the Energy to Lead

# Technology Development Partner

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Managing Director, Energy Supply and Conversion

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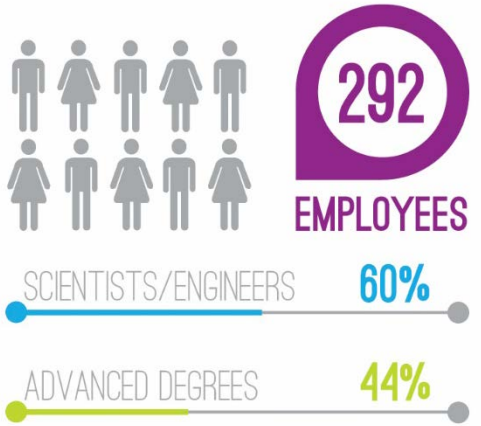
gti

# Company Overview

**ESTABLISHED 1941**

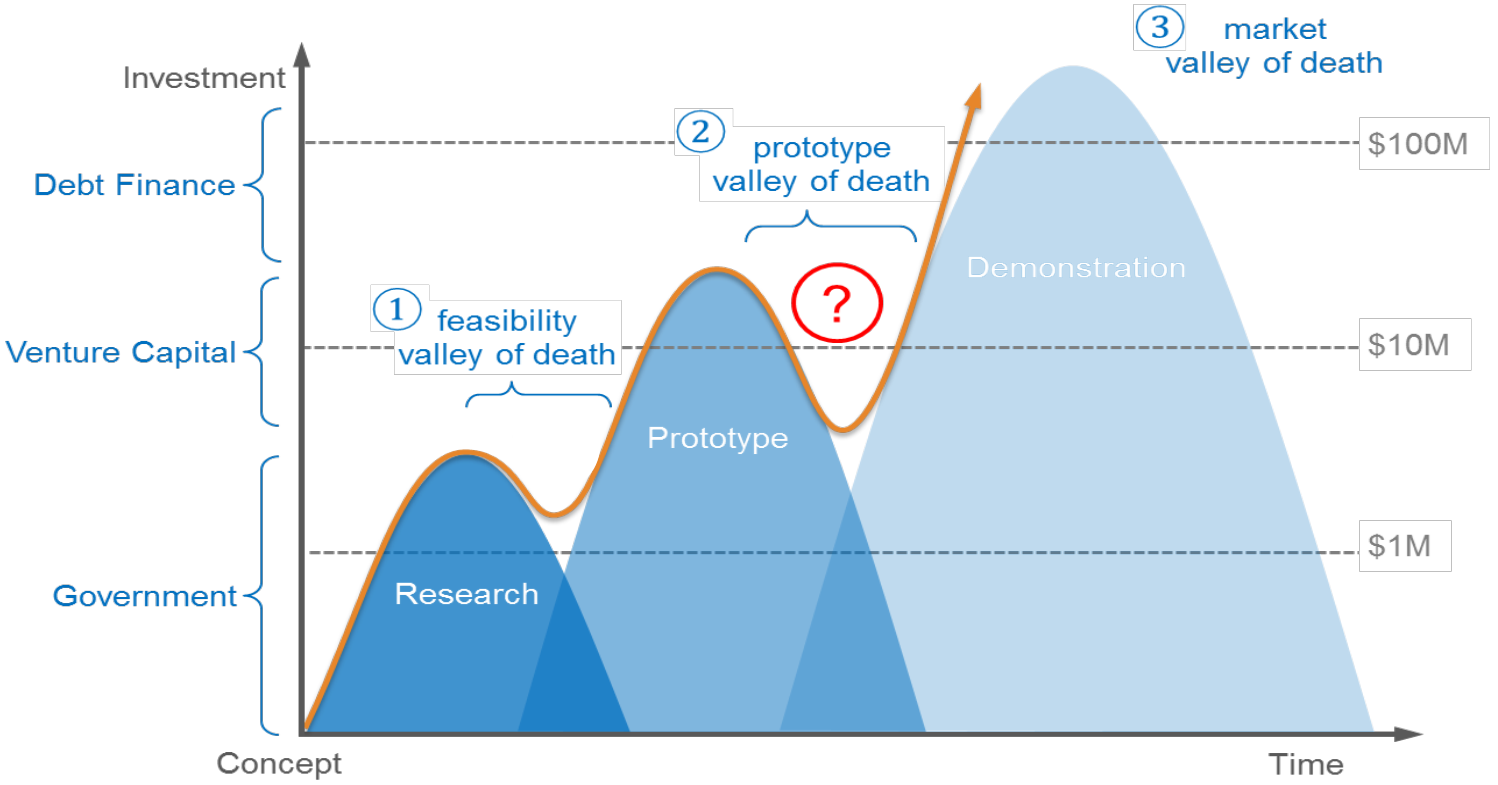
- Independent, not-for-profit  established by the natural gas industry
- GTI tackles important energy challenges transforming raw technology into practical solutions
- Providing energy research, development and technology deployment services, consulting and training to industry and government clients
- Offerings spanning the energy value chain
- Coal technology R&D for over 70 years

## Our Staff



# Three Valleys of Death

## Mountains to Climb to Reduce Technical Risk



# Risk Reduction Tools

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

# GTI Gasification Development History

**Development Focus**

Supply Security –
Substitute Natural Gas (SNG)

Industrial Fuel Gas

Biomass, Renewables

Syngas to Power - IGCC

Flex Fuel and Advanced Gasification Test Facility

Syngas to Products
Fuels, Chemicals, SNG


U-GAS Pilot Plant and PDU

HYGAS purchased by Chinese chemical company in 2013

HYGAS Pilot Plant

bluegas coal to SNG
China Wanxiang Holdings

800 TPD demo in planning with Yangquan Coal Industry Group

Early PDU

Zaozhuang - 2007

Yima - 2012

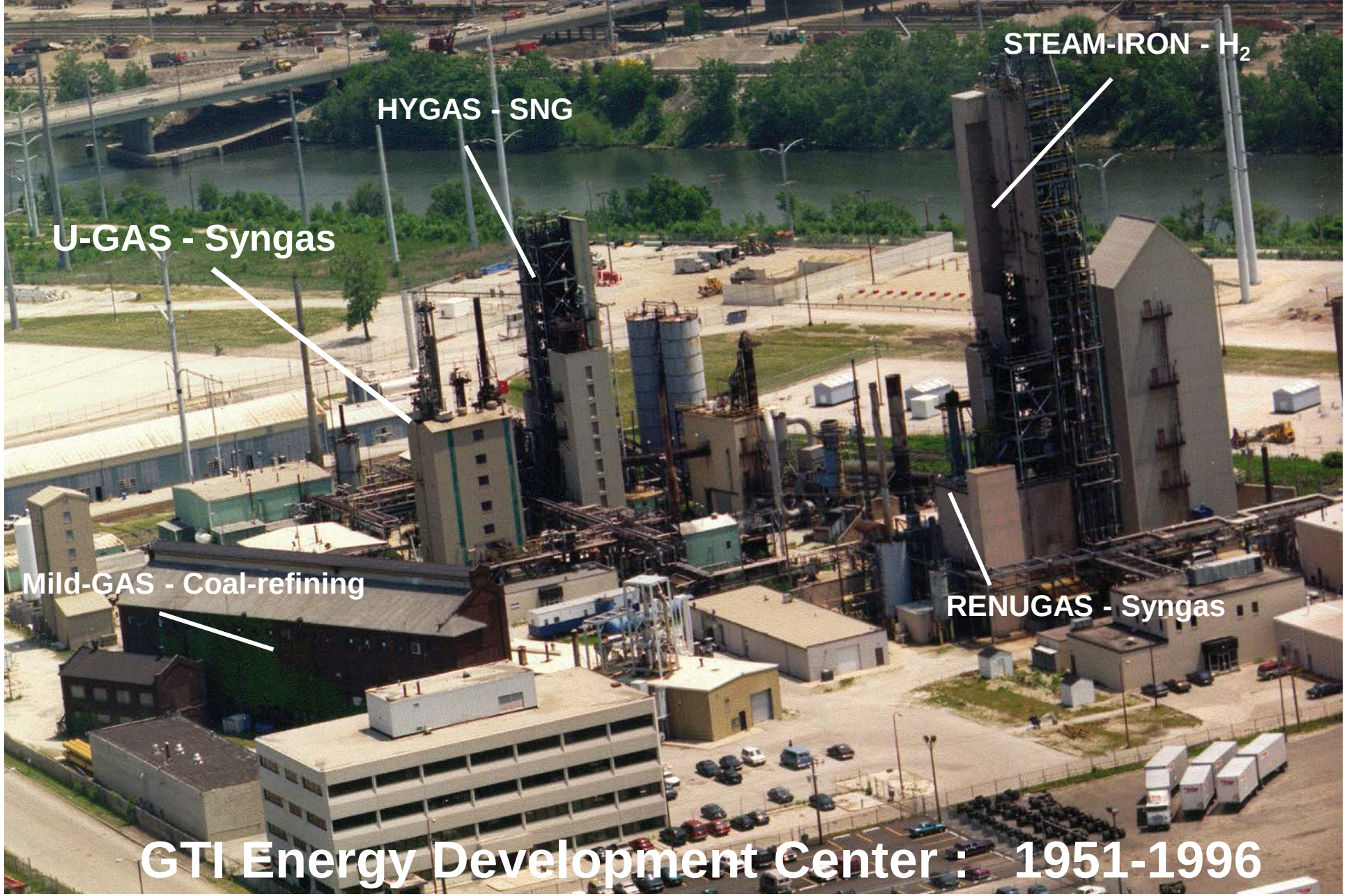
Lab Facility - 1947

Dr. James L. Johnson

1941 1950 1960 1970 1980 1990 2000

IGT

SES SYNTHESIS ENERGY SYSTEMS


STEAM-IRON - $H_2$
HYGAS - SNG
U-GAS - Syngas
Mild-GAS - Coal-refining
RENUGAS - Syngas
GTI Energy Development Center : 1951-1996


# Pilot-Scale Gasification R&D Facilities

# Clean Coal Development Pathway
# $10^{10}$ Scaleup

# 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 petcoke
- Catalyst added, removed and recovered successfully, as predicted; pilot plant at SGS processed more than 250 tons of coal & petcoke
- Validation by investors and partners


| Primary Demonstration Goals | Results |
|---|---|
| Minimum 85% carbon conversion | 85%-90% |
| Feed rate minimum | Achieved |
| Operate at steady state conditions | Exceeded |
| Methane yield approaching equilibrium | Achieved |
| Proof of concept | Achieved |
| Mass balance | Achieved |

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

# Advanced Gasifier Testing

## in partnership with AEROJET ROCKETDYNE

18 tons per day Pilot Plant at GTI started Dec 2009

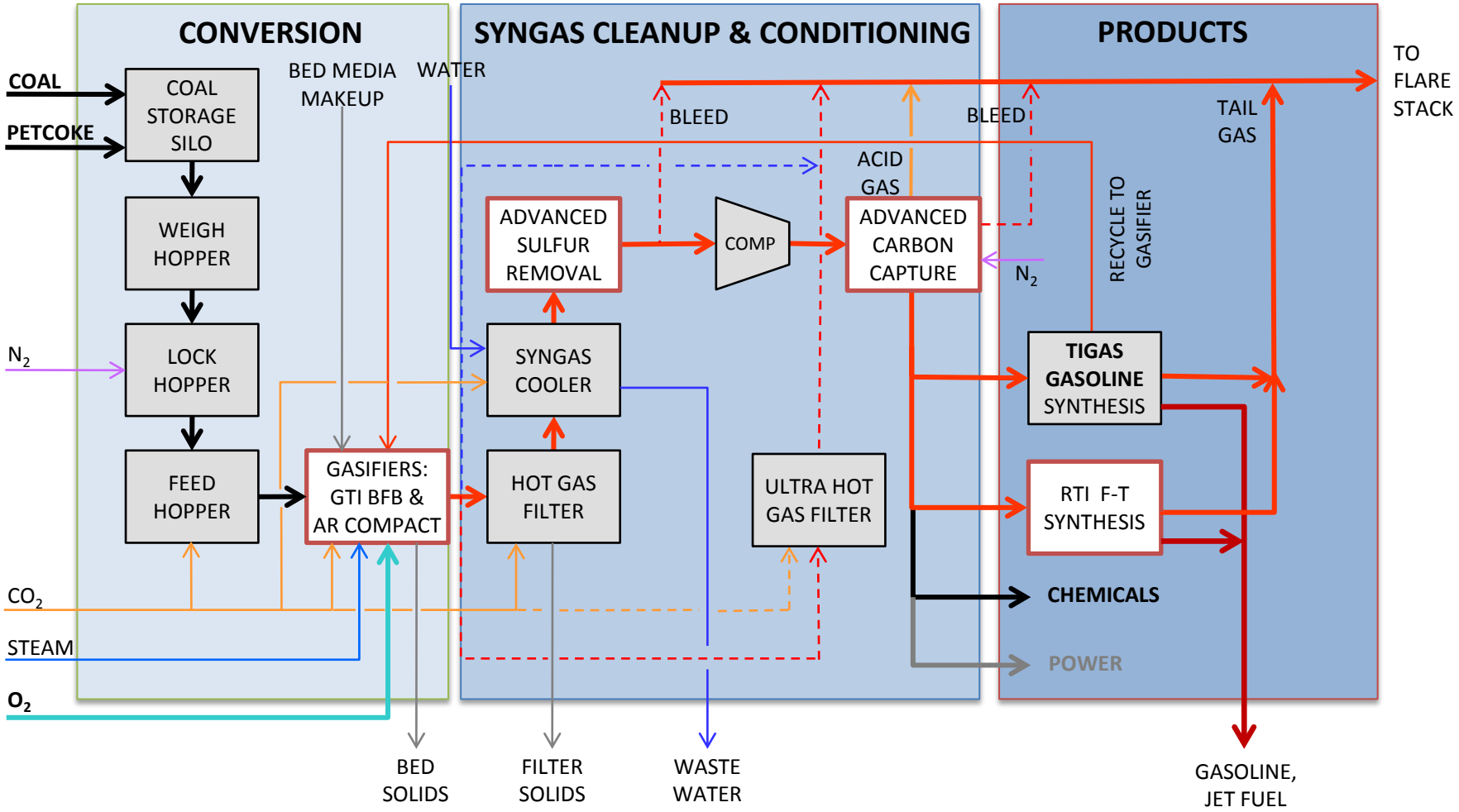
**Injector**

**Gasifier**

- 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**

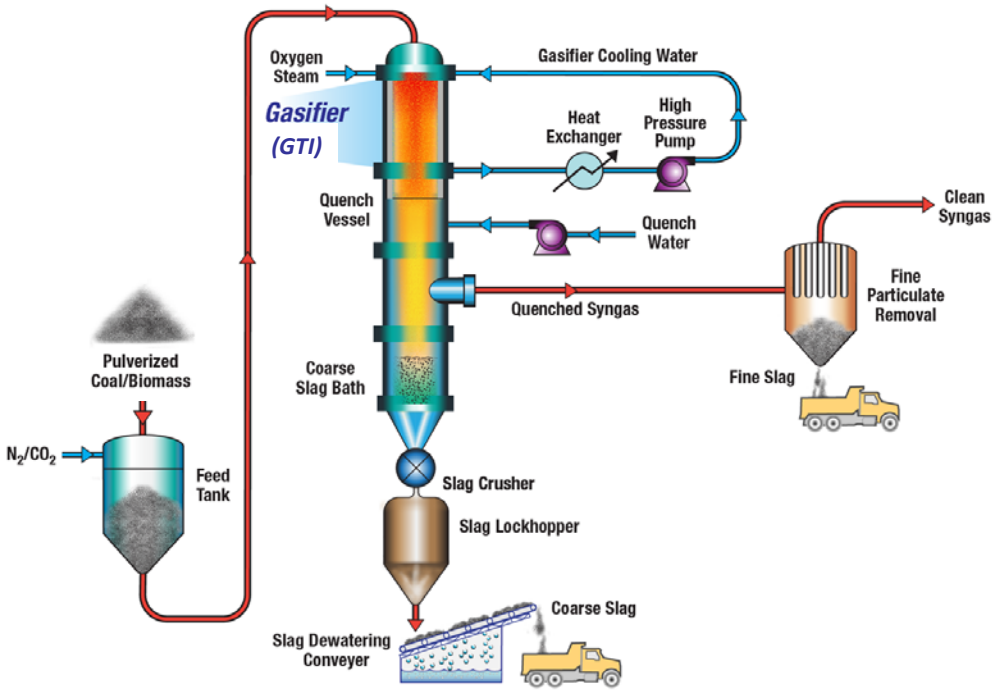
# Integrated Process Testing



# Continuous Improvement

| | |
|---|---|
| Advanced technology | • Advanced compact gasifier |
| Advanced manufacturing | • Selective laser melting manufacturing of components |
| Analytical tools | • On-line sampling and continuous monitoring |
| Facility capabilities | • Syngas quality management |
| Integrated process testing | • Piloting syngas production, conditioning, and gasoline synthesis |

# 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

## 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

## 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)

# Experience in Gasifier Development

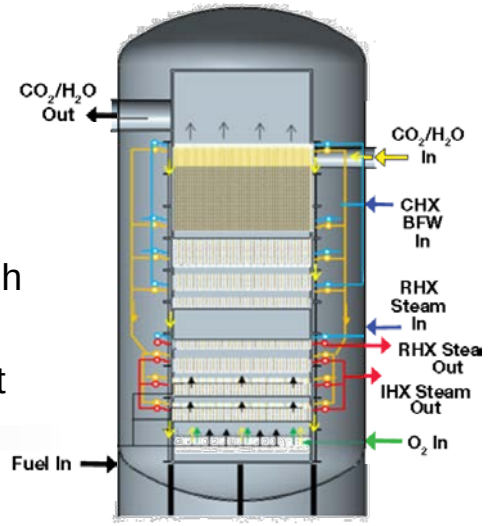
| | | | | |
|---|---|---|---|---|
| **Deploy** | licensed | sold | | TBD |
| **Demonstrate** | ✓ | | | planned* |
| **Pilot** | ✓ | ✓ | ✓ | ✓ |
| **Develop** | ✓ | ✓ | ✓ | ✓ |
| **Invent** | ✓ | ✓ | | |
| | **U-GAS** | **HYGAS** | **GPE bluegas** | **AR Gasifier** |

** Cooperation with Yangquan Coal Industry (Group) Ltd.*

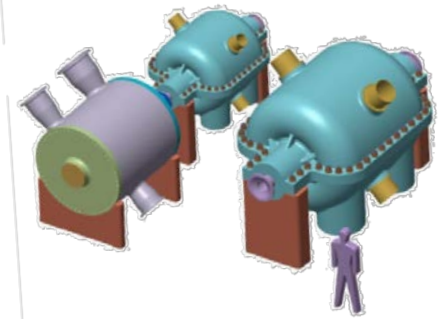
# GTI Clean Coal Power Technology

## Oxy-PFBC

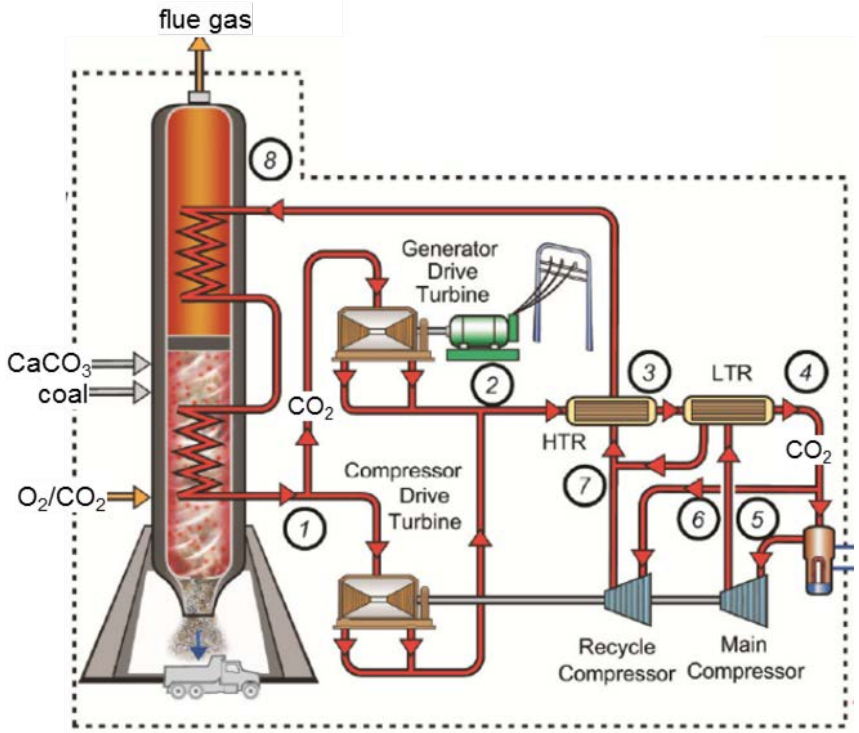
- In-bed convective heat exchangers yield an ultra-compact combustor
- Elutriated flow removes ash and sulfur prior to recycle
- TRL 4: next step pilot plant (20 MW+) demonstration




## Supercritical $CO_2$ 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

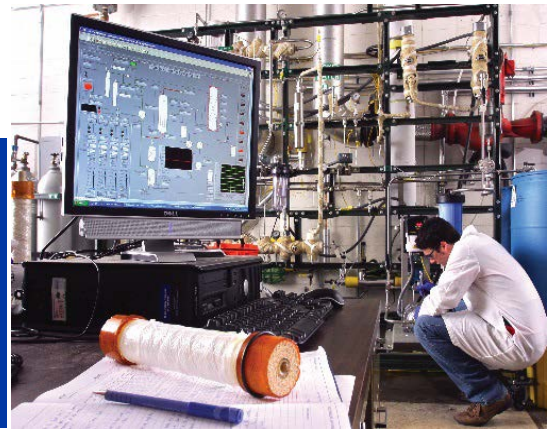



- Produce electric power with near zero emissions
- Produce pure $CO_2$ for EOR or storage
- Rankine or Brayton cycle configurations

# 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

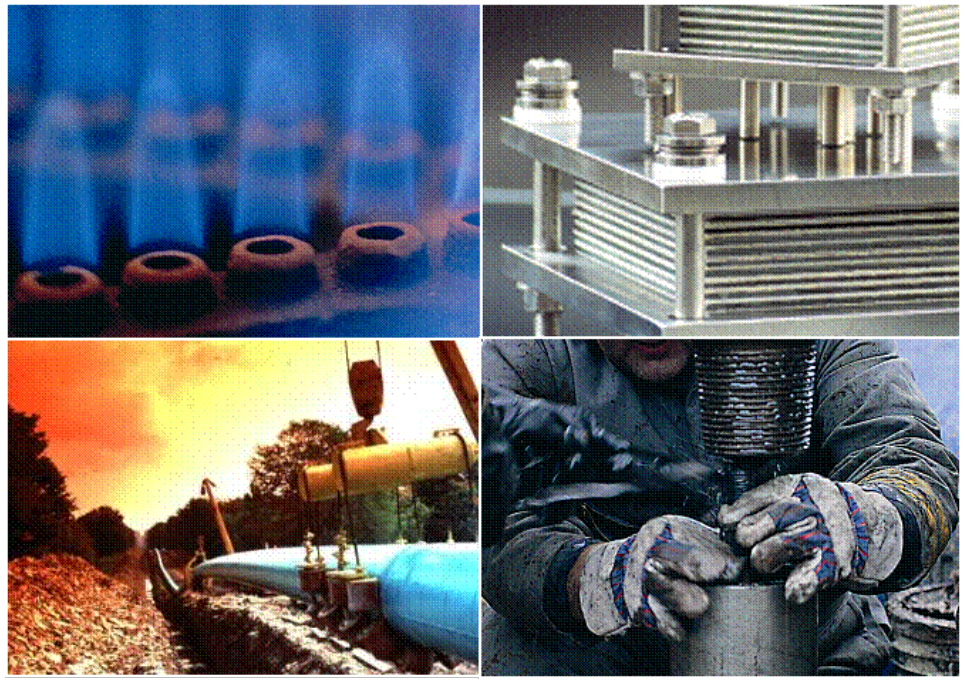
**Technology Transfer**

- 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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