AEROJET ROCKETDYNE
A GenCorp Company

Dry Solids Pump Program Status

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Aerojet Rocketdyne

Pittsburgh Coal Conference
Beijing, China

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50 Years of Aerojet Rocketdyne Engines

1,748 Launches

ACTIVE

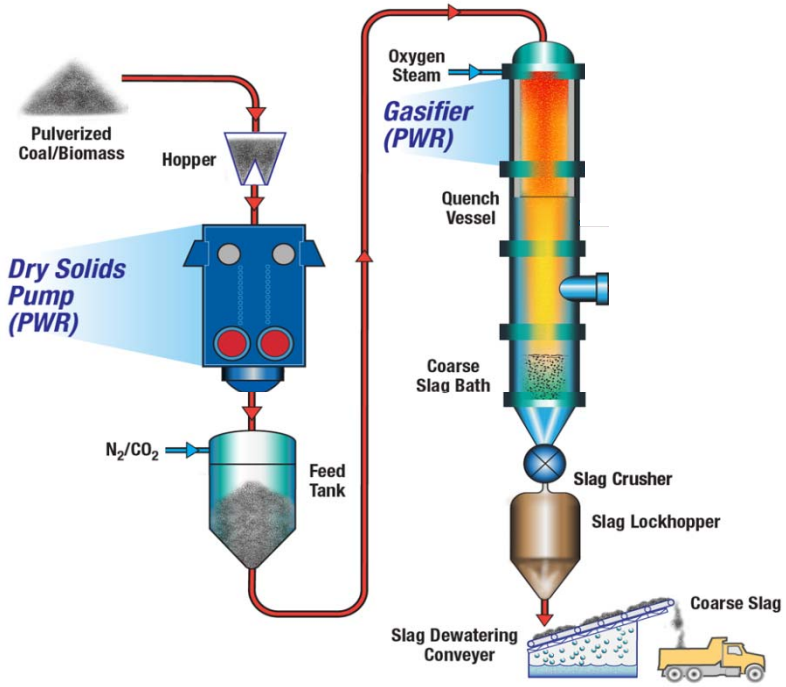
Redstone	Navaho	Jupiter	Thor	Atlas	Saturn	Saturn	Titan	PK	Space	THAAD	Delta	Atlas	Delta
				I/II	I/1B	V	Centaur-T		Shuttle		I/II/III	III/V	IV
85	11	46	380	568	19	13	17	51	135	22	350	34	17

AR #1 in Liquid Rocket Propulsion

Compact Gasification System

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

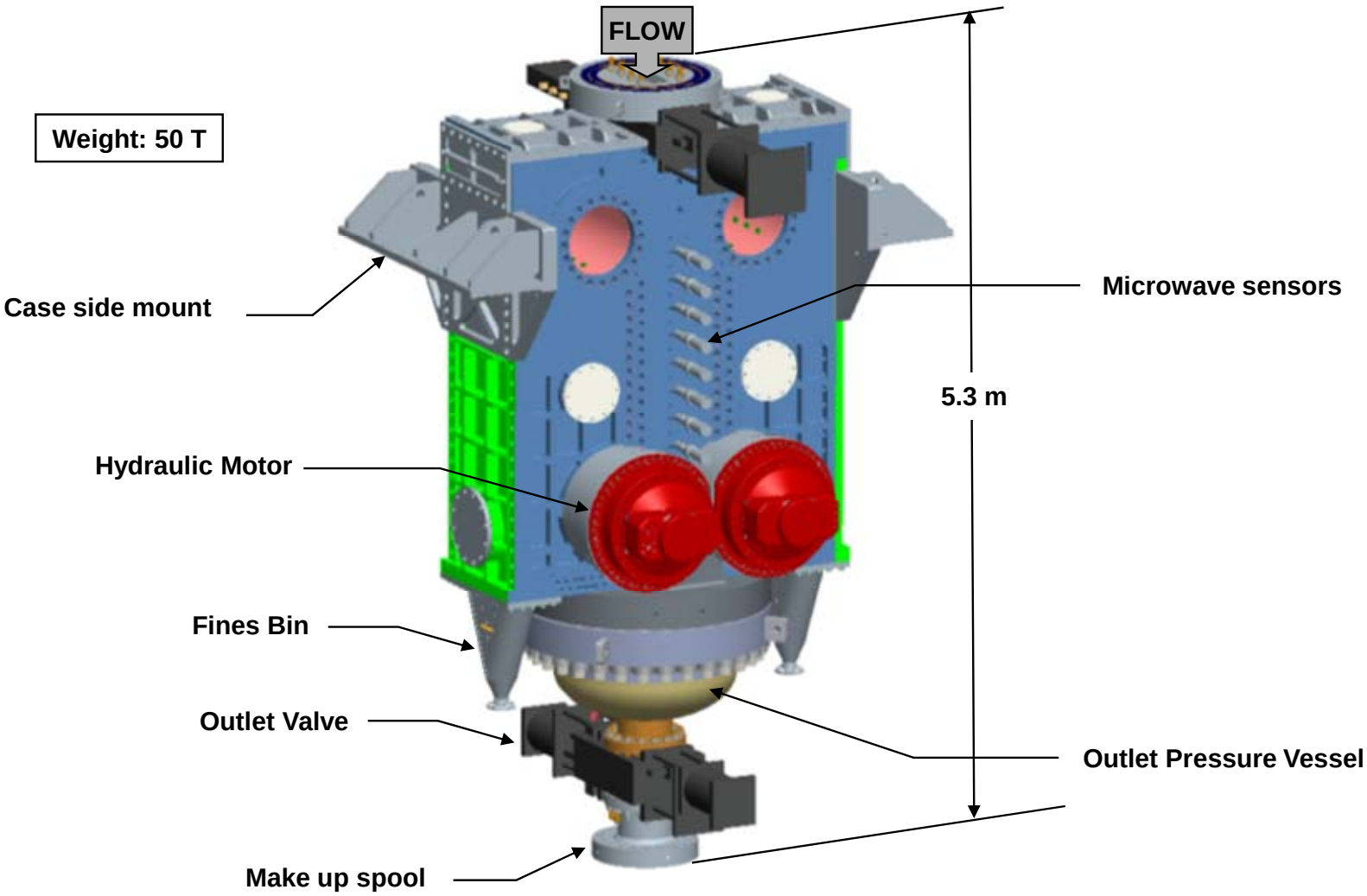
Testing Initiated March 2012
EERC – North Dakota



Reduces customer capital and operating cost by 20%

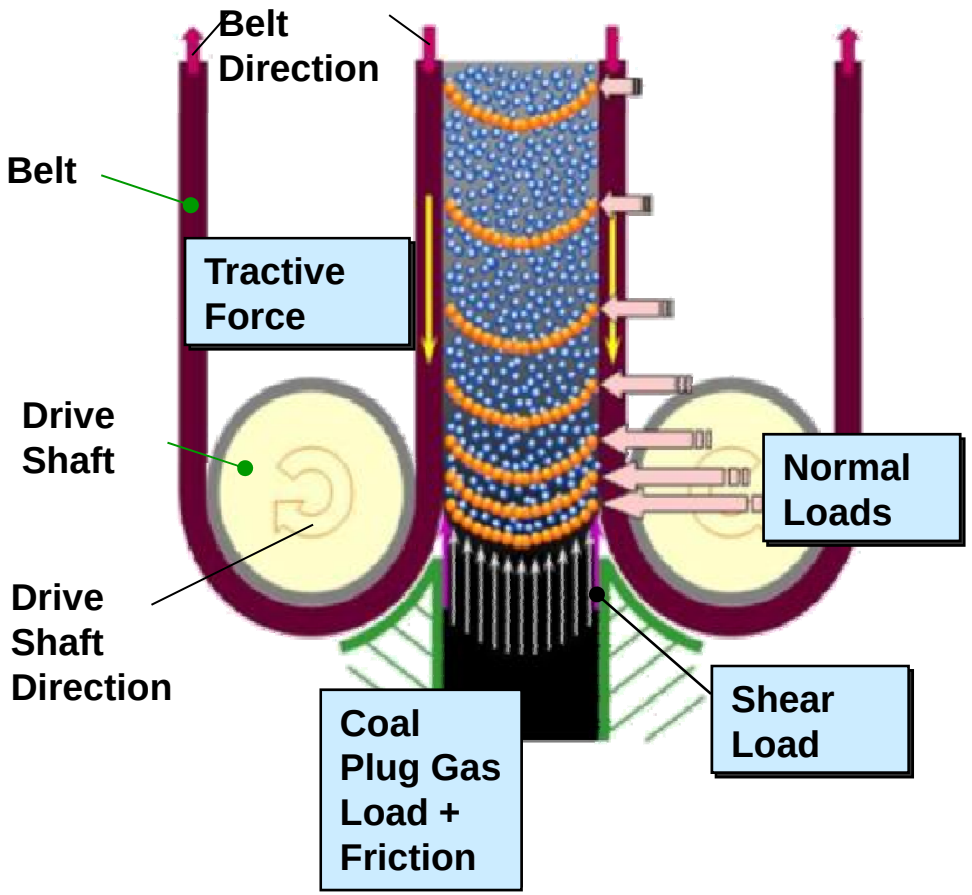
Successful Testing Completed April 2011
Gas Technology Institute - Illinois

Pump – Major Components



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)

- Capacity – 400 - 600 TPD
- Operating Pressure – 1000 psi
- Ultra Dense Flow – No plugging
- Flow Splitter – Even distribution

Solids pump (Underway)

- Discharge 400 TPD at 1200 psi
- 500 hours of operation
- 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

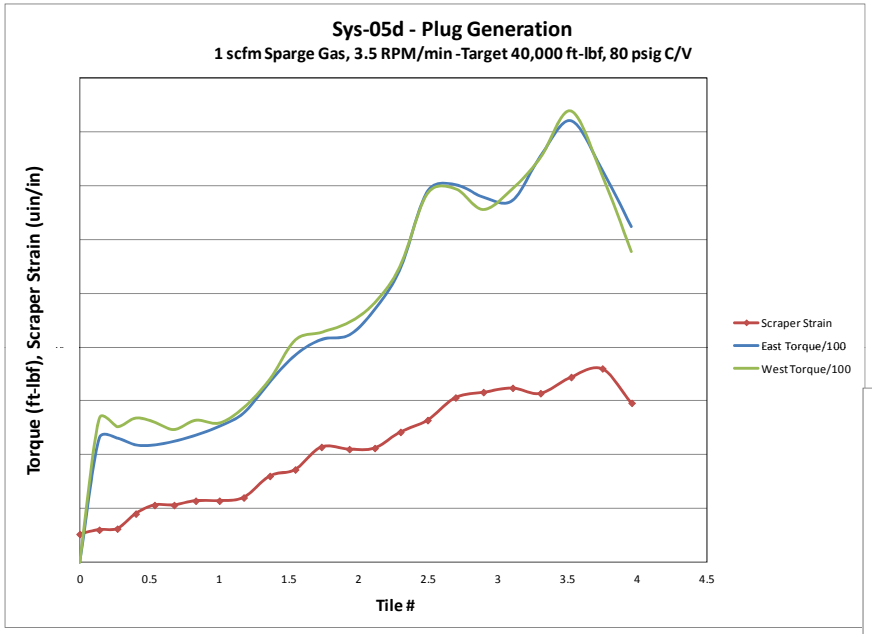
Machining

Precision Boring

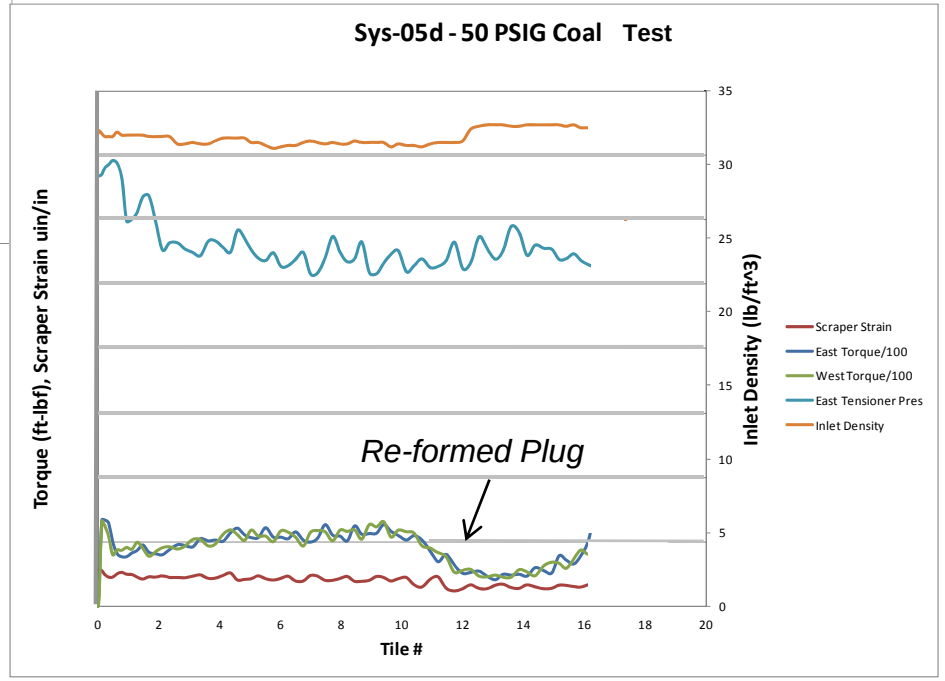
Assembly

Pump Installation

Dry Solids Pump Test Profile



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



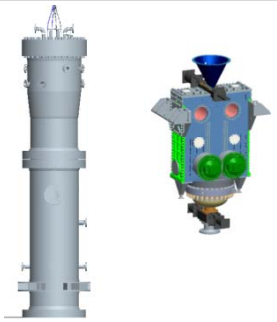
Plug evidenced by increasing motor torque and scraper strain at zero coal flow conditions

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
  - Stand-down to modify components for improved performance
    - Belt and link-to-link clearances
  - Adding sensors for enhanced monitoring of internal pump operations
- Next testing series will include:
  - Short-term testing at pressures up to 300 PSI
  - Performance mapping tests to understand and control upset conditions
  - Long duration testing at pressures up to 1200 PSI
  - Alternate feedstock testing to validate pump operation for range of fuels
- Target is 500 hours of operation

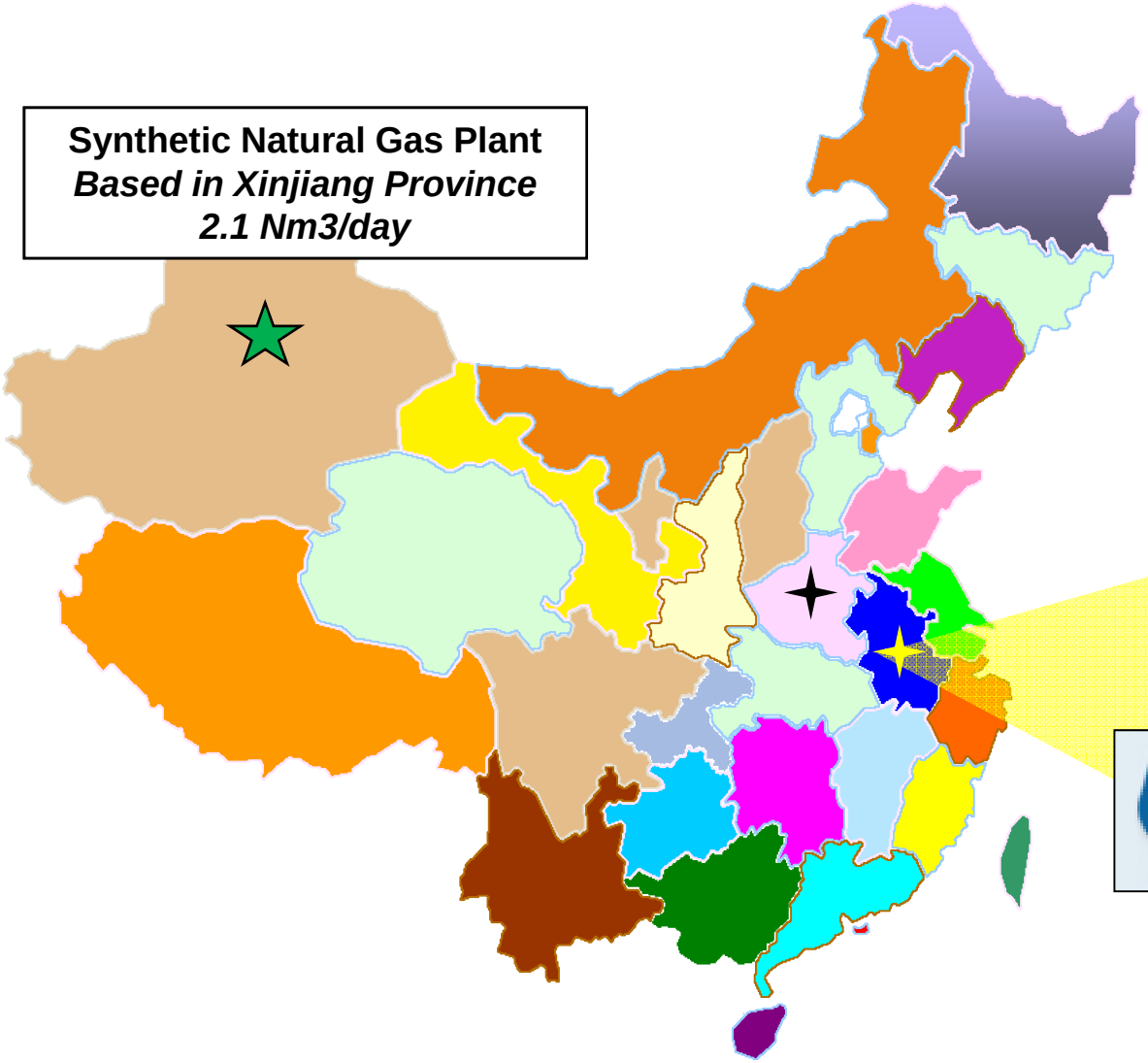
Gasification Plant Study to Produce Synthetic Natural Gas

Aerojet Rocketdyne



Commercial Gasifier and Dry Solids Pump

Synthetic Natural Gas Plant
Based in Xinjiang Province
2.1 Nm3/day



Collaboration with East China Engineering Science and Technology Co.
Hefei, China

China Commercial Plant Economic Study

- **Study basis: 2.1 B Nm^3/yr SNG product**
  - **Domestic China coal**
  - **Approximately 15,000 STPD coal input using PWR technology**
- **Comparison of AR to leading gasification technologies in China**
  - **Domestic Dry Feed Gasifier**
  - **Western Dry Feed Gasifier**
  - **Slurry Fed Gasifier**
- **Capital costs generated by ECEC for gasification island syngas output**
  - **Scaled to support SNG output target**
- **Operating costs generated by ECEC captures utilities consumption specific to each technology**
  - **Coal feed**
  - **Power requirements**
  - **Oxygen, steam, process water, nitrogen, etc.**

Economics Comparison of China Based 2.1B Nm^3/day SNG Plant

Compact Gasifier System Offers Lowest Cost of Product

	TECHNOLOGY				
Parameter	Aerojet Rocketdyne	Dry Feed (Western)	Dry Feed (Domestic)	Slurry	Units
Capex	377689	500058	347291	426377	10,000 RMB
Annual Revenue	517106	513031	511404	511404	10,000 RMB/yr
Annual Cost	270280	372212	370093	319734	10,000 RMB/yr
Annual Profit	151438	83245	84540	115795	10,000 RMB/yr
Syngas Cost	318.3	445.5	437.7	373.3	RMB/kNm^3
Payback	3.65	5.41	4.52	4.3	yr
FIRR	48.26	24.7	33.02	35.95	%

15%-25% Cost Of Syngas Advantage vs. Slurry Fed

Gasification Plant Studies Supports AR Cost Advantages

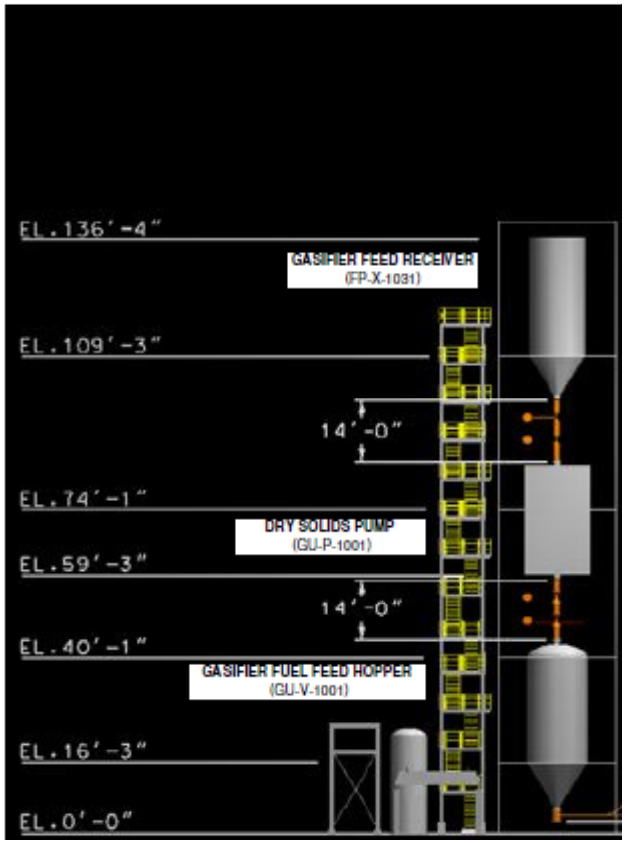
	Power (IGCC)	Power (IGCC)	Hydrogen	Hydrogen	Hydrogen	Syngas
Compared Versus	GE	Shell	GE	GE	GE	Siemens
Feedstock	Coal	Coal	Coal	Petcoke	Petcoke	Coal
Capex Benefit	10%	20%	24%	21%	23%	27%
Cost of Product Benefit	15%	21%	27%	24%	27%	29%
Study Performed By	NETL (Worley Parsons)	NETL (Worley Parsons)	NETL (Worley Parsons)	Jacobs	PWR Pilot Plant (2011)	ECEC (China Location)

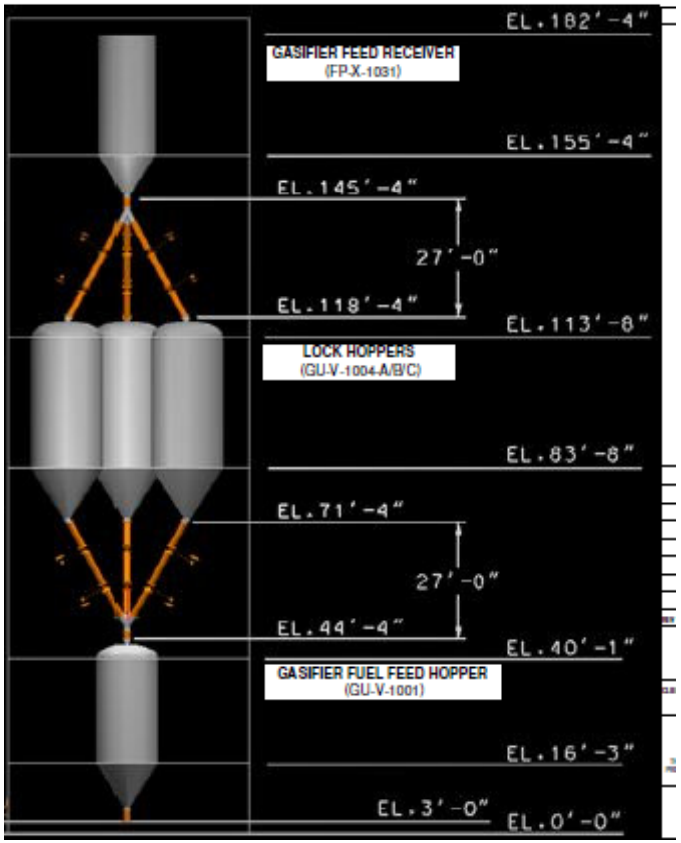
Overall Plant Cost Savings

- **10% to 27% lower capital cost**
- **15% to 29% lower cost of product**

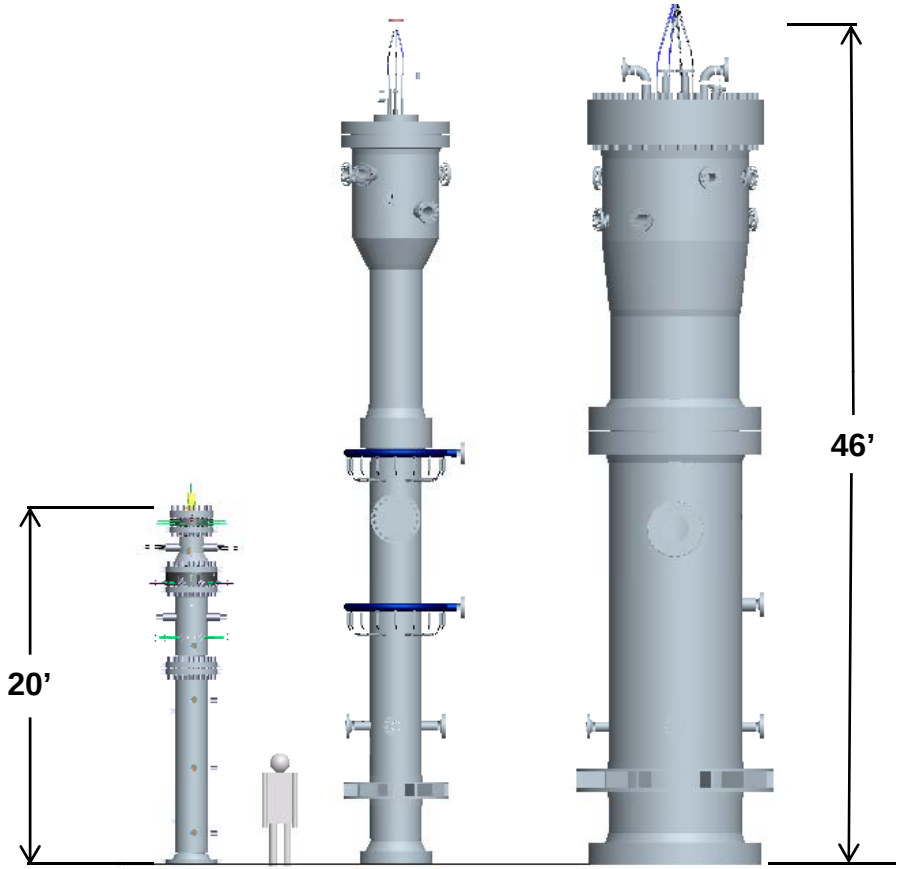
DSP Reduces Feed System Capital Cost

DSP Reduces Feed System Infrastructure
To Reduce Capital Cost by 60% (USGC Basis)





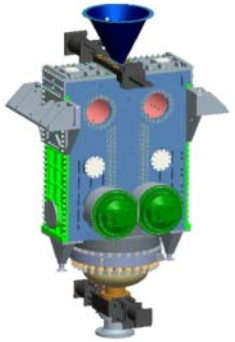
PWR Initiating Demonstration and Commercial Hardware Design



Pilot Plant 18 TPD | **Demo Plant 400 TPD** | **Commercial Plant 3,000 TPD**

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 400 tpd Dry Solids Pump testing verifies design approach and will continue performance testing and develop operating procedures.**
- **The 18 tpd pilot plant gasifier will resume testing this year to validate modifications for improved performance with low quality coals.**
- **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?