



GAS TECHNOLOGY INSTITUTE

Woody Biomass to Zero Carbon Fuels

Dan LeFevers
Senior Development Leader
Gas Technology Institute

November 2017

GTI at a Glance...

- > Not-for-profit research, with 76 year history
- > Research Facilities
 - 18 acre campus near Chicago
 - 200,000 ft², 28 specialized labs
- > Staff of over 350 across the country
- > 1000 patents; 500 products
- > Commercial partners take our technologies to market



Offices
& Labs



Energy & Environmental Technology Center

Flex-Fuel
Test
Facility

GTI U.S. Office Locations

Alabama

- Birmingham

California

- Davis
- Davis (Davis Energy Group)
- Los Angeles (BKi)
- Oakland (BKi)
- San Ramon (Fisher Nickel)
- West Sacramento (BKi)
- Woodland Hills

Illinois

- Chicago (LocusView)
- Des Plaines (*Headquarters)

Massachusetts

- Needham

New York

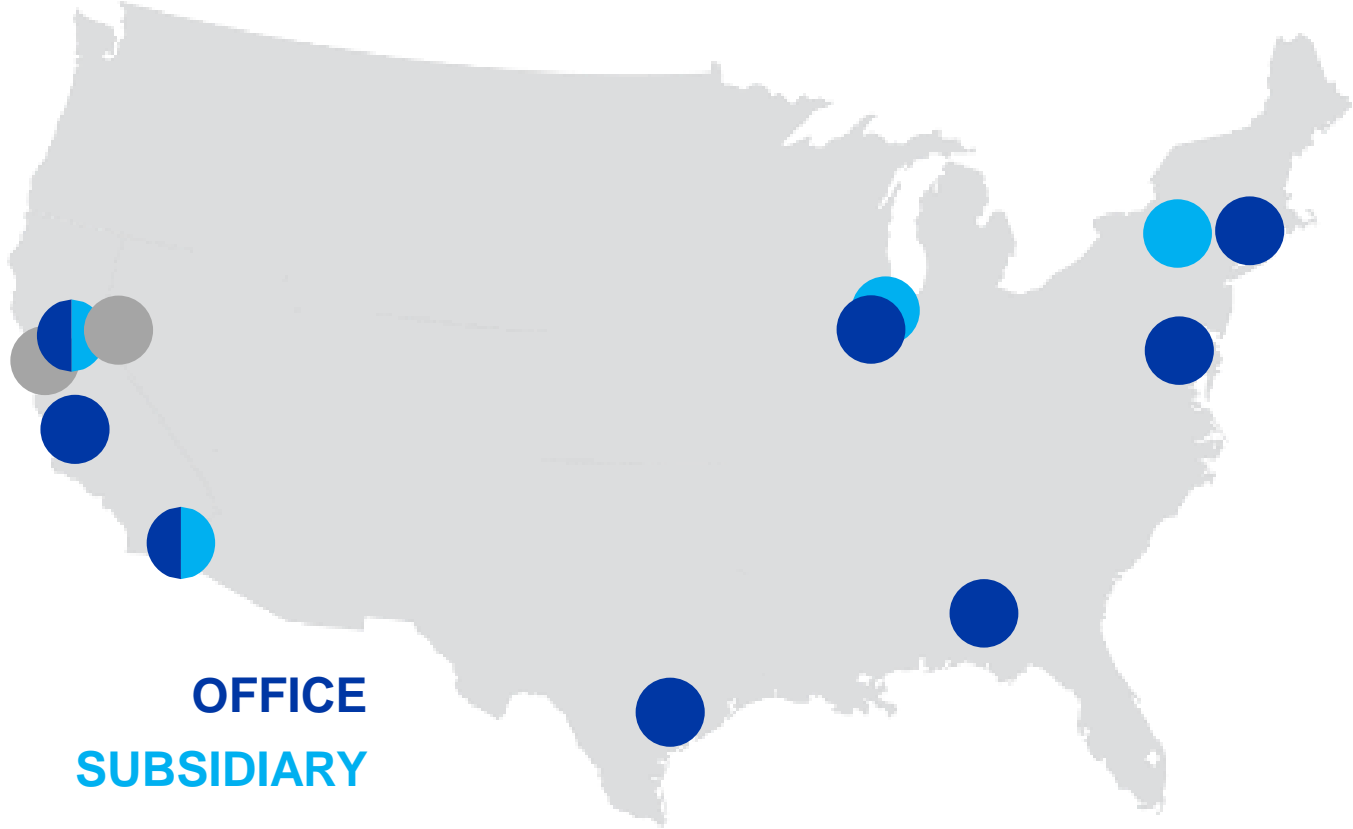
- Cazenovia (CDH Energy Corporation)

Texas

- Houston

Washington, DC

- Capitol Hill



OFFICE
SUBSIDIARY

GTI Gasification Development History

Development Focus

Supply Security –
Substitute Natural Gas (SNG)

Industrial Fuel Gas

Biomass, Renewables

Syngas to Power - IGCC

Syngas to Products

Fuels, Chemicals, SNG

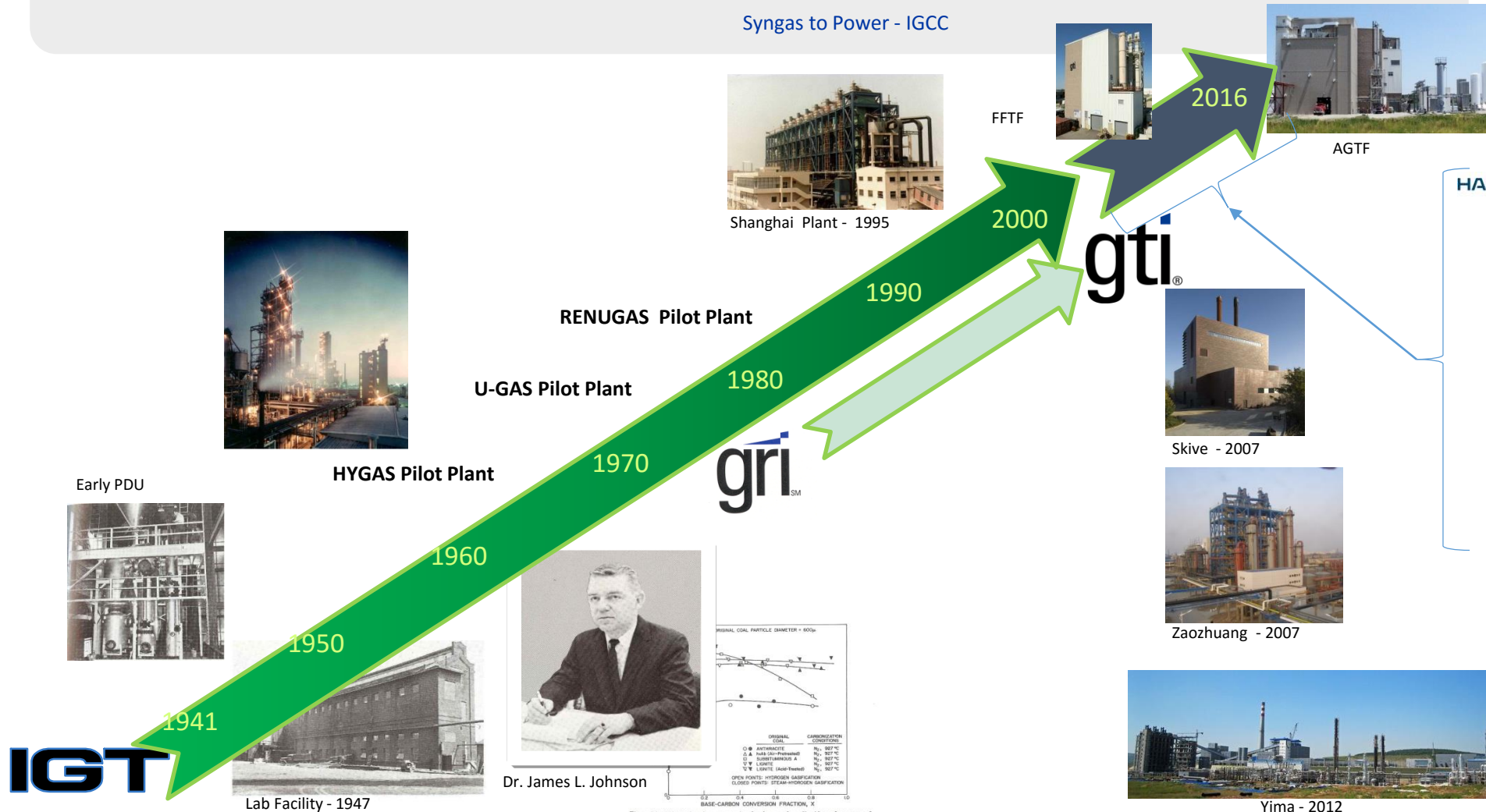


Figure 25 Effect of carbon conversion level on carbon dioxide surface areas of different coal chars gasified in a thermobalance apparatus at 927 °C, 35 atm, in hydrogen and steam-hydrogen mixtures. Data from Johnson [121].

Gasification Technology Development Platform



- 5 MW_{th} fluidized bed and entrained flow gasifiers at 400 psig, air- or O₂-blown
- 20 TPD coal or biomass
- 800 lb/h natural gas POx
- Hot and ultra-hot gas filtration
- Catalytic syngas reforming
- Syngas compression to 1000 psig
- Sorbent and solvent acid gas removal
- Syngas synthesis to products
- Operational since 2007

Problem

How to ensure the continued valuable use of woody biomass and agricultural waste resources in the wake of closing bio-mass power plants

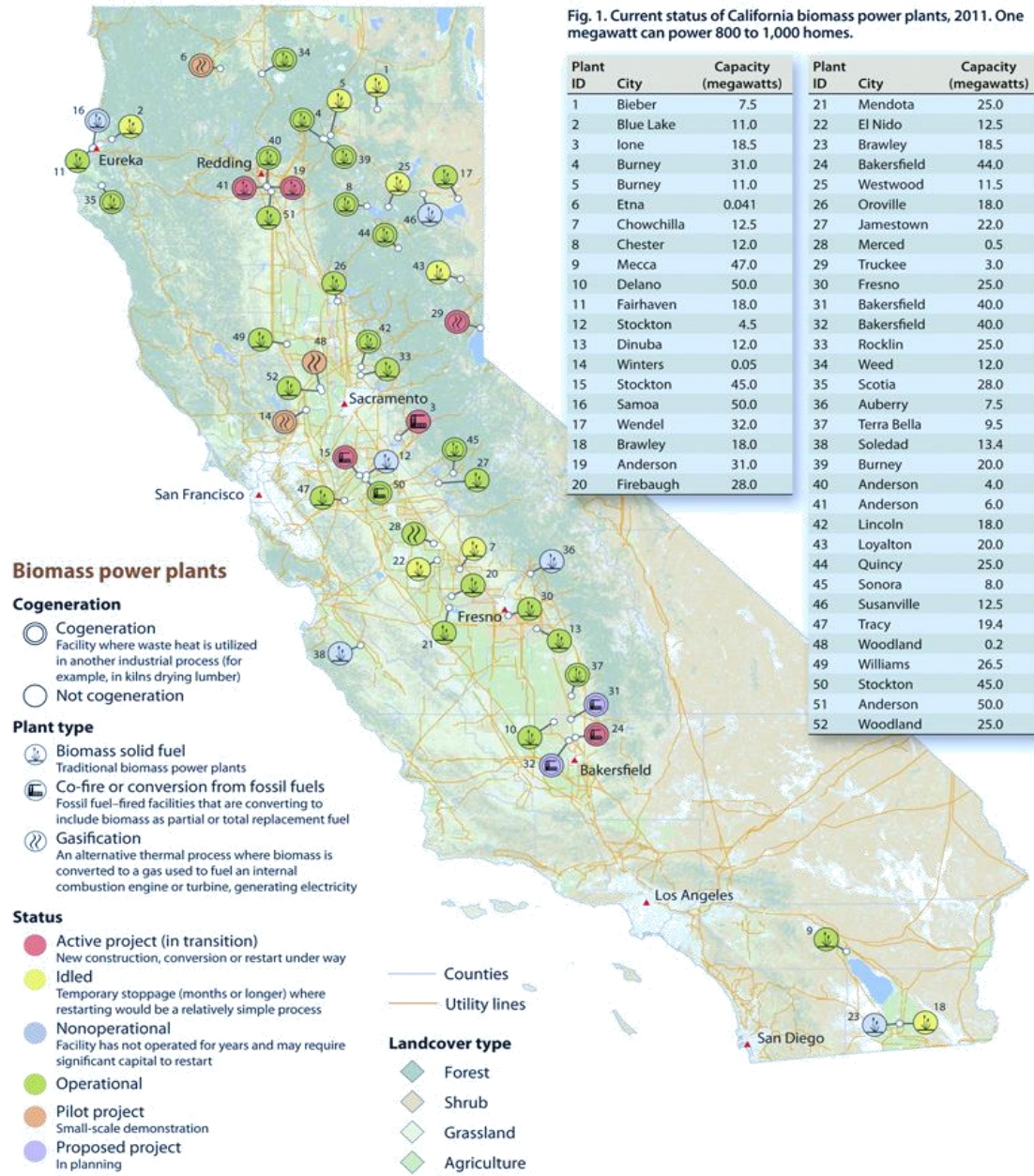
Solution

Produce and distribute a renewable biofuel that

- Can be used in existing ultra-low NOx heavy-duty engines, homes, businesses and for power generation
- Has a zero or less than zero carbon footprint
- Can be produced and delivered using existing infrastructure

Zero Carbon Fuel Produced by Wood and Agricultural Waste Streams

- Utilizes existing renewable waste feedstock
- Provide a zero-carbon fuel for transportation or other end-use sectors
- Seamless use by energy consumers – zero end-user costs
- Addresses need to reduce black carbon pollution
- Utilizes existing renewable power infrastructure maintaining and expanding rural job opportunities
- Transported via existing pipeline infrastructure for efficient distribution
- Storable renewable energy – ready when needed
- Highly efficient conversion of renewable feedstock to usable energy – 62-68%



Problem
California biomass power plants are closing, in part, due to competition from other renewables

California
52 existing biomass power plants = 1,075 MW_e total capacity
RNG potential = 65 BCF annually = 4x NGV use in 2012 = 5% non-power use in 2012

Opportunity
transform existing biomass power plants to RNG production facilities

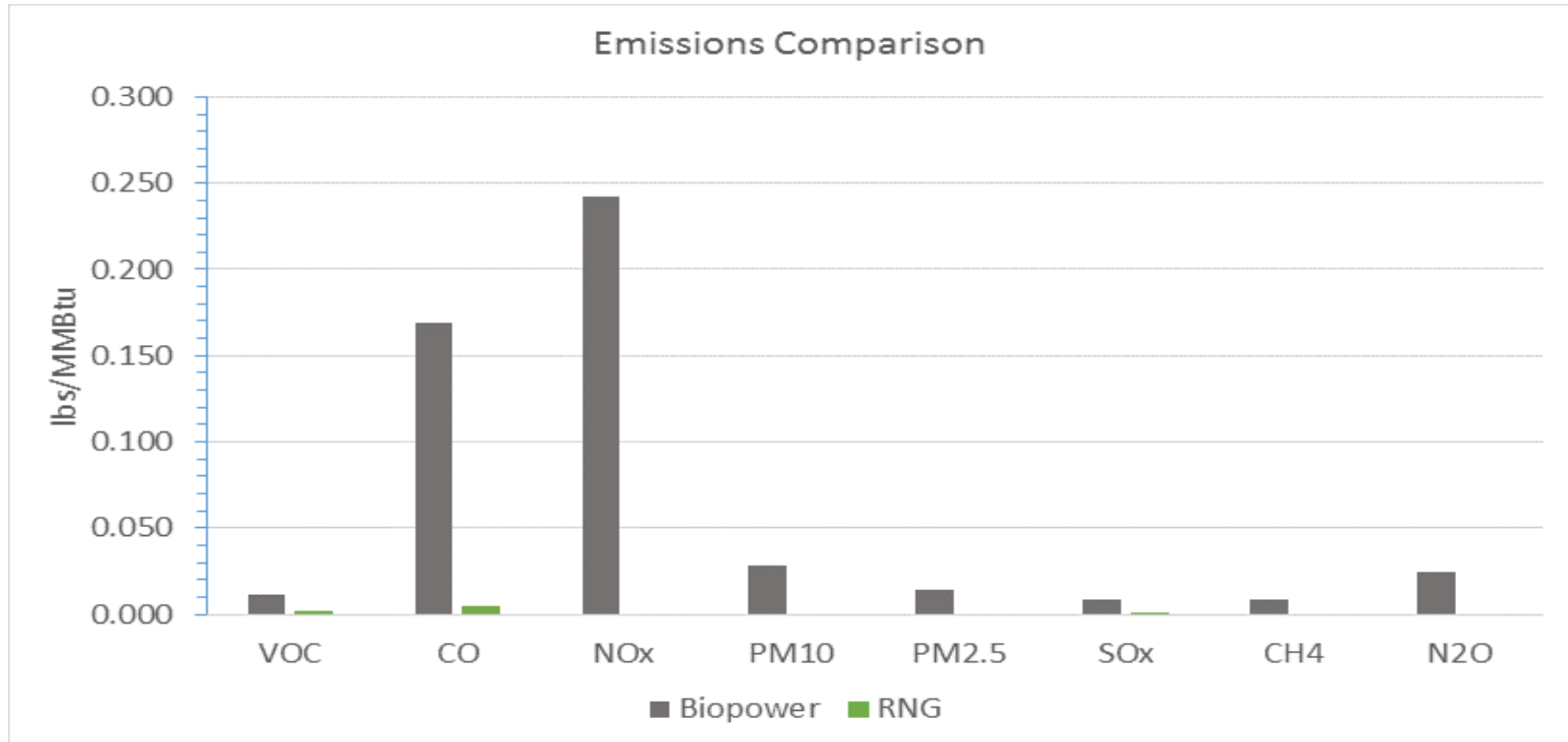
Potential to Integrate with Host Site

Integrate with existing biomass power plant to reduce deployment costs

- Feedstock handling
- Thermal integration
- Utilities
- O&M expertise



Emissions Profile Compared to Existing Biomass to Electricity Facilities



Source of biopower data: Assessment of the Emissions and Energy Impacts of Biomass and Biogas Use in California, Provided to the California Air Resources Board by Marc Carreras-Sospedra, Professor Donald Dabdub University of California, Irvine; in collaboration with Robert Williams California Biomass Collaborative, January 14, 2015

Why a Site-Specific Engineering Design Study is Needed?

- Five years of 5-MWth pilot plant tests at GTI, plus larger-scale commercial deployment of process components, have satisfied technology risks sufficiently for world-class vendors to make commercial offerings for the RNG process equipment.
- A generic, greenfield plant design estimate has been completed at a 200 MWth scale in the Bio2G project in Sweden, but:
 - that size is 3-4 times too big to match the typical biomass resource aggregation at existing biomass power plants.
 - many cost factors differ between Sweden and North America
 - the study does not provide an estimate for the value of existing infrastructure at a wood-fired power plant site to reduce CAPEX (and thus the required selling price of RNG).
- The economic competitiveness of RNG from gasification of wood and syngas methanation can be determined now that reputable, world-class technology vendors have commercial equipment for this application.
- Engineering design and costs will easily translate to other biopower sites as well as greenfield opportunities at the scale of the study.

Why a Site-Specific Engineering Design Study is Needed? (Cont.)

- Synergies and economies of using a biomass power facility as host site need to be understood:
 - Wood supply access
 - Fuel processing and handling
 - Natural gas pipeline injection options
 - Water access
 - Utilization of site acreage
 - Local support
- Technology providers need to provide commercial cost estimates for a specific scale representative of the market opportunities:
 - Feed prep and gasification island
 - Gas processing
 - Methanation and polishing
- Site-specific equipment layouts and connections for RNG production need to be developed and the cost estimated.
- FEL-2 fidelity CAPEX and OPEX (+/- 30%) values are needed to confirm RNG production cost and quantify the value of integration with host site

Commercial RNG Plant Timeline

Tasks	Year 1				Year 2				Year 3				Year 4				Year 5			
Complete Site Specific Engineering Design (+/- 30%)	█	█	█	█																
Commitment for building RNG Plant <ul style="list-style-type: none"> Engage utilities, State, other potential RNG buyers and investors Plant Design (+/- 10%) Off-take agreement 					█	█	█	█	█	█	█									
Build and Test RNG Facility													█	█	█	█	█	█	█	█
Start-up and Shakedown																			█	█

The Technologies

Fluidized-Bed Gasifier References



**80 ton per day
Gasification Pilot Plant
in Finland using biomass
& coal**



**Advanced Gasification Test Facility
Des Plaines, IL using wood and coal**



**800 ton per day U-GAS®
coal gasification plant in
Shanghai, China**



**165 ton per day CHP
Plant in Skive,
Denmark using wood**

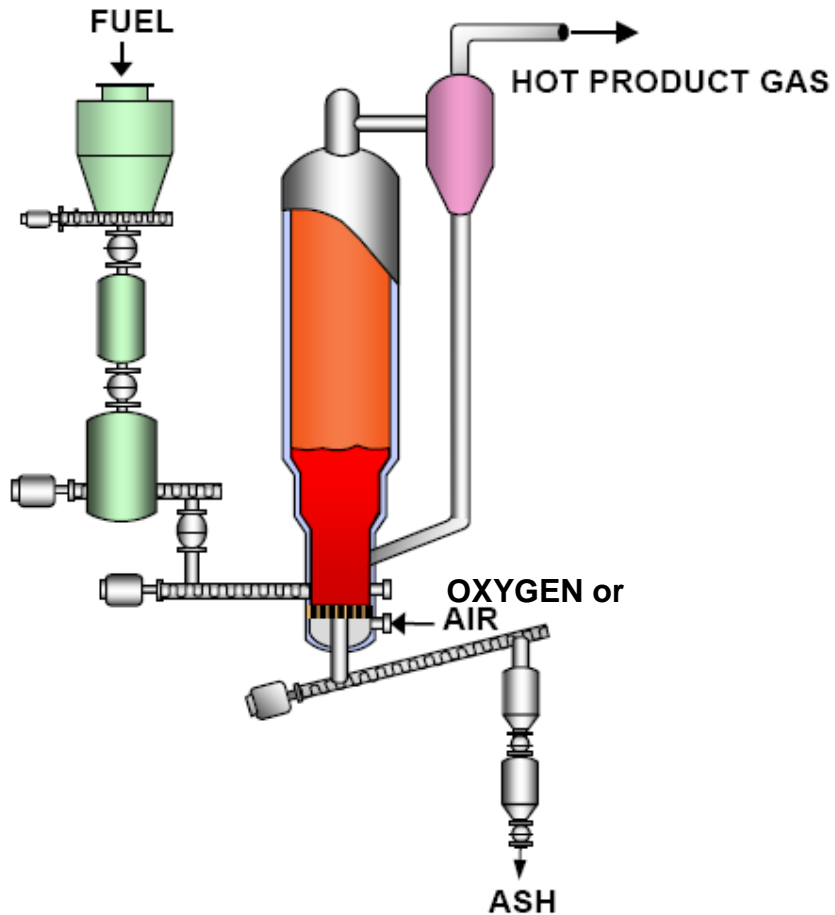


**2 x 400 ton per day in
Zao Zhuang City, China using coal**



**3 x 1200 ton per day U-GAS® in
Henan Province, China using coal**

GTI-Andritz Fluidized-Bed Biomass Gasifier



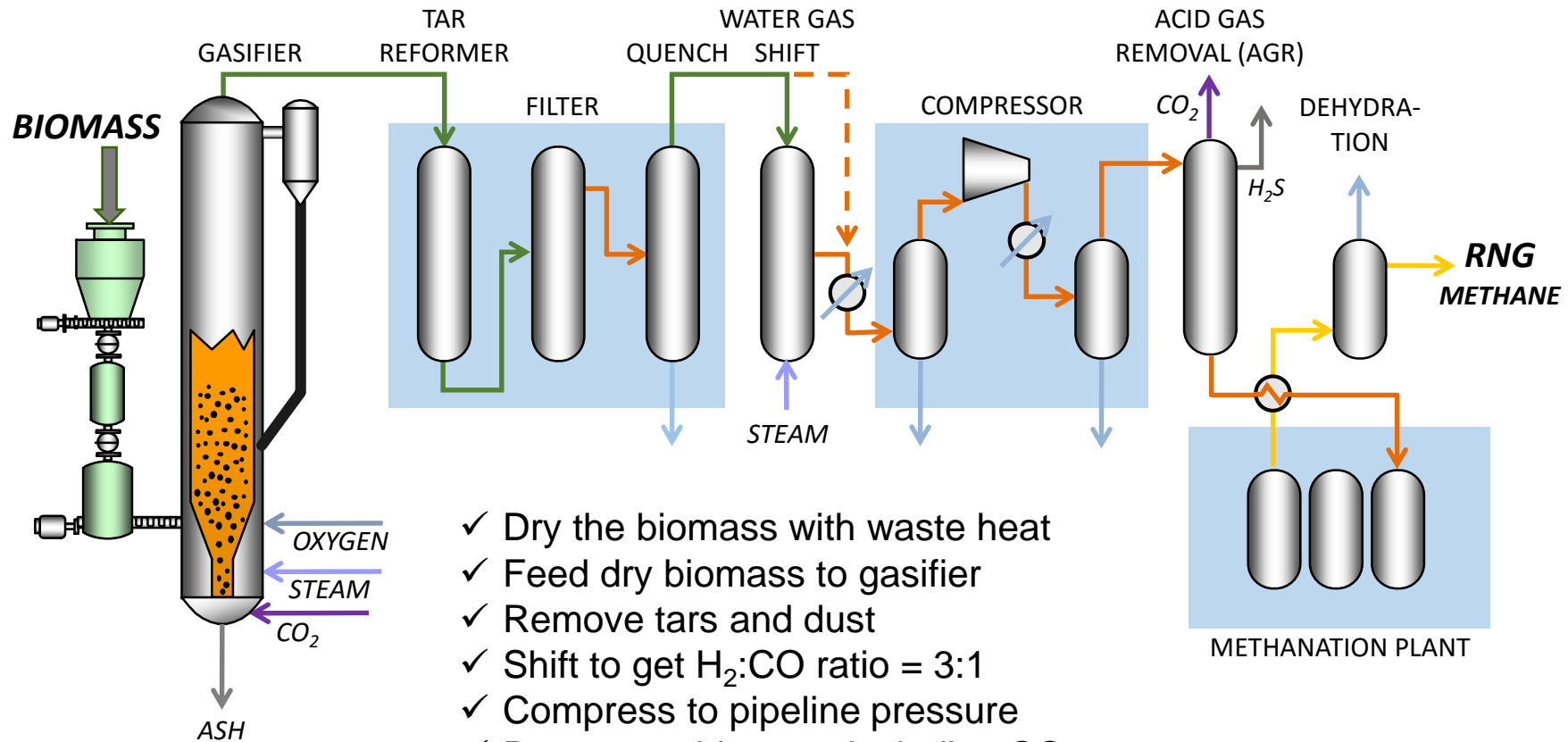
- > Efficiency
 - carbon conversion 95-98%+
- > Flexibility
 - biomass, coal, and combinations
 - high- to low-quality fuels
- > Versatility
 - Air-blown, enriched-air or oxygen
 - Atmospheric to high pressure
- > Operability
 - simple, single-stage, deep bed thermal flywheel
 - low temperature with long component life
 - good turndown capability, 30 – 50%

Biomass Feedstocks Tested in Gasifier

- Hard wood chips
- Soft wood chips
- Hard & soft wood mix
- Forest residue
- Bark
- Paper mill waste
- Wood pellets
- Saw dust
- RDF pellets
- Wheat straw
- Willow
- Alfalfa
- Rice straw
- Oil palm
- Bagasse


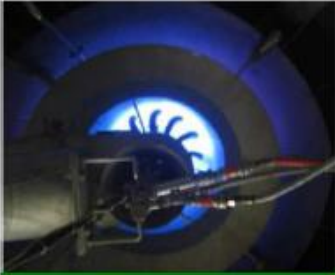





The RNG process



- ✓ Dry the biomass with waste heat
- ✓ Feed dry biomass to gasifier
- ✓ Remove tars and dust
- ✓ Shift to get H₂:CO ratio = 3:1
- ✓ Compress to pipeline pressure
- ✓ Remove acid gases including CO₂
- ✓ Convert syngas to methane
- ✓ Remove remaining moisture

ANDRITZ biomass gasification applications

Circulating Fluidized Bed (CFB) gasifiers		Bubbling Fluidized Bed (BFB) gasifiers		
Fuel gas for kilns	Fuel gas for fossil fueled boilers	Co-generation (gas engines)	Power generation (IGCC)	Biorefinery
<ul style="list-style-type: none"> 10-100 MW_{fuel} 40-350 MMBtu/h Atmospheric Air blown Fossil fuel replacement 	<ul style="list-style-type: none"> 10-150 MW_{fuel} 40-500 MMBtu/h Atmospheric Air blown Fossil fuel replacement with co firing 	<ul style="list-style-type: none"> 10-50 MW_{fuel} 40-200 MMBtu/h Low pressure 3 bar (40 psi) Air blown Fuel gas for gas engines 	<ul style="list-style-type: none"> 30-200 MW_{fuel} 100-700 MMBtu/h Pressurized 20 bar (290 psi) Air or O₂ blown Fuel gas for gas turbines 	<ul style="list-style-type: none"> >100 MW_{fuel}/unit >350 MMBtu/h/unit Pressurized 10 bar (150 psi) Oxygen blown Syngas for chem. processing
Pulp & Paper and cement industries	Utilities and all industries with large fossil fuel fired boilers	Utilities (distributed power generation)	New mid-size power plants, repowering	BTL/SNG producers P&P industry
				
Fuel gas	Fuel gas	Green power	Green power	Bio liquids

ANDRITZ pressurized BFB gasifiers

Gasifier – engine CHP plant in Skive, Denmark

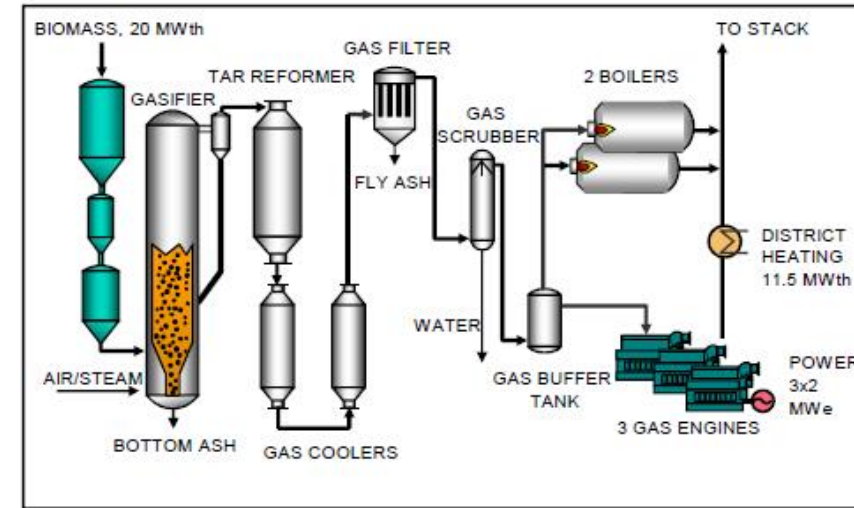
BFB Gasifiers



Fuel gas for CHP generation in Skive, Denmark

Gasification Plant process

- Air blown, low pressure BFB gasifier
- Limestone based bed material
- Catalytic tar reforming (dusty reformer)
- Gas cooling and filtration
- Gas scrubbing
- System pressure 3 bar (40 psi)
- In commercial operation since 2008
- “Dusty” monolith type catalysts in tar reformer by Haldor Topsøe since 2009
- Test platform for catalyst development (slip stream reactor by Haldor Topsøe) and hot gas filter related testing
- Process equipment development to achieve higher availability
- Availability > 90%



E.ON Bio2G project

Biomass to Bio-SNG (Biomethane)

Facts

- SNG production capacity 200 MW (680 MMBtu/h) + heat & electricity
- Forest residues as feed stock
- To be located in Malmö/Landskrona
- Awarded for EU / NER300 support of 203 M€

Technology

- Pressurized oxygen blown gasification (Andritz, Finland)
- Gas cleaning and methanation, (Haldor Topsøe, Denmark)



(source, E.ON)

Bio-SNG

From wood to a pipe-line quality product

Haldor Topsøe has been active in the field of methanation for decades now, as CO conversion to CH₄ is a necessary step of purifying the syngas for ammonia production. However, producing methane as a product is commercially new since the first modern reference has been started up by Topsøe in 2013.

Bio-SNG aims at producing methane that meets the local natural gas network specifications, via 2nd generation biomass gasification. Virtually, any sort of biomass (and even waste) is suitable for SNG as soon as it can be gasified. After gasification, the syngas has to be cleaned so that it can be processed catalytically in the methanation section. The whole process is illustrated in the block diagram below. All these steps are essential to yield a clean enough syngas (CO, H₂, CO₂) than can be methanated.

The methanation reaction is very exothermic, thus creating a violent exotherm in the reactor. Unfortunately, thermodynamics dictates that the methanation reaction equilibrium is favored at low temperature. In large scale SNG plant, we have developed the TREMP process, a series of adiabatic fixed beds with intermediate cooling, that is excellent at recovering heat as superheated steam. The large scale of these plants makes it a high performing process.

When it comes to bio-SNG, the size of the plant is generally much smaller than what we see with TREMP. A cascade of adiabatic reactors is no longer the best option to carry out methanation in a cost effective way. As a solution, Topsøe has developed a concept that focus on reaching SNG specifications in a single boiling water reactor.



Figure 1: Bio-SNG block diagram

Tar reforming

The very first step

Biomass gasification is usually carried out in a fluidized bed reactor that operates at temperatures between 800 and 900 °C. The raw synthesis gas from the gasification unit contains a variety of impurities that will cause deactivation and poisoning of the catalyst installed in the bio-SNG. In addition, heavy tar components may cause physical blocking of equipment and catalyst at low temperatures and should thus be removed. Furthermore there is a significant heating value potential associated with the tar compounds which contributes to improve the global performance of the plant.

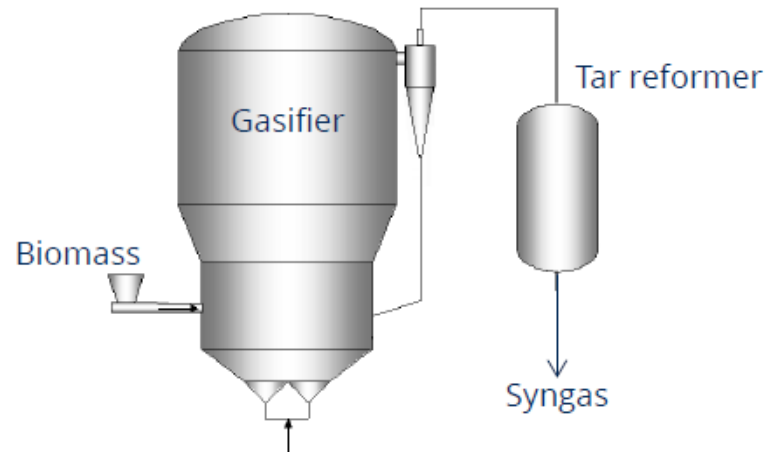


Figure 2: Tar reformer direct connexion to the gasifier



Classic operating conditions:

- 2500 ppm tar (toluene, benzene, naphthalene)
- 100 ppm S, particulates
- 850-930 °C, 1-20 bar g

Benefits:

1. Increased gas production
2. Convert poly-aromatic components to an extent that allows cooling the syngas for further processing without fouling or precipitation
3. Utilize the high temperature levels from gasification for increased efficiency



Figure 3: Monolithic tar reformer catalyst

Other cleaning steps

Sulfur, olefins and other poisons

Tar cleaning is by far the most discussed cleaning step in the literature. However, it is crucial to remove other impurities down to ppm level so that the gas can be processed in the methanation section.

Topsøe has developed a variety of catalysts to clean the syngas generated from biomass.

Olefin hydrogenation: a biomass fed gasifier produces low amounts of olefins that have to be removed. Topsøe hydrogenation catalyst converts olefins to their corresponding paraffin at low temperature.

Organic sulfur hydrogenation: organic sulfur is not caught by downstream sulfur adsorbent. It is therefore important to convert all sulfur containing species to H₂S that can be easily removed with our adsorbent

H₂S removal: Topsøe has a long list of references with H₂S removing catalyst. Our catalyst ensures safe operations bringing sulfur levels down to ppb.

Other guards: depending on the feedstock origin, species such as Cl (organic or HCl), Fe, As, Carbonyls or ammonia must be removed. We have developed solutions in order to yield a poison free syngas.



Figure 4: Gas cleaning catalyst



Figure 5: Sulfur adsorbent

Methanation section

Boiling water reactor

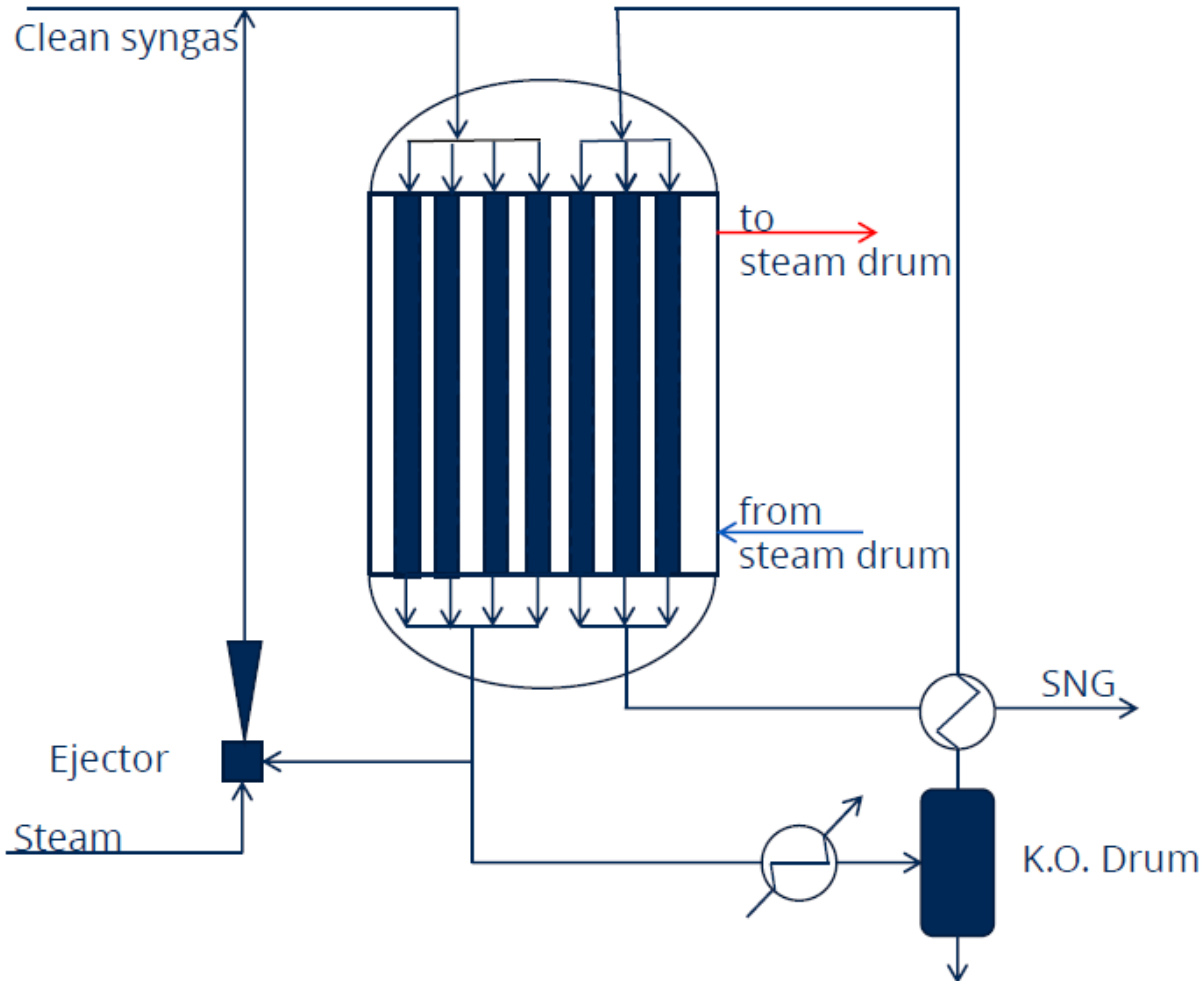


Figure 6: 2 passes boiling water reactor arrangement for methanation

Methanation is carried out in a multitubular reactor where the heat of reaction is transferred to boiling water. The technology comes from Topsøe methanol process and has been adapted to methanation. Tests were carried out already in the 80s'. A low temperature methanation catalyst ensures total conversion of the carbon oxides.

Saturated steam is produced in the associated boiler. A possible lay-out is illustrated here.

Operational conditions:
Temperature = 250 - 350°
Pressure = 15 - 30 barg
Material of construction: low alloy steel
Catalyst : Commercial Topsøe catalyst



Figure 7: Low temperature methanation catalyst

Summary

- Project will leverage millions of dollars of previous pilot-scale testing funded by GTI, UPM, Andritz, USDOE, Haldor Topsoe, Pall Corporation, and design work sponsored by European Commission and E.ON.
- RNG technology team members are world experts in gasification, gas clean-up, and conversion technologies.
- RNG technology suite is commercially available, with performance guarantees.
- Project will determine CAPEX and OPEX to produce approximately 3,000,000 MMBTUs of RNG from woody biomass annually.
- Team is ready to provide low carbon fuel solutions for carbon reduction goals and mandates.
- The next step is the site-specific engineering design.
- The Site specific engineering design will be of the Stockton Biomass facility
- Funding support for project from California agencies and from utilities in California and Oregon