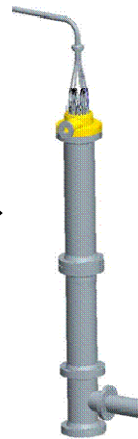
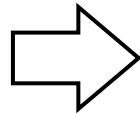


Pratt & Whitney Rocketdyne (PWR) Compact Gasification System



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Director, Energy Systems

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Pratt & Whitney Rocketdyne
A United Technologies Company

GTC Annual Conference
October 2006

**Leveraging 50 Years of Rocket Engine Technology
to Reduce Cost and Increase Plant Availability**

Gasification Market is Poised for Rapid Growth



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Market Drivers

- Increasing price of oil & natural gas
- Low cost, abundant coal & petroleum coke
- Environmental regulations
- Gasification business maturation & technology advances

Growth Barriers

- High capital cost
- Low plant availability



PWR's objective is to address these barriers with the compact gasification system

Rocket Engine Technologies Enable Compact Gasifier

Rocket Engine Technologies

- Rapid Mix Injector →
- Cooled Membrane Wall →
- Rapid Spray Quench →

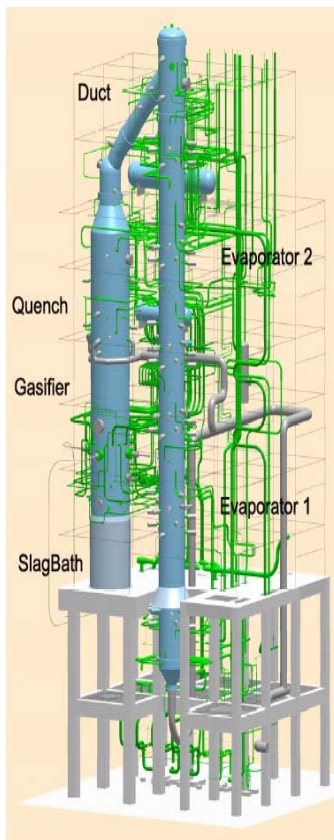


- 5000° F flame temperature gasifies most feedstock within 3 ft of injector
- Rocket engine cooling technology keeps metal temperatures below 800° F
- Plug flow provides uniform residence time for high carbon conversion
- High pressure and water quench enables low cost H₂ production and CO₂ sequestration
- Dry feed minimizes oxygen consumption and gasifies all ranks of coal

**Rocket engine price < \$10 per kW thermal
(much less than current gasification systems)**

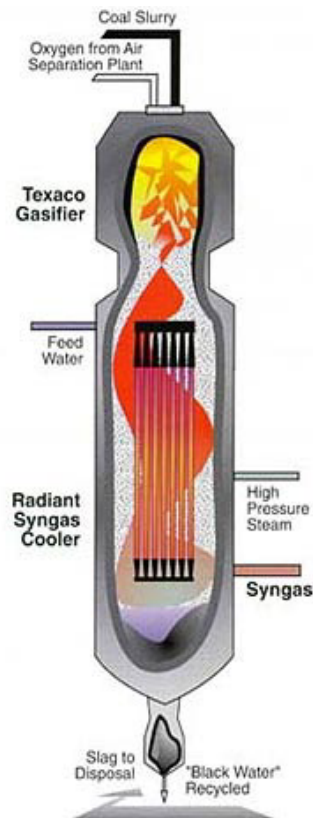
Compact Gasifier Reduces Cost and Improves Plant Availability

Current Market Leaders



Source: Shell paper (2004)

PWR Compact Gasifier



Source: DOE paper (2006)



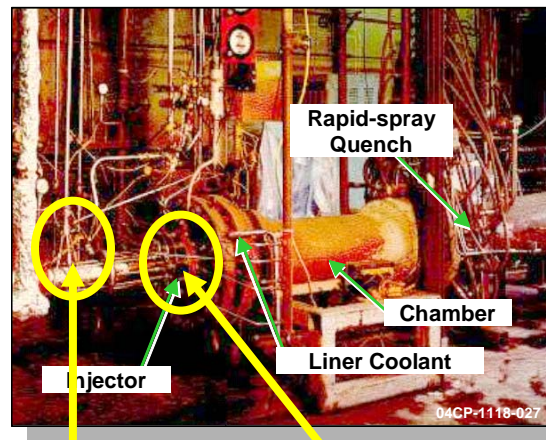
- 90% size reduction
- 50% lower cost (gasification system)
 - Factory fabrication
- 99% availability (gasification system)
 - Long life components
 - Rapid repair
 - Short scheduled outages
- 80% to 85% cold gas efficiency
 - Dry feed system
 - 99% carbon conversion
 - Low oxygen consumption
- Low cost gasification of all ranks of coal & petcoke

Proof of Concept Tests Completed in 1975-1985

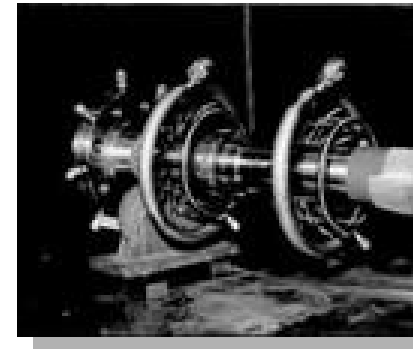
Dense Phase Dry Feed System



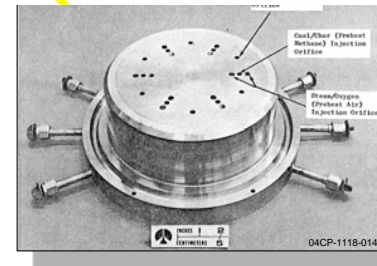
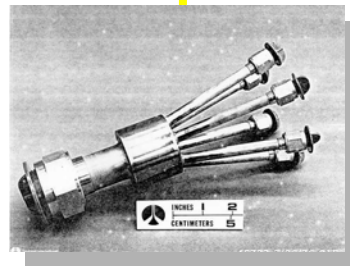
Compact Gasifier in Horizontal Position



Rapid Spray Quench



Flow Splitter



Rapid Mix Injector

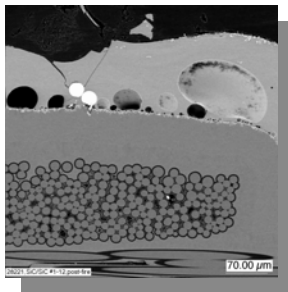
- Gasified coal, petcoke, and biomass (20-40 TPD)
- Performed only short duration tests (< 1 hr)

Gasifier Development Status



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**Completed
CMC Material
Tests at Albany**



- DOE Albany tests showed excellent slag adhesion with no reactions
- Additional tests planned for ORNL

**Completed
CMC Tests
at CANMET**



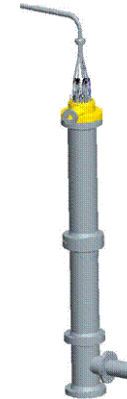
**CMC liner test
successful
with 26 starts
and high
temperature
excursions**

**Defined Pilot Plant
at GTI (18 TPD)**



- Pilot Plant to be located at GTI Flex Fuel Test Facility
- Will demonstrate single injector in full-length gasifier

**Designing
Commercial
Gasifier (400 TPD)**



- Design is scalable to 3000 TPD by replicating injectors
- Fixed length
- Inside diameter:
~ 1 ft for 400 TPD
~ 3 ft for 3000 TPD

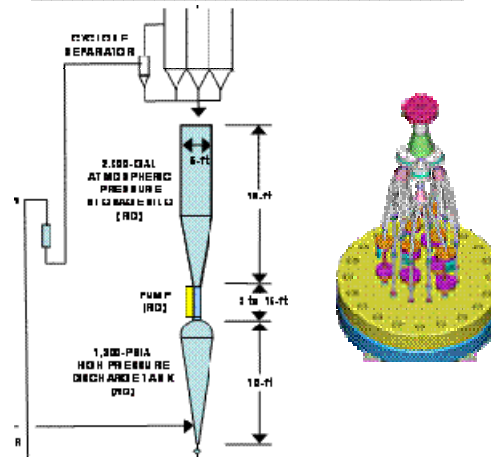
Dry Solids Pump and Feed System Development Status

Constructing Cold Flow Test Facility at EERC (400 TPD)



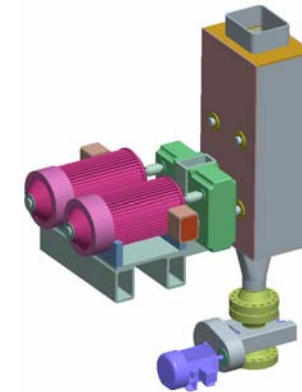
- Flow splitter tests to begin in early 2007 in batch mode
- Dry solids pump to be added later for continuous operation

Fabricating Feed System & Flow Splitters (400 TPD)



- Flow splitters are commercial size
- Will demonstrate full flow operation and turndown to 33% flow

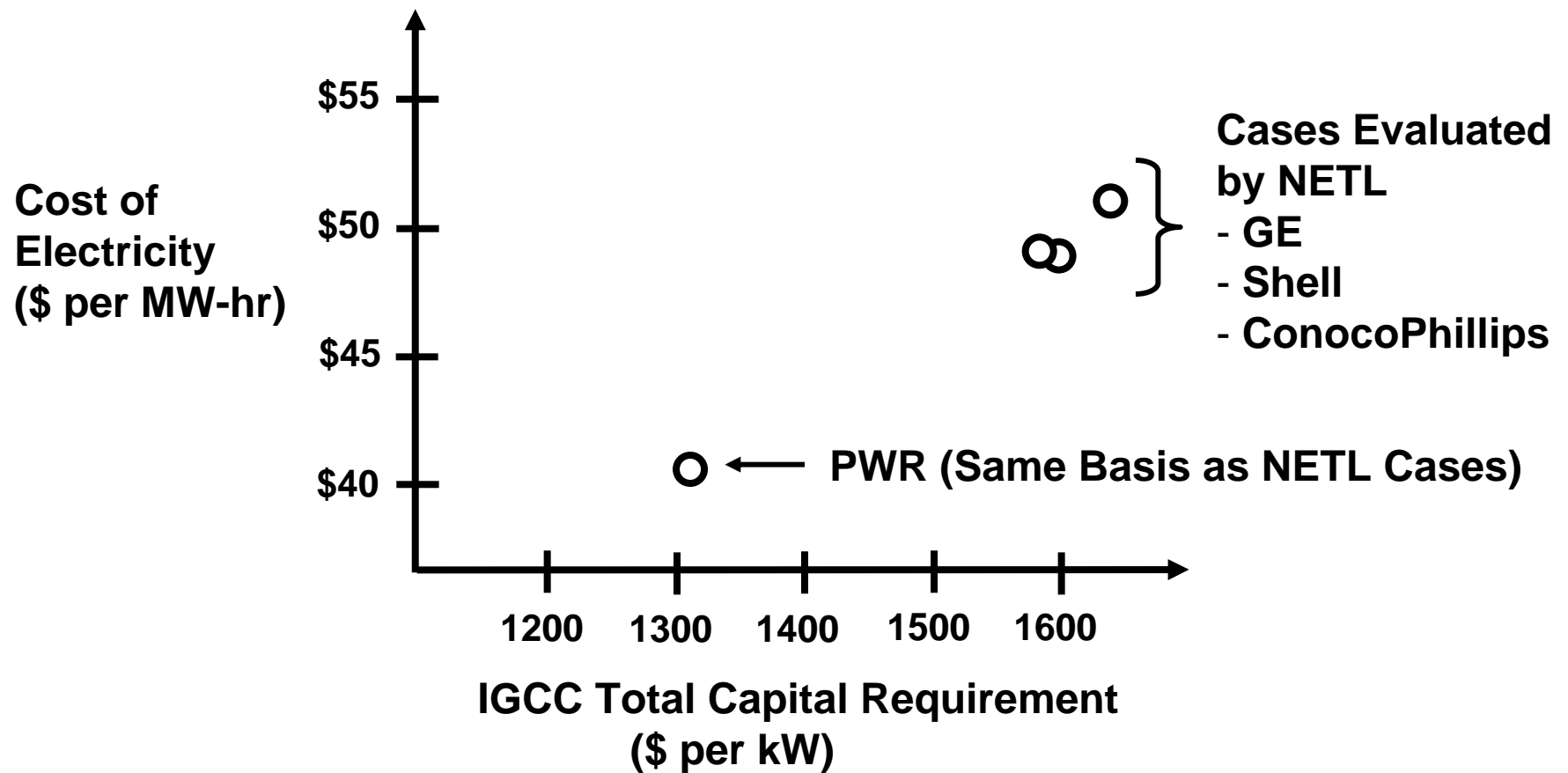
Designing Dry Solids Pump (400 TPD)



- Design is scalable to 3000 TPD
- Throat area:
 - ~ 8 in² for 400 TPD
 - ~ 60 in² for 3000 TPD

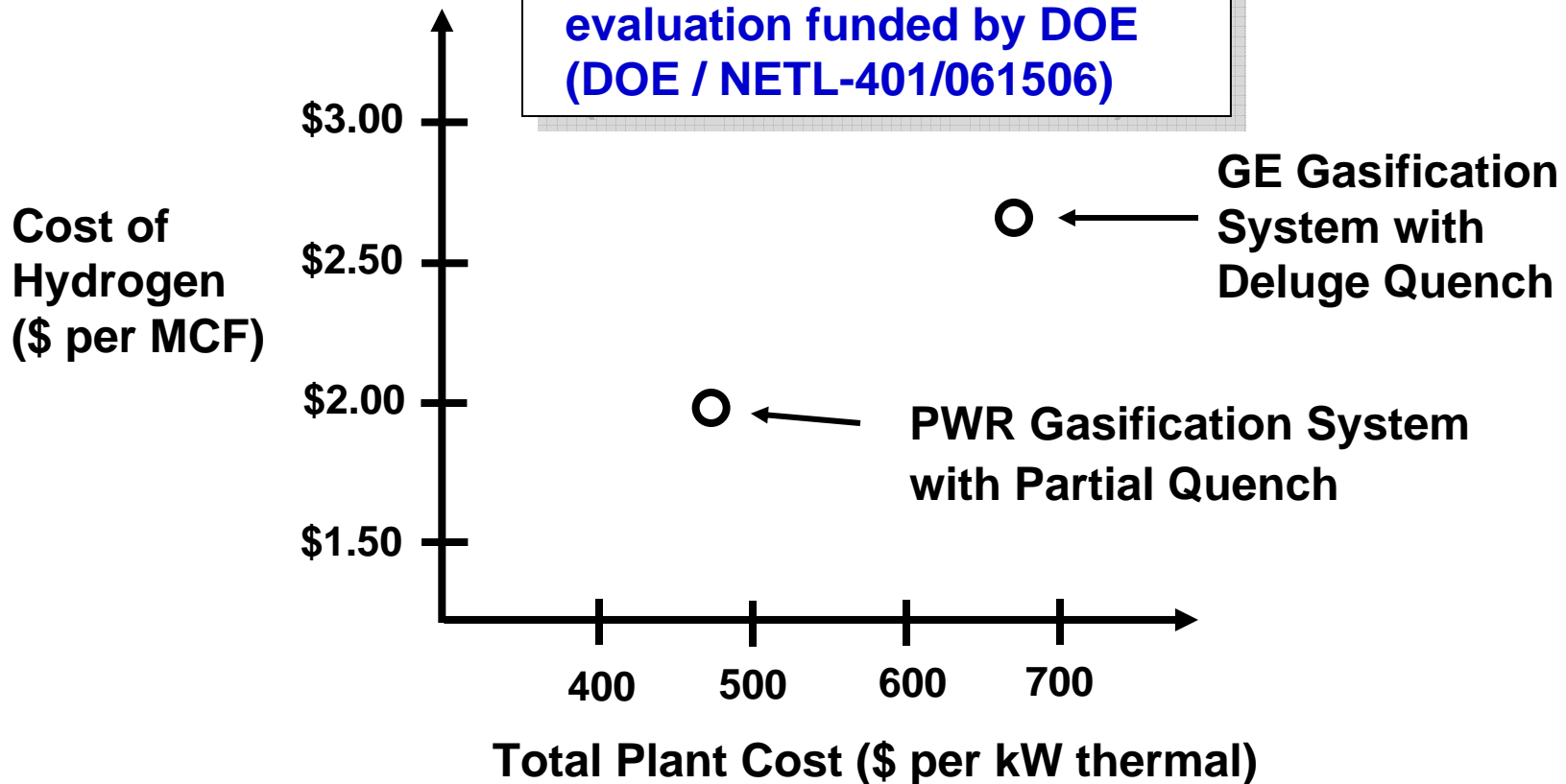
IGCC Power Plant Cost Comparison in 2004 Dollars

- \$300 M capital cost savings for 1000 MW plant
- \$1 B savings for first 15 years of operation



Coal to Hydrogen Plant Cost Comparison in 2006 Dollars

- 28% lower plant capital cost
- 25% lower cost of hydrogen
- Based on independent evaluation funded by DOE (DOE / NETL-401/061506)



Compact Gasification System Mature Availability Estimate

<u>Component</u>	<u>MTBF</u> (yr)	<u>MTTR</u> (hr)	<u>FOR</u> (%)	
• Gasifier				• MTBF = Mean Time Between Failure
• Injector	2	12	0.07	• MTTR = Mean Time to Repair (Downtime)
• Cooled Wall	10	48	0.05	• FOR = Force Outage Rate
• Quench	10	60	0.07	
• Pump & Feed System	0.4	10	0.29	
• Solids Separation System	0.7	18	<u>0.29</u> 0.77%	

- **Mature availability ~ 99% (negligible scheduled outages)**
- **Redundancy typically not needed, but can be provided at low cost for high reliability applications**

Business Model

**PWR Licenses
Technology & Provides
Key Components**



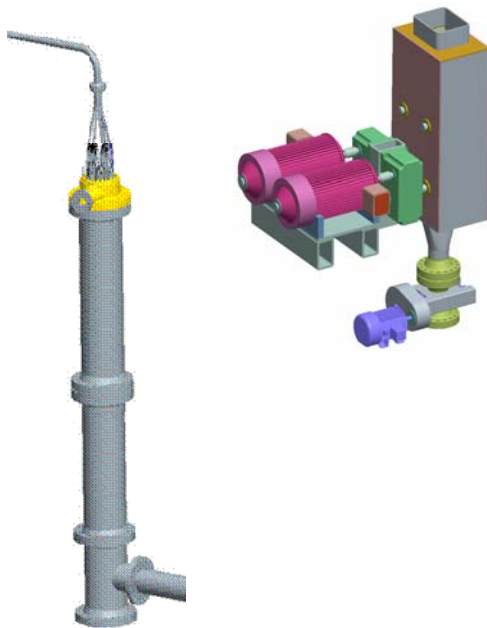
**Licensees Design
& Construct Plants**



**End Customers Own
& Operate Plants**

**Compact
Gasifier**

**Dry Solids
Pump**



- License Technology to:
 - Gasification System Providers
 - EPC Contractors
 - End Customers
- Provide Licensees with:
 - Key Components
 - Integration Support
 - Aftermarket Services

**Objective is to Complement Existing
Industry Capabilities & Technologies**

Commercialization Approach



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- **Team with licensees & launch customers**
- **Collaborate on technology development & integration**
 - **Compact Gasifier**
 - **Dry Solids Pump**
- **Demonstrate technology in existing plants (2007 design start)**
 - **Parallel trains & upgrades**
 - **Gasification plants**
 - **Steam methane reformers**
- **Develop standardized designs to simplify manufacturing & operations support**

Acknowledgement



Pratt & Whitney
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- **Development of the Compact Gasification System is supported by the U.S. Department of Energy under Award No. DE-FC26-04NT42237**
- **However, any opinions, findings, and conclusions expressed herein are those of the authors and do not necessarily reflect the views of the DOE**

Questions?