Carbon Accounting in Forest Management

This article describes how baselines and harvesting are included in carbon accounting. Content provided by the Forest Owner Carbon and Climate Education (FOCCE) program.

Updated: February 1, 2023

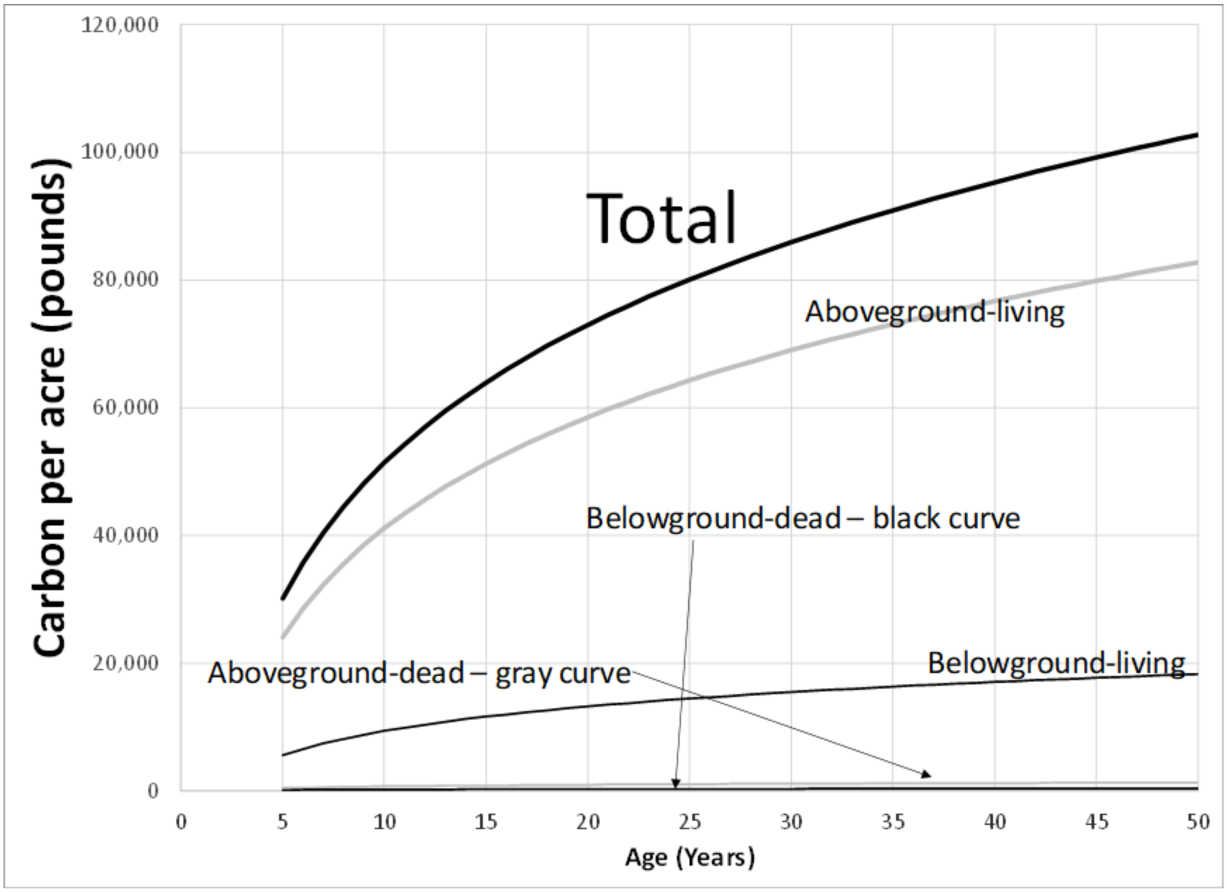
Forest interior looking into open area. Photo credit: Keri Griffin-Rowles

Forest owners who want to be paid for sequestering carbon need to understand which carbon qualifies as additional and permanent.

Measuring Carbon Over Time

How much carbon is in living woody biomass varies over space and time, depending on tree species, stand density (e.g., number of trees per acre), silvicultural management (e.g., fertilization), and tree age. The USDA Forest Service has an open access database called the Forest Inventory Analysis (FIA). This database can be used to estimate the average amount of carbon stored in a typical acre in the United States, based on tree species and location. The "carbon lookup tables(https://www.fs.usda.gov/nrs/pubs/gtr/gtr_nrs202.pdf)" offered by the US Forest Service were created using FIA data and describes forest carbon values based on region, forest type, and stand age.

A planted pine stand provides a good illustration of how carbon storage changes over time. FIA data were used to develop Figure 1, which shows the amount of carbon sequestered over time for a planted slash pine stand in Mississippi. The concepts presented here can also be applied to an uneven-aged or mixed hardwood forest as well.



(https://extension.psu.edu/media/wysiwyg//extensions/catalog_product/53b02714228042d59f1e9151b9c4b191/p/i/picture22-pn.png)

Figure 1. Carbon per acre estimates for planted slash pine stands in Mississippi using data from the USDA Forest Service Forest Inventory and Analysis (FIA) program.

In this figure, given relative scale, the grey line for "above ground living" biomass increases over time compared to the thin black line for "below ground living" biomass which remains flat. This means each year the amount of carbon stored per acre tends to increase meaningfully above ground, but not much below ground.

After the trees are first established, the rate of carbon sequestration increases, but then it eventually starts to level off as the trees mature. You can see this between years 5 to 15 where the grey line is slightly steeper in slope compared to years 25 to 45. These changes are often referred to as the rate of carbon sequestration, or change in carbon (pounds or tons) over time (year). Rates can change depending on the age of the stand.

In most cases, only the above ground living biomass is considered in a carbon offset scheme, because living biomass can be easily managed to provide additional storage. Managing carbon in the soils and below ground living biomass, however, is also an important part of climate-smart forestry.

Setting the Baseline

Setting a baseline is critical for determining when carbon storage is "business-as-usual" and when it is "additional" and can be sold in a market. Reforestation, or planting trees, is a common strategy for removing additional carbon sequestration. The baseline amount of carbon in a reforestation project is zero, because there were no trees to begin with. It is assumed that the forest was unlikely to occur unless planted and after planting the land would remain forested into the future. If slash pine trees were planted the total amount of carbon would approach 100,000 pounds per acre at year 45 (Figure 1). The carbon stored in a planted forest is typically not accounted for during the first five years, due to higher rates of tree mortality and measurement error.

Delaying harvest is another common strategy and is often referred to as an Improved Forest Management (IFM) practice. The baseline in a delay harvest scheme is the average amount of live woody biomass per acre just before harvest. If the starting point in Figure 1 was set at 25 years (when southern pine stands are financially mature for harvest), then the baseline amount of carbon would be 80,000 pounds of total carbon. Delaying harvest another 5 years is predicted to provide an additional 8,000 pounds of carbon stored beyond the baseline amount. Keep in mind that when a stand has been cut (business-as-usual) another forest may start to grow after harvest. Any carbon sequestered after a harvest would also have to be accounted for when estimating how much additional carbon was stored by changing management activities.

There are several key challenges to determining an appropriate baseline for offset projects that include multiple properties of land.

- If the average amount of living woody biomass across all the properties is used as the baseline, then some properties may already exceed or be below average at the time of enrollment. This can be problematic when trying to determine which properties will provide more benefits and what is fair compensation.
- There will always be some proportion of properties that do not fit the business-as-usual assumptions about harvesting. In other words, some owners original intentions about harvesting can change due to circumstance. Carbon accounting procedures tend to be more accurate when baselines are more representative of these kinds of changing conditions.
- In cases where the period of contract is shorter than the window of optimal harvest, payments for delaying harvest may not cover the whole period of "harvest risk". Longer contracts can offer more assurances that a harvest was truly delayed.

Since working with multiple properties can be complicated, how much error is acceptable when measuring the baseline is of continuous debate.

Permanence

During respiration up to half of the carbon taken in by a forest is stored to create new woody biomass. Wood that is buried underground, where there is little oxygen, can hold onto carbon for centuries. Increased use of fossil fuels has allowed the carbon from ancient forests to reenter the atmosphere enhancing the greenhouse effect. A true carbon offset should provide the same benefits as never extracting fossil fuels from the ground in the first place. This is why the concept of permanent storage or "permanence" is fundamental to the role of a carbon offset.

Permanence in a forest carbon offset project has been defined by the California Air Resources Board as carbon emissions avoided for at least 100 years. However, climate models show that even when a carbon dioxide molecule has been removed from the atmosphere, a portion of the effects on temperature can still linger for thousands of years. This means that the impacts of fossil fuels emissions can never be fully erased, only mitigated.

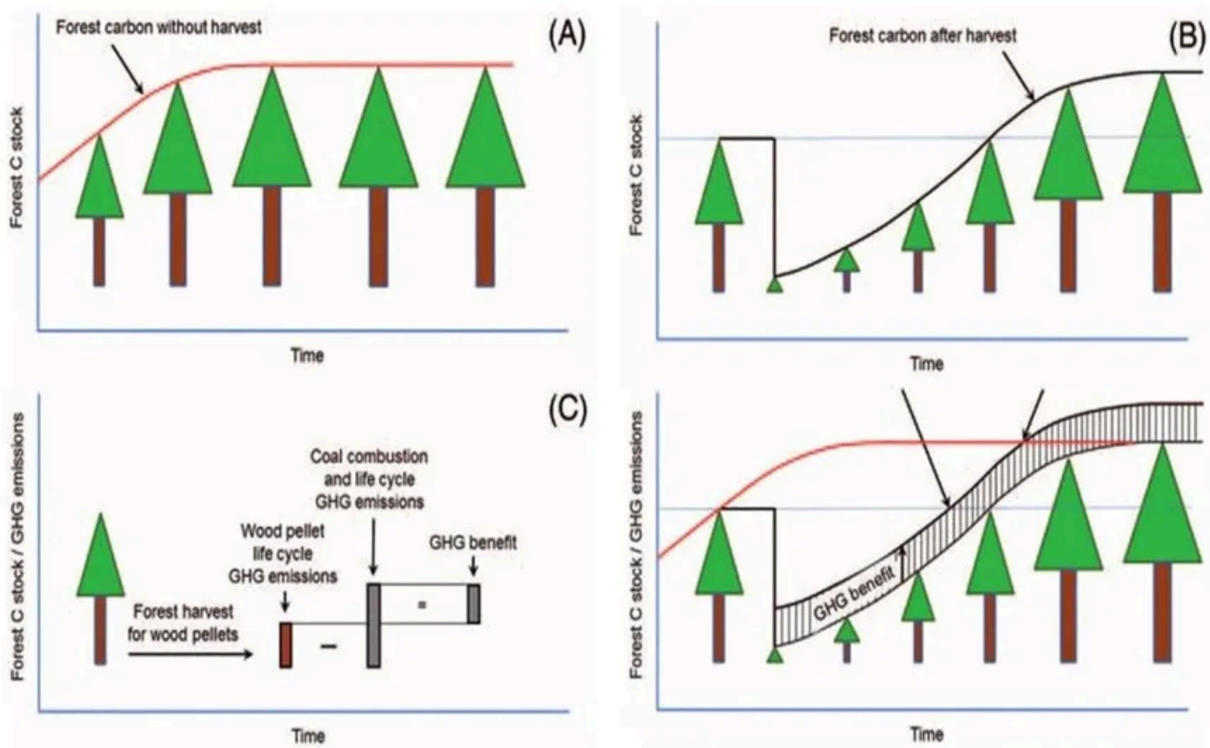
The challenge with using living forests as a carbon offset is that the carbon is temporarily locked up. Most trees have life spans of less than 100 years, either because the species is short lived or due to forest management. Carbon is gained and lost on a regular cycle, as trees grow, die, decompose, and grow back again. Because of this, the carbon accounting in living biomass is really the quantification of total carbon "gains versus losses" within the project area over time. Forest management activities help carbon gains persist into the future, by maintaining a certain amount of woody biomass above a prescribed baseline. Unfortunately, forests are also vulnerable to unplanned disturbance (e.g., wildfire) which can reverse the carbon storage benefits. This is why forests are sometimes considered a leaky reservoir for carbon. Moving forest carbon into certain kinds of wood products can help slow down the leak by extending the carbon storage time.

Harvesting and Carbon Accounting

Working forests are an important source of sustainable wood products, which means that they are occasionally harvested. Currently, there is more wood grown than harvested in the US (i.e., tons of living woody biomass). Between 1990 and 2016 up to 15% of US greenhouse gas emissions were offset due to voluntary and unintentional slowdowns in harvesting on public and private lands. When harvesting does occur, the impact on forest carbon often depends on the type of harvesting that is being conducted.

Clear cutting a forest resets carbon storage in the living above ground biomass to almost zero. Vegetation and woody debris may still have carbon, but this is typically not included in some carbon offset projects. Clear cutting is an uncommon management practice on family forest lands in the US except when the forest is a planted stand, the species being managed (e.g., white pine) benefits from clear cut treatments, or the owners want to clear the land for other uses. Forest lands that are cleared and converted to other uses typically become a permanent carbon source. Forests that are cleared, but new trees grow back, are considered a temporary carbon source. That land eventually becomes a carbon sink again when the new forest exceeds the age of the original forest.

A study published in the Journal of Forestry shows that wood products, such as biofuels, can help working forests restore important climate benefits at a faster rate after harvesting. In this example, the climate benefits provided by biofuels are included in the carbon accounting. Figure 2 shows an increase in forest carbon stocks over time (panel A), but carbon stocks decrease temporarily when the stand is harvested (Panel B). If the wood from the harvest is used to make biofuel or wood pellets, a portion of greenhouse gas (i.e., GHG) emissions can be offset by displacing the use of fossil fuels (Panel C). The benefits of displacing use of fossil fuels allows the carbon debt from the harvest to be repaid sooner (Panel D).



(https://extension.psu.edu/media/wysiwyg//extensions/catalog_product/aff1a6878ab541368e1ffbde880e1be0/c/a/carbonbiofuelandharvest2-jp.jpg)
Figure 2. Carbon accounting in a forest when wood pellets (i.e., bioenergy) are included in the carbon life cycle analysis.

Selection harvesting methods, or partial cuttings, are generally more common in natural forests on family forest lands. This is when only certain trees are harvested. Sometimes the trees are selected for their commercial value, and sometimes to help improve stand health and wildlife habitat. The harvested trees are eventually replaced through planting or natural tree regeneration. If done correctly, species composition and tree age classes remain relatively the same, and the volume of carbon remains relatively stable over time. Reducing or delaying a selection harvest allows the average age of the forest to increase, thereby increasing the total amount of live woody biomass and carbon stored.

Annual Rates and Carbon Accounting

In a carbon offset project, total carbon gains and losses within a designated area are quantified in order to generate an offset. However, calculating an average rate of carbon gains for different types of forests can be useful for planning and making predictions about the value of a project. The average annual rate of carbon sequestration for the slash pine forest in Figure 1 can be calculated by dividing the total amount of carbon stored by total number of years. This is illustrated in the following equation,

100,000 pounds carbon per acre ÷ 45 years = 2,222 pounds of carbon per acre per year.

In other words, a carbon project that includes slash pine forests will sequester an average of 2,222 pounds of carbon per acre per year.

The economic value of additional carbon storage is based on how much greenhouse gas emissions are avoided by preventing carbon from entering the atmosphere. When forest carbon is released through decomposition it binds with oxygen molecules to form carbon dioxide (CO_2), a common greenhouse gas. Carbon dioxide has about 3.6667 times the atomic weight of carbon alone. So, when converting forest carbon into atmospheric CO_2, use the following equation,

2,222 pounds of forest carbon × 3.6667 = 8,147 pounds of CO_2 emissions avoided

A carbon credit sold in a market is typically traded using metric tons. Converting pounds of emissions avoided to metric tons can be done using the following equation,

8,147 pounds of CO_2 × 0.000453592 = 3.69 metric tons of CO_2 emissions avoided

In this final equation, it is determined that on average one acre of slash pine forest offsets about 3.69 metric tons of CO_2 emissions per year. In reality, there can be a lot of variation from site to site due to differences in stand age, site quality, silvicultural management, and planting density. To estimate total carbon gains and losses at the site level one would first need to determine the total amount of woody biomass per acre, as the baseline, and then track changes in the amount of woody biomass resulting from changes in forest management.

Closing Thoughts

- The total value of a forest is greater than its carbon storage benefits. For example, trees located near surface waters help protect stream health by controlling water temperatures and stream side erosion. Forests in urban areas help provide recreational benefits and provide corridors for wildlife to pass through. Working forests provide wood products that help displace the use of other more fossil fuels intensive products (e.g., plastics, concrete). The sustainable management of forests under climate change requires that all the values associated with that particular forest also be taken into consideration.
- The slash pine illustration in this article is an example of a tree species that is highly efficient at storing carbon because it is a densely planted fast-growing species. In reality, most forests in the US are not as efficient and offset about 1 to 2 tons of CO_2 emissions per acre per year. This is because over the landscape forests differ in tree species, age classes, stand density, and silvicultural management. You can learn more about the average rate of carbon sequestration in different tree species and in your state by checking out the links below.

This article was produced by the Forest Owner Carbon and Climate Education (FOCCE) program(https://sites.psu.edu/focce/). What do you think? Please take this short survey.(https://pennstate.qualtrics.com/jfe/form/SV_3QPSh3PvOisHwmW)

Related FOCCE Articles and Resources

- How to Manage Forests for Carbon (https://extension.psu.edu/how-to-manage-forests-for-carbon-an-introduction-for-family-forest-owners)
- Conversions Commonly Used When Comparing Timber and Carbon Values (https://extension.psu.edu/conversions-commonly-used-when-comparing-timber-and-carbon-values)

- The Economic Value of Private Forests and Climate Change Mitigation (https://extension.psu.edu/the-economic-value-of-private-forests-and-climate-change-mitigation)
- Carbon calculator for Loblolly Pines (https://docs.google.com/spreadsheets/d/1EWTjcqnzFVILLAqGsD3qs7ovUg-Vwido/edit#gid=287994003) and Guidebook (https://drive.google.com/file/d/1Bl3is0rBad8zLAhx-QJy98VkCTL0XKPX/view).
- Quick Estimates of Carbon in Loblolly Pine Plantations Using Carbon-Basal Area Ratios (https://extension.msstate.edu/publications/quick-estimates-carbon-loblolly-pine-plantations-using-carbon-basal-area-ratios)

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Conversions Commonly Used When Comparing Timber and Carbon Values

This article will describe how to convert timber and carbon values from one unit to another. Content provided by the Forest Owner Carbon and Climate Education (FOCCE) program.

Updated: January 31, 2023

Stacked pile of cut logs. Photo credit: Calvin Norman

Introduction

You may be wondering why some measurements for forest carbon are based on units used for merchantable or harvested wood. In a delay-harvest scheme, only the timber most likely to be harvested is included in the carbon accounting. This ensures that delaying harvest results in additional carbon storage or a change from the "business as usual" outcome.

If you decide to delay a timber harvest, then you may want to be compensated for forgoing expected timber revenues for a short time. For the choice to be economically efficient you would need to compare the value of the timber "today" with the value of the carbon and the timber "tomorrow". The following conversions will help you keep track of the units describing carbon and timber values.

Conversions for Conventional Forestry Measurements

Foresters traditionally used measurements such as cords or thousand board feet (mbf) to describe the volume of harvested wood. Today foresters are more likely to use English units such as cubic feet (a volume measure) and tons to quantify wood. Tons and cubic feet are also useful for converting to metric units and calculating the amount of carbon in wood.

A typical rule of thumb for converting a cord of softwood logs (e.g., pine species) to tons and pounds (lb.) is as follows:

1 cord = 2.68 tons = 5,360 lb.

A typical rule of thumb for converting a cord of hardwood logs (e.g., oak or maple species) to tons and lb. is as follows:

1 cord = 2.90 tons = 5,800 lb.

Why are there more tons in a cord of hardwoods than softwoods? The reason for this is the specific gravity of wood. Specific gravity is the measure of a wood's density in comparison to water. If wood were the same density as water, the specific gravity would be 1.00.

This is an important consideration since tree species with different specific gravity (along with tree size) will have different amounts of carbon for the same volume. Pines and other softwoods store less above-ground carbon per unit of volume compared to hardwoods like oak, hickory, and beech, which store more carbon per unit of volume. Regardless of the species, the amount of carbon stored will always increase as tree size increases.

Greenwood Weight and Carbon

The term "green" is wood that has been recently cut and therefore has not had an opportunity to dry out. Typically, the weight of wood is reduced by half when dried in a kiln. Kiln drying of wood is simply the process of removing moisture from the wood. This means that if a slash pine tree that weighs 989.2 lb. (wood and bark) was cut down and dried, it would only weigh 437.8 lb.

After estimating a dry weight, most foresters use another convention that assumes that 50% of the wood's dry weight is solid carbon. This means the 437.8 lb. of dried out slash pine wood is expected to contain approximately 218.9 lb. of carbon. While the 50% rule for drying works very well for softwood species, it can undervalue hardwoods species since the wood is denser.

Converting Carbon to Carbon Dioxide

Forest carbon remains in a somewhat solid form until disturbed by decomposition or combustion. When oxygen is added the carbon transforms into carbon dioxide (CO_2), which acts as a greenhouse gas in the atmosphere. If a forest owner wants credit for carbon storage, it is important to know how much CO_2 is being prevented from entering the atmosphere by delaying harvest.

Carbon has an atomic weight of about 12, and the two oxygens each have an atomic weight of about 16. Adding the weights together (12 + 16 + 16) results in a total atomic weight of 44. In other words, CO_2 has about 3.667 times the atomic weight of carbon alone. So, when making this conversion, 1 unit of carbon equals 3.667 units of CO_2. In the example for a slash pine tree, the storage of 218.9 pounds of carbon equals 802.7 pounds of CO_2 being prevented from entering the atmosphere.

Converting Carbon Dioxide to Carbon Credits

Carbon credits are sold in metric tons of CO_2 emissions avoided from entering the atmosphere. If you are working with lb. (pounds), it must be converted to metric tons in order to calculate prices and conduct trading. Keep in mind that an English ton is slightly less than a metric ton. One metric ton of CO_2 emissions avoided for 100 years is generally equal to one carbon credit.

Innovation in carbon trading schemes have led to some alternative mechanisms for carbon accounting. For example, a harvest deferral credit (HDC) is generated by the forest owner and represents a certain amount of carbon emissions that have been temporarily reduced by delaying harvest for one year. The Verra registry recently determined a one-year HDC provides about 1% of the climate mitigation benefits compared to a verified carbon credit.

Putting it Together

Below are a few examples of how to convert a predicted amount of additional woody biomass into CO_2 emissions avoided can be found in Table 1. Keep in mind that all conversions need to consider: (1) the transfer of values from English to metric units, (2) whether or not the wood is dry, and (3) the final carbon value represents avoided emissions of CO_2.

Table 1. Units commonly used in forestry for use in carbon accounting.

	Cubic feet (ft^3)	Cubic meters (m^3)	Wood wet (lb.)	Wood wet (English ton)	Wood dry (English ton)	Wood dry (metric ton)	Carbon (metric ton)	CO_2 (metric ton)
a. One cord of green stacked pine logs, with space for air and bark	128	3.62	5,360	2.68	1.34	1.20	0.60	2.20
b. One cord of green stacked pine logs, with the space for air and bark removed	90	2.54	5,360	2.68	1.34	1.20	0.60	2.20
c. 2,000 lb. of green pine wood and bark	29	0.822	2,000	1	0.50	0.45	0.22	0.81
d. 2,000 lb. of green mixed hardwood, wood, and bark	28	0.787	2,000	1	0.60	0.54	0.27	0.99

In scenarios (a) and (b) the cubic foot volume of wood is slightly different because one scenario includes the space between the logs and the other does not. This doesn't affect the weight, they are both 5,360 lb., but if you intend to calculate weight based on cubic feet, you need to account for the gaps between logs (solid weight).

Since we know the weight of a green pine cord in pounds, we can calculate the number of tons by dividing 5,360 lb. with 2,000 lb. (the weight of one English ton), to arrive at 2.68 tons. Green wood weighs about twice as much as kiln dried wood, so to calculate the dry weight, the green value is then divided by 2 to arrive at 1.34 tons of dry wood.

The English ton (2,000 lb.) is somewhat less than a metric ton (2,205 lb.). To convert from English to metric units, 1.34 tons is multiplied by 0.90 to get 1.20 tons. To estimate carbon, the total weight of the dry wood is divided in half, so that 1.20 tons of dry wood is estimated to have 0.60 tons of carbon. Finally, to determine how much the carbon stored represents avoided CO_2 emissions, the carbon value is multiplied by 3.67 (the atomic weight of CO_2) to get 2.20 tons of CO_2 avoided.

Moving on to scenarios (c) and (d), we understand the weight in one short green ton is always 2,000 lb. The cubic foot volume of wood in these scenarios is slightly different, however, because one contains pine species and the other contains mixed hardwood species.

The dry weight of the pine is expected to be about 50% of the green weight. However, the dry weight of hardwoods is a little more, with the wood sometimes representing 60% of the green weight and water presenting 40% of the green weight.

To convert from English to metric units, the ton value is multiplied by 0.90 to get 0.45 and 0.54 tons, respectively. The amount of carbon in dry wood is assumed to be half the weight of dry wood, at 0.22 and 0.27 tons, respectively. These values are then multiplied by 3.67 (the atomic weight of CO_2) to get 0.81 and 0.99 tons of CO_2 respectively. Notice that one ton of green hardwood can sometimes equal almost one ton of CO_2 emissions avoided.

Closing Thoughts

- Delaying harvest means a delay in payments for timber. Moreover, payments for forest carbon only occurs after the carbon is sequestered. So, taking part in a carbon program means a real change in expected income. Since money is more valuable today than in the future, it is necessary to use discounting to "bring back" potential revenues from the future and compare them with other options today using the same baseline. Be sure to read FOCCE article "Long-Term Financial Planning for Timber and Carbon".
- The CO_2 emissions avoided represents only part of the value of a carbon credit sold in a carbon market. The price of a carbon credit also depends on guarantees that the offset will be permanent (100+ years) and will not result in leakage (i.e., cause harvests in other regions to increase). Forest owners may find carbon payments tend to be higher for projects with longer contracts.

This article was produced by the Forest Owner Carbon and Climate Education (FOCCE) program(https://sites.psu.edu/focce/). What do you think? Please take this short survey.(https://pennstate.qualtrics.com/jfe/form/SV_eeRLPFlBFtYJhem)

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- Carbon Accounting in Forest Management(https://extension.psu.edu/carbon-accounting-in-forest-management)
- Forest Carbon Pools(https://extension.psu.edu/forest-carbon-pools-where-are-they)
- How Much Should I be Paid to Manage Forest Carbon? (https://extension.psu.edu/how-much-should-i-be-paid-to-manage-forest-carbon)
- Long-Term Financial Planning for Timber and Carbon(https://extension.psu.edu/long-term-financial-planning-for-timber-and-carbon)

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Genus	Species	Common	Basic SG	SG @ 12%	Moisture Content, %*					Weight of one cubic meter, in kilograms				Weight of one cubic foot, in pounds			
					Heartwood	Sapwood	Average	Range Low	Range High	12% MC	Average Green	Low Green	High Green	12% MC	Average Green	Low Green	High Green
		Hardwoods															
Acer	saccharinum	Maple, Silver	0.44	0.47	58	97	78	71	84	470	781	752	810	29	49	47	51
Acer	saccharum	Maple, Sugar	0.56	0.63	65	72	69	67	70	630	944	937	950	39	59	58	59
Betula	papyrifera	Birch, Paper	0.48	0.55	89	72	81	78	83	550	866	853	880	34	54	53	55
Betula	lenta	Birch, Sweet	0.6	0.65	75	70	73	72	73	650	1035	1030	1040	41	65	64	65
Betula	alleghaniensis	Birch, Yellow	0.55	0.62	74	72	73	73	73	620	952	950	953	39	59	59	60
Carya	cordiformis	Hickory, Bitternut	0.6	0.66	80	54	67	63	71	660	1002	976	1028	41	63	61	64
Carya	tomentosa	Hickory, Mockernut	0.64	0.72	70	52	61	58	64	720	1030	1011	1050	45	64	63	66
Carya	glabra	Hickory, Pignut	0.66	0.75	71	49	60	56	64	750	1056	1032	1080	47	66	64	67
Carya	ovalis	Hickory, Red	0.62	0.68	69	52	61	58	63	680	995	978	1013	42	62	61	63
Carya	pallida	Hickory, Sand	0.62	0.68	68	50	59	56	62	680	986	967	1004	42	62	60	63
Carya	aquatica	Hickory, Water	0.61	0.62	97	62	80	74	85	620	1095	1059	1131	39	68	66	71
Celtis	occidentalis	Hackberry	0.49	0.53	61	65	63	62	64	530	799	795	802	33	50	50	50
Fagus	grandifolia	Beech, American	0.56	0.64	55	72	64	61	66	640	916	900	931	40	57	56	58
Fraxinus	americana	Ash, White	0.55	0.6	46	44	45	45	45	600	798	796	799	37	50	50	50
Juglans	nigra	Walnut, Black	0.51	0.55	90	73	82	79	84	550	926	911	940	34	58	57	59
Liquidambar	styraciflua	Sweetgum	0.46	0.52	79	137	108	98	118	520	957	912	1001	32	60	57	63
Liriodendron	tulipifera	Yellow-poplar	0.4	0.42	83	106	95	91	98	420	778	763	793	26	49	48	50
Magnolia	grandiflora	Magnolia, Southern	0.46	0.5	80	104	92	88	96	500	883	865	902	31	55	54	56
Malus	sylvestris	Apple	0.61	0.67	81	74	78	76	79	670	1083	1076	1090	42	68	67	68
Nyssa	sylvatica	Tupelo, Black	0.46	0.5	87	115	101	96	106	500	925	903	946	31	58	56	59
Nyssa	biflora	Tupelo, Swamp	0.46	0.5	101	108	105	103	106	500	941	935	946	31	59	58	59
Nyssa	aquatica	Tupelo, Water	0.46	0.5	150	116	133	127	139	500	1072	1046	1098	31	67	65	69
Platanus	occidentalis	Sycamore, American	0.46	0.49	114	130	122	119	125	490	1021	1009	1033	31	64	63	65
Populus	tremuloides	Aspen, Quaking	0.35	0.38	95	113	104	101	107	380	714	704	725	24	45	44	45
Populus	deltoides	Cottonwood, Eastern	0.37	0.4	162	146	154	151	157	400	940	930	950	25	59	58	59
Quercus	kelloggii	Oak, California Black	0.56	0.61	76	75	76	75	76	610	983	982	984	38	61	61	61
Quercus	rubra	Oak, Northern Red	0.56	0.63	80	69	75	73	76	630	977	967	987	39	61	60	62
Quercus	falcata	Oak, Southern Red	0.52	0.59	83	75	79	78	80	590	931	924	938	37	58	58	59
Quercus	nigra	Oak, Water	0.56	0.63	81	81	81	81	81	630	1014	1014	1014	39	63	63	63
Quercus	alba	Oak, White	0.6	0.68	64	78	71	69	73	680	1026	1012	1040	42	64	63	65
Quercus	phellos	Oak, Willow	0.56	0.69	82	74	78	77	79	690	997	989	1004	43	62	62	63
Tilia	americana	Basswood, American	0.32	0.37	81	133	107	98	116	370	662	635	690	23	41	40	43
Ulmus	americana	Elm, American	0.46	0.5	95	92	94	93	94	500	890	888	892	31	56	55	56
Ulmus	crassifolia	Elm, Cedar	0.59	0.64	66	61	64	63	64	640	965	960	970	40	60	60	61
Ulmus	thomasii	Elm, Rock	0.57	0.63	44	57	51	48	53	630	858	846	870	39	54	53	54
		Average	**0.52**	**0.58**	**81**	**83**	**82**			**577**	**937**	**923**	**951**	**36**	**58**	**58**	**59**
		Softwoods															
Abies	balsamii	Fir, Balsam	0.33	0.35	88	173	131	116	145	350	761	714	807	22	47	45	50
Abies	grandis	Fir, Grand	0.35	0.37	91	136	114	106	121	370	747	721	774	23	47	45	48
Abies	procera	Fir, Noble	0.37	0.39	34	115	75	61	88	390	646	596	696	24	40	37	43
Abies	amabilis	Fir, Pacific Silver	0.4	0.43	55	164	110	91	128	430	838	765	911	27	52	48	57
Abies	concolor	Fir, White	0.37	0.39	98	160	129	119	139	390	847	809	886	24	53	51	55
Calocedrus	decurrens	Cedar, Incense	0.35	0.37	40	213	127	98	155	370	793	692	894	23	49	43	56
Chamaecyparis	lawsoniana	Cedar, Port Orford	0.39	0.43	50	98	74	66	82	430	679	647	710	27	42	40	44
Cupressus	nootkatensis	Cedar, Yellow	0.42	0.44	32	166	99	77	121	440	836	742	930	27	52	46	58
Juniperus	virginiana	Cedar, Eastern red	0.44	0.47	37	115	76	63	89	470	774	717	832	29	48	45	52
Larix	occidentalis	Larch, Western	0.48	0.52	54	119	87	76	97	520	895	843	947	32	56	53	59
Picea	mariana	Spruce, Black	0.41	0.42	52	113	83	72	93	420	748	707	790	26	47	44	49
Picea	engelmannii	Spruce, Engelmann	0.33	0.35	51	173	112	92	132	350	700	633	767	22	44	39	48
Picea	sitchensis	Spruce, Sitka	0.37	0.4	41	142	92	75	108	400	709	646	771	25	44	40	48
Pinus	strobus	Pine, Eastern White	0.34	0.35	98	219	159	138	179	350	879	810	947	22	55	51	59
Pinus	taeda	Pine, Loblolly	0.47	0.51	33	110	72	59	84	510	806	746	866	32	50	47	54
Pinus	contorta	Pine, Lodgepole	0.38	0.41	41	120	81	67	94	410	686	636	736	26	43	40	46
Pinus	palustris	Pine, Longleaf	0.54	0.59	31	106	69	56	81	590	910	842	977	37	57	53	61
Pinus	ponderosa	Pine, Ponderosa	0.38	0.4	40	148	94	76	112	400	737	669	806	25	46	42	50
Pinus	resinosa	Pine, Red	0.41	0.46	32	134	83	66	100	460	750	681	820	29	47	42	51
Pinus	echinata	Pine, Shortleaf	0.47	0.51	32	122	77	62	92	510	832	761	902	32	52	48	56
Pinus	lambertiana	Pine, Sugar	0.34	0.36	98	219	159	138	179	360	879	810	947	22	55	51	59
Pinus	monticola	Pine, Western White	0.36	0.48	62	148	105	91	119	480	738	686	790	30	46	43	49
Pseudotsuga	menziesii	Douglas-fir, Coastal	0.45	0.48	37	115	76	63	89	480	792	734	851	30	49	46	53
Sequoia	sempervirens	Redwood, Old Growth	0.38	0.4	86	210	148	127	169	400	942	864	1021	25	59	54	64
Taxodium	distichum	Baldcypress	0.42	0.46	121	171	146	138	154	460	1033	998	1068	29	65	62	67
Thuja	plicata	Cedar, Western Red	0.31	0.32	58	249	154	122	185	320	786	687	885	20	49	43	55
Tsuga	canadensis	Hemlock, Eastern	0.38	0.4	97	119	108	104	112	400	790	776	804	25	49	48	50
Tsuga	heterophylla	Hemlock, Western	0.42	0.45	85	170	128	113	142	450	956	896	1015	28	60	56	63
		Average	**0.40**	**0.43**	**60**	**152**	**106**			**425**	**803**	**744**	**862**	**27**	**50**	**46**	**54**

Table 1. Specific gravity, green moisture content, and weight of selected North American wood species.

* Green heartwood and sapwood moisture content data taken from Table 4-1, 2010 Edition of the Wood Handbook.

Modular/Mobile Wood Processing Technologies

The list below are examples of currently available technologies for processing forest biomass on a modular/mobile scale. They are representative of technologies and are not to be considered as endorsement of particular manufacturers or being vetted.

The target audience of this document are communities, Resource Conservation Districts, Fire Safe Councils, land managers, and other entities that are looking for options to utilize their forest management residue, short of building a stationary bioenergy plant that takes many years to finance and build. For land managers who are implementing forest management activities in remote areas, away from major roads, or on small tracts of land, large investments in fixed assets are impractical as well as infeasible due to limited access to markets for potential products. With no revenue to balance expenses, the common practice is often to pile and burn residuals as the least cost option.

The purpose of this document is to provide an overview for a range of processing equipment currently available to convert woody biomass on-site into a variety of products instead of just burning it. "Range" in this context generally encompasses purchase price, equipment size, feedstock consumption and sizing, as well as variety of products.

Each project site has specific circumstances, including but not limited to availability, accessibility, quality, and volume of feedstock, proximity to demand centers for products, operating and maintenance constraints, as well as financial capabilities. The modular and mobile equipment listed here can provide opportunities to evaluate distributed, scalable and/or temporary use cases for forest biomass while at the same time mitigating the risk of large stranded assets. These technologies may also provide opportunities for communities to utilize wood waste while determining the scope and scale of potential stationary facilities.

The information in this document can only inform a part of the due diligence process necessary prior to any project implementation. As such, it describes available conversion technologies in general. However, locally specific factors such as economic analysis; sustainability analysis; air quality impacts; code compliance; impacts on soils; impacts on wildfire reduction/forest productivity; necessary permitting; markets for products, etc. are beyond its scope.

While this list is rather comprehensive as of fall 2020, it is neither static nor final. As technologies continue to evolve and management objectives as well as markets change, we consider this to be a living document that should be revised annually.

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Contents

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Waste Reduction

Roll-off FireBox	Air Burners
Pollution control device for open burning of clean wood waste (air curtain burner, incinerator).	
Landing size	Less than 1/8 acre for machine, 1 to 4 acres for feedstock pile.
Equipment footprint	S116R = 7' x 25'; S119R = 7' x 28'
Utilities req'd on site	None, diesel powered
Air permit req'd?	Yes - Title V Operating Permit (40 CFR part 70)
Emissions	Lowest Particulate Matter possible (<1 lb/ton). Air Burners are ACB tested and certified by the US EPA. Certified testing data for Air Burners machines is available for customer permit support.
Ground disturbance	No heat impact, Roll-Off units have a floor
Transportation (Equipment)	Roll-off container truck, the FireBox meets ANSI spec for Cable Hoist or "J" Hook type trucks.
Transportation (Product)	If biochar is produced, it can be transported by small truck.
In use in California?	Yes
Spec sheet	S-116R, S-119R
Pricing (Equipment)	$110,000 - $122,000
Pricing (Product)	Biochar is sold from approximately $100 to $140/cubic yard.
Operating Costs	$6.00/hour + labor
Material/Feedstock quality	Clean wood waste, stumps, trees, (incl partially burned), slash, tumbleweeds and C&D wood waste.
Material/Feedstock sizing	Up to 18' in length, no dense material like chips or sawdust
Sorting required?	No sorting, grinding, chipping or any preprocessing required
Preferred moisture content	Not an issue
Consumption rate	2 to 5 tons/hour
Production rate	Biochar (if collected) approximately 10 cubic yards/day
Comments	

FireBox	Air Burners
Pollution control device for open burning of clean wood waste (air curtain burner, incinerator).	
Landing size	Less than 1/8 acre for machine, 1 to 4 acres for feedstock pile.
Equipment footprint	Smallest 7' x 24'; largest 12' x 41'
Utilities req'd on site	No utilities for diesel powered. For electrical drive 480V, 3PH
Air permit req'd?	Yes - Title V Operating Permit (40 CFR part 70)
Emissions	Lowest Particulate Matter possible (<1 lb/ton). Air Burners are ACB tested and certified by the US EPA. Certified testing data for Air Burners machines is available for customer permit support.
Ground disturbance	No heat impact with optional floor or 4" depth w/o floor.
Transportation (Equipment)	Transport off-site with any flat deck trailer or lowboy type trailer. Reposition on-site by dragging, all FireBoxes are "skid" based.
Transportation (Product)	Carbon ash and Biochar is returned to the soil around the machine or collected and sold.
In use in California?	Yes, by CalParks, CAL FIRE, municipalities, growers, and National Parks.
Spec sheet	FireBox Spec Sheet
Pricing (Equipment)	$99,000 - $168,000
Pricing (Product)	Biochar is sold from approximately $100 to $140 per cubic yard.
Operating Costs	$6.00/hour to $7.50/hour + labor
Material/Feedstock quality	Clean wood waste, stumps, trees, (incl partially burned), slash, tumbleweeds, and C&D wood waste.
Material/Feedstock sizing	Up to 29' in length, no chips or sawdust.
Sorting required?	No sorting, grinding, chipping or any preprocessing required
Preferred moisture content	Not an issue
Consumption rate	4 to 13 tons/hour
Production rate	Biochar (if collected) approximately 10 -15 cubic yards/day
Comments	This technology is designed to reduce one of the most damaging climate forcers, "Particulate Matter." The International Panel on Climate Change (IPCC) ranks PM (also called Black Carbon) as the number 2 most significant climate forcer. Air Burners machines have been well proven to significantly reduce or eliminate PM with the added economic benefit of burning very fast.

BurnBoss®	Air Burners
Pollution control device for open burning of clean wood waste (air curtain burner, incinerator).	
Landing size	Machine and one day's feedstock pile, approximately 1/4 acre.
Equipment footprint	8' x 20'
Utilities req'd on site	None, diesel powered.
Air permit req'd?	Yes - Title V Operating Permit (40 CFR part 70)
Emissions	Lowest Particulate Matter possible (<1 lb/ton). Air Burners are ACB tested and certified by the US EPA. Certified testing data for Air Burners machines is available for customer permit support.
Ground disturbance	Heat impact less than 4" deep and 4' x 12'
Transportation (Equipment)	DOT approved trailer, towing with HD pick-up truck
Transportation (Product)	Ash and biochar is returned to the soil around the machine or collected and sold.
In use in California	Yes, BurnBoss® was originally designed for CAL FIRE. Currently used by CalParks, CAL FIRE, municipalities, growers, and National Parks.
Spec sheet	BurnBoss T24
Pricing (Equipment)	Approx. $53,000
Pricing (Product)	Biochar is sold from approximately $100 to $140 per cubic yard.
Operating Costs	$1.30 per hour + labor
Material/Feedstock quality	Clean wood waste, stumps, trees, (incl partially burned), slash, tumbleweeds, and C&D wood waste
Material/Feedstock sizing	Needs to fit in the 4' by 12' opening. No chips or sawdust.
Sorting required?	No sorting, grinding, chipping or any preprocessing required.
Preferred moisture content	Not an issue
Consumption rate	10 to 20 cubic yards/hour
Production rate	If biochar is collected, approximately 1 - 2 cubic yards/day.
Comments	A towable FireBox. Designed in cooperation with CAL FIRE and the US Forest Service, the BurnBoss brings the FireBox advantages to smaller jobs, in particular those supporting wildfire mitigation in the wildland urban interface.

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Baler

Biomass Baler	Forest Concepts
Slash compactor for more efficient transport, storage, and handling.	
Landing size	N/A
Equipment footprint	8’ x 22’
Utilities req’d on site	N/A
Air permit req’d?	Yes - Title V Operating Permit (40 CFR part 70)
Emissions	Model 2054 will be CARB compliant
Ground disturbance	N/A - Street legal trailer
Transportation (Equipment)	Towable with 1-ton truck
Transportation (Product)	Flatbed truck, trailer
In use in California	Yes (for demos)
Spec sheet	in development
Pricing (Equipment)	$100,000 - $175,000 depending on options
Pricing (Product)	N/A
Operating Costs	Depends on configuration and use
Material/Feedstock quality	Brush, slash, vegetation management trimmings
Material/Feedstock sizing	length <= 4′ , diameter <= 12″
Sorting required?	No
Preferred moisture content	Any
Consumption rate	N/A
Production rate	1 bale/hour, size: 32” x 48” x 64”, ~1,300 lbs each
Comments	

Biochar

Carbonator	Tigercat
Advanced wood debris conversion system to biochar (air curtain burner)	
Landing size	350' radius
Equipment footprint	40' x 11'-10"
Utilities req'd on site	Water supply (this can be provided by way of water truck)
Air permit req'd?	Yes - Title V Operating Permit (40 CFR part 70)
Emissions	Engine: EO# U-R-022-0218;
Ground disturbance	57 psi
Transportation (Equipment)	Lowboy trailer
Transportation (Product)	Steel container
In use in California	Yes
Spec sheet	6050 Carbonator
Pricing (Equipment)	~$700,000
Pricing (Product)	$
Operating Cost	~$20/ton
Material/Feedstock quality	clean logs, partially burned trees, limbs, brush, stumps and other wood based debris
Material/Feedstock sizing	max. 25' length
Sorting required?	Not required
Preferred moisture content	N/A
Consumption rate	15-20 tons/hour
Production rate	1,800 - 2,200 lbs biochar/hour
Biochar certification	
Comments	

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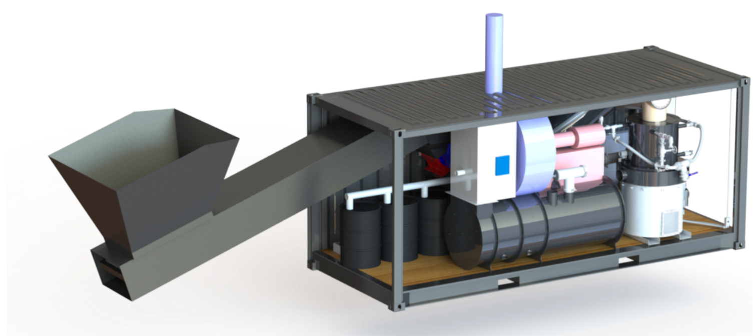
Chartainer	All Power Labs
Containerized combined Heat and Biochar (CHAB) pyrolyzer system (in development)	
Landing size	300 sqft
Equipment footprint	8' x 40'
Utilities req'd on site	No electricity required--works in a totally off-grid context
Air permit req'd?	No
Emissions	Third-party testing has been done, the results are being finalized. Wood gases are flared.
Ground disturbance	
Transportation (Equipment)	20' shipping container
Transportation (Product)	
In use in California	First deployment is Yosemite National Park, 2020
Spec sheet	Chartainer
Pricing (Equipment)	Beta units are $300k, final version will be $150/200k.
Pricing (Product)	Biochar can be sold in a Local Carbon Network scheme for ongoing revenue. See https://localcarbon.net/
Operating Cost	
Material/Feedstock quality	wood chips, nut shells, and other woody biomass (e.g. stone fruit pits).
Material/Feedstock sizing	1/8 inch - 2 1/2 inch
Sorting required?	Generally no. This is a fairly fuel-flexible machine if you have any standard chipper.
Preferred moisture content	<30%, generally none. This is a fairly fuel-flexible machine if a standard chipper is available.
Consumption rate	250 kg/hour
Production rate	500 kW thermal, 18%+ biochar yield by mass
Biochar certification	International Biochar Initiative (IBI)
Comments	

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ARTi Biochar	www.ARTi.com
Containerized biochar pyrolyzer system	
Landing size	600 square feet
Equipment footprint	40’ x 8’
Utilities req’d on site	200-600V (1 or 3 phase), 10GPM water supply, small propane 20lbs tanks, optional gen set or solar system
Air permit req’d?	Depends on location where equipment is deployed
Emissions	NOx, SOx, O2, PM, VOC, CO2, H2O, Analysis with Third-party testing for when it is required
Ground disturbance	Land leveling and concrete pad recommended
Transportation (Equipment)	Trailer, 40’ container
Transportation (Product)	Bulk Bags
In use in California	No
Spec sheet	Biochar Reactor (link), Biomass Dryer (link)
Pricing (Equipment)	1 Pyrolysis train Reactor and Dryer in a 40’ container $250K
Pricing (Product)	$250/ cubic yard of biochar (bulk)
Operating Cost per Ton of Biochar	Labor $50, Electricity 100KWh $15, to start: Propane 2lb $1, Internet $10
Material/Feedstock quality	Biomass waste: wood products: woodchips, pellets, sawdust, shavings, tree clearing residues; Crop residues: Corn husks and cobs, rice and oat hulls, hemp stocks; Manures, byproducts and sludges: chicken litter, bio-solids, DDG, cow fibers, horse bedding, etc. Restrictions apply.
Material/Feedstock sizing	<1 in particle size or we add grinder on the front end
Sorting required?	No. Magnetic separator and screener available for metals and big rocks if needed.
Preferred moisture content	less than 20%, more need to include the dryer
Consumption rate	10 to 50 tons per day of biomass depending on model
Production rate	2 to 10 tons per day of biochar, 5 to 50 MMBTU/Hr of thermal
Biochar certification	Started process, but not currently done
Comments	Excess Heat applications available. Handling equipment available: trough, transfer auger, super sacks filling equipment. Biochar Milling and Classifier available.

B-1000	[Biochar Solutions Inc.](#)
Containerized biochar pyrolyzer system	
Landing size	500 x 500 ft
Equipment footprint	50 ft x 50 ft
Utilities req'd on site	3 phase 30 Amps 480 Volts
Air permit req'd?	Site dependent – we have data
Emissions	Gas and PM data are available
Ground disturbance	Needs at minimum a dirt level pad
Transportation (Equipment)	1 or 2 flatbeds
Transportation (Product)	Bulk bag on a pallet
In use in California	Yes
Spec sheet	www.biocharsolutions.com
Pricing (Equipment)	$400,000
Pricing (Product)	$200/cubic yard
Operating Cost	1 unit of labor + power as stated + cap ex over 5 years (a model is available)
Material/Feedstock quality	Clean dry wood chip
Material/Feedstock sizing	0.50 – 4.0 in chip or grind
Sorting required?	Clean dry chip
Preferred moisture content	15%
Consumption rate	1 ton per hour inbound
Production rate	1-2 yard of char per hour and 3 to 6 MMBTU thermal
Biochar certification	IBI
Comments	Preferably placed in proximity to a heating load

Retort	Exeter Retort
Wood debris conversion system to biochar.	
Landing size	
Equipment footprint	~9’ x 5.5’ (with trailer: ~12.5’ x 7.2’)
Utilities req’d on site	None
Air permit req’d?	No
Emissions	During start-up similar to a small bonfire, then clean except for flame from the temperature control valve.
Ground disturbance	None
Transportation (Equipment)	Towed
Transportation (Product)	Bulk bagged or smaller bags
In use in California	No
Spec sheet	The Exeter
Pricing (Equipment)	~$18,000 - $22,300 (£14,350 GBP; £17,650 GBP with trailer).
Pricing (Product)	$ variable
Operating Cost	Labor cost/burn, some simple fettling required during lifetime.
Material/Feedstock quality	any solid woody biomass and animal bones
Material/Feedstock sizing	length <= 7′ , diameter <= 6″ , but diameter can exceed 6” if wood cut to shorter lengths. Split wood ideal.
Sorting required?	No
Preferred moisture content	<20%, but will process green wood
Consumption rate	~60 cu ft/day
Production rate	~30 cu ft/day biochar (assuming 50% conversion efficiency by volume)
Biochar certification	None
Comments	Flue-gas capturing under development (capture, cool, clean and store syngas for use in generator/CHP unit)

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Flame Cap Kiln	Custom
Low-tech wood debris conversion to biochar.	
Landing size	
Equipment footprint	92” x 70”
Utilities req’d on site	Water supply for quenching
Air permit req’d?	No
Emissions	Similar to a well-tended small bonfire
Ground disturbance	Heat
Transportation (Equipment)	Pick-up truck, utility trailer, 4 people
Transportation (Product)	Bulk bagged or smaller bags
In use in California	Yes
Spec sheet	
Pricing (Equipment)	~$1,200
Pricing (Product)	$ variable
Operating Cost	Variable
Material/Feedstock quality	Slash, tree and vineyard prunings, reed
Material/Feedstock sizing	length <= 4′ , diameter <= 4″
Sorting required?	Yes
Preferred moisture content	<20%
Consumption rate	11 cu yd/day
Production rate	2 cu yd/day (conversion efficiency ~15-22% by volume)
Biochar certification	None
Comments	

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Power/Heat Generation

PGFireBox®	Air Burners
Advanced wood debris conversion system to power/heat (air curtain burner, co-gen, CHP)	
Landing size	Less than ¼ acre for machine. 1 to 4 acres for brush pile.
Equipment footprint	Approx. 40' x 40' and Cooling 20' x 8'.
Utilities req'd on site	Grid connection, 480V 3PH
Air permit req'd?	Yes - Title V Operating Permit (40 CFR part 70)
Emissions	Lowest Particulate Matter possible (<1 lb/ton). Air Burners are ACB tested and certified by the US EPA. Certified testing data for Air Burners machines is available for customer permit support.
Ground disturbance	Heat impact 4" depth.
Transportation (Equipment)	Easily moved on three flatbed trucks. All three machines are road legal dimensions, no special road permits required. All accessories pack into the three units for transportation.
Transportation (Product)	Ash and biochar is returned to the soil around the machine or collected and sold.
In use in California	Yes, currently purchased by municipalities. The PGFireBox qualifies for landfill diversion credits. Agricultural and Forestry markets.
Spec sheet	PGFirebox® - 100kW, 500kW, 1,000kW
Pricing (Equipment)	Approx. $830,000 to $4,200,000
Pricing (Product)	$
Operating Cost	Labor. The machine generates power for itself and energy (thermal or electric) to sell plus the sale of waste elimination.
Material/Feedstock quality	Clean wood waste, stumps, trees, (incl. partially burned), slash, tumbleweeds, and C&D wood waste.
Material/Feedstock sizing	Up to 29' in length, no chips or sawdust.
Sorting required?	No sorting, grinding, chipping or any preprocessing required
Preferred moisture content	Not an issue
Consumption rate	7 to 13 tons/hour
Production rate	Biochar (if collected) approximately 10 - 15 cubic yards/day
Comments	This will revolutionize recycling, a portable system turning waste into power, allowing more finished products to come out of the forest and allowing large electrical machinery to run on batteries. Waste will be the fuel replacing diesel.

Power Pallet	All Power Labs
Advanced wood debris conversion system to power/heat (co-gen, CHP).	
Landing size	50 sqft
Equipment footprint	75” x 56”
Utilities req’d on site	Electrical hookup: utility grid, microgrid, or directly powering machinery/storage, etc.
Air permit req’d?	No
Emissions	Emissions profile available upon request, validated from third-party testing and permitted in California.
Ground disturbance	
Transportation (Equipment)	Pallet/Crate
Transportation (Product)	Wire, pipe
In use in California	Yes
Spec sheet	PP30
Pricing (Equipment)	$65,000
Pricing (Product)	Biochar, electricity, and heat can be negotiated as part of ongoing revenue in a Local Carbon Network scheme. See https://localcarbon.net/
Operating Cost	
Material/Feedstock quality	Woody biomass (wood chips, nut shells, stone fruit pits) with processing (chipping and some sorting)
Material/Feedstock sizing	1/2 inch – 1 1/2 inch (1 cm – 4 cm)
Sorting required?	Yes
Preferred moisture content	5% – 30%
Consumption rate	1.0 kg/kWh
Production rate	25 kW electric, 50 kW thermal, 5% yield biochar 50 kW electric, 100 kW thermal, 5% yield biochar
Biochar certification	International Biochar Initiative (IBI)
Comments	Machinery can be paired with an atmospheric water generator for water extraction from biomass or an adsorption chiller for combined cooling, heating, and power.

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Power Pallet Hybrid Container	All Power Labs
Modular power plant converting clean wood waste into on-site, on-demand electricity in a variety of configurations for both on, off-grid, and microgrid use.	
Landing size	650 sqft
Equipment footprint	23’ x 16’
Utilities req’d on site	Electrical hookup: utility grid, microgrid, directly powering machinery/storage, etc.
Air permit req’d?	
Emissions	Emissions profile available upon request, validated from third-party testing and permitted in California.
Ground disturbance	
Transportation (Equipment)	20’ shipping container
Transportation (Product)	Wire
In use in California	No
Spec sheet	PPHC130
Pricing (Equipment)	Finalized product will be ~$300k
Pricing (Product)	Electricity and heat can be negotiated as part of ongoing revenue in a Local Carbon Network scheme. See https://localcarbon.net/
Operating Cost	
Material/Feedstock quality	Woody biomass (wood chips, nut shells, stone fruit pits) with processing (chipping and some sorting)
Material/Feedstock sizing	1/2 inch - 1 1/2 inch (12-40 mm)
Sorting required?	Yes
Preferred moisture content	<80%
Consumption rate	250 kg/hour
Production rate	250 kW electric, 500 kW thermal.
Comments	Beta unit requiring further development.

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Syngas/Biochar/Bio-Oil Production

Containerized Pyrolysis Module	Biogreen
Thermochemical conversion through torrefaction, pyrolysis, or gasification processes to convert useful energies or resources from waste products.	
Landing size	
Equipment footprint	40’ x 8’
Utilities req’d on site	400V 3PH, 100 kW; water for char cooling: 4m3/hour
Air permit req’d?	No
Emissions	None
Ground disturbance	
Transportation (Equipment)	40ft shipping container
Transportation (Product)	Wire, barrel, bulk bagged
In use in California	No
Spec sheet	Biogreen CM 600
Pricing (Equipment)	>$1MM
Pricing (Product)	$ variable
Operating Cost	
Material/Feedstock quality	Wood chips, sawdust, nut shells, dry sludges, plastics, RDF/SRF (Refuse derived fuel/Solid recovered fuel), calorific fractions of municipal and industrial waste;
Material/Feedstock sizing	<=20mm
Sorting required?	
Preferred moisture content	10% - 20%
Consumption rate	Up to 16 tons/day
Production rate	Up to 4.8 tons/day biochar; up to 8 tons/day bio-oil; up to 10 MJ/m3, up to 450 kW (9 MWh/day) syngas
Biochar certification	None
Comments	

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Modular Gasification Unit	VGrid Energy
Thermochemical conversion through gasification process to electricity and biochar.	
Landing size	1,000 sq ft
Equipment footprint	9' x 29', 4' x 11'
Utilities req'd on site	Water for cooling, power grid access if net metering
Air permit req'd?	
Emissions	Meets San Joaquin Valley Air Pollution Reqs
Ground disturbance	Concrete slab or rock bed
Transportation (Equipment)	2 trailers; 1 gasifier + 1 genset
Transportation (Product)	Super sacks or drums
In use in California	Yes
Spec sheet	BioEnergy Server – Model 100
Pricing (Equipment)	$450,000
Pricing (Product)	variable
Operating Cost	3 people per 5 units
Material/Feedstock quality	Wood pellets, small wood chips, nut shells, other as reviewed
Material/Feedstock sizing	<=3/4 inch
Sorting required?	must remove small fines
Preferred moisture content	<20% or heat required to dry on input
Consumption rate	250 lbs/hour
Production rate	up to 35 lbs/hour, depending on feed rate
Biochar certification	Certified in CA for animal feed and soil amendment
Comments	

Solid Fuel

Pelleting line	EcoKraft
Sawdust to heating pellets	
Landing size	
Equipment footprint	~6' x 30'
Utilities req'd on site	Electricity (400V 3PH)
Air permit req'd?	No
Emissions	None
Ground disturbance	None
Transportation (Equipment)	Pallet/Crate
Transportation (Product)	supersacs, bins
In use in California	No
Spec sheet	PL1
Pricing (Equipment)	~$110,000
Pricing (Product)	$
Operating Cost	
Material/Feedstock quality	clean sawdust and shavings
Material/Feedstock sizing	<=6mm
Sorting required?	
Preferred moisture content	
Consumption rate	~ 400 lbs/hour
Production rate	~ 400 lbs/hour
Comments	

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Briquetter	RUF
Briquetting of wood shavings, sawdust, wood chips.	
Landing size	
Equipment footprint	Various; smallest 52” x 59”, largest 118” x 130”
Utilities req’d on site	Electricity (400V 3PH)
Air permit req’d?	No
Emissions	None
Ground disturbance	None
Transportation (Equipment)	
Transportation (Product)	
In use in California	Yes
Spec sheet	Wood and Biomass Briquetter
Pricing (Equipment)	$35,000 to $300,000
Pricing (Product)	
Operating Cost	Varies by machine and materials
Material/Feedstock quality	wood chips, saw dust
Material/Feedstock sizing	shavings, sawdust, chips
Sorting required?	No
Preferred moisture content	<15%
Consumption rate	various; smallest 120 lbs/hour, largest 3,300 lbs/hour
Production rate	various; smallest 120 lbs/hour, largest 3,300 lbs/hour
Comments	

Lumber

Portable sawmill	Wood-Mizer
Whole logs to cants and boards.	
Landing size	
Equipment footprint	
Utilities req'd on site	no
Air permit req'd?	
Emissions	
Ground disturbance	
Transportation (Equipment)	Trailer
Transportation (Product)	Trailer
In use in California	
Spec sheet	
Pricing (Equipment)	$3,000 to $16,000
Pricing (Product)	
Operating Cost	
Material/Feedstock quality	logs
Material/Feedstock sizing	
Sorting required?	
Preferred moisture content	
Consumption rate	
Production rate	
Comments	

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Erosion Control

WoodStraw® ECM	[Forest Concepts](#) [Mountain Pine Manufacturing](#)
Engineered wood strand erosion control mulch.	
Landing size	NA (bales may be delivered on pallets for staging)
Equipment footprint	NA
Utilities req'd on site	NA
Air permit req'd?	
Emissions	NA
Ground disturbance	NA
Transportation (Equipment)	NA
Transportation (Product)	Tarped flatbed truck or dry van like hay
In use in California	Yes
Spec sheet	www.woodstraw.com
Pricing (Equipment)	$ NA
Pricing (Product)	$ Volume dependent, call for pricing
Operating Cost	
Material/Feedstock quality	
Material/Feedstock sizing	
Sorting required?	
Preferred moisture content	
Consumption rate	
Production rate	
Comments	WoodStraw® bales are transported long distances by tarped flatbed trucks just like hay. Bales can be palletized to simplify loading, handling at work centers, and reloading. There are either 20 or 24 regular bales per pallet and three large bales per pallet. Regular bales are the same cross section as hay bales but shorter to keep the weight around 50 lbs to meet FS ergonomic standards. Large bales are around 800 lbs depending on moisture content.

Wood Shred	USDA Forest Service
Wood strand erosion control mulch.	
Landing size	
Equipment footprint	
Utilities req'd on site	
Air permit req'd?	
Emissions	
Ground disturbance	
Transportation (Equipment)	
Transportation (Product)	
In use in California	
Spec sheet	Wood Shred
Pricing (Equipment)	$
Pricing (Product)	$
Operating Cost	
Material/Feedstock quality	clean logs, partially burned trees
Material/Feedstock sizing	
Sorting required?	
Preferred moisture content	
Consumption rate (x per hour)	
Production rate (x per hour)	
Comments	