IEA Bioenergy
Technology Collaboration Programme

Country Report USA 2020

Research special report

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Research special report

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Summary

This report is based on contributions from research associates of the listed research institutions and offers an overview on the research activities in biomass gasification in the United States of America. Only major research institutes and centers with pilot-scale facilities are included in this report; institutions such as Universities (or other similar) that have small-scale or single-purpose lab-scale capabilities are not included.

Research Centers and Institutes

THE NATIONAL RENEWABLE ENERGY LABORATORY (NREL)

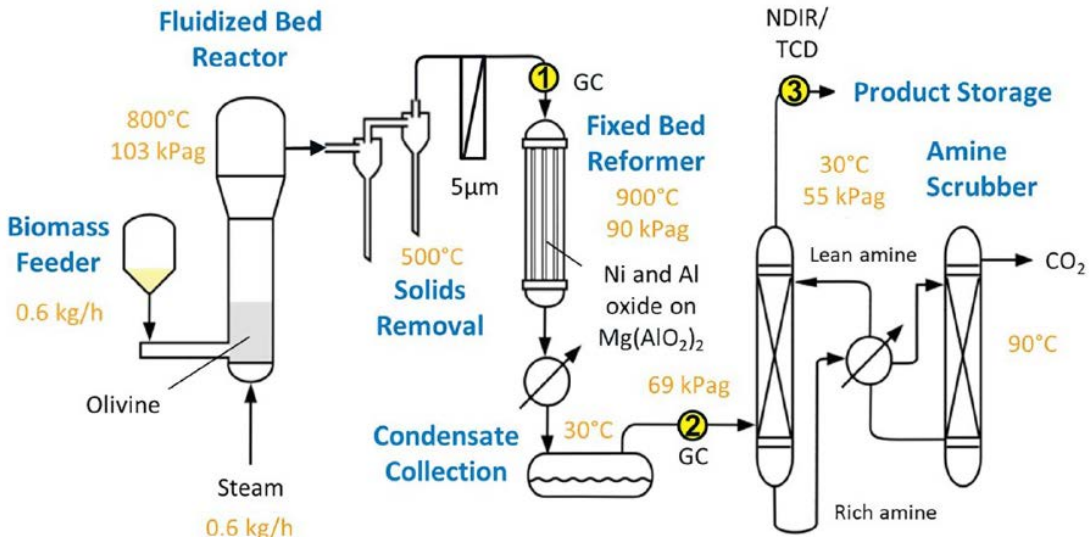
The National Renewable Energy Laboratory (NREL) was established in 1977 and is located in Golden, Colorado. NREL specializes in the research and development of renewable energy and energy efficient technologies. Research within NREL's Catalytic Carbon Transformation Center focuses on the conversion of biomass or waste carbon sources to transportation fuels and co-products and utilizes a variety of capabilities across laboratory-, bench-, and pilot-scales. The focus of this research is to explore and develop new technologies, understand process fundamentals, and de-risk integrated processes to support commercial adoption and market impact. Research covers a wide range of topics and specialties from fundamental chemistry and biology, materials characterization, catalyst design, analysis, computational modeling, and integrated process evaluation.

Testing facilities include NREL's Research Gasifier (NRG), and the Thermal and Catalytic Process Develop Unit (TCPDU) - a 0.5 ton/day piloting facility.

NRG

Producing syngas from biomass sources results in a variety of challenges that cascade throughout the process from syngas makeup, associated cleanup steps (e.g., tar removal), and syngas catalytic conversion to fuels and chemicals. The NRG is a lab-scale gasification system designed to study the conversion of biomass and waste carbon sources to purified syngas and final products. It includes the capabilities to evaluate a variety of biomass feedstocks (e.g., woody, grasses, and residues), control syngas quality through the use of industrially scalable cleanup methods, evaluate reformer and scrubbing technologies and materials, and high-pressure storage to enable subsequent conversion to fuels and chemicals either onsite or shipped to our research partners.

The NRG system consists of a dual-screw K-Tron hopper metered to provide ~0.5 kg h^{-1} biomass into a 10 cm (ID) fluidized bed reactor utilizing an olivine bed material. Gasification occurs at 800 C and 103 kPa under steam conditions. Gas cleanup includes multiple cyclones and hot gas filtration at 500 C to remove solids followed by a fixed bed reformer held at 900 C and 90 kPa. Utilization of a nickel catalyst in this reformer enables increased syngas yields while removing hydrocarbons. Final gas cleanup includes an acid-gas scrubber to remove CO_2 and H_2S. One of the unique advantages of this system lies in the associated analytical capabilities. The syngas composition can be measured at a variety of points along the system and analysis includes GC, IR, and mass spectral techniques.



Thermal and Catalytic Process Development Unit (TCPDU)
The TCPDU is a 0.5 ton/day facility designed to de-risk thermocatalytic processes based on pyrolysis and gasification technologies. In the gasification configuration, the TCPDU is composed of a 20 cm fluidized bed reactor for initial volatilization of biomass at 800 C, a thermal cracker to complete gasification at elevated temperatures, and back-end solids removal and gas cleanup options to produce a final syngas product. Solids removal systems include a dual cyclone arrangement with optional hot gas filtration. Multiple catalytic reforming reactors are available to support project needs. These reactors can be used independently, in parallel, or in series and include fluid beds, packed, bed, and recirculating regenerating reactors. Online analytical capabilities are available at multiple access points to monitor syngas quality and composition throughout the process. Analytical tools include molecular beam mass spectrometry, gas chromatography, thermal conductivity detection, and nondispersive infrared. The facility is designed to modular and allows for partners to evaluate their materials within our reactor systems, or to bring in their own reactor skids to evaluate unique unit operations.

Detailed characteristics of the TCPDU in gasification mode system are shown in Table 1. Additional information can be found at: https://www.nrel.gov/bioenergy/tcpdu.html

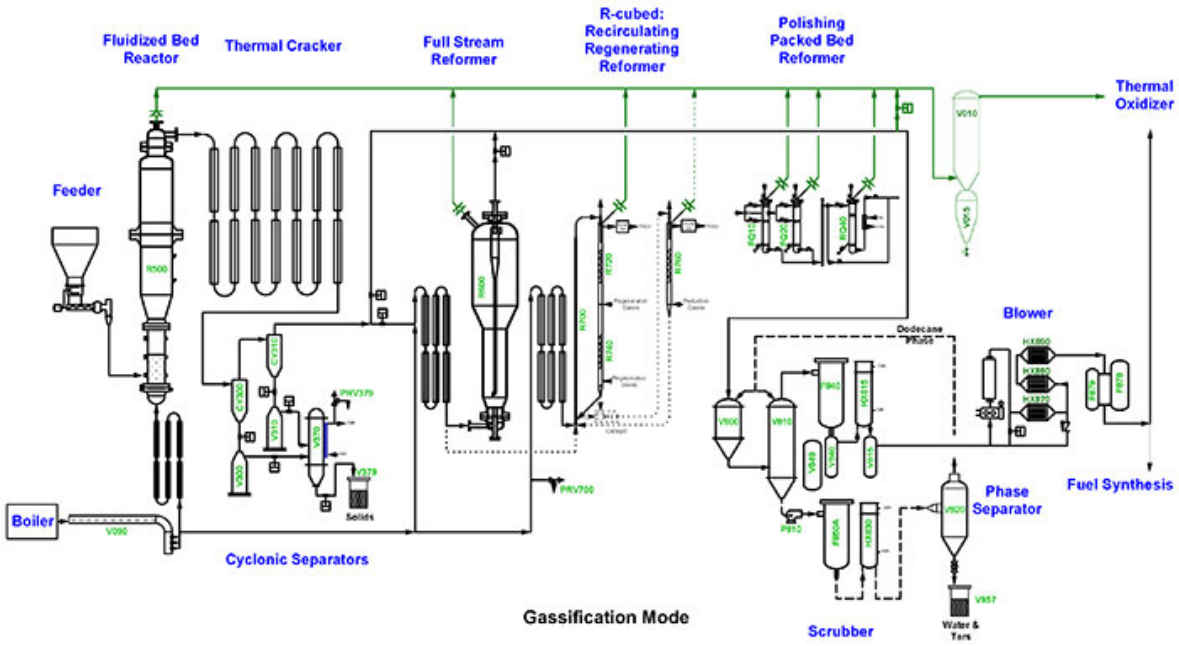


Table 1. TCPDU in gasification mode

Unit Operation	Scale (diameter, throughput, volume, etc. as appropriate)	Operating Conditions (Temp, pH, etc. approximate or range is acceptable)	Max Continuous Run time (hrs)	Acceptable Feedstocks and specifications (e.g. pine pellets, lignin cake at <30% moisture)	Throughput per day (feedstock or product)
Feed System (loss-in-weight feeder, rotary valves, feed transfer screw)	10 to 20 kg/h biomass	Atmospheric temperature and pressure	Unlimited	Pellets < 10% moisture: woody and herbaceous feedstocks acceptable	Up to 0.5 Metric Tonne per day (MTD) feedstock
Gas Feed System	15 to 30 kg/h super-heated steam and/or nitrogen	650 °C ~600 kPa	Unlimited	Steam and/or Nitrogen gas	0.5 MTD feedstock

Unit Operation	Scale (diameter, throughput, volume, etc. as appropriate)	Operating Conditions (Temp, pH, etc. approximate or range is acceptable)	Max Continuous Run time (hrs)	Acceptable Feedstocks and specifications (e.g. pine pellets, lignin cake at <30% moisture)	Throughput per day (feedstock or product)
Two-stage Reactor (Fluidized Bed Reactor FBR, coupled to Entrained-Flow Reactor EFR)	FBR: 8-inch diameter bed EFR: 1-1/2-inch diameter, 29 m length	FBR: 650 C at 5-15 sec residence time EFR: up to 900 C at 2-4 sec residence time	~72 hours	Crushed pellets entrained in steam/nitrogen; Olivine or other fluidizable bed material	0.5 MTD feedstock
Dual-cyclone char & ash removal system	Full-stream, 1-1/2 inch inlet/outlet; 4-inch diameter barrel	400 to 500 °C	~72 hours	Steam, syngas, nitrogen, char and ash, tars	0.5 MTD feedstock
Fluidized Bed Reformer (Optional)	Full-stream, 14-inch diameter bed	500 to 900 °C, Residence time 5-15 sec	~72 hours	Steam, syngas, nitrogen, tars] Fluidizable catalyst bed material	0.5 MTD feedstock
Polishing Packed Bed Reformer (Optional)	Full-stream, 3 packed-bed vessels, 6-inch diameter	500 to 900 °C, Residence time 0.5 – 1.5 sec	~72 hours	Steam, syngas, nitrogen, tars; packed bed catalyst	0.5 MTD feedstock
Circulating Riser Reactor System	Partial-stream* 4-inch diameter riser with 6-inch diameter regeneration vessels	500 to 900 °C, Residence time 1 – 2 sec Catalyst:Biomass ratio range 8:1 or higher	~72 hours	Steam, syngas, nitrogen, tars; Geldart Group A or B catalysts; Steam and/or air regeneration; Steam and/or nitrogen stripping	Up to ½ full stream. With minor modifications, system can be operated at full stream capacity.

Unit Operation	Scale (diameter, throughput, volume, etc. as appropriate)	Operating Conditions (Temp, pH, etc. approximate or range is acceptable)	Max Continuous Run time (hrs)	Acceptable Feedstocks and specifications (e.g. pine pellets, lignin cake at <30% moisture)	Throughput per day (feedstock or product)
Scrubber System: steam condensation and collection	Full-stream, 1-1/2 inch piping	40 to 50 °C	~72 hours	Steam, syngas, nitrogen, tars	0.5 MTD feedstock
Online Analytical (GC, NDIR, TCD)	Sample stream,1 L/min gas	Atmospheric temperature and pressure	Unlimited, but taken offline to calibrate daily	Light and permanent gases, sulfur species	N/A
Online MBMS	Sample stream,1 to 3 L/min hot gas	350 to 400 °C	~72 hours	Gasification vapors including tars	N/A

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IOWA STATE UNIVERSITY

Iowa State University (ISU) has two biomass conversion pathways being demonstrated at throughputs greater or equal to 0.5 tons of dry biomass per day (TPD). A 0.7 TPD fluidized bed fast pyrolysis unit and a 0.5 TPD fluidized bed air blown gasifier are located at ISU's BioCentury Research Farm (BCRF). Both conversion pathways utilize an on-site separate biomass preparation facility to size reduce and dry biomass as needed for the conversion.

Unit Operations

Biomass Processing

Biomass size reduction and drying for both the fast pyrolysis and gasification units occur in the Biomass Preparation Facility at the BCRF. This biomass preparation system includes a bale chopper and rough grinder capable of processing large round or square bales of herbaceous biomass such as corn stover, bean stover or switchgrass. These rough size reduction unit operations are integrated to a continuous feed, natural gas-fired belt

dryer. The belt dryer is integrated with a hammer mill, where biomass is typically milled to 1/8"-minus particles. The finished feedstock is transferred to storage containers or super-sacks and transferred to the fast pyrolysis and gasification units for processing. The biomass preparation system is not currently integrated with the fast pyrolysis or gasification units. Table 1 summarizes the biomass processing system characteristics. Qualified staff are available to operate this system.

Gasification

The gasification unit at ISU is a bubbling fluidized bed capable of processing 0.5 dry tons of woody or herbaceous biomass per day (Figure 1). Reactor operating conditions are typically between 700-850° C and 0-20 psig. Air or steam and oxygen can be used as fluidization agents. Total gas flow rate through the system is approximately 610 standard liters per minute (SLPM). A pair of custom cyclone filters remove particulate from the gas stream, which is then passed through a novel gas cleaning system. A tar scrubber removes heavy tar, a sulfur scrubber removes sulfur-containing species, and water scrubber removes nitrogen-containing species, resulting in production of cleaned syngas. A slipstream can be pulled after the tar scrubber and passed through a light tar scrubber at a flow rate of 12 SLPM. Table 2 summarizes the gasification system characteristics. Qualified staff are available to operate this system.

Table 1. Biomass Preparation Unit Operation Summary

Unit Operation	Max Continuous Run Time	Feedstock Specifications	Throughput per day
Bale Processor/ Rough Grind	12 hrs	Large round or square bales of corn stover, bean stover, grasses	2.5 dry tons
Belt dryer	12 hrs	Rough or fine ground material with moisture content <60%	2.5 dry tons
Hammer mill	12 hrs	Rough ground material with moisture content <15%	2.5 dry tons

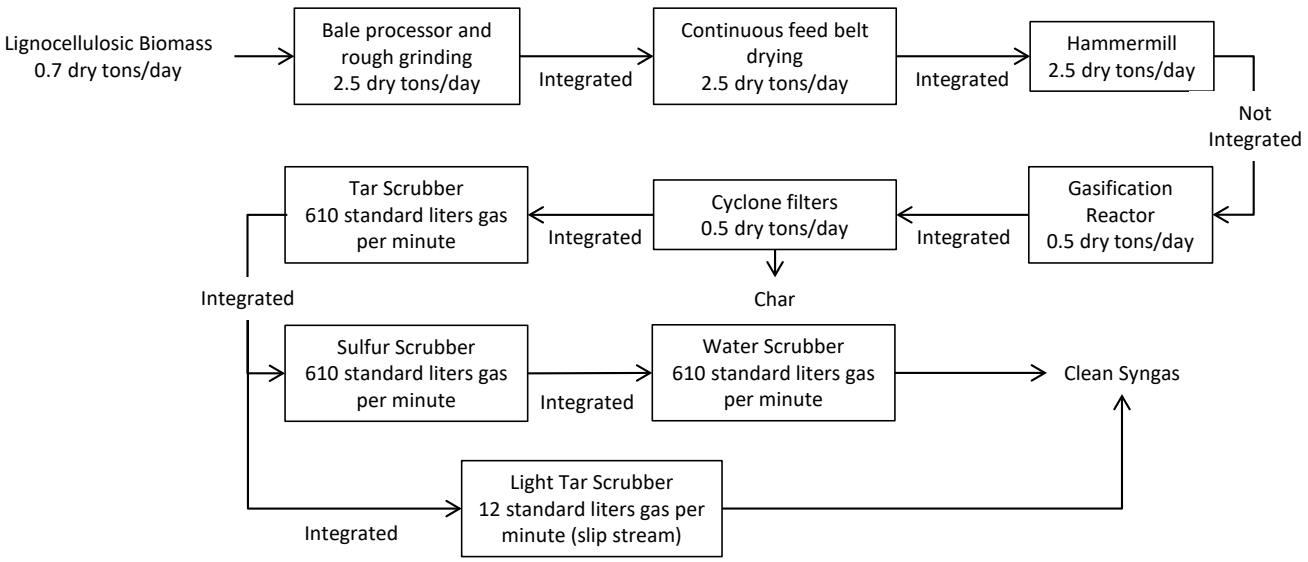

Figure 1. Iowa State University Gasification Block Flow Diagram

Table 2. Gasification Unit Operation Summary

Unit Operation	Operating Conditions	Max Continuous Run Time	Feedstock Specifications	Throughput per day
Biomass feed system	Ambient Temperature, 0-20 psig	16 hrs	1/8”-minus herbaceous or woody feedstock at <15 wt% moisture	0.5 dry tons
Gasification reactor	700-850° C, 0-20 psig	16 hrs	1/8”-minus herbaceous or woody feedstock at <15 wt% moisture	0.5 dry tons
Cyclone filters	700-850° C, 0-20 psig	16 hrs	Syngas and char	0.5 dry tons
Tar Scrubber	90-200° C, 0-20 psig	16 hrs	Syngas	0.5 dry tons
Sulfur Scrubber	425° C, 0-20 psig	16 hrs	Syngas	0.5 dry tons
Oil Scrubber	65-425° C, 0-20 psig	16 hrs	Syngas	0.5 dry tons
Light Tar Scrubber	80-105° C, 0-20 psig	16 hrs	Syngas	12 SLPM slip stream

Integration

As described in sections 1 and 2, individual unit operations within the biomass preparation, pyrolysis and gasification units are fully integrated. However, the biomass preparation system is not integrated with the conversion technologies. Woody biomass is received at the BCRF in chip form from multiple sources. Herbaceous biomass such as corn stover, bean stover and switchgrass is received in large round or square bales. Moisture content of the feedstock can vary widely, ranging from 15-60%. New unit operations have been frequently integrated into these conversion technologies and can be implemented rapidly by experienced full-time engineering staff. The BCRF has space, facilities, and utilities available to integrate additional unit operations.

A state-of-the-art thermochemical products analysis laboratory is located in the Biorenewables Research Laboratory on the ISU campus. This facility houses a wide array of analytical instruments to perform qualitative and quantitative analysis of biomass, bio-oil, syngas and char. This includes three integrated GC-MS-FID-TCD systems, a Time of Flight (TOF) MS, three GC-FID systems, two GC-MS systems, three HPLC units, a multi-angle light scattering (MALS) detector, two TGA units, an Ion Chromatography detector, an Inductively Coupled Plasma detector, a viscometer, a Karl Fischer moisture analyzer, a bomb calorimeter, and an elemental analyzer for C,H,N,S, and O quantification. These laboratories are operated and managed by the Bioeconomy Institute (BEI) at ISU under the direction of Dr. Robert Brown. Four full-time scientific staff members oversee training and operation of the laboratory. Additional shared instrumentation facilities on the ISU campus also include NMR, XRD, and SEM capabilities. These facilities are also managed and operated by full-time scientific staff.

Data for the gasification operations are stored using Rockwell and Delta V control and data acquisition software, which is exported to MS Excel files. Additional mass balance and yield data are added to these files, which are stored on shared access drives. Operation of the gasification and biomass preparation systems require a minimum of two experienced operators at all times.

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GAS TECHNOLOGY INSTITUTE (GTI)

GTI is an independent, non-profit research, development and training organization addressing global energy and environmental challenges to enable a secure, abundant, and clean energy future. For 75 years, GTI has been developing technology-based solutions for industry, government, and consumers at every phase of the technology development cycle, from concept to commercialization.

GTI has a unique set of pilot-scale syngas production facilities with wideranging capabilities. These facilities can satisfy the testing requirement of TRL 5 and beyond. It can host pre-combustion technology validation in a relevant environment using syngas derived from the thermochemical gasification of a wide range and combinations of coals, petcoke, biomass, and natural gas feedstocks. GTI's seasoned operating and analytical staff provide for safe operation 24/7 during your testing campaigns.

GTI operates a fluidized-bed and an entrained-flow gasifier, air- or oxygen-blown. We can provide up to 3,000 lb/hr of syngas that can be compressed to 65 bar. Our online sampling systems for permanent gases, C1–C6 hydrocarbons and sulfur gases with 2-minute cycle time, and various offline sample analysis allow typical mass balances within 10%. Data integrity and information distribution is tightly controlled to provide separation of intellectual property between clients as well as within GTI. In most cases, we are able to provide in-kind cost sharing for government projects. The following provides more details on how we can support your technology development program.

SAMPLING AND ANALYSIS CAPABILITIES

GTI's pilot-scale gasification campus features innovative sampling and analytical systems and comprehensive diagnostic capabilities. Our systems support parametric and long-term testing and assure that we and our clients have fully-developed performance characteristics and operational procedures for commercial plants. We have developed and implemented sophisticated analytical approaches to equip the pilot plants with "in-situ" gas sample extraction and conditioning probes, suitably conditioned transport lines, and a suite of analytical instruments. Some analysis examples are: Permanent gases, sulfur gases, C1-C6 hydrocarbons, BTEX analysis, tars speciation, GC/MS complex unknown analysis with NIST library matching as well as dedicated process analyzers for near real-time reporting of low-level permanent gases, H_2S, SOx, NOx, etc. Some offline analysis include gasoline-range hydrocarbon analysis, diesel-range hydrocarbon/ wax analysis, NH_3/HCl, HCN and trace metals performed by our American Association for Laboratory Accreditation (A2LA) certified laboratory.

GTI PILOT-SCALE SYNGAS PRODUCTION FACILITIES

GTI has a unique set of pilot-scale syngas production facilities with wideranging capabilities. This complex, in Des Plaines, Illinois, includes a pressurized fluidized bed U-GAS® gasifier as well as an advanced pressurized entrained flow R-GAS™ gasifier, with associated syngas cleaning and conditioning systems. The GTI gasification facilities can receive and handle fuels in crushed, pulverized or pelletized form. A nitrogen inerted, 6000 ft3 silo is available for fuel storage. Fuel can be received in bulk bags or pneumatic truck with fuel transferred into and out of the silo by inerted pneumatic and/or mechanical transport systems.

Syngas handling capabilities include cyclone separators, hot gas filters, a tar reformer, fixed-bed sorbent vessels, sulfur scavengers, a scrubber, syngas compression to 1000 psig, a high pressure gas-liquid contactor for acid gas treatment, and a natural gas-fired flare with capacities suitable for pilotscale demonstration of many syngas clean-up and conversion processes. The pressure capability of the facility will support gasifier operations up to 400 psig and syngas acid gas removal/ synthesis to 1000 psig. Available utilities include medium pressure steam, pressurized O2 and CO2, high pressure deionized quench water, low- and high-pressure nitrogen, cooling water, instrument/plant air, electricity, and natural gas. With the opportunity to utilize existing fuel feed and syngas handling equipment, the required equipment skids can be expected to fit into one or more available areas in GTI's existing process buildings. These capabilities and their flexibility have been proven in several gasification and syngas treatment demonstration testing programs with different demands, including numerous one- to two-week test campaigns to validate key unit operations of biomass-to-liquids and coal-to-liquids technologies, involving gasification, hot gas filtration, catalytic tar reforming, syngas scrubbing, and liquids synthesis. Besides coal and biomass feedstocks processing, demonstrated capability is in place to generate syngas from natural gas in a non-catalytic partial oxidation (POx) reactor.

GTI TECHNOLOGY DEVELOPMENT FACILITY CAPABILITIES

GTI's pilot scale gasifiers are housed in two main buildings in the Emerging Energy Technologies Campus at GTI's headquarters location in Des Plaines, IL. Table 1 summarizes the operating conditions of GTI's gasifiers. GTI provides an excellent testing facility with matching personnel: Project managers that facilitate technology developer interactions and coordinate site resources, process engineers who assist with test planning, data analysis, operational troubleshooting, design, installation and safety reviews, analysis specialists who ensure accurate and thorough analysis of process streams and operations personnel for construction, maintenance, and safe and efficient testing. Our fully trained staff is available for safe 24/7 operations. The facilities operate on Emerson DeltaV™ process control systems with multiple control rooms and operator stations. Data integrity is maintained by providing technology developers secured access to only the data pertaining to their process, thus maintaining isolation of proprietary information generated during test campaigns. GTI works with the technology developers to define and implement data separation. We keep information separate for each developer to protect confidentiality. We provide restricted office space and control room access for the technology developers. The information distribution in GTI is also controlled. As a result, at any time GTI can have multiple technical teams working on similar projects in the facility. The required utilities, safety systems, and ancillary facilities such as temporary storage area for feed materials, cooling tower, cryogenic oxygen, nitrogen, and carbon dioxide storage and distribution, compressors, steam boiler with superheater, and circulating chiller are operated as required. The facility has the

capability to flare all of the syngas produced, which allows any volume of syngas up to the full process flow to be used in slipstream tests by the process in evaluation during a campaign.

OPERATION CONDITIONS	U-GAS®	R-GAS™
Nominal feed rate	20 tpd	18 tpd
Capacity	6 MWth	5 MWth
Syngas Production	3000 lb/hr	2500 lb/hr
Pressure	8-15 bar	15-27 bar
Nominal Temperature	1400°F – 1800°F	2500°F – 4000°F
Diameter	11 in	6 in
Technology	Fluidized bed	Entrained flow
O_2 – Blown Tests	Yes	Yes
Air – Blown Tests	Yes	No

CAPABILITIES + EXPERTISE

Gasification Technologies for Coal and Biomass

GTI continues to be a leader in developing, proving, and implementing gasification technologies and integrated systems for converting coal, biomass, and other solid fuel feedstocks into syngas.

Liquid Fuels from Syngas

GTI has expertise and experience in the conversion of synthesis gas to liquids, such as the Haldor Topsøe TIGAS® process.

Substitute Natural Gas

GTI conducts work on a number of routes, including catalytic gasification, to produce substitute natural gas (SNG) that can meet the pipeline specifications for distribution and use in the current natural gas infrastructure.

Syngas Processing Systems

GTI provides technical and economic process expertise and solutions for comprehensive fuels processing, including a variety of syngas cleanup options, and syngas utilization applications.

Integrated Energy Systems

With expertise and experience in related areas such as combustion, heat transfer, and fuel cells, GTI can assist in developing approaches and packaged products for integrated systems and solutions.

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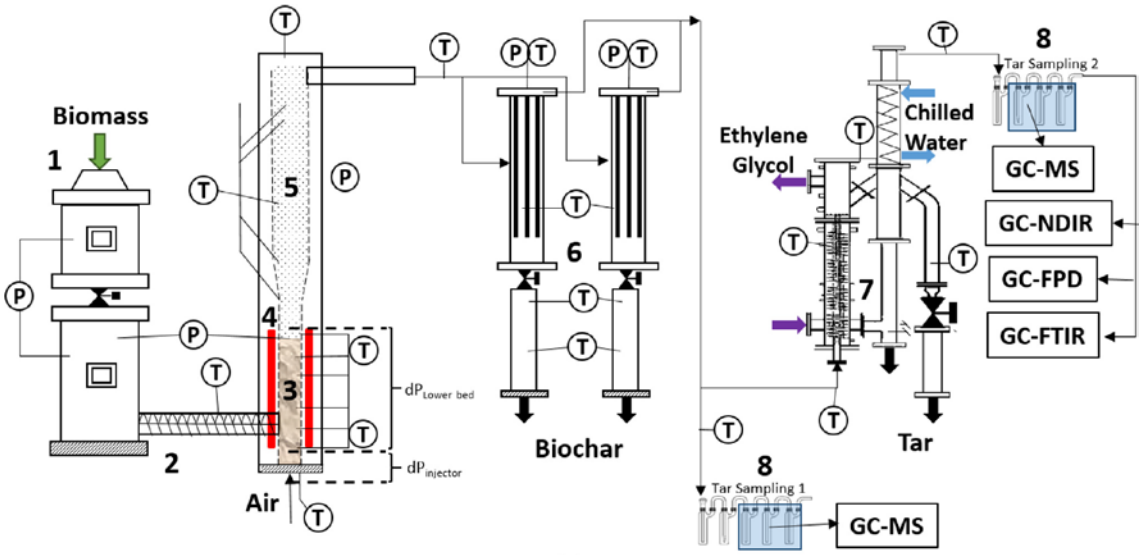
AUBURN UNIVERSITY

Figure 1 shows the Auburn University (AU) pilot scale pressurized fluidized bed gasification system consisting of a biomass hopper and a water-cooled screw feeder, a main fluidized bed gasification reactor, two sets of HTFs (high temperature filter), a quench cooler, and other items including a gas analyzer and a Labview based gasifier controller. A feedstock storage tank located outside the facility that can store 6.23 m^3 of biomass is connected to a biomass hopper inside the facility through a flexible screw auger conveyer. It was designed so that the conveyed biomass initially dropped in the top of a lock hopper (70 cm height × 70 cm diameter), and then the biomass was transferred down to the main feed hopper (163 cm height × 76 cm diameter). The hopper system was designed to handle a pressure up to 650 psi during the gasification operation with nitrogen gas to prevent a back flow of syngas toward the hopper. A K-Tron® gravimetric feeding system is installed inside the feed hopper to facilitate a precise biomass feed rate to the gasifier. A water jacket around the biomass screw feed keeps the biomass cool to prevent possible biomass combustion or softening before it reached inside the gasifier. The main reactor (137 cm height × 10 cm diameter) with a freeboard (170 cm tall × 22.9 cm diameter) is filled with quartz sand (particle size ranging from 150 to 300 µm) as a fluidization bed medium for the biomass gasification. The sand bed height is about 30–33 cm (12–13 in) throughout the operation. Insulated ceramic electric resistance heaters are installed to maintain the gasification operating temperature. A diffuser plate is used for fluidizing carrier gas. A jet of 1.27 cm (½ in) in diameter is located at the center of the diffuser plate of 10 cm (4 in) in diameter. Since the gasification reactor is operated in pressurized conditions, nitrogen gas kept a positive differential pressure between the outer shell of the reactor and the main reactor because the Inconel reactor was not designed to handle the elevated pressures.

The produced syngas from the main reactor is delivered to the HTFs for biochar removal. Once the first HTF finished its cycle by filtering the biochar, the valves are switched to another HTF for biochar filtering. Char from the first HTF is removed and dropped into a bin. Finally, the syngas is delivered to a cooler equipped with cooled ethylene glycol and water chillers to remove the tar products and dry the syngas. A National Instrument-cRIO system with Labview software was used to control the AU gasification system and monitor the data. Over 50 control outputs are installed with over 80 analog inputs and 84 digital inputs.



(a)

(b)

Figure 1. AU pilot scale pressurized gasification system (a) schematic diagram and (b) actual reactor (blue) and hopper (white). 1. biomass hopper; 2. injection screw; 3. fluidized bed gasifier; 4. gasifier heater; 5. freeboard; 6. high temperature filter; 7. wet scrubber; 8. tar sampler 1 and tar sampler 2; P stands for pressure transducer and T stands for temperature transducers; dP stands for differential pressure.

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Commercialization Update

Fulcrum Bioenergy/Sierra Biofuels: (11MM GPY)

1) MRF operational since 2016; at landfill 10 miles from biorefinery
    a) 350,000 tons per year raw MSW -> 175,000 tons per year prepared MSW
    b) 20 TPH throughput
2) Gasification/FT under construction
    a) MSW feedstock/TRI indirectly heated fluid bed steam reforming gasifier
    b) Johnson Matthey DAVY™/BP fixed-bed FT
    c) Start-up in Q1 2021
3) Recently pivoted from jet fuel to FT wax
    a) Off-take with Marathon Oil Co., Wax to be refined by Marathon
        i. Martinez, CA is being converted to renewable diesel facility
    b) Other offtakers include United and Cathay Pacific, BP Air, World Fuels
    c) FT jet fuel capability to be added in Phase II
4) Plant is 'full scale'; scale up (3X) planned with parallel trains
    a) 12 new projects currently planned/underway

Red Rock Bio; (15MM GPY)

1. Pathway: gasification to Fischer-Tropsch
2. Technology providers
    a. Gasification: TCG Global steam reforming
    b. FT technology: Velocys and Emerging Fuels Technology
        i. Parallel FT trains
    c. Hydroprocessing: Haldor Topsoe
3. Feedstock: forest residue (136,000 tons per year)
4. Products: cellulosic renewable jet, diesel, and naphtha fuels
5. Offtakes: Southwest Airlines, FedEx Express
6. First commercial project status
    a. Capacity: 15 MGY
    b. Anticipated construction completion: Q1 2021

Red Rock Biofuels Lakeview, OR: Aerial view on September 4, 2020, looking SW

Other Commercialization Activities

Aries Clean Energy

- Downdraft gasifier for biochar and syngas-to-power applications
- Fluid bed gasifier for production of syngas
- Projects

  1) Linden, NJ; fluidized bed gasification of bio-solids (Linden Roselle Sewerage Authority)

  - Processing 430 TPD biosolids; 22 TPD biochar and power
  - Construction underway; operational in Q1 2021

  2) Holloway Bioenergy; Lost Hills, CA

  - Aries down-draft gasifier; Ag wastes from California's Central Valley
  - 165 TPD ag waste feedstock producing 86MWe/D and 5,000 TPY biochar
  - Operational Q3 2021

  3) Lebanon, TN

  - Aries down-draft gasifier; wood wastes and bio-solids diverted from landfill
  - 420KWe/D and biochar
  - Operational since 2017

Sierra Energy

- DoD project (Ft. Hunter Liggett, CA; Army base)
- Gasifier: FastOx technology; blast furnace design (~2,200 ºC)
- 'Commercial' project underway to produce FT liquids and power
  - Basically a waste minimization project
    - 20 MTD military waste + woody biomass
    - 500 KWhe electricity

Frontline BioEnergy

- Pressurized fluid bed (10 Bar)
- Air or oxygen with steam (TarFreeGas®; PMFreeGas®)
- Projects
    - San Joaquin Renewables; San Joaquin, CA
        - RNG from Ag wastes
        - 15 million gallon-equivalents of RNG
        - Engineering in progress; approvals for injection in existing pipelines received

SunGas Renewables

- Spinoff from GTI
- Pressurized fluid bed technology
- Incorporates catalytic tar reforming technology from Andritz and Haldor-Topsoe
- Several FT projects in advanced stages of engineering
    - First commercial deployment planned for Gulf coast USA to produce hydrogen or chemical precursors

Aemetis – Lanzatech

- 60 GPY cellulosic ethanol project suspended
- InEnTec gasification technology to be used