Workshop on Storage Systems for Renewable Energy

April 2010
Siemens Energy Sector

<table>
<thead>
<tr>
<th>Energy products and solutions – in 6 Divisions</th>
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</thead>
</table>

[Images of industrial equipment and people working]
### Integrated Gas Turbine Portfolio

**Gas Turbines for Utility & Industrial Applications**

<table>
<thead>
<tr>
<th>Model</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGT5-4000F</td>
<td>278</td>
</tr>
<tr>
<td>SGT6-6000G</td>
<td>266</td>
</tr>
<tr>
<td>SGT6-5000F</td>
<td>198</td>
</tr>
<tr>
<td>SGT5-3000E</td>
<td>188</td>
</tr>
<tr>
<td>SGT5-2000E</td>
<td>163</td>
</tr>
<tr>
<td>SGT6-3000E</td>
<td>121</td>
</tr>
<tr>
<td>SGT-1000F</td>
<td>68</td>
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<td>SGT-800</td>
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<td>SGT-700</td>
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<tr>
<td>SGT-600</td>
<td>25</td>
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<tr>
<td>SGT-500</td>
<td>17</td>
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<tr>
<td>SGT-400</td>
<td>13</td>
</tr>
<tr>
<td>SGT-300</td>
<td>8</td>
</tr>
<tr>
<td>SGT-200</td>
<td>7</td>
</tr>
<tr>
<td>SGT-100</td>
<td>5</td>
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</tbody>
</table>

*Integrated gas turbine portfolio*
Hydrogen as Fuel for Combustion Turbines
DOE H2 Program – Part of “Clean Coal” Strategy
US DOE H2/IGCC Turbines Program

“The objective of this project is to design and develop a fuel flexible (coal derived hydrogen or syngas) gas turbine for IGCC and FutureGen type applications that meets DOE turbine performance goals.”
3 Effects of Hydrogen Combustion on Turbomachinery

Compared to natural gas, hydrogen combustion leads to a lower mass flow rate and to a different composition of the product gases, with an higher water content that in turn influences the molecular weight and the specific heat of the mixture. The most relevant effects on the operation of a gas turbine are: (i) a variation of the enthalpy drop in the expansion, (ii) a variation of the flow rate at the turbine inlet which, in turn, affects the turbine/compressor matching, (iii) a variation of the heat-transfer coefficient on the outer side of the turbine blades, affecting the cooling system performance.
ADVANCED GAS TURBINE COMBUSTION SYSTEM DEVELOPMENT FOR HIGH HYDROGEN FUELS

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Siemens Power Generation, Inc., Mellinghofer Str. 55, Muelheim ADR 45473, Germany
Large Turbine Programs for H2

Siemens – DOE Advanced H2 Turbine Program
Technology Development is Key to Meeting Program Goals

IGCC Plant
- Improved Efficiency
- Fuel Flexibility
  - NG, Syngas, H₂
- Low Emissions
- Reduction in Plant Cost $/KW
- CO₂ Sequestration Ready

Engine
- Firing Temperature
- Exhaust Temperature
- Pressure Ratio
- Mass Flow
- Fuel Dilution
- ASU Integration

Combustion
- Modeling
- Technologies
- Rig Testing
- Turbine Aerodynamics
- Cooling and Leakage
- Operational Flexibility

Materials
- TBC & Bondcoats
- Alloys
- Fabricated Airfoils

Sensors
- Emissions and Fuel Sensors
- TBC Monitoring
- Tip Clearance Monitoring

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Hydrogen As Turbine Fuel

4. Siemens / DOE Advanced Hydrogen Turbine
- Development Timeline

Intermediate

- SGT6-5000F H2+Syngas
- SGT6-IGCC H2+Syngas

FutureGen

2010 Goal

DOE Turbine 2010 Goal:
- 2-3% pt improvement in CC efficiency
- 20-30% reduction of CC capital cost
- 2 ppm NOx on Syngas

FutureGen & DOE 2012 Goal:
- Showcase of near zero emissions coal-based power plant
- Demonstrate Carbon Sequestration Capability

Long-term

- Advanced GT H2+Syngas

Phase 1
Conceptual Design

Phase 2
Development and Validation of Component Technologies

DOE Turbine 2015 Goal:
- Demonstrate Carbon Sequestration ability
- 3-5% pt improvement in CC efficiency
- 2 ppm NOx on H2 fuel

Phase 1


Phase 2

Phase 3 (Not in current award)

With the 2-step approach, DOE intermediate and long-term goals are addressed. Technology infusion from the Advanced GT to FutureGen & 2010 GT will be realized.
But....
Hydrogen Capability Currently Exists for Industrial Units

- Siemens has considerable experience in refinery gas fuels containing high levels of H2
- Some experience with Synthetic Fuels containing H2 and CO; heavily diluted with Nitrogen (not commercial)
- Package changes necessary due to H2 fuel
- Wet injection methods applied to provide exhaust emission suppression
Gas Fuel Species

- Tailgas
- Blast furnace
- Air blown gasification
- Steel process
- Syngas / O2 gasification (60-85%)
- Wellhead - Very High inert (60-85%)
- Landfill / digester / sewage
- Wellhead - High inert (25-50%)
- Coke Oven
- MCV Refinery (25-50%)
- Wellhead - High hydrocarbon
- HCV Process
- LPG

Gas species:
- CO2
- N2
- CO
- H2
- C3H8
- C2H6
- CH4
- NG
- NG with H2
- LNG
- HCV Refinery
- HCV Process
- LPG
## Existing Turbine Capability for H2 Fuels

<table>
<thead>
<tr>
<th>Gas Turbine</th>
<th>Plant Location</th>
<th>Main Features</th>
<th>Fuel</th>
<th>Startup</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGT-200</td>
<td>Many Locations</td>
<td></td>
<td>80-85% H₂</td>
<td></td>
</tr>
<tr>
<td>SGT-500/600</td>
<td>Many Locations</td>
<td></td>
<td>20-90% H₂</td>
<td></td>
</tr>
<tr>
<td>VM5</td>
<td>Dortmund, Germany</td>
<td>Compressor Drive GT</td>
<td>Blast-Furnace Gas</td>
<td>1960</td>
</tr>
<tr>
<td>VM5</td>
<td>Handan, China</td>
<td>Compressor Drive GT</td>
<td>Blast-Furnace Gas</td>
<td>2000</td>
</tr>
<tr>
<td>CW201</td>
<td>Chicago, USA</td>
<td></td>
<td>Blast-Furnace Gas</td>
<td>1960</td>
</tr>
<tr>
<td>V93</td>
<td>Luenen, Germany</td>
<td>First CC plant in the world with integrated LURGI coal gasification</td>
<td>Syngas</td>
<td>1972</td>
</tr>
<tr>
<td>2XSGT6-3000E</td>
<td>Plaquemine, USA</td>
<td>CC plant with integrated DOW coal gasification</td>
<td>Syngas</td>
<td>1987</td>
</tr>
<tr>
<td>4XSGT6-3000E</td>
<td>Sweeney Cogeneration L.P., USA</td>
<td>CC Plant</td>
<td>0 – 30% H₂</td>
<td>1998</td>
</tr>
<tr>
<td>SGT5-2000E</td>
<td>Buggenum, Netherlands</td>
<td>CC plant integrated with coal gasification (hard coal and biomass blend)</td>
<td>Syngas</td>
<td>1994/5</td>
</tr>
<tr>
<td>V94.3</td>
<td>Puertollano, Spain</td>
<td>CC plant integrated PRENFLO coal gasification (coal and petroleum coke blend)</td>
<td>Syngas</td>
<td>1997/98</td>
</tr>
<tr>
<td>2XGT5-2000E</td>
<td>Priolo Gargallo, Italy</td>
<td>CC plant with integrated GE heavy-oil (asphalt) gasification</td>
<td>Syngas</td>
<td>1998/99</td>
</tr>
<tr>
<td>SGT5-2000E</td>
<td>Servola, Italy</td>
<td>CC plant with steel-making recovery gas</td>
<td>Steel-Making Recovery Gas</td>
<td>2000</td>
</tr>
<tr>
<td>SGT5-2000E</td>
<td>Sannazzaro, Italy</td>
<td>CC plant with integrated SHELL heavy-oil gasification</td>
<td>Syngas</td>
<td>2005</td>
</tr>
</tbody>
</table>

Table 1. Operating Experience with Syngas and Hydrogen Fuels
## Experience with Hydrogen

### High Hydrogen Fuel Applications (up to 85% H2 vol%)

<table>
<thead>
<tr>
<th>Customer</th>
<th>Location</th>
<th>Driven Unit</th>
<th>CHP</th>
<th>Combustion Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taiyo Oil</td>
<td>Japan</td>
<td>Gen</td>
<td>Yes</td>
<td>Dual fuel</td>
</tr>
<tr>
<td>Petromed (BP Oil)</td>
<td>Spain</td>
<td>Gen</td>
<td>N/A</td>
<td>Gas</td>
</tr>
<tr>
<td>Gulf Oil</td>
<td>UK</td>
<td>Gen</td>
<td>Yes</td>
<td>Dual Fuel</td>
</tr>
<tr>
<td>Gulf Oil</td>
<td>UK</td>
<td>Gen</td>
<td>Yes</td>
<td>Dual Fuel</td>
</tr>
<tr>
<td>ESB Trans power</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Powergen Conoco</td>
<td>UK</td>
<td>Gen</td>
<td>Yes</td>
<td>Gas</td>
</tr>
<tr>
<td>Powergen Conoco</td>
<td>UK</td>
<td>Gen</td>
<td>Yes</td>
<td>Gas</td>
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<td>Gen</td>
<td>Yes</td>
<td>Gas</td>
</tr>
</tbody>
</table>

**Total Running Hours > 600,000 With H2 > 65%**
SGT-200-1S Hydrogen Application (COG)
Hydrogen Embrittlement

- Ensure fuel system pipework and fitting of suitable material
- Martensitic steels particularly susceptible
- Stainless steel ("300" series) used as standard (pipework and fittings)
Hydrogen Use For Power Production?

Conclusion

- **Wait**
  - DOE’s long-term program for use of H2 fuel (from coal) in large-scale utility power projects

- **Don’t Wait**
  - Use commercial products suitable for high-content H2 fuel in industrial-sized Distributed Generation/ Cogeneration
  - Allows proof of concept for high H2 content fuels
  - Provides high efficiency projects for municipalities, universities, etc.