Key technologies for a hydrogen-based energy system

Hydrogen Solutions – Gabriele Schmiedel
@ Niedersächsische Energietage
Nov. 4th 2019
To decarbonize the global economy by 2100 we need to take more than one measure

Politics force worldwide decarbonization

G7 summit, 2015:
Decarbonization of the global economy by 2100: Greenhouse gas emissions reductions of 40% to 70% by 2050 (baseline: 2010)

COP21, 2015:
195 countries adopt the first universal climate agreement: Keep a global temperature rise this century well below 2°C

COP23, 2017:
The 197 Parties discussed how and how far they can implement decarbonization measures

Renewables installation increase

Global Wind Installations (GW)¹

2008 2017
115 150 181 220 270 302 349 417 467 514
+18%

Global Solar PV Installations (GW)¹

2008 2017
15 23 40 70 98 137 174 224 297 391
+43%

But CO₂ emissions stagnate

Global CO₂ Emissions (Gt)²

2008 2017
29 29 30 31 31 32 32 32 32 33
+1.3%

Sources: ¹IRENA, Renewable Capacity Statistics 2018; ²IEA

Renewables integration; Decarbonization of every industry; Changes in legislation
Hydrogen from renewables enables large scale long term storage and sector coupling

- Hydrogen for ammonia production, petroleum refinement, metal production, flat glass, etc.
- Hydrogen as alternative fuel or as feedstock for green fuels
- Hydrogen blending (gas grid)
- Remote energy supply/Off-grid

**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 green fuels
- **Energy**: Hydrogen blending (gas grid), Remote energy supply/Off-grid
There are three considerable technologies of water electrolysis

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Alkaline Electrolysis</th>
<th>PEM Electrolysis</th>
<th>High temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyte</td>
<td>KOH(^3)</td>
<td>Polymer membrane</td>
<td>Ceramic membrane</td>
</tr>
<tr>
<td>Circulated medium</td>
<td>KOH(^3)</td>
<td>Water</td>
<td>Steam</td>
</tr>
<tr>
<td>Operational temperature(^1)</td>
<td>60 - 90 °C</td>
<td>RT(^4) - 80 °C</td>
<td>700 - 900 °C</td>
</tr>
<tr>
<td>Technical maturity(^1)</td>
<td>Industrially mature</td>
<td>Commercially available</td>
<td>Lab/ demo</td>
</tr>
<tr>
<td>Field experience(^1)</td>
<td>Existing/ available</td>
<td>In development/ limited</td>
<td>Not possible, not available</td>
</tr>
<tr>
<td>Cold-start capability(^2)</td>
<td>In development/ limited</td>
<td>Existing/ available</td>
<td>Not possible, not available</td>
</tr>
<tr>
<td>Intermittent operation(^2)</td>
<td>Existing/ available</td>
<td>In development/ limited</td>
<td>Not possible, not available</td>
</tr>
<tr>
<td>Scalability to multi Mega Watt(^2)</td>
<td>Existing/ available</td>
<td>In development/ limited</td>
<td>Not possible, not available</td>
</tr>
<tr>
<td>Reverse (fuel cell) mode(^1)</td>
<td>Not possible, not available</td>
<td>Not possible, not available</td>
<td>Not possible, not available</td>
</tr>
</tbody>
</table>

Source: 1) Fraunhofer; 2) IndiWede; 3) KOH: Potassium hydroxide; 4) room temperature
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 OH\(^1\)
  - ~150k Nm\(^3\) of H\(_2\)

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

\(^1\) Operating Hours; Data OH & Nm\(^3\) as of July 2019

Unrestricted © Siemens AG 2019

Page 5, Nov. 2019

Siemens Hydrogen Solutions
Silyzer 200
High-pressure efficiency in the megawatt range

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

65 %
Efficiency
System

20 kg
225 Nm³
Hydrogen production per hour

1.25 MW
Rated stack capacity
Silyzer 300 – the next paradigm in PEM electrolysis

<table>
<thead>
<tr>
<th>Power demand per full Module Array (24 modules)</th>
<th>17.5 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>System efficiency (higher heating value)</td>
<td>75 %</td>
</tr>
<tr>
<td>to build a full Module Array</td>
<td>24 modules</td>
</tr>
<tr>
<td>hydrogen per hour per full Module Array</td>
<td>340 kg</td>
</tr>
</tbody>
</table>
The modular design of Silyzer 300 can be easily scaled to your demands.

<table>
<thead>
<tr>
<th>Module</th>
<th>Module array</th>
<th>n+1 Customized solution</th>
<th>Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Module" /></td>
<td><img src="image2" alt="Module array" /></td>
<td><img src="image3" alt="Customized solution" /></td>
<td><img src="image4" alt="Plant" /></td>
</tr>
<tr>
<td>Between 12 and 24 modules</td>
<td></td>
<td></td>
<td>Scale up to the necessary demand</td>
</tr>
</tbody>
</table>

Modular concept to cover wide production rate

![Diagram](image5)
Hydrogen production cost depends on site and technology specific drivers

### Site specific drivers

- **Electricity price**
- **Operation time**

### Technology specific drivers

- **Efficiency**
- **CAPEX**
- **Maintenance cost**

---

2. € 6 ct./kWh: e.g. onshore wind (4-6ct./kWh) or PV in Germany.
3. € 3 ct./kWh: Reachable in renewable intense regions like Nordics (Hydro Power), Patagonia (Wind), UAE (PV).

---

Unrestricted © Siemens AG 2019
Siemens Hydrogen Solutions
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>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>2020</td>
<td>UAE</td>
<td>DEWA Expo 2020</td>
<td>Dubai Electricity and Water Authority (DEWA)</td>
<td>1.25 MW</td>
<td>Silyzer 200</td>
</tr>
<tr>
<td>2019</td>
<td>Australia</td>
<td>Hydrogen Park SA (HyP SA)</td>
<td>Australian Gas Infrastructure Group (AGIG)</td>
<td>1.25 MW</td>
<td>Silyzer 200</td>
</tr>
<tr>
<td>2019</td>
<td>Sweden</td>
<td>Food &amp; Beverage</td>
<td>Food &amp; Beverage Company</td>
<td>2.5 MW</td>
<td>Silyzer 200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>Austria</td>
<td>H2Future¹</td>
<td>voestalpine, Verbund, Austrian Power Grid (APG)</td>
<td>6 MW</td>
<td>Pilot Silyzer 300</td>
</tr>
</tbody>
</table>

¹ 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.
Hydrogen from renewables enabling the decarbonization of the mobility sector

**Renewable electricity generation**

- Intermittent Renewables:
  - Solar
  - Wind
  - Geothermal
  - Biomass
  - Hydro

- Continuous Renewables

**Grid Integration**

**Conversion / Storage**

**Applications**

Zero emissions!!!

<table>
<thead>
<tr>
<th>Alternative fuel</th>
<th>Min. kg H₂/100 km</th>
<th>Max. kg H₂/100 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>7.5</td>
<td>8.0</td>
</tr>
<tr>
<td>9.0</td>
<td>15.0</td>
<td></td>
</tr>
<tr>
<td>23.0</td>
<td>34.0</td>
<td></td>
</tr>
</tbody>
</table>

Green fuel as an alternative instead of critical viewed bio-fuel (made of plants e.g. wheat, corn etc.)

Hydrogen from renewables enabling the decarbonization of the mobility sector

Grid stabilization

H₂ generation

PEM electrolysis

H₂

Mobility

Synthesis reactor

CO₂ source

Green fuel

Alternative fuel

Siemens Hydrogen Solutions
Hydrogen from renewables enables large scale long term storage and sector coupling

- **H₂ injection** into the existing natural gas grid. Today’s gas grids can manage up to 10% H₂ content¹.

- **Re-electrification** of H₂ with a stationary fuel cell power plant.
- **Blending the conventional fuel** with H₂ for a power generator (gas turbine/engine).


Intermittent Renewables
- Solar
- Wind
- Geothermal
- Biomass
- Hydro

Continuous Renewables

Grid Integration
- Grid stabilization
- H₂ generation
- PEM electrolysis

Conversion / Storage
- Energy
- Grid injection
- Re-electrification

Applications

Hydrogen from renewables enables large scale long term storage and can be re-electrified

- **Fuel cell ~0.3 MWel**
  - ~20 kg/h H₂ demand
- **Gas engine ~0.28 MWel**
  - 100% H₂
  - ~20 kg/h H₂ demand
- **Gas turbine ~5 MWel**
  - Natural gas with H₂ blending of 26 vol% (H₂)
  - ~20 kg/h H₂ demand
Siemens Hydrogen Gas Turbines for our sustainable future – The mission is to burn 100% hydrogen

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

1 ISO, Base Load, Natural Gas Version 2.0, March 2019

Unrestricted © Siemens AG 2019

Page 14 Nov. 2019 Siemens Hydrogen Solutions
Future of Energy is about decarbonization through “Sector-Coupling” with the key component electrolyzer

Cornerstones of a Future Energy System

- PEM Electrolyzer are one of the key component of a hydrogen based economy
- Sector Coupling” is the key lever for decarbonization of all end-user sectors
- Hydrogen production costs with electrolysis are already competitive
- Siemens gas turbines are ready to support a hydrogen-based energy world
- Regulatory Framework: Set decarbonization targets, technology-open, the end of the energy-only market
Disclaimer

This document contains statements related to our future business and financial performance and future events or developments involving Siemens that may constitute forward-looking statements. These statements may be identified by words such as “expect,” “look forward to,” “anticipate” “intend,” “plan,” “believe,” “seek,” “estimate,” “will,” “project” or words of similar meaning. We may also make forward-looking statements in other reports, in presentations, in material delivered to shareholders and in press releases. In addition, our representatives may from time to time make oral forward-looking statements. Such statements are based on the current expectations and certain assumptions of Siemens’ management, of which many are beyond Siemens’ control. These are subject to a number of risks, uncertainties and factors, including, but not limited to those described in disclosures, in particular in the chapter Risks in Siemens’ Annual Report. Should one or more of these risks or uncertainties materialize, or should underlying expectations not occur or assumptions prove incorrect, actual results, performance or achievements of Siemens may (negatively or positively) vary materially from those described explicitly or implicitly in the relevant forward-looking statement. Siemens neither intends, nor assumes any obligation, to update or revise these forward-looking statements in light of developments which differ from those anticipated.

Trademarks mentioned in this document are the property of Siemens AG, its affiliates or their respective owners.

TRENT® and RB211® are registered trade marks of and used under license from Rolls-Royce plc.
Trent, RB211, 501 and Avon are trade marks of and used under license of Rolls-Royce plc.

Note: All performance at ISO conditions is estimated and not guaranteed. All information is subject to change without notice.
Gabriele Schmiedel
Executive Vice President
Hydrogen Solutions
Guenther-Scharowsky-Str. 1
91058 Erlangen

Tel.: +49 (9131) 17-40153
E-Mail: gabriele.schmiedel@siemens.com

siemens.com/silyzer