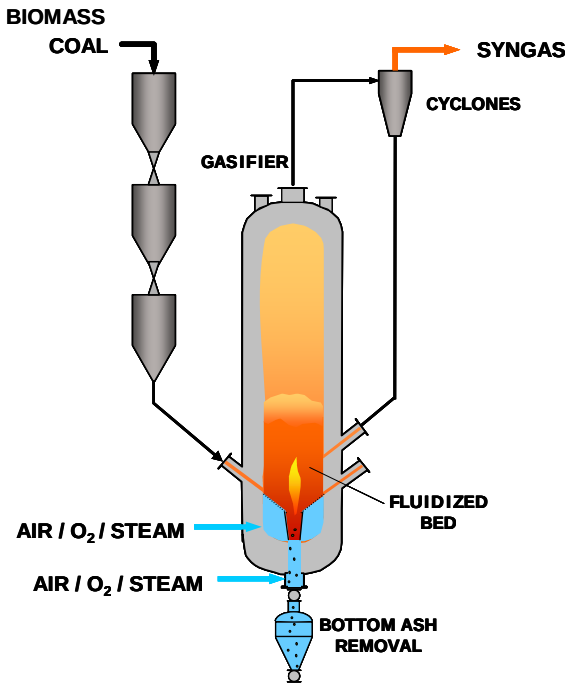
The GTI Gasification Process

The on-going escalation in oil and gas prices, coupled with increasingly stringent environmental regulations, open new opportunities for environmentally advantaged gasification technologies. The GTI gasification process is based on a single-stage fluidized bed for production of low-to-medium heating value synthesis gas or 'syngas' from a variety of feedstocks. Two versions of the process were developed more or less in parallel, with the U-GAS® technology developed for gasification of all ranks of coal and the RENUGAS® technology for gasification of highly reactive fuels such as peat, biomass, pulp mill residues and wastes. Through this development process it was determined that a single gasifier design could be used for all of these fuels, including mixtures such as biomass and coal.

GTI's gasification process is an excellent technology for many industrial market applications requiring fuel gas or synthesis gas to produce or co-produce process heat, hydrogen, chemicals and/or electric power. The inherent fuel flexibility of fluidized bed gasifiers permits the use of lower cost opportunity fuels including all ranks of coal, petroleum coke, biomass and industrial wastes, either alone or in combination. The GTI gasification technology has been developed and tested with over 25 different feedstocks from around the world including various forms of biomass, wastes, metallurgical cokes and all ranks of coal from lignite through bituminous. The GTI gasification process can provide a means for industry to cost effectively cope with rising fuel costs and environmental restrictions while improving overall plant performance.



In the GTI gasification process, fuel is dried to the extent required for handling purposes and conveyed into the gasifier from a lockhopper system. Within the fluidized bed, the fuel reacts with steam and air or oxygen at a temperature of 840 °C to 1100 °C (1550 °F to 2000 °F). The temperature for gasification depends on the type of fuel used and is

controlled to maintain high carbon conversion and non-slagging conditions for the ash. The GTI process accomplishes four important functions in a single-stage fluidized bed gasifier. It decakes, devolatilizes, and gasifies fuel, and if necessary, agglomerates and separates ash from the reacting char. The operating pressure of the gasifier depends on the end use for the syngas and may vary from 3 to 30 bar (40 to 435 psia) or more. After cleaning, the product gas can be used as industrial fuel gas for process heating, synthesis gas for production of ammonia, hydrogen or liquids, and for power generation via IGCC or fuel cells.

Fuel is gasified rapidly within the fluidized bed and produces a gaseous mixture of hydrogen, carbon monoxide, carbon dioxide, water vapor and methane, in addition to hydrogen sulfide and other trace impurities. If the operating temperature required to achieve acceptable carbon conversion exceeds the fuel ash softening temperature, the ash concentration of the fluidized bed is allowed to increase until a condition is reached that allows the ash particles to agglomerate into larger particles. The agglomerated particles are denser than the surrounding bed material and can thus be selectively removed from the bed.

Reactant gases, including steam, air and/or oxygen are introduced into the gasifier in two areas: 1) through a sloping distribution grid at the bottom of the bed, and 2) through a terminal velocity-controlled ash discharge port at the center of the distribution grid. In both agglomerating and non-agglomerating operating modes, ash is removed by gravity from the fluidized bed and discharged into a lockhopper system for depressurization and disposal. In both operating modes, the gasifier maintains a low level of carbon in the bottom ash discharge stream, making overall carbon conversion of 95% or higher possible. Cold gas efficiencies of over 80% can be achieved.

Fines elutriated from the fluidized bed are typically separated from the product syngas by up to three stages of external cyclone separators, one or two of which may return the fines to the fluidized bed for increased carbon conversion. The product syngas is essentially free of tars and oils due to the temperature and residence time of the gases in the fluidized bed, simplifying downstream heat recovery and gas cleaning operations.

When used to gasify biomass or highly reactive wastes, an inert material such as sand, limestone or dolomite is used to maintain the fluidized bed. In this case, most of the ash from the fuel leaves the fluidized bed with the product syngas, with the bottom ash discharge serving primarily to discharge tramp material entering with the biomass or waste feed.

Due to its dry feeding system (as opposed to slurry or paste feeding), non-slagging operation and increased gas and solids residence times compared to entrained bed gasification technology, the GTI gasification process is capable of handling a wide range of fuels with a broad range of fuel properties (Tables 1 and 2).

TABLE 1. Feedstocks Processed in the GTI Gasification Process

Bituminous Coals

- Western Kentucky No. 9 , Providence (washed and run-of-mine)
- Western Kentucky No. 9 and 11, Camp
- Illinois No. 6, Peabody No. 10 and Crown III
- Pittsburgh No. 8, Champion and Ireland
- Australian, Bayswater No. 2, Sydney Basin
- Polish, Silesia
- French, Merlebach (run-of-mine)
- Utah (run-of-mine)
- Colombian
- Chinese, Shen Fu
- Indian, North Karanpura Coal Field (washed and run-of-mine)

Low Rank Coals

- Montana Rosebud, Colstrip
- Wyoming, Big Horn
- North Dakota, Freedom
- Saskatchewan Lignite, Shand

Coke, Char, Peat, Wastes

- Metallurgical coke, U.S. 'Bethlehem', Polish, and Chinese
- Western Kentucky No. 9 coal char
- Illinois No. 6 coal char
- Finnish Peat, Viidansuo and Savaloneva
- Automobile Shredder Residue

Biomass

- Finnish waste wood and paper mill waste
- Danish willow
- Danish straw
- Pelletized alfalfa stems
- Pelletized U.S. waste wood
- Bagasse

GTI Gasification Process Development History

Early development testing was conducted at near atmospheric pressure with low-volatile coal chars and metallurgical coke in a 24 ton/day pilot plant built in 1974. With support from the U.S. natural gas industry together with the U.S. Department of Energy (DOE) and its predecessor agencies, the process development was extended to encompass pressurized operation at 60 psia with caking bituminous coals from 1977 through 1980. During this time, over 125 air, enriched-air, and oxygen-blown test campaigns were conducted in the GTI Pilot Plant, with more than 3,000 tons of a wide variety of coals

processed in over 11,000 hours of operation. In 1983, a 5 ton/day, 300 psia process development unit (PDU) was designed and built, with modifications in 1985 bringing the operating pressure up to 510 psia. A total of 39 air, enriched-air and oxygen blown test campaigns were conducted in the PDU at pressures ranging from 115 to 465 psia. Over 80 tons of bituminous, subbituminous and lignite coals were processed in 2000 hours of pressurized operations, including in-situ desulfurization testing with limestone injection to the fluidized bed.

TABLE 2. Fuel Flexibility - Range of Feedstock Properties

Feedstock Property	Tested Range
• Moisture Content, %	1 - 41
• Volatile Matter, %	3 - 69
• Fixed Carbon, %	6 - 83
• Sulfur, %	0.2 - 4.6
• Free Swelling Index (FSI)	0 - 8
• Ash Content, %	0 - 41
• Ash Softening Temp, T_1, °C / °F	1045 – 1370 / 1915 – 2700+
• Heating Value, HHV, kJ/kg / Btu/lb	12770 – 31600 / 5490– 13590

In 1989 the GTI gasification technology was licensed to Tampella Power Inc., who built a multi-fuel pressurized pilot plant in Tampere, Finland to further develop and demonstrate the technology for air-blown IGCC power generation with coal and biomass. This fully integrated plant includes all gasification island components from fuel preparation through waste heat recovery and hot gas clean-up. The facility processes up to 42 tons/day of coal and 60 tons/day of biomass at pressures up to 435 psia. The plant has logged 3,800 hours of operation with 5,900 tons of fuel processed in 26 test runs. The tested fuels include coal (Polish, Colombian, coke, German lignite) and biomass (wood, paper mill wood waste, forest residue, willow, straw, alfalfa) and mixtures of coal and biomass. Gas generated in the plant is combusted in a heat recovery boiler producing district heat for the city of Tampere.

In the early 1990's, GTI developed a commercial-scale gasification project in China based on the U-GAS technology, a coal-fueled variant of the GTI gasification process. Located in a coal-based chemicals production complex in the Wujin Chemical Industry Area southwest of Shanghai, the plant includes eight parallel, low pressure, air-blown gasification trains producing fuel gas from Chinese Shen Fu bituminous coal. The fuel gas was used to fire an existing battery of coke ovens, freeing up the higher heating value coke oven gas for blending into town gas. Each train of gasifiers processes about 150 tons per day of coal and produces 500,000 Nm^3/day of fuel gas. Commercial operation started in 1995 and by 2001, the plant had logged over 77,000 hours of gasifier operation, processed over 220,000 metric tons of coal, and produced over 1 billion Nm^3 of fuel gas for commercial use. This plant is currently mothballed due to a lack of demand for the town gas.

More recently, with the support of the natural gas industry and the State of Illinois, GTI has constructed a unique test platform to address the need for more thorough evaluation of gasification and related technologies as well as other processes for the thermal and chemical conversion of feedstocks to fuel.

With initial test operations begun in early 2004, GTI's state-of-the-art, Henry R. Linden Flex-Fuel Test Facility (FFTF) evaluates innovative gasification technologies and facilitates the commercialization of advanced gasification and downstream end-use technologies.

The FFTF is located on GTI's research campus in Des Plaines, Illinois, and is currently configured with an 11-inch diameter fluidized bed gasifier in a versatile platform for testing all ranks of coal and other solid fuels, including biomass. The facility's flexible design allows testing of a variety of gasification, gas cleanup, and gas processing schemes independently or as integrated systems for both fuel gas and synthesis gas production.

To maximize the energy and environmental performance information gathered during test operations, innovative sampling and analytical systems have been designed and implemented in the facility, enabling unparalleled systems evaluations. Simultaneous on-line analyses of gas compositions from raw gas concentrations to ultra-clean levels allow for near real-time assessment of the performance of integrated gasification and gas conditioning systems. Comprehensive and accurate diagnostic capabilities make cost-effective testing of technologies and systems at the facility possible.

The FFTF is designed to operate at up to 400 psig and can be used in conjunction with:

- Coal: 10 tons per day (tpd) w/air, 20 tpd w/oxygen
- Biomass: 20 tpd w/air; 40 tpd w/oxygen
- Downstream syngas clean-up and separation systems
- Advanced Power Conversion Systems (fuel cells, small turbines, reciprocating engines)
- Coal conversion to liquids, hydrogen and SNG
- CO_2 capture technology

Recent Gasification Studies

GTI teamed with Nexant to evaluate gasification alternatives for industrial applications in a study funded by DOE. This study evaluated an array of design alternatives for employing the GTI technology at industrial scale for IGCC. It determined the costs associated with plant operations using both eastern bituminous coal and lignite and compared the use of air and oxygen. The study evaluated several sulfur removal technologies as alternatives to conventional amine + Claus systems. Two applications were evaluated, one incorporated GTI's fluidized-bed gasifier coupled with two General Electric (GE) combustion gas turbines and heat recovery steam generators (HRSGs) to co-produce power (25 MW) and high pressure steam at a specific industrial complex in upstate New York. This study was cofunded by a major industrial plant in the Northeast and their state energy agency. The second application evaluated the GTI gasifier at a larger (250 MW) lignite-fueled IGCC power plant located in North Dakota. The studies indicated positive return on investment (ROI) from 8 % to 19% for the various cases considered, with designs expected to meet emission targets established by DOE in the roadmap for 2010.

A series of five air-blown coal gasification tests were completed in the FFTF with high-ash (35-40%) coals from the North Karanpura Coal Fields in India. Over 15 tons of run-of-mine (ROM) coal and about 27 tons of washed coal were gasified at pressures between 100 and 300 psig. Based on the pilot-scale FFTF results, carbon conversion in excess of 95% is anticipated in a commercial-scale GTI gasifier with Indian coal.

GTI successfully completed a series of 250 psig, air-blown coal gasification tests in the FFTF with three different coals in support of a Siemens Power Generation program, co-

funded by the National Energy Technology Laboratory of the U.S. DOE, for the development of novel syngas cleaning systems. The results demonstrated the effectiveness of the Ultra-Clean Process (UCP) to economically achieve the most stringent cleanup for sulfur species, halide species, mercury, and particulate matter expected for chemical and fuel synthesis applications (total sulfur species < 60 ppbv, halides < 10 ppbv, mercury < 0.01 ppbv, and particulate < 0.1 ppmw) in advanced, near-zero emission, efficient multi-production energy plants. These tests also highlighted the ability of the GTI team to conduct multi-fuel, rapid-turnaround testing of gasification-based technologies in the FFTF in a cost-effective manner.

Gasification tests with biomass were completed in the FFTF using the pilot-scale GTI gasifier. Eighteen tons of pelletized wood fuel was gasified in three operating periods of air-blown gasification. Two different inert bed materials, olivine and alumina beads, were tested to compare their effect on tar and oil concentrations in the syngas produced. An advanced syngas sampling system based on dilution cooling to preserve the compositional integrity of the samples entering a suite of on-line analytical instruments was also successfully commissioned and demonstrated.

The FFTF has also been used in pilot-scale testing of a proprietary process for methane production via catalytic gasification. The project included laboratory and bench-scale testing of various catalyzed feedstocks, modification of the pilot-scale gasifier and associated equipment to meet the new process requirements, and performance of a series of pilot-scale tests with several selected catalyzed feedstocks.

Oxygen-blown gasification tests were carried out in the FFTF in the first half of 2008 to support fuels and process technology assessments for both coal and biomass applications of fluidized bed gasification. These tests focused on producing syngas suitable for conversion to liquid fuels and chemicals products.

Commercial Deployment Projects

Synthesis Energy Systems, Inc. (SES) has worldwide exclusive rights for coal applications of GTI's gasification technology (coal is defined in the license terms and includes coke), and for coal and biomass blends with biomass less than 40% of the fuel supply. SES has non-exclusive license for biomass applications including blends in which biomass is greater than 40% of the fuel supply. Carbona Corporation has developed a biomass gasification offering based on the GTI fluidized bed technology which they had licensed on a non-exclusive basis, and have an agreement with GTI for joint development of this gasifier for biomass-to-liquids applications.

SES currently has three active projects, all in China, that are at different stages of development:

- **Hai Hua.** On October 22, 2006, Synthesis Energy Systems Inc. signed a co-operative joint venture contract with Shandong Hai Hua Coal & Chemical Company Ltd. ("Hai Hua") for the development, construction and operation of an approximately $25 million syngas production plant utilizing U-GAS® technology in Zaozhuang City, Shandong Province in China, as well as a contract for the purchase and sale of syngas and other gasification byproducts (ash, elemental sulfur, hydrogen and argon). The plant is designed to produce approximately 28,000 standard cubic meters per hour of gross syngas. Construction of the plant was completed in the third quarter of 2007 and the plant is now in operation.

- **Golden Concord.** On May 25, 2007, SES executed a co-operative joint venture contract with Inner Mongolia Golden Concord (Xilinhot) Energy Investment Co., Ltd. ("Golden Concord"), a subsidiary of one of China's largest independent private power producers to develop, construct, operate, and manage an approximately $96 million coal gasification, methanol and DME production plant utilizing the U-GAS® technology to process low quality, high ash lignite coals made available from Golden Concord's coal mine in Xilinguole, Inner Mongolia and other mines in the area. The facility is expected to produce syngas which will be used as a feedstock for a 225,000 tonne per year methanol plant and, in turn, a 150,000 tonne per year DME plant. Groundbreaking was in the second quarter of 2007 with operations scheduled to begin in the first quarter of 2010.

- **YIMA**. On April 27, 2007, SES entered into a non-binding preliminary co-operative agreement with YIMA Coal Industry Group Co., Ltd. ("YIMA"), a company partially owned by the Chinese government, for the construction of an approximately $250-$350 million integrated coal-to-methanol (ultimately into DME) plant in Henan Province, China. When completed, the plant is expected to have an hourly capacity of approximately 360,000 standard cubic meters of gross syngas and an annual capacity of 1 million tonnes of methanol or 660,000 tonnes of DME. The estimated total cost represents the estimated capital expenditures for both the gasification and methanol/DME portions of the plant.

Synthesis Energy Systems, Inc. and CONSOL Energy Inc. the largest producer of bituminous coal in the United States, have entered into an agreement to perform engineering, environmental and marketing activities to analyze the feasibility of projects that would use GTI's gasification technology to convert coal and preparation plant tailings provided by CONSOL Energy's coal mining complexes located in the eastern United States into higher-value products which may include methanol, mixed alcohols, other liquid fuels, ammonia and SNG. The projects will initially be focused geographically within CONSOL Energy's Northern Appalachian mine sites in Pennsylvania, West Virginia, and Ohio. CONSOL Energy mining complexes produce an estimated 20 million tons per year of coal preparation plants tailings that include un-recovered coal that could be used to make valuable liquid and gas products rather than be land filled as waste.

Carbona Corporation licensed the GTI gasification technology for biomass applications and has a commercial project in Skive, Denmark providing 11.5 MWth of district heating and 5.5 MW of electric power using wood pellets as the fuel. This combined heat and power project is completing the commissioning phase in early 2008.

Carbona has teamed with global forestry company UPM-Kymmene to co-operate on the development of the technology for biomass gasification and synthesis gas purification. GTI gasification technology as developed by Carbona will be used for the production of synthesis gas that will feed a Fischer-Tropsch based second generation biodiesel production facility. Testing will be carried out at the FFTF in 2008 in parallel with the design of a commercial plant.

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