Hydrogen in the near Future in the Power Industry

Dr. Vinayaka Nakul Prasad, Corporate Strategy
**CO₂ emissions reduction has so far been focused on power, but all sectors in economy must contribute**

Global CO₂ emissions and projections

**Shares in global CO₂ emissions by sectors**

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

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

- **Continuous emission reduction required**

- **Increased future focus for emission reduction**

**Sector Coupling**
Hydrogen solves two problems – time-shifting of energy and feedstock for chemical processes

Hydrogen can time-shift energy…

… and use this stored energy to displace carbon intensive hydrogen in chemical and other processes
Green H₂ market expected to grow from small size today to GW ranges due to increased decarbonization efforts

Key market drivers

- Regulatory support to promote H₂ and other renewable based energy forms
- Decarbonization self commitments of players
- Economic pressure due to e.g., increase in CO₂ price

Hydrogen market by 2050 – Tripling with shift to green hydrogen and commercial markets

<table>
<thead>
<tr>
<th>Energy source for H₂ production</th>
<th>Today</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80’ t</td>
<td>250-550’ t</td>
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Exemplary top down use cases

<table>
<thead>
<tr>
<th>Market</th>
<th>Installed electrolyzer capacity required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td></td>
</tr>
<tr>
<td>H₂ direct use</td>
<td></td>
</tr>
<tr>
<td>- H₂ supply for up to 100k fuel cell heavy trucks</td>
<td>20 GW</td>
</tr>
<tr>
<td>E-fuels</td>
<td></td>
</tr>
<tr>
<td>- 1% substitution of rail &amp; road transport fuel in EU</td>
<td>15 GW</td>
</tr>
<tr>
<td>Industry</td>
<td></td>
</tr>
<tr>
<td>- 50% H₂ based decarbonization of 30% of key players with self commitment in steel industry</td>
<td>6 GW</td>
</tr>
<tr>
<td>Energy</td>
<td></td>
</tr>
<tr>
<td>- 3% substitution of natural gas in EU &amp; North AM (e.g., blending in gas distribution grid)</td>
<td>47 GW</td>
</tr>
</tbody>
</table>

1 Based on market reports and regulatory support for hydrogen in Europe | 2 Thyssen Krupp Europe, POSCO, Salzgitter, Arcelor Mittal Europe, Tata Steel, voestalpine, SSAB

Hydrogen economy will support CO₂ reduction... depending on legislation and emergence of scalable solutions

Production

- Natural Gas
  - Reforming
  - Steam Methane Reforming
  - Capture
  - CO₂
  - Reforming
  - Pyrolysis
  - Solid C
  - Natural Gas
  - H₂O
  - Renewable Power
  - Electrolysis
  - Hydrogen

Transport Pathways ¹)

- Grey H₂: 1.3 ³)
- Blue H₂: 1.9 ³)
- Cyan H₂: overlapping blue with green
- Green H₂: 3.5 ³)
- Red H₂

Consumption

- Physical
  - Pure H₂ or Blended H₂
  - Liquid H₂ or Adsorbed H₂

- Synfuel / Chemical
  - Methanol
  - Ammonia

- Electrical
  - Electricity

- Storage
  - H₂

- Refineries/GTL
  - ~30%

- Chemicals: ammonia, methanol, resins and polymers
  - ~60%

- Other industries: hydrogen
  - <5%

- Metal processing: hydrogen
  - ~5%

- Future use: synthetic fuels (e.g., e-methanol, e-kerosene), re-electrification

1) Processes after H₂ production are independent of the production type, it’s always the same chemistry; maybe certificate trading;
2) Quantitative growth potential in a decarbonized environment;
Abbreviation: CCS – Carbon Capture and Storage; SMR – Steam Methane Reforming; NG – Natural Gas; 3IEA 2019 (The future of hydrogen)
What can Siemens offer to the P2X customers?
Siemens competence along the value chain

Siemens covers important parts of the value chain to deliver Power-to-X projects on turnkey basis.

Solution provider for Power-to-liquids (i.e. Methanol)
- One face to the customer
- Overall system design
- Integration of Siemens products and technology & products from external partners

Wind Park
- Onshore wind
- Offshore wind
  Siem.-Gamesa

Photovoltaics
- Solar Fields/ Storage Systems
  External Sourcing

Power Grid
- Transmission
- Distribution
- Substations
- Transformers
- Power cable systems

Electrolysis
PEM technology
Silyzer 300

Machinery
- Compressors
- Storage systems
- Water treatment
- Elec. equipment
- Mech. equipment
- Turbines/engines (back up power)

CO₂ Capture
- Capture from flue gas (PostCap)
- DAC: external

N₂ Supply
- Air separation: external

Synthesis
- Partnering
  - CH₃OH
  - CH₄
  - NH₃
- Own concepts
- Novel, flexible methanol reactor concept in R&D stage

DAC: Direct air capture: Under development; no Siemens activities | CCU: Carbon Capture and Utilization | typical share in value addition

Dr. Vinayaka Nakul Prasad
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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 OH¹
~150k Nm³ of H₂

2015
Silyzer 200
~86,500 OH¹
~7.3 m 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
Silyzer 300 – Full Module Array
The next paradigm in PEM electrolysis

Silyzer 300 – full module array (24 modules)

17.5 MW
plant power demand

> 75.5 %
plant efficiency

24 modules

335 kg
hydrogen per hour
to build a full module array

1 HHV = 39.41 kWh/kg; air cooled plant without gas management at ISO conditions
H2FUTURE
A European Flagship project for generation and use of green hydrogen

Project
- Partner: VERBUND (coordination), voestalpine, Austrian Power Grid (APG), TNO, K1-MET
- Country: Austria
- Installed: 2019
- Product: Silyzer 300

Use cases
- Hydrogen for the steel making process
- Supply grid services

Challenge
- Potential for “breakthrough” steelmaking technologies which replace carbon by green hydrogen as basis for further upscaling to industrial dimensions
- Installation and integration into an existing coke oven gas pipeline at the steel plant
- High electrolysis system efficiency of 80%

Solutions
- Operation of a 12-module array Silyzer 300
- Highly dynamic power consumption – enabling grid services
- State-of-the-art process control technology based on SIMATIC PCS 7

6 MW
Power demand based on Silyzer 300

1,200 Nm³
of green hydrogen per hour

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 programme and Hydrogen Europe and NERGHY

Dr. Vinayaka Nakul Prasad
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EU funded HYFLEXPOWER Project
A CO₂ free power-to-power path using DLE

![Diagram of HYFLEXPOWER project](Image)

**Source:** [http://www.hyflexpower.eu/](http://www.hyflexpower.eu/)

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Hydrogen does not produce CO₂ emissions, but challenging physical properties require rapid design and testing cycles

Challenges

- **Higher diffusivity** requires re-certification of sealing, upgrade to stainless steel materials …
- **Lower volumetric energy content** requires larger flows to be handled by fuel system
- **Higher reactivity** pushes flame towards burner and increases risk of explosion or flashback
- **Higher flame temperature** can lead to local hotspots if imperfectly mixed and thus increased NOx emissions

1. High fidelity CFD
   High fidelity CFD tools like LES can provide automated optimized designs

2. Rapid prototyping using AM
   Additive manufacturing reduces lead time and enables better designs

3. High-pressure testing at engine conditions
   Facility in Berlin allows for high-pressure burner tests at engine conditions

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Values shown are relative to natural gas (indicative only)
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 Output¹</th>
<th>H₂ capabilities in vol. %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>50Hz</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SGT-9000HL</td>
<td>593 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT-8000H</td>
<td>450 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT-4000F</td>
<td>329 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT-2000E</td>
<td>187 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT-9000HL</td>
<td>405 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT-8000H</td>
<td>310 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT-5000F</td>
<td>215 to 260 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT-2000E</td>
<td>117 MW</td>
<td>30</td>
</tr>
<tr>
<td><strong>60Hz</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SGT-A65</td>
<td>60 to 71/58 to 62 MW</td>
<td>30</td>
</tr>
<tr>
<td>SGT-800</td>
<td>48 to 62 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>100</td>
</tr>
<tr>
<td>SGT-700</td>
<td>33/34 MW</td>
<td>100</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>55</td>
</tr>
<tr>
<td>SGT-400</td>
<td>10 to 14/11 to 15 MW</td>
<td>60</td>
</tr>
<tr>
<td>SGT-300</td>
<td>8/8 to 9 MW</td>
<td>65</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>65</td>
</tr>
</tbody>
</table>

**Higher H₂ contents to be discussed on a project specific basis**: 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.

1 ISO, Base Load, Natural Gas; Version 3.4, July 2020

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Hydrogen experience in DLE combustion
Built on continuous development experience across the fleet

Applications for 3rd generation DLE
- Renewable grid support Natural gas with added H₂
- Hydrogen rich fuels
- Refinery Fuel Gas with high H₂ content
- Industry off gases

Available solutions Hydrogen levels for 3rd generation DLE at ≤25 ppm NOx
- SGT-600 60% H₂
- SGT-700 55% H₂
- SGT-750\(^1\) 40% H₂
- SGT-800 50% H₂

Medium power range gas turbines SGT-600, -700 and -800 with 3rd generation Dry Low Emission system
Continuous improvement of our DLE design and engine testing steady increase H₂ admixing capabilities

3rd generation DLE burner

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>H₂ Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Atmospheric and high pressure tests in 2008, 2009 and 2012</td>
<td>≤80% H₂</td>
</tr>
<tr>
<td>2012</td>
<td>Engine test of SGT-700 in 2012 and 2014</td>
<td>55% H₂</td>
</tr>
<tr>
<td>2014</td>
<td>SGT-700 continuous operation since Sept. 2014 (&gt;10% H₂)</td>
<td>40% H₂</td>
</tr>
<tr>
<td>2016</td>
<td>High pressure test of SGT-750(^1)</td>
<td>50% H₂</td>
</tr>
<tr>
<td>2017</td>
<td>Full string test of SGT-800 ≤ 50% H₂</td>
<td>50% H₂</td>
</tr>
<tr>
<td>2018</td>
<td>≤80% H₂ Full engine test SGT-600</td>
<td>100% H₂ high pressure test</td>
</tr>
<tr>
<td>2019</td>
<td>Roadmap to 100% CO₂ neutral Engine operation</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) The SGT-750 is already equipped with a 4th generation Dry Low Emission burner design
Zero Emission Hydrogen Turbine Center
The future energy system

Develop the gas turbine test facility towards a zero emission demonstrator plant by:
− Utilize power from turbine test runs to produce hydrogen in an electrolyzer
− Installing solar panels for continuously hydrogen production
− Use produced hydrogen as turbine fuel to reduce LNG consumption

Three year project
− Operation planned to start in 2021
The HL-class: Experience and technology unite to build the future

A decade in the making...

Ultra Low Nox Rig Test (2008)
Full pressure testing achieving >30% hydrogen by volume

DOE H2 Program (2005-2015)

Conclusion: Adv. combustion system capable of 60% hydrogen by volume and 40% nitrogen

ACE - Advanced combustion system for high efficiency
Burner Adjustment/Exchange for Industrial Gas Turbines

Main systems requiring modification when upgrading to higher H₂ content

- Fire Protection System
- Gas Group IIC electrical equipment
- H₂ compatibility of plant auxiliary and peripheral systems
- Additional Flame Control and Combustion Monitoring Systems
- Burner Adjustment/Exchange
- Fuel Gas System material and set-up

Consequences and solution

- Project specific evaluation and decision on required modifications
- Power output control to ensure compliant NOx emission levels
- Conventional/non-H₂ fuels may be required for start-up and shutdown
- Re-certification with respective authorities might be required
Partnership for hydrogen-fueled gas turbines in a sustainable, hydrogen-based energy world

Hydrogen capabilities in Gas Turbines

• All newly built Siemens gas turbine types capable to burn different levels of hydrogen in the fuel mix
• Smaller hydrogen contents not requiring any modification compared with standard natural gas turbines (new unit applications)
• Siemens with a roadmap in implementation to burn 100% hydrogen fuel in gas turbines

Conclusions

- Existing assets and future investments in gas turbines are protected also in a fully decarbonized world
- Carbon-free power generation in gas turbines with green hydrogen
- Hydrogen-capable gas turbines with increased fuel flexibility to burn both hydrogen and natural gas
- Siemens gas turbines fully compliant with emission limits when burning hydrogen