Gasification and Dry Solids Pump Status

Alan Darby
Program Manager, Gasification

Gasification Technology Council Conference
Colorado Springs, Colorado
October 13-16, 2013
PWR acquired by GenCorp June 14, 2013

Our new name is Aerojet Rocketdyne
Compact Gasification System

- Next generation Gasification System that is environmentally friendly and lower cost than existing systems

Testing Initiated March 2012
EERC – North Dakota

Successful Testing Completed April 2011
Gas Technology Institute - Illinois

Reduces customer capital and operating cost by 20%
POX Unit Testing Under ARPA-e Program

- Built Low Cost pilot plant injector
  - Replaceable oxidizer orifices, faceplate
  - Configure for NG or coal by replacing oxidizer orifices

- Test Partial Oxidation (POX) unit over broad range of conditions
  - Anchor performance model
  - Data for turbo expander

- Initiated testing August 2013
  - Outlet temps 1800°F to 2400°F
  - Steam/carbon ratios 0.1 to 0.3
  - ~0.1 second residence time
  - 75%-95% methane conversion
  - Soot formation well below equilibrium
  - 1.9 H2/CO molar ratio
Compact Gasifier Technology Advances

- Upgraded gasifier outlet to improve slag discharge function
  - Demonstrated reliable, stable operation in hot-fire testing on coal
  - Eliminates slag build-up, misdirected flow of hot syngas

- Successfully completed 100 hrs of PRB and ILL#6 testing with upgraded injector and liner configurations

- Successful testing of high pressure torch ignition system
  - Suitable for light off on NG, propane, DME at ~1,000 psia
Dry Solids Pump Status

- Pump testing initiated March 2012
- Four major test activities since initiating test program
- Modifications underway to improve pump operations at higher pressures
Pump Mode of Operation

- Operation based on “solids lock-up” physics that has achieved 1,000 psi solids injection in prior DOE-funded tests
- Design uses “solids plug” gas seal also proven in prior DOE-funded research
- “Linear” concept advantages:
  - Higher efficiency
  - Scalable to large capacities
  - Feed material flexibility
Feed System and Pump Development

Feed System (Completed 2008)
- Capacity – 400 - 600 TPD
- Operating Pressure – 1000 psi
- Ultra Dense Flow – No plugging
- Flow Splitter – Even distribution

Solids pump (Testing Initiated 2012)
- Discharge 400 TPD at 1200 psi
- Standard “Utility” grind feedstock
- Multiple feedstocks to be tested
- Validate computer models
- Refine operating procedures
- Twice efficiency of Lock Hoppers
- Reduced feed system capital cost
Pump Manufacturing

Castings

Machining

Precision Boring

Assembly
Dry Solids Pump Test Profile

Plug evidenced by increasing motor torque and scraper strain at zero coal flow conditions.

Pump start-up shows reduced torque as new plug forms at low discharge tank pressures.

Motor Torque indicates Re-formed Plug.
Pump Testing Status

- Shake-down testing started March 2012
  - Confirmed fundamental and mechanical operating concept;
    - Lock up and mechanical delivery
    - Seal plug generation - gas seal at low pressure
  - Modify components for improved performance
    - Belt and link-to-link clearances
    - Added sensors to monitor internal pump operations

- Upcoming test series will include:
  - Short-duration testing at pressures up to 300 PSI
  - Performance mapping tests to develop control and safety logic
  - Long duration testing at pressures up to 1200 PSI
  - Testing with Ill #6, PRB, and Lignite coals to validate pump operation for a range of fuels
Compact Gasification Plant Study to Produce Synthetic Natural Gas

2.1 B Nm³/yr SNG product
– Approximately 15,000 STPD coal input using AR technology

Comparison to leading technologies:
– Domestic & Western Dry Feed Gasifiers
  – Slurry Fed Gasifier

Capital costs generated by ECEC for gasification island syngas output
– Scaled to support SNG target

Operating costs specific to each technology
– Coal feed
  – Power requirements
  – Oxygen, steam, process water, nitrogen, etc.

Collaboration with East China Engineering Science and Technology Co. Hefei, China
## Economics Comparison of China Based 2.1B Nm³/yr SNG Plant

### Compact Gasifier System Offers Lowest Cost of Product

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Aerojet Rocketdyne</th>
<th>Dry Feed (Western)</th>
<th>Dry Feed (Domestic)</th>
<th>Slurry</th>
<th>Units</th>
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<tr>
<td>Capex</td>
<td>377689</td>
<td>500058</td>
<td>347291</td>
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<td>Annual Profit</td>
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<td>83245</td>
<td>84540</td>
<td>115795</td>
<td>10,000 RMB/yr</td>
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<tr>
<td>Syngas Cost</td>
<td>318.3</td>
<td>445.5</td>
<td>437.7</td>
<td>373.3</td>
<td>RMB/kNm³</td>
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<tr>
<td>Payback</td>
<td>3.65</td>
<td>5.41</td>
<td>4.52</td>
<td>4.3</td>
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</table>

### 15%-29% Cost Of Syngas Advantage
### Gasification Plant Studies Supports AR Cost Advantages

<table>
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<tr>
<th>Compared Versus</th>
<th>Power (IGCC)</th>
<th>Power (IGCC)</th>
<th>Hydrogen</th>
<th>Hydrogen</th>
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<td>27%</td>
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<td>Study Performed By</td>
<td>NETL (Worley Parsons)</td>
<td>NETL (Worley Parsons)</td>
<td>NETL (Worley Parsons)</td>
<td>Jacobs</td>
<td>PWR Pilot Plant (2011)</td>
<td>ECEC (China Location)</td>
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</table>

**Overall Plant Cost Savings**
- 10% to 27% lower capital cost
- 15% to 29% lower cost of product
PWR Initiating Demonstration and Commercial Hardware Design

Primary Scaling Tools

- Gasifier: CFD (Computational Fluid Dynamics) model
- Pump: GSD (Granular Solid Dynamics) model

Demo Pump (400+ TPD)
Commercial (1,000 TPD)
Summary

- The 18 tpd pilot plant gasifier completed Pox and coal gasification tests this year to validate modifications for improved gasifier performance.

- The 400 tpd Dry Solids Pump testing verifies design approach and will continue performance testing and develop operating procedures.

- PWR gasification technology is ready for demonstration scale operation and is seeking commercial demonstration partners to provide a host site.

- For questions, please call Alan Darby, 818-586-0975 (USA).
Acknowledgement

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Questions?