the Energy to Lead

Natural Gas End Use RD&D In North America

William E. Liss
Managing Director, End Use Solutions

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gti

GTI Overview

- Not-for-profit RD&D organization with extensive 70 year history
- Facilities
  - Over 7 hectare campus near Chicago, IL
  - 28 specialized labs
- Staff of 250
  - 170 engineers, scientists engineers covering all fields
  - In-house IP, Contracts, Licensing
- Focus on all aspects of natural gas value chain: Production, Delivery, End Use

Offices & Labs

Flex-Fuel Test Facility

Energy & Environmental Technology Center

GTI's End Use Solutions Sector

Residential/Commercial

> Building systems and appliances

Power and Steam Generation

> Industrial boilers

> Engines, turbines, fuel cells

Transportation

> Alternative fuel vehicles and infrastructure

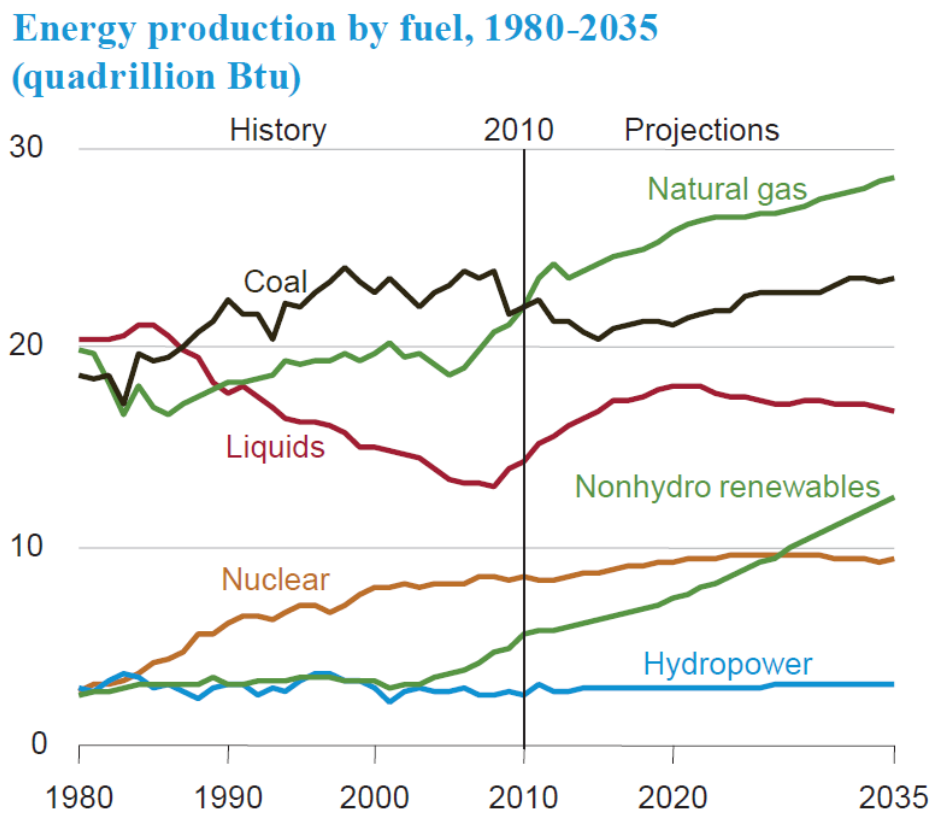
> Focus on natural gas vehicles

Industrial Processes

> Metals, glass, petrochemicals, paper, food, others

- About 50 engineers, scientists, technicians
- Extensive experience and facilities
- $20-25 million annual RD&D – with additional in-kind support from partners

Natural Gas Energy Production Leadership and "Golden Age of Gas"



DOE-EIA AEO 2012

Natural Gas is the leading energy source made in US. Confluence of new production techniques & shale formations has fundamentally and ***profoundly shifted the future trajectory of energy supply and use***.

Natural Gas End Use RD&D Drivers

North American Perspective

- Maintaining competitive position of natural gas in **residential and commercial** applications
  - Competitive positioning vis-à-vis electricity is critical
  - Displace fuel oil and LPG use
  - **Source energy** and smart energy policies
- **Industrial** competitiveness and economic growth
  - Natural gas as a catalyst for growth and new jobs
- **Power generation** and CHP
  - Efficient use of natural gas for power and enabler for intermittent renewable generators

- **Transportation**
  - Cost-effective vehicle and fueling options for fleets, commuters
- **Renewables**
  - Solar thermal and bio-methane options integrated with natural gas

RD&D Process and Positioning

Risk/ Reward			
	High		Breakthrough Technology
	Low	Continuous Improvement & Adaptation	
		Near Term	Long Term
		Development Time	

Multi-Dimensional RD&D Portfolio Elements

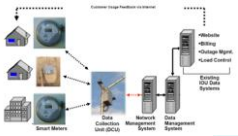
Transportation
Power Gen
Industrial
Commercial
Residential

	Applied Science	Technology Development	Product Development	Commecial-ization	Policy, Regulatory, Codes & Standards
Near-Term (1-2 Years)					
Mid-Term (3-5 Years)					
Long-Term (>5 Years)					

← Industry →

← Government →

Residential and Commercial Technologies and Products


Smart Energy Grid

Solar Thermal Panel

Venting Innovations

Real-time Energy Monitor

Gas Heat Pump

NGV Filling Station

Tankless/Solar Hybrid Water Heater

Interior Piping

Radiant Tubing

Plug n Play Utility Room

MicroCHP

Residential

Various RD&D activities to address:

- Energy efficiency
- Renewables
- Smart Grid functionality
- New & expanded natural gas uses → cooling, onsite power, vehicles

Smart Energy Grid

Solar Thermal Panel

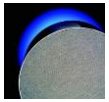
Radiant Heating

CHP Systems

Gas Heat Pump

High Efficiency Boilers

Waste Heat Chiller/Heater


Humidity Control

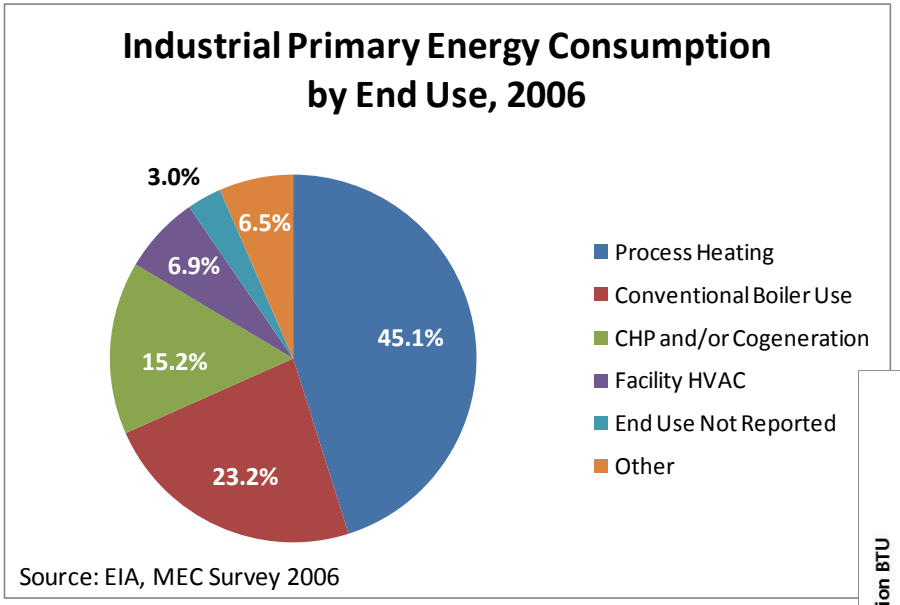
Solar Hybrid Water Heating

NGV Filling Station

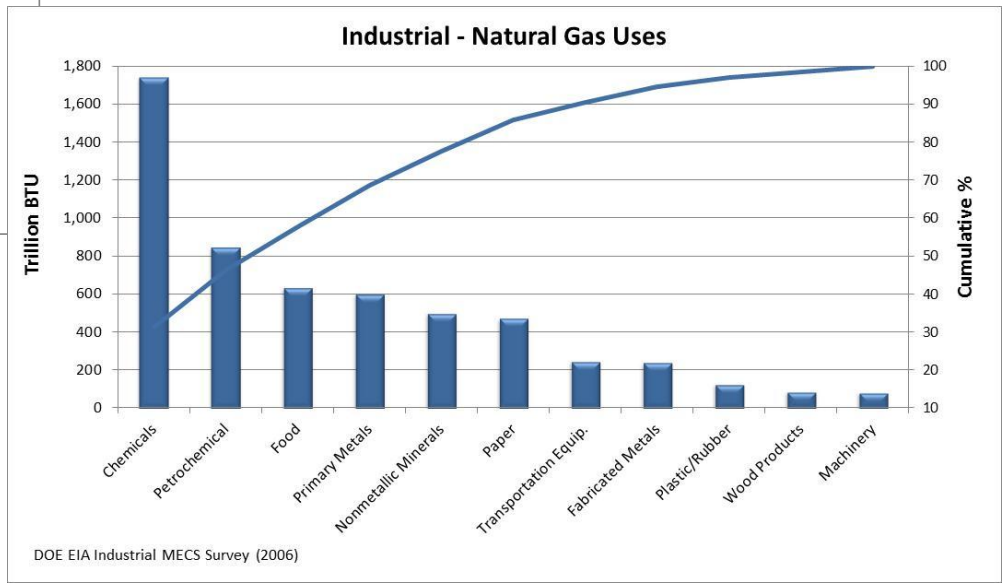
Commercial Food Service

Commercial

Industrial Natural Gas Uses



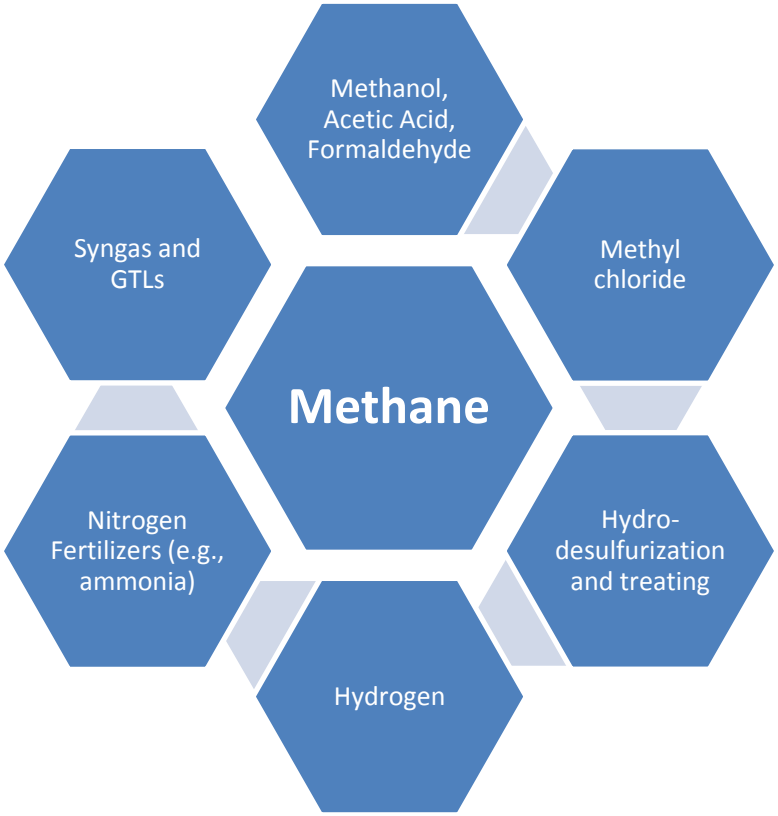
Source: EIA, MEC Survey 2006

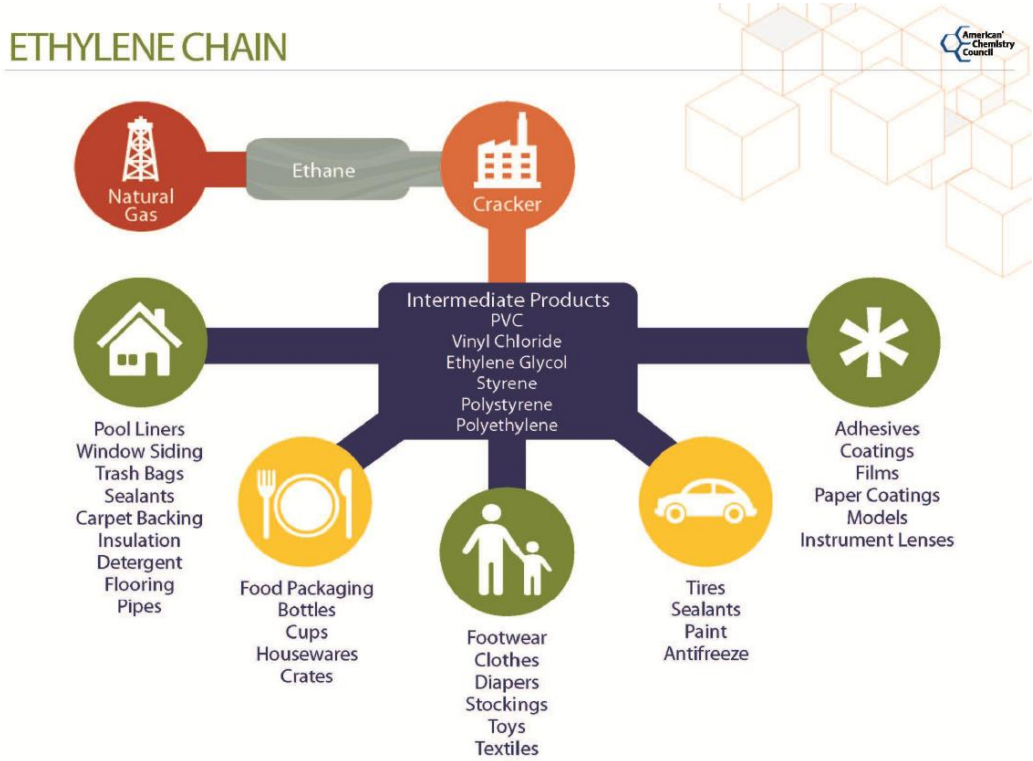


DOE EIA Industrial MECS Survey (2006)

Chemicals and Petrochemicals

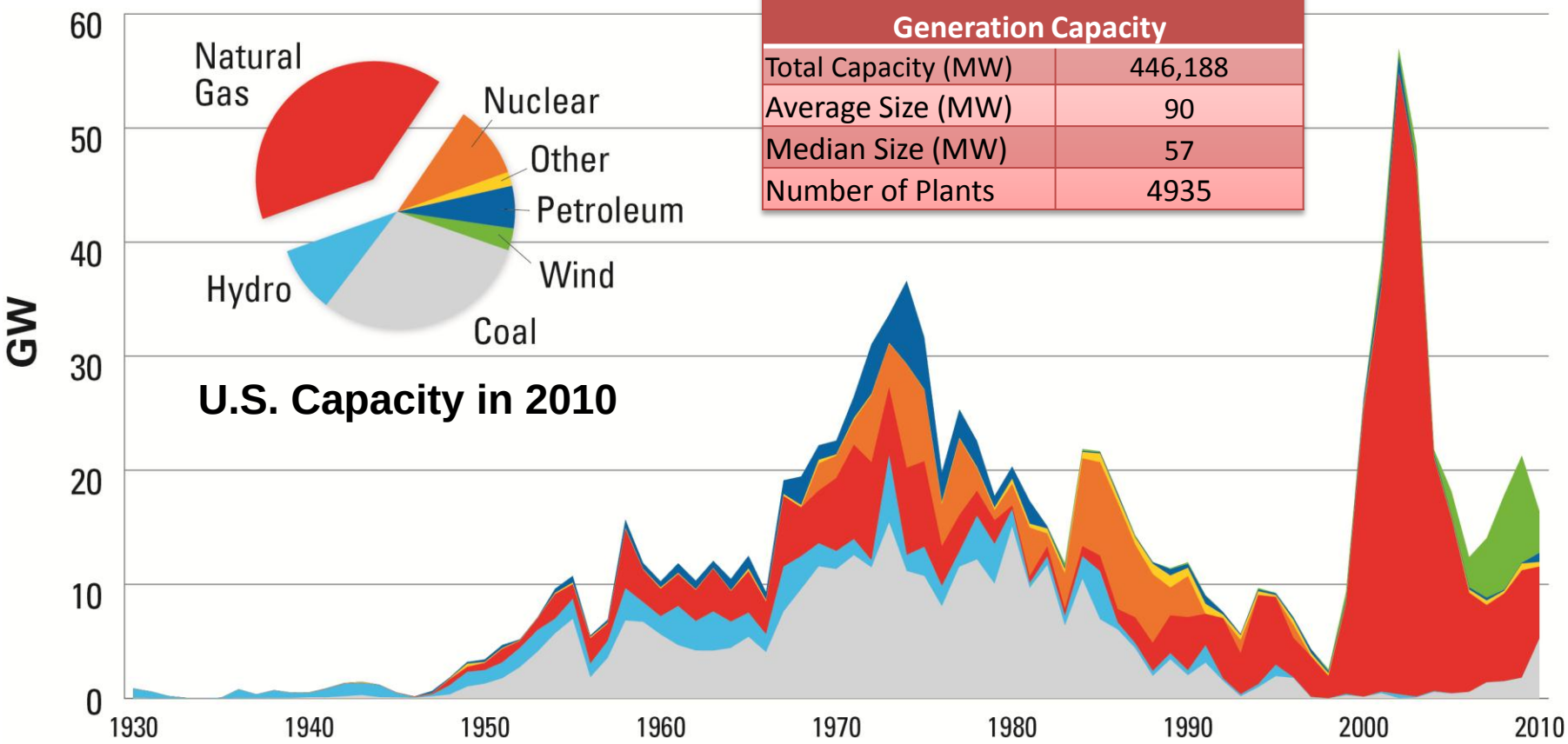
Methane & Ethane – Small, But Powerful Precursors





Source: American Chemistry Council

U.S. Power Generation Market Shifting to Natural Gas



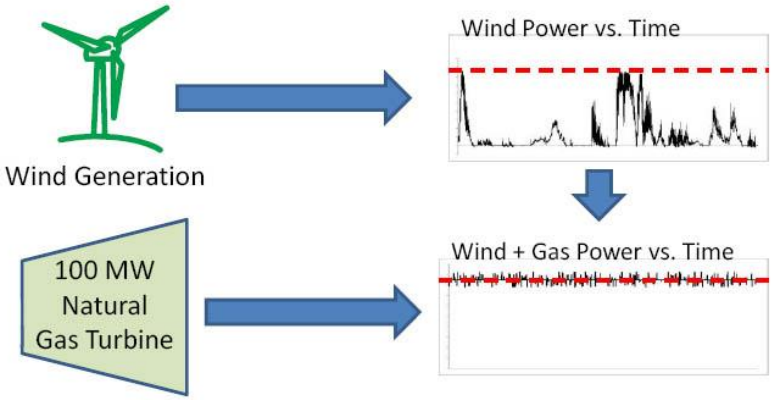
Natural Gas Power Generation Capacity	
Total Capacity (MW)	446,188
Average Size (MW)	90
Median Size (MW)	57
Number of Plants	4935

Natural Gas & Renewables

Synergies & Necessities

> Natural gas and intermittent renewables (e.g., wind, solar) can be complementary

- Natural gas power generation can help renewable power's intermittency challenges
- Natural gas is a supplemental heat source for solar thermal power
- Natural gas is also a complement to bio-gas/ bio-methane use



Adapted from Hittinger, Carnegie Mellon

Natural Gas Distributed Generation and CHP Products

Gas Engines

Gas Turbines

Fuel Cells

Microturbines

Micro CHP Systems

Source: freewatt (Honda engine)

Source: Bosch, WhisperGen (Stirling)

Source: CFCL (SOFC)

Source:
Marathon (engine)

Source: Clear Edge Power (PEMFC)

Source:
Yanmar (engine)

Opportunities to Reduce Liquid Fuel Dependence

- Natural gas can help displace traditional liquid fuels
  - **Residential/commercial/industrial heating and fuel oil use**
  - **Transportation (on and off-road)**
    - Direct and indirect routes
  - Save consumers on fuel costs
  - Meet key policy objectives: Energy security, lower import reliance, enhance balance of trade, air quality improvements

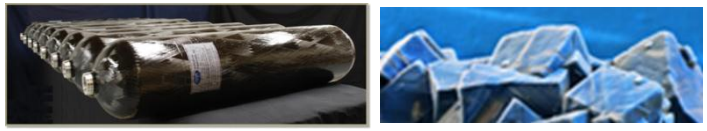
Transportation Sector and Natural Gas Vectors

- Broadly defined, natural gas can have a big footprint in transportation sector
  - Indirect and direct uses
- **Indirect uses**
  - **Petroleum refining**
  - **Ethanol production**
  - Other new indirect vectors (e.g., GTL, electric vehicles, etc)
- **Direct uses**
  - **NGVs (CNG, LNG)**

GTI's NGV RD&D Focus

- **Vehicles and On-Board Storage**
  - Develop/demonstrate new engines & vehicles
    - Cummins ISX12 G, other high-efficiency, low-emission engines
  - New vehicle platforms (e.g., heavy-duty hybrids)
  - Components: NGV storage advances (CNG, LNG, ANG) and related fuel delivery devices
- **Infrastructure**
  - Demonstrate & deploy new products and station solutions
  - Components: new compressors, dispensing, fuel quality, small fleet and home fueling
  - New approaches to reduce cost and position natural gas industry to enable infrastructure expansion

New Engines and Vehicles



Advanced Storage and Components

Infrastructure Advancements

U.S. and International NGV Markets

Different Market Attributes

Country	Natural Gas Vehicles	GGE/Year	BCF/year	GGE/ Vehicle/Year	Tank Technologies
Iran	2,859,386	1,608,972,185	198	563	Type I
Pakistan	2,850,500	1,374,930,471*	169	482*	Type I
Argentina	2,044,131	827,655,981	102	405	Type I, III
Brazil	**1,702,790**	**569,204,057**	**70**	**334**	**Type I**
India	1,100,000	530,581,834*	65	482*	Type I
United States	**112,000**	**361,760,341**	**44**	**3,230**	**Type I, III, IV**
Ukraine	200,019	285,962,937	35	1,430	Type I
China	600,000	289,408,273*	36	482*	Type I, III, IV
Italy	761,340	213,714,228	26	281	Type I, II,III
Bangladesh	200,000	204,894,167	25	1,024	Type I

Per vehicle U.S. NGV demand is greater than other markets and rely more on lightweight composite cylinders.

High-performance ultra-low emission engines with improved cost differential; no urea SCR or particulate filters as seen on diesel platforms

Substantial 155 diesel gallon equivalent on-board storage; 700-900 mile range possible.

Source: N. Sirosh, Quantum Technologies
* Estimated values

NGVs Good for On-Road… AND Off-Road…

Marine

Rail

Mining/E&P

Material Handling Equipment

Example GTI Efforts With International Entities

- High-efficiency combination space and water heating units (Rinnai, others)
- Gas engine heat pumps (e.g., Aisin)
- Res/Comm CHP systems – engines (e.g., Honda/freewatt, Yanmar)
- Res/Comm CHP – fuel cells (CFCL, others)
- Res/Comm CHP - Stirling
- High-temperature industrial heat recovery CHP system (Alstom)
- Submerged Combustion Glass Melter (multiple international licensees)
- High-temperature heat recovery (ArcelorMittal)
- Small-scale liquefaction (Linde Corp)
- Advanced burners (Bakaert)
- Solid-state natural gas quality sensor (CMR Group)
- Solar thermal systems (Apricus)
- Various projects with North American-based multi-nationals
  - A.O. Smith, Cummins, many others
  - Includes confidential efforts
- Various international gas utilities (mainly information exchange)
- GTI's Education & Training group conducts international activities

Example Collaborative Topics

- Lower cost tankless and combination space & water heating products
- Natural gas heat pump water heater or steam generator (COP=1.5+)
- Advanced res/comm gas heat pumps for space conditioning (higher COPs, lower cost)
- Cost-competitive high-efficiency (e.g., >50% electrical efficiency) micro CHP
- Waste heat to power systems
- High-performance burners for industrial processes and manufacturing (e.g., radiant)
- Low-temperature heat and water recovery and systems (energy/water nexus)
- Distributed hydrogen production and C_1 chemical conversion routes
- Distributed natural gas to liquids (drop-in substitutes for petroleum fuels)
- High-performance ultra-low emission NGV engines; hybrid and near-zero emission NGVs
- Use of natural gas in large on and off-road vehicles
- Low-pressure adsorbed natural gas (ANG) storage; conformable natural gas storage vessels
- High-performance NGV dispensers
- Home fueling systems for NGVs
- Low-cost hybrid solar thermal/natural gas systems
- Crosscutting technologies (various): Advanced controls, sensors, smart technologies, materials, heat transfer systems, etc

Example Collaborative Topics for Medium-Term Impact

Res/Comm	Industrial	Transportation	Power/CHP	Cross-cutting
Lower cost tankless and combination space & water heating products	High-performance burners for industrial processes and manufacturing (e.g., radiant)	High-performance ultra-low emission NGV engines; hybrid and near-zero emission NGVs		Crosscutting technologies (various): Advanced controls, sensors, smart technologies, materials, heat transfer systems, etc
Natural gas heat pump water heater or steam generator (COP=1.5+)	Natural gas heat pump water heater or steam generator (COP=1.5+)	Use of natural gas in large on and off-road vehicles		
Advanced res/comm gas heat pumps for space conditioning (higher COPs, lower cost)	Low-temperature heat and water recovery and systems (energy/water nexus)	High-performance NGV dispensers	Cost-competitive high-efficiency (e.g., >50% electrical efficiency) micro CHP	Low-cost hybrid solar thermal/natural gas systems – including higher-temperature systems
	Distributed hydrogen production and C_1 chemical conversion routes	Home fueling systems for NGVs	Waste heat to power systems	
	Distributed natural gas to liquids (drop-in substitutes for petroleum fuels)	Low-pressure adsorbed natural gas (ANG) storage; conformable natural gas storage vessels		

Summary

- GTI involved in range of natural gas end use RD&D efforts
  - Emphasis on near to mid-term
  - Applied technology development leading towards commercialization with manufacturing partners
  - Res/Com, Industrial, Onsite Power/CHP, Transportation
- Work in collaboration with natural gas industry, manufacturing partners, and government agencies
  - Leverage funds to achieve market impact