Power-to-X and Hydrogen to Decarbonize Energy

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Power-to-Hydrogen as a basis for sector coupling – Convert electricity in chemical form as energy carrier and feedstock

### Power generation
- **Renewable energy**
  - Wind
  - Solar
  - Hydro

### Conversion
- **Direct air capture**
  - Capture from flue gases (power, industry)
- **Synthesis**
  - Haber-Bosch synthesis
- **Air separation**
  - N₂

### Applications
- **Largely carbon-neutral fuels**
- **Chemical feedstock**
- **Electricity**
- **Direct use for mobility**
- **Electricity**
- **Chemical feedstock**
- **Heat**
- **Chemical feedstock**
- **Fertilizer**
- **As a carrier for H₂ or direct use for energy**

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**Electricity-based molecular hydrogen, methanol and hydrocarbons as well as ammonia**

**Source:** Siemens
Various countries demonstrate strong potential for PtX production / exports …

Source: Frontier Economics
Power-to-Fuels – Decarbonizing the Mobility Sector

**Methanol as a base chemical to:**
- Blend with fossil fuel
- DME and MTBE as an add-in to fuels
- Methanol-to-Gasoline process
- Synthesis of hydrocarbon chains as the future fuel

**Business drivers/objectives**
- Green Methanol market with huge potential and the option to displace Bio-Ethanol
- Green Methanol market price expected increase to 800–1000 $/t near-term driven by RED-II and other regulation
- Contributes to the EU’s objectives of decreasing CO₂ emissions through carbon neutral fuels

**Description**
- Lowest levelized cost of electricity and high load factors from wind and partly solar
- Hydrogen production at large scale and competitive with fossil generation cost
- Export Green Methanol to Europe (premium price)

**Fuel processing**
- Blending
- DME/MTBE
- MTG

**Fuel Options**
- Methanol to Gasoline process
- Synthesis of hydrocarbon chains as the future fuel
Hydrogen from electrolysis becomes competitive

Highly available, low-cost renewable power already generates green e-Hydrogen at costs of conventional hydrogen from steam methane reforming (SMR)

Source: Siemens; Note: Main impact by WACC; electrolyzer CAPEX, OPEX, electrolyzer efficiency, lifetime

- **Levelized cost of hydrogen via electrolysis**
  - US$/kg
  - Reallabore: Locations with high renewable power cost (e.g. Germany)
  - Large-scale commercial: Locations with lowest renewable power cost (e.g. Chile)
  - Grey hydrogen: 1.5 – 2.5 US$/kg H2 from SMR

- **Price of electricity**
  - US$ct/kWh
  - 2 – 6 US$/kg e-Hydrogen production cost

- **Hydrogen production cost**
  - Real lab: 2,000 h/a
  - Large scale commercial: 4,000 h/a
  - Grey hydrogen: 6,000 h/a

**Note:**
- **Water electrolysis:**
  - 80% (we) efficiency at 150 bars
  - 50% (re) efficiency at 150 bars
  - Terminal efficiency: 100% - 20% WE - 20% RE - 50% RE - 50% RE - 50% RE - 50% RE - 50% RE

**Key points:**
- **Water electrolysis**
  - 80% (we) efficiency at 150 bars
  - 50% (re) efficiency at 150 bars
  - Terminal efficiency: 100% - 20% WE - 20% RE - 50% RE - 50% RE - 50% RE - 50% RE - 50% RE

**Key metrics:**
- **Cost drivers**
  - CAPEX
  - OPEX
  - Electrolyzer efficiency
  - Lifetime

**Chart:**
- **Horizontal axis:** Price of electricity (US$ct/kWh)
- **Vertical axis:** Levelized cost of hydrogen via electrolysis (US$/kg)
- **Legend:**
  - Reallabore: Locations with high renewable power cost (e.g. Germany)
  - Large-scale commercial: Locations with lowest renewable power cost (e.g. Chile)
  - Grey hydrogen: 1.5 – 2.5 US$/kg H2 from SMR

**Graphs:**
- **Reallabore:**
  - 2,000 h/a
- **Large-scale commercial:**
  - 4,000 h/a
- **Grey hydrogen:**
  - 6,000 h/a

**Price of electricity (US$ct/kWh):**
- **Range:** 1.0 to 8.0

**Levelized cost of hydrogen via electrolysis (US$/kg):**
- **Range:** 1.0 to 8.0
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\(^1\)
~150k Nm\(^3\) of H\(_2\)

World's largest Power-to-Gas plants with PEM electrolyzers in 2015 and 2017 built by Siemens!

**2015**
Silyzer 200
~86,500 op.h
~7.3 mio Nm\(^3\) of H\(_2\)

Biggest PEM cell in the world
Built by Siemens!

**2018**
Silyzer 300

**2023+**
Next generation
Under development

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

\(^1\) op.h.: operating hours; Data op.h & Nm\(^3\) as of Jan. 2019.
Siemens Hydrogen Gas Turbines for our sustainable future – The mission is to burn 100% hydrogen

<table>
<thead>
<tr>
<th>Gas turbine model</th>
<th>Power Output</th>
<th>H₂ capabilities in vol. %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heavy-duty gas turbines</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SGT5-9000HL</td>
<td>593 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT5-8000H</td>
<td>450 MW</td>
<td>30</td>
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<tr>
<td>SGT5-4000F</td>
<td>329 MW</td>
<td>30</td>
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<tr>
<td>SGT5-2000E</td>
<td>187 MW</td>
<td>30</td>
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<tr>
<td>SGT6-9000HL</td>
<td>405 MW</td>
<td>30</td>
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<tr>
<td>SGT6-8000H</td>
<td>310 MW</td>
<td>30</td>
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<tr>
<td>SGT6-5000F</td>
<td>215 to 260 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT6-2000E</td>
<td>117 MW</td>
<td>30</td>
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<tr>
<td><strong>Industrial gas turbines</strong></td>
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</tr>
<tr>
<td>SGT-A65</td>
<td>60 to 71/58 to 62 MW</td>
<td>100</td>
</tr>
<tr>
<td>SGT-800</td>
<td>48 to 6 MW</td>
<td>50</td>
</tr>
<tr>
<td>SGT-A45</td>
<td>41 to 44 MW</td>
<td>100</td>
</tr>
<tr>
<td>SGT-750</td>
<td>40/34 to 41 MW</td>
<td>40</td>
</tr>
<tr>
<td>SGT-700</td>
<td>33/34 MW</td>
<td>55</td>
</tr>
<tr>
<td>SGT-A35</td>
<td>27 to 37/28 to 38 MW</td>
<td>100</td>
</tr>
<tr>
<td>SGT-600</td>
<td>24/25 MW</td>
<td>60</td>
</tr>
<tr>
<td>SGT-400</td>
<td>10 to 14/11 to 15 MW</td>
<td>65</td>
</tr>
<tr>
<td>SGT-300</td>
<td>8/8 to 9 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT-100</td>
<td>5/6 MW</td>
<td>65</td>
</tr>
<tr>
<td>SGT-A05</td>
<td>4 to 6 MW</td>
<td>2</td>
</tr>
</tbody>
</table>

Values shown are indicative for new unit applications and depend on local conditions and requirements. Some operating restrictions/special hardware and package modifications may apply.

Higher H₂ contents to be discussed on a project specific basis

Legend:
- **DLE burner**
- **WLE burner**
- **Diffusion burner with unabated NOx emissions**
Future of Energy in Europe is about Decarbonization through Sector Coupling and a new Market Design

Cornerstones of a Future Energy System

- **Decarbonization of Energy**: Transforming the conventional generation capacity into low-carbon assets
- **Sector Coupling**: Leveraging renewables in power sector to decarbonize heat, mobility, industry
- **Power-to-X and Hydrogen**: Key technology for sector coupling and fuel for decarbonization of energy
- **Mobility**: Need to reduce carbon footprint from mobility creating demand for hydrogen and green fuels
- **Regulatory Framework**: Set decarbonization targets, technology-open, the end of the energy-only market