PtL for Aviation

Erneuerbarer Kraftstoff aus CO2, Wasser und Strom für eine saubere Luftfahrt

Necessity and Opportunity to mitigate Climate Change

18-09-2018 Klaus Ullrich

Investors

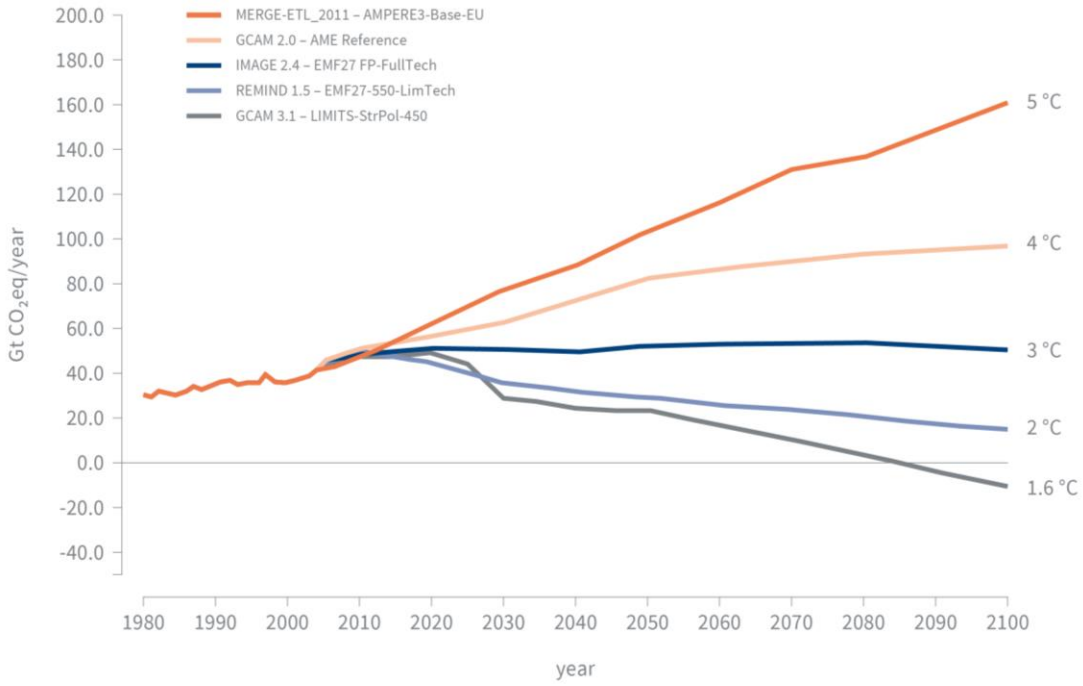
Sunfire – Excecutive Summary

- 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**

The Objective: Mitigating Climate Change

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

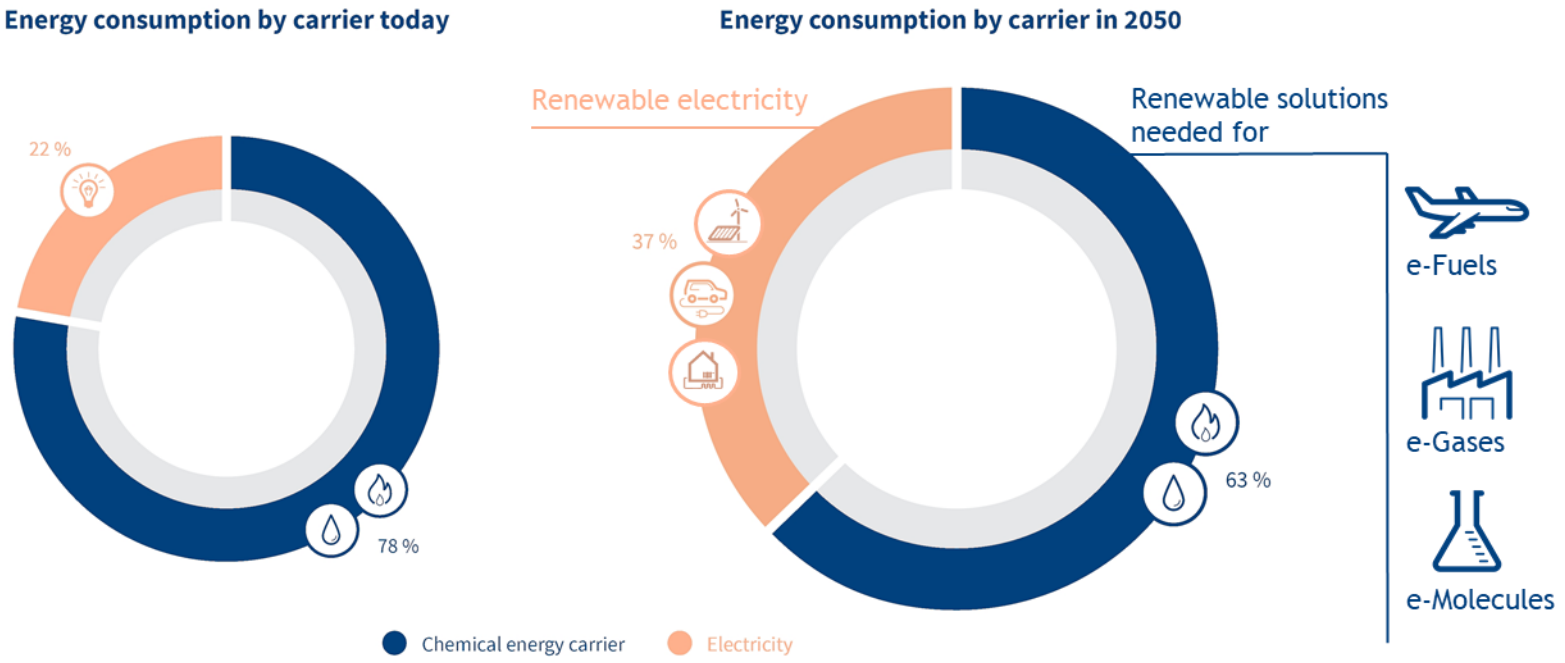
+ 3 °C: Forests in the Arctic and the loss of most coastal cities

+ 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

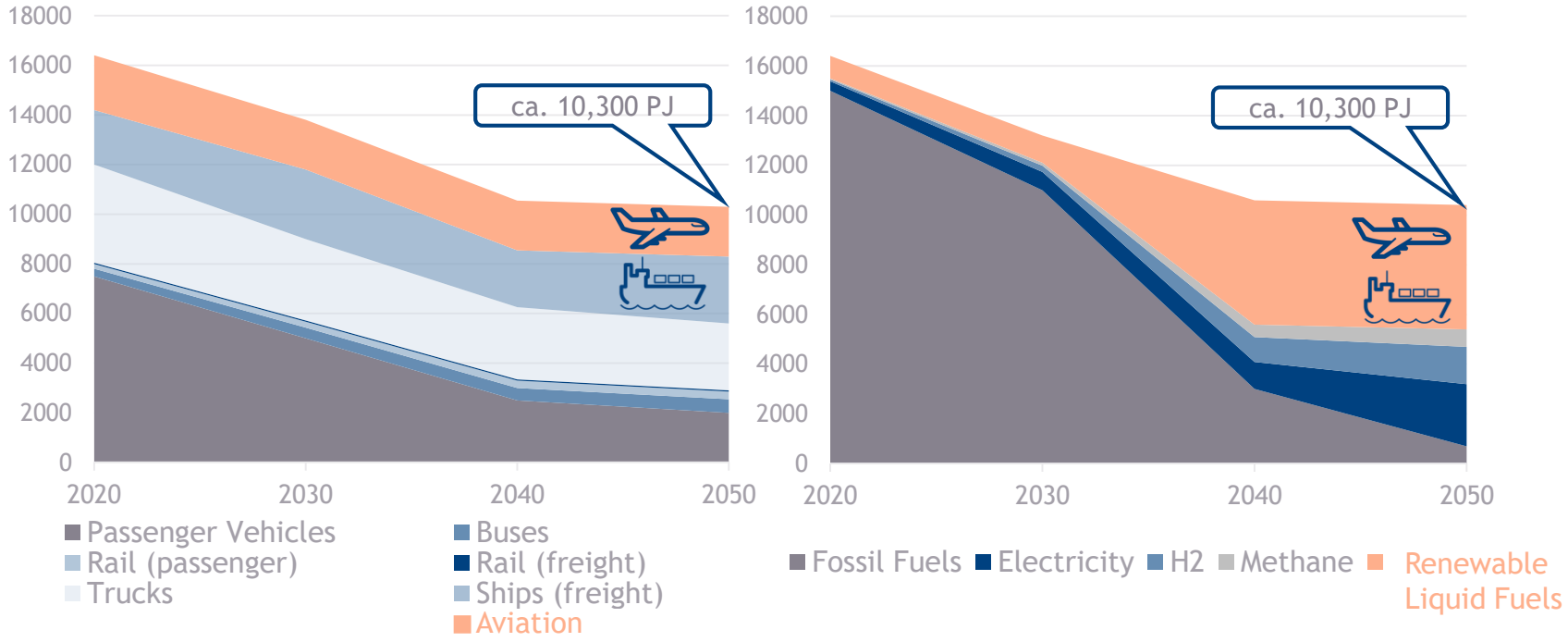
+ Even in scenarios with large increase of direct electrification liquid energy carrier remain necessary to cover the global energy needs in 2050



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

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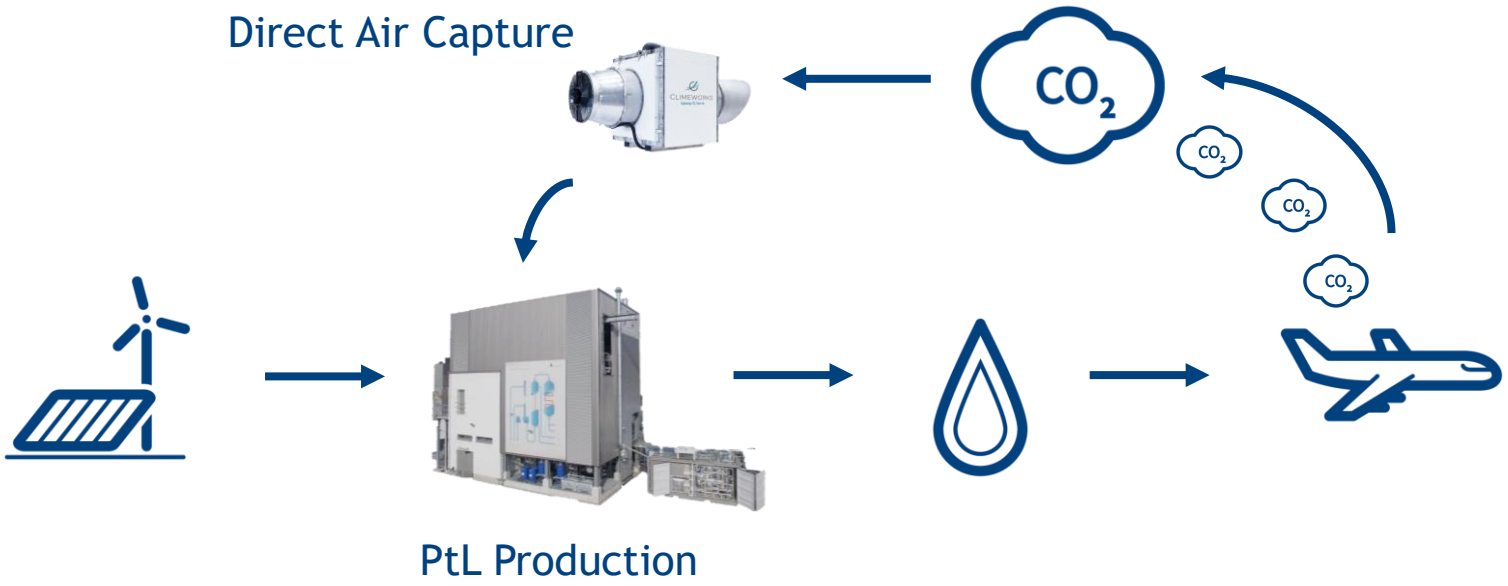
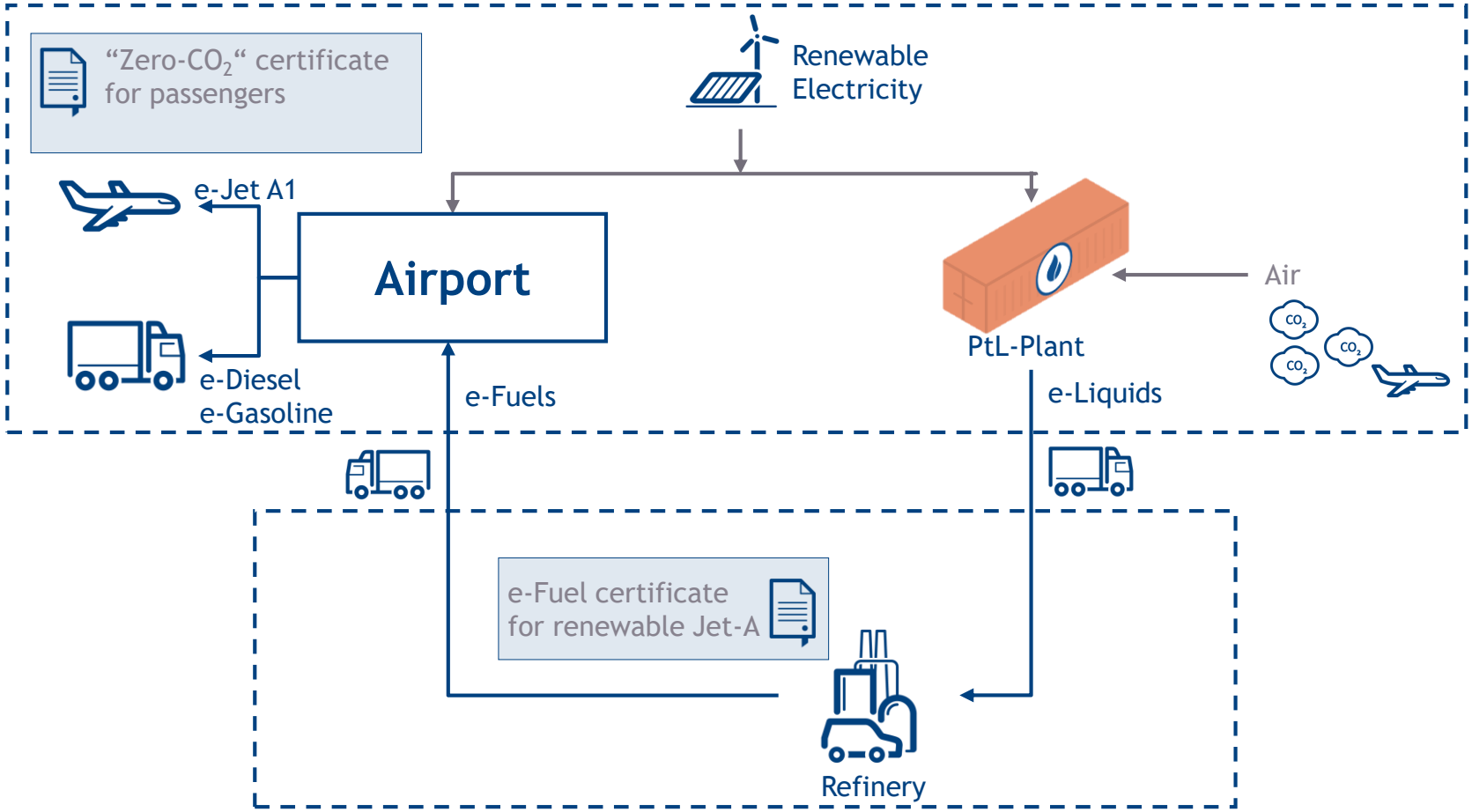
The Solution: Power-To-Liquid

CO_2 neutral Aviation - A reality already today!



+ Jet-A Fuel from renewable energy, CO_2 and Water
+ Air to Tank – Tank to Air: The perfect CO_2 Recycling Loop
+ No Adaptation of Aircrafts nor Infrastructure needed!

Lokal Production of CO_2-neutral Jet-A



e-Fuel - Highest Potential and Fastest Scale Up

- Zero cost for infrastructure
- ASTM certified and drop-in capable (up to 50 %)
- 85 % reduction in CO_2 emissions compared to fossil fuel
- Clean combustion: No Sulphur content, reduced particle emissions

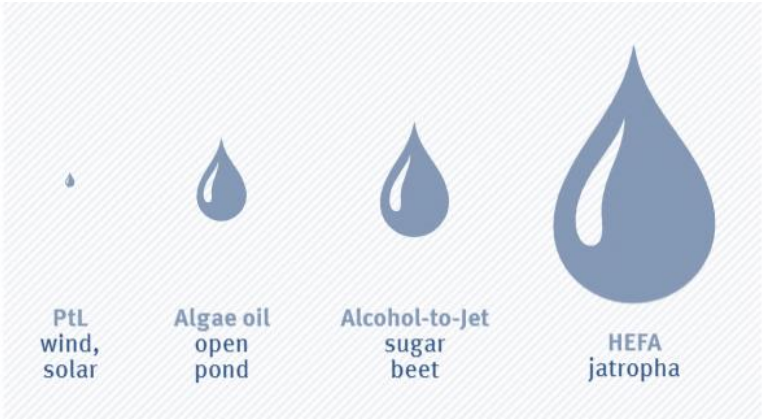
Sunfire makes use of existing assets instead of changing processes and infrastructures individually.
No disinvest – no stranded assets

Jet-A compatibility of Sunfire e-Fuel tested within Demo-SPK Project of the German Federal Ministry of Transport

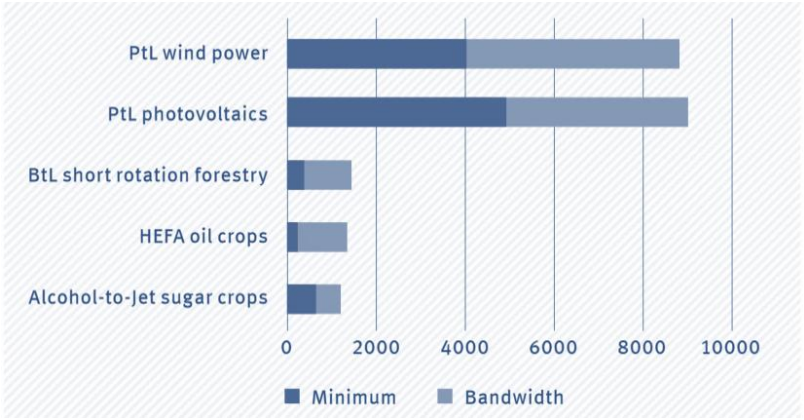
Source: German Federal Environment Agency - **Power-to-Liquids, September 2016**
Tremel (2018) - Electricity-based fuels, ISBN: 978-3-319-72458-4, SpringerNature

e-Fuel - The most Ecological Option for Aviation

+ Negligiable water consumption
+ 8x more efficient use of land area compared to biological alternatives



Volumetric representation of water consumption for different renewable Kerosin solutions



Achievable Air-Milage for a A320neo per ha of land

Source: German Federal Environment Agency - **Power-to-Liquids, September 2016**

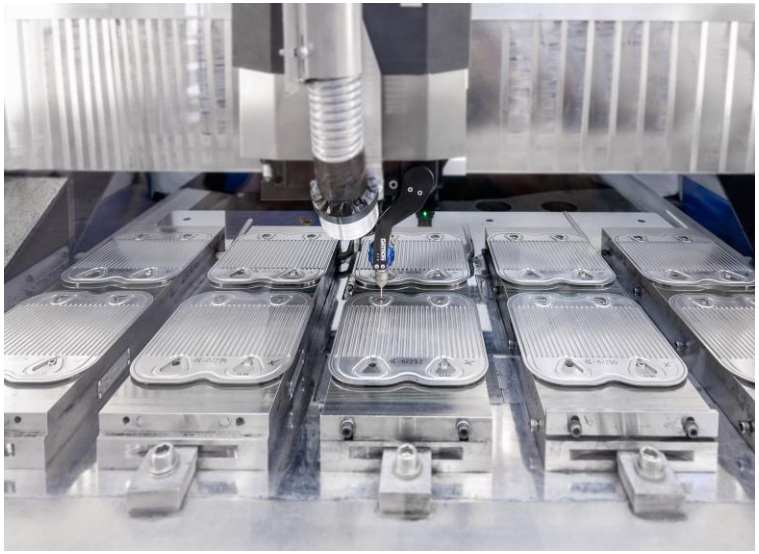
The Technology:
Cost Efficient through Sunfire Design

Core USPs of Solid Oxide Electrolysers

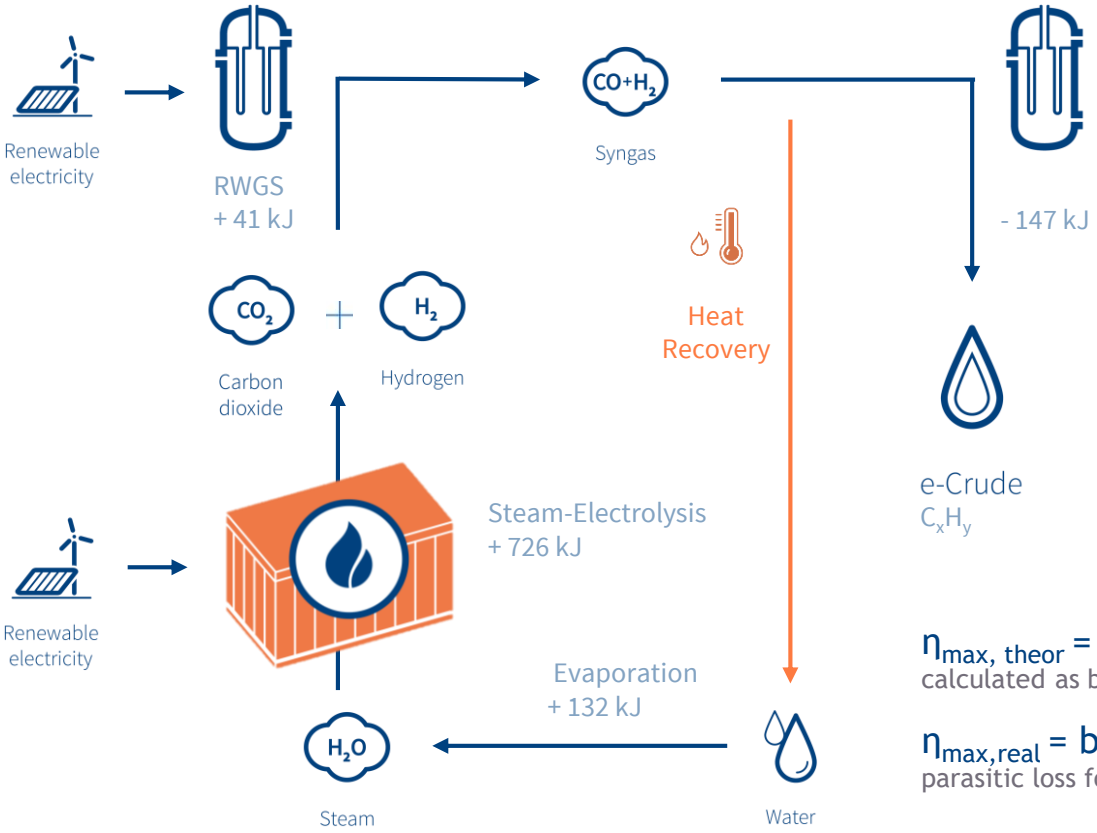
+ **Highest efficiencies** leading to lowest total cost of ownership (TCO)

+ **Direct conversion of carbon molecules** to provide clean solutions for the energy transition in all sectors

+ **Flexible operation** for adjustments of output from part load to full load in a short timeframe



Step 1 Improvement: Steam-Electrolysis + RWGS + Synthesis



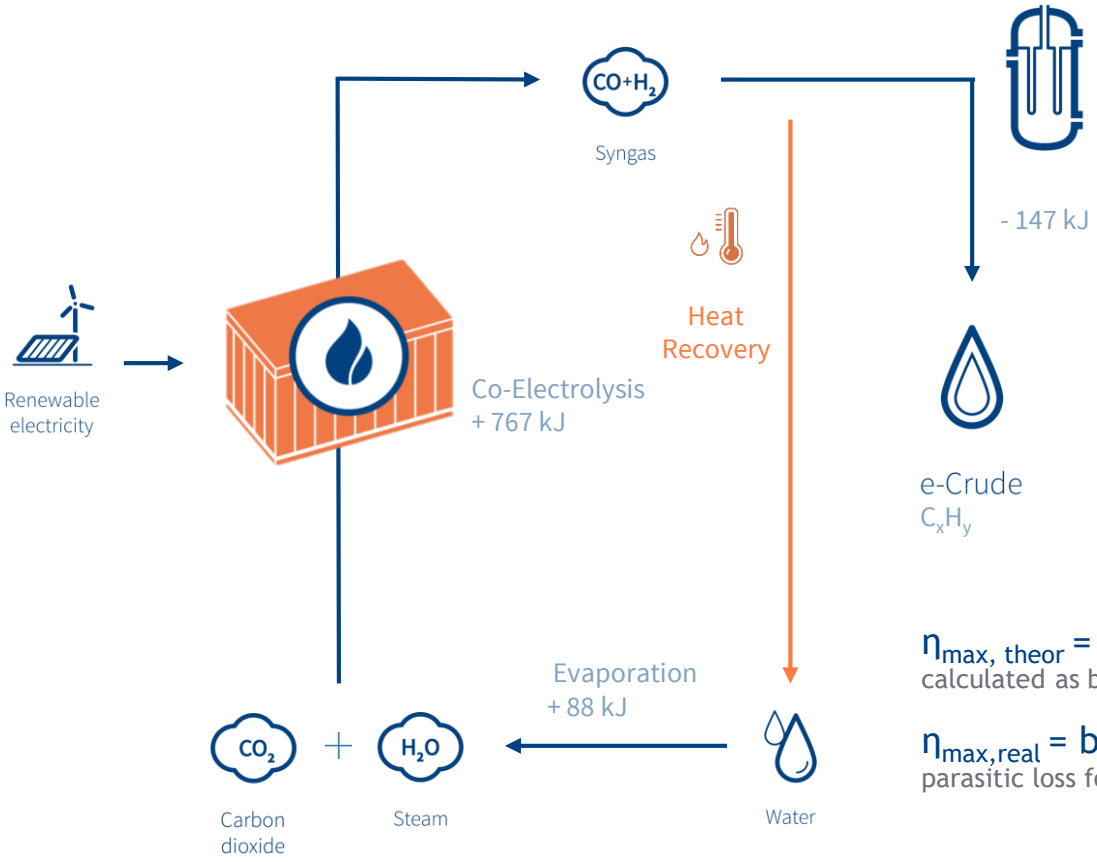
SOEC steam-electrolysis achieves higher efficiency as waste heat can be used

$\eta_{max,\ theor}$ = 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

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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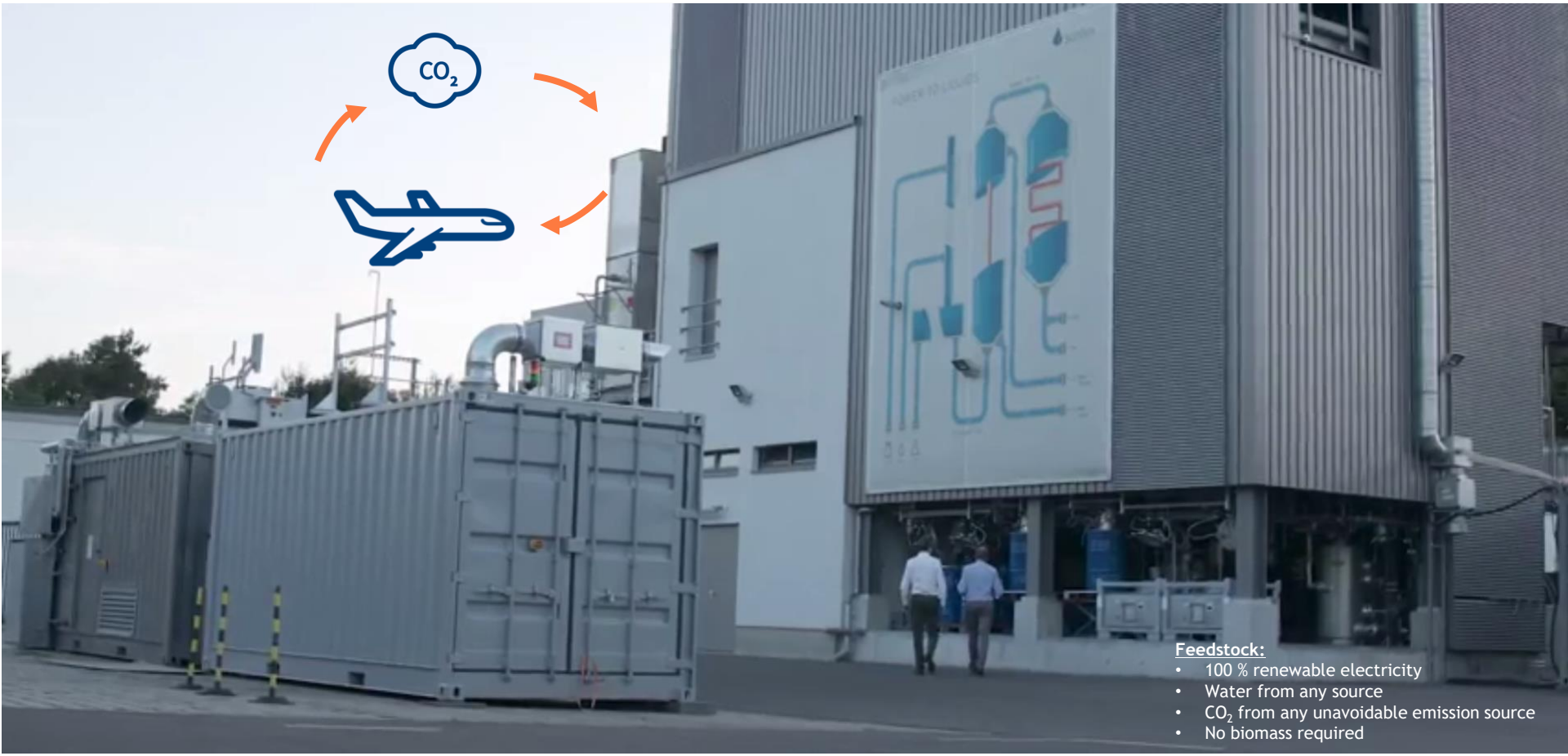


Sunfire PtL Demonstration Plant

- 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 Outlook

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 %

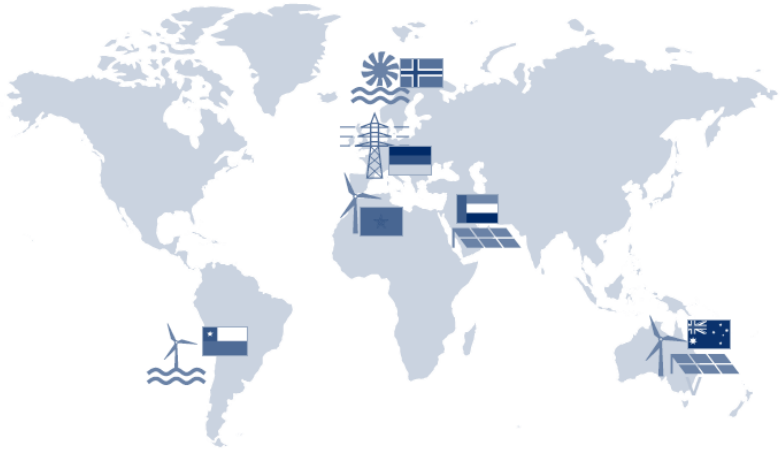
1) Ludwig Bölkow Systemtechnik, Renewables in Transport 2050, 2016
2) UBA, Erarbeitung einer fachlichen Strategie zur Energieversorgung des Verkehrs bis zum Jahr 2050 (72/2016), 72/2016
3) LUT, Techno-Economic Assessment of Power-to-Liquids (PtL) Fuels Production and Global Trading Based on Hybrid PV-Wind 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

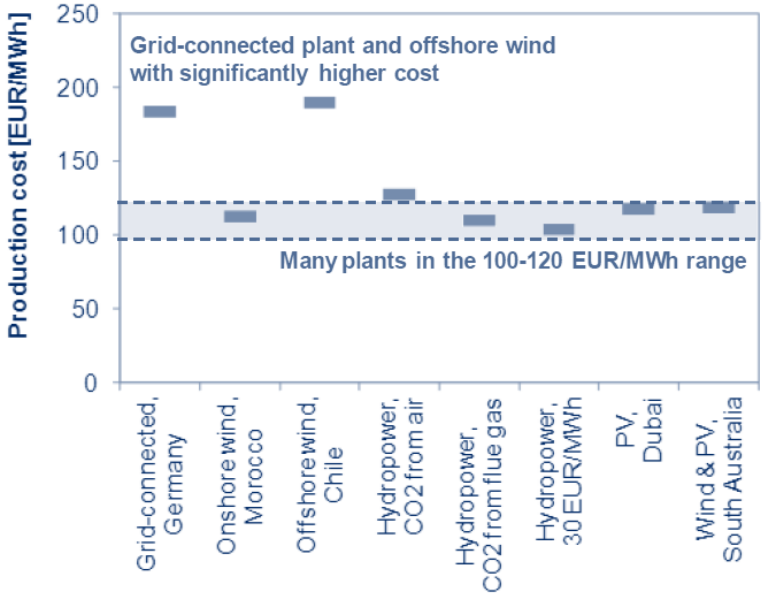
Spread of cost projections: 85 – 160 €/MWh

+ 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

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

Sunfire Company

Impressions and Overview

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

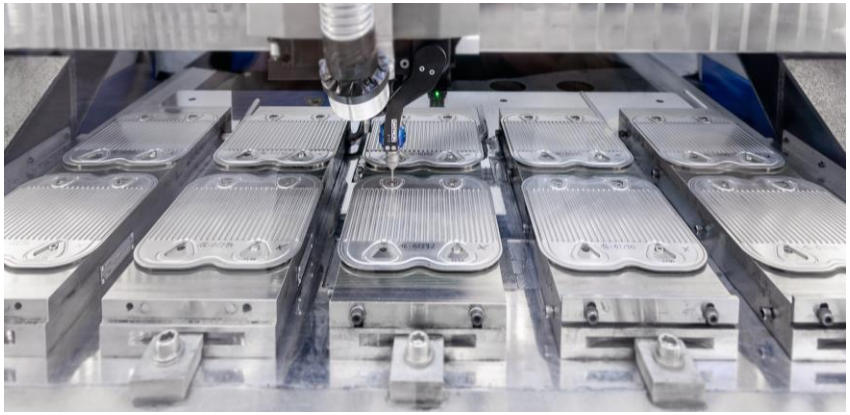
Investors

ELECTRANOVA CAPITAL
idinvest PARTNERS
INVIEIN CAPITAL CEZ GROUP
KFW
TOTAL

Impression

Sunfire Headquarter in Dresden

e-Fuels plant



Stack production

Test facilities

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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 aviation fleet
- Economically competitive with renewable fuel solutions and long-term competitiveness with today's fossil gasoline prices
- Most ecological approach
- Sufficient renewable power and CO_2 supply in Europe available

THANK YOU!

ENERGY
EVERYWHERE

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