PRODUCTION OF RENEWABLE HYDROGEN AND SYNGAS VIA HIGH-TEMPERATURE ELECTROLYSIS

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Head of Large Systems Development
Sunfire GmbH

Heat-to-Fuel interfaces to advanced Power-to-Gas and Power-to-Liquids Technologies (e-fuels), 2021-03-08/09
AGENDA

1. SUNFIRE INTRODUCTION
2. SOEC ELECTROLYSER TECHNOLOGY
3. MARKETS AND APPLICATIONS
4. TECHNOLOGY DEMONSTRATION
5. SUMMARY AND OUTLOOK
Sunfire at a glance

- Established in 2010, Sunfire is a leading electrolysis company.

- Sunfire offers both pressure alkaline (AEL) and solid oxide (SOEC) electrolyzers, providing a unique product portfolio suitable for every hydrogen application.

- Fewer than ten credible electrolysis companies face a politically set EU green hydrogen market of EUR 18 bn until 2030; Sunfire is one of them.

- Green hydrogen from electrolysis is a once-in-a-generation opportunity.

Key facts

- > EUR 100 million Funding
- > 250 Employees
- >20 Industrial projects
- 500 MW / 200 MW p.a. 2025 production AEL / SOEC

Locations

- Dresden (HQ)
- Neubrandenburg
- Fornebu
- Norway
- Germany
- Switzerland
- Monthey
OUR MISSION

We provide superior electrolysis solutions to produce renewable hydrogen and e-Fuel.

Sunfire electrolyzers convert renewable electricity into renewable hydrogen and e-Fuel, enabling a carbon-neutral industry, mobility and energy sector.

Electrolysis at its Best

- Water
- Renewable electricity
- CO₂

Electrolyzers
- SOEC
- Alkaline

Hydrogen

e-Fuel produced from syngas

Industries
- Steel, refineries and chemicals

Transportation
- Aviation, maritime, road and rail

Energy
- Heating and power generation

Production of Renewable Hydrogen and Syngas

1) Solid oxide electrolysis cells
TECHNOLOGY COMPARISON

SOEC and Alkaline each have individual strengths that are valued by customers

Core Advantages

- Highest conversion efficiency (84%\textsubscript{LHV to AC})\textsuperscript{2}
- Industrial off-heat integration via steam provision
- CO\textsubscript{2} reduction capability

SOEC

“The Game-Changer”

Electricity demand

\(\text{O}_2\) gaseous

H\textsubscript{2}O or H\textsubscript{2}O + CO\textsubscript{2}

Core Advantages

- Proven technology (> 20 years)
- Competitive price (650 EUR/kW\textsubscript{AC})
- CO\textsubscript{2} reduction capability

Alkaline

“The Established”

Electricity demand

\(< 100^\circ\text{C}\) liquid

H\textsubscript{2}O

Core Advantages

1) External vaporization lowers energy demand by 16% while better kinetics allows additional efficiency increase. In total, SOEC provides > 20% more hydrogen or syngas output per kWh\textsubscript{el}

2) Referring to overall system efficiency given steam @ 150°C and atmospheric hydrogen pressure
Stacks are integrated into modules which are integrated into electrolyzer systems.

**Cell**
- 0.125 kW

**Stack**
- 3.7 kW
- × 30

**Module**
- 225 kW
- × 60
- × 12

**System**
- 2.7 MW

1. **Membrane electrode assembly**
2. **Glass sealing**
3. **Nickel foam**
4. **Sheet metal cassette**
5. **Cathode contact**

1. **End plates**
2. **Cells**
3. **Stack tensioning**

1. **Stack unit**
2. **Gas processing unit (GPU)**
3. **Supply and discharge unit (SDU)**

1. **Block (= 4 modules)**
2. **Fluid interface unit (FIU)**
3. **Power electronics**

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**Generation**

- **Generation 0**
  - 2014-2017

- **Generation 1**
  - 2017-2020

- **Generation 2**
  - 2021-2024

- **Generation 3**
  - from 2025 onwards

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Production of Renewable Hydrogen and Syngas
Due to the dissociation of steam, SOECs require less energy compared to liquid water.

SOEC has a theoretical minimum stack efficiency advantage of 16% assuming optimal low-temperature conversion.

One-third of the total energy comes from heat → SOECs require less renewable electricity.

Compared to state-of-the-art low temperature electrolysis, SOECs achieve a 30% higher conversion efficiency on a system level.
**UNIQUE FEATURES OF SOEC ELECTROLYSIS**

Hydrogen and syngas production

**HyLink**
Renewable hydrogen as feedstock for industries

Use of steam where waste heat is available → Ideal for coupling with exothermic synthesis processes

Conversion efficiency\(^1\): > 84 \%\textsubscript{LHV to AC}
Hydrogen output: 750 Nm\(^3\)/h (12 modules)
Power consumption: 3.6 kWh/Nm\(^3\)
Hydrogen quality: > 99.99 Vol.-%

**Applications**

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**SynLink**
Clean syngas as feedstock for green hydrocarbon products

Direct conversion of CO\(_2\) and H\(_2\)O to syngas in one single process step is unique to SOEC.

Conversion efficiency\(^1\): > 82 \%\textsubscript{LHV to AC}
Syngas output: 750 Nm\(^3\)/h
Power consumption: 3.85 kWh/Nm\(^3\)
Syngas (H\(_2\) / CO) ratio: 1.5 ... 3.5

**Applications**

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1) Referring to overall system efficiency given steam @ 150 °C
SOEC ELECTROLYSER TECHNOLOGY

Technology status and targets

### Efficiency

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
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<tbody>
<tr>
<td>HyLink</td>
<td>84 %</td>
<td>86 %</td>
<td>88 %</td>
</tr>
<tr>
<td>SynLink</td>
<td>82 %</td>
<td>84 %</td>
<td>86 %</td>
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### Durability

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack lifetime</td>
<td>40,000 h</td>
<td>60,000 h</td>
<td>75,000 h</td>
</tr>
<tr>
<td>Degradation</td>
<td>20 mΩcm² / kh</td>
<td>8 mΩcm² / kh</td>
<td>7 mΩcm² / kh</td>
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</table>

### Levelized cost of hydrogen

1) Lower heating value to alternating current
2) Assuming electricity costs of EUR 35 / MWh

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
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<tbody>
<tr>
<td>HyLink</td>
<td>EUR 5.00 / kg₅H₂</td>
<td>EUR 2.30 / kg₅H₂</td>
<td>EUR 2.00 / kg₅H₂</td>
</tr>
<tr>
<td>SynLink</td>
<td>EUR 5.00 / kg₅H₂</td>
<td>EUR 2.30 / kg₅H₂</td>
<td>EUR 2.00 / kg₅H₂</td>
</tr>
</tbody>
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**HyLink efficiency & power consumption:**

88 %₅LHV,AC → 104%₅HHV,AC → 3.4 kWh/Nm³ → 38 kWh/kg
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Production of Renewable Hydrogen and Syngas
MARKETS AND APPLICATIONS

Sunfire target markets

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<thead>
<tr>
<th>E-Fuel</th>
<th>Steel</th>
<th>Refineries</th>
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<tr>
<td>6 GW</td>
<td>4 GW</td>
<td>4 GW</td>
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</table>

EU electrolyzer demand until 2030

- **SynLink**: Proprietary Co-Electrolysis achieves superior efficiency and lowest e-Fuel costs
- **Renewable Fuel Partnership**: Strategic bond with Neste, largest renewable fuel producer
- **e-Fuel**: Production at spots with low electric costs and high RES share
- **Paving the path to renewable aviation and maritime transports**

Revenue potential\(^1\)
- **EUR 2,700 m**

- **HyLink**: Electrolyzer achieves superior efficiency and lowest H\(_2\) costs in the market
- **Steel EPC Partnership**: Strategic alliance with SMS group – the world’s leading steel EPC
- **Steel industry is among the largest contributors of greenhouse gas emissions – 7-9% of total emissions**
- **Direct Reduced Iron (DRI)** saves up to 95% of CO\(_2\) emissions

Revenue potential\(^1\)
- **EUR 850 m**

- **HyLink**: Electrolyser achieves superior efficiency and lowest H\(_2\) costs in the market
- **Refineries need to fully decarbonize their value chain until 2050.**
- **As per RED II, fuel suppliers need to reach an average share of renewables of 14% in 2030**
- **Substituting fossil-based with renewable hydrogen is a low-cost way to increase the share of renewables in transportation.**

1) Cumulated revenues 2020-2030
Co-electrolysis: High-efficient Power-to-Liquid applications

**Legacy PtL technology**

- Low-temperature electrolysis
- RWGS\(^1\)
- Synthesis process
- PtL product

\[ \text{H}_2\text{O}(l) \rightarrow \text{H}_2 + \text{CO} \]

\[ \eta_{\text{theor}} = 69\% \quad \eta_{\text{real}} = 45\% \]

**Sunfire PtL technology**

- Co-electrolysis
- Heat and off-gas recovery
- Synthesis process
- PtL product

\[ \text{H}_2\text{O}(g) \rightarrow \text{H}_2 + \text{CO} \]

\[ \eta_{\text{theor}} = 81\% \quad \eta_{\text{real}} = 60\% \]

- Legacy Power-to-Liquid (PtL) technologies require 3-step process including a CAPEX-intensive and inefficient Reverse-Water-Gas-Shift (RWGS) reactor.
- Sunfire’s Co-Electrolysis technology results in a 2-step-process with lower CAPEX investments.
- 30% higher efficiency due to fewer process steps and heat integration from downstream exothermic synthesis process (e.g. Fischer-Tropsch)

**Norsk e-Fuel**

25 MW alpha \(\times\) 5 = 1 GW (total)

1) Reverse-Water-Gas-Shift reaction is required in order to generate carbon monoxide (CO)
#1 GrInHy: Production of renewable hydrogen for green steel-making

| Objective | Supply of 100 tons of renewable hydrogen for green steel making. |
| Technology | 150 kW Sunfire HyLink (2016) and 720 kW Sunfire HyLink Gen. 1 (2020) |
| CAPEX | Total budget EUR 4.5 million (2016) and EUR 6 million (2020); Sunfire budget EUR 2 million (2016) and EUR 3 million (2020) |
| Achievements | 15,000 hours operating period, efficiency of up to 82 % proven in GrInHy1 |
| Upscaling | Salzgitter Steel works has a strategic commitment to achieve zero-carbon steelmaking by 2050 (project name “SALCOS”). |

### Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>2016</td>
<td>1st FCHJU funding granted</td>
</tr>
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<td>2017</td>
<td>Start of operation 150 kW HyLink</td>
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<tr>
<td>2018</td>
<td>2nd FCHJU funding granted</td>
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<tr>
<td>2020</td>
<td>Start of operation 730 kW HyLink</td>
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Salzgitter, Germany
#1 GrInHy: Production of renewable hydrogen for green steel-making

- GrInHy1.0 - Reversible SOC system with 3 operation modes
  - electrolysis for hydrogen production and downstream injection in pipeline
  - hydrogen fuel cell for power production
  - natural gas fuel cell for power production

- Technical specification

<table>
<thead>
<tr>
<th>Operation Mode</th>
<th>SOEC mode</th>
<th>H2-SOFC mode</th>
<th>NG-SOFC mode</th>
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<tbody>
<tr>
<td>rSOC AC Power</td>
<td>143 kW</td>
<td>30 kW</td>
<td>25 kW</td>
</tr>
<tr>
<td>HPU AC Power</td>
<td>12 kW</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hydrogen Production</td>
<td>40 Nm³/h</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>50…125 %</td>
<td>30…100 %</td>
<td>30…100 %</td>
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<tr>
<td>rSOC AC Efficiency</td>
<td>84 %ₐHV</td>
<td>47 %ₐHV</td>
<td>50 %ₐHV</td>
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</table>
#1 GrInHy: Production of renewable hydrogen for green steel-making

**Objectives of GrInHy2.0**

- Electrolyser scale-up to 720 kW_{el,AC}
- Hydrogen production 200 Nm³/h (18 kg/h) → up to 37 Nm³/h per module
- Efficiency 84 %_{el,LHV} (< 40 kWh_{el,AC}/kg)
- Operating times (target):
  - > 15,000 h system
  - > 20,000 h stack
**Objective**
Supply of 960 tons of renewable hydrogen to a biofuel refinery

**Technology**
2.5 MW Sunfire HyLink Gen. 2

**CAPEX**
Total budget EUR 10 million, Sunfire EUR 6 million

**Targets**
16,000 hours operating period, efficiency of up to 84% (planned)

**Upscaling**
Neste as a strategic investor of Sunfire plans to decarbonize all of its refineries by 2050.

**Timeline**
- 2019: FCHJU funding granted
- 2020: Official project start
- 2021: Start of erection
- 2022: Start of production

**Session: Demonstration projects**
Multigawatt high-temperature electrolyser to generate green hydrogen for production of high-quality biofuels

**Tuesday, the 9th of March 2021**

Julie Mougini, Head of Hydrogen Technologies Laboratory, CEA
### AGENDA

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<tr>
<td>5</td>
<td>SUMMARY</td>
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Summary

• **SOEC Electrolysis** achieves an up to 20% higher efficiency compared to LTE technologies if steam is available → ideal partner to all integrated synthesis processes

• **Technology is ready** for deployment in large scale, although there are still challenges due to missing long-term experiences

• **Hydrogen for refineries** offers an immediate CO$_2$-reduction potential via blend in existing vehicle fleet

• **Capability of Co-Electrolysis** paves the path to competitive e-Fuels in the transport sector

• **Direct Reduced Iron (DRI)** process using green hydrogen allows a nearly complete decarbonization of the iron and steel industry
Acknowledgement

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RENEWABLES EVERYWHERE

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