Public Interest Energy Research (PIER) Program

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Biomass Gasification - DRAFT

Prepared for: California Energy Commission
Prepared by: California Biomass Collaborative,
University of California, Davis

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CALIFORNIA BIOMASS COLLABORATIVE

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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- Transportation

Biomass Gasification is the interim report for the CREC Task 7 project (contract number 500-11-020conducted by the University of California. The information from this project contributes to Energy Research and Development Division's PIER Program.

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Abstract

Basic biomass gasifier reactor types and general performance are described. Organizations that have published gasifier databases are listed (though databases are not all current or complete). Status of biomass gasifier for CHP applications in Europe and California are discussed with brief case studies or descriptions included.

Approximately 90 listings are contained in a recently compiled (December 2014) database of predominantly biomass gasification technology suppliers (See Appendix). Information includes company name, country, web address and short description of the technology, including gas cleaning system and technology status if known. Also energy capacity and technology status (any operating references?) are mentioned when information was found.

Renewable synthetic natural gas produced via thermal gasification is discussed including status of some demonstration and commercial projects in Europe.

For a discussion of gasification of municipal solid waste, the reader if referred to CREC Task 6 Report: Survey of MSW Conversion Options.

Keywords: Type keywords here
Biomass, gasification, status, database

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Abbreviations

APL	All Power Labs
BAB2E	Bay Area Biosolids-to-Energy Coalition
BFB	Bubbling Fluidized Bed
CBE	Concord Blue Energy
CFB	Circulating Fluidized Bed
CHP	Combined Heat and Power
CPC	Community Power Corp.
CVA	Central Valley Ag. Grinding
FICFB	Fast Internal Circulating Fluidized Bed
FT	Fischer Tropsch
GE	General Electric
IEA	International Energy Agency
kW	Kilowatts
kWe	Kilowatts, electricity
kWth	Kilowatts, thermal power
MSW	Municipal solid waste
MW	Megawatt
MWe	Megawatt, electricity
MWh	Megawatt-hour
MWth	Megawatts, thermal power
NETL	National Energy Technology Lab
PDU	Process Development Unit
PEM	Proton Exchange Membrane (fuel cell type)
PM	Particulate Matter
PSI	Paul Scherrer Institute
RSNG	Renewable Synthetic Natural Gas
SMUD	Sacramento Municipal Utility District
SNG	Synthetic Natural Gas
WWII	World War Two
ZWE	Zero Waste Energy

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Introduction

1.1 Gasification

Gasification is the conversion of solid or liquid carbonaceous feedtstocks into a gaseous fuel (synthesis gas, producer gas), principally CO, H_2, methane, and lighter gaseous hydrocarbons [1]in association with CO_2 and N_2 depending on the process used. Gasification processes also produce liquids (tars, oils, and other condensates) and solids (char, ash) from solid feedstocks.

Gasification processes are designed to generate fuel or synthesis gases as the primary product. Fuel gases can be used in internal and external combustion engines, fuel cells, and other prime movers. Gasification products can be used to produce methanol, Fischer-Tropsch (FT) liquids, and other fuel liquids and chemicals (Figure 1). Gasification of solids and combustion of gasification-derived fuel gases generates the same categories of products as direct combustion of solids, but pollution control and conversion efficiencies may be improved.

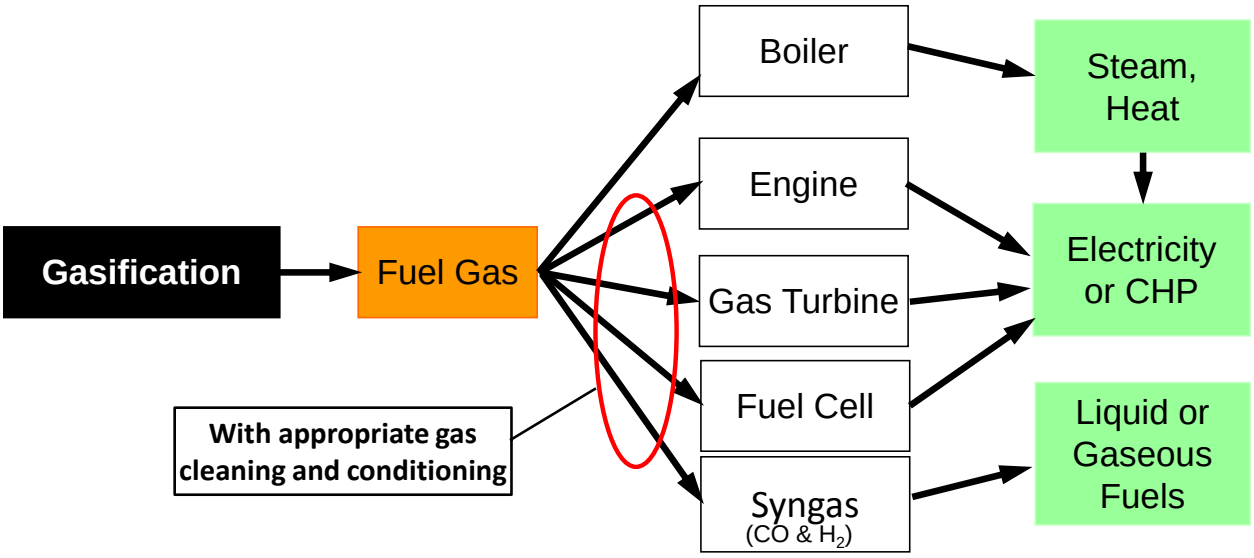


Figure 1. Gasification applications schematic.

The overall process is endothermic requiring energy input for the reactions to proceed. Most gasification systems operate between 600°C and 1500°C. Gasifiers can be directly heated (autothermal), indirectly heated (allothermal) and designed to operate at atmospheric or elevated pressures.

Directly heated gasifiers generate the necessary heat-of-reaction by means of partial oxidation of feedstock within the gasification reactor. Air is normally used for partial oxidation gasification but oxygen (or oxygen enriched air) can be used which reduces or avoids nitrogen gas carrying through and diluting the product gas.

[1] e.g., ethane, ethene, propane, etc.

With allothermal or indirect gasification, heat is supplied from an external heat source through heat exchangers (i.e., heat pipes utilized by Agnion) or heated media transfer (i.e., hot bed sand from dual fluidized bed reactors e.g., Repotec). Allothermal gasification systems allow little to no diluent nitrogen in the product gas, and, if steam injection is used, results in significantly higher H_2/CO ratios which are favorable for the synthesis of certain chemical or liquid energy carriers.

The main gasifier reactor types or designs include fixed bed, fluidized bed, entrained flow systems.

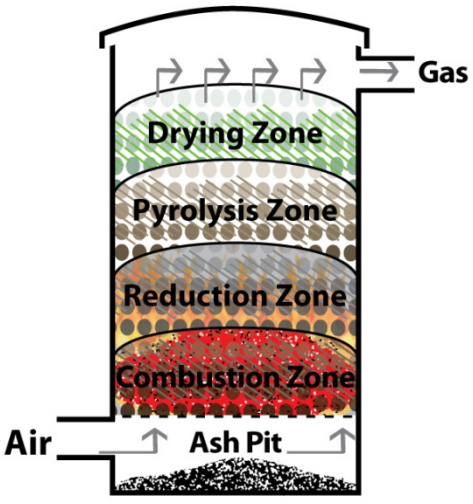
1.2 Types of Gasifiers

Gasifier types or designs include the fixed bed (updraft or downdraft), fluidized bed ("bubbling" bed, circulating fluidized bed) entrained flow and dual bed (or dual reactors). (Figures 2-8). The units can operate at atmospheric or higher pressure. The gasification medium is generally either air (air-blown), oxygen (oxygen-blown), steam, or combinations of these.

1.2.1 Fixed Bed Gasifiers

1.2.1.1 Updraft Design

The fixed bed updraft gasifier is considered the simplest configuration. Air (oxidant) flows countercurrent to the feedstock (Figure 2; (Knoef 2005)). It is suitable for relatively high moisture fuels (as high as 60% wet basis) but produces a large amount of tar and pyrolysis products in the produced gas. Consequently, this configuration is best suited for direct heat applications in which the gas can be burned without much (or any) gas cleaning or tar removal. For power or fuels applications, extensive gas cleaning would be required. Updraft systems have relatively high carbon conversion efficiencies (low carbon / charcoal in the output) and are suitable for small to medium scale (Figure 9).

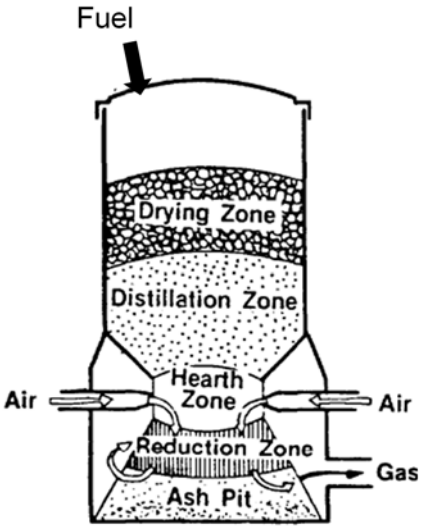


Source: (Jenkins 2010)

Figure 2. Updraft gasifier schematic

1.2.1.2 Downdraft Design

Air and fuel flow concurrently in the fixed bed downdraft gasifier (though the fuel moves much slower than the air). Air (or oxidant) can enter at the top with the fuel in the open core design, or, more often at an intermediate level to better control location of the high temperature oxidation zone (Figure 3 shows this configuration). Product gas usually exits near the bottom of the reactor after the reduction zone. Fuel moisture requirement is more critical than for the updraft design and should be < 30%. The main advantage of the downdraft gasifier is the potential for low tar gas production if properly operated using fuel with appropriate moisture content and particle size. The system produces a carbonaceous char residue and is best suited for small scale (~ 15 – 500 kWe) [see Figure 9 for relative appropriate scales]. This type of gasifier was used to fuel more than 1 million 'wood gas' vehicles during WWII.



Source (Jenkins 2005)

Figure 3. Downdraft gasifier schematic

1.2.2 Fluidized Beds

Fluidized bed reactors contain a bed of relatively small particles of inorganic material (often sand or small diameter ceramic beads or gravel). The bed is 'fluidized' by blowing hot oxidant up from the bottom. Individual particles are lifted by aerodynamic drag, and become suspended or entrained on the gas stream at velocities for which the drag force becomes equal to or exceeds the particle weight. When fluidized, the bed behaves much like a liquid. When the bed media is hot enough, biomass is injected either into the bed and can begin to combust or gasify depending on the amount of oxygen available

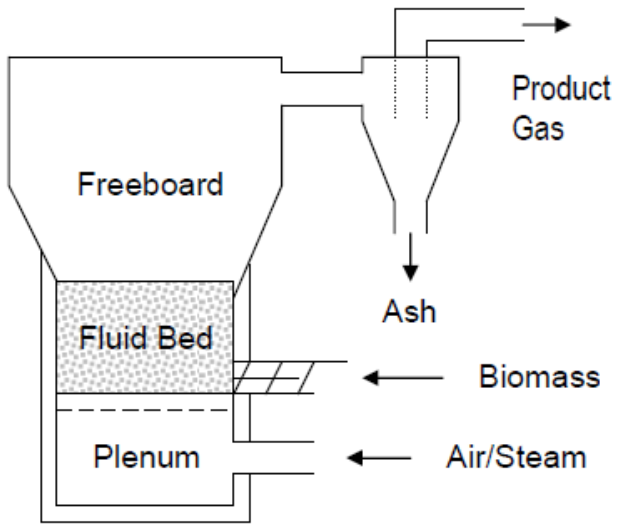
Fluid bed gasifiers were originally developed for large-scale coal gasification. Advantages of fluid bed systems include:

- Higher volumetric specific capacity because of well-mixed, high-heat transfer and reaction rates
- Larger capacities are possible (~ 5-500 MWth feedstock input (Figure 9)
- Better feedstock flexibility (can accept larger ranges of moisture, ash content, particle size and bulk density)
- Can tolerate somewhat lower ash melting points because of lower reaction temperatures (though bed will agglomerate and lose fluidization if temperature approaches ash melting point).
- Tar production is lower than for updraft gasifiers but not as low as properly operated downdraft designs.

Fluid bed gasifiers are generally more complex than the fixed bed designs and require more precision in control of fuel and oxidant as well as higher parasitic energy load) needed for fluidization.

1.2.2.1 Bubbling Fluidized Beds

Bubbling fluidized bed (BFB) reactors have relatively slow velocity air, oxygen, or steam flow (compared to circulating fluid beds) and therefore have lower particle entrainment in the gas leaving the reactor. The bed material is concentrated in the lower dense-bed region because the freeboard section above the bed has a larger diameter and lower gas velocity (Figure 4). The gas velocity in the freeboard section is too low to continue to suspend bed particles, which fall back into the bed region. The design is simple but has lower capacity and potentially less uniform reactor temperature distribution than circulating fluidized beds.

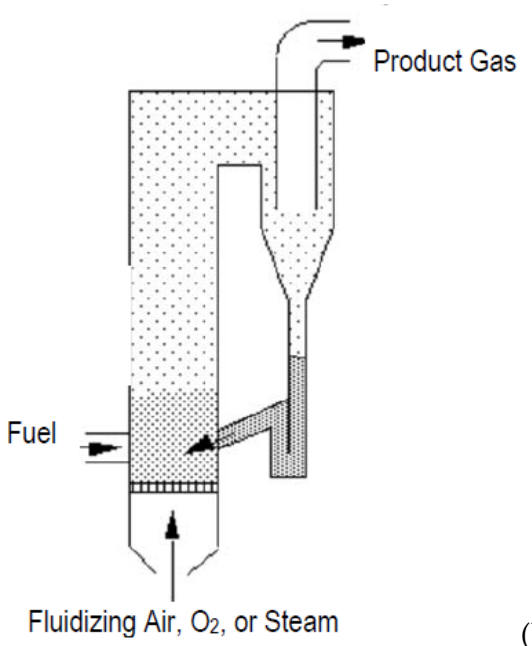


(Jenkins 2005)

Figure 4. Bubbling bed reactor

1.2.2.2 Circulating Fluidized Beds

The circulating fluidized bed uses higher gas velocities but offers higher conversion rates and efficiencies. Instead of a freeboard section, the reactor diameter remains essentially constant, which keeps bed and fuel particles suspended. The bed material flows up with the fluidizing gas and is carried over into a cyclone which separates most of the particles from the gas stream which are then re-injected (recirculate) into the lower part of the bed (Figure 5). Ideally, the fuel particles are small enough to completely react before being carried over into the cyclone, but in practice large fuel particles recirculate with bed media until small and light enough to be carried out with the product gas exiting the cyclone or other separation device. Oxygen fired circulating fluidized bed gasifiers are candidates for the production of hydrogen and liquid fuels.



(Jenkins 2005)

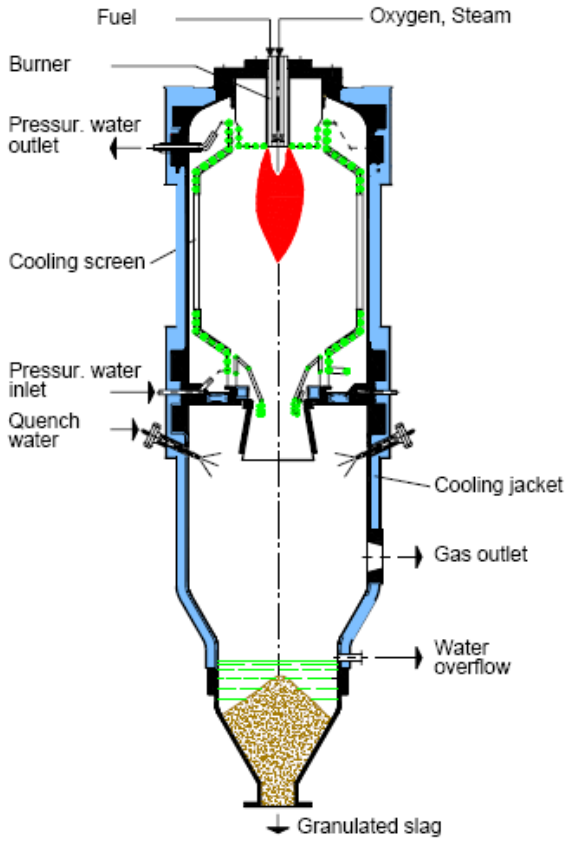
Figure 5. Circulating fluidized bed reactor

1.2.2.3 Entrained Flow Gasifiers

Entrained flow gasifiers are used extensively by the petroleum industry to convert petroleum residues (e.g., petroleum coke) to useful products and energy. Most coal gasification is done with entrained flow systems.

Entrained flow gasifiers have high gas velocities and high material throughput. Consequently, time for reaction (residence time) is short which requires the feedstock to be of very small particle size, a liquid or liquid slurry (Figure 6). The systems are generally oxygen blown and can be pressurized or atmospheric. High temperature (>1250 °C) is generated from combustion

in oxygen which melts the ash (sometimes called slagging gasifier) and requires reactor cooling. Little to no tar is formed as the feedstock is essentially completely converted to H_2, CO, CO_2, and H_2O. Entrained flow gasifiers are suitable for large scale (> 100 MWth input- Figure 9). Bioliq in Germany plans to use a pressurized, oxygen-blown entrained flow gasifier to convert pyrolysis oils to syngas for liquid fuels production.



(Volkmann 2004)

Figure 6. Schematic of an entrained flow gasifier

1.2.2.4 Dual-bed Indirect Gasifiers

Indirect-heat, or allothermal, gasification systems produce gas with little to no diluent, and, if steam injection is used, results in significantly higher H_2/CO ratios; favourable for the synthesis of any liquid or gaseous energy carrier. A main technical challenge for allothermal gasifiers is the heat transfer into the reactor.

Common indirect gasifiers consist of dual fluidized bed reactors that circulate bed material (sand) from one to the other. Combustion occurs in one reactor and heat is transferred with the hot sand as it moves to the gasification reactor. Cool sand and char moves back to the combustion chamber for re-heating. The Fast Internal Circulating Fluidized Bed (FICFB) that has been operating in Güssing, Austria since 2002 is an example of a dual fluid bed autothermal gasifier (Figure 7.).

Agnion, from Germany, has developed an allothermal gasifier that uses heat pipe technology to transfer heat from the fluid bed combustor to the gas producer reactor, rather than circulating hot sand. Agnion calls the system "Heatpipe-Reformer" (Figure 8.).

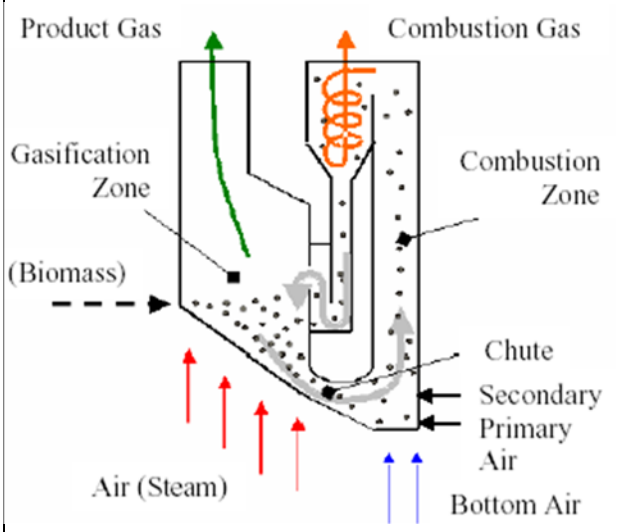


Figure 7.Schematic of the Fast Internal Circulating Fluidized Bed (FICFB) gasifier, Güssing, Austria

(Bolhar-Nordenkampf, Bosch et al. 2002)

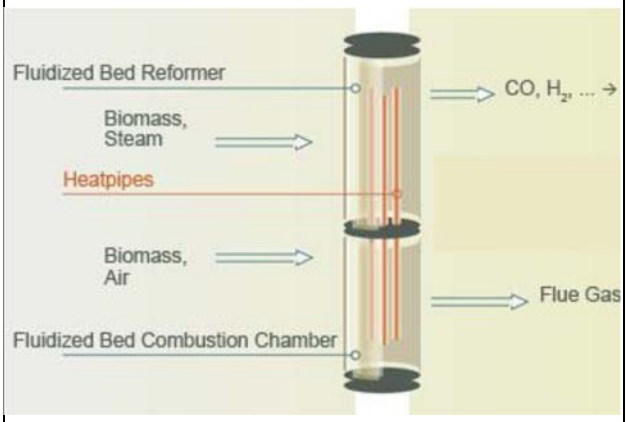


Figure 8. Schematic of the agnion heat-pipe reformer gasifier

(Gallmetzer, Ackermann et al. 2012)

1.2.3 Raw Product Gas Characteristics

Air-blown gasifiers produce a low energy gas (~ 150 Btu ft-3) composed of CO, H_2, CO_2, CH_4, higher light hydrocarbons, H_2O, PM, alkali vapors, nitrogen and sulfur compounds, and 40-50% N_2. The N_2 is a diluent and is from the air gasification medium (Table 1).

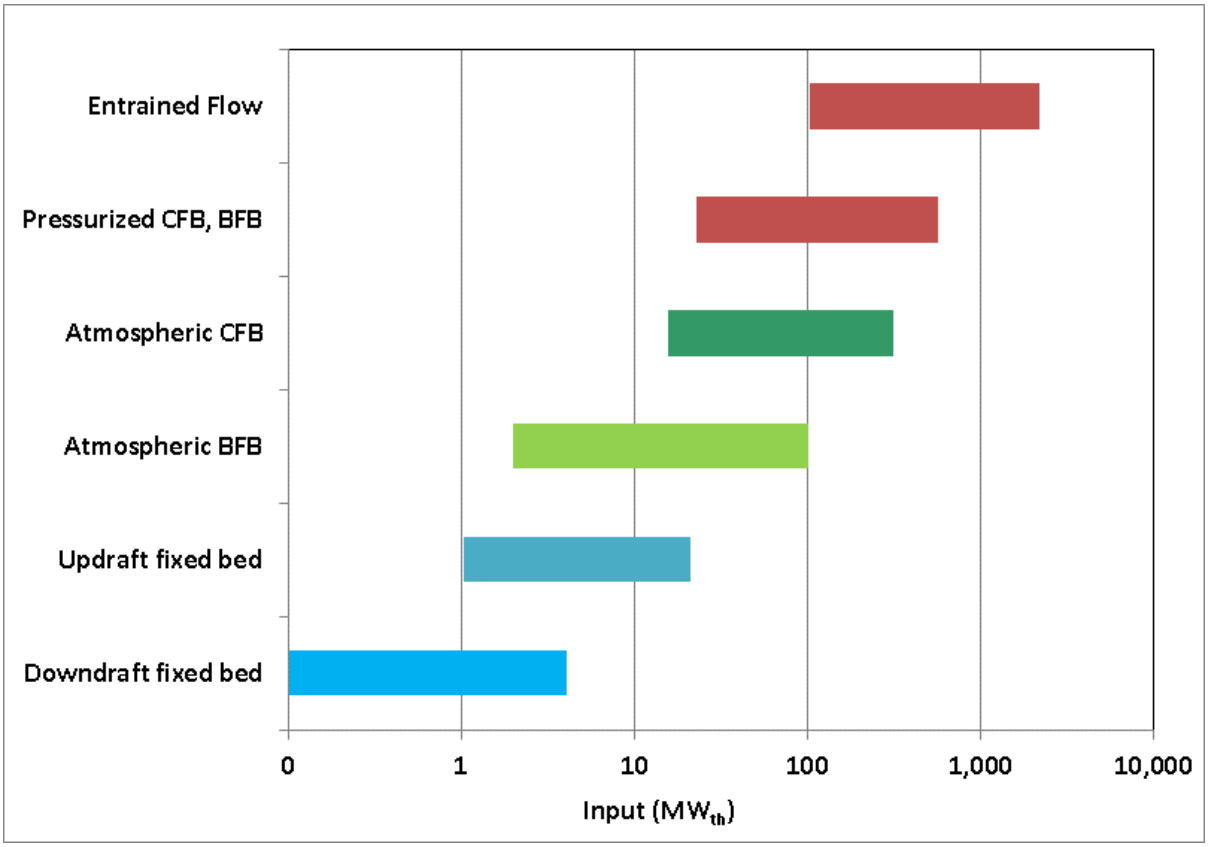
Oxygen-blown gasifiers produce a medium energy gas (~ 350 Btu ft-3) composed of similar compounds but much less nitrogen. An air separation plant is needed to create a pure or enriched oxygen stream to use for the gasification medium.

Properly designed and operated air-blown indirect gasifiers produce a medium energy gas because the combustion reactor is separate from the gas producing reactor. The products of combustion and the air borne nitrogen are therefore separate from the synthesis gas stream.

Table 1. Approximate composition of raw syngas from gasified biomass

	Air-blown Producer Gas (vol. %)	Oxygen-blown Synthesis Gas (vol. %)	Indirect-fired-steam gasification Synthesis Gas (vol. %)
CO	22	38	19
H_2	14	20	20
CH_4	5	15	8
C_2H_2 and higher	low	5	3
H_20	2	4	38
CO_2	11	18	11
N_2	46	trace	trace
	Plus tars, PM, and other		

Sources: (Gebhard, Wang et al. 1994, Proll, Siefert et al. 2005)



(Knoef 2005, Ruiz, Juarez et al. 2013, Speight 2014)

Figure 9. Gasifier Capacity Ranges (fuel energy input basis)

1.2.4 Tar production and gasifier type

Tar refers to condensable organic compounds in the product gas that can accumulate under certain operating conditions in the gas appliance, transfer lines, inlet devices, and other surfaces and generally limiting or degrading performance of the device using the producer gas (boiler, engine, etc.) (Milne, Evans et al. 1998).

Tar definitions include "*organics condensing above 100 C", "organics produced by gasification, and are generally assumed to be largely aromatic"* (Milne, Evans et al. 1998), and "*all organics boiling at temperatures above that of benzene*" (IEA 1998). Often referred to as "condensables" or "heavy hydrocarbons", the lack of a consistent technical definition for tar made comparison of results across research groups and equipment types difficult. This led to the IEA Gasification Task embarking on development of the "Tar Protocol". The European or EU Tar Protocol defines tar as the:

> "*generic term for all organic compounds present in the gasification product gas excluding gaseous hydrocarbons (C1 through C6)*"(CEN 2006)

In general, downdraft gasifiers produce relatively low tar, updraft gasifiers produce high-tar gas with fluid bed and entrained flow gasifiers falling somewhere between the two (Table 2). The higher the temperature (and duration) that intermediate and product gases experience in the reactor, the lower the tar, in general.

Table 2. Tar in raw gas by gasifier class

	Fixed Bed		Fluidized Bed		
	Updraft (counter current)	Downdraft (co-current)	Bubbling	Circulating	Entrained
Mean tar content (g Nm^{-3})	50	1	12	8	10
Range of tar (g Nm^{-3})	1-160	0.01-6	1 - 150	1 - 150	2 - 30

Sources: (Milne, Evans et al. 1998, Morf 2001)

STATUS

Researchers at UC Riverside reported that more than 100 gasifier facilities worldwide have been built since 1979 that had operated using solid waste feedstocks that included biomass, municipal solid waste (MSW) or industrial wastes(Welch 2009). Facility scale ranged from 500 to 200,000 tons per year. It is not known which are still operating. Others claim that more than 100 solid waste gasifiers are operating in Japan(Arena 2012, Whiting 2012).

1.3 Databases

The International Energy Agency (IEA) Task 33 (Thermal Gasification) has an online database of thermal gasification projects in the participating countries as well as several entries from Canada, the UK, New Zealand, Japan and Turkey.[2] It contains about 140 projects and including combined heat and power (CHP), syngas and fuels applications and indicates if they are planned or built. It does not appear to be updated or current as some entries are known to be out of date or no longer correct.

The National Energy Technology Lab (NETL) maintains several gasification databases which are comprised mostly of large capacity (> 100 MW) coal projects but also contains some biomass-to-liquid fuels thermal projects (no biopower projects were noted).[3]

Tom Miles (TR Miles Technical Consultants Inc.) maintains a biomass gasification discussion listserv and associated website with a list of gasifier developers and projects that receives additions from list serv participants.[4]

1.4 Biomass CHP Systems

1.4.1 Biomass Gasification Manufacturers Database

Approximately 90 listings are contained in a recently compiled (December 2014) database of predominantly biomass gasification technology suppliers (See Appendix). Information includes company name, country, web address and short description of the technology, including gas cleaning system if known. Also energy capacity and technology status (any operating references?) are mentioned when information was found.

Most of the information came from a survey of the Internet with a limited number of phone follow up . An initial list came from the CA Statewide Wood Energy Team (SWET) efforts[5]. Contributions also were provided by the Bioenergy Resource Center, Burlington VT.

Major sources of information included Gasification BioEnergy List (http://gasifiers.bioenergylists.org/ ;TR Miles Technical Consultants Inc.), IEA BioEnergy Task 33: Thermal Gasification of Biomass (http://www.ieabioenergytask33.org/), a list produced by Black & Veatch for the Sacramento Municipal Utility District (SMUD), and individual company webpages.

[2] http://ieatask33.org/content/thermal_gasification_facilities . Participating countries are: Austria, Denmark, Italy, Germany, Finland, The Netherlands, Norway, Sweden, Switzerland, and the US.
[3] http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasification-plant-databases : Separate databases available for US proposed projects, non-US proposed, and one for projects in China.
[4] http://gasifiers.bioenergylists.org/content/gasification-systems-and-suppliers
[5] Angela Lottes, Nick Gouletete, Peter Tittmann, Ricky Satomi, and Rob Williams

1.4.2 Europe

There are numerous small to large scale biomass CHP systems in Europe with development continuing due to generally higher energy prices in Europe, extensive greenhouse gas reduction policies (that have in general been in place longer than those in California), and extensive distributed or district heat networks in Northern European countries. In addition to the well publicized biomass gasification CHP facilities at Gussing, Austria, Skive and Harboore, Denmark, Lahti, Finland and many others[6], there are newer facilities and technology providers that are worth evaluating. A few with systems ranging from about 40 kWe to multiple MWe are mentioned below. They are taken from the gasifier database in the Appendix.

Urbas

Urbas is an Austrian industrial and energy company offering 100 – 200 kWe CHP units using fixed bed gasifiers and engines (not clear if downdraft or updfaft). It is not clear if a wet system is used for gas cleaning. There are several reference facilities listed in the brochure including an apparent 1 MW site using a 5x 200 kWe combined unis in Terni, Italy[7]. .

http://www.urbas.at/

Figure 10. Urbas CHP Faciilty (150 kWe, 300 kWth)

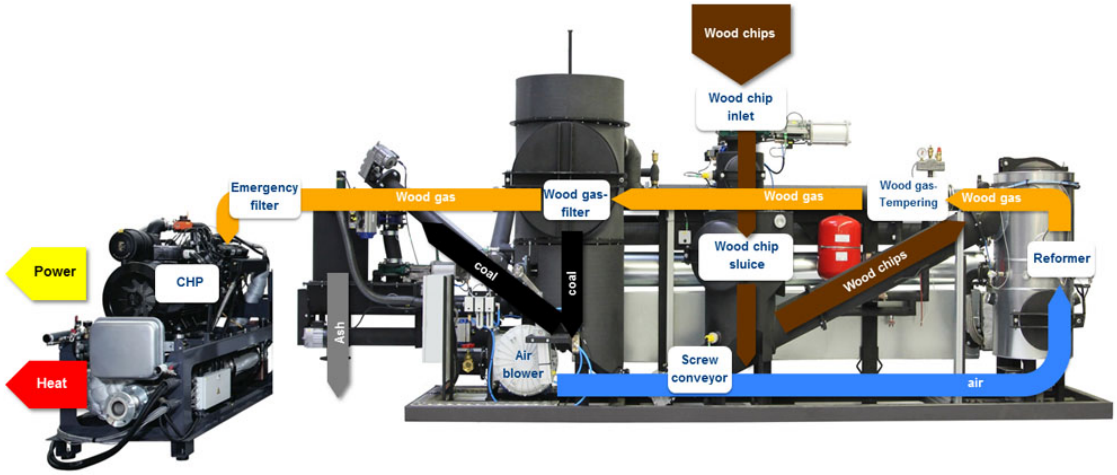
Spanner

Metal working company in Germany with ties to automotive industry there. The Gasifier appears to be a small, automated downdraft type, possibly developed by Bernd Joos. System

[6] See Country Reports and Meeting Minutes for IEA Bionergy Task 33: Thermal Gasification of Biomass (http://ieatask33.org/) and Williams, R. B. (2005). Technology assessment for advanced biomass power generation - Final Report for SMUD ReGen program, University of California, Davis. *CEC PIER Contract 500-00-034*.

[7] http://www.urbas.at/assets/dokumente/kwk_en.pdf

capacity is 30-45 kWe and uses gas temperature modulation and a fabric filter for cleaning. It is not clear if water scrubbing is used or whether condensate collects. Many systems purported to be in operation[8].



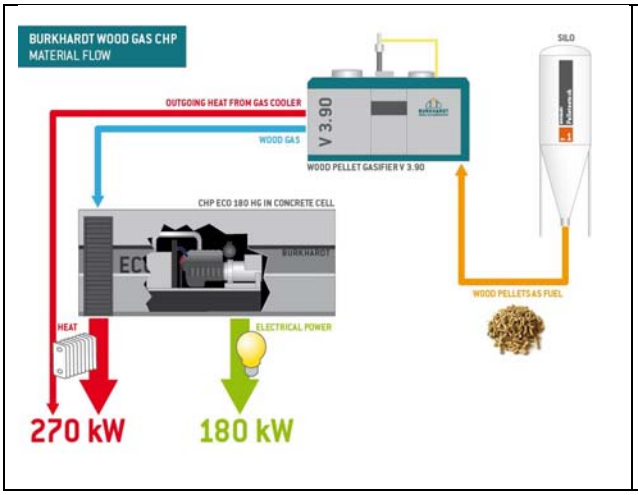
http://www.holz-kraft.de/en/

Figure 11. Spanner gasification CHP set

[8] See http://www.holz-kraft.de/images/pdfs/Holz%20Kraft%20Prospekt%20en.pdf

Burkhardt Energie

Turnkey wood pellet gasifiers (including CHP) modules. Electric capacity is 180 kW. Website indicates more than 300 units installed and operating. These systems require spec wood pellets but otherwise are highly automated. The gasifier is a "stationary fluidised bed". Systems are highly monitored and automated, including some onboard real-time gas analysis for monitoring and control. Uses MAN engines, apparently with dual-fuel (diesel)- technical specs mention pilot fuel consumption of 4 litre/h. It is not clear what gas conditioning system is used and whether there is liquid discharge.



Burkhardt System Schematic
http://www.burkhardt-gmbh.de

5 x 180 kWe wood pellet gasifier and engine-gen sets

Figure 12. Burkhardt

Bio&watt, Italy

Apparent "stratified – downdraft – twin fire" fixed bed gasifier, water scrubbing and wet ESP, recip. engine. The vendors claim no liquid discharge, but there is no description for how scrubber water is treated, though there is a thermal oxidizer for burning char and pyrolysis oils (perhaps the tar water?). A 300 kw facility in Pomarico, and a 200 kWe facility Matera, Italy may be operating.

EQTEC, Spain

Fluid bed (bubbling) reactor. Claim 1, 5 and 6 MW facilities operating or commissioning (2015) in Europe. Technical descriptions indicate pox tar reformer, hot gas filtration and water scrubbing cooling for final cleanup. Seems to be working w/ General Electric (GE) Jenbacher engine company and may be marketed as GE integrated biomass gasification systems.[9]

[9] See: http://www.eqtec.es/fitxer/572/Eqtec%20GasifierTechnology_ENG.pdf

http://www.eqtec.es

Figure 13. EQTEC gasifier image, 1 MWe facility

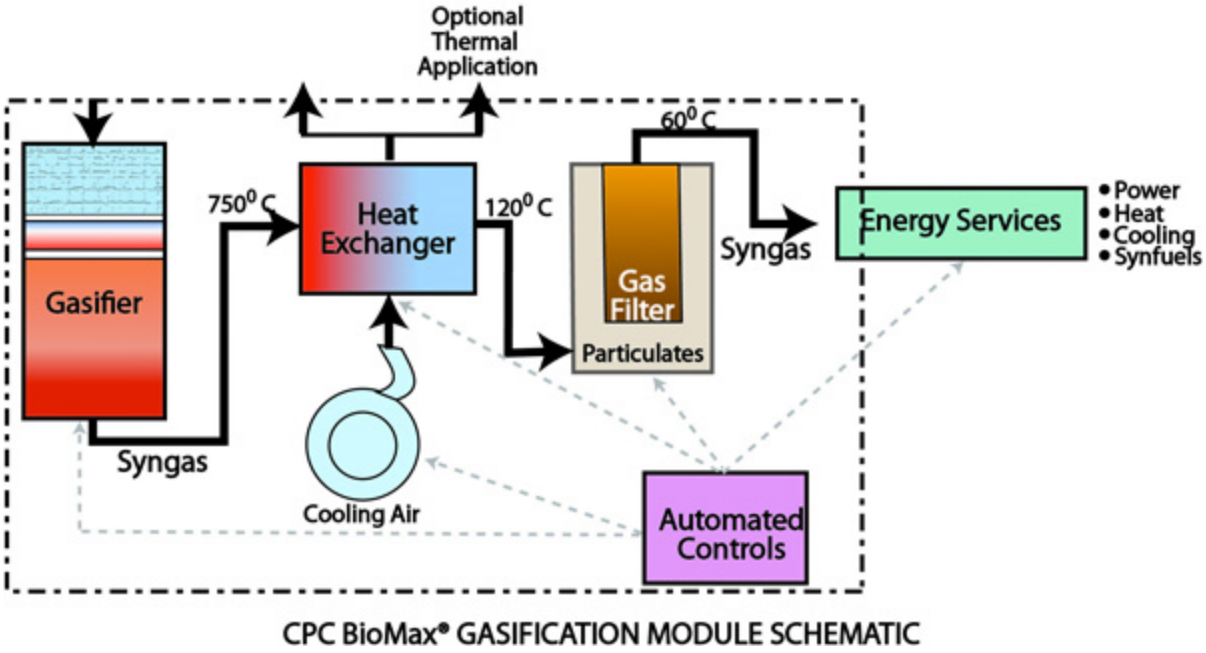
1.4.3 California

1.4.3.1 Community Power Corporation

Community Power Corp. (CPC) has developed an automated, containerized gasification system that uses dry gas filtering and cleaning. The gasifier is a modified open core downdraft design with multiple, modulated air injection nozzles at mid and lower bed level. Gas exiting the gasifier is cooled to about 120^{o} C and then passes through a set of bag filters removing particulate matter with some condensed tar. Gas temperature exiting the filter is about 60^{0} C which is normally above the water and tar dewpoint. The warm gas then is used to fuel spark ignition engine-generator sets for power production. An important positive feature of the CPC system is that no liquid scrubbing is used in the gas cleaning process, little to no condensed liquids accumulate, and no tar contaminated liquid that would need disposal or treatment is created (Figure 14).

CPC received early funding from the Energy Commission to demonstrate a 12 kWe unit Northern California in the early 2000's.[10] Larger systems have been built and demonstrated since.

[10] CEC PIER 2002 Annual Report (http://www.energy.ca.gov/reports/2003-03-28_500-02-076F.PDF)



Source: http://www.gocpc.com/images/stories/CPC-Gas-Production-Module-Schematic.jpg

Figure 14. CPC system schematic.

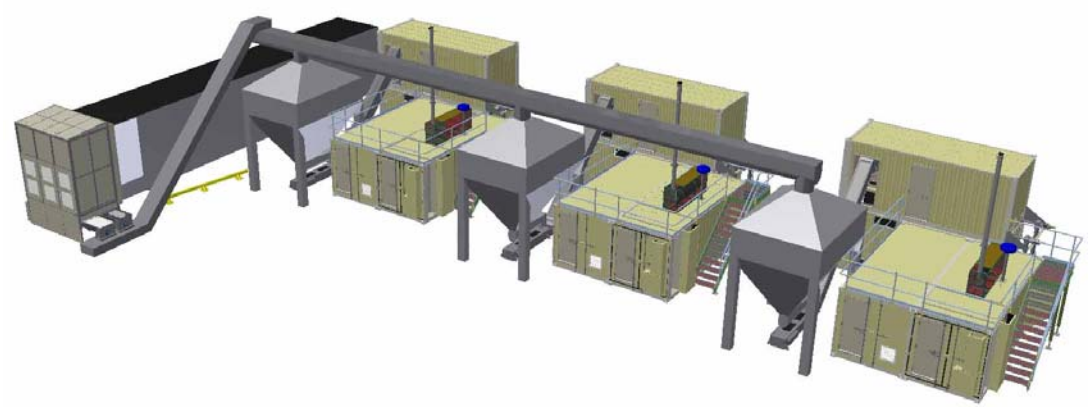
Capacity of the current unit is 100 kW. CPC systems have been deployed in numerous grant-supported demonstration projects but few, if any are considered commercial (profitable). Capital cost of the 100 kWe system ranges from about $7500 – $10,000/kW installed (personal communication CPC 2013). Levelized cost of energy would then be more than $200/MWh.

A 50 kW system fueled by walnut shells was demonstrated for several years at Dixon Ridge Farms near Winters, CA. That was replaced by a 100 kW in late 2012 which also has been operating well. (Figure 15).

A facility with up to 300 kWe capacity, also fueled by walnut shells is being installed and commissioned at a mushroom grower in Colusa, CA [11] . CPC will bundle 3 x 100 kW systems into a so-called energy farm (Figure 16).

[11] http://www.gocpc.com/more-information/biomax-overview.html#farm

Figure 15. CPC Biomax 100 at Dixon Ridge Farms.



Source: http://www.gocpc.com/more-information/biomax-overview.html#farm

Figure 16: Proposed 3 x100 kW CPC system at Premiere Mushrooms

1.4.3.2 West Biofuels

West Bioufels is developing gasifier-based CHP and biofuel solutions and operates a research and development facility in Woodland CA. Originally operating a Kuni indirect-dual-bed gasifier, they have now installed a ~ 3-5 ton/h Repotec FICFB (Austria) gasifier for research and development and to explore commercial applications in California and North America (Figure 17). The West Biofuels FICFB is currently being commissioned.

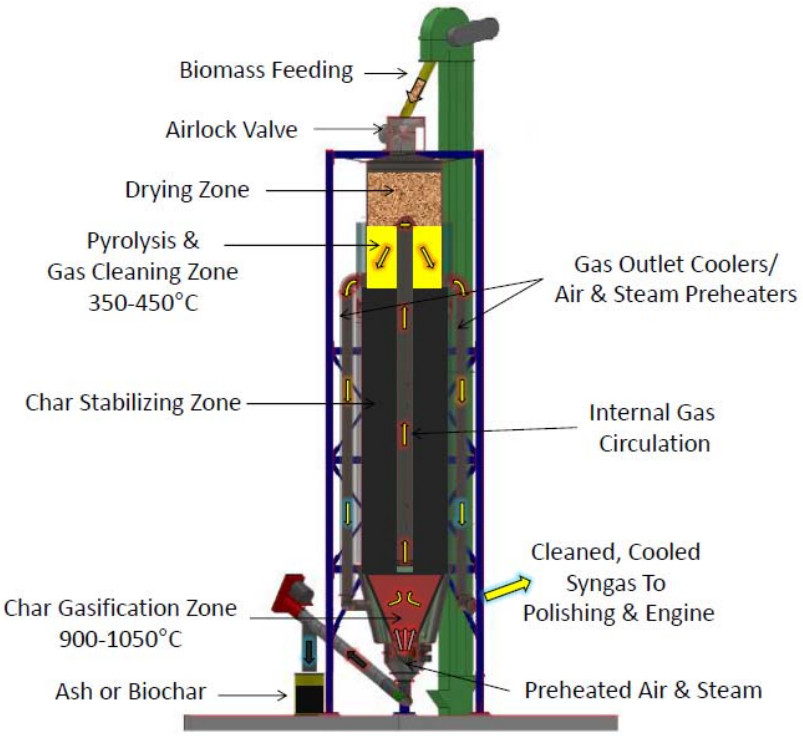
(Photo: Matt Summers)

Figure 17. FICFB reactor installed at West Biofuels

West Biofuels is also developing a second gasification technology developed by Inser, in Italy. The "Circle Draft" gasifier is a unique modified downdraft reactor that recirculates the product gas through the charcoal bed before exiting the reactor (Figure 18). This arrangement is

purported to produce a low-tar gas. Though the design has been piloted in Italy, tar production data are not available.

The Circle Draft reactor is less complex than the FICFB and would have a lower capital cost. West Biofuels will start commissioning the Circle Draft in early 2015 and develop performance information.



(Matt Summers)

Figure 18. Schematic, Inser "Circle Draft" gasifier

West Biofuels is a recent awardee of a $2 million Energy Commission grant to develop a modular system to facilitate forest fuel reduction treatments[12].

[12] NOPA _ PON–14-303: Advancing Cleaner, Less Costly, More Reliable Distributed Generation to Enable Customer Solutions and Zero-Net Energy Communities. http://www.energy.ca.gov/contracts/PON-14-303_NOPA.pdf

1.4.3.3 Phoenix Energy

Phoenix Energy has installed and commissioned two small biomass gasifiers in California and is developing a number of other projects in the state. A 500 kWe facility was commissioned in 2011 near Merced (Figure 19), and a 1 MWe began commissioning at Central Valley Ag Grinding (CVAG) near Oakdale in late 2012 (though the CVAG facility has since changed direction ([see below]).

Figure 19. Phoenix Energy Gasifier, Merced

The Merced and CVAG gasifiers and gas cleaning equipment were supplied by Ankur Scientific, India. Ankur sells a standard downdraft (throated, or Imbert style) gasifier. Caterpillar spark-ignition engines with 3-way catalytic converters for emissions control were specified.

Ankur gas cleaning consists of a cyclone, water scrubber, mist removal, gas chiller, sawdust filter bed, and finally a pleated filter (Figure 20). Scrubber water is injected into the hot gas for cooling and tar condensation. A fairly large amount of tar-contaminated water is created which needs treatment and/or disposal.

Both facilities have experienced difficulties while commissioning. Overproduction of tar caused accumulation and clogging of scrubber piping and tuyere tips (air nozzles) were overheated and burned or consumed, among other issues. [13,14] Primarily because of the large quantity of tar produced and difficulty in its management, the CVAG facility is planning to forego power production and instead use the producer gas to fuel a rotary drum dryer which should be able to better tolerate tar in the gas.[15]

The Merced facility reportedly operates intermittently depending on electricity price and whether there is a buyer for the biochar that is also produced.

Maximum capacity for a throated downdraft gasifier is recommended not to exceed 500 – 700 kWe) (Bridgwater 1995, Knoef 2005).

Phoenix Energy is also part of the project teams developing the Cabin Creek 2 MWe CHP facility in Placer County and the 1 MWe CHP project at North Fork. Phoenix will likely specify a different gasification technology supplier than Ankur for these projects.

[13] Stangle, G. (2010). Personal communication.
[14] Doug Snider (2013). Personal communication.
[15] Doug Snider (2015). Personal communication.

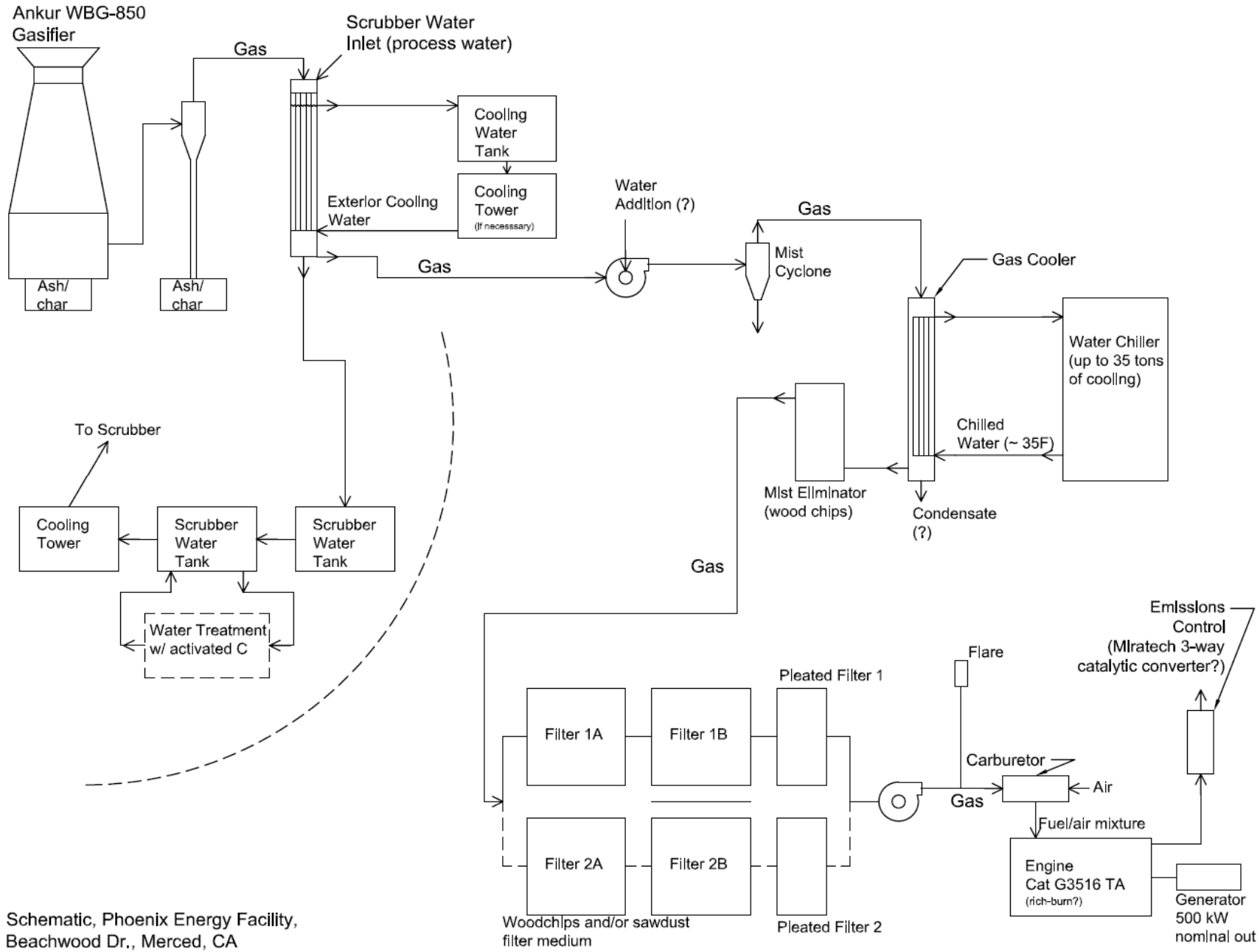


Figure 20. Phoenix Energy, Merced: Ankur Gasifier and gas cleaning

1.4.3.4 Sierra Energy

Sierra Energy is developing a modified updraft oxygen blown gasifier based on a blast furnace design used in the steel making industry (Figure 21). It operates at high enough temperature to melt the ash or inert material present in feedstock (slagging gasifier) and should accept a wide range of feedstock types from petcoke, tires, MSW and biomass.

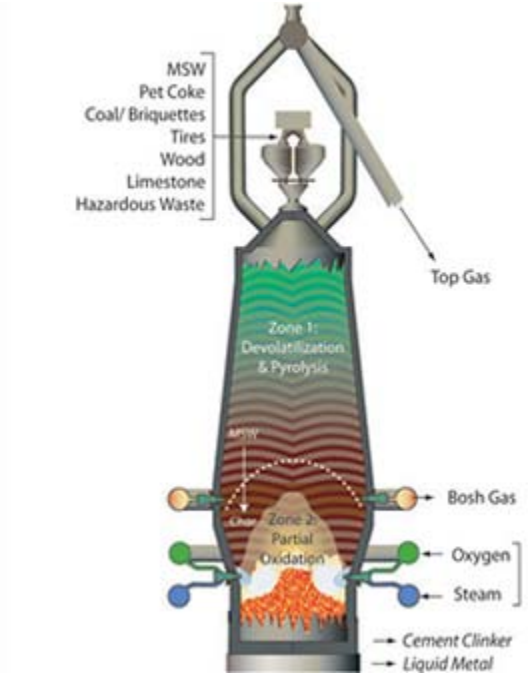


Image source: www.worldfuels.com

Figure 21. Sierra Energy "FastOx" gasifier.

Sierra Energy is targeting high energy and/or high disposal cost (high tipping fee) materials for feedstock (petcoke, coal, used tires, medical waste, MSW) but also is interested in biomass (or biomass/MSW) projects for the renewable attributes of the energy produced. Energy products include CHP, high quality syngas for fuels or chemical production as well as hydrogen.

Sierra Energy has received a multi-million dollar grant (or grants) from the Energy Commission to demonstrate commercial scale bioenergy at the Port of Sacramento. They have also received a several million dollar grant from the Dept. of Defense to demonstrate modular distributed generation fueled by onsite waste at Fort Hunter Liggett in Monterey County. The location of the Energy Commission demonstration grant has been transferred from the Port of Sacramento to Fort Hunter Liggett.

The project at Fort Hunter Liggett is expected to begin commissioning in 2015[16]

[16] http://www.biofuelsdigest.com/bdigest/2014/11/05/4-minutes-withmike-hart-ceo-sierra-energy/

1.4.3.5 City of San Jose

The City of San Jose and technology partner Harvest Power received a $1.9 million grant from the Energy Commission in 2010 (for PON-09-604- Alternative and Renewable Fuel and Vehicle Technology Program)[17] The proposed goal of the project was to demonstrate production of a renewable synthetic natural gas (RSNG) of quality suitable for upgrading to vehicle fuel from the thermal gasification of urban woody biomass and biosolids.

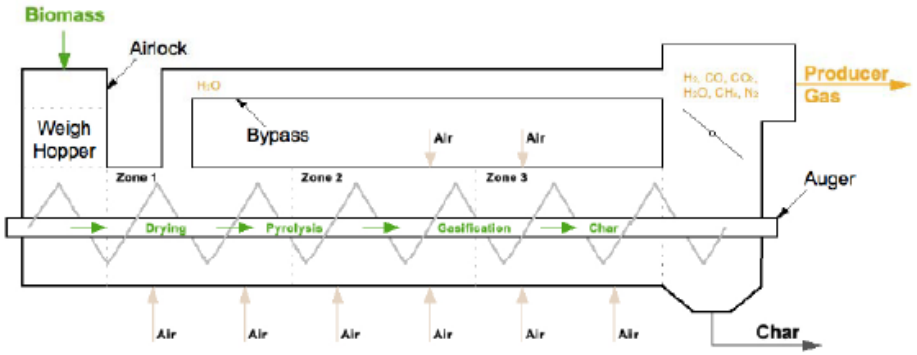
The technology partner Harvest Power was working with and planned to use an indirect-heat steam gasfication process followed by methanation from a system developed by Agnion (Germany).

A Draft Feasibility Study was developed and issued to the Energy Commission in November 2013. Due to a change in Harvest Power's technology emphasis, the Project partner was changed to a team consisting of JUM Global LLC (JUM) and Zero Waste to Energy (ZWE) with plans to use the Concord Blue Energy's (CBE) gasification technology. The project also proposed to change the output product from a crude renewable natural gas to a "high quality" CO and H_2 syngas suitable for upgrading to hydrocarbons or chemicals. CBE also has developed an indirect-heat steam gasification system; all partners combined are defined in this Study as the "Development Team".

However, due to project delays, the new technology partner (JUM Global, LLC) could not make a firm commitment to CBE and lost their place in line for timely manufacture of a CBE reactor.

ICM Technology

Subsequently, JUM brought on ICM which has licensed a gasifier from Phoenix Bioenergy (different entity than the Phoenix Energy mentioned above). The ICM/Phoenix Bioenergy gasifier is a horizontal cylinder with internal auger which slowly rotates to move feedstock through the reactor (Figure 22). Air is continuously injected at multiple locations along the gasifier.



(Source: ICM)

Figure 22. ICM gasifier schematic

[17] www.**energy**.ca.gov/contracts/**PON-09-604_NOPA**.pdf

The gasifier was originally intended for heat applications via close-coupled combustion of the product gas. ICM operated a demonstration facility at a transfer station in Newton, Kansas on and off from 2009 through 2012 during which time a variety of feedstocks were tested (3,200+ hours of operation over 42 months). Most of the product gas was flared, but about 10% of gas was burned in a thermal oxidizer/ boiler system to demonstrate steam production.

While air-blown direct gasification usually is not proposed for high quality or fuels-grad syngas because of low volumetric energy content of the product gas (containing approximately 50% N2), ICM is planning to modify and test the reactor using oxygen instead of air for the gasifying agent.

There is little time remaining on the grant. All demonstration must occur by end of March, 2015. No hardware has yet been placed at the site (January, 2015).

1.4.3.6 SMUD Gasification Based CHP Request for Interest

In October 2014, the Sacramento Municipal Utility District (SMUD) issued a Request for Statements of Interest (RSOI) in the development of a biomass gasification project for combined heat and power (CHP) application in Sacramento, California. [18]

SMUD is targeting at least a 3-megawatt (MW) project size, using clean wood waste. HP Hood, the likely project host, could possibly use (buy) heat from the project. SMUD indicates that a feedstock availability assessment shows there is sufficient nearby wood waste to support 3+ MW-scale facility.

A number of responses were received which are currently being evaluated by SMUD.[19] SMUD would enter into a power purchase agreement for the electricity.

1.4.3.7 Small CHP Active Development Projects.

Cabin Creek Project, Placer County

This is a proposed 2 MW gasification CHP facility that would be adjacent to a closed landfill near Truckee, CA. The goal is to use local forest thinning material that otherwise might be open burned or hauled out the area. Phoenix Energy will build and operate the facility. The technology has not been publicized but is thought not to be an Ankur system which Phoenix Energy has installed near Merced and at Central Valley Ag. Grinding (Section 1.4.3.3).

Northfork, Madera County

The North Fork Community Development Council is planning to implement a 1MW bioenergy generation facility at the town's former Mill Site. The project is a strategic step to producing green energy and finding economic uses for biomass material generated by forest management

[18] https://www.smud.org/en/about-smud/news-media/news-releases/2014/2014-11-04-gasification.htm
[19] Lemes, Marco (2015). SMUD. Personal Communication.

and hazardous fuel treatment activities in the area. It is also an important step towards redeveloping the mill site and restoring the town's economy. It is believed Phoenix Energy is the developer but no information on technology selection is available.

Wilseyville, Calavaras County

The Wilseyville Woody Biomass Product Yard is a proposed economic development project. The proposal includes a 2 to 3 MW biomass/CHP plant; a small saw-mill; wood-drying kilns; forest and green waste chipping for lawn and soil amendments; native plants greenhouse for landscapes and reforestation; wholesale firewood; and agricultural and architectural posts and poles production.
A feasibility study of local woody biomass sources in the area has been completed in 2012, but project status is not known.

1.4.3.8 Blue Lake Rancheria

The Blue Lake Rancheria in Humboldt County and the Schatz Energy Research Center (Humboldt State University) is installing a biomass-to-fuel cell distributed energy demonstration project funded in part with an Energy Commission grant.

The project has specified a gasifier from Proton Power, gas upgrading equipment (for removing CO and other fuel cell contaminants from product gas), and a 175 kW PEM fuel cell from Ballard Power Systems.

The Proton Power gasifier is an opaque process optimized to produce high H_2 concentration from solid biomass ("Hydrous Pyrolysis)". Post-cleaning gas composition is claimed to be 65% H_2, 30% CO_2, 5% CO. The company has a demonstration project using switchgrass feedstock and 3 Caterpillar gensets (750 kW capacity) in operation at Wampler Sausage in Tennessee.

1.4.3.9 All Power Labs

All Power Labe (APL) is located in Berkeley, CA and produces 15 kW "Power pallet" turnkey gasifier based power systems ("personal scale power"). The technology is batch fed downdraft gasifier. Target market is "personal scale power" and rural electrification or off grid generation. Batch system allows for~ 6-8 hours operation. The Mendota Beet Energy Group has a "Power pallet" to investigate potential for gasification-to-power as part of the biorefinery effort. APL has developed a CHP unit compliant with EU regulations and has option for continuous operation/feed (Figure 23). APL is developing a 100kW container based gasifier. A 100 kW unit was demonstrated at the University of Minnesota (US DOE grant) and APL was recently the winner of a $2 million Energy Commission grant to develop a modular power plant able to convert forest fire remediation waste into on demand clean energy[20].

[20] NOPA _ PON–14-303: Advancing Cleaner, Less Costly, More Reliable Distributed Generation to Enable Customer Solutions and Zero-Net Energy Communities. http://www.energy.ca.gov/contracts/PON-14-303_NOPA.pdf

(Source: http://www.allpowerlabs.com)

Figure 23. APL “Power Cube” CHP unit.

1.4.4 Bay Area Biosolids-to-Energy Coalition BAB2E

Composed of nineteen Bay Area water treatment agencies, the Bay Area Biosolids-to-Energy Coalition (BAB2E) was formed to create a local sustainable solution to biosolids management by utilizing the remaining energy. Most of the participating agencies presently utilize a combination of hauling biosolids for land application and/or alternative daily cover at landfills but more restrictive land-application regulations are motivating the coalition to seek a long term, sustainable, and publicly acceptible alternative.

The coalition was formed in 2006 and has been investigating potential biosolids conversion technologies. Also with an Energy Commission demonstration grant, a number of projects using innovative technologies were attempted including two that would make hydrogen;

- Intellergy – Steam/CO2 gasification and reforming to produce H2 gas
- Chemergy – Aqueous bromine & biomass reaction forming HBr, then electrolyzed to H2

Neither of these demonstrations was built due in part to difficulty obtaining sufficient match funds.

BAB2E also conducted an RFP process for commercial scale biosolids conversion. MaxWest (Florida) and SCFI (SCFI) were selected for negotiations to build a project.

MaxWest offers a fluid bed gasifier with close-coupled combustion of the product gas for heat that is used to dry the biosolids to a suitable moisture content for gasification. While there is little

to no byproduct energy (other than drying the biosolids), the system would serve as an energy neutral method to dispose of biosolids. Unfortunately, MaxWest went into bankruptcy proceedings in July, 2014 and the project with BAB2E is not likely to occur.

SCFI offers a supercritical water oxidation system for converting, mineralizing, or stabilizing organic materials. The process creates some useable heat (possibly for steam or hot water) and potentially a concentrated CO_2 stream. BAB2E and SCFI are negotiating terms of a project.

1.5 Renewable Natural Gas Systems

Biomass derived methane (biomethane) is normally produced from biogas created by anaerobic fermentation (anaerobic digestion) of appropriate substrates. Gas production potential from anaerobic digestion depends on feedstock characteristics. Materials with high starch and/or lipid and low lignocellulose content produce relatively large amounts of biogas (methane) compared to high lignin, low carbohydrate substrates. Bulk mixed wastes that include lignocellulosic components convert to biogas with energy efficiency of 20-40% (energy in biogas divided by energy in substrate) (McKendry 2002).

Biomethane can also be produced via thermal gasification with appropriate raw gas cleaning and reforming to a synthesis gas followed by methanation and upgrading to biomethane (Figure 24). Methane synthesized via this thermal gasification / methanation route is sometimes called synthetic natural gas (SNG) and renewable SNG (RSNG) if derived from biomass. Overall efficiency for RSNG would be ~ 65% for commercial scale facilities (Kopyscinski, Schildhauer et al. 2010, Mensinger, Edelstein et al. 2011, Aranda, van der Drfit et al. 2014). Overall thermal efficiency of biomass to RSNG to electricity would be ~30-33% if burned in a combined cycle natural gas power plant (assumes 50% efficient combined cycle power plant).

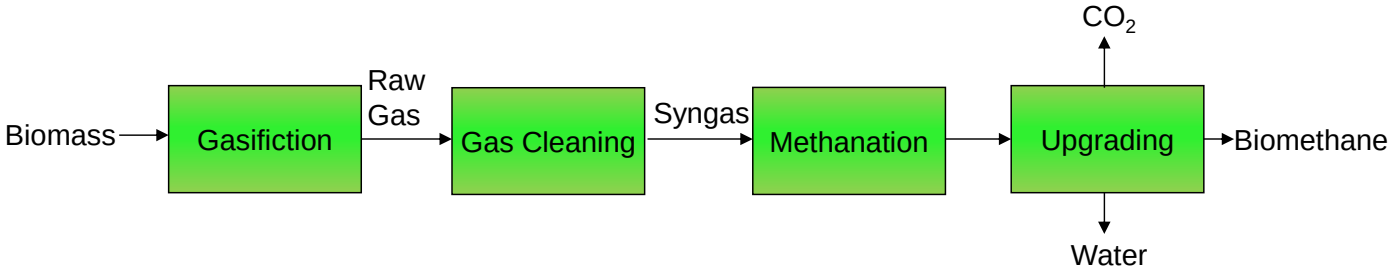


Figure 24. RSNG Process Schematic

1.5.1 Biomass-to-SNG Demonstration Projects

The Paul Scherrer Institute (PSI) has developed a fluidized bed methanation reactor (based on the Comflux technology) for use on a portion of the product gas at the Güssing, Austria allothermal

gasification CHP plant. Initial demonstration with a 10 kW_{SNG}[21] reactor took place between 2003 and 2008 which included a run of more than 1,000 continuous hours. The 10 kW_{SNG} demonstration led to development of a 1 MW_{SNG} process development unit (PDU), complete with gas upgrading, also at the Güssing site. In 2009, a 250-hour run of the 1 MW_{SNG} PDU was completed producing about 100 m3·h-1 of SNG (Kopyscinski, Schildhauer et al. 2010).

In the Netherlands, ECN (a research lab) and the utility HVC are building a 12MWth wood fueled gasification CHP facility that will include demonstration of RSNG production (Bush 2012). There are plans for a follow-on 50 -100 MW_{SNG} commercial scale demo (Aranda, van der Drfit et al. 2014).

The GAYA Project in France intends to build and demonstrate a 20-60 MW_{SNG} commercial scale demonstration facility possibly as early as 2017(Aranda, van der Drfit et al. 2014). GAYA is a research consortium composed of technology providers and academic institutions.

1.5.2 Announced Commercial Wood-to-RSNG Projects

GoBiGas, Sweden

The GoBiGas project in Sweden, is undergoing commissioning. It is a 20 MW_{SNG} wood-to-RSNG facility. It employs allothermal gasification technology by Repotec (same as used at the Güssing, Austria CHP facility). There is an 80 -100 MW SNG Phase II facility planned with a possible 2017 start. (Göteborg Energi 2012).

National Grid Gas Distribution, UK

This project seeks to prove the technical and economic feasibility of thermal gasification of waste to renewable gas. It will test and demonstrate this by taking a waste derived syngas from Advanced Plasma Power's (APP) Gasplasma® demonstration facility, located at Swindon and upgrade it through a dedicated conversion and clean up plant to a pipeline quality gas. Methanation equipment is being installed with demonstration planned to start mid-2015.

E.ON, Sweden

The European utility company E.ON is siting a 200 MW_{SNG} wood-to-RSNG facility in Sweden. Named "Bio2G" (second-generation biogas), E.ON, in partnership with the Gas Technology Institute (GTI) and others, has tested methanation reactors and is developing designs for up to 600 MW_{SNG} capacity (Stahl 2011, Bush 2012).

[21] kWsng refers to gas production capacity (energy flow rate of product SNG)

1.6 Gasification of Municipal Solid Waste

Please refer to the CREC Task 6 Report: Survey of MSW Conversion Options (Williams and Zhang 2013).

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APPENDIX

Biomass Gasification Manufacturers Database- Internet Survey with some phone follow up (very few phone follow-ups). Initial list was from CA Statewide Wood Energy Team efforts (Angela Lottes, Nick Goulette, Peter Tittmann, Ricky Satomi, and Rob Williams). Contributions also came from Bioenergy Resource Center, Burlington VT. Major sources of information included Gasification BioEnergy List (http://gasifiers.bioenergylists.org/ ;TR Miles Technical Consultants Inc.), IEA BioEnergy Task 33: Thermal Gasification of Biomass (http://www.ieabioenergytask33.org/), a list produced by Black & Veatch for SMUD, and individual company webpages.

Country	Manufacturer	URL	Comments
Australia	Entech	http://www.entech-res.com/wtgas/	close-coupled gasification/combustion or staged combustion for heat or steam power. Web diagram shows a reciprocating/stepped grate type furnace (starved air) followed by thermal oxidizer for gas. Apparently facilities in Poland and Taiwan mostly using bio-hazardous waste, also slaughter house waste.
Austria	Cleanstgas	http://www.cleanstgas.com/en/technology/cleanstgas-innovation/	Joint venture of EBNER Industrieofenbau and KWB Die Biomasseheizung (Austria). Developing "medium sized wood gas power plants". Claim low tar production, staged gasification?? Not clear if any facilities other than a demonstration. See http://www.cleanstgas.com/fileadmin/templates/cleanstgas/docs/IB_Cleanstgas_2013_A4_AT_Low.pdf
Austria	Craftwerk / Syncraft	http://www.syncraft.at/sce/en/GF_heizkraftwerk.php	"CraftWERK" floating bed gasification technology. Appears to have an 'alpha' and 'beta' demonstration faciities (250 kWe). Beta included CHP. Company also develops scrubbing technologies for producer gas including water and RME solvents.
Austria	FICFB (See Repotec)	http://www.ficfb.at/	FICFB = fast internal circulating fluidized bed. Reactor design by Hofboaur, U. Vienna
Austria	OkoFen	http://www.oekofen-usa.com/en-us/products.html	small residential pellet boiler coupled with Stirling engine - OkoFEN_e TECHNOLOGY (w/ Stirling engine)
Austria	Repotec	http://www.repotec.at/index.php/references.html	Multiple demonstration and functional facilities. This is the technology used at Gussing, Austria which has been operating since ~ 2000. Well known and documented demo CHP project. West Biofuels in Woodland, CA is working with technology provider iln attempt to build/market projects in the US. West Biofuels is modifying their demo reactor into the Gussing design (dual fluid bed indirect gasifier- air-blown...)
Austria	**Urbas**	http://www.urbas.at/default.asp	Austrian Industrial and energy company offering CHP units using fixed gasifiers and engines (not clear if downdraft or updfaft design but chunked wood photos in brochure imply downdraft). Not clear if wet system used for gas cleaning. Apparently has several reference gasification CHP plants. Literature indicates capacities ~ 100 to 200 kWe per gasifier. Apparently a 1 MW site using a 5x 200 kWe combined facilityin Terni, Italy. http://www.urbas.at/assets/dokumente/kwk_en.pdf
Austria	Xylogas	http://www.xylogas.com/index_e.html	Austrian company. Downdraft based CHP. ~ 200 kWe per reactor. Brochure claims ~ 2 operational facilities, w/ 2+ more in development. Brochure implies a wet scrubbing method for gas cleaning, but no details. http://www.xylogas.com/PDF/Brosch%FCre%20-%20Holzvergasungs-Kraftwerk-Englisch.pdf
Belgium	Xylowatt	http://www.xylowatt.com/	"NOTAR" staged down-draft design - can be air or oxygen blown. Gas cleaning includes organic solvent scrubbing and sub-dewpoint cooling before use. City of Tournai a NOTAR®1000 gasification module that converts wood into syngas. 300kw electrical 600kw heat. In Gedinne, building a NOTAR 2000 unit for 600 kWe + heat. Have an oxygen-blown design for demonstration for LIFE OxyUP project.
Bellingham	New Range Power	http://www.newrangepower.com/about-nrp.html	Partnered with "Diversified" for manufacturing. Youtube video shows a typical looking downdraft with wet scrubbing. Does not appear any active facilities exist

Canada	Enerkem	http://enerkem.com/en/home.html	BFB gasifier. MSW and wood waste conversion to fuels and chemicals. Commissioning 10 MM g/y ethanol/methanol facility in Edmonton.
Canada	Ensyn	http://www.ensyn.com	http://www.ensyn.com/technology/key-rtp-facilities/ renfrew, Ontario facility processed about 75 tonnes of dry wood waste a day for conversion into fuel. Developing palm oil biomass conversion facility.
Canada	Krann Engineering	http://krann.ca/index.html	BC Canada. Purportedly markets an updraft close-coupled combustion system for heat applications mainly. Not clear if operating units exist.
Canada	Nexterra	http://www.nexterra.ca/files/gasification-technology.php	Several heat or boiler based power systems built, maybe still operating. One engine facility known at UBC but rumors are tar cleaning a problem for continued operation.
Denmark	**Babcock & Wilcox Voland**	**http://www.volund.dk/**	Much expericenc with biomass power including 4 MWth updraft woodchip gasifier built for the municipality of Harboøre (Jutland, Denmark), was commissioned in December 1993. Fully automated facility on weekends and holidays. Reported 4MWe facility commissioned in 2008 to be built in southern Italy but not clear if this happened.
Denmark	Biosynergi	http://www.biosynergi.dk/en/	75 kWe pilot plant operating for more than 4,000 hours (gasifier) and 3,400 hours (electricity generation) .Marketing larger systems. Limited details otherwise.
Denmark	Dall Energy	www.dallenergy.com/Projects.52.aspx	supposedly active facility in warrick mills, USA. needs follow-up. relatively new company
Denmark	Pyroneer	http://www.dongenergy.com/pyroneer/Pages/index.aspx	Only has a single demonstration facility. Facility currently operating at Asnaes Power Plant in Dennmark.. "low temperature gasification" using dual fluid beds, pyrolysis reactor and char gasifier". Seems intended for co fueling gas at a coal power plant. Demonstrated in straws and biosolids
Denmark	Weiss	http://www.weiss-as.dk/side5619-aid-3887-mid-190-params-89.html	Commercialization attempt of DTU Viking 2-stage gasifier, apparently. 0.5 Mwe, 0.9 MWth demo plant commissioning in Hillerord, Denmark. Scaled up Prototype Viking 2-stage gasifier at the Danish Technical University, working on another 500kw facility in Hillerød, Denmark with Weiss A/S at the contractor and Dall Energy as consultants. Primarily seems a combustion CHP company (biomass), no other gasification references listed. http://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/Forskning%20-%20PSO-projekter/10204%20Slutrapport%20Hillerod.pdf
Finland	Andritz Carbona	http://www.andritz.com/pp-gasification-andritz-carbona	Andritz Carbona offers several types of gasifiers including CFB, BFB, atmospheric, pressurized, air blown, and oxygen blown. The BFB gasifier in Skive is a descendent of the GTI Renugas design. Commercial unit producing power via reciprocating engines in Skive, Denmark. Pilot plants in Chicago and Finland. Commercial demonstration in Hawaii.
Finland	Condens Oy - Novel	-	Kokemaki facility in Finland established in early-mid 2000s. Updraft Novel gasifier w/ tar reforming. 1.8 Mwe and 3.1 MW th. Believe facility is no longer operating.
Finland	EntiMos	http://www.entimos.fi/inenglish.htm	2008 announcement of new facility, can't find more recent news. Had produced wood-gasifier-based CHP plants.
Finland	**Volter**	**http://www.volter.fi/en/page/2**	CHP units. Downdraft type gasifier, gas is cooled and filtered in fabric filter, no liquid scrubbing. Claim several reference installations in Finland. Marketed in the UK under ArboElectroGen
Germany	A.H.T. Pyrogas / AHT Services GmbH	http://www.aht-pyrogas.de/en/gasification-technology/doppelfeuer-gasification.html	Manufactures 7th generation Doppelfeuer, Downdraft and Updraft gasifiers. 1MW unit can be linked for up to 10 Mwe - Unclear whether they use gas turbines or engines? AHT Services claim 3 wood-to-gas energy references in Germany and one in Japan (see http://www.aht-energy.com/en/products/renewable-energy-generation/clean-gas-solutions.html)

Germany	**Agnion (Entrade)**	**http://www.agnion.de/en/**	Indirect heat steam gasification. Uses heat pipe technology to transfer heat from char combustion into gas producer chamber. Website indicates maybe 1 or 2 recently started facilities on wood. Was involved with San Jose and Energy Commission on grant to build a local demo but backed out due to activity in Europe. Also may have a demonstration project in Hawaii w/ the University
Germany	Bellweather	http://www.bgt-online.eu/index.php?lang=english	Turnkey Gasification Plant for treating calorific waste in Vaslui/Romania with a capacity of 90 000 t/a. other reference in Romania as well Turnkey Gasification Plant for treating calorific waste in Brasov/Romania with a capacity of 100 000 t/a. Last active in 2010 Need more technical information, current status of facilities unknown
Germany	Bioliq	http://www.bioliq.de/english/67.php	Looks like they only have a pilot plant under construction. Model is to use distributed pyrolysis plants to central gasification for fuels production
Germany	Burkhardt Energie	http://www.burkhardt-gmbh.de/en/home_site/	Turnkey wood pellet gasifiers (including CHP) modules - 180 kW systems. Website indicates more than 300 units installed and operating. Requires spec wood pellets but otherwise highly automated operation, Gasifier is a "stationary fluidised bed". System is highly monitored and automated including some onboard real-time gas analysis for monitoring and control. Uses MAN engines, apparently dual-fuel (diesel)- specs mention pilot fuel consumption of 4 litre/h. No liquid discharge?
Germany	Choren	www.choren.com	Apparently this company might be in bankruptcy.
Germany	Concord Blue Energy	http://www.concordblueenergy.com/	"Blue Tower". Indirect heated steam gasification. Uses hot ceramic beads to transfer energy into gas producer. Beads are heated from hot combustion gas from burning the char, or from burning natural gas or product gas. 6 facilities in operation, 3 under construction, 4 offices worldwide Claim to have at least one plant in Japan using wood chips
Germany	GTS Syngas	http://www.gts-syngas.com/en/home.html	Sister company to BTS Biogas (Germany). Not clear if any facilities built or operating.
Germany	Holzenergie wegscheid	http://www.holzenergie-wegscheid.de/?lang=en	Germany; Downdraft gasifier for CHP. Claims dry gas cleaning system. Website indicates ~ 10 recent installations, Europe. ~ 150 kWe per gasifier it seems
Germany	Kuntschar	http://www.kuntschar-holzgas.de/en/	Downdraft (?) system w/ dry gas cleaning (cyclone followed by hot gas filter, then cooled in air-gas heat exchanger). Specifies 15% moisture, chunked wood fuel pieces (1-3" pieces) w/ 2% max, fine composition. Looks to be < 200 kWe capacities. Not clear what is operating but pdf on the website indicates a 6 gasifier system in Italy has 900 kWe and 1,380 kWth capacity.
Germany	Mothermilk	http://www.mothermik.de/engl/prod-1holzver-e.html	Unclear if commercial operational facility exists. Apparently downdraft system w/ wet scrubbing and ESP gas cleanup. Mentions that tar sludge and used water require proper disposal.
Germany	NRG Consultants/ HR Energiemanagement GmbH	http://www.holzvergaserwerkstatt.de/#!biomass-power/ccxf	Small skid-mtd. turnkey systems up to 29 kW. Much like APL in Berkeley. Similar to Website is current, no listings of active facilities. http://media.wix.com/ugd/ec3d60_d5e9e8792b8945f9b7a89f7b8440efde.pdf

Germany	**Spanner**	**http://www.holz-kraft.de/en/**	Metal working company in Germany with ties to automotive industry there. Gasifier appears to be a small automated downdraft, possibly developed by Bernd Joos. System seems similar to APL, has fabric filter, not sure if water scrubbing is used or whether condensate collects. Many systems purported to be in operation. See http://www.holz-kraft.de/images/pdfs/Holz%20Kraft%20Prospekt%20en.pdf
Germany/ Italy	Pyrox	http://www.pyroxitalia.com/en/gasification-plants-projects	Developed and piloted in Germany mid 2000s. Pyrox Italia claims 2 or 3 CHP plants ~ 850 kWe. Schematic looks like downdraft system w/ wet scrubbing, maybe ESP PM removal. Appear to be downdraft system. Uses some heat to dry fuel. Gas cleaning uses a cyclone followed by water scrubbing and finished by an ESP which is cleaned with RME (a wet ESP?). No mention of fate used water and RME. Claims three projects in Italy in the past 3 years (850 kWe, 850 kWe, and 995 kWe)
India	**Ankur Scientific**	**http://www.ankurscientific.com**	Large number of installations in India and region. Rice husks, other ag. residues, wood residues. Basic downdraft, throated design. Water scrubbing with tarry water disposal issue for gasification. Phoenix Energy in CA uses this technology for Merced and CVAG installation. Operational issues, tar disposal, slagged ash, tyeres burned/consumed - intermittent operation, unclear of currently operating.
India	Bioresidue Energy Technologies Ltd	http://betpl.net/home	Based on technology from the Indian Institute of Science, Bangalore. Seems to have a lot of functional projects, but are all primarily in india.
India	Chandurpur Works	http://www.chanderpur.com/project-executed-client-testimonial.html	Several facilities implemented, but it appears that most are based in India. Many facilities use thermal rather than electricity component of gasification. Experience is in air blown for power generation. Dual zone configuration is unique.
India	Infinite Energy	http://www.infiniteenergyindia.com/biomass-gasifiers.html	Apparently has installations in India, Africa. Not clear if any in Europe or North Americal. Has multiple models available for purchase.
India	Netpro	http://www.netprorenewable.com	Several facilities mostly in India. Schematic implies downdraft w/ typical wet scrubbing, and settling tank., has worked with other groups such as xylowatt and DESI. http://www.netprorenewable.com/installations.html. NETPRO was established in the year 1994, promoted by 'DASAG Energy Engineering Limited', Switzerland.
India	Radhe	http://radheenergy.com/	Limited information
Ireland	Imperative Energy-Gaeletric	http://www.imperativeenergy.ie/	CHP installations using combustion boiler systems (especially Schmid boilers)
Italy	Advanced Gasification Technology	http://www.agtgasification.com/eng/prodotti_agt.htm	Need to Verify if actually functioning technology. Based on old correspondence and images in brochures and websites, etc. I believe the AGT gasifier is the one marketed by Biogen and Reliable Renewables. There do appear to some installations in Italy. See http://www.biochar-international.org/sites/default/files/Pozziposter.pdf seems like they only make gas - no clear integration of gas engine or turbine generation
Italy	Bio&watt	http://www.bioewatt.com/eng/layout.html	Apparent “stratified – downdraft – twin fire” fixed bed gasifier", water scrubbing and wet ESP, recip. engine. Claim no liquid discharge but does not describe how scrubber water is treated, though there is a thermal oxidizer for burning char and pyrolysis oils (perhaps the tar water?) Possibly 300 kw facility in Pomarico, and a 200 kWe facility Matera, Italy.

Italy	Caema Engineering S.r.l.	http://www.caemaenergia.com/index.jsp	Italy, possibly 1 MW units in Parma and Belluno :Molino (2012) IEA Task 33 Italy Report. Some web hits indicate these are Ankur units licensed to Caema. Webpage says associated w/ TerruziFercal (which Phoenix Energy may be looking at).
Italy	Inser	http://www.inser.it/documenti/CIRCLEDRAFT_ENG.pdf	Italy. Circle Draft design. Demonstrated . Working w/ West Biofuels in Woodland, CA for US demo.
Italy	Terruzzi Fercalx Energy Group	http://www.terruzzifercalxgroup.com/en/prod_impiantigasificazione.php	Website indicates updraft & downdraft models available but not clear if any are operating. It has been reported that Phoenix Energy (CA) is considering a Terruzzi system for the Cabin Creek project.
Japan	Ebara	http://www.eep.ebara.com/en/company/	Offers a range of combustion and gasification systems. Mostly for plastics, MSW and ash melting applications in Japan.
Netherlands	ECN/Dahlman, Milena Technology	http://www.milenatechnology.com	Associated with the Energy research Centre of the Netherlands. No current operational facility. Demonstration facility has been running since 2008 and another demonstration plant in Alkmaar is being built. http://www.milenatechnology.com/milena-gasification-technology/. Dahlman offers a commercial-size gasification unit using Milena Technology / also Dahlman has rights to OLGA tar removal technology developed by ECN. (does not appear to be implemented in any facility) Milena does not appear to be a commercial enterprise rather focuses on developing technology for other groups(verify?)
NL	**Synvalor**	**http://www.synvalor.com/technology**	Netherlands. Involved in fluid and fixed bed gasifier systems. Indicate that "working references" are available, but do not list them
New Zealand	Linear Power	http://www.powerhearth.net/	Linear hearth downdraft. -- portable unit. Unknown is being manufactured or location of operational facilities. Website current (2012) Needs more follow up
South Africa	Carbo Consult and Engineering	http://www.carboconsult.com/	, appears to have several larger scale facilities as well as a small scale portable demonstration unit. Web diagrams indicate water scrubbing w/ water storage/settling tank.
Spain	EQTEC	http://www.eqtec.es/en/business-areas/waste-gasification/eqtec-gasifier-technology	Fluid bed (bubbling) reactor. Claim 1, 5 and 6 MW facilities operating or commissioning (2015) in Europe. Indicate pox tar reformer, hot gas filtration and water scrubbing cooling for final cleanup. Seems to be working w/ GE Jenbacher and my be marketed as GE integrated biomass gasification systems. http://www.eqtec.es/fitxer/572/Eqtec%20GasifierTechnology_ENG.pdf
Sweden	Cortus	http://www.cortus.se/index.html	Indirect heating with steam and char. 500 kW is testing facility scaling to 5MW "WoodRoll" gasifier Schatz Energy Research Center has done diligence on this company for the Blue Lake project. Jim Zoellick at SERC.
Switzerland	BR Engineering	http://br-engineering.ch/	Developer of wood gasification systems. Appears to be partnered w/ or using GTS Syngas gasifier. Not clear if any units are built or operating but appears to have gasification CHP facility at Nidwalden, Switzerland : http://www.holzverstromung-nidwalden.ch/holzverstromung_technik.asp?id=02
Switzerland	Powerhouse Energy (Pyromex)	http://www.powerhouseenergy.net/IRM/content/home.html	The pyromex gasifier is a rotary hearth using electrical heat for pyrolysis. Marketed for MSW and waste water sludge. No known operating facilities, perhaps a demo plant. Apparently demonstrated on biosolids (sludge) in EU "Neptune" project http://www.eu-neptune.org/Neptune%20Newsletter/2ndnewsletter_Neptune.pdf
UK	Arbor Electro Gen	http://www.arborhp.com/heat-and-power-solutions/arborelectrogen	UK entity marketing the Finnish Volter 30 and 40 (See Volter entry). .Also market 200, 400 & 800 kWe systems, origin, manufacture not known. The larger systems employ a "double-fire" fixed

			bed gasifier and uses wet scrubber followed by wet ESP for gas cleaning. No information on fate of removed tar and tar saturated water. Operational reference facilities not listed on website.
UK	Biomass CHP	http://www.biomasschp.co.uk/index.php	Heat from the process is recycled to dry the wood. Current plant can produce up to 600kWth if dryer fuel is used. 300kW operational facility in Larne, Northern Ireland at the Killwaughter Chemical Company. New demonstration plant at Wilton under construction. Functional 200kW demonstration plant in Blackwater Valley. Formerly Exus energy. Downdraft system.
UK	Biomass Engineering Ltd	http://www.biomass.uk.com/	Data sourced from Directory of Industrial Biomass Boilers and Combined Heat and Power Equipment. Web Data not available. Biomass Engr. Ltd. looked promising ~ 5-10 years ago with several projects claimed built and near operating in Germany and the UK but is not clear if they still operate. Also, was claiming they changed from water scrubbing system to using biodiesel as scrubber fluid which migh allow the spent scrubber fluid to be injected into gasifier for disposal - but not confirmed (Rob 2/17/14). Website claims planning approved for 4.8 MW CHP in UK (JAn 2015)
UK	Ecocycle Group	http://ecocyclegroup.com/press_releases/new_office.html	Company installing / commissioning (2015) 6+ Mwe CHP in Walesw using Torbed gasifier and 6 engines. See Torbed entry.
UK	Refgas-UK	http://www.refgas-uk.com/	Downdraft system. Apparently only facility is at University of East Anglia (UEA) has a 4MW facility (2009). 2MW in heat and 2MW in electricity. Not known if still active. http://www.waste-management-world.com/articles/print/volume-11/issue-1/features/wood-waste-comes-good.html
UK / NL	Torbed / Torftech / Torrgas	http://torftech.com/	Develops torftech technology (torroidal fluid bed it seems) for many applications and the "torbed" for biomass gasifier / combustor. Torrgas process to use torrefied biomass and torbed reactor to make syngas for RNG production. Ecocycle Group commissioning 6+ MWe CHP plant using Torbed gasifiers and recip engines.
US	Able Green Solutions		ABLE GREEN SOLUTIONS (AGS) and TRIO SERVICES, LLC offer a pyrolysis technology. Minimal web presence and no facilities known.
US	Adaptive Arc	http://www.adaptivearc.com/	Plasma assisted gasification. Operated a unit at Mexico City using MSW for ~ 1 year.Has a demo-unit at UC Riverside undergoing testing. No known operating plants. Targeting high value (high tip , high energy content) waste materials. Jim Jungwirth looked into this technology 2010/ 2011
US	All Power Labs	http://www.gekgasifier.com/	~ 20 kW "Power pallet"> . Batch fed downdraft for rural electrification, off grid, 6-8 h/d. Have developed a CHP unit with CE certification (Europe). Many units sold, and they are developing a 100kW container based gasifier- available in 2016?. $2 MM award for forest based wood conversion using Powertrainer (CEC PON 14-303) Can also link pallets for increased power generations.
US	AlterNRG Westinghouse Plasma Division	http://www.westinghouse-plasma.com/projects/	Functional units are primarily waste to energy systems, not gasification systems. Currently has one operational demonstration gasifier and a couple under construction. Requires more follow-up. Supposedly can accept wood waste and clean wood chips. Most facilities are international but demonstration gasification facility is in PA
US	Beltran Technologies	http://www.beltrantechnologies.com/	Website indicates downdraft or updraft air/steam blown gasisifier & wet ESP with engine gen-set. http://www.beltrantechnologies.com/images/PDFs/techreport_waste_to_watts.pdf Websearch indicates Beltran is associated with firms in Phillipines and China marketing these gasifier systems.
US	Biogen	http://www.biogendr.com	Believe this is marketing the AGT technology. Manufacture in Dom. Republic, downdraft gasifier, under contract with Robert Bros Sawmill in MA

US	Chiptec	www.chiptec.com/chiptec_website_nextgen_002.htm	Staged combustion mostly for heat applications. Projects have been implemented at Green Mountain College, Eastern Illinois University and Middlebury College. Need followup on technical information
US	Cirque Energy	http://www.cirque-energy.com/whatwedo/deployablegasificationunits.html	Developing mobile (deployable) gasification systems for military and commmercial. Opaque technology. 175-500 kW units. Maybe early 2015 demonstrations. See http://www.cirque-energy.com/cirqueblog.php . "Cirque Energy is working in partnership with Northrop Grumman Corporation to bring to market a Deployable Gasification Unit (DGU) that can use solid waste to provide fuel or supplement traditional fuels used to generate combined heat and power (CHP). For the MBES project, four DGUs will work in parallel to process the urban wood waste to generate clean, renewable electrical energy."
US	Coaltec Energy	http://www.coaltecenergy.com/	Under fire grate technology? Seems focused on manure feedstocks for heat application (dry manure feedstock, heat animal housing…) with three manure facilities listed on website. Coaltec gasifier was used by MaxWest initially until MaxWest switched to a fluid bed design (MaxWest went bankrupt, 7/2014).
US	Diversified Energy	http://www.diversified-energy.com/index.cfm?s_webAction=hydromax	Hydromax molten metal based gasifier. Demonstration status. Had a CEC grant for Samoa, CA pulp mill. Was this transferred to San Bernardino
US	Energy-Inc Park	http://www.energy-inc.com/technology/index.html	Apparently located near Las Vegas , offer the ATCT conversion technology described as "pyrolytic gasification". No indication of existing facilities.
US	Foster Wheeler	http://www.fwc.com/getmedia/ebd91004-e144-4bc1-8a40-20d17207c3e9/Factsheet_Polaniec_Project_032613.pdf.aspx	Several CFB, BFB gasifiers for steam, heat (4-50 MWth steam). Mostly Finland and Sweden (205 MWe Polaniec Project - solid fuel combustion facility) has technology for other sizes of biomass gasification, but company focus seems to be on large scale facilities
US	Frontline Bioenergy	http://www.frontlinebioenergy.com/	BFB reactor. One commercial scale facility installed at CVEC (Chippewa Valley Ethanol Company) in 2008 (75 t/d).
US	ICM Inc.	http://www.icminc.com/products/advanced-gasification.html	Horizontal cylindrical gasifier w/ staged under fire air using auger to move material through. Licensed technology from Phoenix (Florida). Have experience w/ one demo in MidWest. Currently working w/ JUM and San Jose to fulfill CEC demo project
US	Intellergy	http://www.intellergy.com/	Was involved in CEC demo grant w/ BAB2E but could not come up with cost share. No operating plants.
US	MSW Power	http://www.mswpower.com/Products/GEM/Specifications.aspx	Small downdraft system w/ engine container built. Developed w/ DOD funds and demonstrated at Edwards AFB (results not known). MSW focused, unknown if it does direct woody biomass to power conversion. Does not appear to have any operating facilities
US	Outotec / Energy Products of Idaho	http://www.outotec.com/en/About-us/Our-technologies/Fluidized-bed-for-energy1/Energy-systems/	Fluid bed systems - combustion or gasification mode. Believe all gasification applications are close-coupled combustion
US	PHG Energy	http://www.phgenergy.com/company	PHG is related to Associated Physics of America (APA). Apparently has purchased gasifier IP from APA (Rob 2/17/14). Downdraft system. One operating facility, MSW to steam then power, Covington Tennessee
US	Phoenix Bioenergy	http://phoenixbioenergyusa.com/	Horizontal auger gasifier. This is the technology licensed by ICM (who may be doing modifications)
US	Planet Green Solutions	http://www.planetgreensolutions.com	Facility implemented at Goldmark Farm in Ocala, Florida. Small downdraft systems (up to 120 kW) , automated, turnkey. Photos show some kind of gas cleaning but do not describe. Uses chunked fuel and requires briquetting if raw particle size too small. No indication of number of units

US	PRM Energy	http://www.prmenergy.com/wood-fuel-andor-distillery-residue-gasification-system/	Air-blown updraft systems. Long time operator using rice hulls and straws. Heat and steam as well as engine power systems. May be suitable for wood. Seems to be only a prototype for woody biomass. Most functional products are for straw and rice husk gasification
US	Proton Power	http://www.protonpower.com/	Opaque process to produce high H2 concentration from solid biomass ("Hydrous Pyrolysis)". Gas composition 65% H, 30% CO2, 5% CO. Development w/ Demonstration using switchgrass feedstock and 3 Cat gensets (750 kW capacity) at Wampler Sausage in Tennessee. Selected for Blue Lake Rancheria (BLR) Biomass Project (Gasifier to fuel cell project)(Schatz, Blue lake Rancheria and CEC).
US	Radian	http://www.radianbioenergy.com/technology.html	This company looks like a derivative of Emery Energy (Ben Phillips, CEO) which has been in the coal/biomass gasifier R&D business for 10+ years. Viewing the Radian website, it seems that they are still involved in pilot and demo work with a gasifier being installed in Laramie Wyoming for research purposes. It does not appear they have any commercial operating facilities. See http://www.emeryenergy.com/index.html
US	Sierra Energy	http://www.sierraenergycorp.com/fastox-pathfinder/	Unit called the fast-ox pathfinder. No implemented operational facilities. Focus on general waste to energy, not biomass to energy. Started in Iron manufacturing/consulting, then branched out into gasification. Does Rob know more about them? Needs Follow-up. Sierra Energy is moving from its demonstration facility at the Department of Defense's Renewable Energy Testing Center to its new facility supporting the U.S. Army at Fort Hunter Liggett. Focus seems to be on waste to diesel conversion technology
US	**Vgrid**	**http://www.vgridenergy.com/**	Developed in Mike Cheiky's "Future Lab", (CoolPlanet biofuels and biochar), Vgrid is purported to be downdraft gasifer and modified diesel genset, with proprietary V-Grid technology. Looking at rural electrification w/ units ~ 100 kWe capacity. Involved w/ UC Riverside in CEC EPIC proposal.
US	West Biofuels	**http://www.westbiofuels.com/**	Pilot scale R&D facility in Woodland. Developing Repotec gasifier for CHP/fuels in North America. Also piloting INSER circle draft gasifier.. $2 MM award for forest based wood conversion (CEC PON 14-303)
US	ZeroPoint	http://www.zeropointcleantech.com/company	Purported stratified downdraft gasification technology. Gas cleaning system not known. Has a facility in Newry, Ireland and Schwarze Pumpe, Germany.
US	Associated Physics of America	http://www.associatedphysics.com/ProdServices/Gasification.html	Subsidiaries include EverGreen Gasification Technologies. APA developed and licensed or sold the gasifier technology to PHG Energy (Rob 2/17/14)
US	**Community Power Coproration**	**http://www.gocpc.com/**	Downdraft system w/ multiple midlevel modulated air injection points for temperature/tar control. 100 kW maximum size to date. Low tar gas production, long time demo on walnut shells. Not so successful w/ green forest wood chips. Long history of grant supported demonstration projects. Not clear if any commercial units have been sold. Believe the Dixon Ridge operation is owned by MaxWest w/ contract to sell power to Russ Lester. 3 x 100 kW facility reported being installed in Colusa, CA (Premier Mushrooms)