Siemens Perspective on Hydrogen Turbines
Energy System Decarbonization is Necessary

H2-Fueled Gas Turbines Required to Supplement Non-Dispatchable Resources
What Happened Last Month?

Siemens, along with other GT manufacturers made a commitment to hydrogen.
What Is The Commitment? (1)

Now:
- 3-5% hydrogen

2020:
- 20% hydrogen

2030:
- 100% hydrogen

DOE H2 Program provides basis for development
What Is The Commitment? (2)

Call to Action

• Gas turbines required to balance renewables on grid

• Greater speed in the transition

• R&D investment (public and private)

• No favored technologies

Combustion development for retrofit and new builds
# Siemens Perspective on Hydrogen Turbines
## Barrier to Successful Transition

### Approach
- H-Class Technology with Siemens premixed hydrogen combustion system
- Dual Fuel Capability
- Design concept close to a conventional CCPP
- One-on-one configuration
- Triple-pressure Heat Recovery Steam Generator
- Siemens novel SCR system

### Power Output
<table>
<thead>
<tr>
<th></th>
<th>60 Hz</th>
<th>50 Hz</th>
<th>400 to 450 MW</th>
<th>580 to 650 MW</th>
</tr>
</thead>
</table>

### H₂ Consumption
<table>
<thead>
<tr>
<th></th>
<th>60 Hz</th>
<th>50 Hz</th>
<th>530 t/d</th>
<th>760 t/d</th>
</tr>
</thead>
</table>

### CCPP Efficiency
<table>
<thead>
<tr>
<th></th>
<th>&gt; 60%</th>
</tr>
</thead>
</table>

### Fuel
- Main: Hydrogen (98 to 99%), NG (1 to 2%)
- Auxiliary: Natural Gas

### NOₓ Emission
- DeNOₓ: 2 ppm

### Turndown
- 40 % (Gas Turbine Load)

---

**H₂ infrastructure not sufficiently developed for LGTs – Focus shifted to smaller sizes**

- No credit taken for use of LiqH₂ fuel as heat sink
- No debit taken for on-site LiqH₂ refrigeration load
- No increase in GT firing temperature over current level
- Minimum use of steam as diluent
- ISO ambient air (15°C, 1.013 bar, 60% rel. hum.)
Where are we right now?
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>SGT5-9000HL</td>
<td>567 MW</td>
<td>5</td>
</tr>
<tr>
<td>SGT5-8000H</td>
<td>450 MW</td>
<td>10</td>
</tr>
<tr>
<td>SGT5-4000F</td>
<td>329 MW</td>
<td>10</td>
</tr>
<tr>
<td>SGT5-2000E</td>
<td>187 MW</td>
<td>10</td>
</tr>
<tr>
<td>SGT6-9000HL</td>
<td>388 MW</td>
<td>27</td>
</tr>
<tr>
<td>SGT6-8000H</td>
<td>310 MW</td>
<td>5</td>
</tr>
<tr>
<td>SGT6-5000F</td>
<td>250 MW</td>
<td>25</td>
</tr>
<tr>
<td>SGT6-2000E</td>
<td>117 MW</td>
<td>27</td>
</tr>
<tr>
<td>SGT-A65</td>
<td>60 to 71 / 58 to 62 MW</td>
<td>15 / 10 / 20 / 45</td>
</tr>
<tr>
<td>SGT-800</td>
<td>48 to 57 MW</td>
<td>15 / 10 / 20 / 45</td>
</tr>
<tr>
<td>SGT-A45</td>
<td>41 to 44 MW</td>
<td>15 / 10 / 20 / 45</td>
</tr>
<tr>
<td>SGT-750</td>
<td>40 / 34 to 41 MW</td>
<td>10 / 5 / 15 / 30</td>
</tr>
<tr>
<td>SGT-700</td>
<td>33 / 34 MW</td>
<td>10 / 5 / 15 / 30</td>
</tr>
<tr>
<td>SGT-A35</td>
<td>27 to 37 / 28 to 38 MW</td>
<td>15 / 10 / 20 / 45</td>
</tr>
<tr>
<td>SGT-600</td>
<td>24 / 25 MW</td>
<td>15 / 10 / 20 / 45</td>
</tr>
<tr>
<td>SGT-400</td>
<td>13 to 14 / 13 to 15 MW</td>
<td>10 / 5 / 15 / 30</td>
</tr>
<tr>
<td>SGT-300</td>
<td>8 / 8 to 9 MW</td>
<td>10 / 5 / 15 / 30</td>
</tr>
<tr>
<td>SGT-100</td>
<td>5 / 6 MW</td>
<td>10 / 5 / 15 / 30</td>
</tr>
<tr>
<td>SGT-A05</td>
<td>4 to 6 MW</td>
<td>3 / 15 / 30 / 65</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. Any project >25% requires dedicated engineering for package certification.

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

DOE H₂ Program Combustion System Designed To Fit

Siemens working to support potential demo plant
Our hydrogen combustion experience is built on continuous development experience across the fleet

Example: Medium power range gas turbines SGT-600 to SGT-800

Steady increase of our H₂ admixing capabilities based on continuous improvement of standard DLE burner design. SGT-600 / -700 / -800 all equipped with same burner design 3rd generation DLE.

- SGT-600: 60% H₂
- SGT-700: 55% H₂
- SGT-750: 40% H₂
- SGT-800: 50% H₂ available at ≤ 25 ppm NOx

- Operation on Refinery Fuel Gas with high H₂ content
- Renewable grid support within 10 minutes up to full load
- In combined cycle power plants, BACT is fulfilled with Siemens DLE Hydrogen turbines, e.g. 2ppm NOx, CO, and VOC with a SCR

SGT-600 Test at 79 vol-percent run January 2019 (50% energy content)
Siemens Aeroderivative gas turbines’ high hydrogen fuel capability is built on robust designs and field experience

**Inherently Fuel Flexible**

**Aeroderivative Combustors** using diffusion flame technology (WLE) offer the capability to operate on a wide range of gas fuels without the auto-ignition, flashback, and flame stability challenges encountered with DLE designs. Water injection can be added for NOx emissions reduction, and liquid fuel capability is available on all standards.

- **SGT-A65**
- **SGT-A45**
- **SGT-A35 Variants**

**AGT Fleet Experience**

- **+100k hours** of recorded operation with aeroderivative combustors on high hydrogen fuels (up to 78 vol%) at petrochemical sites in Europe and North America since 1968
- Proven operation on fuels with Wobbe indices from 25 to 80 MJ/m³
- Extensive experience with online swings in gas fuel composition and dual fuel units are capable of online fuel transfers

**Development Testing**

Atmospheric rig testing completed in 2011 with the SGT-A65 and SGT-A45 combustor (Phase V) using methane-hydrogen mixtures and 100 vol% H₂ to compare emissions characteristics

The 100% hydrogen fuel capability of SGT-A35, A45, and A65 aeroderivative technology has been validated through testing and backed by considerable fleet experience with high hydrogen fuels
Thank You! Questions?

John Marra
H-Frame Gas Turbine Engineering Management
E-mail: john.marra@siemens.com
Phone: 407-736-4190 (Office)