Placer County
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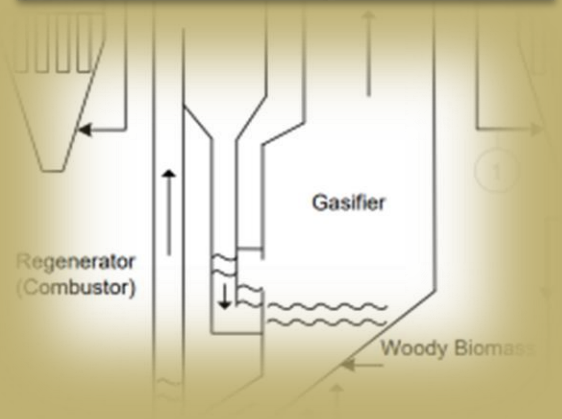
CLERE
California Law Empowering Renewable Energy



Woody Biomass Gasification Technology in California

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Gasifier process flow diagram source: https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2020-055.pdf

Woody Biomass Conversion Technology in California

The State of California is facing a massive undertaking to attempt to treat a million acres of California's forested lands in coming years. This challenge will result in millions of tons of forest wood waste that will either be left on the ground to decay and contribute to further fire threat or be open pile burned. Another alternative is processing this wood waste for other products, one of those being energy. This paper explores the main technological pathways for transformation of forest wood waste to energy.

What Systems are Used in California Today to Convert Wood Waste to Electricity?

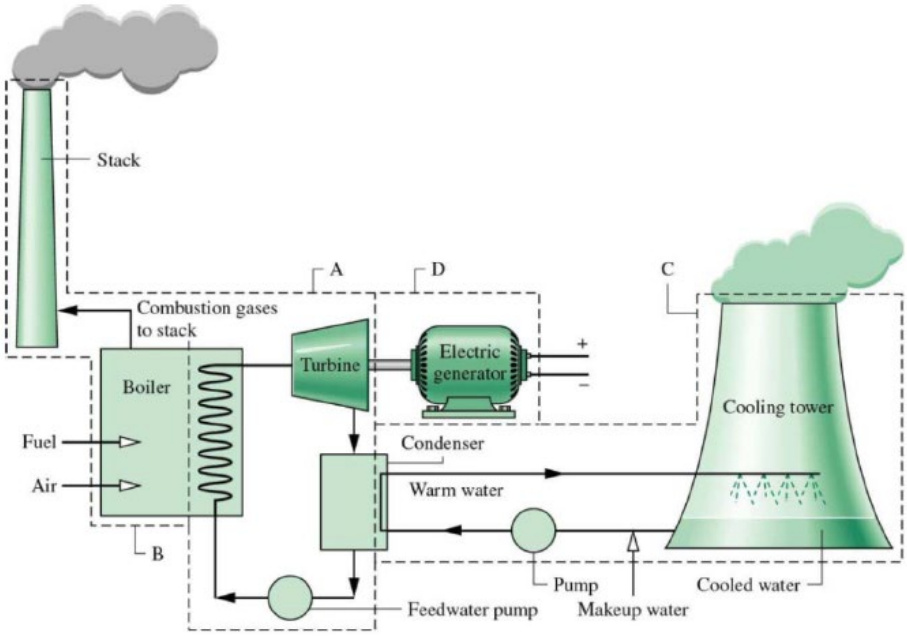

Figure 1. Woody biomass direct combustion / boiler / steam turbine (Rankine cycle) (UC Davis 2013).

Conventional biomass energy technology (Figure 1) directly combusts wood chips in stoker or fluidized bed combustion chambers. The gaseous products pass through a series of heat exchangers to heat water and produce high pressure steam. The high-pressure steam drives a turbine to produce electricity and/or is used for direct process heating. Direct combustion boilers are carefully tuned to operate with an optimum amount of excess air (oxygen) – just enough to fully combust the biomass to extract the maximum amount of energy possible, resulting in a carbon-depleted ash.[1]

[1] When direct combustion systems are discussed, the word "gasify" is sometimes used to describe the wood waste breakdown process that occurs when biomass is initially exposed to elevated temperature inside the combustion chamber. However, the gasified biomass is rapidly and fully oxidized in the combustion chamber, distinct from "gasification" systems that will be described below.

Currently, there are 30 direct-combustion biomass facilities in operation in California with a total state-wide capacity of 640 megawatts (MW) (CEC, Accessed 2022). Facility capacities range from 5-65 MW.

What are the Challenges Facing Current Direct Combustion Systems?

Existing wood waste biomass energy facilities operating in California are controversial:

- **Most were developed many decades ago.** While they use well-demonstrated, permitted direct-combustion technology and air pollution control systems, their air pollution emissions are not as low as they could be using state-or-the-art systems.[2] Retrofit control system upgrades on existing plants have been considered; however, they are expensive and rarely cost-effective in achieving emission reductions. In particular, the addition of Selective Catalytic Reduction (SCR) for enhanced NOx control is complicated. The need to reheat the flue gas following the existing primary fine particulate matter control device combined with the potential poisoning of the catalyst by various wood waste combustion gas contaminants makes SCR challenging.

- **High supply costs.** Facilities often require long distance transport of biomass from the harvest location. Many existing biomass energy facilities are located far away from the forest where the wood waste is harvested. Transportation cost often is a key variable for operation viability. While feedstock delivery and tipping fees vary throughout the State, often there is a wide gap between what the biomass energy facility will pay and the cost of biomass processing and transport.

- **High Emissions near DACs.** Facilities are often located in disadvantaged communities (DACs) where emissions are a concern to those living in close proximity. Facilities are often built in the industrial exurbs and are disproportionately located near low-income, minority, and tribal communities. This brings environmental and health concerns to the neighbors.

- **Limited Use.** Direct-combustion systems are limited to only produce electricity or process heat. As discussed below, they are not flexible like gasification/pyrolysis systems which can produce liquid or gaseous fuels for off-site use.

- **They produce a wood ash byproduct.** As will be discussed below, production of biochar from gasification and pyrolysis systems has many advantages that ash does not.

- **Misconception of driving forest management objectives.** Some have expressed concern about the potential for wood biomass feedstock operational demand that could drive forest management decisions for the sole purpose of bioenergy production. If this were to occur, it may have adverse ecological impacts. However, there are many reasons why this does not occur in California. Primarily the economic markets for wood make use outside of timber or wood products untenable. The Legislature also added safeguards regarding biomass sourcing issues when it created the Bioenergy Market Adjusting Tariff (BioMAT) through the passage of SB 1122. Under that legislation, the "by-products of Sustainable Forest Management" must be used for

[2] None-the-less, today's direct combustion criteria, toxics, and greenhouse gas emission profiles are significantly improved compared with open pile burning or wildfire alternatives, which is often misunderstood.

facility feedstock procurement to ensure wood sourced from ecologically harmful management strategies were excluded from the Program. In 2013 CAL FIRE produced a whitepaper for the CPUC that would define the eligibility criteria within the Program, which is still used today.

- **Lapse in environmental compliance.** While ensuring environmental compliance is the responsibility of individual owners/operators, some facilities in the biomass industry are alleged to be frequently out of compliance with environmental regulations. This issue is not unique to the biomass industry; however, it is frequently referenced as a downside to biomass systems in California. Like many other industrial processes, large biomass facilities are made up of complex systems with equally complicated pollution control equipment. Even under ideal operating conditions, unforeseen problems can suddenly arise, making it difficult for the operator to correct the problem prior to experiencing an emissions violation.

The Benefits of Smaller Scale Direct Combustion Systems

Based on these issues, the State has been focusing on supporting modern small-scale (5 MW and smaller) facilities, which are able to mitigate or completely avoid many of these concerns. Also, it is important to note that by their nature, small facilities emit less (as they are smaller systems). Because they require less feedstock, they can source their fuel locally and minimize transportation costs and impacts. In addition to this, reduced feedstock requirements and a small physical footprint allows for these facilities to be constructed and operated in more remote areas of the State, simultaneously providing flexibility for facility siting, and reducing the likelihood of air quality impacts to surrounding residences, businesses, or others.

Another added benefit to modern small-scale boiler systems is their overall air pollution emissions are considerably smaller; not only because of the overall scale of the operations/feedstock consumption rates, but because a new facility can be designed with technologically advanced air pollution control equipment, such as ceramic catalytic filtration systems, which are not equally compatible with large-scale conventional system retrofits. The main challenge in this context is that the costs for building small facilities is high and difficult to be profitable. Despite this, there is a variety of commercially dispatchable small-scale boilers available to the California market today. We have compiled a list with examples of such companies for reference, located as Attachment “A”.

As policy makers grapple with managing staggering amounts of woody biomass waste, they are considering next steps beyond existing conventional combustion electricity producing operations. Many are encouraging advanced technologies -- including gasification and pyrolysis -- as the next generation of system design to increase efficiency, reduce emissions, and provide liquid and gaseous fuels for the transportation and commercial/industrial sectors. Gasification and pyrolysis technology has been a commercial product in many places around the world for some time. Yet, the status of gasification technology readiness in California varies and barriers remain to its widespread adoption.

What is Gasification?

Gasification (and pyrolysis) is a thermochemical process where, under conditions of elevated temperature and limited oxygen (or no oxygen in the case of pyrolysis), solid or liquid biomass feedstock are converted

into a “producer gas” (also referred to as “syngas”). The syngas is composed primarily of carbon monoxide, hydrogen gas, and light hydrocarbons such as methane. Gasification/pyrolysis can be conducted in various system arrangements, including fixed bed, fluidized bed, rotary kiln, or auger reactors.[3] For gasifiers, heat needed to keep the unit running is provided by supplying a limited amount of air and burning a small portion of the biomass. For pyrolizers, heat is provided indirectly by externally burning a small fraction of the syngas.

The raw syngas is then usually cleaned to remove tars and other contaminants. It may also be transformed, condensed, and catalytically converted into specialty gases (such as synthetic natural gas or hydrogen gas) and/or liquid fuels (such as Fischer-Tropsch liquids, methanol, mixed alcohols, or bio-oil). The cleaned syngas is then typically combusted on-site in a boiler, engine, or gas turbine to produce electricity and/or useful heat. If hydrogen gas or synthetic natural gas are produced, they may be used directly for electricity in a fuel cell, or sent for use offsite. Liquid product fuels may also be combusted on-site in boiler, engine, or turbines, and/or transported for use off-site. Figure 2 shows potential syngas options.

Through this process, a solid, charcoal-like byproduct is also produced, called “biochar”. Biochar characteristics and production are highly dependent on system design and operation. Many claim biochar has the potential to store carbon over 100 years without decomposition, and is widely accepted as a solution for climate mitigation (Leng 2019). It has use as a soil amendment or for filtration media. It significantly enhances soil biological productivity and water-holding and fertilizer-holding capacity, which provides crop nutrition and improves plant growth (Sohi 2010). It also removes toxic elements and sand pollutants from the soil, prevents soil leaching and fertilizer runoff, and maintains soil moisture levels protecting crops during droughts and floods (Sohi 2010). Presently, synthetic and other bio-based fertilizers dominate the agricultural sector but with awareness of biochar’s benefits gradually spreading among farmers, significant momentum is building for widespread adoption in agricultural activities.

There were approximately 90 gasification technology suppliers operating throughout the world as of 2015, some of which are doing business in California (Williams 2015). To better understand current opportunities, the District has engaged in a survey of existing technology companies that produce gasification systems that are available in California and have completed at least one successful pilot demonstration of their technology. Please see Attachment B for results of our gasification system survey.

[3] Gasification systems can also use fluidized bed or bubbling bed systems, but these are different from the fluidized or bubbling bed combustion boiler systems.

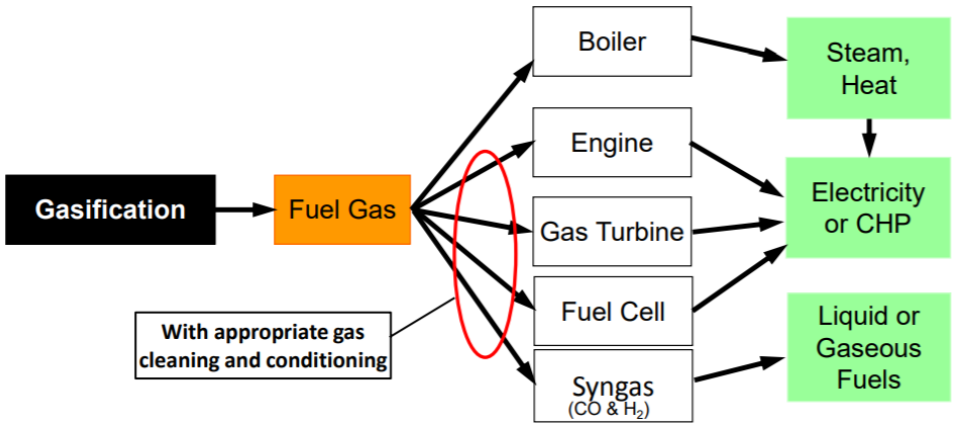

Figure 2. Gasification applications schematic (UC Davis 2015).

Why Use Gasification?

Gasification and pyrolysis systems have potential advantages compared with conventional combustion steam boiler systems:

- Higher electricity conversion efficiency when using syngas fueled engines, gas turbines, and fuel cells (30-50%) compared with conventional direct combustion steam boiler/turbine (20%). This translates to significant greenhouse gas emission reductions per unit of electrical energy produced.

- Lower criteria and toxic air emissions due to combusting a cleaned and homogenized syngas and ability to more easily utilize advanced controls such as Selective Catalytic Reduction and oxidation catalysts for NOx and VOC control.

- Potential for no need for water (or low need). Many direct combustion steam boiler systems have large water requirements. Certain gasifiers may use limited water for syngas clean-up. Small gasifiers are also particularly suited for use of non-water heat transfer fluids for electricity production (such as Organic Rankine Cycle engines).

- Production of higher value liquid and gas fuels such as hydrogen and renewable synthetic natural gas. Use of hydrogen for transportation in fuel cells has been identified as a significant potential contributor to achievement of future California GHG reduction goals. A fuel cell uses the chemical energy of hydrogen or another fuel to cleanly and efficiently produce electricity or store energy (DOE, Accessed 2022). Fuel cells have several benefits over conventional combustion-based technologies currently used in many power plants. They have higher efficiencies, are quiet to operate, and have near-zero emissions (DOE, Accessed 2022). Like batteries, fuel cells produce an electrical current at a fixed voltage, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied. While cost, performance, and durability are still key challenges in the fuel cell industry, CARB has a dedicated program to fuel cell development in

California as a prominent solution to transportation and stationary sources of emissions (CARB, Accessed 2022).

- Production of renewable natural gas through the "methanization" of the syngas. This process has been widely demonstrated to produce methane from coal and can be adapted for biomass gasification systems. If capital and operating costs can be reduced, this resource could be used and distributed through the existing natural gas infrastructure for distribution.

- Production of high value biochar. Biochar is a byproduct of gasification systems and roughly yields 10% of the original feedstock where the remaining 90% is converted to producer gas (Yaashikaa et al. 2021). Biochar production can be greatly increased by removing additional oxygen and steam and by decreasing the reaction temperatures, but at the cost of producing less useful syngas.

What are the Challenges for Successful Gasification?

Gasification/pyrolysis systems are the next step in technology development for biorefineries that produce liquid and gaseous fuels as substitute for fossil fuels used for transportation. However, gasification has some well-known technical hurdles:

- **Syngas clean up:** Clean-up is critically important when syngas is to be reformed for liquid or gaseous fuel production or used directly in engines, gas turbines, or fuel cells. Often, syngas has to meet strict quality standards for downstream catalysts, filters, fuel use or synthesis (Li 2014). Raw biomass gasification, or gasification of biomass without a pretreatment, can produce syngas with problematic contaminants including tar, alkali and alkaline-earth metals, and nitrogen compounds. Syngas clean-up can be very challenging and expensive and is regularly cited as the costliest aspect of gasification (Schwartz 2020). Research is needed to develop more active catalysts, hot-gas filtration to remove catalyst contaminants prior to tar reforming, feed pre-processing to reduce tar formation during gasification, and scale-up. The California Energy Commission has recognized this problem and proposed funding from their Electric Program Investment Charge (EPIC) to tackling tar and other impurities in gasification for their 2018-2020 Triannual Investment Plan, however the proposal never made it to implementation (CEC 2017).

  CEC investment in this persistent problem would have focused on research to eliminate the reliability risks of gasification due to tar build up. Proposed Initiative 4.4.1, CEC's research description states:

  > "The operating temperatures (typically around 700-900C) prevent complete cracking of the tar compounds which when condensed, could result in costly damage to the reforming catalysts, as well as the clogging of transfer lines and damaging of compressors, or other downstream devices like engines used for power generation. This problem often results in the need for after gasification cleanup. Catalysts are expensive and contribute to the higher cost of thermochemical gasification systems that employ them (catalysts). Cost-effectively solving

the problems caused by tar and other troubling impurities will help bring down the costs of thermochemical conversion systems" (CEC 2017).

This issue continues to need research support.

- **Feedstock size consistency Requirements:** Gasifier performance can be particularly sensitive to woody biomass feed particle size. In many cases it is difficult for current feedstock preparation and pretreatment systems (chippers and grinders) to consistently produce feeds with an acceptable particle size distribution (Waste to Wisdom 2018; Summers 2019). Inconsistent particle size (both too small and too large) can result in gasifier "bridging" or "channeling" and excessive tar formation (Waste to Wisdom 2018).

- **Developing Industry Standards:** Converting organic waste to a renewable natural gas has been within our technological capacity for many years now, and most current efforts are focused on identifying any harmful constituents. Once standards like are in place, there will be a better-defined path to developing functioning commercial sites. This work has recently been done for the dairy gas and landfill gas industries, and funding has recently been awarded to the Office of Environmental Health Hazard Assessment (OEHHA) to also provide such analysis on the renewable natural gas produced through the gasification of forest and agricultural biomass. As a step in this direction, the CPUC adopted D. 22-02-025 implementing a procurement program for renewable natural gas and requiring the three Investor-Owned Utilities to fund pilot projects using forest and agricultural biomass.

- **Infrastructure Considerations:** Depending on the final product of the gasification system, the lack of needed infrastructure for distribution can further complicate or drive up the cost of implementation. As an example, systems which produce renewable natural gas for injection into a utility's supply must be in close proximity to an existing pipeline to make the project cost-effective. Likewise, systems which produce biofuels or compressed gasses meant to be delivered off-site must have access to existing freight lines. These requirements should be taken into consideration when siting new facilities and balanced with the preference of constructing the facilities in close proximity to biomass feedstock, which is usually in a more rural location.

Gasification Today

As described, gasification has potential uses for energy for transportation fuels, as well as for more traditional use for electrical grid needs. The attached list within Exhibit "B" shows many companies engaged in the business of constructing gasification systems. As the State continues to look for useful avenues for wood waste, these technologies are available today, and can be further refined to process this waste stream for good use that helps California handle this immense wood waste stream, while also helping the State move away from fossil energy sources.

Utilization of Biomass to Energy in an Era of Climate Change

New small-scale direct combustion facilities that use advanced air emission control devices, or when such facilities are located in places where air quality is good, can provide much needed outlets for forest biomass or other wood waste that would otherwise burn in a wildfire or end up in a land fill. Such facilities may consider readily available boiler technology paired with emission controls that is scaled at a small size that matches the waste stream and local electricity needs. Gasification facilities are another option that can provide a very efficient process that can be used for electricity production, or can be used to produce renewable natural gas, fuels or hydrogen. Gasification also provides the unique pathway to carbon sequestration with its natural byproduct, biochar, which direct combustion does not provide. As California looks to its future and its dire need to process wood waste, gasification technology is sure be an important pathway to ensure success.

In order to handle the large volumes of wood waste that California will produce as it reduces wildfire severity, in combination with its already large volumes of agricultural and urban wood waste streams will require bioenergy conversion systems that will need policy support tools for successful deployment. Many such efforts are underway, such as the Department of Conservation's biofuel pilot funding program, the "iBank California" loan programs for startup facilities, the CPUC Renewable Natural Gas Proceeding, Cal Fire's biomass utilization grants program, the Governor's Office of Planning and Research and its feedstock aggregations projects, and the Joint Institute for Wood Products Biomass Utilization Plan, adopted by the Board of Forestry in November 2020. As the state becomes more cognizant of the wood disposal needs, more bold ideas are needed, such as (1) possible tax incentives through equipment depreciation pathways for new bioenergy facilities, (2) new insurance opportunities for forest landowners, rural households and bioenergy facilities, and (3) the possibility of utilization of wood products by the state agencies themselves, are examples of bold ideas that should be considered in the near future. It will take all hands-on deck to solve for this incredible challenge as California faces its future in an era of climate change.

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Placer County
AIR POLLUTION CONTROL DISTRICT

Exhibit A: Boiler Waste-to-energy Conversion Technology

Introduction:

This list is for general reference only and is not meant to be an endorsement of these companies, in any way, by the Placer County Air Pollution Control District Board of Directors, Air Pollution Control Officer, or Staff. Readers are advised to do reasonable due diligence on any company listed for their own uses.

Companies with products scalable to 5 MW and below:

NAME	LOCATION	CONTACT INFORMATION
AFS ENERGY SYSTEMS	Pennsylvania, USA	info@afsenergy.com (717) 763-0286
BABCOCK AND WILCOX	Ohio, USA	marketing@babcock.com (330) 753-4511
HEIZOMAT	Germany, Canada	info@heizomat.de (844) 895-4533
HOST	Netherlands	info@host-bioenergy.com +31 (0)53 – 460 90 80
HURST BOILER	Georgia, USA	info@hurstboiler.com (877) 994-8778
KOHLBACH	Austria	info@kohlbach.at +43(4352)2157-333
LINKA	Denmark	linka@linka.dk

		+45 97 34 16 55
MCBURNEY	Tennessee, USA	scs@scsenergy.com (423) 624-1727
MESSERSMITH	Michigan, USA	sales@burnchips.com (906) 466-9010
POLYTECHNIK BIOMASS ENERGY	Austria	office@polytechnik.at +43 2672 890 0
SCHMID ENERGY SOLUTIONS	Switzerland	info@schmid-energy.ch +41 71 973 73 73
SOLAGEN	Oregon, USA	solagen@solageninc.com (503) 366-4210
UNICONFORT	Italy	info@uniconfort.com +39 049.5952052
VIESSMAN	Canada	info@viessmann-us.com (800) 288-0667
WELLONS ENERGY SOLUTIONS	North Carolina, USA	garald.cottrell@wellons.com (360) 750-3500
WEST BIOFUELS	California, USA	info@westbiofuels.com (530) 207-5994

Companies that offer boiler technology - Scalability not confirmed:

NAME	LOCATION	CONTACT INFORMATION
ANDRITZ CARBONA	Austria	welcome@andritz.com +43 316 6902 0
NOOTER AND ERIKSEN	Missouri, USA Milan, Italy	info@ne.com (636) 651-1000
VYNCKE	Belgium	hello@vyncke.com

Placer County
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Exhibit B – Biomass Gasification Technologies & Survey Results

Introduction:

The following list of companies responded to a request from the Placer County Air Pollution Control District through a series of questions pertaining to their specific biomass gasification products and solutions. The purpose of the survey is to share the availability of emerging and existing solutions with the public as well as the broader biomass industry to encourage participation and innovation in clean technologies for the future.

This list is for general reference only and is not meant to be an endorsement of these companies, in any way, by the Placer County Air Pollution Control District Board of Directors, Air Pollution Control Officer, or Staff. Readers are advised to do reasonable due diligence on any company listed for their own uses.

Companies Offering Biomass Gasification Solutions That Responded to the District's Survey

NAME	LOCATION	CONTACT INFORMATION	PAGE
ALL POWER LABS	California, USA	www.allpowerlabs.com/contact (510) 845 1500	B-3
ARIES CLEAN TECHNOLOGIES	Tennessee, USA	Info@ariescleantech.com (615) 813 9400	B-5
ARTi	Iowa, USA	ARTi@ARTi.com (515) 495 5027	B-7
BIOGAS ENERGY INC.	California, USA	Bgannon@biogas-energy.com (707) 243 3019	B-11

NAME	LOCATION	CONTACT INFORMATION	PAGE
EQTEC	Ireland, UK, Spain	enquireies@eqtec.com +44 202 883 7009	B-14
FRONTLINE BIOENERGY	Iowa, USA	frontlinebioenergy.com (515) 292 1200	B-16
MOTE	California, USA	www.motehydrogen.com/contact-us	B-19
NEXTERRA	Canada	inquiries@nexterra.ca (604) 637 2501	B-21
OMNI CONVERSION TECHNOLOGIES	Canada	www.omnict.com/contact-us/ (613) 287 3127	B-23
SIERRA ENERGY	California, USA	sierraenergy.com/contact-us/ (530) 759 9827	B-27
VGRID ENERGY	California, USA	info@vgridenergy.com (805) 482 9040	B-29
VITAL ENERGI	United Kingdom	www.vitalenergi.co.uk/contact/ +44 203 857 9710	B-31

Gasification Technological Survey Responses by Company:

The responses to the survey questions vary in detail and length. District staff has made every effort to compile the information and present it in a meaningful manner. In some cases, the responses included proprietary or confidential information and they have been redacted to ensure that such information is not disclosed.

All Power Labs

Q: Can you please provide a description of your gasification technology and system arrangement?

A: All Power Labs designs, manufactures and deploys mobile biomass gasification systems that convert woody waste into electricity, heat, and biochar. Based in Berkeley, California, APL is a global leader in gasification innovation, with a dozen patents and hundreds of systems shipped to projects in over 40 countries.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: Our system includes syngas conversion technology.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Biochar, Heat, & Electricity.

Q: If your process generates biochar, do you sell it as a marketable product?

A: Yes.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: No.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: 0.25.

Q: What is the useful final product output range for each of your products?

A: 500 kW thermal, 18% yield biochar by mass. Smaller systems produce electricity as well: 25 kW, 50 kW thermal, 5% biochar yield by mass.

Q: What are the efficiency metrics of your product?

A: 85% system efficiency from our smaller platform.

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: [Unanswered]

Q: What is the parasitic load for your technology?

A: [Unanswered]

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: Woody biomass (wood chips, nut shells): Particle size: 1 cm – 4 cm (0.5 in. – 1.5 in.). Moisture content (% by dry weight): 5% – 30%. Ash content <5%.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: Baghouse filter, catalyst.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: [Unanswered]

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: Yes. Third-party tests from Blue Sky on emissions and Enthalpy Labs and IBI certification for biochar.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: Yes. Shasta County AQMD. We have also [have a permit with] SCAQMD.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: Our proprietary technology controls for VOC/tar production and reduction, leaving the biochar very pure and a baghouse filter keeps the small amounts of tars from entering the engine, so that the gases will not foul it.

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: [Unanswered]

Q: What is the "turnkey" purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: [Unanswered]

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: [Unanswered]

Aries Clean Technologies

Q: Can you please provide a description of your gasification technology and system arrangement?

A: Proprietary air blown downdraft gasifier that consumes 55t/d of chipped wood at 10% moisture.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: Our system includes syngas conversion technology.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Heat, Electricity, Biocarbon for agricultural, industrial or commercial applications (aka "biochar" if sold as soil supplement).

Q: If your process generates biochar, do you sell it as a marketable product?

A: Please note we make biocarbon for agricultural, industrial or commercial applications (aka "biochar" if sold as a soil supplement).

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: Our projects make co-heat and power and biocarbon. The co-heat and power is used internally with excess sold over the fence or onto the grid.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: 49.5 tons per day dry basis per gasifier.

Q: What is the useful final product output range for each of your products?

A: 10%-30% biocarbon & 70%-90% syngas.

Q: What are the efficiency metrics of your product?

A: This information is proprietary and depends upon the biocarbon and renewable energy product(s).

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: This information is proprietary and depends upon the biocarbon and renewable energy product(s).

Q: What is the parasitic load for your technology?

A: This information is proprietary and depends upon the biocarbon and renewable energy product(s).

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: ¼" plus to 3" minus, no uniform, free of tramp metal and untreated. We prefer material less than 20% moisture. We try our best to accomplish the moisture reduction with our feedstock supplier through a stacker and reclaimer woodchip pile management to avoid the capital and operating expense of a woodchip dryer.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: Depending upon the minor source criteria pollutant limitations we either use a scrubber and a bag house or a Tri-Mer UltraCat Catalytic Filter Systems.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: We have and our system is carbon neutral to negative depending upon how our biocarbon is utilized and how the woodchips are gathered/scored in relation to fire suppressions or post burn remediation.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: We do. When using a Tri-Mer UltraCat Catalytic Filter Systems NOX 0.026 lbs/MMBtu, SOx 0.005 lbs/MMBtu, CO 0.005 lbs/MMBtu, VOC 0.001 lbs/MMBtu, PM_{10} 0.011 lbs/MMBtu, $PM_{2.5}$ 0.011 lbs/MMBtu.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: Lebanon, TN. The Tennessee Department of Environment & Conservation.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: Our gasification process produce a low tar syngas that is fully oxidized in a thermal oxidizer to maximize renewable thermal energy production form which we derive co-heat and power to meet internal loads and generate heat and power for export.

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: We currently have one of the World's largest downdraft gasifiers operating in Lebanon, Tennessee on wood. It went into operation in 2016. We also are operating one of the World's largest fluidized bed gasifiers operating in Linden, New Jersey on dried municipal biosolids. I went into operation at the end of 2021.

Q: What is the "turnkey" purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: We have elected to no longer offer our downdraft gasification projects on a equipment sale or design build sale basis. We are happy to implement them on a design, build, own, operate and maintain basis or on a JV ownership basis. Our pricing information is proprietary, so we would need to execute an NDA with an interested JV partner prior to disclosure.

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: We are implementing projects throughout North America.

ARTi (Advanced Renewable Technology International)

Q: Can you please provide a description of your gasification technology and system arrangement?

A: Our Biochar Production Units (BPU) transforms biomass into biochar through a process called pyrolysis. By modifying the pyrolysis conditions (temperature and residence time) it promotes the production of pyrolysis gases to self-sustain the transformation of biomass and biochar. Our BPU are assembled inside of a mobile 40ft container and can house up to 5 pyrolysis trains.

Our containerized Units are equipped with all the ancillary equipment necessary for the process, from biomass storage, biomass infeed system, biomass sizing system, drying system, pyrolysis system, and biochar cooling and storage systems. It will vary depending on the client requirements, but in general this is what we recommend.

Depending on the equipment, our single train pyrolysis system capacity operating 24/7 can process 8 tons/day of biomass on a wet matter base and produce 2 tons/day (~700 ton/year) of biochar in optimal conditions.

On the other hand, our five train pyrolysis system capacity operating 24/7 can process 40 tons/day of biomass on a wet matter base and produce 10 tons/day (~3000 ton/year) of biochar in optimal conditions.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: Our system converts a fraction of the syngas into fuel to be used in the pyrolysis process which makes it a self-sustained process once in steady state. Depending on the client requirements, we explore the possibility of turning the syngas into heat and electricity.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Heat, Electricity, Biochar, & Bio-oil.

Q: If your process generates biochar, do you sell it as a marketable product?

A: Yes.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: Yes, at the moment our partners are using the excess heat in drying applications, Water heating application. Other end-product applications are under development.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: 8 tons / day = 0.3 tons per hour on a dry matter base for our single train unit. 40 tons / day = 1.6 tons per hour on a dry matter base for our 5 train unit. Note: only if the feedstock

has a maximum of 20% of moisture content and the particle size less than one inch and higher than a quarter of inch under optimal conditions.

Q: What is the useful final product output range for each of your products?

A: Biochar for agricultural applications (soil amendment). As a filter medium to retain contaminants in effluents. Bio-oil, Syngas turned into heat.

Q: What are the efficiency metrics of your product?

A: For every 8 tons of biomass processed, we produce 2 tons of biochar in optimal conditions (assuming 25% yield). 2 tons are moisture and the remaining 6 tons are dry biomass. From the 6 tons, the remaining 4 tons are syngas. From the 4 tons of syngas, 1 ton of bio-oil could be collected. Each pyrolysis train can produce 4.3 MMBTU/h under optimal conditions.

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: Each pyrolysis trains consumes 6 kW of electricity. Efficiency will depend if the excess heat is being used or not and also on the type of biomass to be processed. The figures below are assuming wood chips on a general basis:

If we have 10 ton biomass (dry) - 6 MMBTU/h:
- 7.5 tons of syngas - 4 MMBTU/h.
- 2.5 tons of biochar - 2 MMBTU/h.

From the 7.5 tons of syngas - 4 MMBTU/h we get:
- Heat of pyrolysis - 2 MMBTU/h.
- Available syngas energy - 2.5 MMBTU/h.

Q: What is the parasitic load for your technology?

A: Parasitic loads:
- Electromagnetic shunt breaker coil <80mW
- PLC and Input/output modules bias - standby <100mW
- Level sensors - standby power
- HMI (always on)
- Communications modules, IoT and router (always ON)
- VFD on-board PLC standby power

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: On the feedstock requirements, before entering the pyrolysis chambers, we require a feedstock with a moisture content below 20% and a particle size less than 1 inch. In case it needs a pre-treatment process, we do have the equipment required for it.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: We install afterburner modules for emission control.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: Yes, we offer LCA and BECCS for our customers.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: Yes, we have done emissions tests with different biomass and analyzed NOx, SO_2, VOC, PM, CO, HAP.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: Our systems are pretty clean. Our unit in Iowa has a small scale equipment, exemption justification document by the Iowa AIR QUALITY BUREAU. One of the testing agencies we us is: COMPREHENSIVE EMISSION SERVICES INC. Iowa State University, College of Engineering-Human Resources. Waukee, Iowa, USA.

We also provide air permitting assistance. We are in the process of getting a valid air permit for several of our units in different states like California and Minnesota.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: In our current biochar product units there is no treatment of syngas, as it is used to self-sustain the pyrolysis process by combusting them and utilizing the heat. We are in development of syngas collection technology.

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: World: Hawaii (~3 years), Ireland (~4 years), Canada (~4 years), China (~5 years), Scotland (in transit).

US: Arizona (~2 weeks), Iowa (~4 years), California (in transit). [as of May 2022]

The units above are not commercially available but we manufacture units considering our customer needs. If interested please contact ARTi@ARTi.com.

Q: What is the "turnkey" purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: Our units have the following costs:

- Single-train system - $750K
- 5-train system - $1.5M
- Operational costs will depend on the customer particular economic activity.
- Maintenance costs:
- Single-train system - $25K per year
- 5-train system - $65K per year

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: Is a modular and containerized unit, movable, it has emission control, the process is self-sustaining in steady state, Internet of things (IoT) implemented for remote monitoring and assistance, includes full automation to control processes involved, qualified technology for carbon credits market, and one year warranty.

ARTi focused in long-term relationships with clients and companion for maintenance and supply all spare parts and after-sales services.

Biogas Energy Inc.

Q: Can you please provide a description of your gasification technology and system arrangement?

A: Pyrolysis of wood waste to produce bio-oil, biochar, and wood vinegar.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: We make pyrolysis gas which we condense into bio-oil or convert directly to electricity. The bio-oil is refined to fuel.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: We make bio-oil, biochar, wood vinegar & heat. With modifications we can also make electricity. We are developing hydrogen production technology.

Q: If your process generates biochar, do you sell it as a marketable product?

A: Yes.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: We are developing technology to convert bio-oil to sustainable aviation fuel, diesel, or hydrogen. We are developing the ability to use surplus pyrolysis gas in a turbine to make electricity.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: Our Roseville [CA] project processes 1 ton/hr and our next project will process 2 tons/hr.

Q: What is the useful final product output range for each of your products?

A: 20 tpd system: 3 tpd biochar, 1,400 gpd bio-oil.
50 tpd system: 7 tpd biochar 3,200 gpd bio-oil.

Q: What are the efficiency metrics of your product?

A: I can share lab analysis of the bio-oil and biochar.

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: [Unanswered]

Q: What is the parasitic load for your technology?

A: We consume 24kW electricity continuously and self-sustaining on heat.

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: Since we grind & dry material at our site we can take anything from logs to chips.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: Dust cyclone. We will meet air emission requirements to operate.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: We have not conducted LCA for GHG. We are looking at carbon capture through oil-well sequestration of bio-oil, but more likely through using bio-oil as asphalt (solid storage).

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: We are currently preparing for Placer County APCD emissions test.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: Placer County Air Pollution Control District is awaiting our test.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: The tar is the bio-oil we export from the site. We don't produce syngas (which requires a catalyst like water or air); we produce pyrolysis gas.

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: Project at Western Placer Waste Management Authority in Roseville was installed in 2021 and is the only operating today.

Q: What is the “turnkey” purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: We do not sell the technology due to its complexity. We develop projects with partners so we finance, own & operate the system.

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: We are looking to develop more projects in California so we'd like to meet potential partners with sites and feedstock.

EQTEC

Q: Can you please provide a description of your gasification technology and system arrangement?

A: Full end-to-end.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: Our system includes syngas conversion technology.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Hydrogen, Biochar, Renewable Natural Gas, Heat, & Electricity.

Q: If your process generates biochar, do you sell it as a marketable product?

A: Yes.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: Yes, for methanation (SNG), Hydrogen, FT (GTL).

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: 1-40 tph.

Q: What is the useful final product output range for each of your products?

A: 1-1.5x of the original feedstock amount depending on the application.

Q: What are the efficiency metrics of your product?

A: [Unanswered]

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: 65-85%.

Q: What is the parasitic load for your technology?

A: 5-15% depending on the application.

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: We process more than 60 different type of feedstock. We specify any pre-treatment as part of our design.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: Our technology has no emissions of NOx, Furans, Dioxin or fly ash. Only, non-hazardous bottom ash and waste water is produced as waste streams.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: Yes.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: Yes, available on request.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: Plants in Europe and currently under construction one in North Fork, California, expected to be commissioned end of 2022.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: Proprietary patented technology for TCR (Thermal Cracker Reactor) and Water Scrubbing.

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: 50,000 tonnes plant operating since 2010 with 7,500-8,000 operating hours every year in Spain. North Fork, CA will be the first plant in US to be commissioned end of 2022.

Q: What is the “turnkey” purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: Depending on the configuration 3.5-6 million per MW. All the plants using our technology achieve unlevered project IRR of 12-16%.

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: We would be happy to provide data on all the variety of feedstocks and applications of our solutions.

Frontline Bioenergy

Q: Can you please provide a description of your gasification technology and system arrangement?

A: The technology to be used at the San Joaquin Renewables project - that Frontline is developing and will build near McFarland, CA - is comprised of Frontline proprietary gasification and gas clean-up equipment as well as equipment and catalysts from other suppliers. Frontline's patented TarFreeGas technology is a multi-modal, pressurized fluid bed that produces a syngas with very low "tar" content. Frontline's patented PMFreeGas technology cools the raw syngas with subsequent removal of alkali and particulate matter. The particulate matter is also called biochar. Frontline also specifies the balance of the gas clean-up, conditioning, and catalytic upgrading sections of the plant. The SJR project will produce a pipeline quality renewable natural gas that will be injected into a major natural gas transmission line and sold as transportation fuel in California.

Frontline equipment and technology can also be used to produce other fuels and chemicals, including, but not limited to hydrogen, methanol, ammonia fertilizer, electricity, and drop-in fuels such as diesel and jet fuel. Biochar is a co-product of the gasification process.

Frontline also has a pyrolysis technology that can convert biomass into bio-oil and biochar.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: Our system includes syngas conversion technology.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Hydrogen, Biochar, Renewable Natural Gas, Heat, Electricity, & Bio-oil.

Q: If your process generates biochar, do you sell it as a marketable product?

A: As described above, Frontline's gasification and pyrolysis technologies also produce biochar. Several projects are in various stages of construction and design, so no biochar sales to date.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: I would not say we have formal partnerships, per se, but we definitely utilize a wide variety of catalysts and equipment in our systems.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: Frontline technology is a feedstock flexible - able to use a variety of biomass feedstocks and also sorted municipal solid waste. Frontline has several projects in design and construction with feedstock rates of 2 tons/hr up to 57.5 tons/hr.

Q: What is the useful final product output range for each of your products?

A: The San Joaquin Renewables project will produce 12,500 MMBtu/day of RNG.

Q: What are the efficiency metrics of your product?

A: [Proprietary]

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: [Proprietary]

Q: What is the parasitic load for your technology?

A: [Proprietary]

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: Gasification and pyrolysis are thermal applications and therefore have the highest efficiencies with dry feedstock. Target moisture content is less than 15%, although feedstocks with up to 25% moisture content can be used. Feedstocks with moisture contents greater than 25% should be dried prior to conversion.

Particle size requirements are project specific. For gasification, generally speaking the particle size specification is 2" minus. For pyrolysis, the size specification is 1/8" minus.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: This is project and product specific. The San Joaquin Renewables project will have very few air emissions and has filed an air permit application that would result in the facility being permitted as a synthetic minor emission source.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: Yes and yes. The San Joaquin Renewables project will include CCS that will result in a carbon intensity of the RNG product of -115 gCO2e/MJ.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: Not yet. The San Joaquin Renewables project anticipated start date is 4Q2025.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: Not yet. An air emissions application has been filed the San Joaquin Valley Air Pollution Control District.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: As previously described, Frontline's TarFreeGas is a proprietary gasifier convertor that produces a syngas with very low tar content. The residual "tar" compounds consist of primarily benzene, toluene, and xylene (BTX), which are essentially equivalent to gasoline and can be separated and sold as such.

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: Currently none. As mentioned, the anticipated commercial operations date for the San Joaquin Renewables project is 4Q2025.

Q: What is the “turnkey” purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: [Proprietary]

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: Feel free to visit the San Joaquin Renewables' website for additional information: www.sjrgas.com.

Mote

Q: Can you please provide a description of your gasification technology and system arrangement?

A: Waste biomass to hydrogen conversion using existing technology at scale

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: Our system includes syngas conversion technology.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Hydrogen, CO2 for storage.

Q: If your process generates biochar, do you sell it as a marketable product?

A: No biochar.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: Yes. All products will and do have offtake agreements.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: 110,000 tons/year.

Q: What is the useful final product output range for each of your products?

A: 20 tpd hydrogen.

Q: What are the efficiency metrics of your product?

A: [Unanswered]

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: [Unanswered]

Q: What is the parasitic load for your technology?

A: [Unanswered]

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: We need chipped biomass around 20% moisture. Standard industry specifications for wood biomass at a 4" minus ground or chipped material type free from contaminates and compliant with California heavy metals limitations per Title 22, Article 11.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: We don't emit criteria and toxic air pollutants.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: Yes. And we are BiCRS, not BECCS.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: Yes.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: No.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: Gas Technology Institute U-Gas Gasifier.

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: Four systems worldwide. One commercial in Denmark.

Q: What is the "turnkey" purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: [Unanswered]

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: [Unanswered]

Nexterra

Q: Can you please provide a description of your gasification technology and system arrangement?

A: Fixed bed updraft gasification technology. We supply complete system from feedstock handling to gasification, heat recovery and air pollution control system.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: We built commercial plants for steam generation for industry, power generation for utilities and hot water heating systems for Universities and District Heating. We can also build systems that have a syngas as a terminal product for further processing to renewable fuels, Hydrogen and chemicals.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Hydrogen, Renewable Natural Gas, Heat, Electricity, and Liquid Fuels.

Q: If your process generates biochar, do you sell it as a marketable product?

A: No.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: We did have a partnership with GE Energy about 10 years ago for application of IC engines operating on Nexterra produced syngas. Not sure that there is a good business case for these technical solutions.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: Our systems are modular, so we can build systems for 2 -12 tph feedstock input capacity.

Q: What is the useful final product output range for each of your products?

A: The systems that generate hot water for District Heating systems or steam for Industrial use are typically in 5-40 MWth product range. Power generation plants are in 5-15 MWel range.

Q: What are the efficiency metrics of your product?

A: The systems that generate hot water for District Heating system or steam for Industrial use are typically very efficient, up to 80% (based on HHV and pending on feedstock moisture content). Power generation plants typical Gross system efficiency is 24-25%, based on fully condensing steam cycle.

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: About 80% for steam plants and about 24-25% for power generation plants.

Q: What is the parasitic load for your technology?

A: Pending on system size, between 200 KW and 1000 KW.

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: Feedstock sizing requirement is 2" minus. Feedstock has to be clean from impurities.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: We use an ESP for final PM control, SNCR for NOx control and multistage combustion for excellent control of CO, VOC, THC and other toxic pollutants. If required, we can use a bag house with Lime and Activated Carbon injection for acid gas emission control.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: We have not done LCA analysis for any of our specific projects. We can participate in BECCS projects.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: Yes, We do have data collected while operating our test facility as well as the data from our commercially operating plants.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: British Columbia Ministry of Environment, UK Ministry of Environment.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: [Proprietary – Subject to NDA signing]

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: We have 3 plants operating in British Columbia Canada between 10 and 12 years each. We have systems in UK operating between 5 and 7 years each.

Q: What is the "turnkey" purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: Each project has its own specifics and it is a custom built using modular gasification technology. It has to be priced separately. We are competitive in our segment of the market.

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: While we do have a commercially available solutions for generating useful thermal and electrical energy from waste wood feedstock, we also have a solutions to generate a syngas that could be further processed into renewable gas, Hydrogen or liquid fuel.

OMNI Conversion Technologies

Q: Can you please provide a description of your gasification technology and system arrangement?

A: OMNI Conversion Technologies offers an integrated modularized OMNI200 Gasification & Plasma Refining System (GPRS™) package that converts a wide variety of energetic

wastes, including unsorted non-recyclable municipal solid waste (MSW) to clean OmniSyngas™, with 100% diversion from landfill. OmniSyngas™ is tailored to end use. End uses of syngas can be to make hydrogen, liquid fuels, chemical precursors, or electricity. The biogenic portion in the waste stream diverted from landfill will avoid the creation of methane and will be converted to a downstream product that will have a low or negative carbon intensity.

The OMNI200 GPRS™ is a complete integrated system, delivered to site in large modules, rather than stick-built. It receives and converts at a rate of 200 tonnes per day (67,000 tonnes per year) a wide variety and mix of energetic wastes into a clean consistent syngas with a predictable heating value and composition. The H2/CO ratio can be tailored to the final application. Multiple units can be readily combined for larger plants.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: Our OMNI200 GPRS System starts from the waste feeding into our feeder and stops at delivering the OMNISyngas. We partner with downstream technology suppliers to further convert our OMNISyngas to other valuable products. For Waste to Hydrogen projects, we work with our partner and will provide an integrated package from waste to H2.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Hydrogen, Renewable Natural Gas, Heat, Electricity, Liquid Fuels, Chemical Precursors: Methanol, ethanol, bio-gasoline, sustainable aviation fuels.

Q: If your process generates biochar, do you sell it as a marketable product?

A: No.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: Yes. We partnership with downstream technology suppliers to make H2, liquid fuels, as well as electricity (GE Jenbacher).

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: 8.33 tonnes per hour.

Q: What is the useful final product output range for each of your products?

A: Low Carbon H2: 4,400--5,200 tonnes; Renewable Natural Gas: 445,500 MMBtu; Bio gasoline: 3.3 m gallons; Ethanol: 20 m litres; Bio jet fuel: 13 m litres; Methanol: 26 m litres.

Q: What are the efficiency metrics of your product?

A: Over 75% LHV cold gas efficiency.

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: Over 75% LHV cold gas efficiency.

Q: What is the parasitic load for your technology?

A: For our OMNI200 GPRS system only, the parasitic load is about 206 kwh/ ton of waste as feed.

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: We require minimal Waste Preparation: No sorting, one stage of shredding to 100mm.one magnet, no rejects.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: There is no air emissions for the creation of OmniSyngas. Dioxins and Furans below level of quantification.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: Yes, we conducted the LCA analysis and follow the IPCC methodology. The final product has very low carbon intensity – can even be negative due to diversion from landfill CH4. Our system also includes the CO2 Capture System.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: We have our PTR GPRS Air Emissions Source Test Results available. We can provide that upon request.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: Not yet.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: Type 1 Gas Clean Up:
* Cold gas efficiency of 75% or more
* Sulphur < 40ppmv
* Particulate at submicron levels
* Tars removal >99.95%
* HCl < 24ppmv
* Dioxins and Furans Non Detectable

Type 2 Gas Clean Up
* Sulfur < 1ppmv
* No particulate
* Tars below dew point; Class 2 tars < 1ppmv
* Ammonia + HCN < 1ppmv
* Alkali < 10ppbv
* Halides < 10ppbv
* Dioxins and Furans Non-Detectable

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: We currently do not have an operating facility running. We have several projects in the Front End Engineering Design stages, in CA, US, Canada, UK, China, etc. We also had our first commercial sales of OMNI200 GPRS in April 2021, in California US.

Q: What is the “turnkey” purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: CAPEX for one unit of our OMNI200 GPRS is in the range of U$35mm-U$40mm, including installation. The OPEX varies, depending on each project specifics.

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: * Feedstock flexibility - Omnivorous and mixed feedstock with minimum requirement of feed preparation
* No sorting, one stage of shredding to 100mm. Metals, glass and plastics can be reclaimed for recycling.
* Wide range of applications, OmniSyngas™ can make heat, power, fuels, hydrogen, chemicals with no fundamental changes to the proven core technology

* Very low carbon intensity – can even be negative due to diversion from landfill CH4
* Less dependence on very long term supply contracts
*Recovered hot air can be used to dry wet feedstock for higher throughput and efficiency
* Over 75% LHV cold gas efficiency
* Low parasitic power usage. (Example: electrical power consumption to make hydrogen is 1/6 that of electrolysis)
* No air emissions during conversion of waste to syngas; only emissions are from end users of the syngas
* 100% diversion from landfill
* Dioxins and Furans below level of quantification
* OmniRock™ can be used in slag cement, as a construction aggregate, or as an abrasive blasting medium
* Small footprint: one unit of OMNI200 GPRS™ 53m long x18m wide X 23m high.

Sierra Energy

Q: Can you please provide a description of your gasification technology and system arrangement?

A: Sierra Energy's FastOx gasification technology is an ultra-high temperature (4.000F) updraft slagging gasifier. The FastOx system uses heat, steam and oxygen to break down waste at the molecular level. Organic materials turn into an energy-dense syngas. Inorganics melt into a non-leaching stone and metals. Waste undergoes complete conversion into high-value salable end products with no waste by-products created.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: We focus on the gasification technology.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Hydrogen, Renewable Natural Gas, Heat, Electricity, and Liquid Fuels.

Q: If your process generates biochar, do you sell it as a marketable product?

A: We generate a non-leaching stone that can be sold as road base, with potential higher-value as a cement additive.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: Yes, we vendor relationships for production of hydrogen, RNG, and methanol processes.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: 100 MTPD in a single gasifier.

Q: What is the useful final product output range for each of your products?

A: We are a vendor of gasification technology. Outputs depend on project developers choice of feedstock, end-product and project configuration.

Q: What are the efficiency metrics of your product?

A: We are a vendor of gasification technology. Efficiency metrics depend on project developers choice of feedstock, end-product and project configuration.

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: Cold Gas Efficiency of around 75%.

Q: What is the parasitic load for your technology?

A: Around 20 to 25%.

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: Shredding. We prefer moisture at 20% or below. Much higher moisture is acceptable but lowers efficiency. There is low-grade waste heat available for feedstock drying if required.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: We are a gasification isle technology vendor. It is a closed process. There are minimal emissions.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: We are a gasification isle technology vendor. An LCA would need to be done on a full project using our technology.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: [Unanswered]

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: [Unanswered]

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: [Proprietary]

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: [Unanswered]

Q: What is the "turnkey" purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: [Unanswered]

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: [Unanswered]

VGrid Energy

Q: Can you please provide a description of your gasification technology and system arrangement?

A: Mobile and scalable high-temperature downdraft gasification system.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: Our system includes syngas conversion technology.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Biochar, Heat, Electricity, and Wood Vinegar.

Q: If your process generates biochar, do you sell it as a marketable product?

A: Yes.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: IC engine.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: 200 lbs from a single unit (multiple units easily arrayed together).

Q: What is the useful final product output range for each of your products?

A: We are a vendor of gasification technology. Outputs depend on project developers choice of feedstock, end-product and project configuration.

Q: What are the efficiency metrics of your product?

A: Per machine per hour ... 100 KW electricity, 40 lbs biochar, 8 gallons wood vinegar.

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: Per machine per hour ... 100 KW electricity, 40 lbs biochar, 8 gallons wood vinegar.

Q: What is the parasitic load for your technology?

A: [Unanswered]

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: No specific spec. We're currently processing pistachio shells under 10% moisture.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: Catalytic converter.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: Yes.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: Yes.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: Yes, multiple.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: Monetize and sell.

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: 7, all in California. Since 2018. Yes, commercially available.

Q: What is the "turnkey" purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: [Confidential]

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: [Unanswered]

Vital Energi

Q: Can you please provide a description of your gasification technology and system arrangement?

A: The Leaf Trio Gasification process utilizes very well proven step grate gasifier to produce syngas. This is then used in a secondary combustor to produce heat for a high temperature steam raising boiler. The whole process is based on advanced conversion technology using ceramics developed in Staffordshire England the home of the potteries. This high tec proven ceramic solution uses ceramic filters and ceramic gas converters to reduce and arrest gas emissions to a minimum making this solution ultra-low NOx.

Q: Does your equipment convert the syngas into a useful product (electricity, heat, fuel, hydrogen), or is the untreated syngas the terminal product?

A: Our system includes syngas conversion technology.

Q: If you have multiple end products, please indicate them by selecting from the list below:

A: Heat & Electricity.

Q: If your process generates biochar, do you sell it as a marketable product?

A: No.

Q: Does your company have partnerships for downstream integration of end-product? If so, please explain below.

A: Our solution is full turn key with a local EPC partner.

Q: What is the woody biomass feedstock capacity/requirement in dry tons per hour?

A: 5-6 TPH.

Q: What is the useful final product output range for each of your products?

A: 5MWe and 10MWt.

Q: What are the efficiency metrics of your product?

A: 90% thermal 25% electrical.

Q: What is the efficiency of your technology on the basis of useful energy output compared to useful energy input?

A: 90% thermal 25% electrical.

Q: What is the parasitic load for your technology?

A: 10-15 % parasitic load depending on the heat source the system is connected to. The more heat used the less the parasitic load.

Q: What are the feedstock specifications for your technology? Is there any upstream treatment required for the feedstock such as woody biomass size reduction, drying, removal of impurities?

A: 9-18 Mj/Kg shredded down to 75 mm in size and less than 50%. Less than 20% ash on a dry basis.

Q: What emission control technologies are used for criteria (PM, NOx, VOC) and toxic air pollutants?

A: Clean staged gasification and combustion, ceramic filtration SNCR and SCR and sub micro removal.

Q: Have you conducted a greenhouse gas life-cycle analysis (LCA) for your product? Have you considered doing Bio-Energy with Carbon Capture and Storage (BECCS)?

A: We do have a carbon capture option that can be offered. Each 5 MWe module will reduce annual carbon emissions compared with fossil fuels by using wood from a sustainable sourced by over 33,000TPA.

Q: Do you have existing emissions test data (criteria or toxics) for your technologies? Describe here.

A: Yes proven system operating at over 90% availability since 2005 and still operating.

Q: Do you have a system in place with a valid air permit? If so, who was the permitting agency?

A: Yes EU IED and clean air.

Q: Please describe the process or technologies you use for syngas clean up and tar management.

A: Ceramic filtration.

Q: How many systems do you have up and running in the world, the US, California? How long have they been operating in above locations? Are they commercially available?

A: 13 commercially available units in operation world wide for over 17 years.

Q: What is the “turnkey” purchase and installation cost for your technology? What is the operation and maintenance cost for your product?

A: Commercially sensitive, but a yield of over a 15% IRR can be achieved depending on feedstock arrangements.

Q: What other important or interesting information would you like to be noted about your technology or end-products? Final comments?

A: Proven, available with ultra-low emissions credentials