Technology Development Partner

Vann Bush
Managing Director, Energy Supply and Conversion

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> Independent, not-for-profit established by the natural gas industry

> GTI tackles important energy challenges transforming raw technology into practical solutions

> Providing energy research, development and technology deployment services, consulting and training to industry and government clients

> Offerings spanning the energy value chain

> Coal technology R&D for over 70 years

Our Staff

- 292 Employees
- 60% Scientists/Engineers
- 44% Advanced Degrees
Three Valleys of Death
Mountains to Climb to Reduce Technical Risk

Investment

1. Feasibility valley of death
2. Prototype valley of death
3. Market valley of death

- Concept
- Research
- Prototype
- Demonstrator

- Debt Finance
- Venture Capital
- Government

Time

- $1M
- $10M
- $100M
## Risk Reduction Tools

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experienced Development Team</td>
<td>• Comprehensive team with science, engineering, operations, analytical, and modeling experience</td>
</tr>
<tr>
<td>Leveraged Facility Assets</td>
<td>• Focus investment on the testing the core technology</td>
</tr>
<tr>
<td>Disciplined Scale-Up Approach</td>
<td>• Prudent increments in scale and complexity of operations</td>
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<tr>
<td>Rigorous Technology Testing</td>
<td>• Full, detailed characterization of potential operating conditions</td>
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<tr>
<td>Validated Performance Modeling</td>
<td>• Anchor performance model with quality data</td>
</tr>
<tr>
<td>Continuous Improvement</td>
<td>• Innovate in pilot plant to address deficiencies and opportunities</td>
</tr>
</tbody>
</table>
GTI Gasification Development History

**Development Focus**
Supply Security – Substitute Natural Gas (SNG)

**1941**
Early PDU

**1947**
Lab Facility - 1947
Dr. James L. Johnson

**1950**
HYGAS Pilot Plant

**1960**
HYGAS Pilot Plant

**1970**
U-GAS Pilot Plant and PDU

**1980**
Zaozhuang - 2007

**1990**
Syngas to Power - IGCC

**2000**
U-GAS Pilot Plant and PDU

**2015**
CHINA
HYGAS purchased by Chinese chemical company in 2013

**2015**
Zaozhuang - 2007
800 TPD demo in planning with Yangquan Coal Industry Group

**2015**
Yima - 2012

**Flex Fuel and Advanced Gasification Test Facility**
Syngas to Products - Fuels, Chemicals, SNG

**Supply Security – Substitute Natural Gas (SNG)**

**Industrial Fuel Gas**
Biomass, Renewables

**Syngas to Power - IGCC**

**Fuels, Chemicals, SNG**

**Biomass, Renewables**

**Industrial Fuel Gas**

**Chinese Chemical Company in 2013**

**GTI Gasification Development Timeline**

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**Experience**

**GTI Gasification Development Timeline**
Pilot-Scale Gasification R&D Facilities
Clean Coal Development Pathway

$10^{10}$ Scaleup

- **Feedstock Properties Tests**
- **Bench-Scale Gasification Tests**
- **Modeling / Simulation**
- **Pilot-Scale Tests**
- **Process Design Package for Commercial Plant**

DISCIPLINED SCALE-UP
U-GAS®

Technology development, improvement, and technical support since 1974

U-GAS technology attributes developed through extensive testing:

- Gasification modes extended to oxygen- and enriched air-blown
- Feedstocks extended to all ranks of coal, high ash coals, biomass and wastes
- Ongoing support for new feedstock qualification
- Model validated for design
GPE bluegas® Verification Testing

- Stable, reliable operation meeting all performance objectives
- Gasification reactor performed as predicted with both PRB coal and pet coke
- Catalyst added, removed and recovered successfully, as predicted; pilot plant at SGS processed more than 250 tons of coal & pet coke
- Validation by investors and partners

From GPE presentation to DOE Shenhua Group Exchange Program Meeting 6-18-2012

<table>
<thead>
<tr>
<th>Primary Demonstration Goals</th>
<th>Results</th>
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<tbody>
<tr>
<td>Minimum 85% carbon conversion</td>
<td>85%-90%</td>
</tr>
<tr>
<td>Feed rate minimum</td>
<td>Achieved</td>
</tr>
<tr>
<td>Operate at steady state conditions</td>
<td>Exceeded</td>
</tr>
<tr>
<td>Methane yield approaching equilibrium</td>
<td>Achieved</td>
</tr>
<tr>
<td>Proof of concept</td>
<td>Achieved</td>
</tr>
<tr>
<td>Mass balance</td>
<td>Achieved</td>
</tr>
</tbody>
</table>
Advanced Gasifier Testing
in partnership with

18 tons per day Pilot Plant at GTI started Dec 2009

- Demonstrated performance:
  - 99% carbon conversion
  - High cold gas efficiency
  - Formed protective slag layer
  - Effective particulate removal

- Tested 7 feedstocks (including high ash, high AFT Chinese coals)

- Verified operating environments
- Validated computer models
- Obtained preliminary life data
- Established operating procedures

> 1100 hours hot-fire testing through June 2015
Integrated Process Testing
## Continuous Improvement

<table>
<thead>
<tr>
<th>Component</th>
<th>Examples</th>
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<tbody>
<tr>
<td><strong>Advanced technology</strong></td>
<td>• Advanced compact gasifier</td>
</tr>
<tr>
<td><strong>Advanced manufacturing</strong></td>
<td>• Selective laser melting manufacturing of components</td>
</tr>
<tr>
<td><strong>Analytical tools</strong></td>
<td>• On-line sampling and continuous monitoring</td>
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<tr>
<td><strong>Facility capabilities</strong></td>
<td>• Syngas quality management</td>
</tr>
<tr>
<td><strong>Integrated process testing</strong></td>
<td>• Piloting syngas production, conditioning, and gasoline synthesis</td>
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Advanced Clean Coal Gasifier

**ADVANTAGES**
- Reduced reactor volume by 90%
- Lower capital cost
- Higher availability (MTBF/MTTR)
- Lower product cost by 15-25%
- Less water use by up to 30%
- High efficiency (99+% carbon conversion)
- Lower oxygen use
- Able to gasify all ranks of coal, petcoke
- Environmentally friendly waste
- Lower disposal costs

**STATUS**
- Acquired by GTI from Aerojet Rocketdyne
  July 2015
- Planning 800 TPD Demonstration in cooperation with Yangquan Coal Industry (Group) Ltd - (presentation of Mr. Feng Zhiwu provides details)

**INNOVATION**
- Leveraging decades of rocket engine development, gasifier utilizes aerospace inspired injectors and high temperature materials
- Approach enables gasification temperatures of nearly 1700°C
- Extreme temperatures enable an ultra-compact design and high efficiency

ADVANCING THE STATE-OF-THE-ART
# Experience in Gasifier Development

<table>
<thead>
<tr>
<th>Deploy</th>
<th>licensed</th>
<th>sold</th>
<th>TBD</th>
</tr>
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<tbody>
<tr>
<td>Demonstrate</td>
<td>✓</td>
<td></td>
<td>planned*</td>
</tr>
<tr>
<td>Pilot</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Develop</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Invent</td>
<td>✓</td>
<td>✓</td>
<td></td>
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</tbody>
</table>

| U-GAS | HYGAS | GPE bluegas | AR Gasifier |

* Cooperation with Yangquan Coal Industry (Group) Ltd.
GTI Clean Coal Power Technology

**Oxy-PFBC**
- In-bed convective heat exchangers yield an ultra-compact combustor
- Elutriated flow removes ash and sulfur prior to recycle
- TRL 4: next step pilot plant (20 MW+) demonstration

**Supercritical CO₂ Cycle**
- Very small systems – high efficiency heat transfer at moderate temperatures
- Allows 2-5x increase in power output for same footprint
- Lowest increase in electricity cost for carbon capture
- Produce electric power with near zero emissions
- Produce pure CO₂ for EOR or storage
- Rankine or Brayton cycle configurations
Carbon Capture Technologies

Carbon capture using solid mesoporous sorbents for integrated gasification combined cycle (IGCC) power plants

Carbon capture for syngas or flue gas with CarboLock hollow fiber contactor (HFC) technology
GTI Experience as Technology Development Partner

Technology De-Risking
- Component development/testing
- Design, construction, and operation of pilot plant
- Process Design Packages for FOAK plants

Technology Transfer
- Consulting during detailed engineering
- Plant commissioning and startup assistance
- Plant debottlenecking and performance testing

Deployment Support
- Market/opportunity analysis, team building
- Project management
- Training/troubleshooting in integrated pilot facility
Tackling Important Energy Challenges and Creating Value for Customers in the Global Marketplace

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