HOCHEFFIZIENTE HOCHTEMPERATUR-CO-ELEKTROLYSE

Das Kopernikus Projekt P2X

09/2019 Andreas Frömmel
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 largely 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/
The Next Level of Energy Transition

Even in scenarios with large increase of direct electrification, liquid and gaseous energy carriers remain necessary to cover the global energy needs in 2050.

Sources: IEA, June 2017; World Energy 2014-2050, Political economist, 2014
MEETING THE CLIMATE OBJECTIVES

Achieving the climate protection goals is only possible with the use of synthetic fuels and gases.

Demand for synthetic liquid energy carriers 2050 in the EU:
up to 2,000 PJ = up to 230 GW installed PtL capacity
(up to 8 GW/a installed capacity from 2020)

“Power-to-fuel applications offer the lowest marginal abatement costs [for volatile renewable energy integration] in the long term.”

“Even in a battery electric drive dominated scenario, the final energy demand of all transport modes in the EU will be met with more than 70 % of e-Fuels in 2050.”
THE SOLUTION: ELECTRICITY BASED LIQUIDS AND GASES (e-Fuels and e-Gases)
We want to achieve a zero emission society in transport, industry and energy sectors via electricity based liquids and gases, making renewable energy available wherever and whenever it is needed.
Sunfire-HyLink 200
Renewable hydrogen - up to 730 kW per system / 200 Nm³ H₂ per hour. The world’s most energy efficient electrolysers, with a system power consumption of down to 3.7 kWh/Nm³ H₂.

Sunfire-SynLink 200
Renewable syngas - up to 790 kW per system / 200 Nm³ syngas per hour. The world’s only electrolysis technology capable of producing syngas directly from H₂O and CO₂.

Highest conversion efficiencies for lowest total costs!
THREE CORE USP

- 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
- Non-toxic, no critical and no expensive materials for easy manufacturing

“When steam can be preferably generated from waste heat sources, such as in steelmaking, high temperature electrolysis is the most efficient technology.”

Prof. Dr.-Ing. Heinz Jörg Fuhrmann, CEO and Chairman of the Executive Board of Salzgitter AG
P2X PRODUCTION PATHWAYS

Renewable Power

Electrolysis

+ H₂

Methanation*

+ CO₂

Fischer-Tropsch Synthesis*

+ CO₂

Methanol Synthesis*

+ N₂

Ammonia Synthesis*

Hydrogen

Methane

Methanol

Propylene

Ethylene

Ammonia

Diesel

Petrol

Jet fuel

Wax

* Exothermic reaction providing steam for e.g. steam electrolysis

Source: dena, Heutige Einsatzgebiete für Power Fuels, 08/2018
„KOPERNIKUS P2X“ WITH SUNFIRE-SYNLINK
Turning renewable electricity and CO\textsubscript{2} into e-Fuels for carbon neutral transportation, especially for transport sectors that cannot be electrified directly.
Synthetic paraffins of high quality as clean raw materials for the replacement of mineral oil in a variety of products in different industries such as Cosmetics, Clothing, Plastic processing and others.
P2X FOR EXISTING INFRASTRUCTURES


Carbon Capturing: CO₂ from air or unavoidable sources.

Renewable Electricity:

Ready-to-use:
Direct effect on existing fleet
Infrastructure compatible
No-regret measure

Sunfire IP*

*Sunfire owns key process patents for production of e-Fuels with electrolysis and Fischer-Tropsch or Methanol synthesis (e.g. WO/2008/014854)
CO-ELECTROLYSIS FOR E-FUELS & E-CHEMICALS

Sunfire-SynLink for e-Syngas production

- Co-electrolysis prototype developed and tested within the framework of the BMBF-funded project Kopernikus P2X
- World’s first integrated Power-to-Liquid (PtL) test facility to synthesize fuels from the air-captured carbon dioxide
- Container-based test facility integrating all four chemical process steps to implement a continuous process
- Partner: Climeworks, Ineratec, Sunfire and KIT
- Currently operation in PtL Plant (@KIT, Karlsruhe (GER))
SUNFIRE-SYNLINK GEN. 0: CO-ELECTROLYSIS SYSTEM

- System design:
  - Proof of concept full co-electrolysis system
  - Co-Electrolyser: max. 10 kW_{DC}
  - Feed: CO₂, H₂O, FTS recycle gas
  - Product: max. 4 Nm³/h syngas

- Successful system operation > 1300 h
- No higher degradation compared to H₂O-SOEC
- Prototype efficiency at 62 %
  (AC > LHV // comprising losses // producing steam)
- Achievable efficiency > 80 %
  by reducing losses (+4%), optimizing power electronics (+4%) and heat recuperation (+10%)

- Various operation modes validated
SUNFIRE-SYNLINK GEN. 0: INTEGRATION IN PTL

- First phase of Kopernikus P2X project
  - Production of Carbon-neutral Fuels from Air, Water and Green Power – Proof of concept
  - Capacity: about 10 liters of fuel per day
  - Analysis and tests of e-fuels and wax in progress
- Second phase of the Kopernikus P2X project started
  - it is planned to develop a plant with a capacity of 200 liters per day
- Third phase of the Kopernikus P2X project
  - a pre-industrial demonstration plant in the megawatt range, i.e. with a production capacity of 1,500 to 2,000 liters per day, will be designed
E-CRUDE

Raw Synthetic Product / Diesel Quality Already

- Fisher Tropsch raw product = Mixture of
  - Naphta C5,…C9
  - Middle Destillate C10…C19
  - WAX > C20
- Material properties depend on actual operating conditions the PtL processes are performed
- Representative Middle Destillate testing confirmed EN590 property

<table>
<thead>
<tr>
<th>FUEL PROPERTIES</th>
<th>EN590</th>
<th>MIDDLE DISTILLATE unrefined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Cetane number</td>
<td>51.0</td>
<td>-</td>
</tr>
<tr>
<td>Cetane index</td>
<td>46.0</td>
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</tr>
<tr>
<td>Density (15 °C)</td>
<td>820 kg/m³</td>
<td>845.0 kg/m³</td>
</tr>
<tr>
<td>Polycyclic aromatic hydrocarbons (PAH)</td>
<td>-</td>
<td>8.0 wt.-%</td>
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<tr>
<td>Sulphur content</td>
<td>-</td>
<td>10.0 mg/kg</td>
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<tr>
<td>Manganese content</td>
<td>-</td>
<td>2.0 mg/l</td>
</tr>
<tr>
<td>Flash point</td>
<td>55.0 °C</td>
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</tr>
<tr>
<td>Carbon residue</td>
<td>-</td>
<td>0.30 wt.-%</td>
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<tr>
<td>Ash content</td>
<td>-</td>
<td>0.010 wt.-%</td>
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<tr>
<td>Water content</td>
<td>-</td>
<td>200.0 mg/kg</td>
</tr>
<tr>
<td>Total impurities</td>
<td>-</td>
<td>24.0 mg/kg</td>
</tr>
<tr>
<td>Corrosiveness to copper</td>
<td>Class 1</td>
<td>Class 1</td>
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<tr>
<td>Fatty acid methylestes (FAME)</td>
<td>-</td>
<td>7 vol.-%</td>
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<tr>
<td>Oxidation stability</td>
<td>-</td>
<td>25 g/m³</td>
</tr>
<tr>
<td>Lubricity (wsd)</td>
<td>-</td>
<td>460 μm</td>
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<tr>
<td>Viscosity (40 °C)</td>
<td>2 mm²/s</td>
<td>4.5 mm²/s</td>
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<tr>
<td>Distillation vol.-% recovered at 250 °C</td>
<td>-</td>
<td>&lt;65 vol.-%</td>
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<tr>
<td>vol.-% recovered at 350 °C</td>
<td>85 vol.-%</td>
<td>-</td>
</tr>
<tr>
<td>95 vol.-% recovered at</td>
<td>-</td>
<td>360 °C</td>
</tr>
<tr>
<td>Cold filter plugging point (CFPP)</td>
<td>-20 °C</td>
<td>0 °C</td>
</tr>
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</table>
SUNFIRE PRODUCTS IN ACTION
**RENEWABLE E-FUELS & E-CHEMICALS**

**Sunfire-SynLink for e-Crude production**

- Powered by renewable electricity, CO$_2$ and steam:
  - Production of more than three tons of 100% renewable e-Crude providing e-Fuels (Diesel, Gasoline) and e-Wax
  - Industrial reactor concept for quick upscaling
- Synthetic fuel with premium properties, verified by AUDI AG
  - High cetane value
  - Excellent combustion properties
- ASTM certified and drop-in capable (up to 50%)
  - e-Jetfuel tested within Demo-SPK Project

*Installation Site*
RENEWABLE E-FUELS & E-CHEMICALS

Sunfire-SynLink for e-Crude production

- Sunfire will build the first commercial e-Fuels plant by 2022 in Herøya, Norway
- Multiple off-take agreements in place for 8,000 t/a
- Unique advantages through location
  - Low electricity prices (ca. 3 ct€/kWh)
  - Continuous supply (>7,000 h)
  - Distribution shipping terminal at site
- 10 potential sites for expansion identified

Business case repetitive in other European countries (e.g. Eastern Europe)!
A POWERFUL ORGANISATION
COMPANY FACTS

Knowhow
- ~ 130 Employees in Dresden and Neubrandenburg
- Full value chain from Ceramics, Engineering, Stack + System Production, up to Synthesis Processes, Service etc.

Patents
- More than 60 patent families (e.g. »process patent sunfire« WO/2008/014854)

Revenues
- Multi-million Euro Revenues in Global Markets since 2011

Investors

Sunfire Headquarters

2019 GLOBAL CLEANTECH
COMPANY

National and international awards for innovative and pioneering technology
NEW SUNFIRE INVESTOR
PAUL WURTH / SMS GROUP

- Invested 20 M€ in Sunfire series-C round in 2018
- World leading EPC contractor in iron and steel plants
- Clear strategy to go from fossil to renewable
- In-house technology for transition readily available
- Ability to support project financing and de-risk large commercial projects in the range of > 100 MW
- Global presence to support sales and project development

Recent Paul Wurth Projects References
SUNFIRE SERVING TO GIGAWATT MARKETS

Leading provider of solutions to produce fuels and gases from renewable electricity
IMPRESSIONS

Sunfire Headquarters in Dresden

Stack production

e-Fuels plant

Test facilities
THANK YOU!

Andreas Frömmel
VP Sales and Marketing

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RENEWABLE E-HYDROGEN

Sunfire-HyLink for e-Hydrogen production

- Powered by renewable electricity and steam:
  - Production of hydrogen for annealing process of Stahlwerk Salzgitter AG for over 2 years
  - Industrial electrolysis concept for quick upscaling
- Upscaling to megawatt-scale currently ongoing
  - High efficiency proven
  - Full integration into integrated steel plant
- Hydrogen production according to technical gas supplier quality requirements

These projects have received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700300 and No 826350.
**FUEL CELL BUSINESS UNIT**

Dual use – additional market access

- Sunfire’s SOC technology is also suitable for direct conversion from gases to power and heat based on the same core component

Fuel cell business with daughter company Sunfire Fuel Cells

- Best in class fuel cell systems to provide power and heat in privat homes – developed and validated together with Vaillant since 2006
- Systems also available for remote application in harsh environments, where fuel cell create a superior solution for remote power supply e.g. in the Oil+Gas sector
- Sunfire fuel cells offer a second market for the Sunfire core components and creates an additional company value