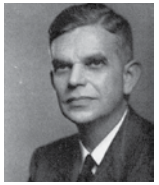

# ANNUAL REPORT 2015

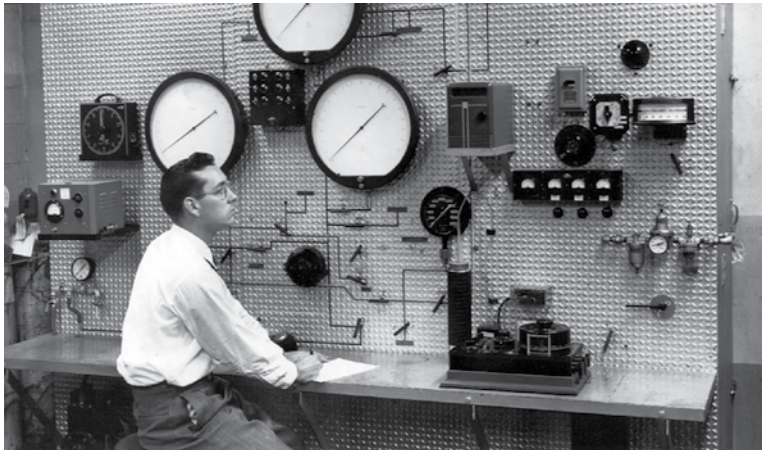

**INSTITUTE OF GAS TECHNOLOGY (IGT)** opens its doors on June 3, 1941. Founded by the gas industry and affiliated with the Illinois Institute of Technology (IIT), IGT specialized in research and education related to gas and byproducts. Dr. Henry Heald was the first president.



From the beginning, IGT's Technical Information Center (TIC) focused on the collection and dissemination of scientific information. and it now hosts the world's largest collection of materials on natural gas technologies and related energy topics.


A new, modern building was designed for IGT by celebrated architect Mies van der Rohe.

Peoples Gas Light and Coke Co. of Chicago also provided a 12,000 square foot site for IGT pilot plant facilities in the southwest part of Chicago.



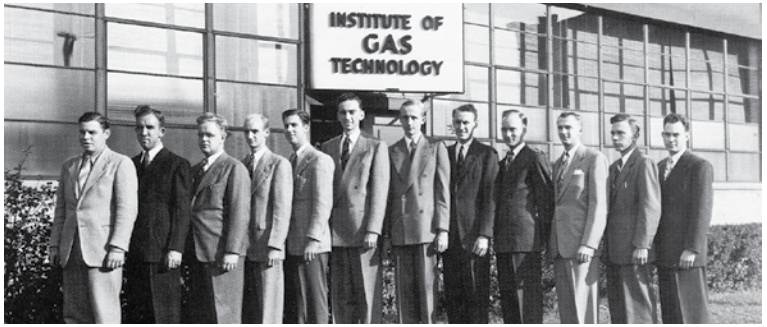
IGT

1940

1970

State-of-the-art equipment acquired—the first computer

IGT's first graduating class




**GAS RESEARCH INSTITUTE (GRI)** was created in 1976 as an organization to manage research for the entire industry. A tariff supported the cooperative research and development (R&D) program that benefitted the gas industry and ratepayers.

Dr. Henry Linden, the head of the IGT for 17 years, became the president of GRI. He was instrumental in its establishment, and served as its president from 1977 until 1987. Dr. Bernard "Bernie" Lee became President and CEO of IGT in 1978.

In 1981, GRI relocated to business offices at 8600 W. Bryn Mawr Avenue in Chicago.

At its peak in 1994, GRI administered funds in excess of $212 million.

Between 1977 and 1984, GRI brought 18 new products and techniques to the marketplace that yielded large benefits to ratepayers and the industry. A conservative estimate of the projected net present value of their economic benefits was $4.8 billion (in 1983 dollars). These benefits, which did not reflect the large potential value of the research and development efforts that were still in progress, are more than ten times the cumulative cost of supporting GRI through the end of 1984.

Dr. Stephen Ban became the President and Chief Executive Officer of GRI in 1987.

By Y2K, GRI amassed an impressive record in its 24 years, delivering about $8.50 of benefits for every dollar it spent.

1980

1990

2000

IGT's staff reaches record levels, peaking at 647 in 1980. From a financial standpoint, this was IGT's most successful decade with revenue that grew to an all-time high of nearly $258 million.

IGT turned to membership to build greater support for the gas industry's technology base by founding the Sustaining Membership Program (SMP) in 1985.


In 1994, IGT moved to an 18-acre campus in Des Plaines, Illinois, 10 minutes from O'Hare Airport. The new headquarters became home to a flexible combination of specialized labs with equipment for design, testing, and analysis of advanced energy technologies.

In April 2000, the strengths of IGT's research performance were combined with GRI's expertise in project management and industry network to create a powerful new organization—**GAS TECHNOLOGY INSTITUTE (GTI)**. John Riordan became President and CEO of GTI in 2000. Employees from GRI's business offices on Bryn Mawr Ave. relocated to the IGT facility in nearby Des Plaines.

Based on a settlement between FERC and the gas industry in 1998, the traditional GRI RD&D program—and the mandatory funding to support it—ended in 2004.

Operations Technology Development (OTD) was launched in 2003 to facilitate collaborative gas operations and infrastructure research.

Utilization Technology Development (UTD) began in early 2004 to address end use issues of interest to the gas industry.

GTI rolled out the Emerging Technology Program (ETP) in 2011 to accelerate the market acceptance of the latest end-use technologies.

AGA was selected to hold the Presidency of the International Gas Union (IGU) from 2015-2018. Joining key North American leaders in this endeavor, David Carroll, GTI's President and CEO is leading the U.S. triennial team as President.

Davis Energy Group (DEG), a California-based R&D and energy consulting firm, was acquired in 2015 to help serve residential and commercial markets with building energy efficiency.

## 2000

GTI Testing Laboratories earned accreditation from the American Association of Laboratory Accreditation (A2LA) to perform mechanical and chemical testing in accordance with ISO/IEC 17025, attesting to our high quality standards.

David Carroll was selected to take over as GTI's President and CEO in 2006 when John Riordan retired.

## 2010

GTI established a satellite office in Davis, California in 2012 to focus on GTI's expanding efforts with local utilities and energy agencies.

In 2013, GTI invested in the start-up of a consulting firm, Enovation Partners, to work with senior management teams in the energy and infrastructure sectors on high-impact strategy, technology, regulatory and operational issues.

GTI acquired subsidiaries Fisher-Nickel and CDH Energy, and created LocusView in 2014 to expand our impact in the market and the value we can bring to customers.

# PROUD PAST, BRIGHT FUTURE

GTI acquired the energy systems portfolio of Aerojet Rocketdyne in 2015, including intellectual property (IP), physical assets, and technologies. Former AR employees joined the GTI team, and we opened a new office in Woodland Hills near Los Angeles, California.

2015

BKi, also based in California, was acquired in early 2016. The company delivers sustainable solutions in energy efficiency, alternative transportation fuels, advanced power generation, and energy storage.

## LEGACY OF CONTRIBUTIONS

For more than seven decades, GTI scientists and engineers have developed high-impact technologies and provided technical insights to unlock the potential of natural gas and other energy resources—helping make them economically and environmentally sustainable, while reducing costs for consumers.

We're proud of our impressive record of success in providing innovative solutions to critical challenges along the entire gas value chain; improving the ways energy is produced, transported, and used around the world. These contributions are the foundation of GTI's reputation as a trusted partner to industry and government.

## RECENT ACCOMPLISHMENTS

In 2015, we bolstered our energy conversion capabilities by acquiring select energy assets from Aerojet Rocketdyne and expanded our energy efficiency expertise with the addition of new California-based subsidiaries. Through these acquisitions, we welcomed an enthusiastic and accomplished group of new employees. We now have more than 100 energy professionals serving customers in the state of California.

GTI's core research operations have increased steadily in both scope and impact. Our pipeline of new and pending business contracts is robust, as important customers from the utility, government, and industry sectors entrust us to develop novel solutions for energy markets while reducing the impact on our planet.

On other fronts, we expanded our intellectual property base, with 19 new patents awarded to GTI inventors, in addition to approximately 150 patents obtained in the Aerojet Rocketdyne transaction. Our commitment to safety was demonstrated once again, with no recordable injuries or lost time accidents. We also launched a corporate environmental sustainability program to reduce the carbon footprint of our own operations.

## MOVING THE INDUSTRY FORWARD

Looking back over 75 years of accomplishments, the value of our organization, measured by both technical innovation and market impact, is clearly evident. As we celebrate this important milestone, we look forward to creating a bright energy future. Society needs innovative solutions to meet the challenges of a post-COP21 world. Affordable and reliable energy is critical for developing nations currently dealing with population growth, urbanization, and poor air quality. Natural gas, coupled with the many technologies under development at GTI and elsewhere, will help ensure that expanding global energy needs will be met responsibly and safely for decades to come.

An unwavering commitment to energy innovation has been part of GTI's DNA for 75 years. But in some ways, our work is just beginning. Thank you for your continued support of GTI's people and programs. We're working hard to make a difference for our industry and for all of you.

David C. Carroll,
President & CEO

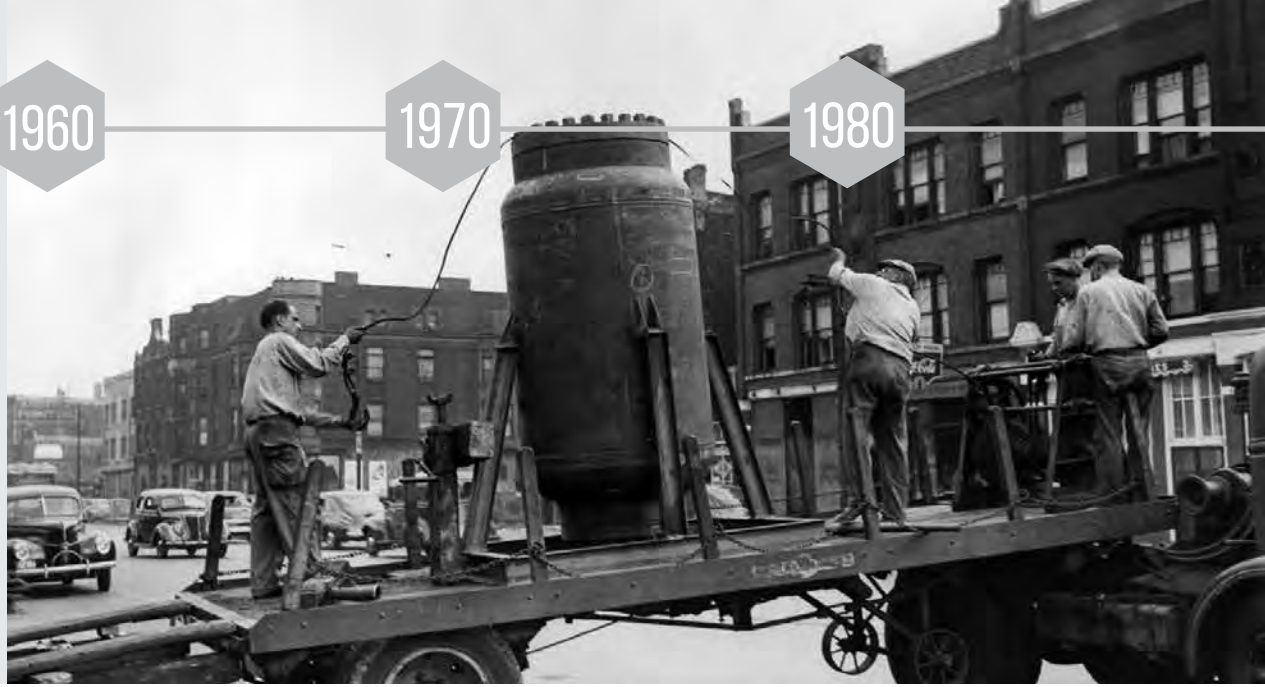
Terry D. McCallister,
Chairman of the Board

1940 1950 1960 1970 1980

# GASIFICATION

Since the 1940s, GTI has been actively involved in gasification research and development (R&D). In the decades that followed, researchers have developed a database for the gasification of fuels from around the world and have extensive experience in the design, construction, and operation of varying types of gasification facilities in the U.S. and Asia.

GTI's program is driven by the need to find the most environmentally friendly way to use abundant coal resources to produce power, fuels, and chemicals.



IGT's earliest projects involved research on coal gasification. The Basic Research Program began work on coal gasification and fluidization, and grew in recognition as a world leader in the kinetics of coal gasification.

IGT completed the construction of a $30 million coal gasification pilot plant by the end of the 1960s, the culmination of research work that had been underway for 25 years. It was the first coal gasification plant to produce substitute natural gas on stream.

1990 2000 2010 **2015**

# HIGHLIGHTS

An extensive program to develop and scale-up coal gasification processes was initiated in 1973. IGT's U-GAS® technology efficiently converted all ranks of coal into high-value synthesis gas, and IGT was awarded several patents on the process.

In 1994, the world's first U-GAS® coal gasification plant based on IGT's patented U-GAS® process was built in Shanghai, China to convert coal into synthesis gas. The process was licensed exclusively to Synthesis Energy Systems, Inc. (SES) for global commercialization in 2006. GTI provides ongoing support on the technology that is installed in over a dozen units for chemicals and metallurgical processes in China.

With over $95 million invested by government and industry, GTI built a unique pilot-scale gasification campus at our Des Plaines, IL headquarters in the early 2000s. These one-of-a-kind, highly instrumented facilities offer innovative sampling and analytical systems and comprehensive diagnostic capabilities to support independent or integrated systems testing.

GTI acquired extensive intellectual property, physical assets, and technologies of Aerojet Rocketdyne's (AR) energy systems portfolio in 2015. GTI has worked closely with AR for ten years, hosting the development of their compact gasifier for coal and natural gas conversion, which has now been rebranded as the R-GAS™ process.

Former AR employees joined the GTI team, and a new office near Los Angeles was established. Researchers are now performing long-duration testing of two high-ash, high-ash-fusion temperature coals in a project with Yangquan Coal Group in China. The partners are also working to finalize a contract to design, build, and operate a large-scale demonstration plant incorporating R-GAS™ advanced coal gasifier technology in China.

GTI is a key partner on a project being led by RTI International to develop a breakthrough hybrid coal-to-liquid process technology to produce jet fuel. Our pilot-scale gasification facility is being used to test RTI's advanced syngas to liquids (STL) process with syngas derived from coal, natural gas, and mixtures to produce the required compositions. By integrating these technologies, the hybrid process is expected to reduce the capital costs associated with conventional conversion processes.

In another project for DOE-NETL and Illinois Clean Coal Institute (ICCI), a combination of natural gas and coal was evaluated to produce a high-hydrogen syngas that could be used for liquid fuels, power, or hydrogen. The project combined GTI's advanced gasification, partial oxidation, sulfur removal and recovery ($SR^2$) process, and hydrogen separation technologies, using a novel membrane. The cost of converting coal to hydrogen or chemical-grade syngas can be reduced by 20-30% using this process, by bringing down capital and operating expenditures, increasing efficiency, and minimizing the expense to lower emissions.

# ENERGY CONVERSION

Beyond finding the most environmentally friendly ways to use abundant coal resources, GTI is also exploring options to extract the most value from other natural resources and provide renewable fuel options with biomass gasification. Solutions with feedstock flexibility will help address climate change concerns and alter the energy landscape.

Environmental research and managing waste materials have also been important priorities for GTI in the last five-plus decades. Energy conversion technologies such as anaerobic digestion and thermal conversion processes showed potential to produce non-fossil methane sources.

Now, global demand for power, hydrogen, liquid fuel and chemical production is growing as access to low-cost resources provides new market opportunities for high-value products.

In the 1970s, research work on anaerobic digestion and thermal conversion processes showed potential as energy conversion technologies focused on peat, kelp, sludge, and industrial wastes to produce non-fossil methane sources. In 1994, a two-phase anaerobic digestion process for sewage treatment produced a clean fuel gas as a byproduct. It was patented by IGT and brought to market as ACIMET.

Environmental technologies took center stage when the Sustaining Membership Program (SMP) was launched, and two important patents came out of IGT's environmental research in the 1980s. The SOLCON Digester, an anaerobic digestion process, was tested at Walt Disney World and performed 80% conversion of biomass to methane. The Methane Enrichment Digester technology produced utility-grade gas from a pilot-scale anaerobic digester, also demonstrating successful results for renewable energy production.

IGT's patented RENUGAS® fluidized-bed biomass gasification technology began a worldwide tour in the early 1990s, with demonstrations in Finland, Hawaii, and the U.S. The technology provides fuel gas for power generation, and can produce syngas for fuel gas, liquid fuels, hydrogen, or substitute natural gas applications. In 2006, a commercial combined heat and power gasification plant in Denmark began using the RENUGAS® process with about 90% efficiency to produce 6 MW of electricity and 12 MW of district heat from wood.

In 2007, campaigns testing integrated syngas production and processing systems were carried out at GTI's gasification campus in support of biomass-to-liquids (BTL) process development. Testing has provided Andritz/Carbona, commercializer of GTI's biomass gasification technology, and their client UPM-Kymmene, a global forestry company, with process data to support the design of a commercial biofuels plant in Europe.

# HIGHLIGHTS

The Gills Onion Advanced Energy Recovery System converts 100% of onion waste by digestion into biogas. GTI led an initiative to clean and condition the biogas to make it suitable for use in an ultra-clean 500 kW fuel cell power plant.

An initiative launched by GTI established parameters for evaluating the suitability of renewable biomethane products derived from dairy waste and landfills for safe and proper introduction into existing natural gas pipelines and to assure compatibility with existing supplies.

In 2013, efforts to convert wood into renewable "drop-in" gasoline in GTI's integrated biorefinery resulted in a renewable fuel that has 74% lower greenhouse gas emissions than petroleum-based fuel. GTI and partners Haldor Topsoe, UPM, Andritz, and Phillips 66, and DOE developed an integrated process that converted syngas into gasoline by fully optimizing pilot-scale gasification, syngas cleanup, and syngas conversion processes.

- A $6.6 million ARPA-E funded Turbo-POx project was completed with positive results. In the project, a reactor was developed, based on key features of the R-GAS™ advanced coal gasifer, to operate as a high-temperature, high-pressure natural gas partial oxidation reactor with a novel expander design. Reactor system testing delivered successful outcomes. Because the method produces both power and liquid fuel, it is an attractive option for associated gas now flared in oil production fields. Assessments suggest that it has promise in other applications where power off-take is available. The amount of co-produced power can be controlled, allowing for flexibility as electricity demands change.

- GTI's patented IH$^{2®}$ thermochemical process has been proven as a very cost-effective route to produce liquid transportation fuels from renewable biomass resources. GTI is building the technology patent family and providing ongoing technical and commercialization support. A global company headquartered in Northern Europe has entered into a licensing agreement for a commercial-scale plant with CRI Catalyst Company (CRI), the exclusive worldwide licensor of the technology. Shell India Markets Pvt Ltd (SIMPL) also announced in 2015 that it will install a 5 ton/day IH$^{2®}$ demonstration plant at their new Technology Centre in Bangalore, India.

- The green gasoline blend created in GTI's integrated refinery was registered by EPA as an approved motor fuel in 2015. An integrated process that converted syngas into fuel by fully optimizing pilot-scale gasification, syngas cleanup, and syngas conversion processes was used to produce more than 10,000 gallons of 92-octane biogasoline for fleet testing, which delivered excellent results.

1940 1950 1960 1970 1980

# UNCONVENTIONAL GAS

GTI helped to unlock the potential of unconventional gas resources in North America in the 1980s with a new collaborative research model that brought together a world-class team of experts from industry and academia with significant investments from the U.S. Department of Energy (DOE) and GRI. Strong industry involvement in field experiments was critical to the success of the program, and the research investments from GRI and DOE sowed the seeds of unconventional gas production far into the future.

These efforts created greater understanding and new exploration and production technologies that increased production of cost-competitive unconventional shale gas, coalbed methane, and tight gas sands. The industry is still using a multitude of GRI-developed tools and techniques that transformed the U.S. energy picture.

Today, GTI is continuing to expand the body of scientific knowledge and providing new tools, data, and thought leadership to ensure the safe, economical, and responsible development of global shale gas.

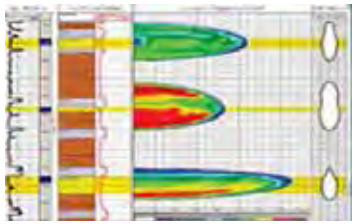
Working with about 40 other organizations in the early 1980s, GRI documented regions with the greatest potential and developed guidebooks, simulators, and other tools to explore options for fracturing a coal formation and optimize all aspects of coalbed methane operations.

In 1983, GRI's hydraulic fracturing research began, leading to "proof-of-concept" experiments at a Rocky Mountain site, verifying a multitude of leading-edge breakthrough technology. GRI developed methods for monitoring the creation of hydraulic fractures and guiding well siting for maximum gas production.

Research on shale formations in Illinois and Texas was key in developing horizontal drilling. GRI researchers worked with Mitchell Energy to drill a horizontal well in the Barnett Shale stimulated with new technology that produced three times more gas than any other well up to that time.

GRI's work in the Michigan geologic basin helped the industry better understand fracture geometry in complex shale formations and develop cost-effective workover procedures. Research helped producers optimize the economics of fracture treatments by targeting more productive zones.

# HIGHLIGHTS



A decade of what GRI learned was embodied in products like the FRACPRO computer-based design and analysis tool that helped design and predict the behavior of hydraulic fractures.

High-resolution seismic images that showed geologic structure and subsurface features between wells helped producers make more informed decisions. GRI-developed FracSeis[SM] microseismic hydraulic fracture mapping for fracture diagnostics is still available as a suite of services from Pinnacle Technologies.

GRI created innovative, cost-effective technologies for treatment of produced water. In 1997, GTI and partners developed the FTE® Process, a freeze/thaw evaporation purification process for treating produced waters created by hydraulic fracturing. During the first decade of the 2000s, GTI led Water Conservation and Management Committees in the Barnett and Appalachian Shales, and assessed water management and reuse technologies for RPSEA. Water-based life cycle modeling provides timely planning and technology guidance for sustainable shale gas water and solid waste management. GTI also completed a techno-economic assessment of produced water management solutions, a joint industry project with 22 companies, in 2011.

The Research Partnership to Secure Energy for America (RPSEA) was awarded a 10-year DOE contract to manage supply research programs. GTI managed the unconventional natural gas research program for RPSEA from 2006-2011 and served as a major technical performer in the program.


GTI hosted the first annual global unconventional gas (GUG) conference in June 2010 in Amsterdam to share lessons learned from the U.S. unconventional gas revolution. Subsequent summits were hosted in Beijing in 2011 and 2012.

GTI also delivered customized workshops on best practices and technical solutions for unconventional gas development and produced water management to European producers and service companies. Reports were completed for the Polish Operators Association on the potential environmental impacts and mitigation strategies during shale gas exploration.

In an $18 million project supported by a public-private partnership, GTI is collaborating with experts from industry and government on a Hydraulic Fracturing Test Site (HFTS). Funded by the U.S. Department of Energy National Energy Technology Laboratory (DOE/NETL) and numerous operators and service companies, the project is targeting horizontal shale wells to reduce and minimize potential environmental impacts, demonstrate safe and reliable operations, and maximize the efficiency of hydraulic fracturing.

Eleven wells were drilled and completed in a Permian basin field in west Texas. A one-of-a-kind through-fracture core sample shows the physical properties of the fractures for observation. Along with comprehensive data, it illustrates how induced underground fractures spread, and will fundamentally alter the understanding of hydraulic fracture propagation, modeling, and effectiveness.


Courtesy of Sheehan Pipe Line Construction Company

# GAS OPERATIONS

Gas transmission and distribution work became prominent in the 1950s as natural gas replaced manufactured gas and extensive construction of natural gas pipelines took place. A safe and reliable natural gas delivery system has been a priority since that time, and GTI has a long history of contributions to the sector.

Over the decades, GTI has developed and brought to market an abundance of hardware and tools that lower system maintenance costs, reduce risks, prevent damage, and enhance safety. One key example is directional drilling, which minimizes excavations and public inconvenience associated with gas infrastructure operations. Today, nearly every directional drilling system on the market functions with GTI technology.

Trenchless technologies and keyhole tools provide substantial labor and time savings and significantly reduced the need for site restoration. Initiatives that assist with integrity management compliance have been vitally important. Making accurate, high-quality data readily accessible for analysis and decisionmaking is a priority. Targeting critical global environmental issues, GTI has focused efforts on detection, quantification, prevention, and mitigation of methane emissions.

GRI leveraged piping expertise and confirmed the suitability of polyethylene (PE) plastic pipe with technology advancements and more than 300 reports, technical papers, software, and studies on plastic pipe topics.

In the late 1980s, IGT developed field kits and new approaches for mitigating microbially induced corrosion (MIC). A pioneer in applying molecular technology to microbial-influenced corrosion (MIC) detection, GTI was the first one to use quantitative Polymerase Chain Reaction (qPCR) techniques in the early 2000s. In 2014, GTI Testing Laboratories became the first U.S. lab to receive A2LA accreditation for qPCR microbial corrosion testing services, and one of only a few laboratories in the world that offers accredited DNA testing. The same year, GTI scientists developed a method to help control the formation of MIC.

The grand opening of the $19 million Pipeline Simulation Facility (PSF) took place in 1995. GRI built the world's most advanced center for testing and evaluation of natural gas pipeline technologies. It provided a controlled but realistic pipeline environment with a high-pressure flow loop to improve the safety of pipeline operations and reduce operating costs. The facility is still in use today.

GRI developed and introduced a slate of award-winning tools that enhance operational efficiency and reduce O&M costs in the 1990s, and they received accolades from industry.

Prolific product development continued, working closely with LDCs and leading manufacturers to bring hardware to market.

Between 2002-2004, GTI and partners developed a common methodology for implementing external corrosion direct assessment (ECDA)/internal corrosion direct assessment (ICDA) protocols. Efforts to provide other protocols, processes, technologies, and training solutions to help operators manage the integrity of their systems have been ongoing.

In 1996, the first national methane emissions inventory was developed in GRI-EPA study, and GTI revisited that critical work in 2009. Researchers determined a more accurate emissions baseline for the natural gas distribution sector by developing a new technique to measure emissions, and then researchers updated the national emission factors (EFs) for pipes. Ongoing efforts focus on implementing the new EFs.

OTD Operations Technology Development

OTD was launched in 2003 to facilitate collaborative gas operations and infrastructure research. Today, 24 members serve over 45 million natural gas customers in the U.S. and Canada.

Researchers adapted commercially available smart phones and tablets to automate field data collection using GPS and GIS systems. Asset lifecycle tracking technology, along with tools and practices for implementation, have been created. GPS-enabled leak surveying and pinpointing technology was commercialized, and GTI launched tech start-up LocusView in 2014 to help bring advanced mobile geospatial technology and services to the natural gas industry.


# HIGHLIGHTS

- A project on vintage pipe delivered useful lifetime prediction models for Aldyl A piping systems and provided meaningful engineering guidance to integrity management teams. Follow-on work to create a decision support tool that addresses fitness-for-service and lifetime prediction is underway.

- A bench-scale electromagnetic acoustic transducer (EMAT) sensor to assess small-diameter and unpiggable pipelines was successfully developed with OTD and the U.S. Department of Transportation (DOT) funding. This will enable pipeline operators to identify defects that are traditionally difficult to find and assess, improving system integrity and public safety. Construction and testing a field prototype will move the technology toward commercialization.

- Working closely with operators and industry stakeholders, GTI is concluding field work collecting and analyzing leak data for buried pipe at a host of sites in the U.S. This high-quality data will improve estimates for activity data and promote the acceptance of new methane emissions quantification methods for compliance with EPA reporting requirements and other regulations under development.

GTI is also developing a tool that can accurately quantify emissions in the field and provide data that can be used for emissions reporting. Researchers are evaluating the use of alternative technologies, such as optical gas imaging cameras, to detect and quantify leaks throughout the natural gas system.

GTI is performing an assessment of fugitive emissions from the natural gas system in commercial buildings for the California Energy Commission that will quantify total building emissions. Researchers are measuring emissions beyond the meter using an approach that focuses on specific points within the structure and nearby exterior locations.

- With funding from OTD, GTI researchers evaluated European systems used to stop gas flow, and identified the patented Kleiss flow-stoppping technology as a good solution to provide significant savings in day-to-day operations while increasing operational efficiencies and safety. Following successful utility demonstrations and equipment optimization for the U.S. market, the team identified a North American commercialization partner—Mainline Control Systems (MCS)—and introduced the system in 2015.

# RESIDENTIAL AND COMMERCIAL ENERGY EFFICIENCY

GTI has a long legacy of promoting the clean and efficient use of energy resources in residential and commercial end use markets. By the mid-1950s, gas utilization research was a major activity. Advanced gas-fired appliances, heating, cooling, and fuel cell power concepts developed by IGT and AGA were showcased in the "Home of Tomorrow", totally powered by natural gas, at the 28th annual AGA meeting in 1969.

Our experts have made significant contributions to codes and standards issues and we have developed factual scientific data regarding the benefits of source energy to support energy efficiency standards. Assessments to verify equipment durability and performance have increased product adoption by providing potential customers with the knowledge and confidence to buy.

We have helped countless businesses and families lower energy consumption, reduce energy costs, and minimize their environmental footprint with our innovative developments.

In 1982, the home heating market was revolutionized with the Pulse Combustion Furnace that delivered operating efficiency exceeding 96%. With GRI support, Lennox Industries, Inc. commercialized the technology and it became one of their most successful products. Over one million units were sold between the early 1980s and mid-1990s.


In the 1990s, researchers developed a new fryer burner design for Pitco, ushering in the era of energy efficient fryers common today. GTI also pioneered the use of modulating burner technology in conveyor pizza ovens to reduce temperature variations, saving energy and improving food quality.

Researchers have led many efforts to introduce natural gas space conditioning equipment to the marketplace. From the mid-1980s through the 1990s, much research work focused on heat pumps for commercial and residential applications. Natural gas-fired desiccant dehumidification helped to provide effective humidity control. Important project work improved efficiency and reduced the costs of heating and cooling, making natural gas more competitive in electric-dominated markets.

GTI developed and field demonstrated many new pieces of equipment that use less energy than traditional models, earning them Energy-star ratings. In the early 2000s, GTI helped lead the way for the introduction of low-oil-volume fryers from several manufacturers that use less oil and energy, saving thousands of dollars per fryer per year.

A compact gas-fired countertop steamer offers enhanced cooking rates while providing energy savings and reduced water consumption. It received a prestigious Kitchen Innovations™ (KI) Awards from the National Restaurant Association in 2008 and is commercially available from Market Forge.

Commercialized by Lincoln, a conveyor oven introduced in 2008 used a GTI-patented airflow system and an advanced energy-management system to reduce energy consumption up to 38%.

# HIGHLIGHTS

UTD
Utilization Technology Development

Introduced in early 2004, UTD helps utilities build technology portfolios and expand efficiency programs. Led by 17 member companies, today it represents over 37 million natural gas customers in the Americas and Europe.

ETP
Emerging Technology Program

GTI rolled out the Emerging Technology Program (ETP) in 2011 to accelerate the market acceptance of the latest end-use technologies.

Partnering with Stone Mountain Technologies and A.O. Smith, GTI designed and demonstrated a novel ultra-high-efficiency Gas-fired Heat Pump Water Heater through laboratory proof-of-concept testing. The system meets $NO_x$ requirements and has an Energy Factor (EF) that is more than twice that of standard gas water heaters.

GTI launched the Carbon Management Information Center (CMIC) in 2007 to help address issues and opportunities in carbon emission controls. GTI experts are playing an instrumental role in bringing greater attention to the many ways that greenhouse gas emissions and energy costs can be reduced. These efforts have contributed to adoption of full-fuel-cycle measures of energy use by DOE, and the inclusion of source energy in building codes from ASHRAE and the International Green Construction Code (IgCC).

In 2014, GTI acquired Fisher-Nickel, a professional services firm located in California with deep expertise in commercial kitchen energy efficiency and appliance performance testing. CDH Energy also became a subsidiary. CDH is a professional services firm located in New York, that specializes in monitoring and energy analysis with a primary focus on distributed generation (DG) and combined heat and power (CHP).

FISHER NICKEL

CDH ENERGY

- We are growing our energy efficiency expertise and capabilities to bring greater value to our customers. In 2015, GTI acquired Davis Energy Group (DEG), a California-based R&D and energy consulting firm, to help serve residential and commercial markets with building energy efficiency. BKi, also based in California, was acquired in early 2016. The company delivers sustainable solutions in energy efficiency, alternative transportation fuels, advanced power generation, and energy storage through program development and implementation and stakeholder engagement.

DAVIS ENERGY GROUP

BKi ENERGY ECONOMICS ENVIRONMENT

- A research team funded by UTD developed low-$NO_x$ combustion systems with five residential furnace manufacturers to meet stringent South Coast Air Quality Management District (SCAQMD) emissions levels. Innovative burner materials, including metal mesh and metal foam, were used to achieve even heat transfer and uniform flame temperatures. Burners based on these designs are currently being developed for commercialization.

- UTD secured the first European member in 2015, Gas Natural Fenosa, increasing membership to 17 companies. The company, headquartered in Spain, has utility operations in multiple countries, including Mexico. UTD now represents over 37 million natural gas customers in the Americas and Europe.

- The gas absorption heat pump (GAHP) technology for residential space heating and commercial water heating is undergoing field testing sponsored by UTD. In laboratory testing and modeling, it demonstrated a Coefficient of Performance (COP) of 1.4 or greater and a financial payback period of as low as three years.

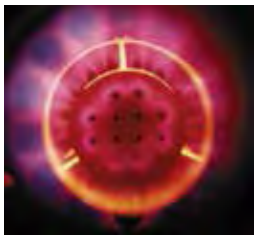
# BURNERS AND INDUSTRIAL EFFICIENCY

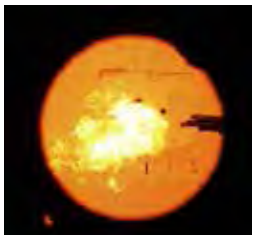
Development of burner technology is a core success story—IGT and GRI have made significant contributions to the strong market position of natural gas in the industrial sector, with more than 65 patents on high-efficiency, low-$NO_x$ burners and systems to control emissions.

Our engineers have deep expertise in industrial combustion, and are proven innovators and technology developers, creating a portfolio of technologies that include efficiency and productivity improvements, low emissions, and waste-heat recovery as an integral part of energy savings. Research projects have addressed the industrial process heating and steam needs of a wide range of industries and improved environmental performance in the manufacturing sector. New equipment can quickly attain high operating temperature, boosting productivity rates and lowering energy and operating costs.

Recognizing the operating cost and emissions benefits of on-site power and combined heat and power, GTI is developing, demonstrating, and deploying new gas-fired technologies for these applications.

Innovative burners reduced emissions and increased heat transfer at a low cost in a variety of applications. One of the most successful IGT-patented burners is the PrimeFire 400 high-luminosity burner from Eclipse that increases heat transfer rate and reduces $NO_x$ emissions by 50%. Other important developments include the Alzeta surface stabilized burners, the CYCLOMAX cyclonic burner from Maxon Corporation, and the forced internal recirculation (FIR) burner.





A notable 1967 achievement was the creation of the specially designed "eternal flame" burner for JFK's permanent gravesite in Arlington National Cemetery.

In a 1990 SMP project, Methane $DeNO_x$ was proven to be an economic $NO_x$ reduction technology for stoker boilers firing municipal solids waste in the U.S. and Japan. The technology, which can also be used for coal or wood, won an R&D 100 Award for innovation from R&D Magazine and an Environmental Prize from the Japan Environmental Agency.

Glass melting has been a focus of IGT research for many decades. In 1993, IGT introduced an advanced method of oxidant staging in high-temperature glass furnaces, called Oxygen-Enriched Air Staging (OEAS). The process was designed to reduce $NO_x$ emissions by 50%-75% to help meet air quality standards while lowering operating and capital costs. It was licensed to Combustion Tec Division of Eclipse, and several furnaces have been converted in North America.

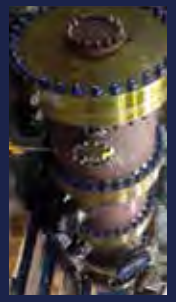
Fast forward to the new millennium, and a wide range of glass was successfully melted in the submerged combustion melting (SCM) unit in 2005. A follow-on project evaluated the means to provide rapid conditioning of glass. In 2008, the first commercial SCM plant began initial operation and the technology demonstrated the potential to consume less energy and lower emissions at 80% lower capital cost while meeting the same range of glass quality and production rates as traditional methods.

# HIGHLIGHTS


GTI led the Super Boiler project that integrated several novel technical concepts to achieve extraordinarily high efficiency and low emissions in a steam generation system. The design combined an ultra-low $NO_x$ burner with a Transport Membrane Condenser (TMC) that captured sensible and latent waste heat and water vapor from exhaust flue gases. In a field test at Specification Rubber Products in 2006, it delivered excellent results, with fuel to steam efficiency consistently in the 93-94% range, and $NO_x$ levels less than 9 ppm. In 2008, the TMC won a Chicago Innovation Award, and was commercialized in 2010 by Cannon Boiler Works as the Ultramizer®.

An innovative FlexCHP package allows flexible steam production while meeting stringent California $NO_x$ emission levels without a selective catalytic reduction (SCR) system. Laboratory tests have shown total system efficiency of 82%-85%, with variable steam production levels. The system reduces emissions significantly across the full range of firing rates, achieving $NO_x$ levels 50% below CARB limits. A 2014 installation in California operates with 82+% system efficiency and system emissions well below 9 ppm $NO_x$. Additional applications are pending, and efforts are underway to transfer technology to a commercializing partner.

Under UTD sponsorship, GTI and Power Flame Inc. are developing an ultra-low-$NO_x$ (ULN) burner for firetube boiler applications to achieve $NO_x$ emissions below 5 ppm. A pre-commercial unit is being prepared for installation at an end-user site in California, with support from the California Energy Commission. GTI also received additional awards from the California Energy Commission in 2015 for projects related to development and demonstration of new industrial energy efficiency measures.



Researchers have completed a feasibility study of an oxy-fired pressurized fluidized bed combustion (Oxy-PFBC) process to generate electricity with near-zero emissions. The technology can economically capture greenhouse gases emitted by coal-fired power plants. Efforts are now focusing on component development and pilot-plant testing to validate the process and mature the technology. In a complementary project, GTI will design, fabricate, and test a supercritical $CO_2$ power cycle heat exchanger for the Oxy-PFBC pilot plant.

GTI and partners are developing a novel double-reflector hybrid solar converter with funding from the DOE Advanced Research Projects Agency-Energy (ARPA-E) and Southern California Gas Company to deliver on-demand heat and power. The ultra-high-efficiency system's double-mirror design is optimized to capture as much of the energy in sunlight as possible, generating both electricity and storable heat (for later use) within the same system. Testing is nearing completion, and the team is working to secure an interested industrial end user for its full-scale field demonstration.

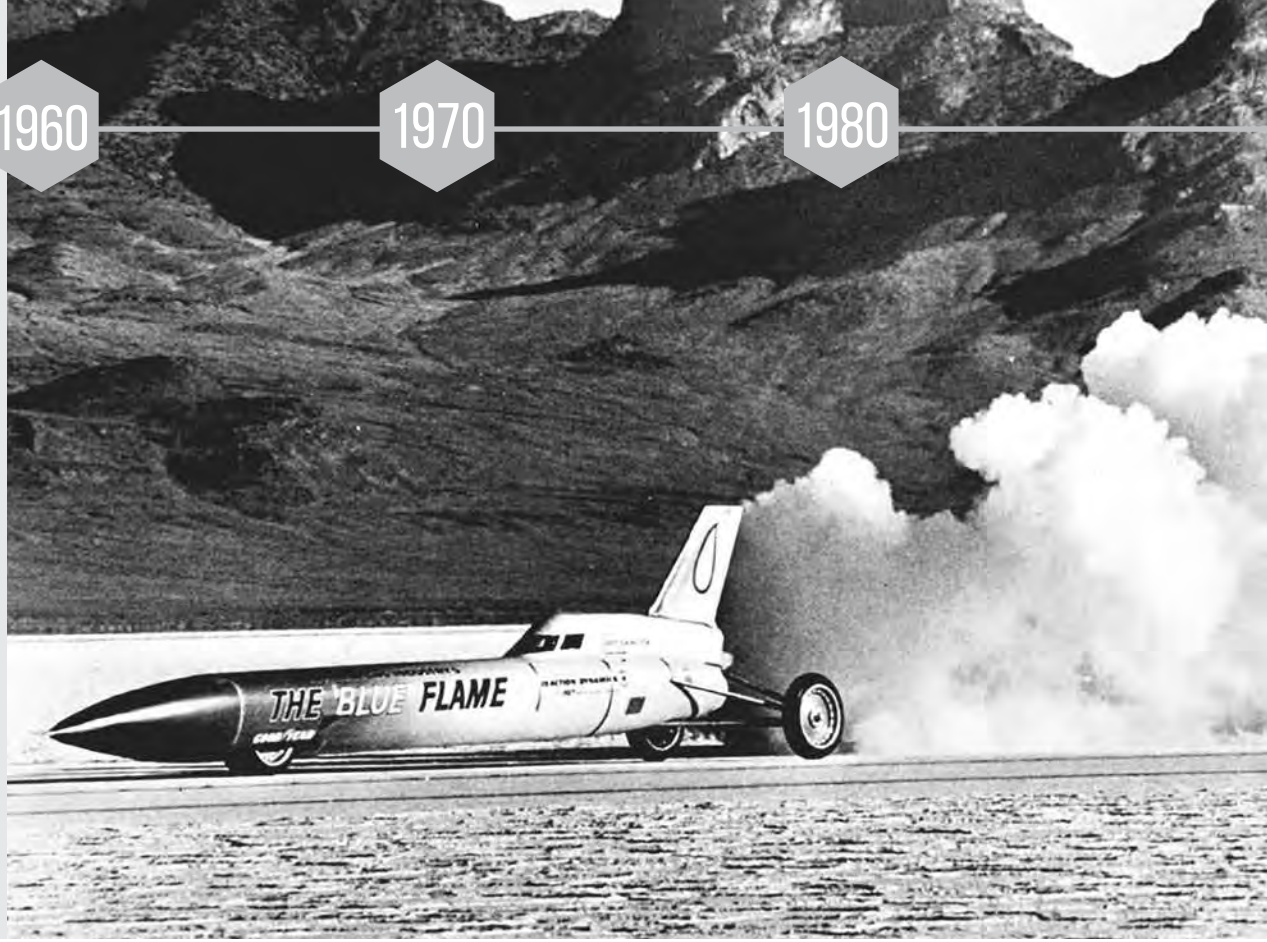
1940 1950 1960 1970 1980

# ALTERNATIVE TRANSPORTATION

In 1970, the LNG-fueled Blue Flame rocket-powered vehicle achieved the world land-speed record of 622.407 mph. IGT managed the design, construction, and formal racing of the car, fueled by methane and utilizing hydrogen peroxide as an oxidant.

This milestone was just the beginning of GTI's prolific work with alternative transportation fuels. For decades, GTI has been generating, advancing, and demonstrating technologies that drive greater adoption of natural gas vehicles (NGVs) and furthered the use of hydrogen ($H_2$) as a transportation fuel. We are delivering infrastructure, vehicle, engine, component, and system solutions for clean transportation.

This wide-ranging program has contributed to the growth in NGV use from about 25,000 vehicles in 1992 to more than 110,000 in 2002 and approaching 160,000 in 2016.




In the 1990s, R&D and commercialization efforts led to significant NGV market penetration. GRI supported development of a wealth of engines and vehicles capable of meeting stringent vehicle emission standards. Researchers also pioneered advances in cylinder safety, codes and standards, and new materials and or lighter-weight, on-board CNG storage cylinders.

GTI has served as the technical lead in numerous hydrogen fueling station projects. In 2006, GTI worked with the University of Texas at Austin to put the first hydrogen fuel cell bus on the road in the state and install the first permanent hydrogen fueling station. In 2012, GTI designed a state-of-the-art hydrogen fueling station for a hydrogen hybrid bus as a part of a year-long demonstration to test and further refine fuel-cell technology for public transit.

GTI assisted Cummins Westport, Inc. (CWI) in developing and demonstrating a number of medium and heavy-duty NGV engines. More than 27,000 8.9L Ultra-Low Emissions NGV engines for transit, refuse-collection, and regional hauling applications have been sold since introduction in 2007. The Cummins Westport 11.9-liter 400-HP NGV engine (ISX12G) has seen rapid market adoption since introduction in 2013 in the large truck, refuse, and bus market.

# HIGHLIGHTS



In 2010, GTI staff took the lead in a major alternative fuels deployment project funded by DOE, working with the City of Chicago and the Chicago Area Clean Cities Coalition, to add green vehicles to existing fleets in record numbers. Nineteen project partners joined the $40 million project that reduced $CO_2$ emissions by 18,000 tons, saved 7.5 million gallons of gasoline, and provided $8 million in fuel savings.

In 2007, GTI partnered with Waste Management Inc. and Linde to demonstrate a GTI-patented liquefaction technology to convert renewable biomethane from the Altamont Landfill in California to liquefied natural gas (LNG) to fuel a fleet of trash haulers. The system displaced 2.5 million gallons of diesel fuel and nearly 30,000 tons of GHG emissions statewide in a year. The EPA and the climate change industry recognized the project for its technology merit.

A new mobile fueling technology developed by GTI debuted at the 2012 Republican and Democratic National Conventions. The FuelMule™ is a portable fast-fill CNG fueling station that gives NGV fleets fueling capability at their home base—or anywhere—without the need to build a fueling station. GTI has worked with Ultimate CNG to bring the technology to fruition and it is being used daily to serve fleets across the country.


- The new CWI 6.7L 260-HP (ISB 6.7) low-emission, high-performance engine will commercially launch in 2016 for use by various medium-duty vehicles such as shuttle and school buses, and transit and vocational vehicles. GTI secured a grant from the California Energy Commission to sponsor pre-commercial demonstration and worked with CWI on the effort.

- A novel home/small fleet CNG fueling compressor has the potential to significantly change the light-duty passenger and light truck NGV market. Developed with $4.3 million in funding from ARPA-E, this technology uses a free-piston linear motor compressor with a single moving part to improve efficiency and minimize service requirements. With support from UTD, a prototype unit has been operated in the lab and is currently undergoing design enhancement and scale-up.

- In a first-of-its-kind demonstration at BMW's manufacturing plant in South Carolina, project partners DOE, BMW, Ameresco, GTI, and the South Carolina Research Authority powered some of the facility's fuel cell forklifts with hydrogen produced on-site from biomethane gas at a nearby landfill. There was no detectable difference in performance of forklifts fueled with hydrogen produced from garbage compared to those fueled with standard hydrogen.

- The new CSA Home NGV Fueling Standard introduced in 2015 (ANSI NGV 5.1) provides mechanical, physical, and electrical requirements for residential fueling appliances (RFAs) that connect to residential utility gas piping systems to dispense natural gas for NGVs. UTD supported GTI participation on the CSA Technical Committee to help shape and define the performance, safety, and installation standards for the next generation of NGV fueling appliances.

- GTI served as the lead technical consultant responsible for the first-ever CNG Transit program launched in the Chicagoland area. GTI assisted in fueling station and site design, equipment bid specifications, and installation oversight for Pace suburban bus (a division of the Regional Transportation Authority) in Markham, Illinois. Pace has received 20 of the 90 dedicated CNG buses that have been ordered and will begin revenue service in the summer of 2016.

1940 1950 1960 1970 1980

# TRAINING

A driving force behind the creation of IGT in the 1940s was the need for training graduate engineers for service in the gas industry. In the first decade, 35 students graduated from the academic program—33 with masters, and 2 with doctorate degrees. Later IGT began offering an undergraduate option for engineering students at IIT.

The program evolved to include training for people already working within the industry to refresh their knowledge and learn new skills. Students could (and still can) earn industry-recognized certification through unique programs concentrated on the technologies and topics most relevant to their own career path.

Throughout the decades, GTI has been responsible for establishing training centers and educating gas personnel across the world. We have trained more than 70,000 gas professionals in a broad array of energy topics in a variety of formats, meeting time and budget constraints with flexible options.

An industrial education program was added in the 1950s to provide supplementary training for gas industry employees. The first home study course on natural gas production and transmission was introduced to offer "continuing education".

GTI sponsored the first global liquefied natural gas (LNG) conference in Chicago in 1968 and continues as an owner of the triennial event.

A Chartered Industrial Gas Consultant (CIGC) certification course series was initiated in 1978. By 1992, nearly 400 gas marketers representing 128 companies in the U.S. and 12 other countries had completed course series and received certification.

In the 1980s and 1990s, IGT was involved in the administration of the Career Development Center in Abu Dhabi, established an Algerian gas institute, and conducted LNG courses in Venezuela, Germany, and Indonesia.

In the 1990s, IGT developed a long-term training plan for the Korean gas industry and hosted programs for Korean gas company personnel. The team also worked with LEMIGAS, Indonesia's Research Center for Oil and Gas Technology, to assist in the development of gas technology training.

The International Gas Research Conference (IGRC) was conceived by GRI, with IGU, AGA, and the U.S. DOE as co-sponsors. The first conference was held in June 1980 in Chicago, and we played a leading role in organizing the event until 2008. The next IGRC will take place in Rio de Janeiro, Brazil in 2017.

# HIGHLIGHTS

In the mid-2000s, GTI and Qatar Petroleum held the first international conference focused on Global LNG Interchangeability, drawing delegates from 15 countries.


GTI developed a four-week training program in English and Spanish for the operators of an LNG receiving terminal, and developed a 15-course e-learning LNG operator training program for another facility.

A new open enrollment course, Understanding LNG Terminals and Terminal Operations, draw unprecedented attendance in the U.S. and Spain in 2008.

Nearly 1,400 students around the globe were trained by GTI in 2012. GTI also partnered with the China Gas Association (CGA) to deliver training courses to an array of Chinese gas utilities, covering natural gas distribution topics.


GTI developed 77 course modules for a new Natural Gas Field Skills Training Program in 2013 to lead safe, effective performance by workers involved in natural gas construction, operations, and maintenance. A new tablet learning tool was also created to deliver customized procedures, standards, and work practices to workers in the field via a digital, mobile environment. National Grid is using these to promote consistent practices and train contractor crews on both fundamental processes and company-specific requirements.

GTI's Pipeline Integrity Management workshops were introduced in 2006. The next year, GTI launched a new modular program for field workers, Certified Operations Technician (COT). In 2009, GTI offered the first session of a new four-day training workshop on Distribution Integrity Management Program (DIMP) regulations.

tcbiomass, the inaugural global scientific forum with a focus on the science of thermo-chemical conversion of biomass, was organized and hosted by GTI in 2009. Successful biennial conferences followed, and tcbiomass2015 featured presentations and posters on the latest industry developments that enable production of clean heat and power, transportation fuels, chemicals, and other high-value products. 300 participants from 21 different countries came together to explore progress in the bioeconomy. The next session is slated for 2017.

- In conjunction with the Florida State College at Jacksonville Fire Academy of the South (FAS), GTI trained more than 150 first responders, firefighters, and area law enforcement in liquefied natural gas (LNG) awareness with content developed specifically for Port of Jacksonville area stakeholders. GTI also provided classroom training and webinars for employees of TOTE's Sea Star Line, which took delivery of the first LNG-powered container ship in 2015.


- A Memorandum of Understanding (MOU) was signed with ClassNK, based in Tokyo, to cooperate in developing education, training, and research for both maritime and the small-scale liquefied natural gas (LNG) industry. Creation of a full slate of LNG fueling training materials and course offerings is underway, and a bunkering simulator will also be constructed.

- Six U.S.-China training workshops covering shale development challenges and solutions brought together international representatives with U.S. companies and agencies to familiarize foreign delegates with the U.S. legal and regulatory framework, supply and service companies, emerging technologies, and business opportunities.

- GTI successfully planned, managed, and hosted several key events during 2015. $CH_4$ Connections 2015 explored critical methane emissions issues from a host of perspectives, presenting upcoming policy decisions and the newest detection and mitigation programs and techniques in the U.S.

- The Shale Exchange provided insight on the shale revolution and its challenges, solutions, and opportunities in the U.S., Argentina, Canada, China, Europe, Netherlands, Mexico, and South Africa. Field operations site visits gave attendees real-life experiences in gas processing, well services, drilling, and hydraulic fracturing treatment operations.

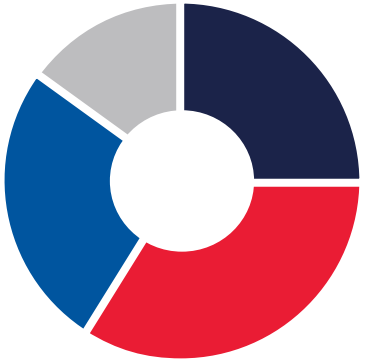
# 2015 FINANCIALS

## IN MILLIONS

| | |
|---|---|
| Project Revenue | $ 61.5 |
| Royalty/Other Revenue | $ 15.6 |
| Total Revenue | $ 77.1 |
| Total Assets | $ 111.9 |
| Total Liabilities | $ 38.3 |
| Net Assets–Unrestricted | $ 73.6 |

**$75.7** million in new business contracts

## CUSTOMER BASE



UTILITIES 25%
FEDERAL 34%
INDUSTRY 26%
STATE/LOCAL 15%

**$33.6** million in contracts under negotiation

**350** energy professionals

## SUSTAINABILITY

GTI launched a Corporate Environmental Sustainability Program with an aim to reduce our footprint as we grow our business. The initial focus was on improving GTI's recycling program, and an awareness campaign was initiated. To keep them out of landfills, large printers and other electronics from GTI's closed Print Shop were turned over to a vendor for reuse and de-manufacturing.


## SERVICE

GTI hosted a Veterans Day Recognition and Service Project that acknowledged the hard work and sacrifice of GTI's very own veterans and assembled toiletry kits with basic supplies to be donated to needy veterans. Other ways we make a difference in our local community are participating in the annual U.S. Marine Corps "Toys for Tots" campaign, United Way annual payroll deduction campaign, and J.P. Morgan Corporate Challenge and hosting a food drive for the local self-help pantry.

**GTI solves important energy challenges, turning raw technology into practical solutions that create exceptional value for our customers in the global marketplace.**

## VALUES

- **Safety.** Nothing is more important than the safety of our employees and our customers
- **People.** We provide opportunities and a stimulating environment for creative employees to learn, grow and make a difference
- **Market Focus.** We must bring solutions to customers that enable their continued success
- **Quality.** We have an obligation to our customers to deliver the very best product GTI can provide
- **Teamwork.** GTI's ultimate success depends on our ability to work together in a manner that delights our customers
- **Integrity.** We obey the law and conduct business in a straightforward, transparent manner

## GTI BOARD OF DIRECTORS

- **Carlos A. Cabrera**, Executive Chairman, Genomatica, Inc.
- **David C. Carroll**, President and CEO, GTI (Ex Officio Director)
- **Arthur C. Corbin**, President and CEO, Municipal Gas Authority of Georgia
- **Marc J. Florette**, Digital Executive Advisor, ENGIE
- **John D. Hofmeister**, Chief Executive, Citizens for Affordable Energy
- **Ronald W. Jibson**, Chairman, President and CEO, Questar Corporation
- **Alexander A. Karsner**, Executive Chairman, Manifest Energy, Inc.
- **J. Bret Lane**, Chief Operating Officer, Southern California Gas Company
- **Terry D. McCallister**, Chairman and CEO, WGL Holdings, Inc. and Washington Gas (Chair)
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- **Rebecca Ranich**, Director, Deloitte Consulting LLP (Retired) (Vice Chair)
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- **John W. Somerhalder II**, Chairman, President and CEO, AGL Resources (Retired)
- **Lori S. Traweek**, Chief Operating Officer, American Gas Association

*Former Board Member, 2009-2015*

- *Thomas E. Skains, Chairman, President and CEO, Piedmont Natural Gas*

**19** new patents

**0** lost-time or recordable accidents

## GTI EXECUTIVE TEAM

- **David C. Carroll**, President and CEO
- **Vann Bush**, Managing Director, Supply and Conversion
- **James F. Ingold**, Vice President of Finance, Treasurer, and CFO
- **Edward B. Johnston**, Vice President, Research Operations
- **Richard M. Kaelin**, Executive Director, Washington Operations
- **William E. Liss**, Managing Director, Delivery and Utilization
- **Jeremy M. Otahal**, Director, Human Resources
- **Rodney C. Rinholm**, Executive Director, Business Development and Education
- **Ronald N. Snedic**, Vice President, Corporate Development
- **Peter N. Witty**, General Counsel and Secretary

*For a complete list of business leaders, visit the GTI website.*


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