Renewable fuels and chemicals from power, CO_2 and steam

20-09-2018 Karl Hauptmeier / Nils Aldag

Investors

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

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

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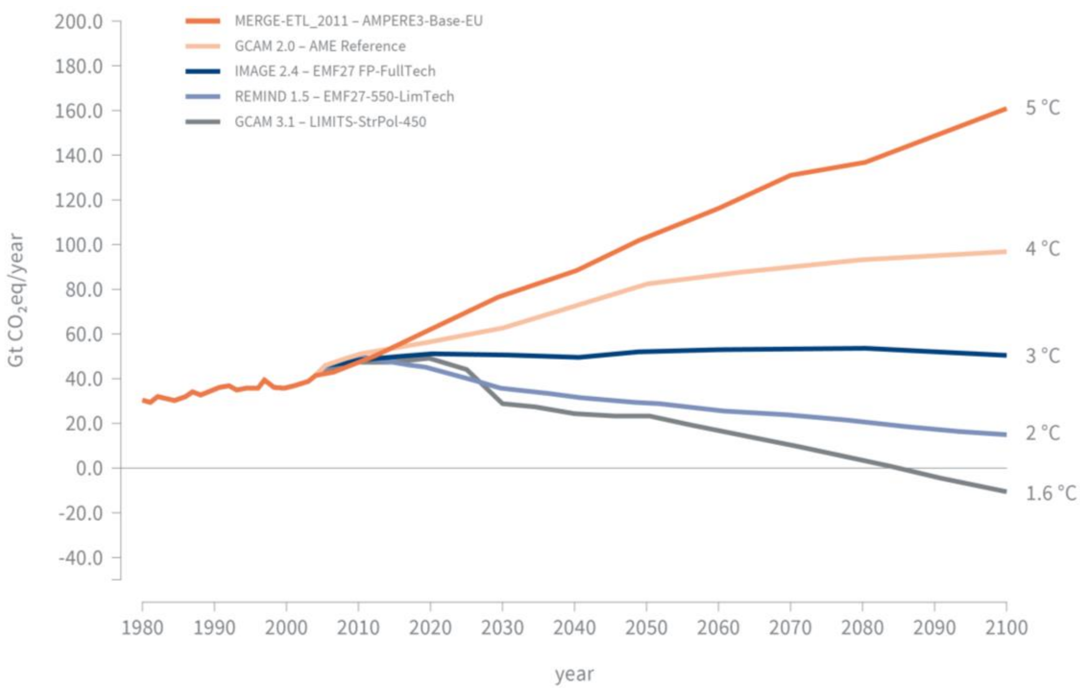
Key Assumptions

- 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

Paris Climate Agreement: The Future has to be Renewable

+ 85 - 100 % renewables needed to reach Paris Climate Target which still leads to significant negative impacts for human civilization



+ 5 °C: End of human civilization

+ 4 °C: Drought in Europe; China, India and Bangladesh mainly desert; Polynesia vanished; American Southwest largly uninhabitable

+ 3 °C: Forests in the Arctic and the loss of most coastal cities

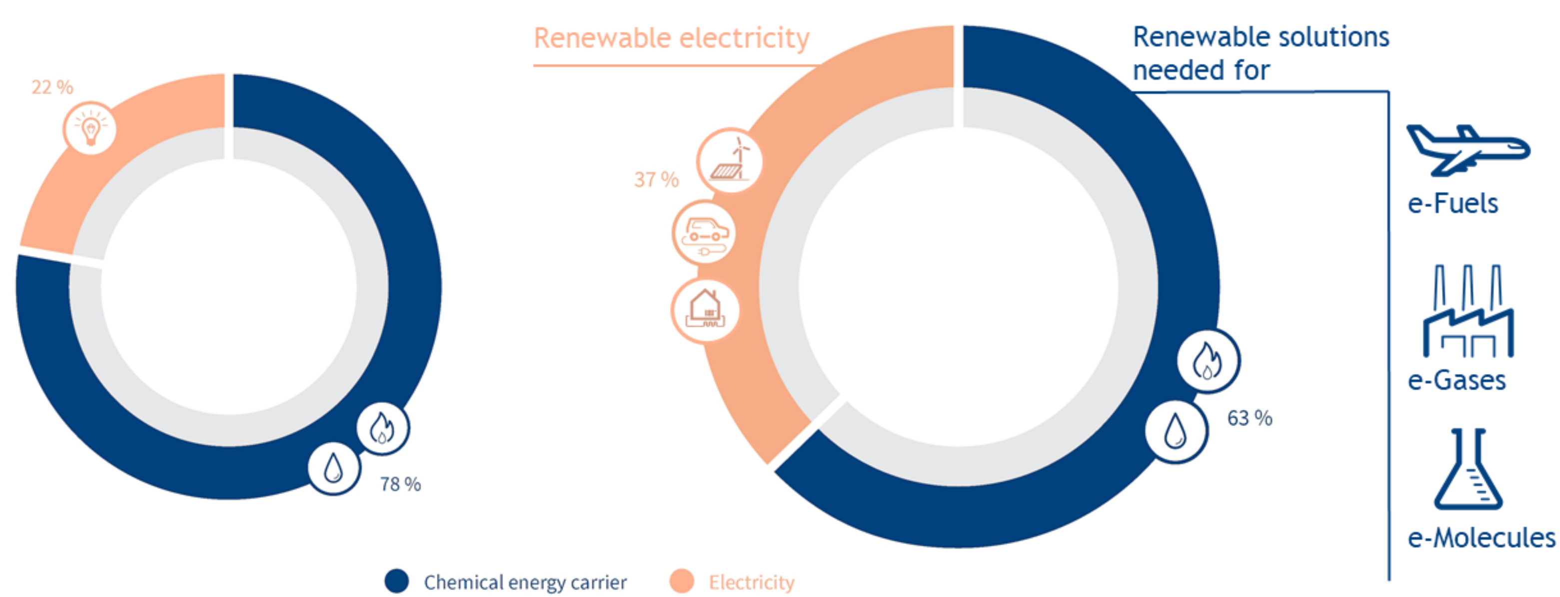
+ 2 °C: Extinction of the world's tropical reefs, sea-level rise of several meters; abandonment of the Persian Gulf

Sources: https://www.pik-potsdam.de/paris-reality-check/
https://www.nytimes.com/interactive/2018/08/01/magazine/climate-change-losing-earth.html

Bringing the Energy Transition to the Next Level

- Even in scenarios with large increase of direct electrification liquid energy carrier remain necessary to cover the global energy needs in 2050

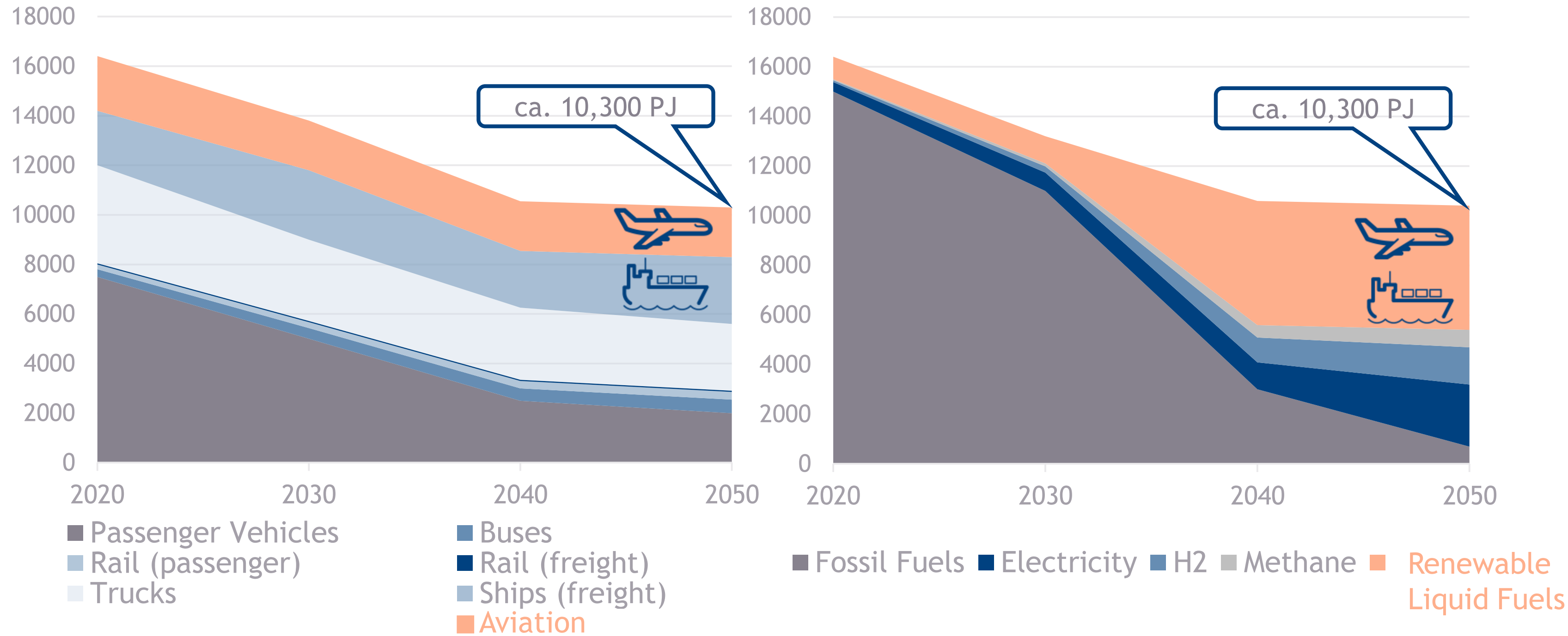
Energy consumption by carrier today **Energy consumption by carrier in 2050**



Source: IEA, June 2017
World Energy 2014-2050, Political economist, 2014

Avaiation - The Prime Example of e-Fuel Necessity

Anticipated primary-energy consumption of the EU transport sector

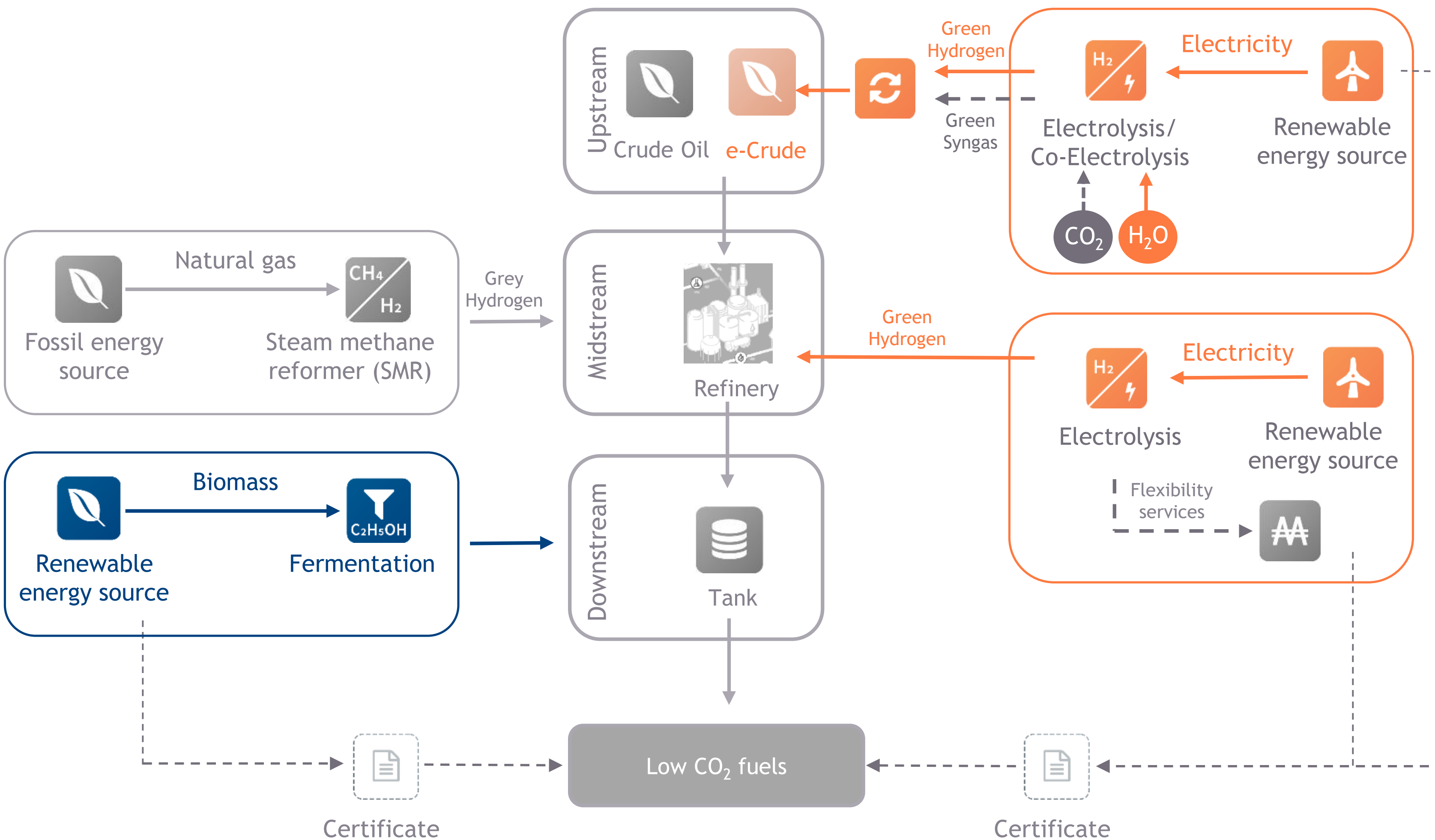


- To achieve CO_2 reduction targets, fossil fuels need to be phased out
- Hard-to-electrify sector will make up 50 % or 5,000 PJ in 2050
- >300 GW of e-Fuels needed in 2050 (>10 GW/a from now)

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

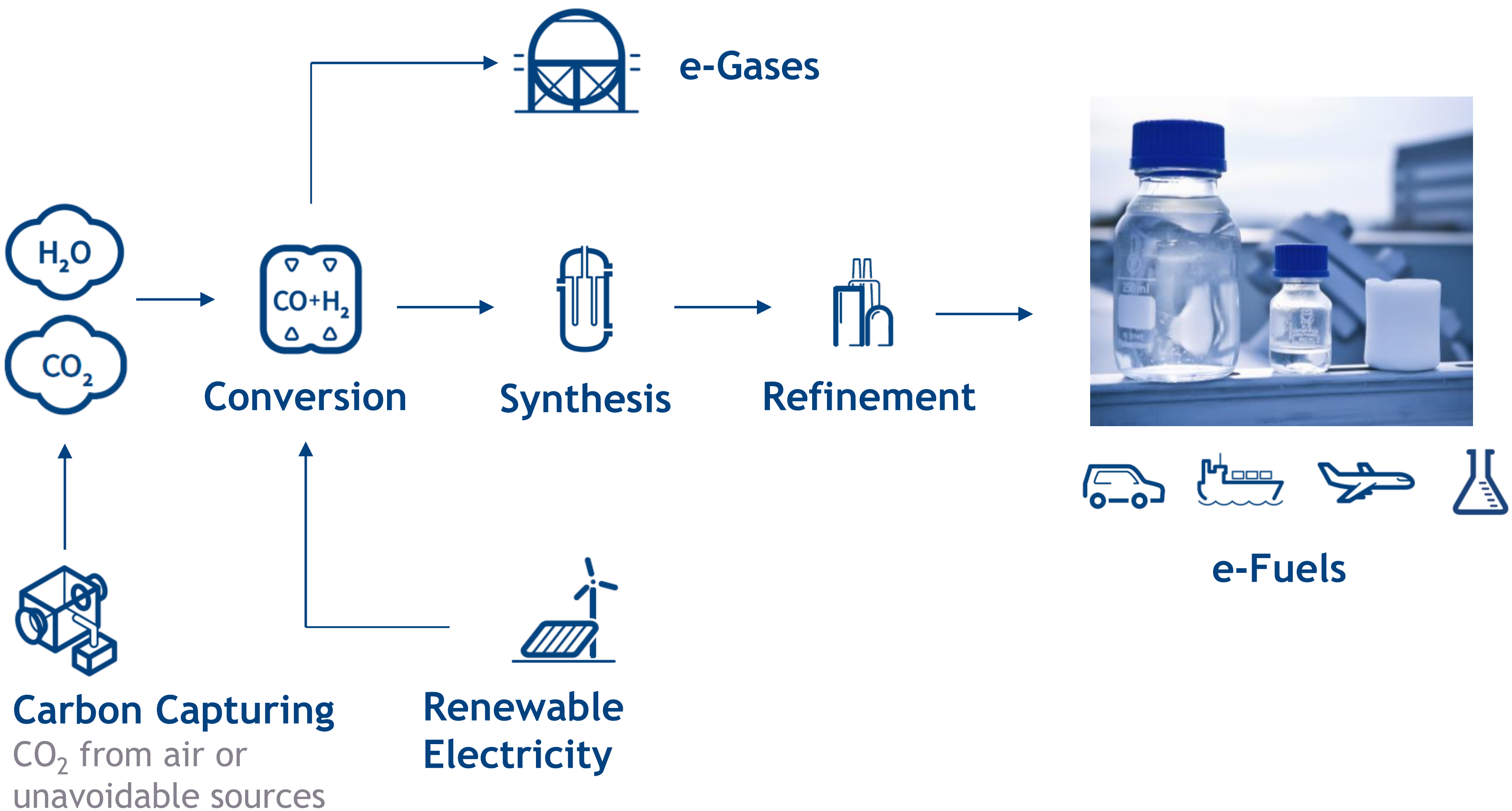
Conventional Process

Advanced Process



Technology

The Power-to-Liquid (PtL) Process



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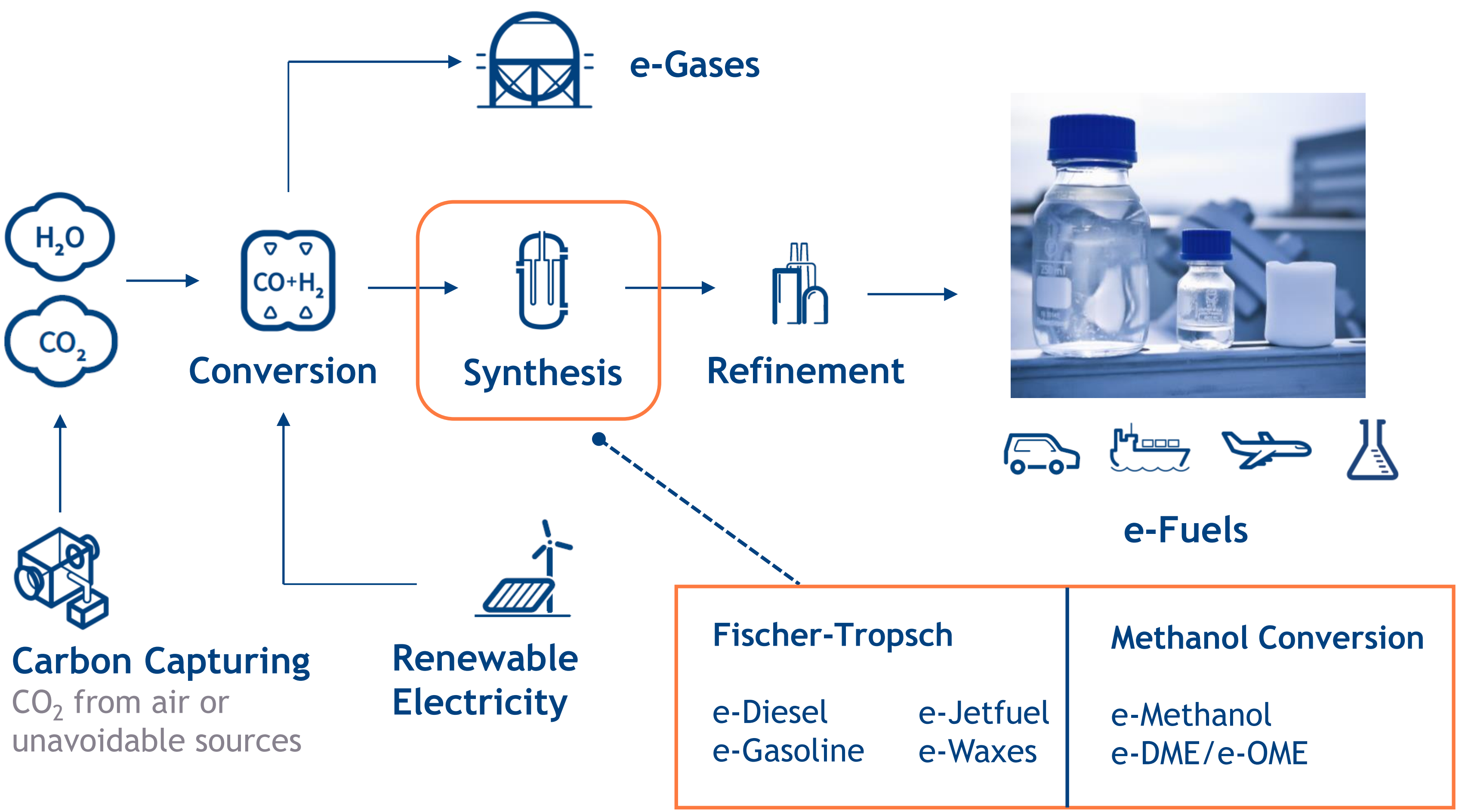

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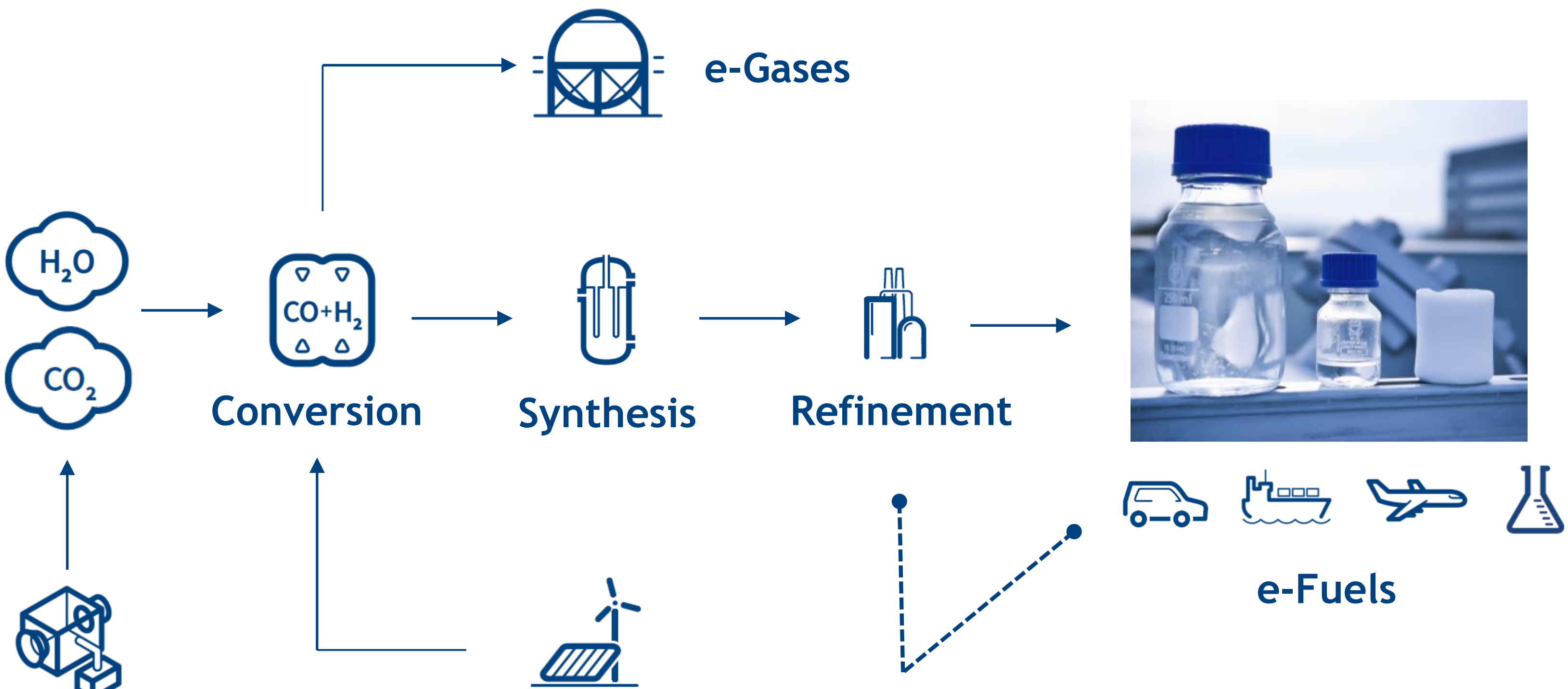
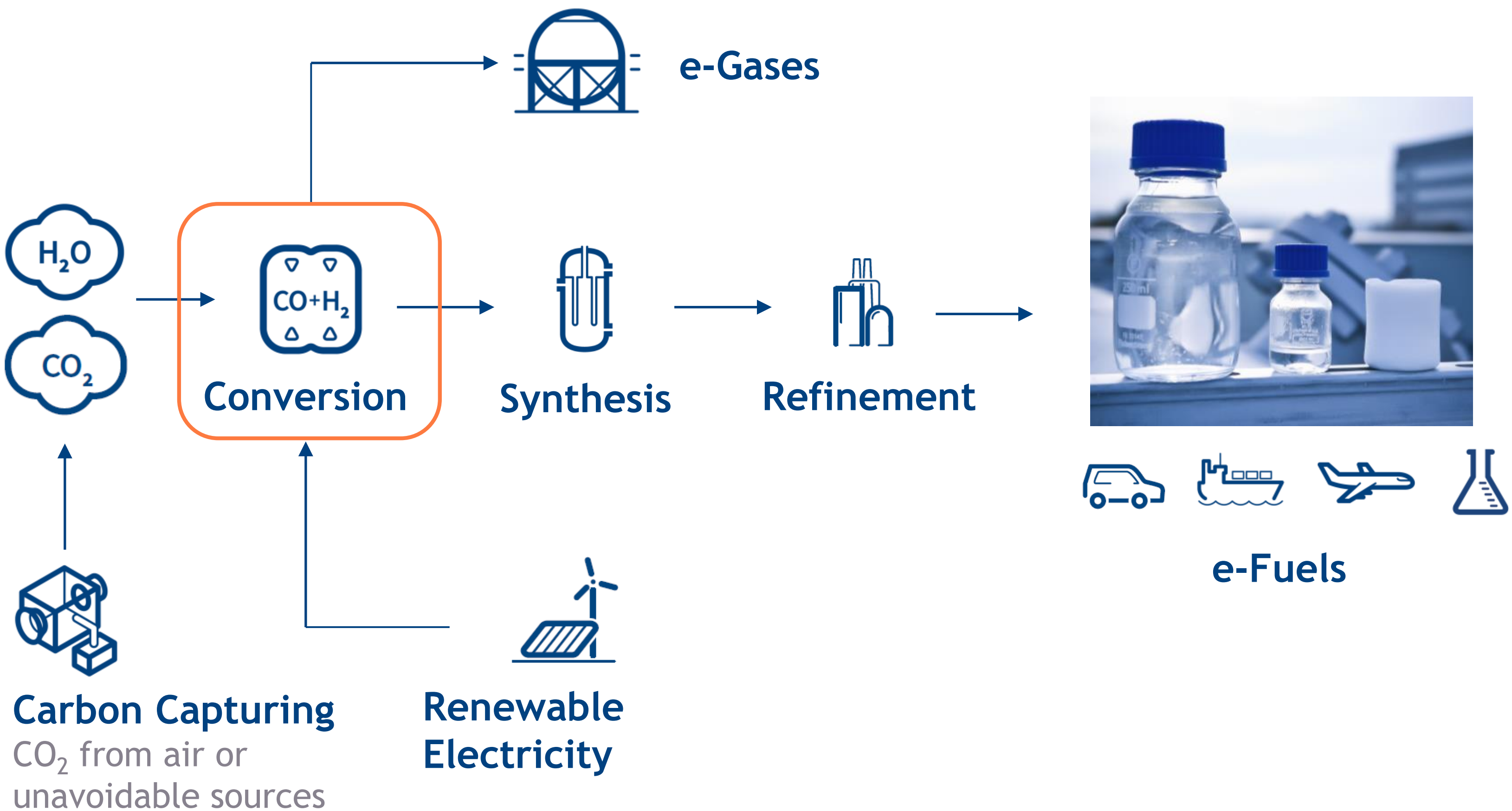


Renewable Liquids: Ready-to-Use

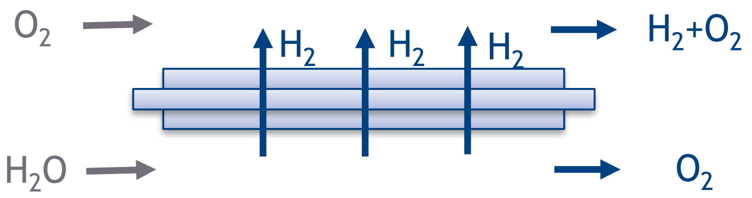
- Direct effect on existing fleet
- Infrastructure compatible
- No-regret measure

The Power-to-Liquid (PtL) Process



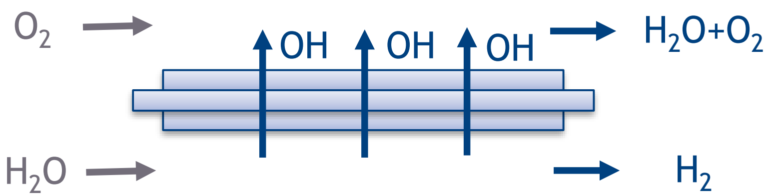
Conversion: Three different electrolysis types (simplified)

PEM electrolysis



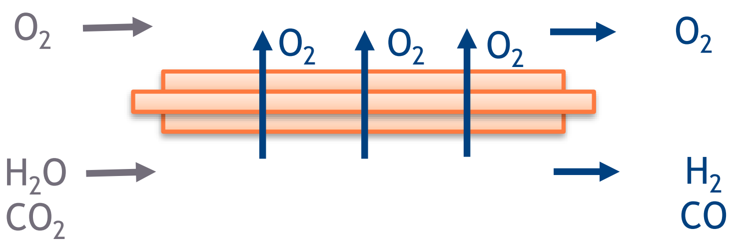
- Hydrogen membrane
- Efficiency: 50-60%$_{LHV}$ or 5-6 kWh/Nm^3
- Low temperature (<100°C)
- Flexible operation from part load to full load (0%-300%)

Alkaline electrolysis



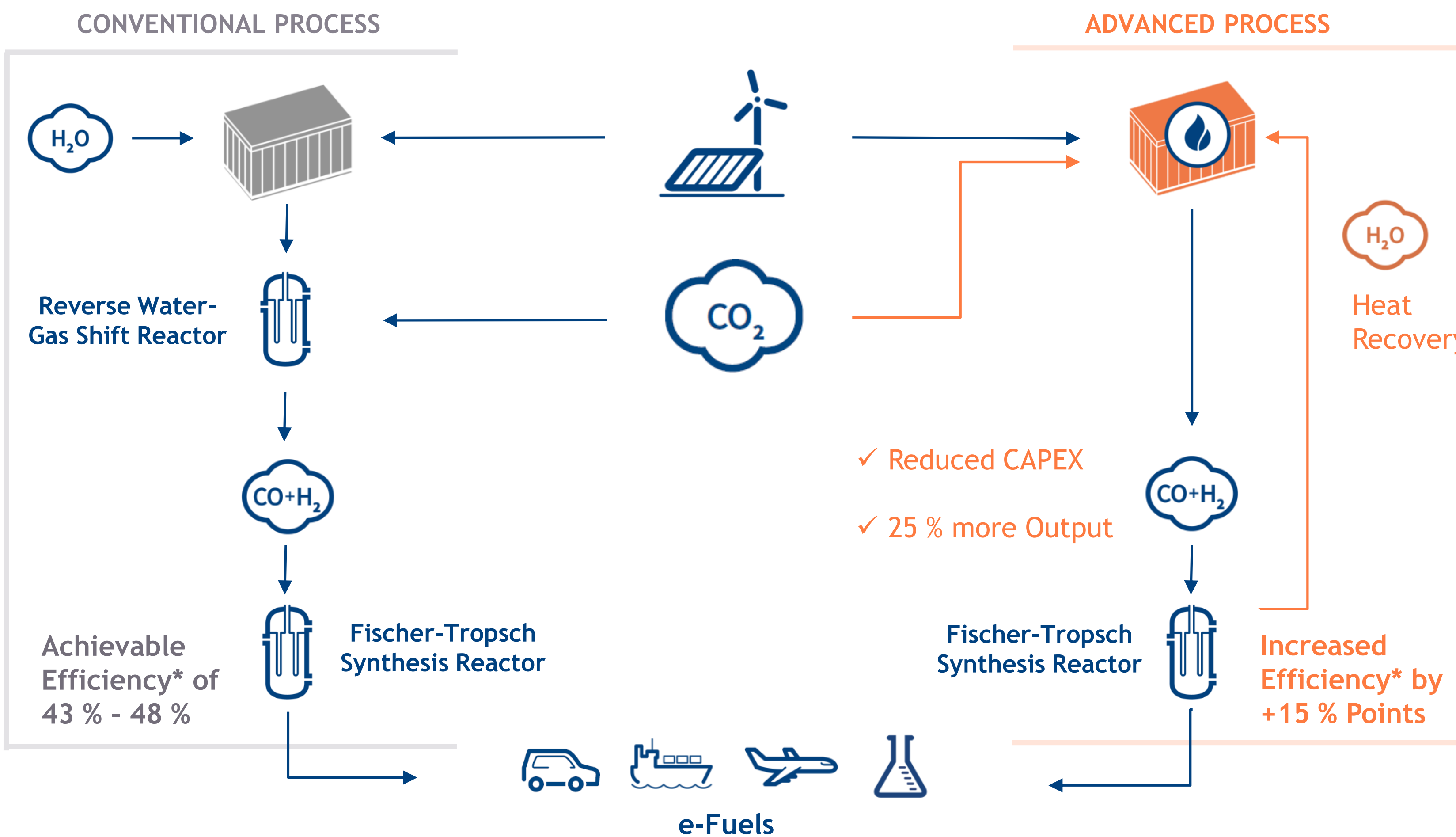
- Hydroxide membrane
- Efficiency: 50-60%$_{LHV}$ or 5-6 kWh/Nm^3
- Low temperature (<100°C)
- Mature technology

SOEC Steam-electrolysis



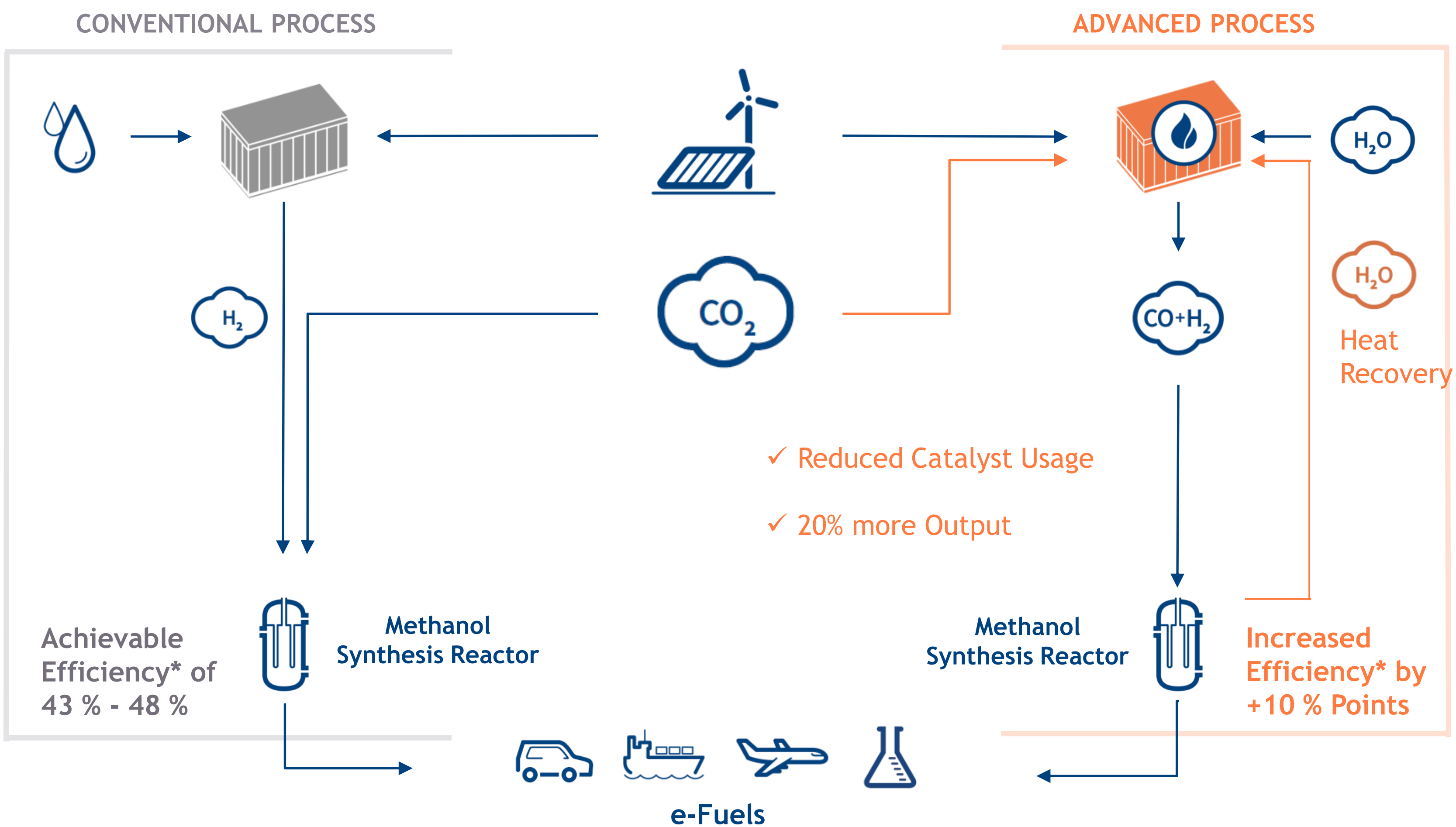
- Oxygen membrane
- Efficiency: 82%$_{LHV}$ or 3.7 kWh/Nm^3
- High temperature (850°C)
- Ability to electrolyse CO_2
- Less mature, most promising economics

PtL Technology Comparison: The Fischer-Tropsch Pathway

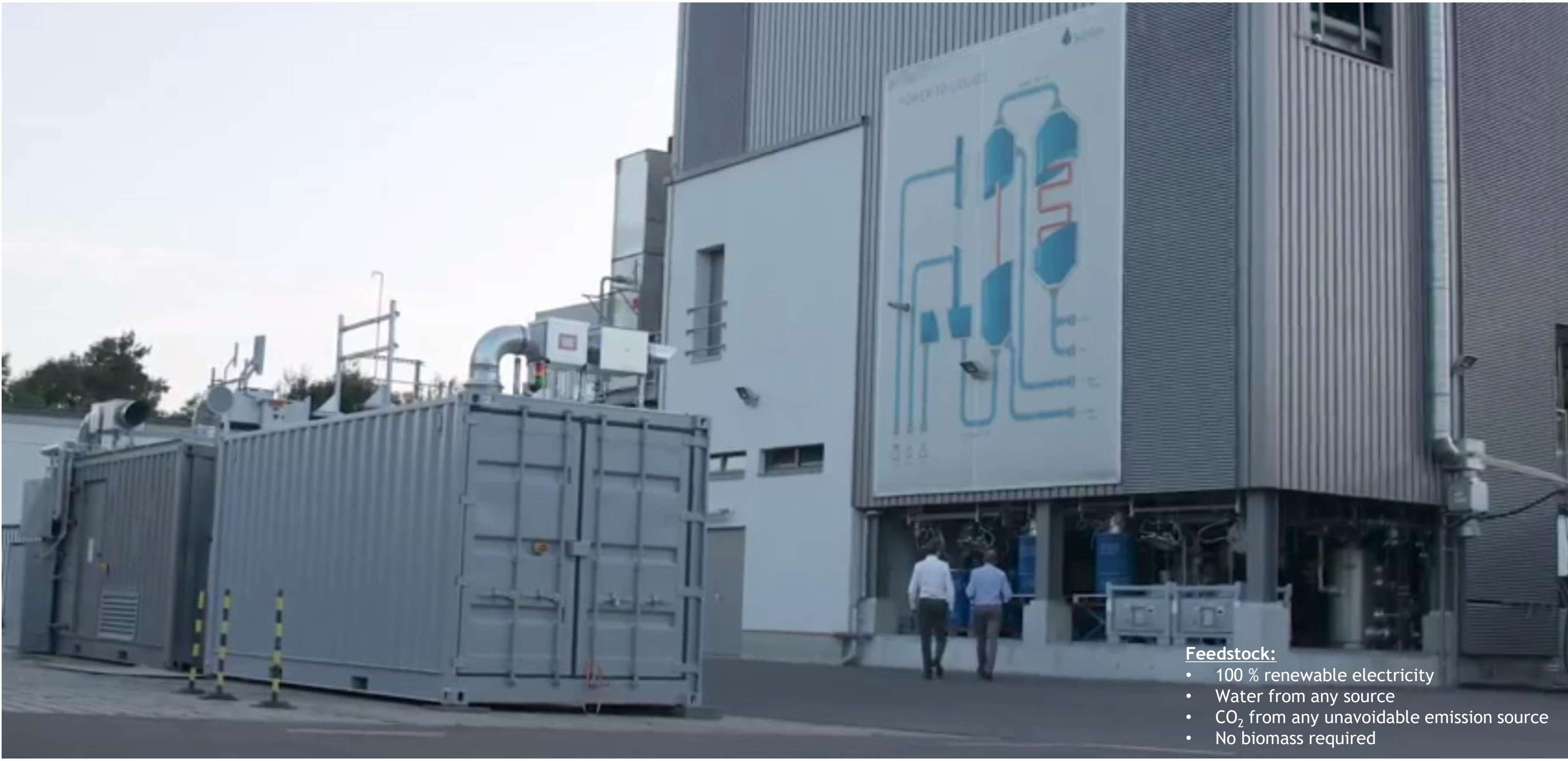


*lower heating value of the fuel (620 kJ/kmol) compared to the electrical energy input

Technology Comparison: Methanol Conversion



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



Sunfire PtL Demonstration Plant

- Sunfire e-Crude production for AUDI AG for e-Diesel, e-Gasoline and e-Wax
- Start of operation: 2014
- Max. production volume: 60 t/a e-Crude
- Audi confirms eco-friendliness (ca. 85 % CO_2 reduction)

Cost Comparisons

Cost Projections in Recent Studies

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

BOSCH

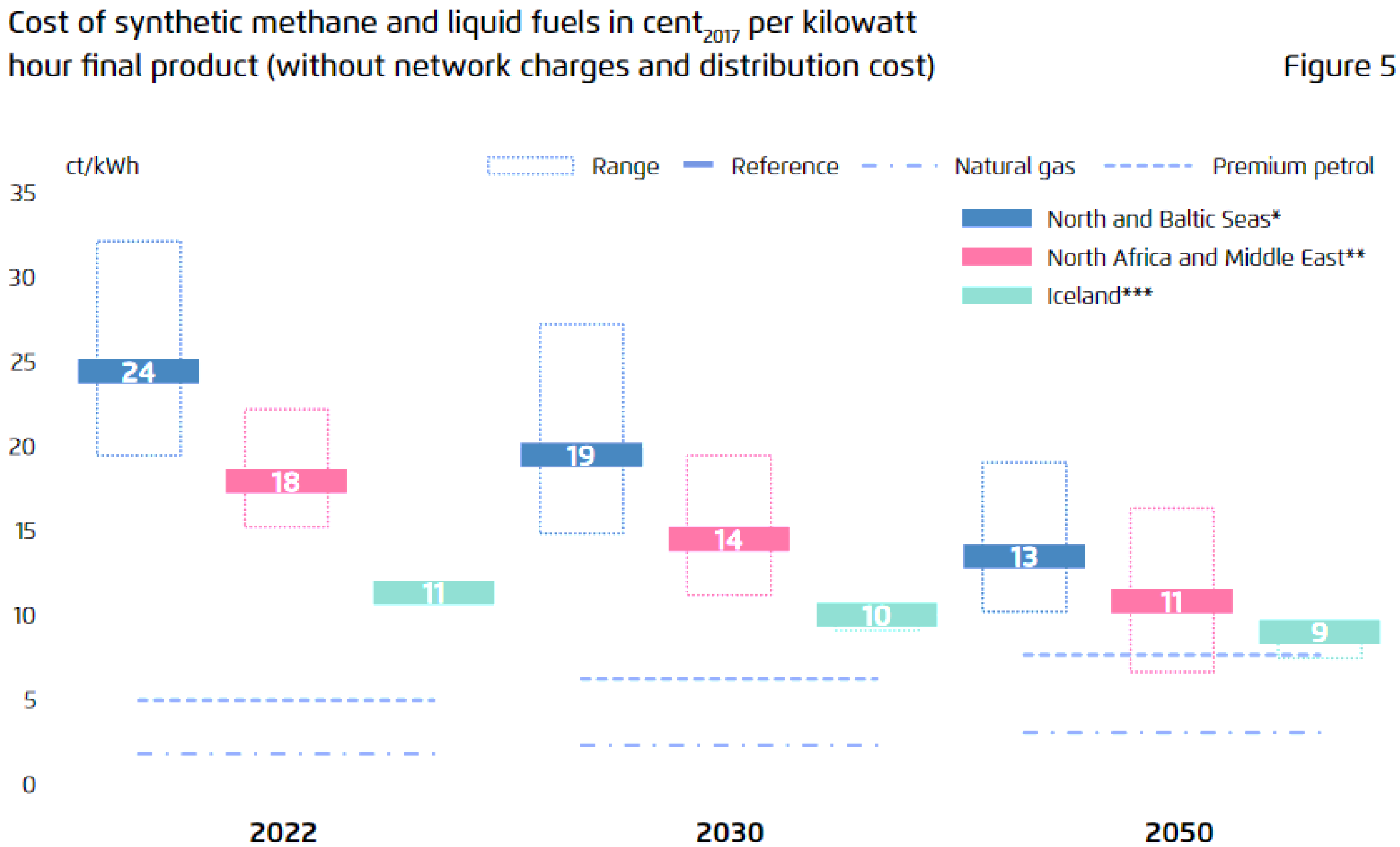
	year	PtL cost [€/MWh]	electricity [ct/kWh]	full load hours	efficiency
LBST[1)]	2016	~ 160	5,5	6.500	~ 45 %
UBA[2)]	2016	~ 140	4,0	3.750	~ 47 %
LUT[3)]	2016	~ 86	1,94	6.840	~ 57 %
Dena/LBST[4)]	2017	~ 100	3,4	6.840	~ 48 %
IWES[5)]	2017	~ 115	3,8	6.292	~ 48 %

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**

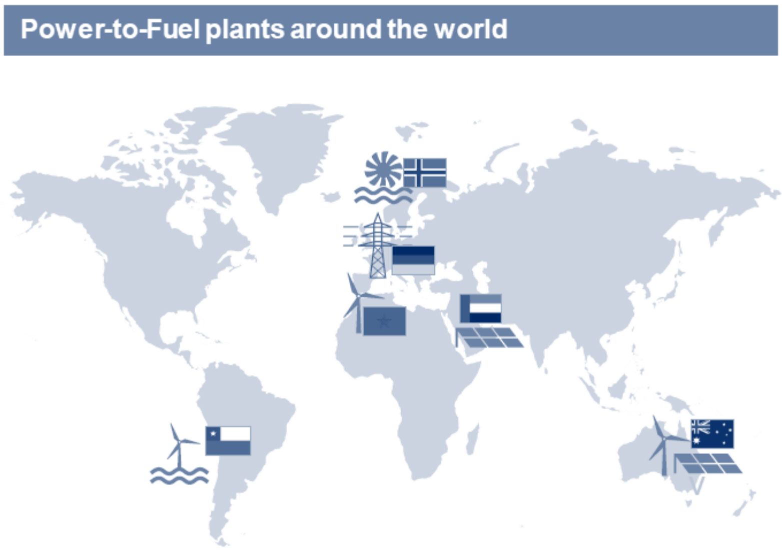
+ Studies converge for assumptions
+ Key driver for costs is the price of electricity and operation hours
+ Sunfire agrees with electricity costs, but sees lower full load hours and higher efficiencies

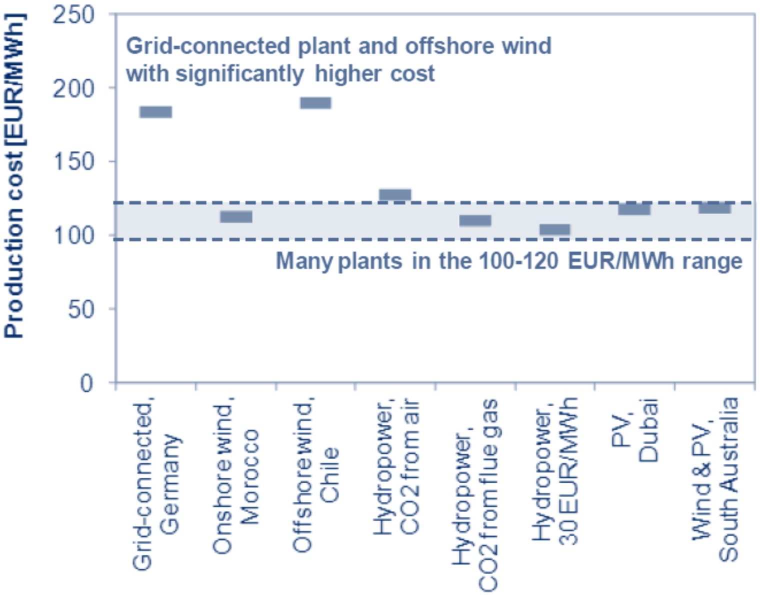
Cost Projections in Recent Studies



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

Cost Projections in Recent Studies





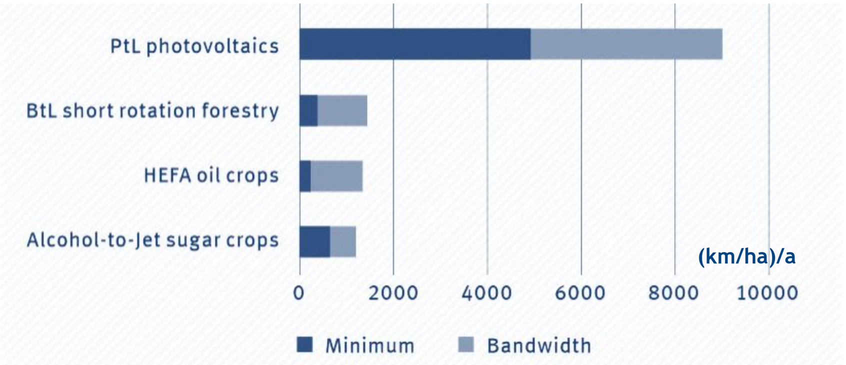
+ Production price range between 100-120 €/MWh (0.9-1.1 €/l) expected

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

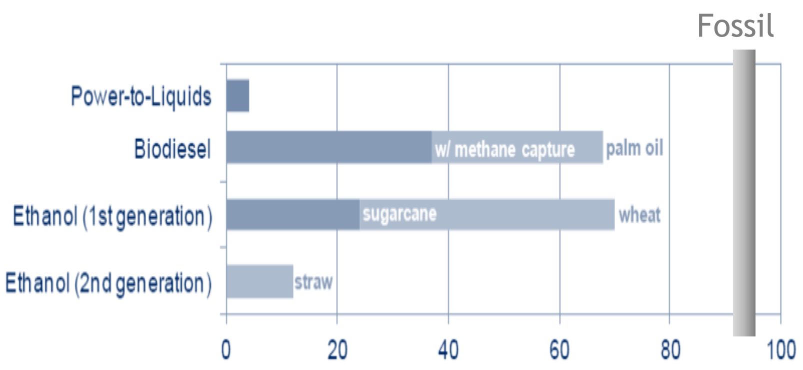
Summary

e-Fuel - Highest Potential and lowest Ecological Footprint

- **Usable in hard to electrify sectors,** such as chemicals, aviation, shipping and long distance transport
- **8x more efficient use of land area** compared to biological alternatives
- **85 % reduction in CO_2 emissions** compared to fossil fuel
- **Clean combustion:** No Sulphur content, reduced particle emissions



Achievable air mileage for an A320neo per ha of land



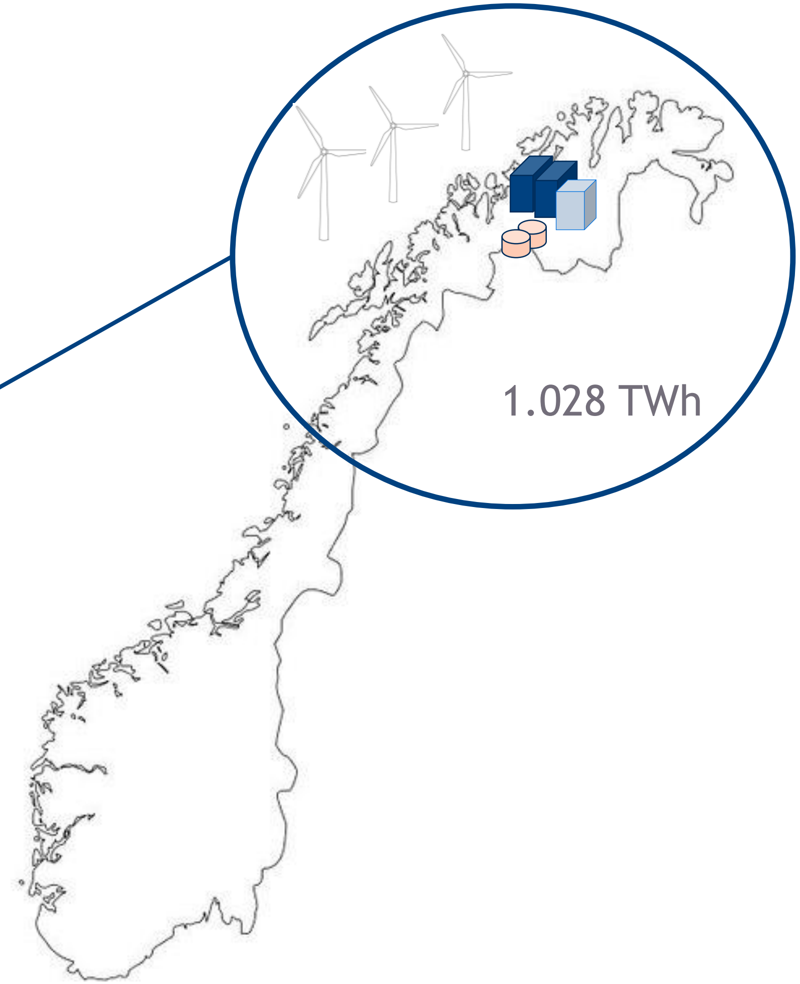
Life cycle green house gas emissions (gCO2eq/MJ)

Sunfire makes use of existing assets instead of changing processes and infrastructures individually.
No disinvest – no stranded assets

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

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

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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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
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Patents

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

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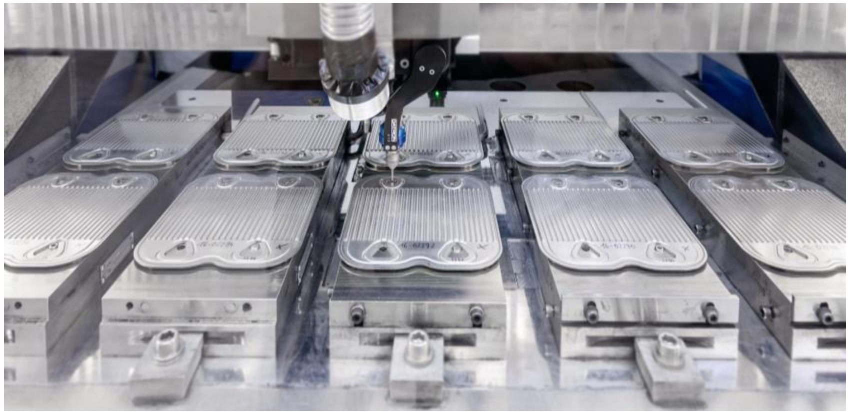
Impression


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

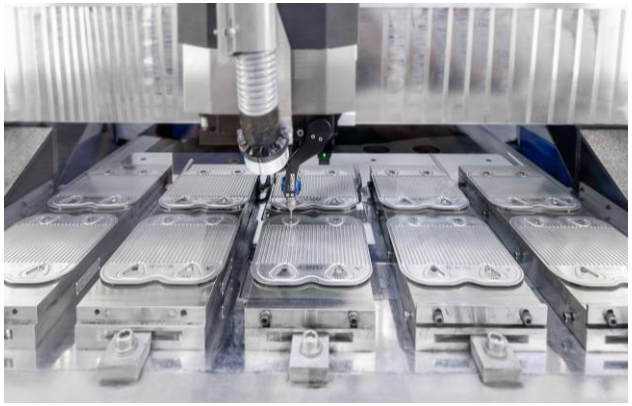
Backup

Details on the Fischer-Tropsch Pathway

Core USPs of Solid Oxide Electrolysers

- Highest efficiency in hydrogen production (82 $\%_{LHV}$ or 3.7 kWh/Nm^3) compared to legacy technologies such as PEM and Alkaline
- Direct conversion of carbon-dioxide to CO in electrolysis mode via co-electrolysis
- Flexible continuous adjustment of output from part load to full load (10 % - 125 %) in a short timeframe

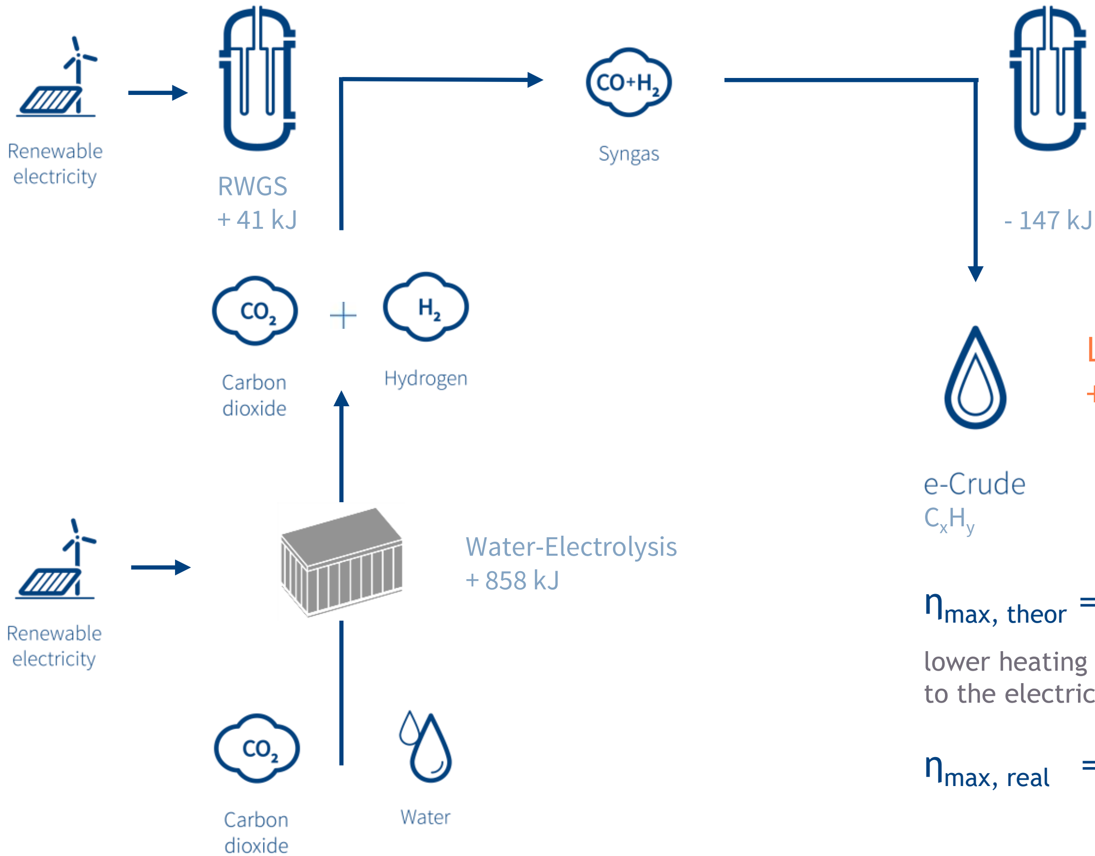
Sunfire promises low costs, high reliability and readiness to scale.



Stack Production in Dresden

System testing in Dresden

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



LHV of fuel
+619 kJ/kmol

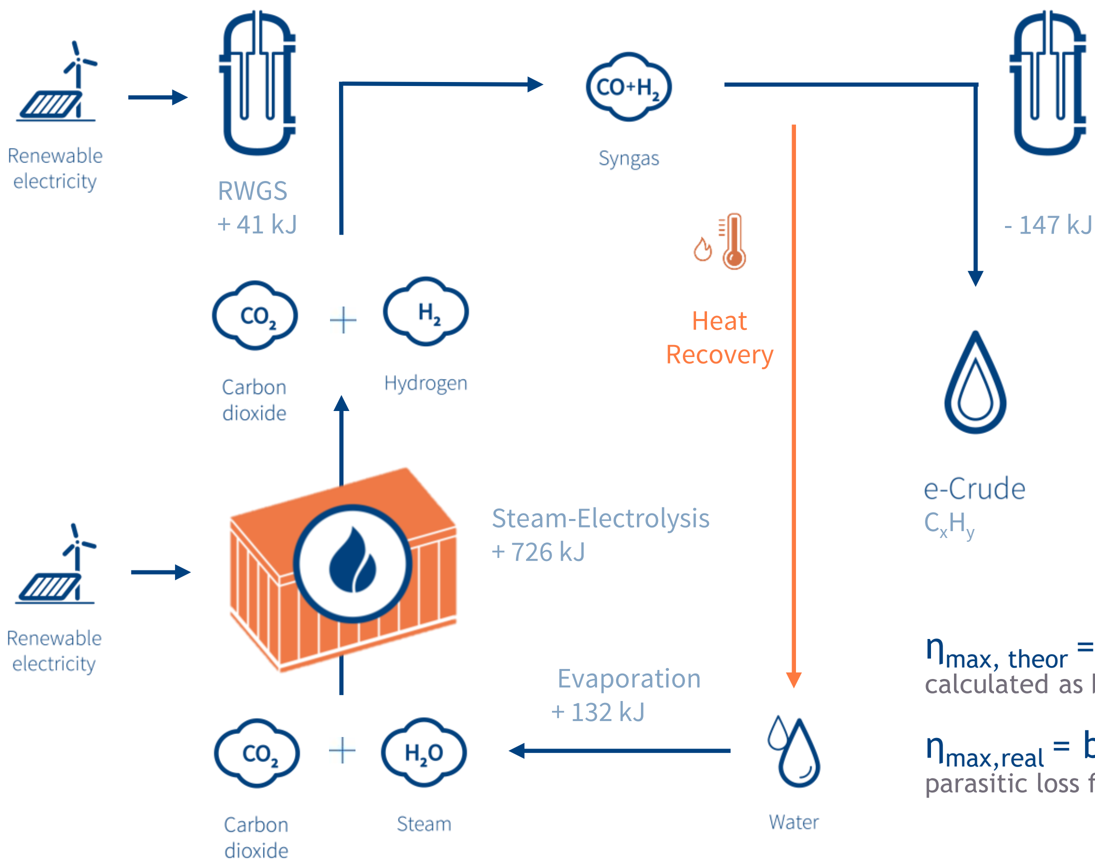
$\eta_{max,\ theor}$ = 69 %

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: Steam-Electrolysis + RWGS + Synthesis



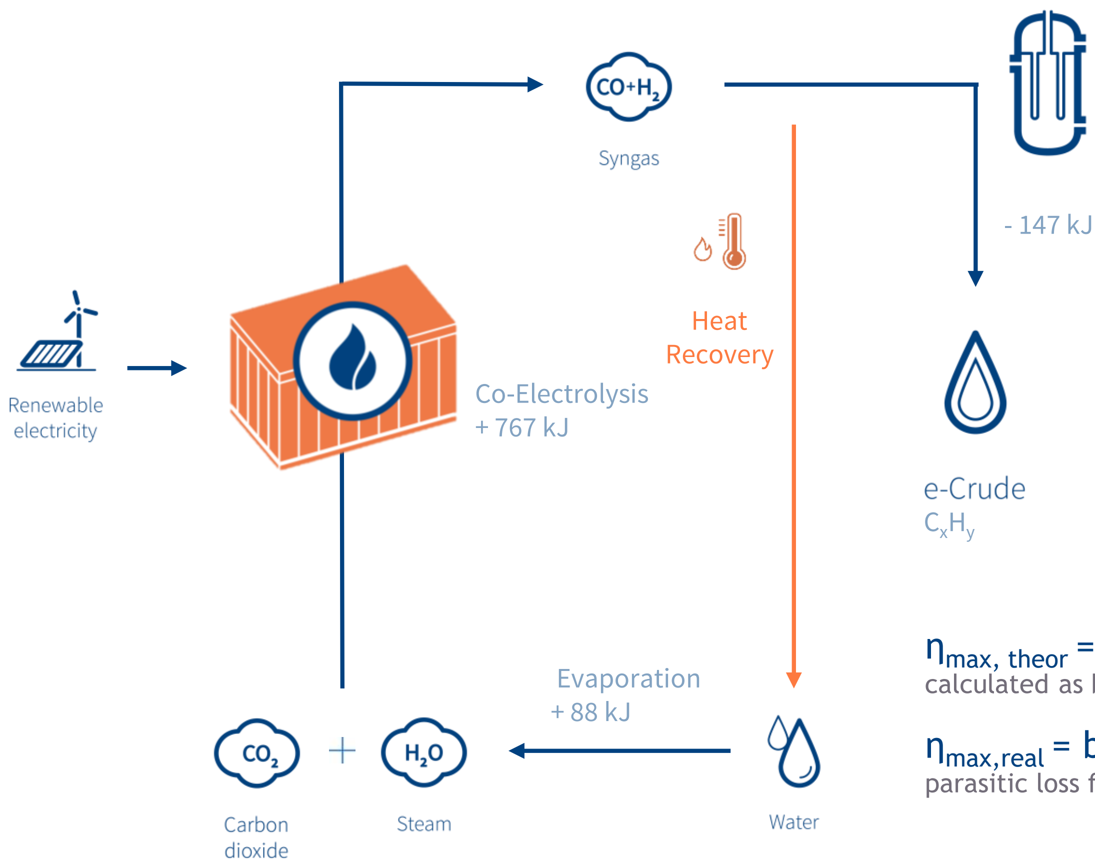
SOEC steam-electrolysis achieves higher efficiency as waste heat can be used

$\eta_{max,\ theor}$ = 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