eFuels
aus der Sicht der Industrie

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Becoming serious – CO₂-emission reduction targets DE

Electricity sector (target: -92.5%)

Industry (target: -81%)

Households/SMEs (target: -92.5%)

Mobility (target: -92.5%)

Agriculture (target: -60%)


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Renewable power generation technologies becomes cost competitive

- Most recent electricity contracts in Middle East are below 24 USD/MWh (e.g. Saudi-Arabia: 17.8 USD/MWh)

- Many countries with low electricity costs are highly interested to invest in green P2X technologies

1. CO₂-reduction is clearly linked with renewables.

2. Enforced extension of renewables is mandatory to reach defined CO₂ reduction targets

Energy storage capacities in the TWh-range will be needed
Different storage technologies for different applications – Hydrogen for large-scale and long-term energy storage

1) such as Ammonia, Methanol or others; 2) Compressed Air Energy Storage; 3) Li-ion, NaS, Lead Acid, etc.

Hydrogen can be stored cost-effectively on a large scale.
Electrical Energy Storage
The common understanding has to be re-defined

- **Energy input**
  - Electricity

- **Conversion “in”**
  - Battery

- **Storage**
  - Electricity

- **Conversion “out”**
  - Electricity

- **Energy output**
  - Electricity

**the classic view:**

- Electricity → Battery → Electricity

**the hydrogen view:**

- Electricity → Electrolysis → Hydrogen
  - Hydrogen → Turbine → Electricity
  - Hydrogen → Fuel cell → Electricity
  - Hydrogen → Burner → Heat
  - Hydrogen → Reactor → Chemicals
Hydrogen is multi-functional
It connects Energy, Mobility and Industry

Photovoltaic

Wind power

H₂ generation

PEM electrolysis

Exports for different applications

Industry

Mobility

Energy
Hydrogen is multi-functional
It connects Energy, Mobility and Industry

Volatile electricity generation  Grid integration  Conversion/ storage  Applications

Photovoltaic

Wind power

H₂ generation

O₂

H₂

PEM electrolysis

Exports for different applications

Industry
Hydrogen for ammonia production, petroleum refinement, metal production, flat glass, etc.

Mobility
Hydrogen as alternative fuel or as feedstock for synthetic fuels

Energy
Hydrogen blending (gas grid)
Remote energy supply/Off-grid
Green (CO₂-free) hydrogen: a broad variety of potential applications

**Industry** *
- Refineries
- Ammonia plant
- Steel production

**Mobility**
- H₂ as fuel for public transport
- Substitute of bio-ethanol admixing
- Carbon-based synthetic fuels

**Energy**
- Re-electrification in H₂-turbines
- Admixing to conventional gas turbines
- Generator cooling

* Besides these: glass, semiconductor, food & beverage
The different use cases for green hydrogen…
….follow a `merit order´ principle

Compared to re-electrification ("power to power") the use of hydrogen in industry or mobility leads more easily to a positive business case.

The three use cases have different maturity, market potential and market starting points.

**current H₂ market prices**

- mobility          ~ 4 – 10 USD/kg
- industry          ~ 1,4 – 5 USD/kg
- energy            ~ 0,7 – 1 USD/kg
\( \text{H}_2 \) production via electrolysis

Economy of operation

**Input parameter:**
- electricity costs [ct/kWh]: 3.2
- capex electrolyzer [€/kW]: 1,000
- utilization rate [hours per year]: 4,000
- product life [y]: 20
- system efficiency [% HHV]: 70
- additional capex [€/kW]: 0
- additional opex [%] *: 5
- interest rate [%]: 0
- depreciation period [a]: 10

*service, maintenance, operation (without electricity)*

**Important:** above chosen parameter are arbitrary values and do not reflect data of Siemens electrolyzers!
E fuels: tightly connected with availability of CO2 sources

- Heavy duty, long distance transport, especially aviation and marine transport require fuels with high volumetric energy density.
- High volumetric energy density can only be achieved by carbon based fuel.
- The production of eFuels requires a CO2 source as feedstock in order to be CO2-neutral.
- Availability and costs of suited CO2 supply are essential for related business cases.
- Electrolyzer technology in the GW range will be required. Up-sizing is mandatory but no critical technical hurdles are expected.
- Low RE electricity prices are the key enabler.

* Besides these: glass, semiconductor, food&beverage
Overall process efficiency decreases when hydrogen is further converted in downstream synthesis plants

**source:** Alexander Tremel, Siemens AG

Realistic process efficiency considering economic perspective

Simulation parameters:
- Electrolysis efficiency: 4.5 kWh/Nm³ (average during operation)
- H₂ loss: 1%
- Aux. power consumption: dependent on synthesis
- Synthesis efficiency: dependent on synthesis (thermodynamic limit as reference)

Realistic process efficiency considering economic perspective:

- Electrolyzer
- Balance of Plant
- Power converter
- Gas treatment/storage (optional)

Chemical synthesis:
- Compression (optional)
- Upgrading

Product options:
- Synthetic Natural Gas: \( \eta_{LHV} = 48.7\% \)
- FT Diesel: \( \eta_{LHV} = 45.3\% \)
- Methanol: \( \eta_{LHV} = 51.6\% \)
- DME: \( \eta_{LHV} = 53.3\% \)
- Ammonia: \( \eta_{LHV} = 49.8\% \)
Methanol is liquid synthesis product with already good fit to existing infrastructure and relatively low cost

source: Alexander Tremel, Siemens AG

### Multi-objective product evaluation based on quantitative and qualitative parameters (starting point: hydrogen)

| Production cost of synthetic product, value (conventional / green), plant CAPEX |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| SNG                             | 4.8             | 4.8             | 4.8             | 4.8             |
| Ammonia                         | 5.8             | 5.8             | 5.8             | 5.8             |
| DME                             | 4.6             | 4.6             | 4.6             | 4.6             |
| FT diesel                       | 5.4             | 5.4             | 5.4             | 5.4             |
| Methanol                        | 8.7             | 8.7             | 8.7             | 8.7             |

| Technology fit to “Power-to-Fuel use case” (smaller scale, complexity, flexible, efficiency) |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| SNG                             | 6.5             | 6.5             | 6.5             | 6.5             |
| Ammonia                         | 4.9             | 4.9             | 4.9             | 4.9             |
| DME                             | 6.3             | 6.3             | 6.3             | 6.3             |
| FT diesel                       | 5.4             | 5.4             | 5.4             | 5.4             |
| Methanol                        | 7.2             | 7.2             | 7.2             | 7.2             |

| Evaluated by infrastructure fit, health and environment issues, energy density |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| SNG                             | 5.7             | 5.7             | 5.7             | 5.7             |
| Ammonia                         | 1.6             | 1.6             | 1.6             | 1.6             |
| DME                             | 5.9             | 5.9             | 5.9             | 5.9             |
| FT diesel                       | 8.2             | 8.2             | 8.2             | 8.2             |
| Methanol                        | 7.0             | 7.0             | 7.0             | 7.0             |

**Summary: Methanol with highest score**

- Evaluation based on green field plant without existing infrastructure (exception see footnote)
- Detailed evaluation is site and customer specific and may result in deviating outcome

<table>
<thead>
<tr>
<th>Total score (0-10 points):</th>
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<tbody>
<tr>
<td>SNG</td>
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* Methanol with highest total score; SNG score strongly depends on local infrastructure

1) Energy density for transport not an issue for SNG; Infrastructure 100% in place

The story will not end with the Silyzer 200/300 – … we are targeting >100 MW

Silyzer portfolio roadmap

- **Silyzer 100**
  - 100 – 300 kW
  - Lab-scale
  - Current commercial product

- **Silyzer 200**
  - 1 MW class
  - Sales release 2018

- **Silyzer 300**
  - >10 MW class
  - Under development

- **Next generation Silyzer >100 MW**
  - >100 MW

- Reduction of specific price (€/kW)
  - 2011 – 2015
  - 2015 – 2018
  - 2018 – 2023+
  - >2030

- >1,000 MW
  - First investigations in cooperation with chemical industry
Project scope and key facts
Development of a decentralized hydrogen energy storage plant

- Location: Mainz (Germany)
- Partners: Stadtwerke Mainz, Linde, Siemens, RheinMain University
- Connected to a wind-farm (8 MW)
- 6 MW peak electrolyzer (3 stacks, each 2 MW)
- 1000 kg H₂ storage (33 MWh)
- 200 tons H₂ target annual output
  - Injection in local gas grid
  - Multi-use trailer-filling
- Funding: ~50% (BMWi)
- Timeline: 10/2012 – 12/2016
Energiepark Mainz – Status
Electrolyzer system

- Efficiency evaluations under consideration of overall purchased electricity and measured H2 production (outlet electrolyzers)
- Data obtained by measurements in Oct 2015
H2FUTURE
Hydrogen from electrolysis for low carbon steelmaking

Project Consortium:
• Verbund (utility/grid operator in AT = Electricity provider)
• VoestAlpine (steel manufacturer = Hydrogen consumer)
• ECN (Energy Research Centre of the NLD)
• Siemens Hydrogen Solutions (Technology provider)

Project description:
EU funded project to show viability of a PEM electrolyzer as flexible load for grid services. Hydrogen used within the steel making/processing to reduce CO₂ foot-print.

Time line:

Electrolyzer:
- 6 MW rated power
- new cell and stack design
- designed for power range of ≈ 10 - 100 Megawatt

More details:
http://www.h2future-project.eu
Summary

- CO₂-reduction targets are clearly linked with renewables. Decreasing generation costs foster new business opportunities.

- Power to X concepts will be essential to reach CO₂ reduction targets. H₂ via electrolysis is a key element for sector coupling.

- The de-fossilation of the mobility sector provides specific challenges. In particular heavy duty transport and aviation require ‘power supplies’ with high volumetric energy density.

- Electricity-based liquid fuels are a major option for above mentioned area. Technical solutions are / will be available.

- However, any market outlook is uncertain since political targets and market regulations are hardly to predict.
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