DE-FE0031615--Hydrogen to Power (H2P)

Official Title, "A Modular Heat engine for the Direct Conversion of Natural Gas to Hydrogen and Power Using Hydrogen Turbines"

UTSR
November 1, 2018
Daytona Beach, FL

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Presentation Outline

- Hydrogen-to-Power System Demonstration Concept
- Program vision
- Key Subsystems description
  - Compact Hydrogen Generator
  - Hydrogen Turbine
- Value proposition/Preliminary Techno-economics
- Phase I Objectives
- Applicable Markets
- Summary
Hydrogen-to-Power System Concept and Options
Vision: DOE Program on Modular Heat Engines

Phase I – System Definition
Create Team: End-Users, OEM’s, NG Distributors, Industrial Gas Co’s
Define System: Requirements, Architecture, Modularity
Assess: Technology Readiness, Technology Gaps, Techno-Economics (Lvl 5), Phase II Test Planning
18 Months

Phase II – Preliminary Design
Perform:
- Tech. Gap Reduction Testing
  - Components & System
Assess:
- Updated Techno-Economics
- Technology Maturation Plan
Design:
- System Design
- Front-End Engr. Design
- Plant Cost Estimate (Level 4)
Up to 48 Months

System Concept Demonstrator
Planning:
- Site planning
- End-user agreements
- Funding Sources
Engineering & Construction:
- Detailed Design
- Site Engineering
- Plant Installation
Operations:
- Start-up & Commissioning
- 1 year+ operations
36+ Months

Vision: Design, build and operate a modular heat engine system for efficient co-production of clean power, CO₂ and H₂
CHG Process Schematic

**Sorption Enhanced Steam Methane Reforming**

\[
\begin{align*}
\text{CH}_4 + 2\text{H}_2\text{O} + \text{Heat(a)} & \rightarrow 4\text{H}_2 + \text{CO}_2 \\
\text{CaO} + \text{CO}_2 & \rightarrow \text{CaCO}_3 + \text{Heat(b)} \\
\text{CH}_4 + 2\text{H}_2\text{O} + \text{CaO} & \rightarrow 4\text{H}_2 + \text{CaCO}_3 \\
\text{Heat(b)} & \sim 95\% \text{ Heat(a)}
\end{align*}
\]

700°C, 20-35 psig

**Catalyst:**
Commercially Available
Ni on Alumina
2mm diameter

**Sorbent:**
Natural Solid Sorbent:
Limestone or Dolomite
<0.2mm diameter

**Calciner Reaction**

\[
\text{CaCO}_3 + \text{Heat} \rightarrow \text{CaO} + \text{CO}_2
\]

850-900°C

**H2 Product Composition**

<table>
<thead>
<tr>
<th>Dry Basis</th>
<th>Wet Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2&gt;94%</td>
<td>H2&gt;75%</td>
</tr>
<tr>
<td>CH4~2.5%</td>
<td>CH4~2%</td>
</tr>
<tr>
<td>CO,CO2,N2~3%</td>
<td>CO,CO2,N2~2.8%</td>
</tr>
<tr>
<td>Bal.=Steam for NOx Control</td>
<td></td>
</tr>
</tbody>
</table>

**To turbine**

**Sorbent is regenerated in the indirectly heated calciner**

**PSA off gas + Natural gas**

**Air**

**Natural Gas and Steam fluidize the regenerated sorbent and deliver to bottom of reactor**
GTI has performed a systematic development of the CHG process, demonstrating each of the key system elements. This has culminated in a pilot plant which is operational and currently being tested.

- **Fixed Bed Tests**
  Demonstrated chemistry with commercial catalyst for wide range of operating conditions.

- **Cold Flow Tests**
  Defined component designs, demonstrated solids handling under wide range of operating conditions.

- **Flash Calciner Tests**
  Validated calcination rate models. Demonstrated operation of short-residence-time calciner.

- **20 MSCFD Pilot**
  Demonstrated SER operations (92% $\text{H}_2$ purity) and solids handling. Catalyst evaluation in process. Current TRL=4.

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**Design Data and Operating Experience**
DOE/Industry H₂ Turbine Development

- Significant H₂-fired turbine development was performed in the last 15 years
- Operational experience with H₂-fired turbines (based on current technology)

From Discovery to Commercialization

GE H₂ Turbine Project – Revolutionizes combustion technology for H₂ and NG fuels

Concept to Market Readiness

COMMERCIALIZATION
Technology available for wide-scale market use

DEMONSTRATION
System demonstrated in operational environment

SYSTEM TESTING
System performance confirmed at pilot-scale

DEVELOPMENT
Technology component validated/integrated

DISCOVERY

Fundamental Studies

2007
TRL 2-3

2011
Pre-Commercial/Prototype Validated in Laboratory Environment

2015
TRL 6-7

2020
TRL 8

National Energy Technology Laboratory

Siemens DLE Hydrogen Gas Turbines for our sustainable future
THE MISSION: Zero CO₂ emissions with 100% H₂

Hydrogen Capabilities and NOx compliance

- SGT-600 → 60% H₂ @ ≤25 ppm NOx
- SGT-700 → 55% H₂ @ ≤25 ppm NOx
- SGT-800 → 50% H₂ @ ≤25 ppm NOx

Product synergies and long experience
- The general geometry of the burners are identical for the SGT-600, 700 & 800
- Full string test in SGT-800 @ 100% load, 2017 (≤50% H₂)
- High pressure test in SGT-750, 2016
- Engine test in SGT-700, 2012 and 2014
- SGT-700 continuous operation since Sept. 2014 (∼10% H₂)
- High pressure and atmospheric tests, 2008, 2009 and 2012

Applications / Customer benefits...
- In Combined cycle BACT® is fulfilled with Siemens DLE Hydrogen products, e.g. 2ppm NOx, CO, and VOC with a SCR
- Power to gas, solar and wind power into H₂ energy storage
- Grid support within 10 minutes up to full load on renewables
- Reduce CO footprint and NOx with 3rd Gen DLE
- Operate on Refinery Fuel Gas with high H₂ content
- Best Available Control Technology

World class leader with Hydrogen in DLE combustion

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## Value Proposition/Techno-Economics (Preliminary)

<table>
<thead>
<tr>
<th></th>
<th>NGCC Standard Case</th>
<th>NGCC w/ Post-combustion CO2 separation</th>
<th>SOTA Heat Engine H2 Via SMR and Natural Gas Turbine modified for hydrogen use (0.399 Utility)</th>
<th>GTI's Modular Heat Engine with Natural Gas Turbine modified for hydrogen use (0.335 Utility)</th>
<th>GTI's Modular Heat Engine Advanced Hydrogen Turbine (0.335 Utility)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Plant Power (MW)</td>
<td>630</td>
<td>559</td>
<td>596</td>
<td>604</td>
<td>761</td>
</tr>
<tr>
<td>Percent of CO2 Recovered</td>
<td>0%</td>
<td>90%</td>
<td>90%</td>
<td>90%</td>
<td>90%</td>
</tr>
<tr>
<td>Total Plant Cost, Capital Costs ($MM)</td>
<td>$431</td>
<td>$828</td>
<td>$952</td>
<td>$548</td>
<td>$771</td>
</tr>
<tr>
<td>Total Overnight Cost ($MM)</td>
<td>$525</td>
<td>$1,008</td>
<td>$1,160</td>
<td>$669</td>
<td>$939</td>
</tr>
<tr>
<td>Total As-Spent Cost ($MM)</td>
<td>$567</td>
<td>$1,087</td>
<td>$1,250</td>
<td>$721</td>
<td>$1,012</td>
</tr>
<tr>
<td>Annual Costs (excluding T&amp;S) ($MM)</td>
<td>$270</td>
<td>$347</td>
<td>$436</td>
<td>$331</td>
<td>$384</td>
</tr>
<tr>
<td>COE (including T&amp;S) ($/MWh)</td>
<td>$58</td>
<td>$87</td>
<td>$102</td>
<td>$77</td>
<td>$73</td>
</tr>
<tr>
<td>System Efficiency (%)</td>
<td>56.9</td>
<td>50.5</td>
<td>39</td>
<td>51.1</td>
<td>56.4</td>
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<tr>
<td>CO2 T&amp;S ($/MWH)</td>
<td>0</td>
<td>$4.00</td>
<td>$3.75</td>
<td>$3.70</td>
<td>$3.04</td>
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<tr>
<td>Cost of CO2 Separation ($/MT)</td>
<td>0</td>
<td>$66</td>
<td>$81</td>
<td>$42</td>
<td>$29</td>
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<tr>
<td>Total CO2 Recovered (MT/day)</td>
<td>0</td>
<td>4,432</td>
<td>5,498</td>
<td>4,478</td>
<td>4,801</td>
</tr>
<tr>
<td>Total CO2 Not Recovered (MT/day)</td>
<td>5,394</td>
<td>492</td>
<td>611</td>
<td>498</td>
<td>533</td>
</tr>
<tr>
<td>BBL of Oil Recovered per Day</td>
<td>0</td>
<td>12,000</td>
<td>17,000</td>
<td>13,000</td>
<td>13,000</td>
</tr>
</tbody>
</table>
Phase I Objectives

1. Define overall system and component parameters via interactions with technology development, turbine OEM’s, and end-user organizations, thus creating a viable system and team

2. Perform detailed thermodynamic cycle and performance analysis of the system

3. Optimizing the size(s) and overall specifications for the key subsystems and components

4. Establish performance baseline for integrated system along with levelized costs

5. Design a modular system concept to take advantage of factory built modules

6. Identify technology gaps and recommend a test plan to close gaps
Hydrogen-to-Power Demonstration System Layout

- 10 modules total

Gas Turbine Module ~10 MWe
42’ L x 8’ W x 9.75’ H

Control Center

CO₂ Compression

Atm. Calciner

HRSG

H₂ Compression

H₂ Generation

Dry Cooler

40’ L x 7.5’ W x 9.25’ H

CO₂ Separation and Cooling

Calciner

Dry Cooler

Gas Turbine Genset
Overlapping Markets

- Distributed Power
- Remote Power
- Power For Oil & Gas Production
- Centralized Power
- CO2 Reuse
  - CO2 Piloting for Oil & Gas
  - Enhanced Oil & Gas Production
  - Urea Makeup
- Transportation
- Surplus H2
  - Distributed Ammonia
  - Infrastructure & Load Following

**Scale**
- Small Scale
- Nexus 25-60 MW\textsubscript{thermal}
- Large Scale

UTSR 2018
Hydrogen Demand Market Expansion

- GTI utilized a recent assessment for CO₂-EOR needs and determined corresponding H₂ demand for power generation using the CHG


Power market assumes U.S. and Europe only following Clearpath scenario #4b based on respective annual power generation
Summary

• Program combines GTI’s Compact Hydrogen Generator (CHG) with a H₂ turbine thus leveraging (a) CHG’s capability to affordably decarbonize natural gas and (b) prior DOE investment in H₂ turbine technology
  • Lowest cost of electricity, 11.5% to 16% better than post-combustion capture

• Enabling technology is GTI’s Compact Hydrogen Generator (CHG), which is currently under development (TRL=5), and offers:
  • One-step conversion of natural gas to H₂
  • Lower product cost vs. current technology
  • Lower CO₂ capture cost vs. current technology

• A phased program has been initiated to advance power generation with hydrogen turbines utilizing CHG

• GTI is evaluating candidate applications and teaming
  • Demonstrate distributed electrical power, use of H₂ for transportation, etc., and low-cost CO₂ for EOR etc.
Thank You!

Turning Raw Technology into Practical Solutions

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