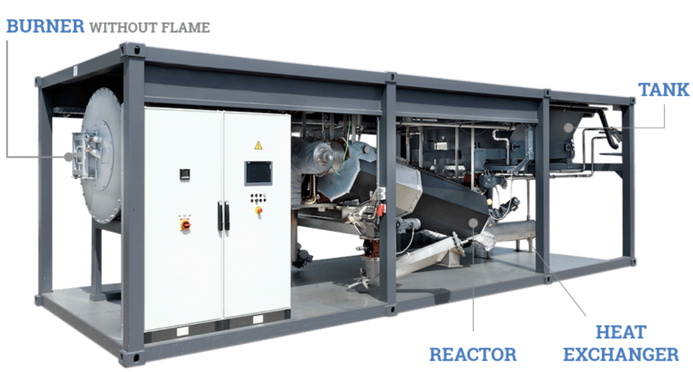
Report on Options for Utilization of Surplus Biomass Coming From the Usal Forest



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Sonoma Ecology Center
December 14, 2018

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Final Report
December 12, 2018

Executive Summary

This report surveys a number of options that the Redwood Forest Foundation, Inc. (RFFI) could employ in its quest to find environmentally beneficial uses for the surplus woody materials (primarily tanoak) generated during management activities in the Usal Forest. These materials include primarily small diameter tanoak logs and forest slash from fuels reduction and sustainable logging operations, and RFFI has been actively experimenting with and considering a number of different processes for turning this material into value-added products. In 2017, tanoak logs that had been removed to allow more vigorous growth from the confiers were processed into biochar, a form of charcoal with agronomic benefits as well as filtration and remediation applications. However the technology that was used, while producing excellent biochar, did not meet required performance standards, prompting exploration into other systems that produce biochar and other co-products, as well as other opportunities such as supplying tanoak for briquette manufacturing and boutique woodworking.

The chart below, taken from a report titled "California Assessment of Wood Business Innovation Opportunities and Markets" (CAWBIOM) that was prepared for the National Forest Foundation in 2015, shows the large variety of potential uses for large-log and small-log woody materials. Each of these opportunities are dependent on a specific set of conditions including wood type and local availability, volume availability, long-term, sustainable feedstock availability, distance from the forest to processing infrastructure, distance to markets for final products, access to financing, assessment of long-term market potential and demand, environmental life-cycle analysis of energy use and carbon emissions impacts, public education about the value of wood as a renewable resource, community safety and health concerns, etc.

Table 4.1 – Full Listing of Business Opportunities Considered for Detailed Analysis

Energy Related	"Traditional" and Engineered Wood Products	By-Products Users	Other
Small Biomass CHP	Laminated Veneer Lumber (LVL)	Air Filtration Media	Activated Carbon
Butanol/Drop in fuels	Fencing	Animal Bedding	Anaerobic Digestion
Cellulosic Ethanol	Finger-jointed Lumber	Compost/Mulch	Biochar
Charcoal	Glulam	Decorative Bark	Cross Laminated Timber
Firewood	Large Scale Sawmill	Decorative Chips	Emerging Bioproducts
Fuel Bricks/Logs	Medium Density Fiberboard	Hardboard	Erosion Control
Large Scale Biomass Power	Oriented Strand Board (OSB)	Liquid Filtration Media	Excelsior
Pyrolysis	Parallam	Whole Log Chips	Extractives
Small Biomass w/o CHP	Particleboard	Wood Plastic Composites	Nanocellulose
Small Gasification CHP	Plywood		Scrimber
Small Gasification w/o CHP	Post and Pole		
Torrefied Wood Pellets	Pulp and Paper		
Wood Pellets	Semi-Mobile Sawmill		
	Shingles		
	Small Scale Sawmill		
	Wooden I-Joists		

Figure 1: Business opportunities for forest feedstocks.

While this report does survey a variety of pyrolysis and gasification technologies that convert biomass into biochar, some of the systems also produce a number of co-products that can be monetized. These co-products include syngas that can be used to generate to electricity or create useful chemical compounds; process heat that can be used to boil water to run steam-powered engines or used in fruit, firewood, or biomass drying operations; bio-oil that can be used to create a range of bio-products including wood vinegar; and torrefied wood (also known as biocoal) that can replace fossil coal as a carbon neutral fuel.

We have focused on technologies and techniques that co-produce biochar since it is our belief that the scaled production and use of biochar represents a simple and effective way to sequester large amounts of carbon in soil for long periods, which, according to the recent dire IPCC report on climate change, is one of the least expensive, large-scale climate mitigation strategies available to us right now. At the same time, biochar use can provide many other beneficial services for farmers and society in general, including reduced water and nutrient needs, increased plant production, and increased soil organic carbon sequestration, especially when blended with compost.

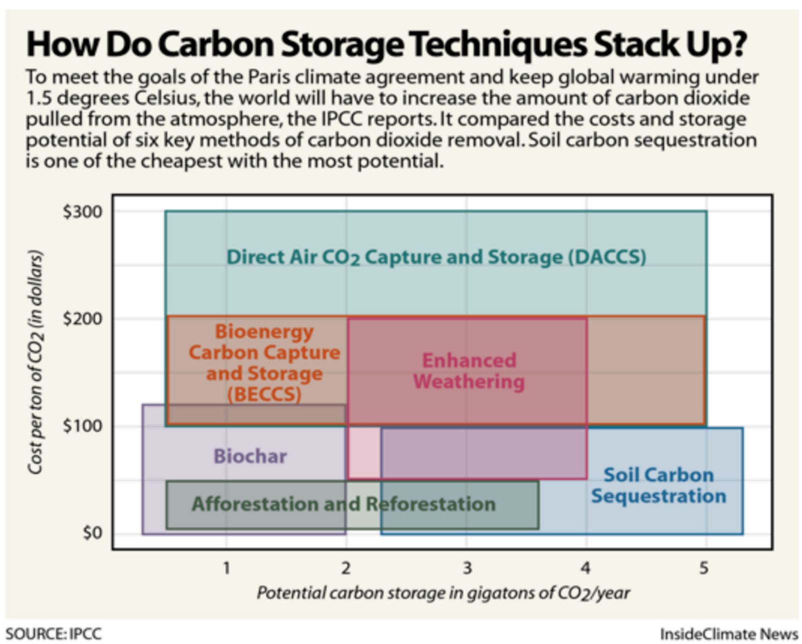


Figure 2: IPCC chart showing biochar as a relatively inexpensive method for carbon removal

We also looked into using tanoak logs as source material for boutique woodworking applications, as well as densifying processed logs and slash into briquettes that could be used as a carbon neutral fuel in a number of ways. We included both low tech and high tech solutions since a combination of processes would likely be needed to address different forest management challenges. And while a few of the technologies process biomass on a similar scale to that generated during the Redwood Forest Foundation's sustainable forestry practices, most would require additional feedstock sources to supply the fuel for a profitable operation. At the end of this report we also included a few contacts for larger, industrial-scale biomass co-gen facilities that would need to be developed on a much longer time frame but that could add more benefit to the larger community.

Since RFFI's mission is focused on the restoration and sustainable management of the Usal and not on product development, almost all of the options we surveyed would fall outside of this core mission and would require partnerships and a significant investment in both time and money to develop. We are not recommending that RFFI invest in any of these technologies, however as a source of an estimated 800 to 1000 tons of clean biomass annually it may be able act as a catalyst to attract entrepreneurial partners willing to contract for this feedstock.

Also, as mentioned, many of these products or processes would be impractical to develop using only RFFI's surplus biomass, given the limited volume of material as well as the sporadic delivery schedule, that would be dependent on tanoak volumes coming from different THP's and shaded fuel break projects. However there is no shortage of surplus biomass, and additional feedstock sources could likely be easily found. Lastly, some of the products that might be manufactured using RFFI biomass (such as laminates) require the use of chemicals, glues, and other toxic materials during that could be problematic to workers and/or the surrounding community. So choosing a sustainably-focused company with a similar sustainability ethic to partner with should be a priority.

A Note About Efficiency and Capacity Numbers

For all of the biomass processing equipment we have profiled in this report we will list both input capacities and output efficiencies (along with other operational data where we were able to obtain it—not all companies returned our calls or emails). It is important to note, however, that these numbers can and will vary during real-world operations depending on a number of important variables, including feedstock type and density, feedstock particle size, feedstock moisture content, process temperature, feedstock residence time, and even ambient environmental conditions at the plant location, plant operator experience, interruptions in feedstock availability.

Some of these variables produce different products such as torrefied wood or biocoal at lower temperatures and syngas for energy production at higher temperatures, and some technologies are highly labor intensive while others are mostly automated. In addition, some technologies are still in the beta testing or proof of concept stage of development, while others have benefitted from multi-generational improvements made over years of operations. No independent evaluations have been done and all data has been gleaned from each technology manufacturer or other sources.

Additionally, some of the technologies are not turnkey, off-the-shelf units. Larger systems are custom built to client specifications, so input and output numbers can vary greatly depending on need. Some are available as self-contained "mobile" of "movable" units and some are designed to be stationary only. However, all require some additional infrastructure or "add-ons" that may or may not be reflected in the quoted purchase price. For example, most units require very dry feedstock (10% to 20% moisture) to reach maximum throughput, so some drying mechanism would likely be needed at the processing location to prepare the material (although some do provide this as part of their system).

Even if the feedstock is obtained in a dry form, some type of housing or cover would be required in Mendocino County to keep the materials dry until needed, especially during winter. Some units would need conveyers, feedstock bins, barrels, product cooling systems, access to electricity or water or both, and these items may or may not be included in the purchase price. When analyzing or comparing costs for different technologies all of the necessary infrastructure must be accounted for—including operator training.

Simple, Low Cost Options

"Kon Tiki" Style Pit Burning

This is an ancient method for making charcoal that has been popularized and used commercially by biochar pioneer Josiah Hunt in Hawaii over the last 10 years. The technique for producing high-quality biochar is amazingly simple and can be used in many locations safely and economically.

Figure 3: Josiah Hunt tending a pit burn, Photo: Josiah Hunt.

This method requires only one attendant (although two are recommended for safety purposes), is very low in smoke pollution, and produces excellent biochar. It is one of the least expensive biomass-to-biochar conversion methods that can be done in many locations safely, and the conversion efficiency can be as high as 15% and 20%. While Josiah uses surplus materials from a local sawmill to make his biochar, forest slash and precut tanoak logs could easily be used instead if prepared properly. According to Josiah, pits should ideally be dug between 6 and 8 feet wide at the top and cone shaped, sloping down to around 4 feet at the bottom with no sharp corners, formed like a soup bowl. The depth should be about 2/3 of the width of the pit at the top.

The pits can be made larger to process more material, but they become harder to manage because of the intense heat and take longer to burn. As shown in the photo above, it is important to leave a “hole” in the center of the burn and just add wood around the sides of the burn, this creates a funnel effect that causes air to be sucked down the sides of the pit and up through the center, allowing more of the smoke to be more cleanly incinerated. Once the pit is filled up it is covered with the soil that was dug out and left to “cook” overnight. It is then uncovered and thoroughly quenched with water and either dug out by hand or with a backhoe or excavator. The biochar can then be safely spread out in the forest.

Depending on the size of the pit and the material used, the yield can be from 4 to 6 cubic yards of biochar. The cost of this method depends on labor, and feedstock acquisition and prep expenses, but is similar to standard open burning.

Conservation Burning

Open pile burning is perhaps the most common, and also one of the least expensive, forms of dealing with surplus biomass both on the farm and in the forest. In the past, pile burning, along with “hack and squirt” chemical applications and “tree girdling” techniques were used by RFFI foresters to treat slash piles and to kill surplus tanoak. However, the organization established a policy of not using chemical agents in the Usal, the girdling technique has not been very effective, and pile burning can be problematic for air quality and soil degradation. So RFFI has been looking for alternatives that could provide more environmental benefits and be less damaging.

Figure 4: Forestry Conservation Burn training in southern Oregon, Photo: R. Baltar

A simple technique called conservation burning, where piles are lit from the top and put out at a critical stage to retain as much carbon as possible, offers an improved option for foresters and farmers that significantly reduces smoke pollution while generating a valuable product, biochar, that can be used to improve soil health. Pollution (specifically particulate matter) generated by open burning, while not a significant issue in Mendocino County on most days, has caused major air quality problems in other parts of California, and some air districts like the San Joaquin Valley Air Pollution Control District. have banned open burning in the last decade. However, some burn permits are now being issued there because the co-gen plants that used to take the surplus ag waste are closing down and there are few other alternatives affordable to growers. As the least expensive method of reducing their surplus biomass materials, open burning has long been the preferred disposal method for farmers and foresters alike.

The Sonoma Biochar Initiative and the Sonoma Ecology Center have been developing this conservation burn technique over the last 5 years. Over 30 workshops and trainings have been held, mostly with grape growers and landowners looking for a more sustainable (and inexpensive) way to handle their ongoing surplus biomass issues. Recently a number of air management districts, including their parent organization CAPCOA, have expressed an interest in developing standards for the practice. Emissions testing on open burn piles vs conservation burn piles are planned for mid-November 2018 by the South Coast AQMD, yielding important data that could help to standardize and scale the technique up and down the state.

There are several key practices that differ between the conservation burn technique and a typical open burn:

- The feedstock is monitored for moisture content and is not burned until it dries out to 20% moisture or less
- The piles are “fluffed up” to allow more air flow
- Piles are lit around the top perimeter, not the bottom (as is now standard practice)
- If it is windy, piles are lit at the top on the downwind side (see photo below)
- Piles are managed to reduce smoke pollution and efficiently burn as much of the material as possible
- Unlike the pit burn, no additional materials are added as the pile burns down
- At a critical time the pile is quenched with water and raked out to save as much of the carbon as possible, and this carbon (called biochar) is processed and utilized as a soil amendment

Figure 5: Top-lit Conservation Burn training at Circle Bar Ranch, Sonoma Photo: R. Baltar

Figure 6: Conservation Burn training at Pine Hawk Cellars, San Luis Obispo. Photo: R Baltar

While the top-lit technique can be used on any burn pile, it is likely best suited to agricultural settings since feedstock size and condition are generally more consistent, leading to a more predictable burn rate and biochar end product. Forestry materials can be used but more care needs to be taken with preparing the piles.

Cost: This is dependent on available labor, machines, and tools, as well as the type of and amount of biomass that needs to be processed. Some additional labor may be required to manage the piles, and water and special tools are required to extinguish and rake out the piles to save the carbon. However, conservation burns generally burn faster than bottom-lit piles, reducing the time required to manage them, helping to offset labor costs.

Advantages: Inexpensive, low emission, more conservation-oriented than simple open burning, produces a valuable byproduct, biochar, that has agronomic benefits while also sequestering carbon. This technique could create a new industry and jobs from startups offering burn services and sales of the biochar.

Disadvantages: Probably the least efficient biomass-to-biochar conversion efficiency, requires seasoning of material and material storage for optimal results, does not utilize the heat or gases produced, may require some extra staff time during the burn and after to process the biochar, can cause some soil damage unless the pile is built on larger logs, but less than a typical open burn pile.

Flame Carbonizing Kilns

A flame-cap, or flame carbonizer kiln (a term coined by biochar pioneer Kelpie Wilson) is a device that carbonizes biomass, usually in the form of branches or small logs, using an open flame and passive countercurrent flow. Below is a diagram explaining the concept. These kilns have long been used in Japan to process surplus farm biomass and the diagram was taken from a Japanese website illustrating the process.

Figure 7: Flame cap kiln diagram, courtesy Kelpie Wilson

There are many designs for this DIY type of kiln, and a few that are currently available commercially in the U.S. or easily manufactured from open source plans will be described below.

Generally, flame carbonizing kilns are open-top containers constructed of sheet steel, and they can be a small size (1-2 cubic meter capacity) for hand loading or a large size (above 2 cubic meters) for machine loading. The container should be shaped to fit the feedstock and can be a cylinder, a truncated pyramid, a truncated cone, a trench, half-cylinder or rectangular box. Like the pit method, the kiln is operated in a semi-continuous mode. More biomass is added to the initial load, as it burns down. The biomass additions are timed so that as soon as one layer becomes charred, a new layer is added, which cuts off air and prevents further oxidation, creating a specialized form of charcoal we call biochar. Biomass is continually added until the kiln is full and then it is quenched in order to save the biochar. Quenching is done with water or by snuffing with a lid or with dirt.

The Oregon Kiln

Company Name: Wilson Biochar Associates
Contact Name: Kelpie Wilson
Address: Cave Junction, Oregon
Phone: 541 218-9890
Website: http://wilsonbiochar.com
Email: kelpiew@gmail.com
Years in Business: 11

Primary Business Focus: Biochar consulting, analysis, writing
Units Available for Purchase? Yes, for $800 FOB from southern Oregon.

Kelpie has been pioneering the use of Oregon Kiln in forestry applications in a number of western states over the last 6 years.

Figure 8: Unloading an Oregon Kiln, courtesy Kelpie Wilson.

Dimensions: 5 foot top base; 4 foot bottom base, 2 feet high

Figure 9: Oregon Kiln in action, courtesy Kelpie Wilson.

Figure 10: 3 Oregon Kilns, courtesy Kelpie Wilson.

As shown above, the kilns can be placed on cement blocks to prevent soil damage, and multiple kilns can easily be managed by one worker. The use of these kilns has been permitted by the North Coast Union AQMD, and several air quality management districts throughout the state (SLO, South Coast, and Northern Sonoma County) are looking into their use as well. These kilns have been accepted for use in forestry settings by the USDA Conservation Stewardship program as a treatment method for fuels reduction materials by converting biomass into biochar, and two landowners, one in Northern California and one in Southern Oregon are the first two selected to help develop the standards and protocols for the use of these kilns. These landowners will be paid $4800 per acre, helping to offset this important forest thinning work and method of returning carbon to the forest ecosystem.

Cost: Kilns can be purchased from Kelpie for $800, or manufactured by any competent welder using open source designs available from Umpqua Community College:

https://drive.google.com/open?id=1faCEN-fMYrb512VGQpM2FqfturIgNXV2

and Kelpie Wilson's website:

http://www.backyardbiochar.net (Click on the Open Source Plans link)

The Kon Tiki Kiln

Figure 11 below shows a Kon Tiki kiln design, pioneered by Hans-Peter Schmidt and Paul Taylor, and more information about this kiln can be found here:

https://www.ithaka-institut.org/en/ct/101

Figure 11: A Kon Tiki kiln is lit.

These Kon Tiki kilns are not available commercially, but as shown above and below, there are many creative ways to produce good quality biochar using DIY methods and a little elbow grease.

Figure 12: Kon Tiki kilns can produce large amounts of high-quality biochar.

The Moxham Kiln:

Australian biochar producer Geoff Moxham experimented with an even larger large tube design that has taken on his name, the Moxham Kiln.

Figure 13: The Moxham Kiln is cleaned after a production run.

Made from surplus heavy-duty metal piping used in large construction projects, this kiln can process most types of woody biomass (wood chips are not recommended), however denser materials (such as firewood-sized chunks of hardwood) will produce the most consistent biochar, and large amounts of biomass can be processed into biochar in a 12-hour burn period. Click the link below for a short video Geoff made on the process.

https://www.youtube.com/watch?time_continue=132&v=PEbHhr8Uwro

Kelpie Wilson has also experimented with this design and a video on her process can be found here:

https://www.youtube.com/watch?v=wUazog4yErQ

Small to Medium-Scale Technologies

CarbonZero

Contact: Nando Breiter
Address: 6999 Astano
Switzerland
Phone:+41 (0)76 303 4477 cell
Skype: ariamedia
Email: info@carbonzero.ch
Website: http://carbonzero.com

Tilting Batch Kilns

Figure 14: The tilting batch kiln prototype.

The tilting batch kiln is designed to produce biochar from sticks and split wood. The tilting mechanism allows for easy loading and unloading of the unit. It is also possible to configure 3 units in a round-robin fashion so that the excess heat from one is used to start the pyrolysis process in another. These units require no electricity, but there is manual labor involved in preparing the feedstock, loading and unloading. This unit is not yet in commercial production and the kilns shown above are prototypes. As of the publication of this report Carbon Zero is looking for financing to start production.

Batch Kiln 100-MK 1

The batch kiln shown below is “available for manufacture”, or in other words it is being produced on a custom-order basis through Carbon Zero. This kiln was not designed for commercial operations but rather for researchers at universities to be able to produce biochars economically from different feedstock sources. The 100 MK-1 unit shown below, which can produce up to 100 kg per batch (approximately ¾ cu yd per batch depending on feedstock), costs about $8,150 US plus shipping from the EU, and requires 2 to 3 months lead time to manufacture and ship.

Figure 15: Batch Kiln 100-MK 1

From the web site:

Simple and easy to use, this batch kiln has a cylindrical body 1.2 meters high and 1.5 meters in diameter. The kiln has an internal combustor (firebox) which hangs from the lid and provides heat to convert the feedstock to biochar. It takes about 8 hours for a batch to be processed, depending on the moisture content, type and size of the feedstock.

The kiln is loaded from the top, and unloaded through a door at the bottom. A hand-driven winch is used to remove the lid for loading. After a burn, the kiln is left overnight to cool before unloading. A single batch can produce up to 100 kg of biochar.

The kiln runs on a two stage cycle. First the feedstock is dried, then it is charred. The design relies on air convection to distribute heat throughout the feedstock bed. It is for this reason that feedstock is limited to split or small diameter wood—no chips or sawdust. During the drying stage small logs are burned in the firebox to provide heat. As temperatures within the kiln rise to around 450 C, the feedstock releases syngas.

Once syngas is available, it is burned in the combustor to maintain suitable charring temperatures.

The kiln is transportable on a small trailer. It is therefore likely that in most areas, air district permits would not be needed. It does however produce some steam and smoke, so it is advisable to locate it away from buildings and people. The kiln does not need electricity to run. It uses a leaf blower included with the kiln to supply air to the internal combustor.

Specifications
Batch time: around 8 hours
Moisture content: up to 40%
Feedstock size: logs, up to 30 cm in length and 10 cm in diameter
Feedstock type: Wood
Feedstock volume: 1.5 cubic meters
Fuel source: logs, up to 15 cm in length and 5 cm in diameter
Char yield: up to 100 kg per batch
Infrastructure used: handheld leaf blower (provided with the kiln)
Price: ~ 8000 Swiss francs excluding shipping ($8,150 US)

Biochar Now

Contact Name: James Gaspard
Address: P.O. Box 1832 Loveland, CO 80539
Phone: 970 593-9100
Website: http://www.biocharnow.com/index.php
Email: info@biocharnow.com
Years in Business: 9
Primary Business Focus: Biochar Production and Sales
Units Available for Purchase? Only Through a joint venture arrangement, but they would handle sales of the biochar. They want to keep control of the tech and have markets in California already.

Biochar Now has been developing their patented kiln technology and specialized biochar products for about 9 years. While they do not sell their kilns outright at this time, they are open to joint ventures where both operating expenses and revenues are shared—primarily to maintain control of the processing process and product quality to make sure a consistent product is consistently produced.

These kilns use slow pyrolysis in a batch system that coverts 11 cu. yds. of shredded woody feedstock into about 3 cu. yds. of biochar per 8-hour period. After 8 hours the patented emissions control stack is removed and the biochar is covered for another 8 hours to make sure it is completely ember-free. The biochar is not quenched with water so that it remains dry for shipping. The kilns, with the specially-engineered emissions control stack, have been analyzed by EPA and the local air district. According to Gaspard, he could have well over 100 kilns in production at his location in Colorado and still meet the strict air emissions standards.

These kilns are operated by Biochar Now in series (see photo below), and many kilns can be managed by one operator, lowering labor costs on a per-kiln basis. A four-kiln operation would cost approximately $100,000 for the kilns, stacks, and computerized controllers. Other system-supporting equipment, such as a tractor, a specialized kiln turning mechanism, and a shredder are needed to efficiently process the material, and these would need to be purchased or available at the processing site. Kiln operations can be monitored remotely over the internet where WiFi is available.

These kilns are designed to produce high-quality biochar only and no co-products (such as bio-oil, syngas for power production, or process heat). The feedstock is converted to biochar at a temperature of about 600C, considered by some to be the optimal temperature to produce the highest adsorptive qualities. The biochar produced weighs approximately 200 pounds per cubic yard, or 10 cubic yards per ton. According to Gaspard, they have doubled hemp yields in field trials with just a 2% application of biochar made in these kilns, and the chemical giant DuPont has had great success using a Biochar Now product to mitigate Mercury pollution in the White River.

Figure 16: Biochar Now kiln being loaded by a Comptech Crambo.

The Biochar Now site is organized with four kilns clustered around a utility pole and then replicated to support the desired number of kilns.

Figure 17: At left, a single kiln showing the patented emissions stack. At right, a series of kilns.

Below is a link to a short TV news story on Biochar Now's operations by a local Colorado news station.

https://www.thedenverchannel.com/news/front-range/colorado-company-turning-beetle-kill-trees-into-organic-bio-fertilizer

Advantages: Relatively inexpensive, low emissions, expected 10 to 20 year kiln product life, easy to operate and maintain, proven track record, joint venture arrangement guarantees efficient operations, short down-times, and marketing assistance, very low emissions profile.

Disadvantages: Relatively low production rate per day unless used in a series, Client must purchase unit and supply needed supporting equipment, no co-products produced. Units are only available through a joint venture agreement.

Other Technologies

Biochar Solutions, Inc.
Contact: Jonah Levine
Address: PO Box 2048
Carbondale CO. 81623
Email: info@biocharsolutions.com
Website: http://www.biocharsolutions.com/

New England Biochar LLC
Adam-Retort
Contact: Bob Wells, Owner and Chief Designer
Address: 40 Redberry Lane, P.O Box 266
Eastham, Massachusetts, 02642
Phone: 508 360-6346
Email: bob@newenglandbiochar.com
Website: https://newenglandbiochar.com

ROI Air Curtain Carbonizers

Figure 18: Three models of the Air Curtain Carbonizer.

These air curtain carbonizers have been redesigned by ROI to produce biochar as a byproduct of the biomass reduction process. While air curtain burners have been around since the 1990's their focus has been on incineration, and no thought was given to altering the design to produce a carbon-rich byproduct until ROI designed these units.

Air curtain burners were originally designed for incinerating large amounts of debris from storms in Florida and other disasters, however forestry professionals and agricultural groups have started using them to process surplus biomass in California and elsewhere. CalFire purchased 10 of the non-biochar producing units to process dead trees in the Sierra, and orchard growers in the Central Valley have permitted three similar units to process orchard clippings and nut waste.

These are the first air curtain burner designs that are fitted with tracks to allow them to be easily moved short distances and positioned or repositioned without heavy equipment.

There are three sizes and designs: the Envirosaver 350 can process up to 10 tons of biomass per hour; the Envirosaver 500 can process up to 20 tons of biomass per hour, and the Envirosaver 400, which is planned but not yet manufactured, will process large amounts of wood chips. Since the main advantages of the Envirosaver 350 and 500 models are that they require minimal pre-processing of the feedstock and that they can process a wide range of materials, we anticipate they will be more popular than the Envirosaver 400. However, in some areas there is a surplus of chips produced by municipalities, tree companies, and land managers, so a market could develop for processing some of these wood chips into biochar.

Figure 19: ROI Envirosaver 350 being loaded.

Figure 20: Envirosaver 350

Figure 21: Envirosaver 350 showing biochar in bin at left.

These machines come with standard, off-the-shelf motors, fans, and other parts, making maintenance and repairs easier than is often the case with custom-built technologies.

As of September 2018, the price quoted for the Envirosaver 350 was $525,000. The price for the Envirosaver 500 was $550,000, plus shipping. This price does include up to a week of training, however some additional equipment could be required to run the system efficiently, such as a conveyer to take the cooled biochar from the machine to either a dump truck or into supersacks for easy transport.

Below are several photos of an Envirosaver 350 unit processing material at a soils company in Houston, Texas. A local forester named Dan Falk, whose family owns 8500 acres of forest and rangeland on the Sonoma County Coast near Gualala, plans on purchasing the Envirosaver 500 model to process logging slash and fuels reduction thinnings, then use a portion of the biochar to restore the degraded rangelands, thereby increasing grass production and reducing feeding costs for his brother's cattle operation. This machine would be shipped in February and available for rent to others (such as Sea Ranch, which has committed to a 1 month rental) in March or April.

All Power Labs

Address: 1010 Murray Street Berkeley, CA 94710
Phone: tel: 510-845-1500
tel: +1-888-252-5324
fax: 510-550-2837
Website: http://www.allpowerlabs.com
Email: info@allpowerlabs.com
Years in Business: 10
Primary Business Focus: Combined Heat and Power Production from Biomass
Units Available for Purchase? The Power Pallet 20 unit is available by special order now, the Power Pallet 30 and Powertainer models should be available by the end of 2018 or Q1 2019.

All Power Labs is a Bay Area company specializing in small-scale, carbon negative biomass power technologies utilizing gasification technology, and recently they have begun promoting biochar production as a key feature of their Power Pallet systems.

These systems convert dense biomass such as wood chips or nut shells into electricity and heat, and can deliver power at under $1.50 per watt. The current model, the PP20, delivers between 15 kW and 18kW of power using just 2.5 lbs of biomass per kW hour to produce this power. Focused primarily on supplying power to off-grid customers, they offer an optional grid tie-in package that "allows their PP20 model to work with other power generating devices such as wind or solar, as well as with additional Power Pallets, utilities, or micro-grids to generate reliable synchronized power."

Figure 22: All Power Labs PP20 CHP Power Pallet

These systems have been in continuous development for 10 years and have undergone a number of improvements and iterations over that time. The size and mobility of this model is a key advantage, and it can be transported in the bed of a pickup truck to where the fuel is, and/or to where the power is needed. The feedstock needed for its operation is often available at little or no cost, and "depending on feedstock selection and use details, the Power Pallet is capable of carbon negative operation."

In order to eliminate manual filling of the 88-gallon hopper, an optional continuous feed airlock controller system is available, however a standard agricultural conveyer is needed that is not provided by APL. This current model does not produce much biochar, and is really designed to produce power. However APL is working on some new designs that will produce much more biochar .

Below are the specifications for the PP20 unit shown above. It costs between $28K and $40K depending on the options requested:

FEEDSTOCK BIOMASS

Size:	12-40 mm/0.5-1.5 in.
Moisture Content:	5-30% dry basis
Approved and Tested w/ normal operating procedures	Nut Shells (e.g. Walnut, Hazelnut) Softwood Chips (e.g. Fir, Pine) Hardwood Chips (e.g. Oak, Ash)
Approved and Tested w/ increased operating effort	Corn Cobs Coconut Shells Palm Kernel Shells
Not Approved dangerous & voids warranty	Coal Tires Plastic Municipal Solid Waste

SHIPPING

Dimensions:	PP20 - Crated Hopper - Crated	145 x 145 x 140 cm/57 x 57 x 54 in. 83 x 83 x 114 cm/33 x 33 x 45 in.
Weight:	PP20 - Crated Hopper - Crated	700 kg/1550 lbs. 91 kg/200 lbs.

FUEL COST COMPARISON (VARIES by REGION)

FUEL	PRICE RANGE
Diesel/LPG	\$0.40 - \$0.75/kWh
Gasoline	\$0.50 - \$1.00/kWh
Gasified Biomass	***\$0.00 - \$0.20/kWh***

PERFORMANCE

Continuous Power Rating:	15 kW@50 Hz/18 kW@60 Hz
Sound Level @ 30 feet:	85 dB(A)
Biomass Consumption:	1.2 kg/kWh, 2.5 lbs/kWh
Run Time per Hopper Fill: approximate @ 250 kg/m³ fuel density	5 kW: 10 hrs 10 kW: 5 hrs 15 kW: 3 hrs
Max. Continuous Operation:	>12 hours
Start Up Time:	10-20 min.

OPERATING CONDITIONS

Ambient Temperature:	5-40°C/40-100°F
Humidity:	5-95% RH
Installed Footprint: without ash vessel or grid tie	1.36 x 1.36 m 53.5 x 53.5 inches
Site Requirements:	Well-Ventilated protected from rain & direct sun

Figure 23: All Power Labs PP20 CHP Power Pallet Specifications.

As stated previously, APL is currently working on several other products, including a 25kW design called the PP30, which will feature a number of improvements over the PP20 as well as producing more power; a much larger 150 kw containerized gasification genset system called the Powertainer; and a "Chartainer" that will be focused on maximizing biochar production.

APL has partnered with some other organizations to create the Local Carbon Network to promote the use of locally sourced green waste byproducts to produce biomass energy using their technology, then donating the biochar co-product to local community gardens.

Here is some information from their website on biochar:

The process of gasification is an incomplete one, and the leftover "waste" our equipment produces from making energy is a stable form of carbon known as 'biochar." Sequestering this carbon is what makes biomass gasification net carbon negative energy production.

While today's APL Power Pallets produce a relatively small amount of biochar byproduct (around 5% of input mass), it is still enough for carbon negativity in the fuel cycle. The round rule of thumb numbers are as follows:

- *1 tonne of dry biomass in produces about 1Mw/hr of electricity and 50kg of carbon byproduct.*
- *50kg of raw carbon once recombined with O2 is the equivalent of 185kg of CO2 in the atmosphere. (mass C x 3.67 = mass CO2)*
- *1 tonne of biomass input to the gasifier can soil-sequester the equivalent of 0.185 CO2 tonnes in the atmosphere.*
- *Avoided CO2 emissions from not burning fossil fuel in the process are added to the wins above.*

Future APL machines will introduce features that enable increased biochar yield of up to 15-20% of input mass, while still co-generating electricity. For now we are just using the post hearth char. You can learn more about our *carbon analysis here**.*

To look at the potential of APL's PP20 and Powertainer models to offset C02, they offer this graphic that makes it easy to visualize:

Offset and Sequestration Compared with Fossil Fuels*

QUANTITIES:	POWER PALLET @15 kW	POWERTAINER @ 150 kW
OUTPUT (MWh/yr) @3500 hr/yr	53	530
CONSUME (tonne biomass/yr) @1.2 kg/kWh	63	630
SEQUESTER (tonne CO_2/yr) @5% biochar output	11	110
(tonne C/yr)	3	30
OFFSET Electrical (tonne CO_2e/yr)	15-93	150-930
CHP (tonne CO_2e/yr)	28-211	292-2120

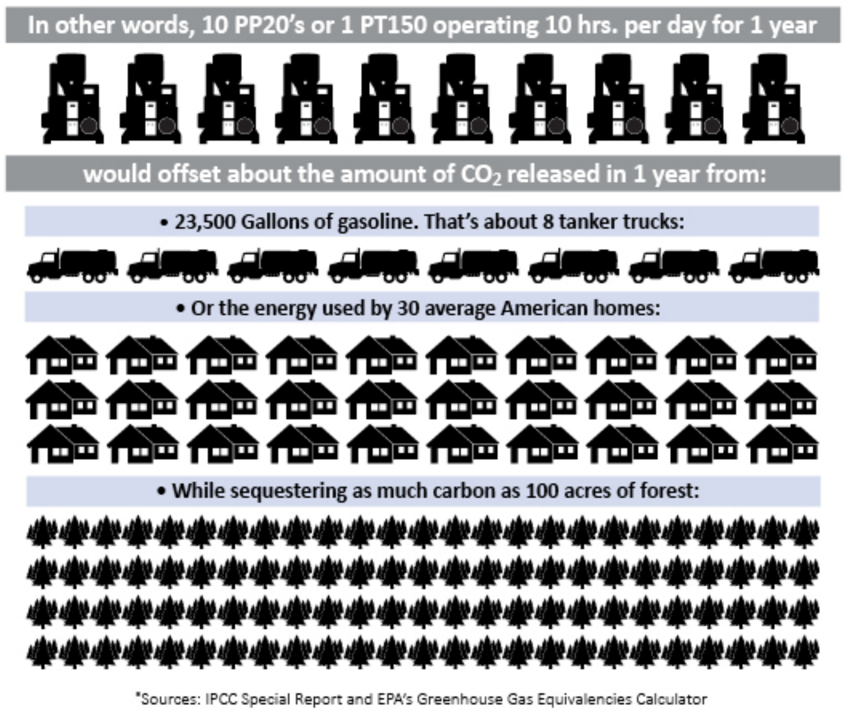


Figure 24: APL carbon offset and sequestration comparison.

As mentioned previously these units can be tied into the grid to take advantage of net-metering income, however they are perhaps used best in "behind the meter" locations where the electricity output matches needs and where local utilities need not be involved, eliminating expensive grid tie-in fees.

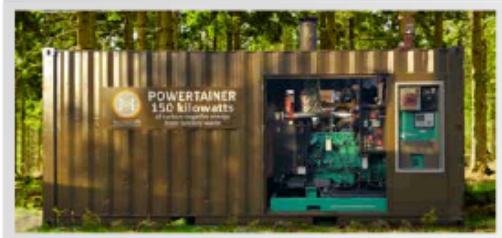
Below is the spec sheet for Powertainer PT150, which is expected to be available by special order in late 2018 or early 2019.

ALL POWER LABS

Carbon Negative Power & Products

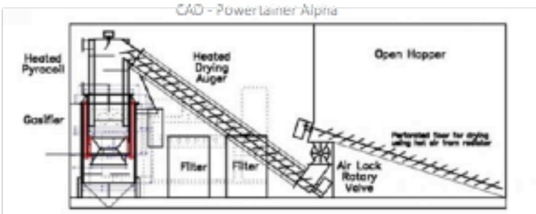
POWERTAINER - PT150

RENEWABLE, AFFORDABLE ON-DEMAND POWER



The **ALL Power Labs Powertainer PT150** is a compact & cost-optimized biomass power generation system, enclosed within a standard 20' shipping container. The system is fully automated & complete–from biomass hopper, gasifier and gas filtering, to engine, generator & electrical output control–all within the shipping container envelope. Designed to address forest-fire mitigation, especially due to beetle and drought tree kills, via a waste-to-energy solution that avoids the air pollution & carbon impact of typical open-burn disposal.

CAD - Powertainer Alpha



PERFORMANCE SPECIFICATIONS

PRELIMINARY VALUES	
Maximum Continuous Power Output [1]	150 kWe @ 60Hz
Minimum Continuous Power Output [1]	30 kWe @ 60 Hz
Thermal Output Coolant Only	150 kWt 1 kWt:1 kWe
System Efficiency Electrical Thermal - Coolant Only	55% 20% 35%
Fuel Consumption	1.0 kg/kWh
Maximum Continuous Operation	24 hours
First Start Fuel Drying	Yes
Form Factor Footprint Standard ISO container	8' x 8' x 20'
Sound Level @ 10 meters	85 db(A)

[1] Actual power will vary depending on fuel type, shape, energy density and moisture content.

OPERATIONS & MAINTENANCE

ESTIMATED VALUES	
Operators/Maintenance Personnel	2
Daily Service Requirement	2 hours/day
Design Yearly Operating Hours	5200
Start-up Time	0.75 hours
O&M Cost - Percentage of Capital Cost	10-15% per annum

BIOMASS FEEDSTOCK

SPECIFICATIONS	
Size	$^1/_2$ inch - $1^1/_2$ inch (12-40 mm)
Moisture Content - Dry Basis	up to 80%
Forest Thinning for Fire Mitigation	Yes
Planned Primary Feedstock[3] Expected Normal Operating Procedure	Nut Shells (e.g. Walnut, Hazelnut) Softwood Chips (e.g. Fir, Pine) Hardwood Chips (e.g. Oak, Ash)
Targeted for additional Testing [3] Possible Increased Operating Effort	Corn Cobs Coconut Shells Palm Kernel Shells
Not Approved Dangerous & Will Void Warranty	Coal Tires Medical Waste Plastic Municipal Solid Waste

[3] Warranty coverage for any particular species of feedstock requires specific testing and approval. Visit *http://www.allpowerlabs.com/fuels* for latest information on feedstock suitability.

All specifications are subject to change without notice

ALL Power Labs - 1010 Murray Street Berkeley, CA 94710 U.S.A.
+1-510-845-1500 Email: sales@allpowerlabs.com Web: allpowerlabs.com

Figure 25: APL spec sheet for the Powertainer 150.

Medium-Scale Technologies

Horizontal Bed Biochar Reactor

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Switzerland
Phone:+41 (0)76 303 4477 cell
Skype: ariamedia
Email: info@carbonzero.ch
Website: http://carbonzero.com

This technology, while not currently in production, shows great promise as a potentially game-changing biochar production design. All of the horizontally designed biochar production technologies we have found thus far use a metal auger to move the feedstock through the system, and cleaning the auger of tar buildup is a common maintenance issue that requires constant attention. Also heat distribution can be uneven. Carbon Zero's design works more like an oven, where feedstock is moved into the pyrolysis chamber with fans, spread our evenly on the chamber floor.

http://www.biochar.info/biochar.large-scale-biochar-production.cfml

Below is an artist's rendering and description of the reactor from the Carbon Zero website

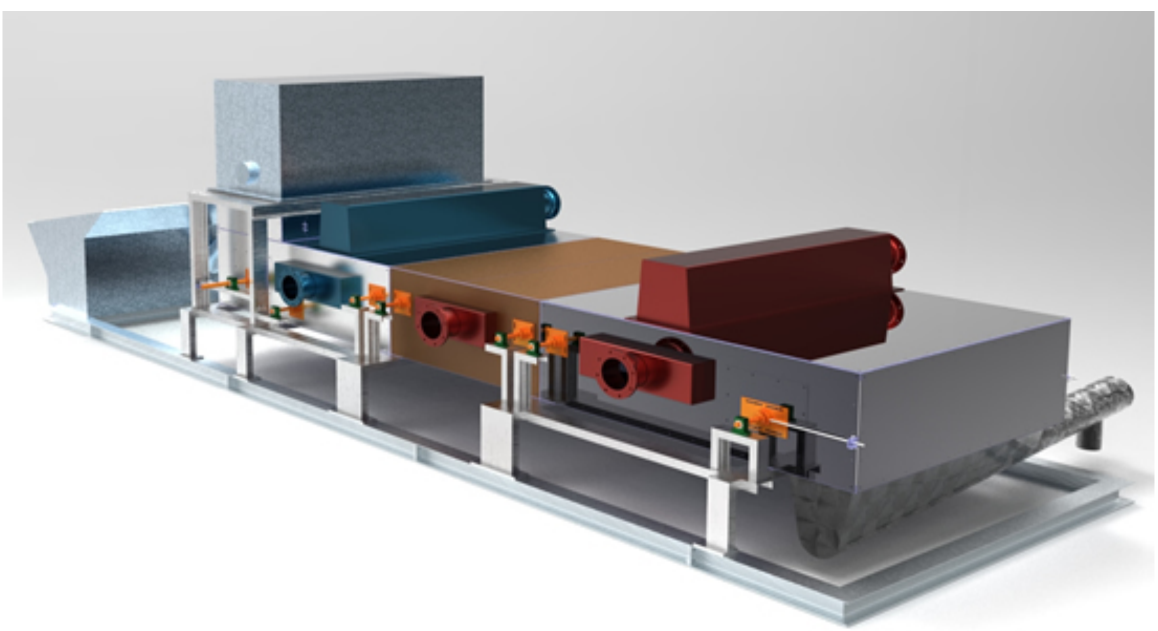


Figure 26: Illustration of a Proposed Horizontal Bed Reactor

From the website:

"The above unit can be used for a variety of feedstocks, it has a pre-dryer, incorporates the ability to closely control process parameters of temperature and residence time. It will a) produce biochar from nearly any feedstock b) condense wood vinegar from the raw syngas stream, c) crack and filter the raw syngas remaining after the condensation step to produce a clean mixture of hydrogen and carbon monoxide, known as syngas, and d) optionally burn the syngas to generate electricity. Syngas can also be used as a replacement for natural gas or propane for heating purposes."

"The challenge we are attempting to address with this system is to maximize the potential for profitability, in particular by monetizing the gas stream in the most economical way possible. In this regard, we have developed a very inexpensive catalyst to crack the syngas for this device. We estimate that the revenue from the combined products of biochar, wood vinegar and electricity should recoup the investment cost for this unit within approximately 4 - 6 months of operation."

"This biochar kiln is manufactured in a modular fashion, in 3 main sections, and its throughput capacity can be easily increased by adding units to the mid-section to make it longer. Its functional capacity can be enhanced by adding sections to fractionate the condensate yield, producing essential oils or chemicals like terpenes for instance. A section can also be added to the end to convert the char to activated char. The feedstock stream required for the lowest capacity unit would be about 16 tonnes of wood chip (@ 20% moisture content) per day. The unit is intended to run 24/7. Once started, this kiln is self-sufficient in terms of energy. Startup is accomplished with either natural or bottled gas."

"The lowest capacity plant will produce, per day, about 4 tonnes of biochar, 2500 liters of wood vinegar, and (optionally) 8400 kWh of electricity. We conservatively estimate revenue per day to be $150 x 4 for the biochar, $1 x 2500 for the wood vinegar, and $ 0.05 x 8400 for the electricity, 600 + 2500 + 420 = $3520 per day. Note that the rate paid for electricity is often at least double the above estimate. The kiln will cost approximately $400,000, and the optional motor genset designed to run on cracked syngas will cost approximately $450,000 - $550,000."

"Heat energy to dry and pyrolyze the feedstock is provided by flaring a portion of the syngas produced and/or recycling waste heat from the reactor and genset. The unit requires a relatively small amount of electricity to run the blowers, feed mechanisms and control electronics. Hence once it reaches operating conditions, it is entirely self-sufficient in terms of energy."

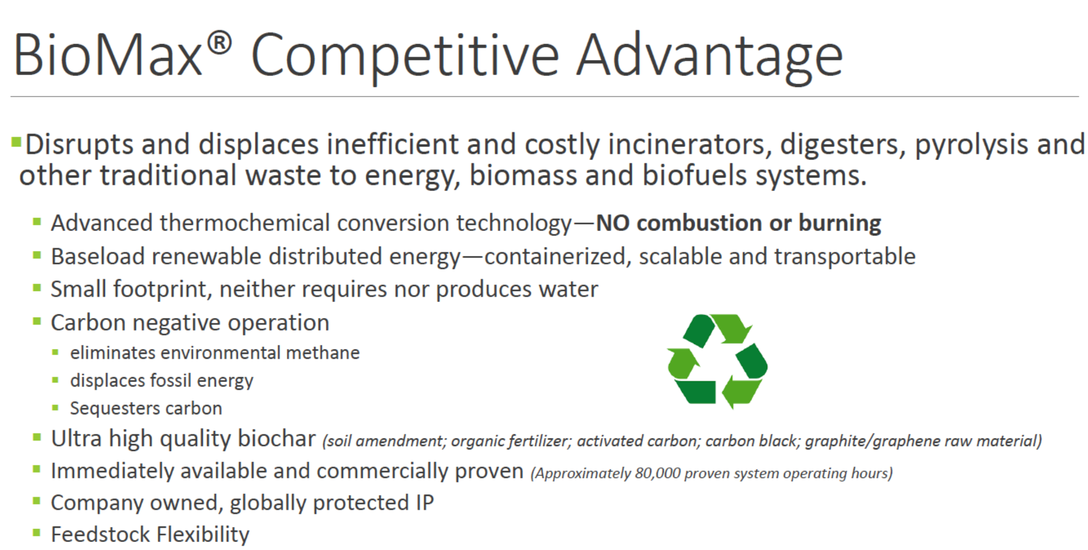
According to Nando Breiter, Carbon Zero CEO, plans to start commercial production of this kiln in New York this year were hampered primarily by tariffs on steel, which made the high-quality steel needed for its construction impossible to obtain because large companies bought up all the inventory prior to the tariffs going into effect. Hopefully, the tariff situation will be resolved soon so these kilns can enter the marketplace.

Advantages and Disadvantages: Given that there is no working model of the Horizontal Bed Reactor we can't give a recommendation either way.

Community Power

Contact Name: Wayne McFarland   Founder, Chairman & CEO
Parent Company: SynTech Bioenergy, LLC
Address: 14800 Grasslands Dr.
Englewood, CO 80112
Phone 815.942.2466
Cell 815.302.3002
Websites: https://www.syntechbioenergy.com
http://www.gocpc.com
Email: wmcf@syntechbioenergy.com
Years in Business: 23 Years
Primary Business Focus: Combined heat and power, and biochar production from biomass
Units Available for Purchase? Yes, and they recently started manufacturing an updated model called the Gen2 Energy System.

Community Power, a wholly owned subsidiary of SynTech Bioenergy, LLC, has been developing their downdraft gasification technology since 1995. They have installed systems in several California locations, with three or four more currently permitted and under construction. During several conversations with CEO Wayne McFarland, and after a site visit to one of their installations in Colusa, California, the Biomax system emerged as one of leading options currently available to process southern Mendocino County surplus biomass—if a suitable location can be found that can utilize the power and long-term biomass supply contracts can be secured in addition to material supplied by the Redwood Forest Foundation. This system has a long track record in the field, is in its second iteration with their Gen2 model with improved metrics, is produced in the U.S., and is fully automated, requiring lower labor costs than other systems.



Figures 27 through 29 below show a system installation at the Premier Mushroom facility in Colusa. These three Biomax 100 energy systems are older models, which have been in operation since 2009, and they will soon be replaced with the new Gen2 units that are now available.

Figure 27: Series of 3 Biomax 100 units at the Premier Mushroom Facility

Figure 28: Feedstock storage system for Biomax 100 units at the Premier Mushroom Facility

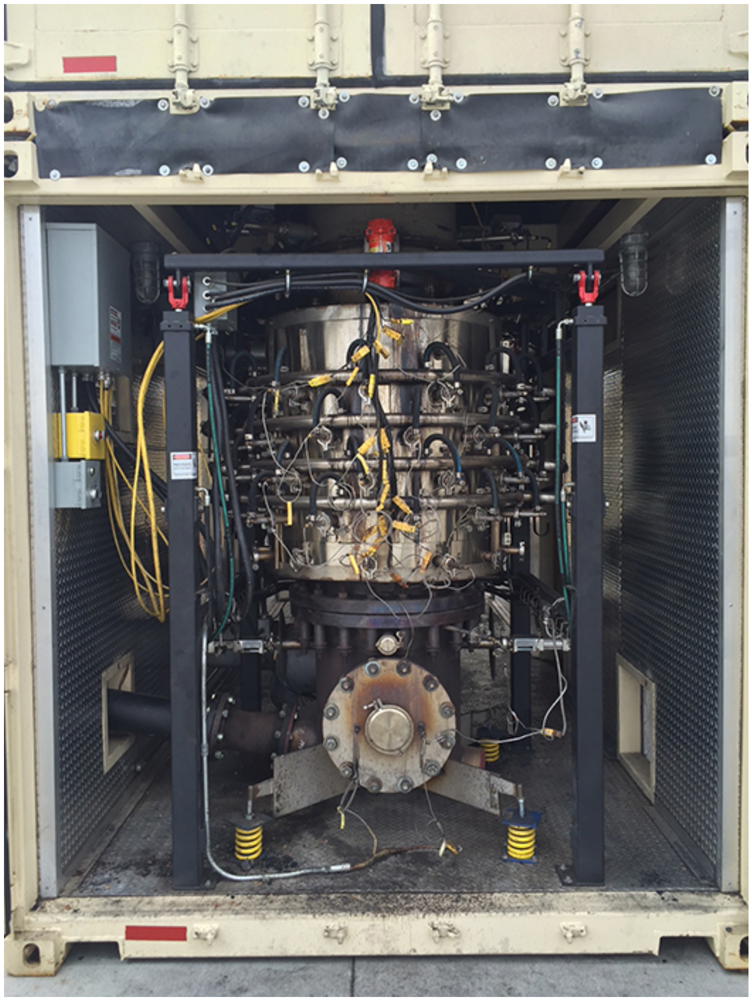


Figure 29: Interior view of a Biomax 100 unit.

From their website:

BIOMAX® SYSTEMS

CPC's BioMax® Gasification Systems convert carbon-rich, biomass feedstocks into a clean producer gas (syngas) containing equal amounts of hydrogen and carbon monoxide, a small amount of methane, some carbon dioxide, water vapor and the balance nitrogen. CPC's proprietary gasification technology enables the producer gas stream from the BioMax® to have extremely low level of tar, such that the systems use no water for gas clean up and produces no waste water that requires treatment before disposal, unlike most gasification systems. The BioMax®systems are fully automated, using software to precisely control material flow, gasification, gas cooling and filtration to produce extremely clean syngas. The systems can also be monitored and controlled remotely. The high degree of automation and remote monitoring capability enables the BioMax® to be able to operate unattended. Unlike thermal energy derived from incineration of organic feedstocks, the BioMax® Systems' syngas is a clean burning renewable fuel gas that can be used as a substitute for gasoline, natural gas, *fuel oil or propane. Using gas-to-liquid Fischer Tropsch technologies, the BioMax® Systems' syngas can be further processed into a number of chemical products including synthetic diesel, jet fuel and more. In the near future, customers will be able to produce liquid fuel (syndiesel) by adding our liquid fuels module (LiquiMax®).*

BioMax® Advantages

1. *BioMax® can be configured for numerous energy services including combined heat and power (CHP), gas only (boilers & driers), and cooling.*
2. *BioMax® is a turnkey system. It is built in ISO 20ft containers and tested in factory, and can be installed in under a week. The customer need only provide a concrete pad, electrical and thermal (if desired) inter-connects.*
3. *BioMax® can operate 24x7, with or without sunlight, with or without wind.*
4. *BioMax® uses highly efficient and advanced proprietary design, down-draft gasifier technology that produces extremely low level of tar in the producer gas.*
5. *BioMax® employs dry filter for gas clean-up. It uses no water or oil scrubbers, produces no waste water (disposal issue); no water ponds required; no waste water treatment system (additional cost) required.*
6. *BioMax®Gen2 is commercially available, proven, building on experience gained with multiple field installations of the Biomax 100 model line.*
7. *BioMax® is fully automated, can be remotely controlled, can operate unattended. System start-up, operation, monitoring, diagnosis and shut down can all be carried out onsite or remotely over the Internet using an iPad, iPhone, PC or similar devices. Important system functions are continuously monitored and logged with three levels of alarms (alerts are sent via the Internet to a smart device or computer). Emergency or scheduled shut downs are automatic and do not require an on-site attendant.*
8. *BioMax® requires low maintenance. Maintenance and Operation BioMax® systems require approximately 30-45 minutes per day for maintenance and to prepare the biomass feedstock.*
9. *BioMax® meets US EPA requirements.*
10. *BioMax® enables biomass 'waste' stream mitigation to reduce or eliminate disposal cost.*
11. *BioMax® produces usable biochar byproduct.*
12. *BioMax® has a compact footprint – 30ft x 30ft (10m x 10m), unlike most renewable energy systems of similar power output.*

Below are some questions posed to Wayne McFarland during several interviews, along with his answers:

RB: What is the minimum volume of biomass inputs annually that would make sense from an economic investment standpoint to purchase one of your units?
WM: This depends on a number of variables not the least among which are what is the value of the power, heat and biochar we'd be producing and what would be the value of the waste remediation savings to either that client, the utility or other potential off-take partners. In short, however, a single BioMax® Gen2+ unit requires about 3 tons per day (actually 2.01#/kWh generated) to operate at best practical and economic efficiencies. We find that a single unit operation is economically feasible in many locations with high power and heat costs and/or where the customer is experiencing either high costs to remediate its waste, where other local biomass can be obtained to feed the unit and/or where biochar has a

good value. The simple answer to your question, however, is "about 3 tons per day" depending, again on all those factors set forth above.

RB: We have an estimated 1000 tons of material annually to process. Is that enough?
WM: Practically speaking, not really. Our newest BioMax® Gen2+ units put out about 175kWe at gross peak output which probably translates to 3-3.3 tons per day of feedstock so you would come up just a bit short. On the other hand, the simple answer would be "yes, 1000 tons or suitable feedstock is sufficient to operate a BioMax® Gen2+ system, though not a full capacity on a continuous and uninterrupted 7/24 basis.

RB:If not, do you have clients that aggregate material from other feedstock partners?
WM: Absolutely, we do this all the time. We would want to insure that the feedstocks are compatible but, in short, we aggregate feedstock all the time to insure projects are fully operational. In fact, of the 4 projects as to which we are in the interconnection process with PG&E in CA, all of them are aggregating feedstock from other sites/producers.

RB: Are your units dependable for 24/7, 365 day service?
WM: Yes. Though, as with any power generating equipment, the systems does require down time for maintenance, service, repairs and upgrades, etc., but BioMax® was designed as a foolproof battlefield technology for the DoD which could be forward deployed to provide continuous and uninterrupted power, heat and liquid fuel to forward operating basis without fail. The system has now been fully redesigned for commercial/business/municipal applications to provide power, heat and biochar on a continuous and uninterrupted around the clock basis, subject to maintenance as noted above, etc.

RB: What, if any, issues have you had with permitting your units in California,
WM: Zero, Zip, Nada…, neither in CA, CO, TX, Japan, Europe or China. Why? Because we meet the most strict environmental emission requirements on the planet and have over 80,000 operating hours of documented low to no-emissions (virtually free) operations to support that claim. For what it's worth, our reactor doesn't even have a vent to the environment. Our only actual interface with the environment is the engine exhaust loop which, due to our proprietary catalytic exhaust system, really puts nothing more into the atmosphere than small amounts of water and some CO_2, both of which are often found to have value for growers such as greenhouse operations. Furthermore, BioMax® neither requires water for operation nor produces water which needs to be cleaned or disposed of.

RB: What would the expected timeline be for an installation?
WM: Right now, we are telling customer to expect their units to be ready, fob our doc, for shipment at about 6 months from receipt of deposit. We expect that will get shortened a bit as we continue ramping to meet demand but right now I'd feel safe at 6 months.

RB: What rate do your clients get from P G & E?
WM: Right now, all of our customers with projects in the PG&E interconnect queue are going to get $0.187/kWh as their feed in tariff under CA's BioMAT program. Remember, as well that many of these projects also recover value from use/sale of harvested heat energy, from the sale of biochar. Others benefit from significant savings or revenue from remediation of waste, as well. There are also some carbon capital opportunities available in some cases.

RB: Do you recommend on-site, "behind-the-meter" use instead of selling into the grid?
WM: This is entirely a case-by-case situation. In most of our pending PG&E projects, we are locating those projects on sites which are not ag waste producers but areas we have selected because they are convenient to a PG&E need. We are working on twice or more than that, however, which are "behind the meter" where the customer will be consuming the power we generate to run their operations. We can go either way so it is always dependent on the specific site/customer and goals in question. Also, you should note that CA still has the SGIP program which allows a huge rebate for self-generated power to the site holder.

RB: Are there still any incentives for small biomass in California?
WM: SGIP as noted above and BioMAT as noted above. Some carbon capital opportunities can also be created in CA as a single BioMAX® can displace/sequester =/-6,800 tons of carbon per year.

What would the turnkey price include, assuming a dryer is needed.
WM: Generally, we quote $1.1 million fob out doc in Denver though there are other site specific expenses required to get the project licensed, permitted in the ground and interconnected to customer/utility. All of that would be laid out in a CapX and OpX budget and economic model we would provide to a purchaser.

What is the training time required
WM: 30 days is a good timeline if it can be coupled with installation and commissioning.

...and is this included in the turnkey price or extra?
WM: It is generally contained within the project specific economic model, CapX and OpX budgets noted above*

**Note: Full CapX and OpX models were provided but we have been asked not to share them in this report. However, they are available with permission from Wayne McFarland.*

These are not inexpensive units, but given the right location with the need for power and access to a local, dependable feedstock source, their flexibility, automated operations and carbon-negative potential may offer a very attractive return on investment and a sustainable and environmentally-friendly addition to any small to medium scale community renewable energy strategy.

Biogreen / ETIA Ecotechnologies

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Phone: +33 344 86 44 20 or +48 784 095 707
Website: http://www.biogreen-energy.com
Email: anna.grochowska@etia.fr
Years in Business: 15
Primary Business Focus: Biomass Power and Biochar Production and Sales
Units Available for Purchase: Yes

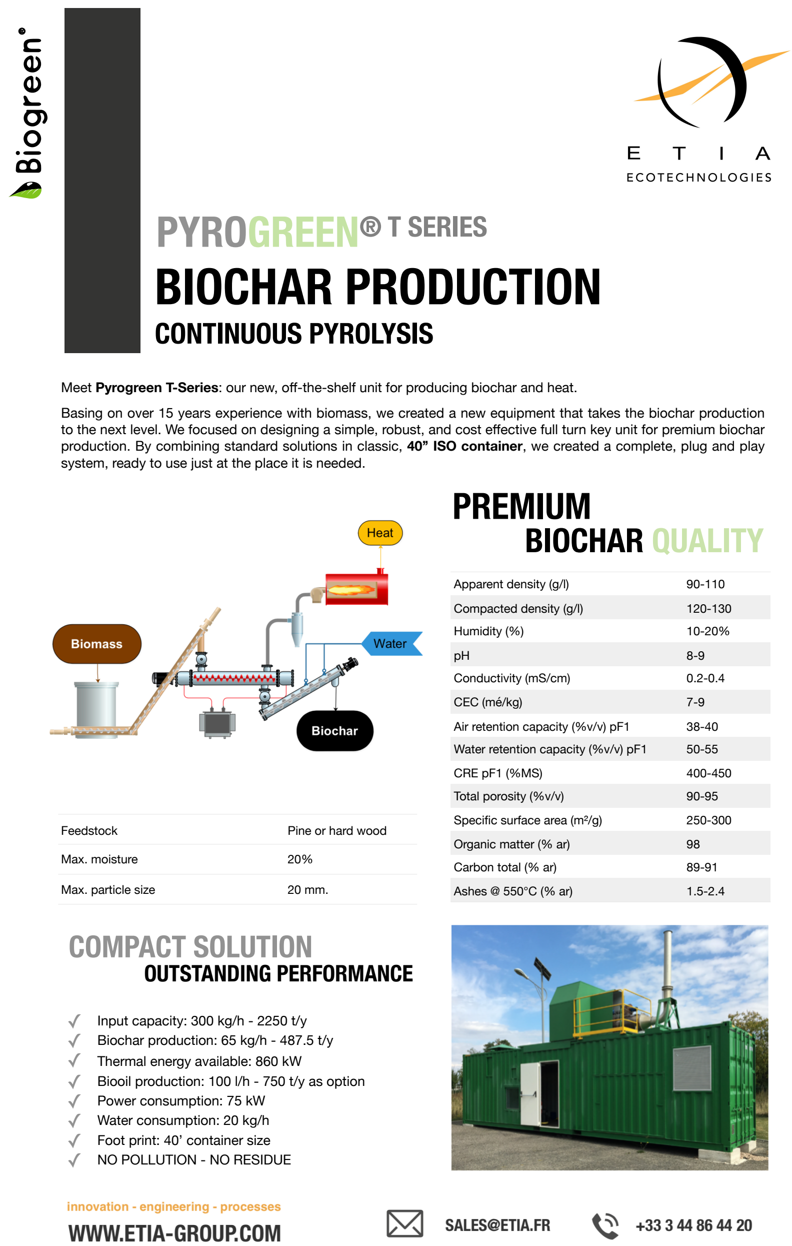
Biogreen is a subsidiary of the French engineering company ETIA that was founded in 1989 and that specializes in "ecotechnologies: environmentally friendly solutions for sustainable development." According to their website, the company has been recognized as one of the most innovative in France, and while this report is concentrating on surplus biomass as a feedstock, this technology can also be used to process a wide variety of materials, including sewage sludge and resource derived fuel (RDF) where such uses are allowed and appropriate.

The Biogreen processing technology was commercialized in 2003, and it offers among the most versatile options that we studied for this report. Using an adjustable, auger-driven pyrolysis process called Spirajoule, the processor is designed to operate optimally between 400C and 800C, in various configurations and operational modes, and their different models can be configured to produce a variable combination of the following products:

- Solid fuel in the form of torrefied wood. (250C to 400C)
- Low, medium, or high temperature Biochar from almost any feedstock (450C to 600C)
- Wood vinegar/Bio-oil compounds
- Syngas that can be cleaned and used to produce renewable energy (700C + via gasification)
- Heat that can be utilized to produce renewable energy

Figure 30: Cutaway illustration of the Spirajoule Pyrolyzer

Biogreen offers 5 different sized units, including a bench-scale unit that can process between 10 and 20 lbs per hour (for research university applications) up to 1.5 tons per hour for a full-sized commercial unit. A mid-sized unit processing about ¼ ton per hour would cost $328,000 US, and the full-sized unit runs approximately $1.6 million US. The units can be configured to be stationary or mobile through containerization. See Figure 3 below for specs on their new T Series “Plug and Play” unit that can produce up to 487 tons per year of high quality biochar from 2250 tons of feedstock, along with 860 kW of available thermal energy, and 750 tons of bio-oil per year with optional equipment.


Biogreen®

ETIA ECOTECHNOLOGIES

PYROGREEN® T SERIES

BIOCHAR PRODUCTION

CONTINUOUS PYROLYSIS

Meet **Pyrogreen T-Series**: our new, off-the-shelf unit for producing biochar and heat.

Basing on over 15 years experience with biomass, we created a new equipment that takes the biochar production to the next level. We focused on designing a simple, robust, and cost effective full turn key unit for premium biochar production. By combining standard solutions in classic, **40” ISO container**, we created a complete, plug and play system, ready to use just at the place it is needed.

Heat
Water
Biomass
Biochar

Feedstock	Pine or hard wood
Max. moisture	20%
Max. particle size	20 mm.

PREMIUM BIOCHAR QUALITY

Apparent density (g/l)	90-110
Compacted density (g/l)	120-130
Humidity (%)	10-20%
pH	8-9
Conductivity (mS/cm)	0.2-0.4
CEC (mé/kg)	7-9
Air retention capacity (%v/v) pF1	38-40
Water retention capacity (%v/v) pF1	50-55
CRE pF1 (%MS)	400-450
Total porosity (%v/v)	90-95
Specific surface area (m²/g)	250-300
Organic matter (% ar)	98
Carbon total (% ar)	89-91
Ashes @ 550°C (% ar)	1.5-2.4

COMPACT SOLUTION OUTSTANDING PERFORMANCE

- Input capacity: 300 kg/h - 2250 t/y
- Biochar production: 65 kg/h - 487.5 t/y
- Thermal energy available: 860 kW
- Biooil production: 100 l/h - 750 t/y as option
- Power consumption: 75 kW
- Water consumption: 20 kg/h
- Foot print: 40’ container size
- NO POLLUTION - NO RESIDUE

innovation - engineering - processes

WWW.ETIA-GROUP.COM SALES@ETIA.FR +33 3 44 86 44 20

Figure 31: Spec sheet on the Pyrogreen T Series Pyrolysis Unit.

Approximate Cost: $436K plus shipping from France. Training is included.

Here are some specs from the website on another unit:

<u>Biogreen CM600 Mobile Unit</u>

Figure 32: Biogreen CM 600 Mobile Pyrolysis Unit.

- Input Capacity: Up to 16 tons/day feedstock at 10%—20% moisture, 3500 tons/year based on 220 run days
- Feedstock type: Biomass Chips ¾ inch minus
- Power Required: 100kW electric or diesel
- Biochar Output: up to 4 tons per day, 85% carbon*
- Torrefied Wood output: up to 8 tons per day*
- Bio-oil Output: 8 tons per day (50 barrels) to be used as liquid fuel or intermediate bio-based molecules extraction*
- Conversion Efficiency: approx. 25%
- Syngas Output: Up to 450 kW (9MWh/day) *
- Residence time and temperature can be adjusted
- Continuous feed. Rated at 7,000 to 7500 hours per year
- Fee includes help with install, setup and training
- Production lead-time is 6 to 9 months
- Maintenance is estimated at 3% of cost per year, replace belts, motors, clean filters, fans, etc.

**Based on 1760 lbs/hr, and a runtime of 20 hrs/day*

Additional info: Biogreen is currently selling biochar for $980 euro per ton, ($1156 dollars US or $0.58 per lb) in France. They are also currently the only supplier in France with EU Biochar Certification. They will analyze a customer's expected feedstock to determine the exact process gas composition, biochar qualities, and other data to help tweak the system for a client's exact needs.

Advantages: This company is focused on building sustainable technologies and has a 15 year track record building pyrolysis biomass conversion technologies. Their machines are highly versatile and can produce a range of products that can be produced to meet changing market needs, including biochars with different characteristics, torrefied wood for briquettes, syngas and heat for power generation, and bio oil that may be synthesized for many purposes. The pricing is very competitive with Community Power's units, which is one of Biogreen's main competition in this sector. Many factors would need to be considered to decide which technology might be the better choice for a given installation location.

Disadvantages: The main disadvantage is that it is a French manufacturer, which could increase downtime if unexpected servicing or a breakdown occurs. Also, parts deliveries could also cause production delays depending on the time of year and economic conditions.

Pyrocal Pty Ltd

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Principal Engineer/Director
Address: 27 Heinemann Road
Wellcamp, Queensland 4350 Australia
Phone: +61 7 4639 2009
Website: https://apple-soybean-cxe6.squarespace.com
Email: enquiries@pyrocal.com.au
Years in Business: 9
Primary Business Focus: Biomass conversion to thermal energy, and biochar production and sales
Units Available for Purchase: Yes

Pyrocal, based in Australia, has been pioneering pyrolysis systems since 2009, and selling commercial systems since 2014. They have installations in eight countries.

From their website:

Pyrocal offer three sizes of BiGchar Continuous Carbonisers. Each of these can be adapted to optimise the production of carbonised products (chars) and/or heat. The table below describes the potential for heat from each model systems. Char production from these systems can be expected to range between 5 and 35% of dry feed, depending on the biomass characteristics and machine settings.
All of our models can be configured as fixed, relocatable or mobile plants. Units can be ganged to provide higher throughputs and processing redundancy.
All of our models can be configured to comply with a wide range of emissions standards.
The chars produced by our systems typically have a high porosity and surface area, however Pyrocal can also offer integrated sizing, conditioning, activation, functionalisation, de-ashing and coking equipment processes to produce a wide range of carbon based products.

Pyrocal CCT System Options

	CCT 12	CCT 18	Dual CCT 18
Nominal biomass processing capacity in kg/hour	250	650	1300
Maximum thermal output* (16MJ/kg LHV fuel) kW	830	2170	4330
Nominal weight of equipment to standard scope kg	4500	5500	8000
Nominal footprint of supplied equipment (excluding biomass and char handling)	Single 40ft High Cube Shipping Container	Single 40ft High Cube Shipping Container	1x20ft + 1x40ft High Cube Shipping Containers
Diesel required for light-up (litres)	15	30	45

******Value available for direct heating. Values depend on biomass and operating mode (char or heat bias).*

Actual performance is subject to the specific type and quality of biomass provided.
Pyrocal's containers are modified and unable to be transported as container freight. They are shipped as general cargo.

Figure 33: Pyrocal CCT System Options

James Joyce, the Principal Engineer at Pyrocal, provided the following information in an email correspondence:

CCT12 (~6 tonnes input per 24 hours) USD $180k
CCT18 (~16 tonnes input per 24 hours) USD $350k
Dual CCT18 (~32 tonnes input per 24 hours) USD $650k

The systems are fully compliant with EPA emissions requirements just about anywhere in the world.

The units generally require the biomass to have a moisture content of less than 35%.

Annual Operating and maintenance costs total to roughly 15% – 25% of the Capital value, eg. $98k/year for the largest system. Most of that cost is labour for operation and maintenance.

Below is a chart with additional specifications:

BiGchar Continuous Carbonisation Technology - Model Options

Machine	*BIGCHAR CCT12*	*BIGCHAR CCT18*	*BIGCHAR Duel CCT18*
Maximum Biomass processing capacity in kg/hr (lb/hr)	250 (550)	635 (1400)	1000 (2200)
Max. thermal output * (16 MJ/kg LHV fuel) kW (MMBTU/hr)	750 (2.5)	1900 (6.5)	3000 (10.2)
Equivalent LPG usage kg/hr (lb/hr)	56 (123)	142 (312)	225 (495)
Max. usable heat when exchanged to water kW (MMBTU/hr)	630 (2.1)	1600 (5.5)	2550 (8.7)
Hot water output for 40oC/72 F temp. rise litre/hr (US Gal/hr)	13480 (3570)	34280 (9060)	54640 (14430)
Drying (water removal) capacity at 4.2 MJ/kg of water removed kg/hr (lb/hr)	640 (1410)	1630 (3580)	2570 (5653)
Nominal weight of equipment to standard scope kg (lb)	2000 (4400)	7000 (15400)	8350 (18370)
Nominal footprint of supplied equipment (excl. biomass & char handling) **m(ft)**	6 x 2.3 (18 x 7'6")	9 x 2.7 (30 x 9)	9 x 2.7 (30 x 9)

Hot water production requires the addition of a heat exchanger, which is not included in the standard scope.
Actual performance is subject to the specific type and quality of biomass provided.

- Value available for direct heating. Values depend on biomass and operating mode (char or heat bias). Please consult Pyrocal.

Figure 34: Additional specifications for the Pyrocal CCT System Options

Listed below is the range of biomass sources that the Pyrocal technology can process.

Note: For the purposes of making biochar, we would not recommend the use of municipal solid waste, industrial residues, or packaging, and pyrolyzing biosolids may have some non food crop uses. The highest conversion efficiencies are possible with the densest feedstocks, so surplus forestry materials and certain agricultural crop residues such as those high in woody fiber or nut shells, for example, would yield the most biochar.

Figure 35: Materials that can be processed by the Pyrocal system.

From their website:

Pyrocal System Operating Principles:

- *Biomass is continuously metered into the top chamber of the rotary hearth, where it rapidly heats, dries and commences to pyrolyse (thermally decompose). The volatile gases released from the biomass mix with a controlled amount of air and ignite. Partial combustion of volatile gases in the hearth provides the heat that makes the process autothermal.*

- *The flaming off-gases travel up through the hearth and then to the thermal oxidiser, where they are mixed with more air and oxidised completely through to water and carbon dioxide.*

- *The biomass is transported through a number of chambers before dropping out into a screw conveyor where it is quenched and discharged as a char product.*
- *The temperature and oxygen profiles in the hearth are controlled to achieve the desired char yield and char quality. Temperatures as low as 450 degrees C or as high as 700 degrees C may be selected.*

- *The thermal oxidiser is controlled to a selected temperature in the range between 725 to 925 degrees C according to the nature of the biomass and the emissions control requirements. Oxygen is monitored and controlled to achieve efficient oxidation of the gases.*

- *Downstream thermal recovery systems (such as a steam boiler) and emissions controls (such as a wet scrubber) are integrated into a complete system.*

- *The entire system is controlled by a PLC programmed to specific installation requirements.*

Figure 36: Illustration of a CCT Installation.

The Continuous Carbonisation Technology (CCT) was developed after a thorough review of conventional and novel thermal treatment technologies. Pyrocal CCT is based on the material handling flexibility of the vertical multiple rotary hearth (eg. the Herreshoff hearth) and the principals of updraft gasification. It was developed to satisfy a need for cost effective conversion of waste biomass to charcoal and energy.

Some of the key technical features include:

- *Mechanical moving bed arrangement, which provides maximum flexibility for a wide range of feedstocks, including light fluffy materials, clumping materials, chips and materials with a very diverse size range.*
- *Direct heat transfer to the incoming biomass. This means there are no heat transfer surfaces in the system to foul or corrode.*
- *Moderate and controllable temperatures in each stage of the hearth and*
- *Controlled two stage oxidation of the released volatile matter, allowing efficient control of air pollutants.*
- *Continuous co-mingling of flammable volatile gases with a controlled airflow, to eliminate flammable gas explosion risks (no hazardous zone design requirements).*
- *Fully autothermal operation (i.e. after startup there is no need for other fuel sources to operate).*
- *Rapid start-up. Typically, cold to full throughput in 40-60 minutes. The materials of construction allow heating from cold to full operating temperature without damage.*

Some unique characteristics of the technology include:

- *Low investment cost compared to both conventional and novel biomass thermal treatment technologies.*

- *Small footprint and mass, requiring very little site preparation and minimal foundations. This is especially useful for operations that need to be relocate to follow seasonally available biomass.*
- *Simplicity in in design: which is a great benefit for troubleshooting and maintenance.*
- *Ease of maintenance: The hearth unit or the just the internals can be completely swapped out in under 6 hours, for on-site or off-site reconditioning.*
- *Flexibility: Pyrocal CCT systems not only handle a wide variety of biomass feedstocks but they can be operated to bias for either carbon product or heat yield.*
- *Separation of the core thermal treatment step from the control of emissions. This allows the optimal processing conditions to be achieved for what are often competing needs.*
- *Ability to handle feedstocks that cause major fouling, slagging and/or corrosion in other technologies.*

Pyreg GmbH

Contact Name: Sohnke Neumann
Address: Trinkbornstraße 15-17
D-56281 Dörth, Germany
Phone: +49 (0) 6747 95 388-0
Website: http://www.pyreg.de/en/biomass/
Email: info@pyreg.de / sales@pyreg.de
Years in Business: 10
Primary Business Focus: Biomass Power and Biochar Production and Sales
Units Available for Purchase: Yes

Pyreg has been a leader in biomass conversion to heat energy and biochar in Germany over the last 10 years, and is the preferred biochar production technology for well-known Swiss biochar researcher Hans-Peter Schmidt. The company has more than 20 Pyreg units installed and running in Germany, Switzerland, Austria, China, Sweden, the U.S., end elsewhere. They have received a technology innovation award and have been nominated for the Diesel Medal and Smart Green Awards.

According to their website, *"the PYREG plant P500 is able to maintain a clean process at optimum efficiency and at a constant quality level…Pathogens, germs and potentially harmful pollutants are neutralized. As the carbonization process is carried out as a whole, formation of polycyclic aromatic hydrocarbons and dioxins is prevented. This fact represents a significant difference to conventional pyrolysis, hydrothermal carbonization (HTC) or to methods based on wood gasifiers."*

"The PYREG process, taking place at medium temperatures between 500°C and 800 °C, is focused on preserving carbon and nutrients contained. Biochar resulting from the PYREG process is distinguished by high porosity and a large internal surface, complete conversion and excellent storage stability."

This pyrolysis technology requires “free flowing and pourable” biomass for efficient operation, with a particle size of less than 1 inch in size.

As shown in Figure 36 below, one Pyreg P500 plant can process up to 1400 tons of biomass annually and produce 300 tons of biochar, or a conversion efficiency of about 21%. Also produced is 10MJ per kilogram of biomass.

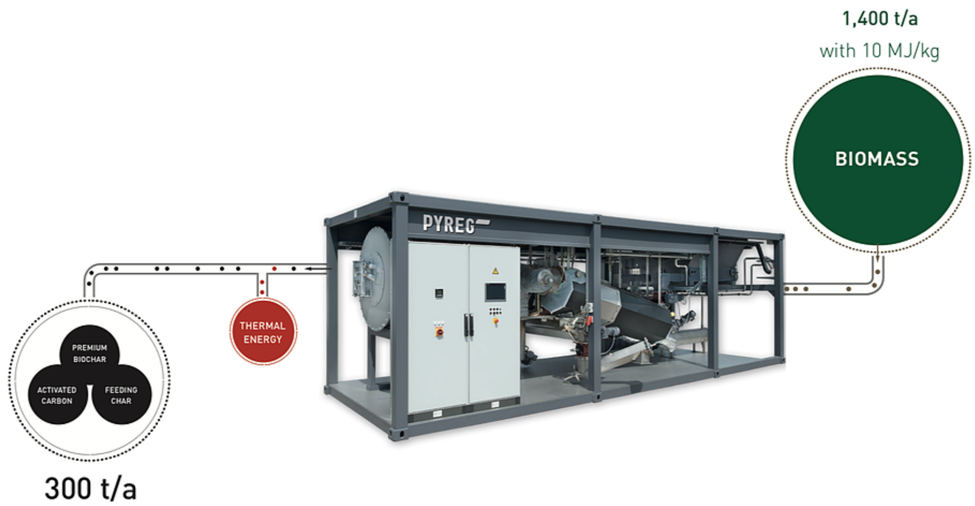


Figure 37: Illustration of a Pyreg P500 Pyrolysis Machine.

COMPONENTS

PYREG Module	l: 9,000 x w: 3,000 x h: 2,800 mm
Technology Module	l: 3,000 x w: 3,000 x h: 2,800 mm

SPECIFICATION

Maximum Energy Input	500 kW, depends on the calorific value of the input material
Annual Throughput	Approx. 1,400 t/a original substance with a calorific value of 10 MJ/kg
Yearly Production	Up to 300 t biochar
Excess Thermal Energy	Up to 150 kW_{th}, to be used for drying of input material
C-Efficiency	Approx. 60 %
Operating Hours	Approx. 7,500 h/a
Power Consumption	Approx. 12 kW_{el}

A complete quote showing income and expenses for a Pyreg P500 BM unit is available as an attachment to this report. As of 11/1/18 the conversion rate of Euros to the dollar is $1.14 dollars per Euro. The quote below shows that the P500 BM unit sells for $549,300 Euros, or $626,202 US, plus shipping and any tariff costs. Site work is expected to cost 60,000 Euros, or $68,400 US, for a total of $694,602.

1	INVESTMENT PYREG plant and peripheral technology			Number	Module price	Investment
				Modules	*€*	*€*
1.1	PYREG Carbonisation unit P500 BM	1	455.000,-	455.000,-		
1.2	PYREG Commissioning P500 BM			1	18.000,-	18.000,-
1.3	Input storage Fliegl Rondomat 20m³	1	37.900,-			37.900,-
1.4	BigBag station with 4 bagging racks			1	29.900,-	29.900,-
1.5	Sub-distribution PYREG UV50	1	8.500,-			8.500,-
	Total Invest PYREG:			**549.300,-**		
1.6	Third party: On-site services: foundation, canopy, electricity, gas, water, chimney, et	1	60.000,-	60.000,-		
	Total investment (net):					*609.300,-*
	Discounts					*0,-*
	Fundings					*0,-*
	Total investment (net):					***609.300,-***

Figure 38: Itemized expenses for a P500 BM Pyrolysis unit

Pyreg technology is a solidly engineered and proven system that produces excellent biochar and usable heat. Another company that is reviewed later in this report, Bioforcetech, uses Pyreg technology in their Silicon Valley pilot plant and tours of their facility, which is located at a water treatment plant, can be arranged.

<u>Ag Energy</u>

Contact Name: David Drinkard, Mechanical Engineer
Address: 7921 E Broadway Avenue,
Spokane Valley, WA 99212
Phone: 509.343.3156
Website: https://ag.energy
Email: info@ag.energy
Years in Business: 8
Primary Business Focus: Biomass Power (Syngas) and Biochar Production
Units Available for Purchase: Yes

Ag Energy was founded in 2010 in Spokane Washington, focused on converting agricultural waste into synthetic gas and biochar. The gas can be used as a fuel for heating or cooling, for electricity production, or can be filtered for pure hydrogen.

Ag Energy units are containerized, fully automated, movable, and customizable for each user's biomass type and energy needs. They are designed to run unattended

24/7, and standard hoppers and conveyers can provide material for up to three days of operation.

Inputs can include field residues such as wheat grass or corn stover, woody biomass from forests, vineyards, or orchards, manures, ag processing wastes, grape pomace, weeds or most any other surplus biomass. Remote operation and monitoring can be done via cellular network, including fault detection, mitigation, and automated shutdown if problems occur. Using input and output modules for feedstock and the biochar, up to three days of unattended operation is possible. Standard connections and other hardware make installation and maintenance relatively simple.

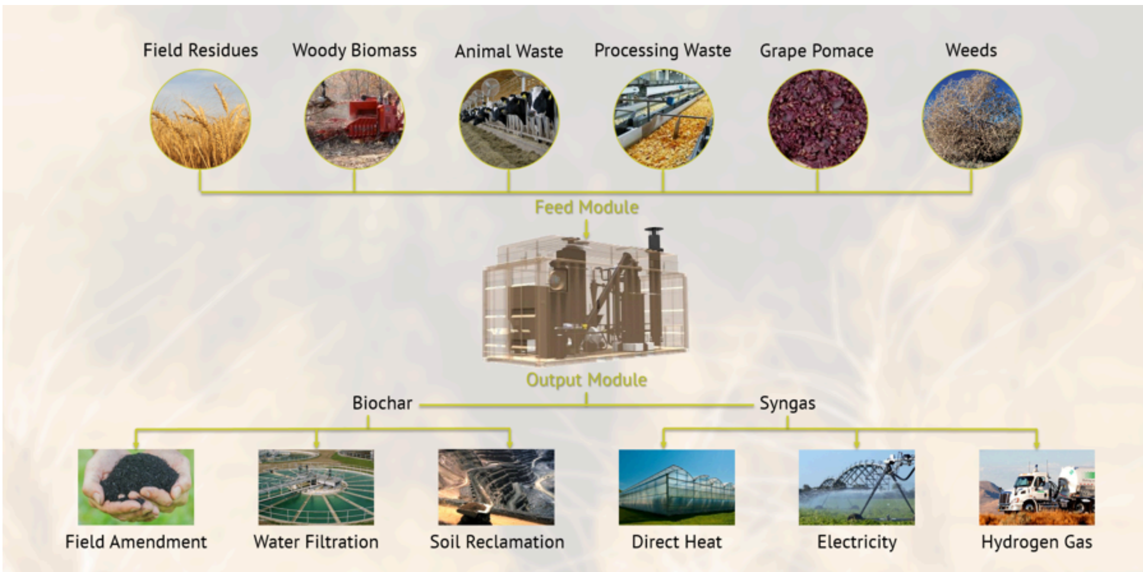


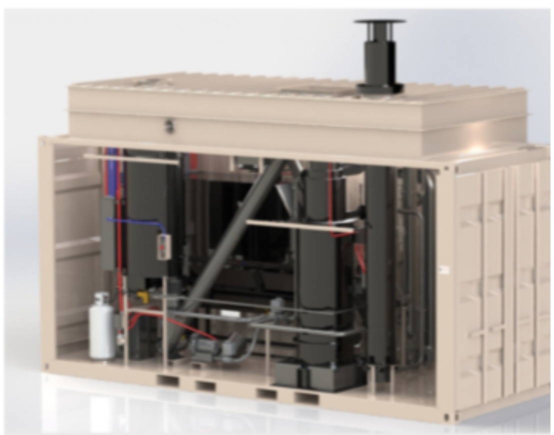
Figure 39: A list of inputs and outputs for the Ag Energy Units.

Currently there is only one model, and the two main co-products generated are syngas and biochar. If more syngas or biochar is desired additional units may be added as shown in Figure 38 below.

Figure 40: Three Ag Energy Units working in series.

The units run on material that is chipped in size to 1” minus, and each unit can process up to 3,000 lbs of biomass per 24 hours, with 20 to 25% conversion rate to biochar (or 600 lbs to 750 lbs) depending on feedstock type, temperature, residence time, moisture content, and the desired percentage of char to syngas output. The syngas can be used to heat a boiler to 180 degrees, then used to heat or cool buildings.

Units run $200K, plus the biomass feed-in modual and the output biochar cooling and packaging module, each estimated to cost between $20K and $50K. Training is estimated to take two weeks and would cost an additional $10,000, and shipping from Spokane, Washington where they are manufactured depends on the final destination, making the total cost between $260K to $300K per unit. Manufacturing time is estimated at 6 months.



Figures 41 and 42: Interior diagram and a photograph showing the mobility of an Ag Energy unit.

According to David Drinkard, a mechanical engineer who has been with the Ag Energy for about 4 years, the company has been providing biochar for a number of University of Oregon and Washington State University field trials on tomatoes, and other crops over the last few years, and they have also been working independently with cannabis growers as well. Using wheat grass biochar, David said growers have seen as high as a 70% increase in production using just 5% to 10 % blend of biochar with their regular soil mixes.

NOTE:

The following companies produce pyrolysis technologies that are in various states of development, however all have working demo units and all have plans to scale production over the next few years.

Heatech

Jeff Collins, Greg Brooks, Mike Ballantine, Development Partners
Phone: 702 296-4202 (Mike Ballantine)
Email: Mike.Ballantine@bendbroadband.com
Website: http://www.heatechservice.com/

Mike Ballantine and Greg Brooks have been involved in a number of pyrolysis-related ventures over the past decade, including construction of a facility in Prineville, Oregon (see https://www.youtube.com/watch?v=8v9hImNW9iY) built primarily to reactivate spent carbon for reuse, and to produce biochar. The technology can process a wide range of other "waste" feedstocks as well. They have now partnered with Heatech Service, a company founded 25 years ago as a service and repair company for heat-treating furnaces and industrial ovens, but now also involved in the design, building, and installation of heating systems. Several new systems are under development, called the Zip Char line, and three new models are planned:

ZipChar 50: Will process 50 cubic feet (approx.. 2 cubic yards) of biomass per hour, with a 30 to 45% conversion to biochar efficiency. Expected Cost: $850K

ZipChar 100: Will Process 100 cubic feet (approximately 4 cubic yards) of biomass per hour, with a 30% to 45% conversion efficiency. Expected Cost: $1.4 million

ZipChar Batch LE. (Still under development)

Genesis Industries

Contact: John Gelwicks
Address: 212 Yacht Club Way. #A-12
Redondo Beach, CA. 90277
Phone: 310. 779-3001 / 310 392-5050
Email: john.gelwicks@egenindustries.com
Website: www.egenindustries.com
Video: https://www.youtube.com/watch?time_continue=1&v=HH4j3ctEGU8

John Gelwicks is a serial entrepreneur who has been involved in a number of varied business activities, including as the owner and operator of a French intensive biodynamic vegetable gardening business, as a solar panel distributor, and as an entertainment industry representative. He founded Genesis industries to promote biochar production technology which built a successful demo unit about 10 years ago that was successfully tested at a composting facility in southern California. Their current design, the CR-2 model shown below, is still in beta form but they are hoping to move to full commercialization “soon.”

From their website:

Pyrolysis Unit Capacity: Model CR-2:

Figure 43: A pilot CR-2 pyrolysis unit from Genesis Industries.

The feedstock capacity of this unit assuming moisture content of 20-25%, is 200kg/hr. Biochar output, 50kg/hr. Energy output is approximately 100-200 KWH in the form of syngas depending on the feedstock. This then can be converted to electrical energy via a small steam turbine or genset at additional cost. Energy outputs are extremely variable due to the great variation in characteristics and properties of organic material. Trial runs need to be conducted on each biomass to get an accurate energy output rating. This unit can be increased or decreased in capacity by 25% to suit the end user’s needs.

Pyrolysis System.

- *Available for nominal 160kg/hr biomass input (assuming: average biomass moisture of 10-12%)*
- *Primary function of this unit is to produce BIOCHAR; a soil amendment.*
- *Pyrolysis gases (Syngas) maintain temperatures and high flow rates through the unit.*
- *Depending on biomass moisture content/energy values, excess Syngas is produced.*
- *Excess pyrolysis gases can be used to power a micro-turbine or furnace/boiler.*
- *Unit designed to process a variety of feedstocks.*
- *Modular design for future expandability.*
- *Minimal electrical demand.*
- *Two x 2.2kw Bonfiglioli Variable speed motor/gearbox drive system.*
- *Thermal ceramic coatings used over mild-steel construction.*

- *Multizone process*
- *Proven Continuous Flow Transport Process*
- *Precision temperature and pressure control*
- *Nitrogen purge system*
- *Low pressure system, < 1bar.*
- *Heat demands balanced in steady state operations*
- *Requires outside energy source for startup; natural gas or propane models available.*

System Controls:

- *Automated temperature control.*
- *Simple operation to allow operator engagement.*
- *Operator safety features.*
- *Automatic Shutdown, including various fail-safe methods.*

Site Requirements:

- *Maximum Footprint: 40 ft x 20 ft x 15 ft high*
- *Electrical Service: 100 Amp max*
- *Water line*
- *Gas supply*

Performance Data:

Each feedstock will be different. The different yields of products are due to varying chemical and structural composition between different feedstocks. To determine actual output for a particular biomass, initial performance testing of each particular feedstock is recommended to establish a range of performance and co-product yields.

Throughput is determined by feedstock density, particle size, moisture content, chemical composition, microporous structure, etc. Our data has been derived from processing various biomass feedstocks. The majority of analysis has centered on waste poultry litter, Almond shell & husk, and Grape Mark (residues remaining from wine grape crushing).

Pyrolysis Unit Capacity: Model CR-3*: (Still in the design phase)*
Feedstock capacity of this unit assuming moisture content of 20-25% will be 1000kg/hr. Biochar output, 250 kg/hr. energy output, 400 kW in the form of syngas.

Large-Scale Technologies

The following companies build community-scale biomass energy plants that could provide a sustainable and beneficial outlet for RFFI's surplus biomass as well as that of many other landowners in the northern Mendocino, southern Humboldt county area. However, a coalition of community organizations and local governments would need to be mobilized to encourage and assist such an effort, which would take many years to approve and major subsidies or incentives help finance. These plants cost from $2 million up to $20 million + and more depending on size and input and output requirements, and finding appropriate sites within communities can be challenging. Long-term contracts with localized biomass suppliers must also be found and negotiated before most financing can be secured.

Phoenix Energy

Greg Stangle, CEO
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SanFrancisco, CA 94129-0166
Phone: 415 286-7822
Email: info@phoenixenergy.net
Website: www.phoenixenergy.net

Phoenix Energy has been pioneering relatively .5 MW to 2 MW biomass gasification technology installations in California over the last 10 years. They built a 500 kW demonstration plant in Merced in 2009 (see Figure 43 below) that produces both electricity and biochar, and have permitted or built 4 or 5 additional plants in various locations within California since then, including in North Fork in the Sierras and at the Napa Valley landfill.

Figure 44: Phoenix Energy Plant in Merced, California Photo: R. Baltar

From their web site:

Phoenix Energy designs and builds small scale (.5 to 2 MW) gasification powerplants fueled by biomass (wood waste, agricultural waste, or other biological waste products). By diverting more waste out of landfills, Phoenix Energy not only helps save money but it also helps to save further environmental damage.

Phoenix Energy biomass gasification power plants are seamlessly integrated with the electrical grid. This means that when you produce more power than you need, you can sell your excess power to the local utility. Similarly, when you need more power than you are generating, you can supplement by taking part of the power from your Phoenix Energy power plant, and part from the power company.

Phoenix Energy biomass gasification powerplants have a tight footprint, needing just 1250 square feet of space. Additionally, the engine can be housed separately and the entire unit is self-contained, minimizing the impact on your land.

Phoenix Energy's model PHX-1000 converts wood into a synthetic natural gas ("syngas" or "producer gas") through the process of gasification. This syngas is then used to fuel a specially modified natural gas genset to produce electricity and heat.

In a process very similar to manufacturing charcoal, the gasification process partially combusts wood in an oxygen starved environment. By depriving the fire of sufficient oxygen the wood does not burn, but rather gives off a flammable gas. As the wood gives off the syngas, it is transformed into biochar. The syngas is then captured, cleaned and cooled before being sent as fuel to the genset which converts the syngas into electricity.

Aries Clean Energy, LLC

Christopher Kidd, Director of Business Development Northeast
Address: 4037 Rural Plains Circle, Suite 290
Franklin, TN 37064
Phone: (615) 471-9299
Email: Info@AriesCleanEnergy.com
Website: http://www.ariescleanenergy.com

Aries Clean Energy builds industrial-scale gasification plants. Founded in 2010 as PHG Energy, and funded by the owners of a multi-state Caterpillar dealership, their goal "*was to further develop a patented gasification technology already in full commercialization and proven as a viable method of cleanly converting wood waste to synthetic fuel gas for industrial use.*"

Figure 42 below shows a chart from their website that details how a plant built in Lebanon, Tennessee produces 92% syngas and 8% biochar by volume of input and is expected to provide 36 MW hours of electricity over 20 years. This plant provides power to a water treatment plant and a combination of sludge and wood chips are used as the feedstocks.

Figure 45: ACE plant in Lebanon, Tennessee

APPROACH: Aries Clean Energy developed the PHG LF64 (64T/day) downdraft gasification system on one acre in Lebanon, Tennessee, that operates on the following specifications:

- **Input Materials:** Waste wood is cut to 1- to 3-inch size; sludge is blended with wood before gasification.
- **Process:** Syngas produced (92% by volume input) is combusted in an industrial thermal oxidizer (an emissions control device). Thermal energy is transferred to heat water, which drives three Organic Rankine Cylinder generators with a total output capacity of 420 Kw per day that offsets the electrical usage at the wastewater treatment plant next door.
- **Output:** 8% of input results in biochar that is 70% carbon and recyclable.

RESULTS: The Aries Clean Energy downdraft gasification system yields waste, energy, and emissions benefits for Lebanon, Tennessee:

- **Waste:** More than 16 million pounds diverted from landfills each year
- **Energy:** More than 36 MW-hrs generated over the 20 year life of the project
- **Emissions:** More than 5,000 pounds of carbon emissions averted annually

Figure 46: Chart from their website showing impact of a ACE gasification plant in Lebanon, Tennessee

Here is a short video discussing the project:

https://www.youtube.com/watch?time_continue=147&v=E_-dXjyjTgs

Note: The video mentions using tires for fuel for the plant as well as wood and sludge. Any biochar made from this mix of materials would not be suitable for agricultural use, however it could be used in industrial processes.

ICM

Address: 310 N. First St.
Colwich, KS. 67030
Phone: 877 426-3113
Website: icminc.com
Video: https://www.youtube.com/watch?time_continue=86&v=7CjYq-oIEvs

ICM, Inc. has built over 100 large-scale plants that use gasification technology to convert biomass into marketable products, including ethanol. Biochar production—a relatively new focus of the company—can be accomplished using certain appropriate feedstocks.

From their website:

ICM's proprietary gasification technology is based on platform technology developed in the early 1980's and has since evolved to its present form – robust, highly efficient, and capable of producing a variety of desirable outputs and co-products. As a means to unlock and harness the energy available in renewable biomass and other waste feed sources, our approach is unparalleled in terms of its features, flexibility, and cost effectiveness. As the company behind and supporting our products, ICM stands out - unmatched in reputation, manufacturing capabilities, organizational strength, and the skills we bring to bear in delivering and implementing project solutions.

Figure 47: ICM gasification plant

For industries and end users looking to make use of non-traditional resources in a sustainable, stable, and environmentally-friendly fashion, ICM's gasification technology offers multiple paths for producing recoverable thermal energy, generating baseload power, addressing waste issues, all while meeting the most stringent efficiency, safety, quality, and environmental objectives.

With thousands of tons of feedstock processed over several thousands of hours of operation, the ICM design has proven to be robust and maintenance-friendly, with minimal downtime. We offer single, modular gasification solutions in the 80 to 450+ ton per day range (which can produce 3 to 16+ MWe net) depending on feedstock conditions such as moisture and thermo-physical properties.

Since 2009, our full-scale demonstration gasification system has successfully processed a wide variety of feedstock. Our application range includes:

- *bark/urban trimmings*
- *corn stover/sorghum stalks*
- *switchgrass and other energy crops*
- *wheat straw/agricultural residuals*
- *poultry litter*
- *paper sludge*
- *construction and demolition waste (C&D)*
- *dry fractionation corn fiber*
- *sugar cane bagasse*
- *biosolids*
- *other opportunity feed sources*

Targeted Outputs:

Syngas or Producer Gas
Electric Power
Recovered Heat
Combined Heat and Power (CHP)
Biochar

West Biofuels

Contact: Matt Hoffman. Controls Engineer
Address: 14958 County Rd 100B
Woodland, CA. 95776
Phone: 720 298-0039 / 530 207-5996
Email: matt.hoffman@westbiofuels.com
Website: www.westbiofuels.com

West Biofuels produces a biofuel plants that utilize a unique combination of updraft and downdraft gasifier technologies they call CircleDraft gasification to create a relatively clean producer gas and biochar co-product. These plants can be configured in increments of 500 kW. One California-based project nearing completion is a 3-megawatt facility in Burney, California that will utilize 22,000 bone dry tons of surplus biomass from local sustainable forestry activities to produce baseload renewable energy.

From their website:

How it works

The CircleDraft gasification combines components of traditional downdraft and updraft technologies to produce a raw producer gas with low contaminant loading, extending the life and reducing the cost of gas conditioning systems. This gravity-fed system contains four temperature sections including the drying zone, the pyrolysis & gas cleaning zone, char stabilizing zone, and char gasification zone. Like an updraft gasifier, air and steam are injected in the bottom of the gasifier in the gasification zone which generates the majority of the producer gas. Unlike a traditional updraft gasifier and more similar to traditional downdraft technology, the producer gas is directed into the pyrolysis zone where the gas is filtered through the pyrolysis char for initial cleaning before reaching the gas outlets and heat exchangers. In the pyrolysis zone, the char provides a course filter to capture the higher-chain contaminants. The char, along with any contaminant loading, continues through the char stabilization zone and to the gasification zone where the heavy contaminants are reintroduced to the high temperature zone to be further broken down. Biochar produced through this process is derived directly from the gasification zone without the introduction of contaminants via producer gas filtration.

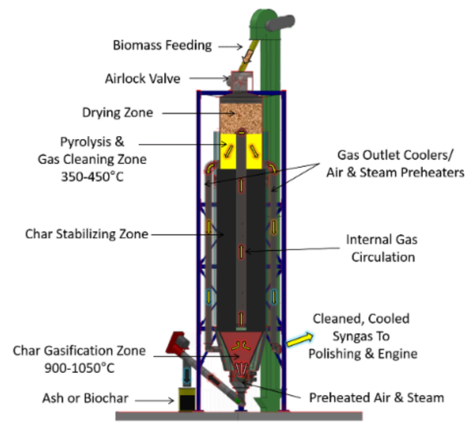

Figure 48: Explanation of the hybrid updraft/downdraft gasification process.

Figures 49 and 50: Installed West Biofuels installations.

System Specifications	
Optimal Size	0.5 MW_e – 5.0 MW_e
Scalable Increments	0.5 MW_e
Feedstock Specifications	
Heating Value	> 7,000 Btu/dry lb.
Moisture Content	15% - 35%
Nominal Feed Rate	~2,000 dry lb./hr/MW
System Production	
Gasifier Efficiency	65% - 80%
Generator Efficiency	28% - 36%
System CHP Efficiency	72% - 80%
Heat Availability	5.5 - 7.0 MMBtu/hr/MW
Biochar Production	200 – 300 dry lb./hr/MW
Syngas Heating Value	140 – 180 Btu/scf
Gas Composition	
H_2	18% - 22%
CO	14% - 18%
CH_4	1% - 5%
CO_2	11% - 15%
N_2	46% - 50%
H_2/CO	1.2 - 1.3
Tars	< 20 mg/Nm^3
Tar Dew Point	15°C

Figure 51: West Biofuels system specifications

Airex Energy

Address: 2500 Bernard-Lefebvre Street
Laval, Québec, Canada, H7C 0A5
Phone: 450.661.6498
Website: http://www.airex-energy.com/en/commercial-plant
Video: https://www.youtube.com/watch?v=bhPoH6WZ4hc

Airex is a Canadian company that uses a special continuous-feed pyrolysis process to produce torrefied pellets (Biocoal FX), biochar (BiocharFX), torrefied wood flour, and highly carbonized biocoke.

Biocoal can be used as a non-fossil drop-in replacement for coal in coal-fired power plants, for domestic heating applications, and in cement/lime kilns; Biochar is a beneficial soil amendment that also has many industrial uses; lightly torrefied wood flour can be used to produce wood-plastic composites; and highly carbonized biocoke can be used for some metallurgical applications. This technology is likely not a good fit for northern Mendocino County because there are few local markets for the products it creates. However, given the right entrepreneurial partner, since it does produce torrefied wood a market could be developed for sustainably produced charcoal briquettes.

From their website:

Torrefaction is a low temperature form of pyrolysis (230 C to 320 C) that removes moisture and volatile organic compounds (VOC's) from raw biomass. The final product, called torrefied biomass or biocoal (black or torrefied pellets) typically contain 70% of the mass and 90% of the energy content of the pretreated material.

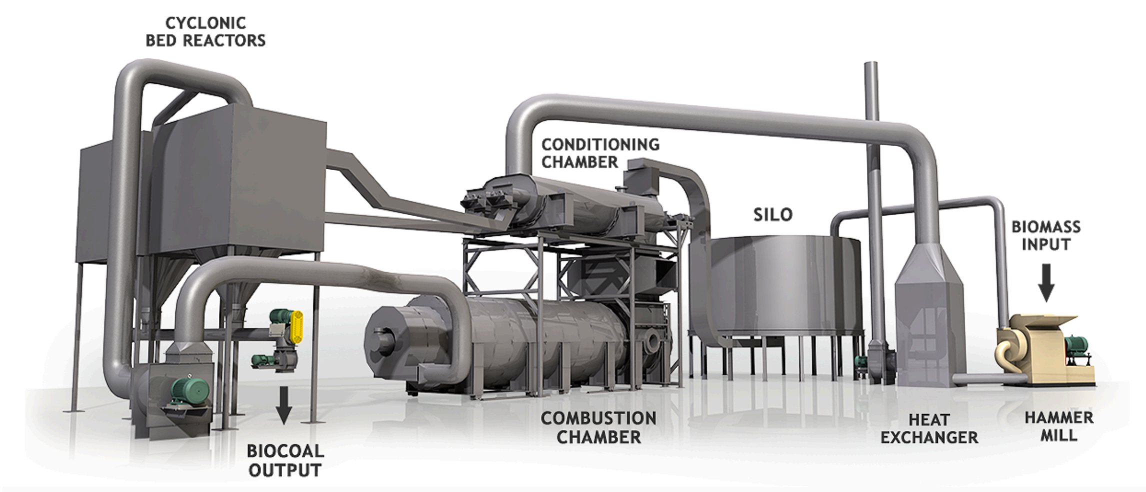

Figure 52: An illustration of an Airex plant.

Bioendev AB

Contact: Johan Berggren, CEO. +4670 589 9636
Email: Johann.berggren@bioendev.se
Lars-Åke Svensson, Sales Manager +46 70 677 06 05
Email: Lars-Ake.Svensson@bioendev.se
Address: Korsvägen 1
SE-91335 Holmsund, Sweden
Website: http://www.bioendev.se/

Bioendev is a Swedish company that has developed an innovative torrefaction technology over the last 10 years, primarily to produce black pellets (or briquettes) used for "heat and power generation, conversion of liquid fuels, and production of green chemicals." The plants can also produce biochar as a co-product.

They are working on the production and sale of commercial-scale torrefaction plants, and they built a 16,000-ton proof-of-concept industrial demonstration unit in 2016 to help perfect the system and for demonstration visits by interested parties.

From their website:

Torrefaction and pelletizing of biomass can provide an important piece in the puzzle of phasing out fossil fuels in favor of renewable alternatives. It shares many of the advantages with fossil coal in terms of energy density, hydrophobicity and burner feeding. It also lacks the challenges of many other renewable alternatives, such as irregular availability.

Black pellets will outcompete its white counterpart with superior properties by delivering more energy per volume and mass unit. Further, the torrefaction process gives;

1. *A hydrophobic product which can be stored outdoors*
2. *Decreases biological degradation in the product*
3. *A more homogenous product, resulting in a wider range of feed stocks*
4. *A product easier to grind and feed in coal plants*

Torrefied biomass can also be used for co-firing with coal, in CHP plants and for industrial applications such as steel and cement production. Torrefied material is also better than non pre-treated biomass for production of liquid biofuels in gasification processes.

Figure 53: Photograph of a Bioendev torrefaction plant.

Bioendev offers patented torrefaction technology for greenfield turnkey torrefaction pellet plants and retrofitted conventional white pellet plants with the capacity from 30-200 kton/year to customers who wants to solve the problems that exist with coal-

usage or conventional biomass. The torrefaction technology can handle a wide range of raw material and the torrefied biomass can be used as powder or be densified through pelletizing or briquetting. Together with standardized drying– and densifying technology our torrefaction plants will produce torrefied biomass with high process control, product quality and ability to customize the final product at a cost that provides good sales margins. Every customer case is unique and vary depending on the opportunities to exploit existing residual heat, machine equipment, geographic location and commodity options.

Bioforcetech

Address: 1400 Radio Rd,
Redwood City, CA 94065
Phone: (415) 508-7603
Email: info@bioforcetech.com
Website: bioforcetech.com
Years in Business:
Primary Business Focus: Waste Management, Converting biosolids into energy and biochar

Bioforcetech is a Silicon Valley company whose parent company, the PE Group, is based in Italy. Its technology converts biosolids, greenwaste, and foodwaste into renewable energy and biochar using a unique drying system and pyrolysis. After 4 years of trial and error and a number of proof-of-concept pilot plants, Bioforcetech built its first full-scale plant in 2017 at the Silicon Valley Clean Water plant in Redwood City that is designed to process 7000 tons of biosolids annually.

According to CFO Valentino Villa, the PE Group has been producing pyrolysis and other technologies for about 30 years, and they currently have 25 systems installed in Europe, with several more under construction. They have been working in the U.S for about 4 years, based in Redwood City, and they currently have several systems under construction in Washington state to process biosolids.

The BioDryer system is managed by Artificial Intelligence using Inspike's PLEXUS technology, providing 24/7 autonomous operation and low maintenance requirements. Using a combination of forced aeration and biological heat from the natural degradation of organic matter, their trademarked and highly efficient BioDryer system is designed to de-water the feedstock prior entering the pyrolysis system. The BioDryer can convert material with an 80% moisture/20% solids content into material with 20% moisture/80% solids /moisture content, and processing 9 tons of material in 40 to 60 hours. See Figures 50 and 51 below.

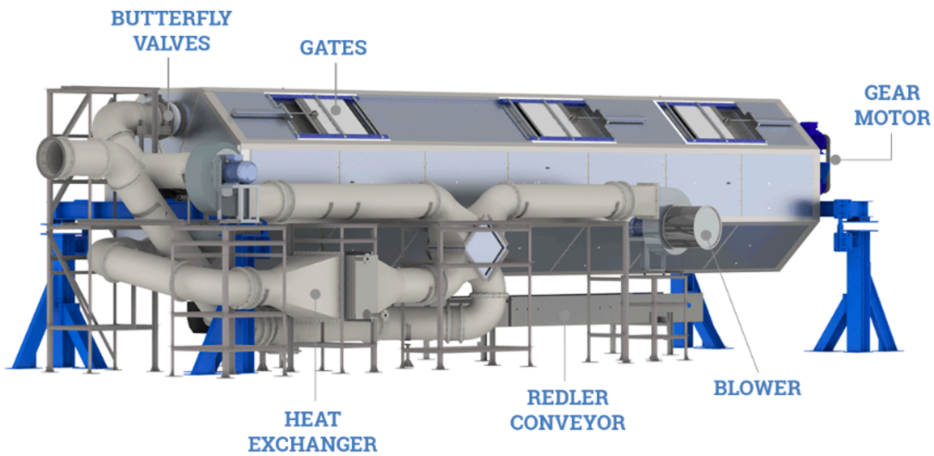

Figure 54: Illustration of the Bioforcetech BioDryer

The Bioforcetech BioDryer (above) reduces the moisture content using 70% less energy than other systems.

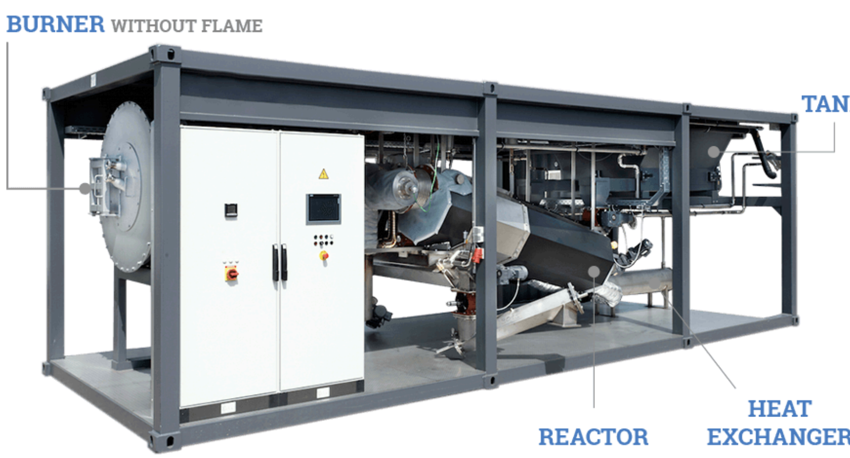

Figure 55: A Pyreg Pyrolyzer used as part of the Bioforcetech system.

A Pyreg pyrolyzer system shown above can be purchased independently. The specialized BioDryer, as explained, is designed for materials with high moisture content such as biosolids, and it can dry wet materials very economically. There are two sizes of pyrolysis systems available, the smaller P-Five system, and the larger P-Three system. Both machines are designed to operate using a number of different feedstocks Below are some specs on each system provided by engineer Valentino Villa.

P-Five System: $750K, plus input and output modules, and training.

- Biomass throughput: 1600 tons per year
- Feedstock can be up to 40% moisture content

- Biochar efficiency: 25% to 30%, or 400+ tons of biochar per year
- 1/3 of the heat is used is recycled back into the system, 2/3 can be used externally, providing 150 kWH of heat energy that can be used to boil water for other purposes
- Designed for 24/7 operation and rated at 8,000 hours per year
- Designed for a 30-year operational life
- Feedstock size: 1" minus
- Compact, 40' X 10' X 10' footprint required
- Unit can run up to 3 days unattended with adequate feedstock storage
- Minor servicing is required every few weeks

P-Three System: $1.5 million, plus input and output modules, and training.

- Biomass throughput: 3800 tons per year
- Feedstock can be up to 40% moisture content
- Biochar efficiency: 25% to 30%, or 900+ tons of biochar per year
- 1/3 of the heat is used is recycled back into the system, 2/3 can be used externally, providing 450 KwH of heat energy that can be used to boil water for other purposes
- Designed for 24/7 operation and rated at 8,000 hours per year
- Designed for a 30-year operational life
- Feedstock size: 2" minus
- 60' X 10' X 15', or 15' X 20' X 20' footprint roptions
- Unit can run up to 3 days unattended with adequate feedstock storage
- Minor servicing is required every few weeks, other servicing required every 4 months

Bioforcetech considers the process upcycling, a process by which "byproducts, waste materials, useless or unwanted materials are transformed into new materials or products of better quality or for better environmental value."

Microwave Pyrolysis

Up to now this report has focused on traditional pyrolysis or gasification systems that use heat generated by some type of combustion process to dry and transform biomass into char, bio-oil, and/or volatile gases. Most of these systems (especially the automated ones) require dry feedstocks that have been reduced in size to produce standardized co-products. Microwave pyrolysis can eliminate the drying step, thereby reducing overall the energy needs of the pyrolysis process. However, creating uniform energy distribution in large-scale plants could be challenging and may restrict its use to smaller machines. Also, it appears that microwave pyrolysis may be more beneficial for use with feedstocks such as tires and plastics—materials that are not suitable for agricultural biochar production—that could be transformed into chemical components used in industrial processes or biofuels.

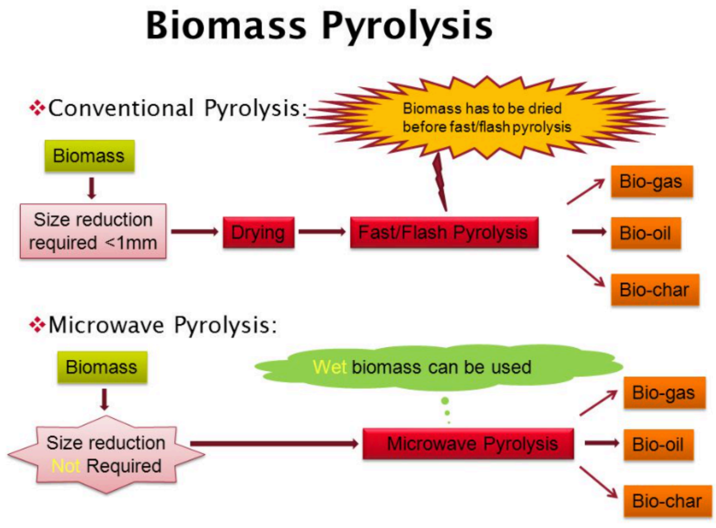

Figure 56: Illustration From PowerPoint By Dr. Hanwu Lei's Research Group, Department of Biological Systems Engineering, Washington State University.

There are a few companies that offer commercial microwave pyrolysis technology at this time, but one that does, the Scandanavian Biofuel Company, calls their process "microwave assisted."

Scandinavian Biofuel Company AS

Adv. Seland DA
Klingenberggt, 7A
NO-0125 Oslo Norway
Email: Mail@ SBiofuel.com

From their Website:

The Microwave Assisted Pyrolysis process is well suited to recycle a variety of waste fractions such as tires, sewage sludge, agricultural waste, waste wood, electronic scrap, cables, plastic waste etc.

Process
Many projects for the pyrolysis of organic waste, in particular plastic and rubber waste such as car tires, have been designed and realized. Very few of these projects have however been successful:
- The quality of the end product depends on the ability to control the temperature through the whole feedstock. Organic materials are in general poor heat-conductors, so this is not easily achieved by conventional pyrolysis techniques. The poor quality of the end product prevents reasonable prices to make the process economical viable.
- Process efficiency and economics depend on continuous processing. This is difficult or impossible to achieve by conventional pyrolysis techniques, as the even heating of

moving material is very difficult. In particular will feedstock containing plastic or rubber represent a challenge, as these materials get sticky when heated.
The Microwave Assisted Pyrolysis technology eliminates the described problems. The microwaves heat by exciting the individual molecules in the organic material. The heating is very accurate and even through the feedstock, and the heat control can be given within very narrow margins.

Advantages
The Microwave Assisted Pyrolysis is, compared to incineration, easily controllable. Incineration is complicated and expensive to control, and will usually create harmful or toxic components that have to be removed from the flue gas.
The pyrolysis is a process with no oxygen present. Consequently oxides cannot be formed. For the same reason dioxins cannot occur, as the formation of dioxins is dependent of the presence of oxygen.

The process is completely enclosed, and all products are collected and duly treated without any emissions to the environment, called dry distillation process. As no oxygen is added to the process, the produced gas will be a concentrated fuel gas with high calorific value.
The feedstock is brought into the pyrolysis reactor through air locks purged with inert gas to prevent oxygen to enter the reactor. It is then heated by means of microwaves to a temperature where the bonds between the solids and the volatiles in the material are broken. The volatile fraction consists of a vapor that is separated into gases and fluids by condensation.

2018 Biochar Industry Report Commissioned by the US Forest Service

The following report was commissioned by the US Forest Service through a Wood Innovations grant and conducted in conjunction with the U.S. Biochar Initiative.

http://biochar-us.org/sites/default/files/news-files/Preliminary%20Biochar%20Industry%20Report%2008162018_0.pdf

http://biochar-us.org/sites/default/files/news-files/Survey%20Highlights_MTedits_0.pdf

NREL National Renewable Industry Map

Below is a link to a National Renewable Energy Lab Map showing amount of forest residues produced per year in Mendocino and Humboldt counties: Mendocino: 52,000 dry tons per year; Humboldt: 104,000 dry tons per year. RFFI's forest residues are roughly 2% of the Mendocino total, showing that there is plenty of additional material available to produce renewable energy and biochar.

https://maps.nrel.gov/biofuels-atlas/?aL=0gBHTu%255Bv%255D%3Dt%26yilN7K%255Bv%255D%3Dt%26yilN7K%255Bd%255D%3D1&bL=clight&cE=0&lR=0&mC=39.31305046371388%2C-122.6019287109375&zL=8

Wood Product Alternatives

Much of the surplus biomass produced during fuels reduction thinning and other sustainable forestry practices in the Usal Forest is tanoak, a fast growing hardwood that is considered of low value and difficult to dry and mill for use in woodworking and construction applications. There are, however, some companies and individuals that do use tanoak to produce a variety of products, and it may be possible to market certain sizes of tanoak logs to these companies. However, many of the companies that do use tanoak are small boutique woodworkers and mills in Oregon or Washington, and it is unlikely that it would be cost efficient to send logs or rough cut lumber long distances (though exactly what this distance limitation is still has to be determined through further research). It may be possible to develop a local Mendocino or Humboldt market for tanoak with help from other organizations, and if a skilled hardwood miller could be brought in from the East Coast to teach locals how to successfully work with it.

From an environmental perspective, utilizing tanoak for use in various woodworking or milling activities does sequester the carbon contained in the wood for some period of time, and is preferable to methods that convert biomass into materials that would simply be burned, such as pellets or briquettes.

Milling and Woodworking

Tanoak has been used for butcher block cutting boards, flooring, furniture, stair treads, truck bedding, pallets, veneer, paneling, ties and mine timbers, fence posts, pulpwood, tool handles, baseball bats, firewood and biofuels. It has also been shown to be excellent feedstock for biochar production.

The bark was once the main commercial Western source of tannin for leather before modern chemicals replaced them (the tan in tanoak is for tannin. Acorn food continues to be important for contemporary California Indians culturally, socially, and spiritually.

An excellent overview of the different qualities and characteristics of tanoak can be found on the Oregon State University Wood Innovation Center website:

http://owic.oregonstate.edu/tanoak-lithocarpus-densiflorus

A list of 8 Oregon-based companies that use tanoak can be found here, however transportation costs would likely be prohibitive:

http://www.orforestdirectory.com/categories/species/tanoak

Another helpful paper on the use of tanoak in construction and furniture applications, prepared by the University of California, can be found here:

https://ucanr.edu/sites/oak_range/Oak_Articles_On_Line/Oak_Woodland_Products_Range_Management_Livestock/Does_It_Make_Cents_to_Process_Tanoak_to_Lumber/

Despite special attention that needs to be given to drying and handling, the paper concludes that tanoak does have "the potential to be an important hardwood resource", and that "it is being increasingly accepted as hardwood flooring and furniture stock in both commodity and niche markets."

In researching local Mendocino companies that might be interested in using Usal tanoak, only one company, Whitethorn Hardwoods, advertised its use of tanoak. There may well be others, but additional research will be needed to find them. A call and email to Whitethorn were not returned seeking more information for this report.

Whitethorn Hardwoods

Bob MCKee and Ken Forden
P.O. Box 400
Whitethorn, CA 95589
707 986-7412
ken@californiahardwoods.net
http://www.californiahardwoods.net/species/Hardwood.info.html

From their website:

Tanoak is a hard, heavy wood that in many ways resembles the true oaks; thus, tanoak is often included in lumber from western oak species. The wood is a light, reddish brown color when freshly cut, but it ages to a tannish, reddish-brown. The sapwood is very wide and is difficult to distinguish from the heartwood. There are broad rays which are conspicuous on quartersawn surfaces. Tanoak is highly rated for hardness, resistance to abrasion, stiffness, and bending strengths. Machinability is comparable or better than commercial eastern oaks. Tanoak finishes well because of its uniform color and is used for flooring, furniture, pallets, veneer, and paneling. Clear-coated flooring products made from tanoak have a warm, pleasant, appearance.

We are a small Hardwood Mill and not a standard retail hardwood lumber supply. Our working hours are not that of a lumber supply house. Because our hours vary we also offer service on any day of the week or weekend by appointment. Please call 707/986-7412 or email ***ken@californiahardwoods.net*** *if you have questions or wish to make an appointment. We are punctual in returning calls or email requests.*

Our operation is unique in California. Our inventory of native California hardwoods is second to none. *We specialize in Madrone and Tan Oak though we have several other species in stock. Cabinet lumber, slabs and flooring are our mainstays. We offer tours by appointment. Our tours involve milling, drying, design, technical advice and inventory examination.*

Another company that brokers tanoak, located in Portland, Oregon, is Sustainable Northwest Wood. With a similar ethic as the Redwood Forest Foundation, this company would appear to be a good potential partner for marketing RFFI's surplus tanoak—except for the long transportation distance.

Sustainable Northwest Wood

Address: 2701 SE 14th Ave.
Portland, OR. 97202
Phone: (503) 239-9663
Website: http://www.snwwood.com/

Figure 57: Tanoak graphic from Sustainable Northwest Wood

A third company using tanoak in their product line is GreenHome Solutions:

GreenHome Solutions

Address:1210 W. Nickerson St
Seattle, WA 98119
Phone: 888-447-9877 toll free
Website: https://www.ghsproducts.com

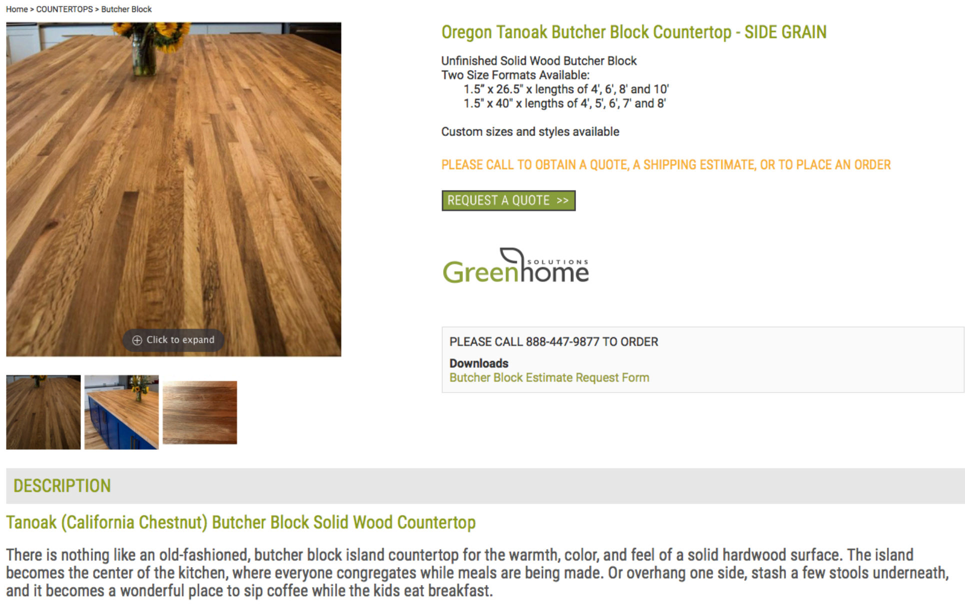

Figure 58: Tanoak Butcher Block table sample from GreenHome Solutions

Briquetting

Briquetting is the process of compressing wood or agricultural wastes and upcycling it into products with a greater value. A comparative life cycle analysis analyzing a number of activities that could be used to reduce post-harvest forest residues, done as part of the Waste To Wisdom grant project funded by the U.S. Department of Energy, concluded that briquetting represents a less environmentally impactful way to process this material than open burning or firewood production, two common practices. Briquettes deliver around 50% more heat pound for pound, and emit significantly lower particulate matter, than cordwood.

Briquette manufacturing and use can be considered a sustainable practice only if surplus materials produced as byproducts of other activities, such as responsible forestry practices, woodworking shops, mills, etc. are used, and if sourcing of these feedstocks is close to the briquetting operation. Care must also be taken to use only safe and non-toxic binding agents, and to develop local markets that do not require long-distance shipping. Briquettes are more versatile than wood pellets since they can be used in a variety of devices, not just pellet stoves. While briquettes are popular in Europe, they are just starting to catch on in the U.S. market.

Humboldt State University's Schatz Energy Research Center, working under the same Waste to Wisdom grant from the Department of Energy, has studied the economics of using transportable conversion facilities for producing biochar, torrefied wood, and briquettes.

http://wastetowisdom.com/wp-content/uploads/2017/09/Economics-of-Transportable-Biomass-Conversion-Facilities-for-Producing-Biochar-Briquettes-and-Torrefied-Wood-Utilizing-Forest-Harvest-Residues.pdf

There are a number of briquetting systems on the market, but the RUF product line appears one of the best suited for woody biomass feedstocks.

RUF US Briquetting Systems

Address: 771 Sugar Lane
Elyria. OH 44035
Phone: 888.778.9504
Fax: 440.328.4626
Years in Business: 50 (Founded in Germany in 1969)
Video 1: https://www.youtube.com/watch?v=RTUUgoZOZ74
Video 2: https://www.youtube.com/watch?time_continue=106&v=lJn3-KJesUc

These machines are heavy-duty, industrial technologies that are relatively easy to run and usually run operator free for long periods, according to a phone interview with Greg Tucholski, their wood briquetting representative. They are operated hydraulically, using three-phase power, and no binding agents or chemicals are used to hold the briquettes together. According to Greg, the high pressure causes the lignin within the biomass feedstock to fuse the material together, and as long as the moisture content of the material is 15% or less, and the feedstock is reduced to ¾ minus and smaller, the briquettes will keep their shape during shipping and hold together during burning—which affects their durability and heating efficiency.

The briquettes provide 70% more BTUs per lb than cordwood, and according to Greg, bark actually has a higher BTU rating than regular heartwood chips, so shredded bark can be blended to create a better briquette as long as it is processed properly.

In order to get a decent return on the investment over a relatively short time frame, it was recommended that a machine that processes 10 to 15 tons per day be purchased. This sized machine would cost $120,000, including delivery to the West Coast and 2 or 3 days of training. A typical package, including an industrial dryer, large storage bins that feed the biomass and receive the finished product, and other infrastructure, would run about $300,000.

Maintenance on the machines runs about $1 per ton of material processed. Filters need to be changed every 2000 hours; the mold that shapes the briquettes need replacing every 5,000 to 10,000 hours, depending on the material being processed. Seals and pistons also need replacing on a regular basis, and it is critical to keep the oil clean and fresh to prevent undue wear.

Greg agreed that the West Coast market for briquettes is not near as developed as in the northern East Coast markets, and that all of the current machines they have installed on the West Coast are in Oregon and Washington, so much time and energy would need to be spent to create a market in California. Briquettes are normally packaged in 20 or 24 lb packages, packed 24 packs per shrink-wrapped pallet. A typical selling price of finished briquettes is $140 to 160 per ton, but can go as high as $200 per ton in some areas. Greg stated that most businesses he has sold machines to find they need to process at least 15 tons per day to enjoy a reasonable return on their investment.

From their web site:

Benefits of RUF Briquetters:

- *Runs operator-free*
- *Operated hydraulically*
- *Controlled by a programmable logic controller (PLC)*
- *Sell resulting metal briquettes or wood briquettes*
- *Reclaim value from cutting fluids (oil, lubricants) from metals*
- *Compact design for easy integration into your plant floor*
- *Engineered for automatic, 24-hour operation with low horsepower*
- *Ready to handle and transport right out of the press*

Get More from Your Materials

How our briquetters turn your scrap into briquettes:

1. *The briquetter is loaded with residual waste.*
2. *The material is transported into the pre-charging chamber by a conveying screw.*
3. *The pre-charger presses the material into the main pressing chamber (to ensure consistent briquette size).*
4. *The main pressing ram compresses the material into the mold and forms the briquette into its final shape and density.*
5. *The reciprocating mold moves sideways and the briquette is ejected by parallel ejectors as a second briquette is formed.*

RUF offers four standard machine sizes, and can also create custom configurations based on individual customer needs. Below are some specs from their wood-based machine brochure. The company has more than 4000 machines installed in over 100 countries worldwide.

Figure 59: RUF Briquetting Machine

MACHINE TYPES

BRIQUETTER SPECIFICATIONS

WOOD	RUF 4 to RUF 11	RUF 100 to RUF 800	RUF 1100+	RUF 1500
Max. throughput rate (lb/h)	120-350	220-1,500	1,700-2,800	2,800-3,300
Power (hp)	5-15	10-50	100	125
Spec. pressure, max. (psi)	10,150-53,650	20,300-24,650	20,300-24,650	24,650
Briquette shape (in)	3 2.4x1.6 2.4x2.4	6x2.4 6x2.8 6x3	9.4x2.8 9.4x3	10x4
Briquette length (in)	1-3	2.5-4	2.5-4	2.5-4
Machine size (in) Length x Width x Height	52x59x75	71x63x79 to 79x79x83	107x91x83	118x130x91
Machine Weight (lbs)	2,800-4,200	6,000-9,300	14,300	26,400

Subject to technical modifications - Capacity depends on the material properties

Figure 60: RUF Briquetting Machine Specifications

Different shapes and sizes of briquettes are available as an end product.

Figure 61: RUF Briquetting Machine available product shapes

Other Briquetting Systems:

KR Komarek, Inc.

Address: 548 Clayton Ct.
Wood Dale, IL 60191
Phone: 847.410.1720
Email: info@komarek.com
Website: http://komarek.com/machines-applications/additional-solutions/#briquetting

Biomass Briquette Systems

Address: P.O. Box 1835
Chico, CA 95927
Phone: 877-474-5521
Email: info@biomassbriquettesystems.com
Website: http://www.biomassbriquettesystems.com

Advantages:

- Briquetting is a relatively simple process that operators can learn quickly, and systems can be automated to require minimal supervision.
- Briquetting could be done on the Andersonia Site with some site improvements, and additional feedstock could be supplied by the onsite mill run by Kelly Paine.
- Briquetting densifies surplus materials into more efficient and hotter burning carbon neutral fuels.
- Briquetting is a relatively clean industrial process and the machinery has a relatively compact footprint.

Disadvantages:

- Significant preprocessing of the feedstock is required and moisture content needs to be controlled, requiring equipment to reduce the feedstock into the right form for the briquetting machine, as well as drying infrastructure.
- Briquetting machines require a housed to keep the feedstock dry during the process and to prevent degradation of the finished briquettes during storage, so a warehouse would need to be constructed, or one would need to be found closeby.
- The market for briquettes is not well developed in Mendocino County, and like biochar, would require significant marketing and branding efforts to build a profitable enterprise.
- Producing briquettes offers no co-benefits as does the biochar production process, and rather than sequestering carbon returns it to the atmosphere even faster than if the material was left to decompose in the forest.

Comparative LCA of Briquetting Logging Residues and Lumber manufacturing CoProducts in the Western US.
https://www.fpl.fs.fed.us/documnts/pdf2018/fpl_2018_alanya-rosenbaum001.pdf

Overview of Briquetting:
http://www.fao.org/docrep/t0275e/T0275E02.htm#Part%201.An%20overview%20of%20briquetting

Cellulosic Ethanol

Cellulosic ethanol production is a complicated process whereby surplus biomass like corn stover, rice hulls, or logging slash can be treated with enzymes to turn it into biofuel. As opposed to corn-based ethanol which requires cropland to be used for energy production rather than food production, cellulosic ethanol has attracted attention because it can be produced from inedible plant sources including wood chips, sawdust, crop residues like nut shells, and even municipal solid waste.

Research facilities such as the National Renewable Energy Lab (NREL) in Colorado have been working on the process for decades and have reduced the cost of production significantly, from around $10 per gallon to around $2, primarily through bioengineering more effective and cheaper enzymes. Based on this progress, DuPont opened a 30 million gallon per year cellulosic ethanol plant in the Midwest in 2016 with incentives and support from the Obama administration and a 2007 EPA mandate for blending ethanol with gasoline to help reduce greenhouse gas emissions. It was touted as the largest biorefinery in the world, using corn stover from some 500 nearby farmers as feedstock, helping to solve a major surplus biomass problem for farmers while bringing extra income as well.

Figure 62: Photo of DuPont's cellulosic ethanol plant in Nevada, Iowa. (From Biofuels Digest)

Faced with increasing uncertainty about the biofuel market, and the Trump administration's efforts to roll back ethanol mandates and general lack of support for renewable technologies, DuPont put the $225 million facility up for sale in 2017. Other cellulosic ethanol producers have become wary of the uncertain future of the biofuels market and sold their plants as well. Abengoa SA, for example, received a $132 million loan guarantee in 2011 from the Department of Energy to build a commercial-scale cellulosic ethanol plant in Kansas. The plant created 300 construction jobs and supported 65 permanent, full-time jobs, while saving 14,900,000 gallons of gasoline and preventing 132,000 metric tons of C02 release annually. They sold their plant in 2015 citing an uncertain market future.

Aemetis, Inc.

One bright spot in the biofuels market is California's leadership and dedication to encouraging innovative technologies that can help meet its greenhouse gas emissions goals. Aemetis, Inc., an industrial biotechnology company, announced earlier this year that it plans on building a $158 million cellulosic ethanol plant in Riverbank, California. With cellulosic ethanol currently selling in California at over $4 per gallon Aemetis, in partnership with LanzaTech, is betting that this high price will continue and is willing to build this plant that will produce about 12 million gallons per year. According to Aemetis CEO Eric McAfee, interviewed for an article in the March 2018 issue of Biofuels Digest:

"With 1.5 million acres of almonds and walnuts in the Central Valley generating about 1.6 million tons of waste wood and nutshells each year, about 160 million gallons of cellulosic ethanol needs to be produced to eliminate the air pollution from burning or decomposition of this material (as well as Construction & Demolition, vineyard, dairy and collected food waste).

"Set to open in 2019, the Aemetis 12 mgy cellulosic ethanol plant is located at the former Riverbank ammunition plant near Modesto. Using waste orchard wood to produce biofuels is projected to generate more than $70 million of revenues from cellulosic ethanol, fish meal and biogas, and about $50 million of annual positive cash flow.

"With about 20 million shares outstanding, each 12-14 million gallon phase is projected to generate $2.50 per share of operating cash flow. Adding two of the 14 million gallon expansions at the same Riverbank site will create a 40 mgy plant. We plan to build until we have four, 40 million gallon capacity cellulosic ethanol plants in the Central Valley."

Given the ever-changing fortunes of ethanol producers over the last 10 years, and given the current pro-oil political atmosphere in Washington, this may be a risky venture. However, given California's strong mandate and public support for climate change mitigation actions coupled with the massive amounts of surplus biomass generated by the agricultural and forestry industries, this is probably the best state in which to grow the cellulosic ethanol industry. One huge difference between standard corn-based ethanol and cellulosic ethanol production is that cellulosic ethanol does not require "energy crops" to be grown, taking up valuable land that should be used for food production. Instead, given the 1.6 million tons of waste wood and nutshells generated from almonds and walnuts alone, producing a biofuel from at least a portion of these surplus materials is a much better option than simply burning, chipping, or landfilling the materials.

Given the enormous cost of building these plants, and the early stage of their development, it would take years for such a plant to be planned, permitted, and built in the Mendocino /Humboldt, so this would be a long-term strategy for RFFI and a coalition of partner organizations and political supporters that would have to be developed. But a preliminary meeting with Aemetis representatives could be set up to explore the idea.

Biofuels Digest Article on Aemetis, Inc.:

https://www.biofuelsdigest.com/bdigest/2018/03/08/commercial-time-aemetis-embarks-on-158-million-cellulosic-ethanol-project-in-california/

Biofuels Digest Background Article on the History and Challenges to Ethanol Use:
https://www.biofuelsdigest.com/bdigest/2018/10/28/behind-the-scenes-with-e15-as-we-peel-back-the-layers/

A Good Earth Island Journal Background Article on Cellulosic Ethanol:
http://www.earthisland.org/journal/index.php/elist/eListRead/is_cellulosic_ethanol_the_next_big_thing_in_renewable_fuels/

A Link to Videos Explaining Cellulosic Ethanol:
https://video.search.yahoo.com/yhs/search;_ylt=AwrgEZ2n7JZbrr0AcBIPxQt.;_ylu=X3oDMTByNWU4cGh1BGNvbG8DZ3ExBHBvcwMxBHZ0aWQDBHNlYwNzYw--?p=cellulosic+biocfuel&fr=yhs-iry-fullyhosted_011&hspart=iry&hsimp=yhs-fullyhosted_011

Firewood

Allowing local firewood providers to access surplus tanoak logs to reduce the piles that have accumulated is still an option that has little or no financial impact on RFFI, however it is the least attractive option we surveyed from an environmental sustainability perspective. After discussing the economics of firewood production and sales with several forestry professionals, it was also deemed to be the lowest margin option with the least environmental benefits, so this option was not included in this report.

Conclusions and Recommendations

This research revealed a number of processing options that RFFI could employ or develop as alternatives to its current practices. The least expensive and likely the easiest options to integrate into current forestry practices workflows would be the use of pits, conservation burns, or kilns to process the slash and small logs into biochar, and to distribute this material back into the forest. Some of the biochar could potentially be collected and distributed through RFFI offices in trade for tax deductible donations. This pathway would likely not require hiring extra staffing or entrepreneurial partners (unless it seemed advantageous to do so).

All other options would require a different level of commitment and financial arrangements along with outside partnerships and investment to cover startup, marketing, and ongoing operational costs, and would also require much more staff time or outside consulting services. These management expenses would have to be covered and built into any business plan that involved RFFI directly, however a more likely scenario would involve establishment of a partnership with an independently funded entrepreneurial venture that would involve RFFI as only a biomass supplier. RFFI, with its access to an ongoing supply of surplus biomass and its many connections with other landowners in the area with a similar tanoak surplus problem (such as New Island Capital), could act both as a catalyst as well as a supplier for this type of entrepreneurial enterprise.

In a recent discussion with Linwood Gill, RFFI's Chief Forester, he outlined a number of challenges with collecting and moving the tanoak logs and logging slash materials out of the forest for processing, and he was in favor of doing the processing as close to the source as possible. Loader and trucking costs run about $250 combined per hour, so a rough estimate of moving a load of logs to Andersonia from the Usal would run about $600 to $800 per load, or more, depending on which THP was being worked on. Having access to a mobile processing unit that could be moved from landing to landing within the forest itself would be the preferred option, and finding a way to utilize any biochar produced within the forest rather than shipping it to farms would also be preferred from a GHG accounting perspective.

Whether the costs to produce the biochar could be covered without marketing the biochar is unknown, and would be dependent on finding grant or private funding pay for its production. Initiatives such as the Biochar Carbon Action Plan that has been proposed to coincide with the release of the film Ice On Fire is one possible approach that could provide funding for turning surplus forestry materials into biochar at no cost to RFFI.

There are several technology suppliers profiled in this report that produce biomass conversion machines that meet the mobility criteria and could be used within the forest, however all of the technologies also produce co-products in addition to biochar that should ideally be utilized, including heat, syngas, torrefied material, and in some cases bio oil. Because each of these co-products requires additional infrastructure to utilize or store the material, choosing the right project partners and production site would be critical.

Of the biochar-related technologies and companies reviewed, four stand out: Community Power, Pyreg, Biogreen, and Ag Energy. Bioforcetech, which has a plant in Silicon Valley and that uses a Pyreg gasifier, is also a company that deserves further research. Using small-scale biomass gasifier technology from All Power Labs to provide power in remote locations where these technologies might be used should also be considered.

Another promising option that also deserves more research and scrutiny is briquetting some of the raw feedstock in addition to producing biochar.

RFFI needs to decide whether it wants to simply develop an in-house solution to the tanoak and forest slash problem that is managed by them in the least expensive way (conservation burns, kiln burns, pit burns), or if partnering with an outside entrepreneur to develop a project that could better utilize the material is the preferred pathway.

For any of the options, processing the material as close to the source of the biomass as possible is desirable, and distributing the co-products produced as close to the conversion facility as possible, would not only be required to make the project profitable but also to keep its carbon footprint to a minimum.

Next Steps

- Determine whether any of the options outlined in this report might be a good fit and complimentary to RFFI's mission, then drill down deeper on the final choice (s) to determine actual costs.
- If any of the options require outside entrepreneurial partners, develop a pitch deck and simple business plan outlining the vision for the desired outcome, ideal location, and financial needs for the operation. Then give presentations to local organizations to start building support and engagement.
- Canvas potential landowner partners near the Usal that could dependably contribute surplus biomass to a commercial operation. This will determine the scale of the technology that can be realistically utilized and transportation estimates can be calculated.
- Research other possible locations other than Andersonia, within a realistic radius of the Usal, where a larger operation could be sited and that could utilize the power generated "behind-the-meter." Warehouse space in a

commercial zone where businesses could be aggregated to purchase power, or large power users such as a water treatment plant should be researched as possible locations.

- Conduct new market research for biochar and briquette sales within a 100-mile radius of the Usal.

In nature there's no such thing as waste

Figure 63: There is no such thing as waste in nature