Coupling of power, fuels, chemicals: perspective for hydrogen and e-fuels production

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De-fossilization of energy sector
Focus on power generation sector alone is not enough

Global CO₂ (eq.) emissions 1980 – 2016
bn tons per year

Global CO₂ emissions share by sectors

- Share on CO₂ emissions: **55%**
- Share of Renewables: **8%**

** Mostly disregarded till now **

- Share on CO₂ emissions: **40%**
- Share of Renewables: **22%**

** Main focus so far **

De-fossilization of power sector is not sufficient. Sectors such as industry, transport and buildings that account for up to 55% of total CO₂ emissions have seen only low levels of renewable penetration.

Source: IEA ETP

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Sector coupling
a key lever for energy system transformation

Sector Coupling – Links and Interactions

Power Sector

- Power-to-Heat (Heat pumps, CHP)
- Power-to-Liquids
- E-Mobility
- Power Storage (central)
- Power Storage (decentral)

Heat Supply

- Heat Storage
- Gas Power Plants
- Fuel Storage

Transport Sector

- Power-to-Gas (Energy Storage)
- Power-to-Chemicals
- Power-to-Gas (Re-Electrification)
- Gas Reforming
- Hydrogen, methane, methanol, ammonia as feedstock for chemical processes

Chemicals

Gas Industry

- Gas Power Plants
- Gas Reforming
- Gas Re-electrification
- Gas Storage, Pipeline System

Source: Based on FENES (OTH Regensburg)

Sector Coupling

Definition
- Link between power sector and energy-consuming sectors

Value Proposition
- Improvement of overall energy efficiency
- Contribution to defossilization of the energy sector
- Supports supply / load balancing (>high share of intermittent renewable generation)
- More diverse and interdependent energy supply

Drivers
- Reduction of green house gas emissions
- Reduction of energy import dependency
- Technological progress (e.g. e-mobility, battery, electrolysis)
From clean power to clean product
Hydrogen opens up multiple entries to the energy- and chemical sectors

**Power Generation**
- Intermittent RES
  - Solar (PV)
  - Wind
- Continuous RES
  - Geothermal
  - Hydro
  - Biomass

**Conversion**
- Intermittent RES
  - Direct air capture
  - Capture from flue gases (power, industry)
- Continuous RES
  - Air separation
  - Water electrolysis

**Products**
- Methane
- Methanol
  - (and secondary products, e.g. MTBE, gasoline, kerosene)
- Fischer-Tropsch products
  - (diesel, wax)
- PtHydrogen
- PtAmmonia
- Haber-Bosch

**Use- and business cases**
- Carbon-neutral fuels - mobility, heat
- Chemical feedstock
- Re-electrification (long-term storage)
- Direct use for mobility (fuel cell)
- chemical feedstock (refinery), separate case, not considered
- Direct use: Re-electrification (long-term storage (turbines, engines)
- Fertilizer
- Chemical feedstock
- As carrier for hydrogen or direct use for energy
Proton Exchange Membrane (PEM) electrolysis
Key technology and efficient way to produce green hydrogen

How does PEM electrolysis work?

- Electrodes are attached on both sides of the proton exchange membrane (PEM)
- Proton exchange membrane
  - is electrolyte
  - Acts as separator to prevent mixing of the gas products

Advantages of PEM electrolysis

- Dynamic flexibility in coupling to wind-, PV- plants
  - High dynamics (ramps)
  - cold start capability with fast start-up and shut-down
- High efficiency
- High H2 - purity
- Low O&M costs
- Pressurized operation (Sylizer 200: 35 bar)
- High power density and small footprint

1973: J.H Russel released his works on PEM electrolysis

PEM principle

```
+ -
\frac{1}{2} O_2 \rightarrow H_2 + H^+
```

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Ireneusz Pyc, Siemens Power and Gas
Silyzer 200
High-pressure efficiency in the megawatt range

5 MW
World's largest operating PEM electrolyzer system in Hamburg, Germany

60 kWh
Specific energy consumption for 1 kg hydrogen

20 kg
Hydrogen production per hour

1.25 MW
Rated stack capacity

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Silyzer 300
the next paradigm in PEM electrolysis

- **17.5 MW** per full Module Array (24 modules)
- **75%** System efficiency (higher heating value)
- **24 modules** to build a full Module Array
- **340 kg** hydrogen per hour per full Module Array (24 modules)

Silyzer 300 – Module Array (24 modules)
Silyzer portfolio scales up by factor 10 every 4-5 years driven by market demand and co-developed with our customers.

Silyzer portfolio roadmap

- **2011**
  - **Silyzer 100**
    - Lab-scale demo
    - ~4,500 op.h
    - ~150k Nm³ of H₂

- **2015**
  - **Silyzer 200**
    - ~24,000 op.h
    - ~2.8 mio Nm³ of H₂
    - World's largest Power-to-Gas plants with PEM electrolyzers in 2015 and 2017 built by Siemens!

- **2018**
  - **Silyzer 300**
    - Biggest PEM cell in the world built by Siemens!

- **2023+**
  - Next generation
    - Under development

- **2030+**
  - First investigations in cooperation with chemical industry

1) op.h.: operating hours

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We have references for our Silyzer portfolio in all applications

<table>
<thead>
<tr>
<th>Year</th>
<th>Country</th>
<th>Project</th>
<th>Customer</th>
<th>Power demand</th>
<th>Product offering</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Switzerland</td>
<td>Energy System Integration Platform</td>
<td>Paul Scherrer Institut</td>
<td>100 kW / 200 kW (peak)</td>
<td>Container solution</td>
</tr>
<tr>
<td>2015</td>
<td>Germany</td>
<td>Argon purification/ Use of H₂ for HRS</td>
<td>Air Liquide, Duisburg</td>
<td>300 kW</td>
<td>Container solution</td>
</tr>
<tr>
<td>2016</td>
<td>Germany</td>
<td>Energy Lab 2.0</td>
<td>Karlsruhe Institute of Technology</td>
<td>300 kW</td>
<td>Container solution</td>
</tr>
<tr>
<td>2015</td>
<td>Germany</td>
<td>Energiepark Mainz</td>
<td>Municipality of Mainz</td>
<td>3.8 MW / 6 MW (peak)</td>
<td>Pilot Silyzer 200</td>
</tr>
<tr>
<td>2016</td>
<td>Germany</td>
<td>Wind Gas Haßfurt</td>
<td>Municipality of Haßfurt Greenpeace Energy</td>
<td>1.25 MW</td>
<td>Silyzer 200</td>
</tr>
<tr>
<td>2017</td>
<td>Germany</td>
<td>H&amp;R</td>
<td>H&amp;R Ölwerke Schindler GmbH</td>
<td>5 MW</td>
<td>Silyzer 200</td>
</tr>
<tr>
<td>2018</td>
<td>Austria</td>
<td>H2Future&lt;sup&gt;1&lt;/sup&gt;</td>
<td>voestalpine, Verbund, Austrian Power Grid (APG)</td>
<td>6 MW</td>
<td>Pilot Silyzer 300</td>
</tr>
</tbody>
</table>

<sup>1</sup> This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735503. This Joint Undertaking receives support from the European Union’s Horizon 2020 research and innovative program and Hydrogen Europe and NERGHY.
Going a step further: from H2 to e-fuels and chemicals ...in mobility, transportation and chemical industry

Pre-feasibility studies for e-methanol, conditions ~ 2025

- CO₂ capture
- Today to mid-term: from industrial sources
- Long-term: from the air

Good weather conditions
Carbon capture
Optimized plant operation
Shipment to consumer site

Economic viability
- E-fuel production cost clearly above market value of fossil fuels
- Production cost decrease due to decreasing CAPEX of renewables and electrolysis
- E-fuel with ~ 90% lower carbon footprint compared to fossil fuels
- E-fuel has the potential to outperform biofuels in terms of:
  - production costs
  - CO₂ avoidance cost
  - food / fuel debate

Market value (€/MWh)
CO₂ emissions (gCO₂-eq/MJ)
CO₂ avoidance costs (€/tCO₂)

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E-fuels: comparative economics of e-methanol are strongly related to electricity costs for hydrogen production

Green-methanol can compete against bio-ethanol at electricity prices less than 30-40 €/MWh

Green-methanol can compete against “black”-methanol only at extremely low electricity costs


1€=1,2 $
Windgas Haßfurt
First power-to-gas plant in Germany in 2016

Facts & figures
- Customer: Windgas Haßfurt
- Country: Germany
- Installed: 2016
- Product: Silyzer 200

Use cases
- Green hydrogen is fed into the local gas network.
- Hydrogen is added to natural gas for a malthouse.

Challenge
- Installation and integration into an existing setting at Stadtwerke Haßfurt GmbH
- Supply of a complete solution (water processing, drying, storage and feeding into the gas network)
- Remote control of plants harmonized with electricity costs

Solutions
- Operation of a SILYZER 200
- Highly dynamic power consumption
- State-of-the-art process control technology based on SIMATIC PCS 7

1.25 MW
rated power based on Silyzer 200
Siemens started an engagement in e-fuels
BMWi-funded R&D project "E2Fuels“ started in Oct. 2018

**Project Structure and Partners**

- **SW Haßfurt**
  Infrastructure site preparation

- **MAN Deggendorf**
  Reactor design, erection, testing

- **FAU Erlangen**
  Scientific support for innovative CO₂ based methanol synthesis

- **TU München**
  Project coordination, system analyses, Funding, project coordination

**Process Concept**

3 H₂ + CO₂ ⇌ CH₃OH (+ H₂O)

**Balance of plant and instrumentation & control for the entire plant**

- **Test plant in Haßfurt**
- **SW Haßfurt**
- **CO₂**
- **3 H₂ + CO₂ ⇌ CH₃OH (+ H₂O)**
- **H₂**
- **Silyzer 200**
- **Compressor**
- **Methanol-synthesis**
- **green e-methanol**

E2Fuels: Erneuerbare Emissionsarme Kraftstoffe - Forschung zur Herstellung und Nutzung in einem sektor gekoppelten Ansatz

BMWi: Federal ministry for Economic Affairs and Energy (funding), PtJ: Projektträger Jülich (executing organization)
## Summary

1. Defossilization of energy supply is a must. Historical focus on power generation sector alone is not enough

2. Sector coupling is a key lever for energy system transformation

3. Hydrogen is one of key elements of sector coupling, it opens up multiple entries to the energy sector

4. PEM electrolysis fits to PV- and wind power use and is an efficient way to produce green hydrogen

5. PEM electrolysis scales up by factor 10 every 4 – 5 years

6. H2 based e-fuels are vital defossilization-elements for road transportation, marine and aviation

7. Comparative economics of “green”– e-methanol are related to electricity costs for hydrogen production

8. "E2Fuels" demonstration and test plant in Haßfurt is a starting point for Siemens engagement in e-fuels
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