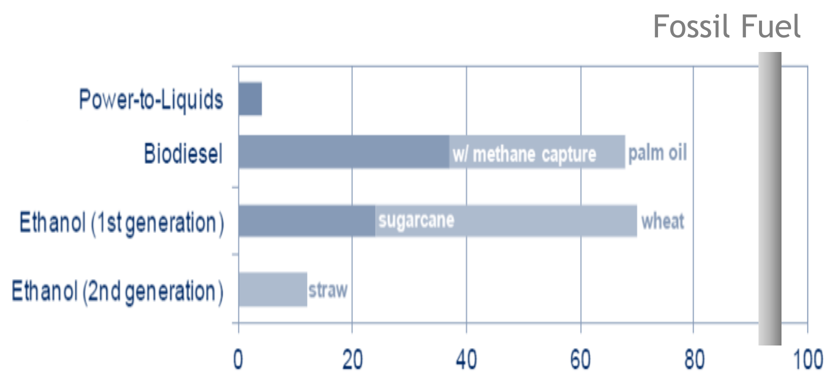
Calculation based on dena/LBST „E-Fuels -The potential of electricity based fuels for low emission transport in the EU", 2017

e-Fuel - Highest Potential and Lowest Ecological Footprint

- Zero cost for infrastructure
- 8x more efficient use of land area compared to biological alternatives
- 85 % reduction in CO_2 emissions compared to fossil fuel



Achievable air mileage for an A320neo per ha of land



Life cycle green house gas emissions (gCO2eq/MJ)

Source: German Federal Environment Agency - **Power-to-Liquids, September 2016**
Tremel (2018) – Electricity-based fuels, ISBN: 978-3-319-72458-4, SpringerNature

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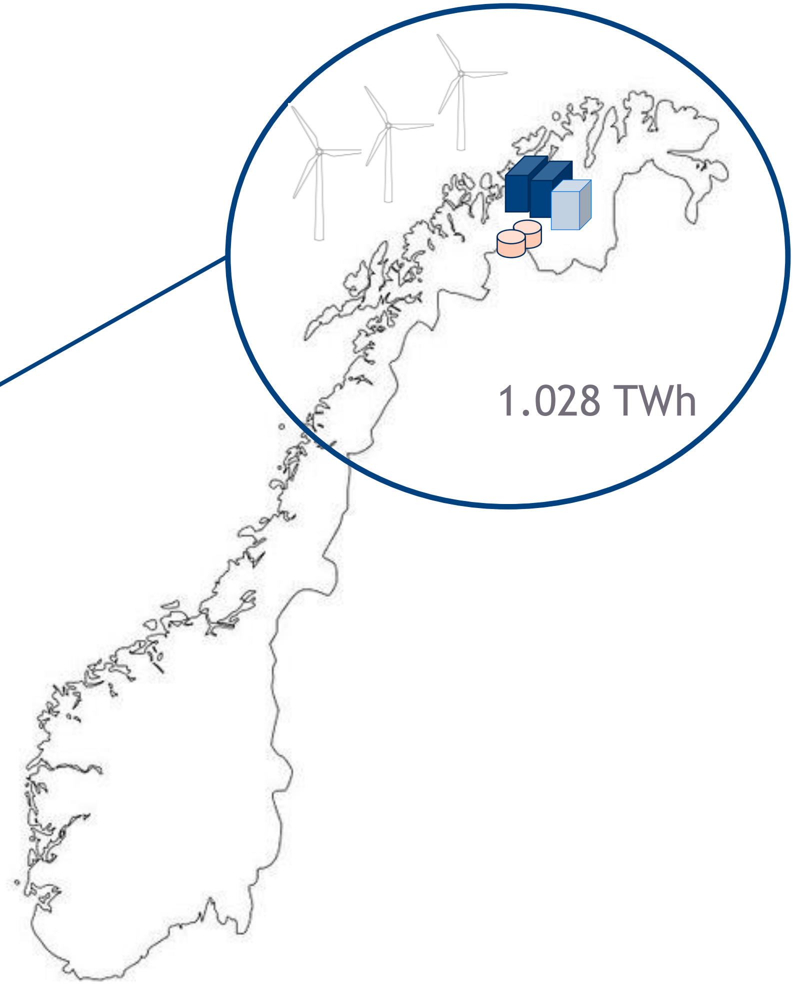
e-Fuel as Enabler for Renewable Energy Build Up

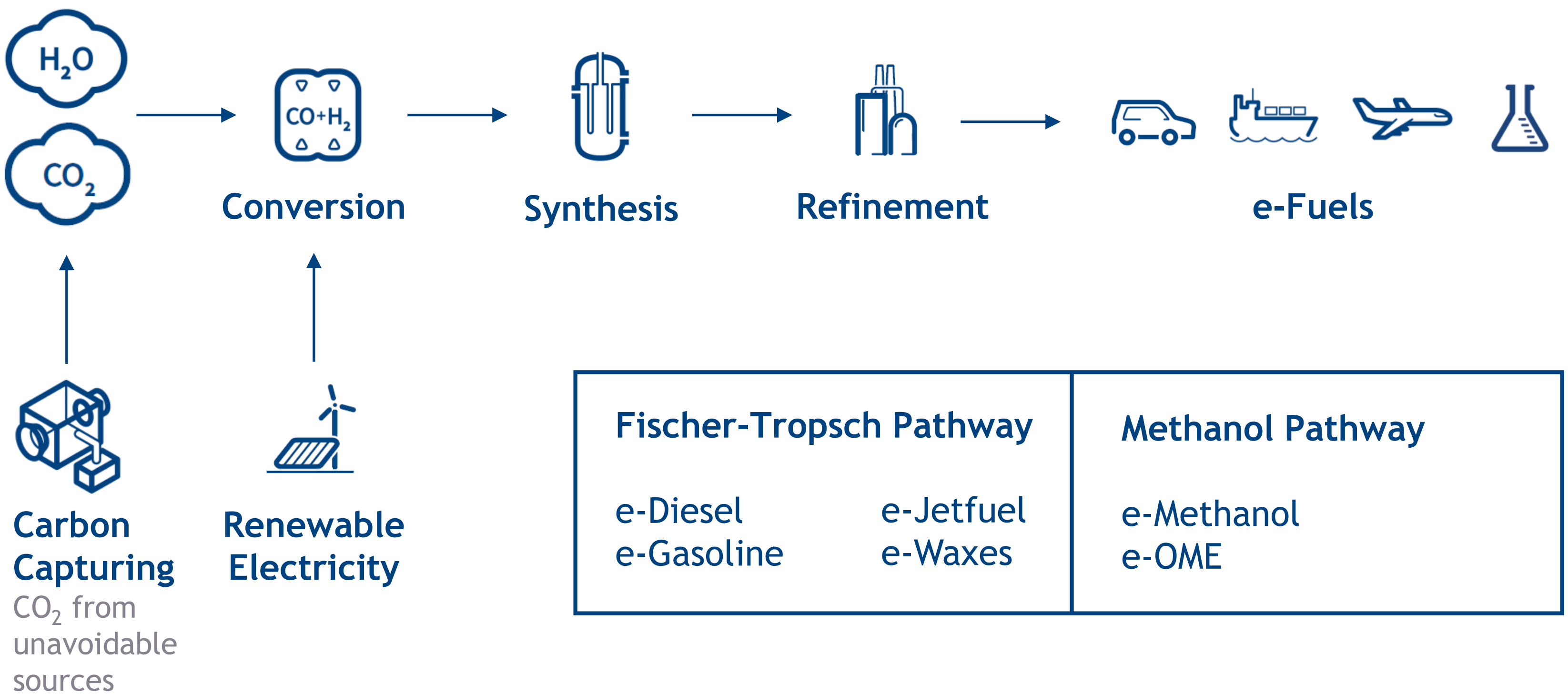
- North-East Norway could cover >20% of EU transport sector power demand
- On-site transformation to e-Fuel allow for transport and storage
- Increases potential



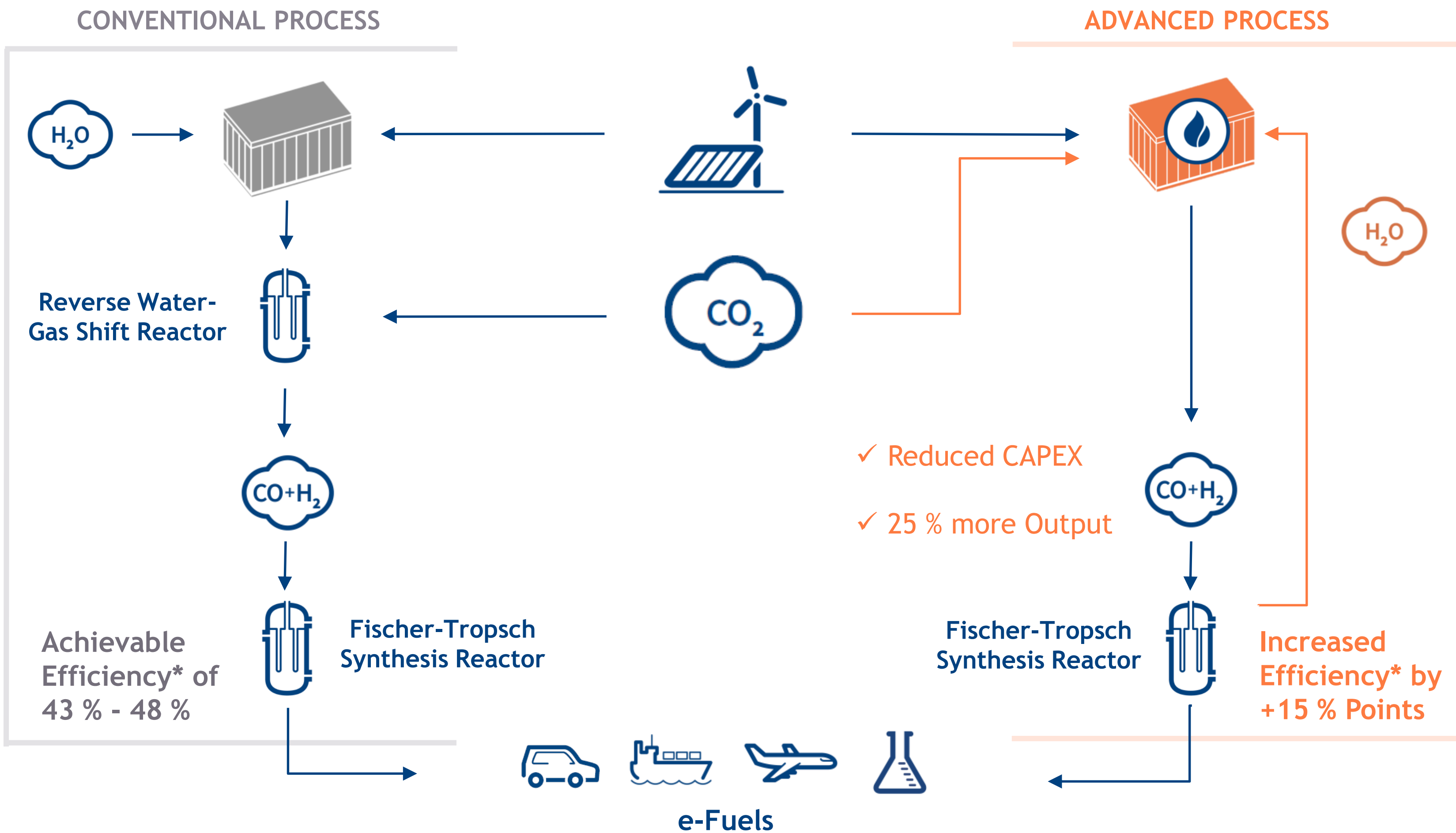
*Values refer to On-Shore Wind Power Potential
Source: NVE

Technology

e-Fuels: Two Main Conversion Pathways Available

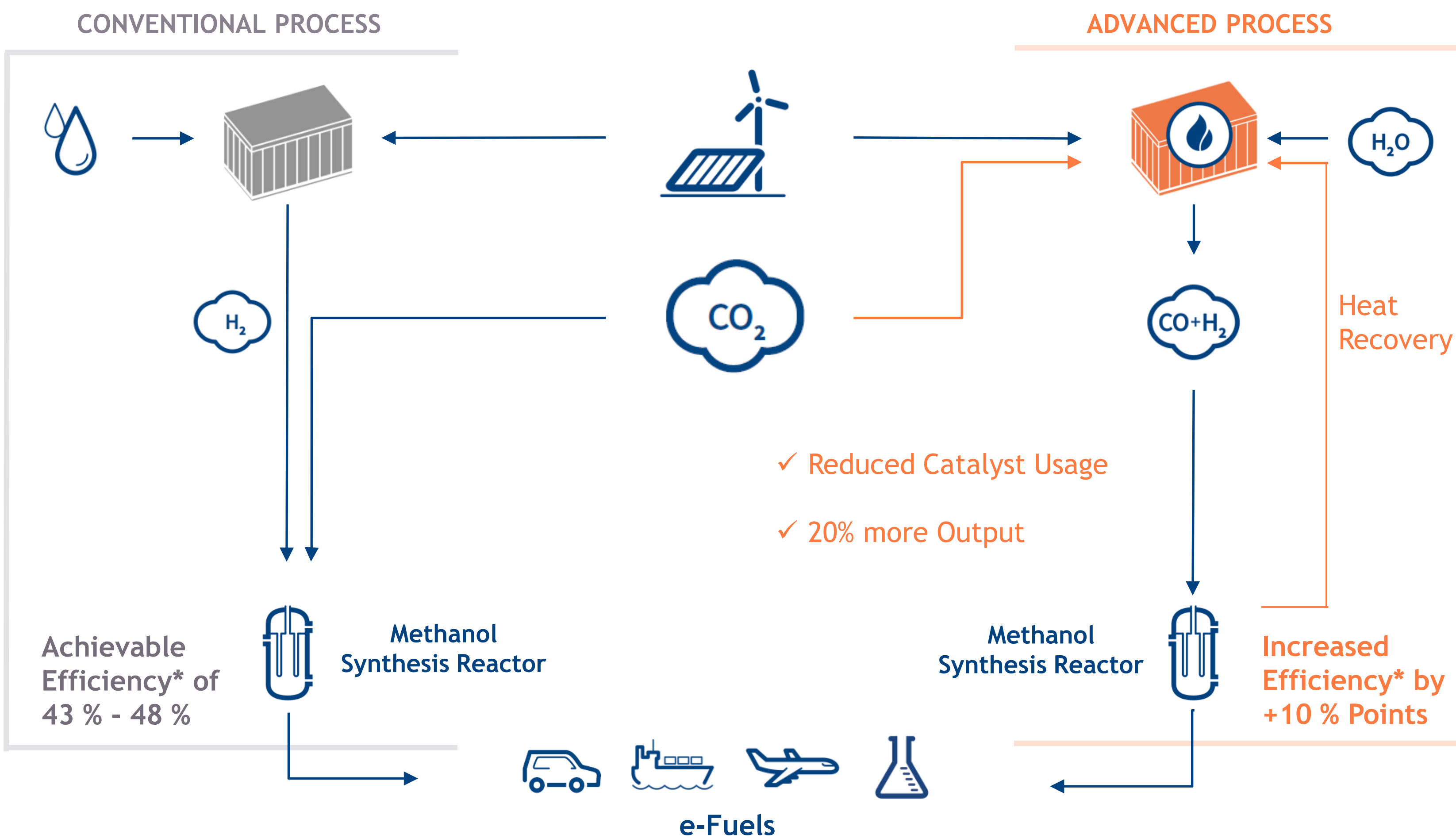


Technology Comparison: Fischer-Tropsch Pathway



*lower heating value of the fuel (620 kJ/kmol) compared to the electrical energy input

Technology Comparison: Methanol Conversion



*lower heating value of the fuel (620 kJ/kmol) compared to the electrical energy input

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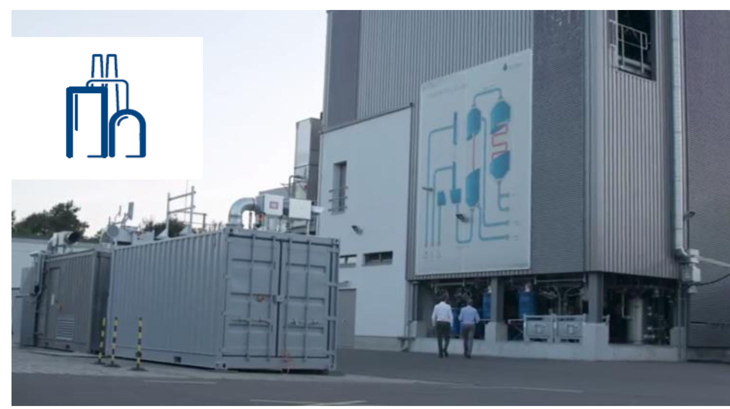
Europe - Global leader in PtL development

Global Leader in CO_2 capture from air (TRL 6-7)
Climeworks, Switzerland / Germany

Global Leader in e-Methanol (TRL 8-9)
Carbon Recycling International, Iceland

Global Leader in green hydrogen generation (TRL 7-8)
Hydrogenics, Belgium / McPhy, France / ITM, UK



Global Leader in e-Crude via Fischer-Tropsch (TRL 6-7)
Sunfire and Ineratec, Germany

*TRL level based on sunfire assessment

Cost Comparisons

Cost Projections in Recent Studies

Long-term e-Fuel production costs for “sweet spots” (Fischer-Tropsch)

BOSCH

	year	PtL cost [€/MWh]	electricity [ct/kWh]	full load hours	efficiency
LBST[1)]	2016	~ 160	5,5	6.500	~ 45 %
UBA[2)]	2016	~ 140	4,0	3.750	~ 47 %
LUT[3)]	2016	~ 86	1,94	6.840	~ 57 %
Dena/LBST[4)]	2017	~ 100	3,4	6.840	~ 48 %
IWES[5)]	2017	~ 115	3,8	6.292	~ 48 %

1) Ludwig Bölkow Systemtechnik, Renewables in Transport 2050, 2016
2) UBA, Erarbeitung einer fachlichen Strategie zur Energieversorgung des Verkehrs bis zum Jahr 2050 (72/2016), 72/2016
3) LUT, Techno-Economic Assessment of Power-to-Liquids (PtL) Fuels Production and Global Trading Based on Hybrid PV-Wind Power Plants, 2016
4) Ludwig Bölkow Systemtechnik and Deutsche Energie-Agentur, E-Fuels – The potential of electricity based fuels for low emission transport in the EU, 2017
5) Fraunhofer IWES, “Mittel- und langfristige Potenziale von PTL- und H_2-Importen aus internationalen EE-Vorzugsregionen”, 2017

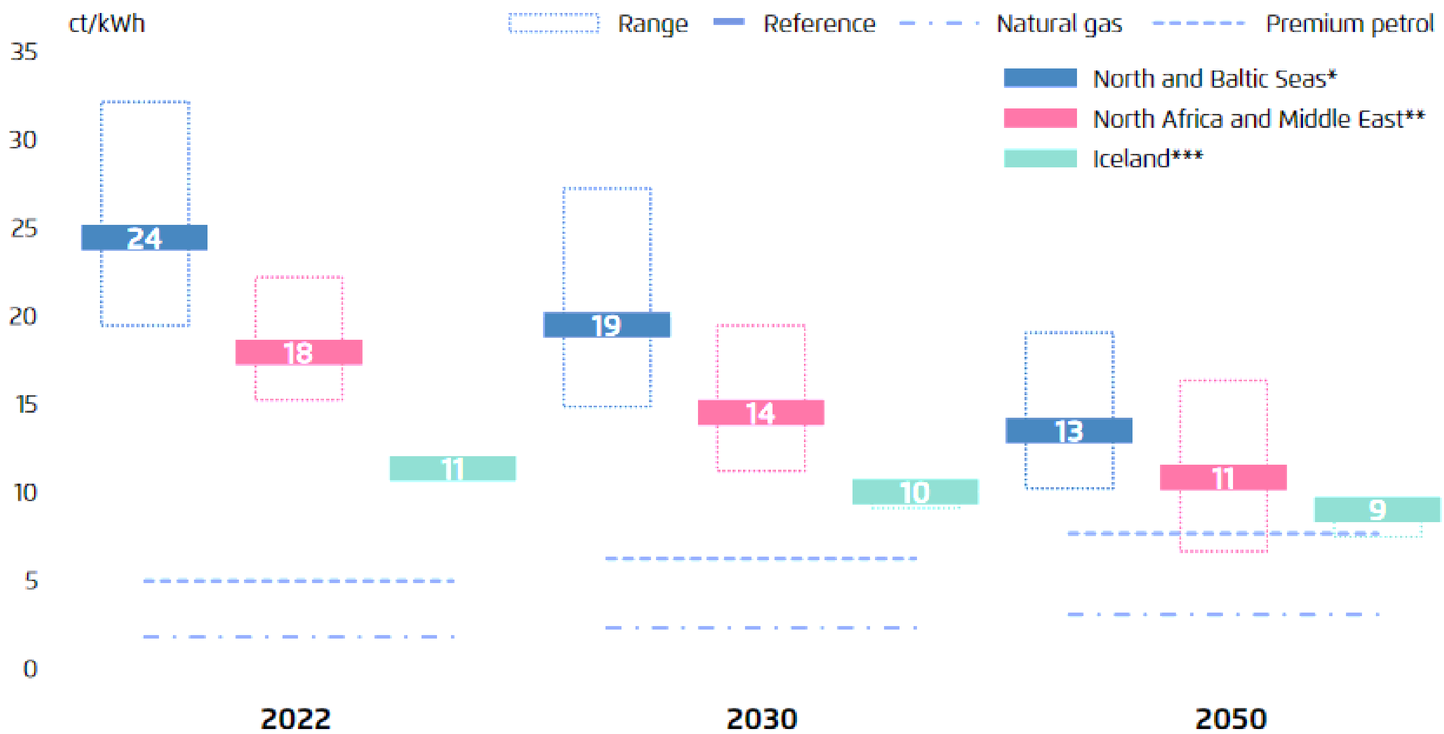
Spread of cost projections: 85 – 160 €/MWh

- Studies converge for assumptions
- Key driver for costs is the price of electricity and operation hours
- Sunfire agrees with electricity costs, but sees lower full load hours and higher efficiencies

Cost Projections in Recent Studies

Cost of synthetic methane and liquid fuels in $cent_{2017}$ per kilowatt hour final product (without network charges and distribution cost)

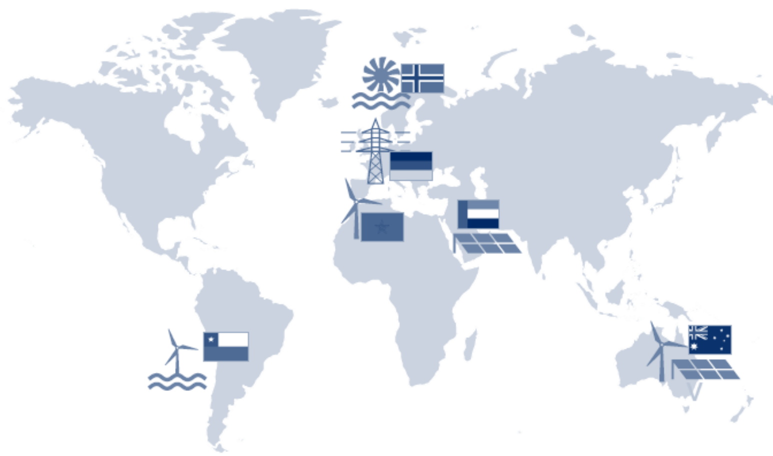
Figure 5

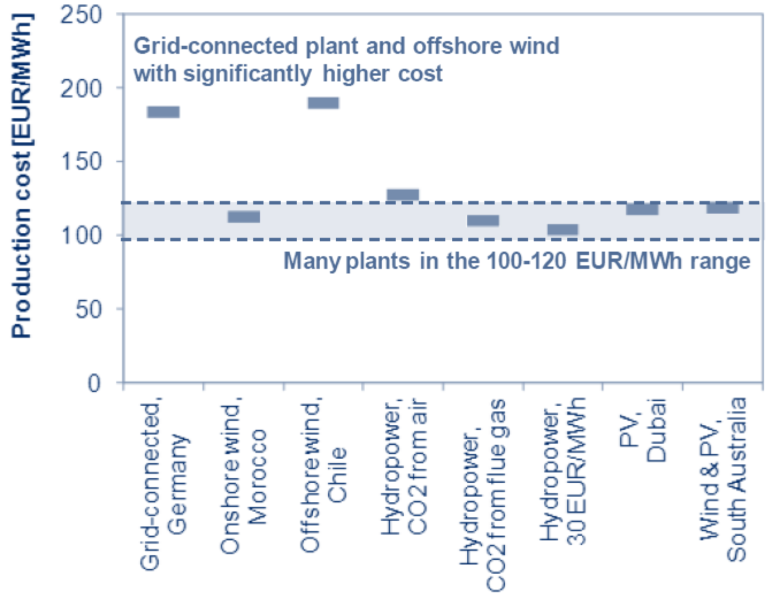


Agora Energiewende / Agora Verkehrswende, The Future Cost of Electricity-Based Synthetic Fuels, 2018

Cost Projections in Recent Studies

Power-to-Fuel plants around the world





+ Production price range between 100-120 €/MWh (0.9-1.1 €/l) expected

Tremel, Electricity-based fuels, ISBN: 978-3-319-72458-4, SpringerNature, 2018

Summary

Key Messages

- Technology is ready for deployment
- Less sunk investment through re-use of existing refining system and fuel infrastructure
- Immediate CO_2-reduction potential via blend in existing vehicle fleet
- No-regret measure to use e-Fuels in passenger mobility first, as long-term mandatory for aviation, navigation, heavy duty and chemical industry
- Economically competitive with renewable fuel solutions and long-term competitiveness with today’s fossil gasoline prices
- Sufficient renewable power and CO_2 supply in Europe available

THANK YOU!

ENERGY
EVERYWHERE

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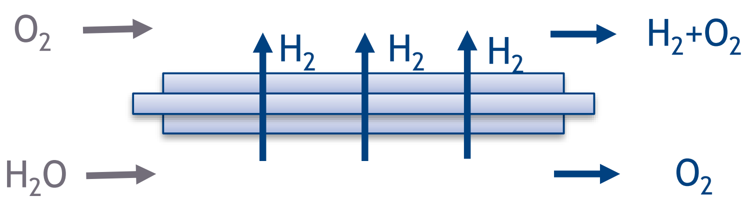
Backup

Details on the Fischer-Tropsch Pathway

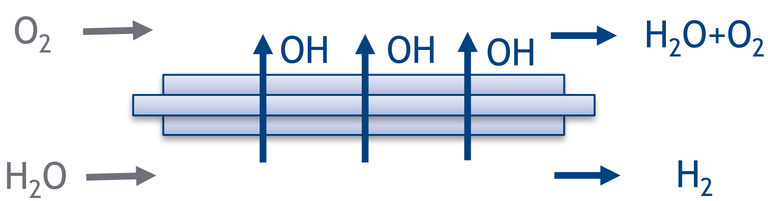
Conversion: Three different Electrolysis Types (simplified)

+ PEM electrolysis



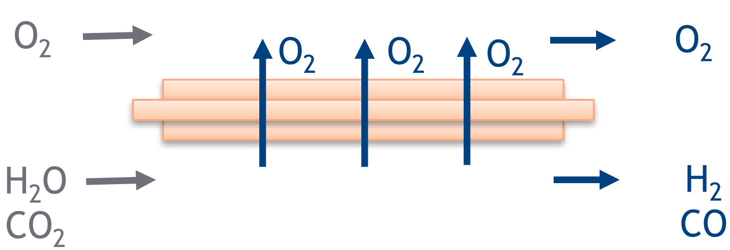
- Hydrogen membrane
- Efficiency: 50-60%$_{LHV}$ or 5-6 kWh/Nm^3
- Low temperature (<100°C)
- Flexible operation from part load to full load (0%-300%)

+ Alkaline electrolysis



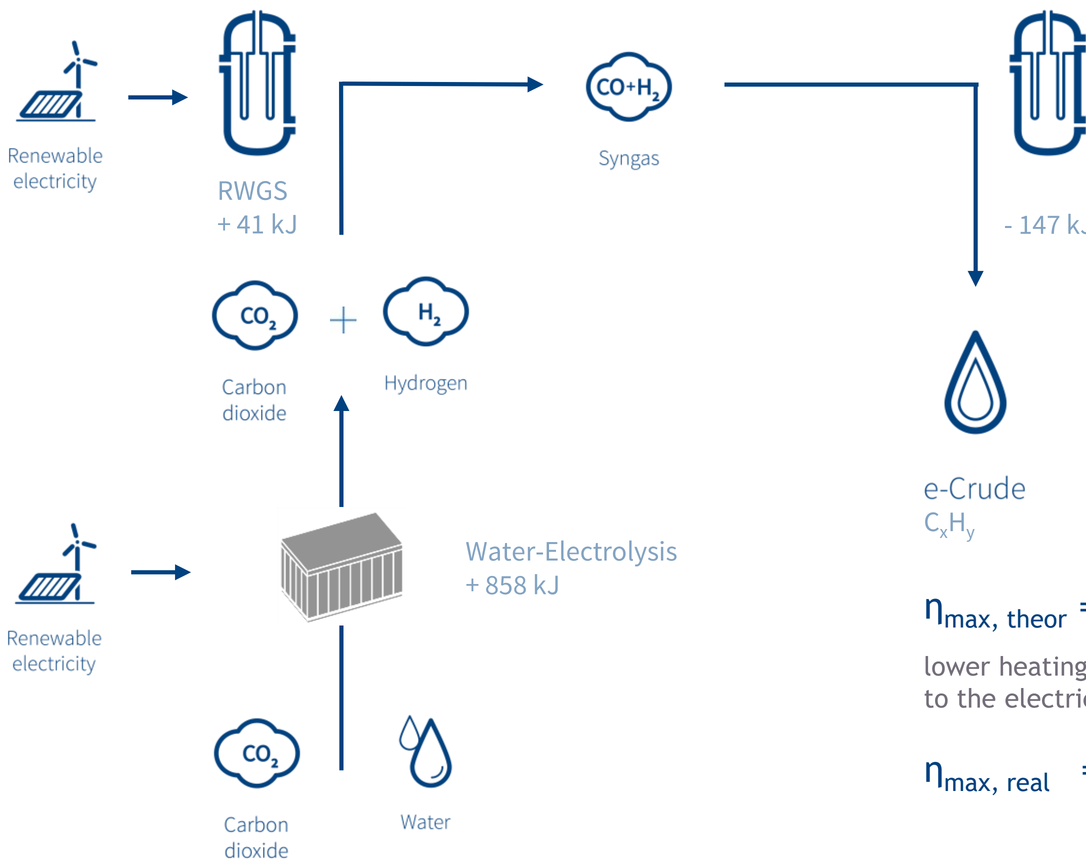
- Hydroxide membrane
- Efficiency: 50-60%$_{LHV}$ or 5-6 kWh/Nm^3
- Low temperature (<100°C)
- Mature technology

+ High-temperature (steam) electrolysis



- Oxygen membrane
- Efficiency: 82%$_{LHV}$ or 3.7 kWh/Nm^3
- High temperature (850°C)
- Ability to electrolyse CO_2
- Less mature, most promising economics

Fischer-Tropsch Pathway: Conventional Water-Electrolysis + RWGS + Synthesis



LHV of fuel
+619 kJ/kmol

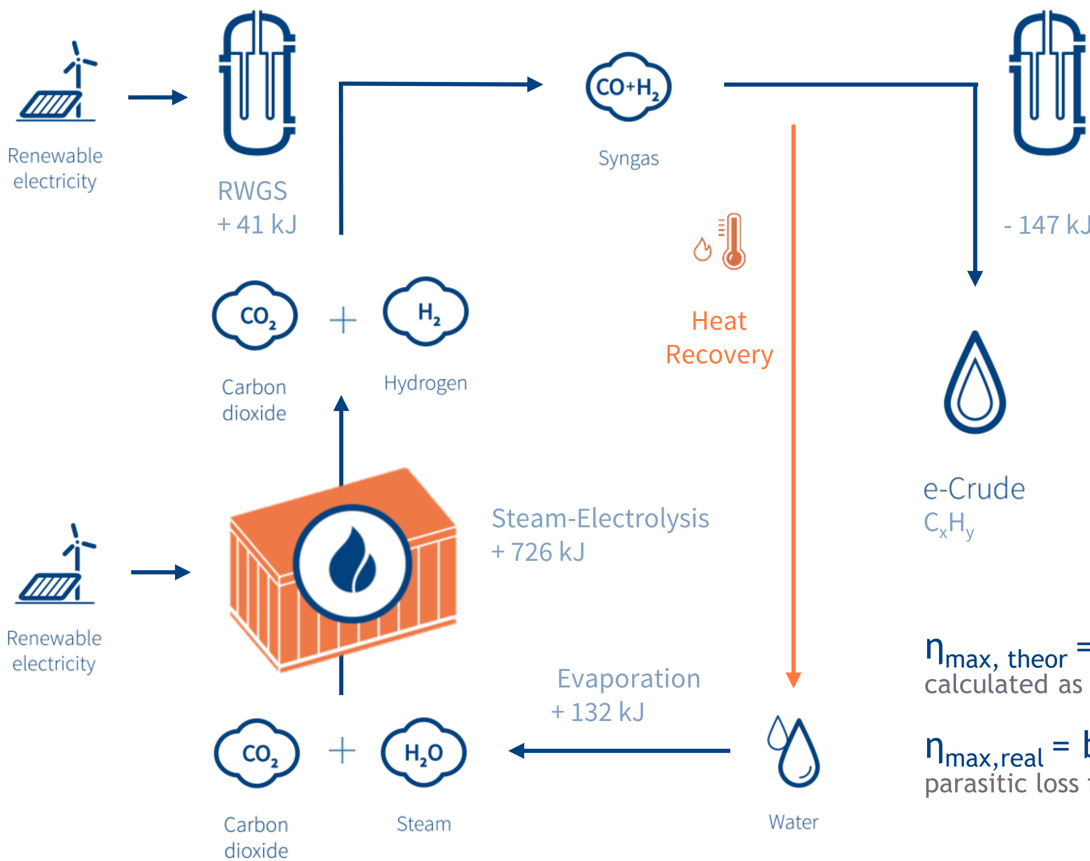
$\eta_{max,\ theor}$ = 69 %

lower heating value of the fuel (620 kJ/kmol) compared to the electrical energy without any parasitic losses

$\eta_{max,\ real}$ = 43 - 48 % BENCHMARK

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

Fischer-Tropsch Pathway:
Step 1 Improvement: Seam-Electrolysis + RWGS + Synthesis



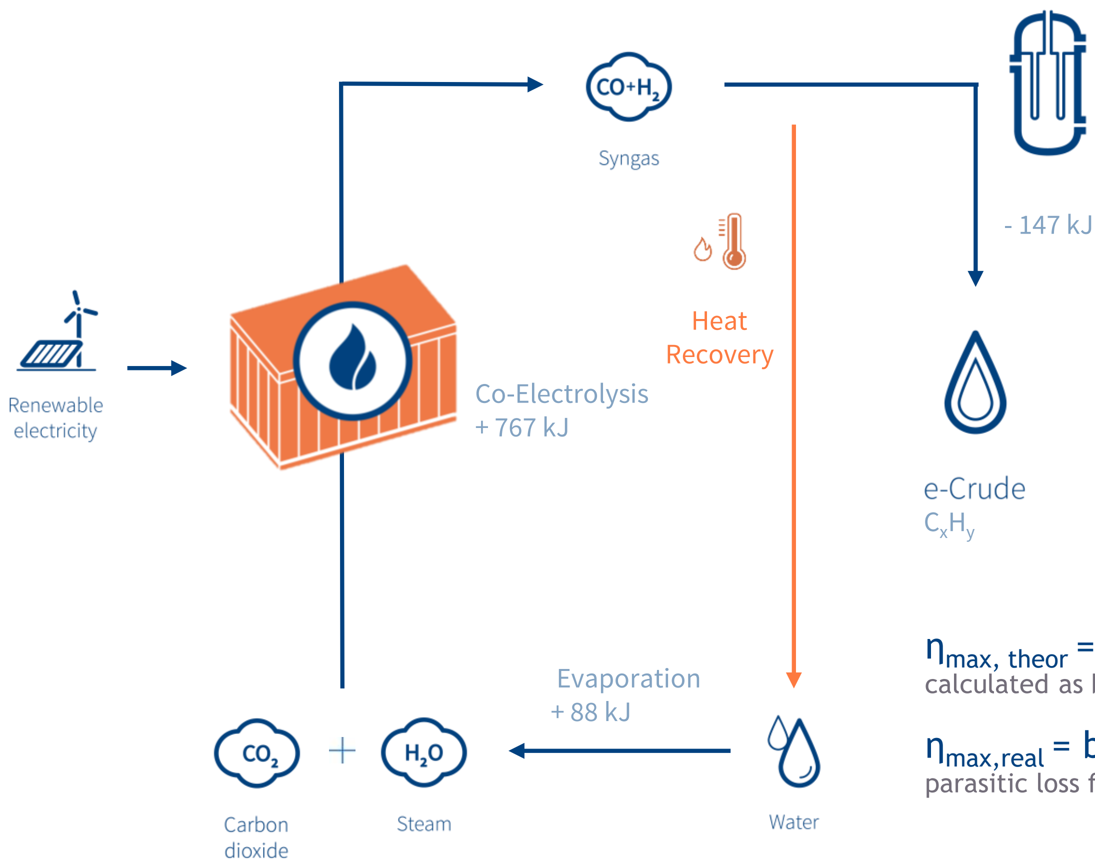
SOEC steam-electrolysis achieves higher efficiency as waste heat can be used

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

$\eta_{max,real}$ = benchmark + 10 % 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
RWGS: Reverse-Water-Gas-Shift-Reaction

Fischer-Tropsch Pathway:
Step 2 Improvement: 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
RWGS: Reverse-Water-Gas-Shift-Reaction

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Sunfire Company

Impressions and Overview

Sunfire - Excecutive Summary

+ Leading provider of electrolysers and fuel cells based on Solid Oxide Technology

+ Serving the emerging gigawatt markets for renewable gases and fuels (e-Fuels, e-Gas, e-Hydrogen)

+ Providing solutions for a variety of fuel cell market segments from micro to mini CHP

+ Delivering game-changer products through highest process efficiency and lowest equipment costs

Company Facts

Knowhow

- ~ 100 Employees
- Skills in Ceramics, Stack + System Production, Engineering, Synthesis Processes, etc.

Patents

- 46 patent families (e.g. »process patent sunfire« WO/2008/014854)

Recognition

- Cleantech 100 Company 2014/2015/2017/2018 (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
- Kanthal Award 2017 for solutions in Sustainability, Quality of Life and Energy Efficiency

Revenues

- Multi-million Euro Revenues in Global Markets since 2011

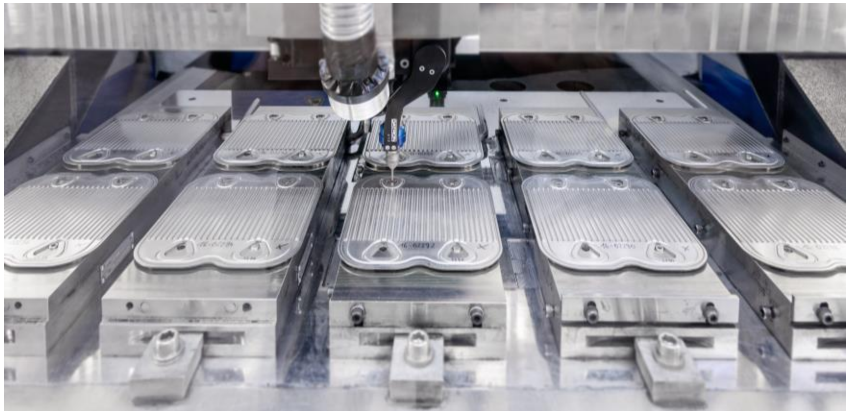
Investors

ELECTRANOVA CAPITAL · idinvest PARTNERS · INVEN CAPITAL CEZ GROUP · KFW · TOTAL

Impression

Sunfire Headquarter in Dresden

e-Fuels plant



Stack production

Test facilities

System Integrators and Customers Worldwide since 2011

Global industry leader in solid oxide technology

- Hundreds of systems installed
- Longest operation in customer applications
- Largest SOC electrolysis installer of the world