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8 Airport Road
Bethel, ME 04217, USA

A Future for Coal Fueled Power Stations!
How they can permanently remove CO_2 from the atmosphere and also produce electricity by using sustainably sourced wood pellet fuel in place of coal.

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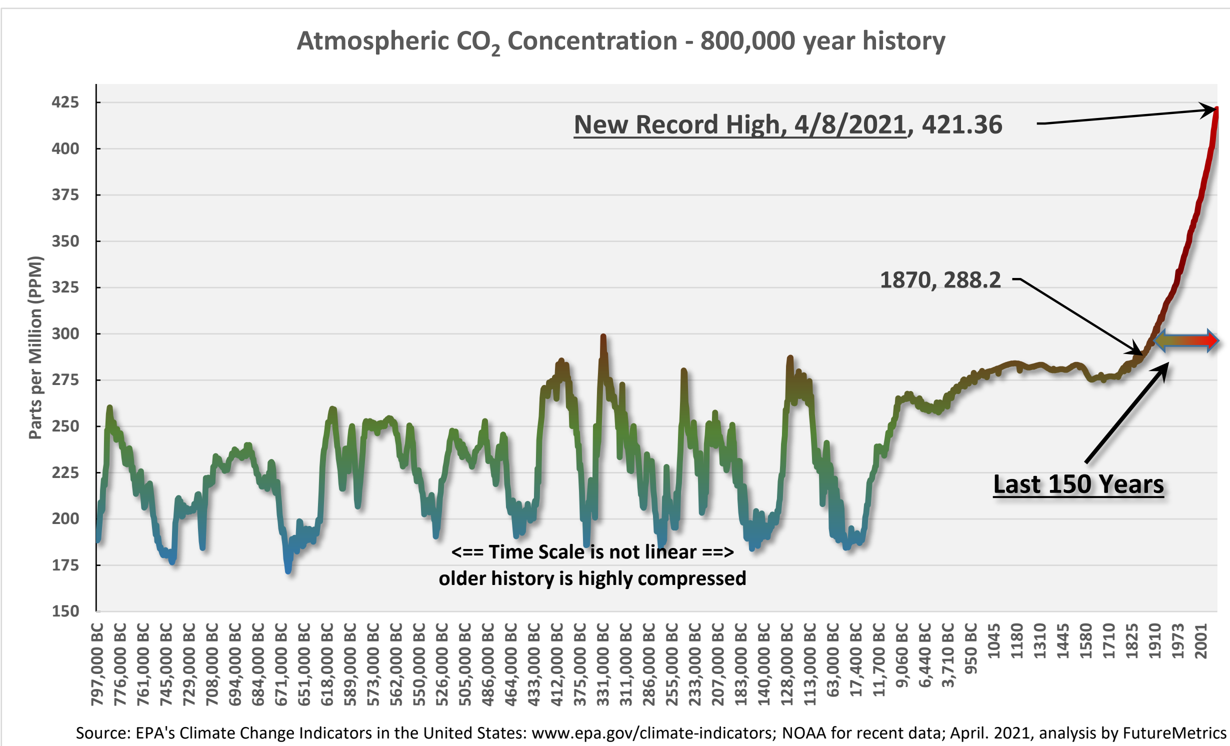
By William Strauss, PhD, MBA, President, FutureMetrics

Carbon capture and storage (CCS) used in conjunction with fossil fueled power generation is appealing. However, the best that CCS can achieve with fossil fuels is to approach CO_2 neutrality. That is, CCS from fossil fuels cycles carbon that has been sequestered over millions of years from out of the ground and then back into the ground. There is no net change in atmospheric CO_2 as a result.

But we can do better. Carbon neutral is good, carbon negative is much better.

And we have to do better. Long-lived CO_2 in the atmosphere will continue to force climate change for centuries[1]. At the current trajectory, it is clear that strategies that are carbon negative are needed.



[1] "Changes to our atmosphere associated with reactive gases (gases that undergo chemical reactions) like ozone and ozone-forming chemicals like nitrous oxides, are relatively short-lived. Carbon dioxide is a different animal, however. Once it's added to the atmosphere, it hangs around, for a *long* time: between 300 to 1,000 years. Thus, as humans change the atmosphere by emitting carbon dioxide, those changes will endure on the timescale of many human lives" NASA, Oct. 2019; HERE.

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This white paper will describe a new perspective on the purpose of utility scale pulverized coal (PC) power stations. An accompanying dashboard is also described in detail below.

If part of an effective strategy for mitigating climate change is to develop ways to optimally subtract CO_2 permanently from the atmosphere, then one of the most efficient and economical ways to achieve that goal is to repurpose selected PC power stations.

This is more efficient and economical than CCS from ambient air for two reasons.

First, in contrast to CCS from atmospheric air where CO_2 concentrations are in the parts per million range (400 ppm = 0.04%), post-combustion CCS is supplied with CO_2 levels in the range of 8% to 15%. That is 200 to 375 times more concentrated than ambient air. This results in higher CO_2 capture per unit of input energy[2].

Second, if the PC power station is modified to use sustainably produced pellet fuel[3], not only does the station serve as the supplier of concentrated CO_2 to the CCS module, but it is also a generator of baseload renewable power.

Think of the station's primary purpose as being a negative CO_2 pump with a by-product of grid-level constant and reliable electricity. This combination results in a highly cost-effective carbon-negative-plus-power solution. This is only possible with the use of upgraded solid fuel suitable for PC power stations made from renewing biomass: i.e., wood pellets[4].

From Start to Finish: How to Subtract CO_2 from the Atmosphere <u>and</u> Produce Baseload Power

The story begins with sustainably managed "working" forests. Working forests have been supplying raw materials to the forest products industry for more than a century. Modern silvicultural[5] practices result in the optimal health and growth rates of the entire forest ecosystem. These practices have evolved in part to make sure that the working forests can produce trees consistently for the industries that depend on them as

[2] "Current economic analysis estimates a cost of \$70–100/tonne of CO^2 for carbon capture from flue gas (Vitillo et al., 2017). With only 400 ppm Co2 in air, a DACC process requires a cost between \$300 and \$1,500 per tonne of Co2 captured (National Academies of Sciences, Engineering, and Medicine, 2019)". Frontiers in Energy Research, December, 2020; https://www.frontiersin.org/articles/10.3389/fenrg.2020.560849/pdf

[3] See a number of FutureMetrics white papers that describe why 23 million metric tonnes of pellets will be used in modified PC power stations in 2021 with, in most cases, no derating and no loss of reliability. https://www.futuremetrics.com/

[4] FutureMetrics has confidence that "version 2.0" of wood pellets will become the standard. Those are pellets that are water resistant, have higher bulk and energy density, create significantly less dust than traditional white pellets, and grind significantly better in the PC power stations pulvreizers with little or no modification required. See HERE for an example.

[5] https://en.wikipedia.org/wiki/Silviculture

their raw material. A corollary is that these managed forest systems are very efficient at converting CO_2 into carbohydrates.

Mills that use wood as a feedstock depend on a daily supply; essentially in perpetuity. Capital investments of hundreds of millions of dollars in sawmills, pulp and paper mills, engineered building product mills[6], and pellet mills are made with an expectation of stable supply and stable cost of feedstocks. That is, their demand cannot exceed the regional working forest's ability to replenish itself. Thus, aggregate demand does not exceed the sustainable regional supply. In the distant past, some forests were exploited unsustainably. Today, management of the resource for long-term sustainability is the foundation for consistent profitable operations.

Unlike the fossil fuel sector, good business practices in the forest products sector lead to good environmental stewardship because nurturing the forest is necessary for long-term and consistent operations. Sawmills cannot move like drilling rigs do after they have depleted a reserve. Adding to that is the fact that in those regions that supply wood to industrial pellet mills that export the pellet fuel, rigorous third-party auditing certifies that the forests are being sustainably managed.

From Start to Finish

As an example, imagine a working forest that is 300,000 hectares in area[7] (about 741,000 acres). 300,000 hectares fits into a circle that has a 31 kilometer (19.2 mile) radius. Obviously in most locations, not all of the land area within that circle will be managed timberland. For this exercise the stylized assumption is that the area is all working forest. If the mills are near the center of the circle, the maximum distance in our stylized model that they have to travel one way is on average less than 31 km (19 miles). In the real world, road networks are not "as the crow flies" distances. However, the point is clear that within a well-managed forest landscape, significant quantities of continuously renewing wood are not long distances away.

This analysis (and the FutureMetrics dashboard's storyline) begins with a working forest that fits into the circle as described above. The next two pages show the dashboard (1) with biomass carbon capture and sequestration (BCCS) enabled, and (2) without BCCS. The pages following will discuss the pathway from start to finish and will also focus on specific components of the dashboard.

The dashboard that accompanies this paper allows the user to select any size working forest to analyze as well as allowing many of the input assumptions to be changed[8]. A direct link to the dashboard is HERE.

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[6] For example, oriented strand board (OSB) https://en.wikipedia.org/wiki/Oriented_strand_board and medium density fiberboard(MDF) https://en.wikipedia.org/wiki/Medium-density_fibreboard .

[7] To put this into perspective, British Columbia, Canada has about 25,000,000 hectares available for logging; or about 83 times more than is in the model used in this analysis. That represents about 42% of the total forested area in BC. The rest is not available and/or is protected. Source HERE. The states of Georgia, South Carolina, and North Carolina in the US have about a combined 22,240,000 hectares of managed timberland; or about 74 times more than is in the model used in this analysis. Sources HERE HERE HERE.

[8] This and many other dashboards are free to use at the FutureMetrics website https://www.futuremetrics.com/.

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From Start to Finish: How to Subtract CO2 from the Atmosphere and Produce Baseload Power

Size of Working Forest = 300,000 hectares

Area = 3,000 Square Kilometers

Which is a circle with a radius of 30.90 km

Area and Radius as:
- (●) Metric
- ( ) Imperial

10 — Average Growth Rate (green tonnes/hectare/year)

Implied typical location for a working forest with this growth rate is Western Canada ?

Average New Growth per Year = 3,000,000 Green Tonnes

5% — Percent of Harvest Left on Forest Floor (temporalily sequestered) ?

Annual Harvest of Mature Stand = 2,850,000 Green Tonnes

35% — Percent of Harvest that Becomes Building Materials or Furniture (temporarily sequestered)

20% — Sequestered? ☐ — Percent of Havest that Becomes Paper or Packaging (not considered sequestered)

Residual Portion of the Harvest that Becomes Pellets = 40%

Green Wood Available for Pellet Production = 1,140,000 Tonnes

45% — Moisture Content of Harvested Wood

6% — Moisture Content of Pellets

Green Wood Needed for Drying = 112,284 Tonnes

Green Wood Available for Pellets = 1,027,716 Tonnes

Conversion Rate of Green Wood to Pellets (includes wood used for drying) = 2.17

Annual Pellet Production = 524,400 Tonnes

Click Here to Open a Summary Window Based on Current Dashboard Settings

Dashboard by FutureMetrics

FutureMetrics Website

Power and CO2 Emissions Produced from the Pellet Fuel

Power

4.9 — MWh/Tonne of Pellets = 17.6 GJ/Tonne

40% — Power Plant Efficiency

MWh's per Year = 1,027,824

10.0 — Avearge Annual Consumption per House (MWh's) ?

The Equivalent of 102,782 Homes are Supplied with Renewable Power

Each Image = 10,000 Homes

CO2

50% — Carbon Atoms per Unit of Bone Dry Wood

Implies Hardwood Softwood Blend

Tonnes of Carbon Sequestered in the Pellet Fuel is 282,622 and the CO2 Released in Combustion is 1,037,222 Tonnes ?

BCCS?

(●) Yes ( ) No

With BCCS, 1,037,222 Tonnes of CO2 is Permanently Removed from the Atmosphere resulting in a Carbon Negative Outcome

4.2 — Average Tonnes of CO2 Emitted per Car per Year ?

BCCS is Equivalent to 246,958 Cars being Permanently Removed from Driving

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Click Here to Open a Summary Window Based on Current Dashboard Settings

Dashboard by FutureMetrics

FutureMetrics Website

With No BCCS, 1,037,222 Tonnes of CO_2 is Cycled Back into the Growing Stands of the Working Forest Resulting in a Carbon Neutral Outcome

Power and CO_2 Emissions Produced from the Pellet Fuel

CO_2

50% — Carbon Atoms per Unit of Bone Dry Wood

Implies Hardwood Softwood Blend

Tonnes of Carbon Sequestered in the Pellet Fuel is 282,622 and the CO_2 Released in Combustion is 1,037,222 Tonnes [?]

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MWh's per Year = 1,027,824

10.0 — Avearge Annual Consumption per House (MWh's) [?]

The Equivalent of 102,782 Homes are Supplied with Renewable Power

Each Image = 10,000 Homes

BCCS?

( ) **Yes** (•) No

Without BCCS, the power station still produces renewable electricty that is carbon neutral in combustion. See FutureMetrics white papers and dashboards regarding the carbon footprint from the pellet fuel supply chain.

However, without BCCS, CO_2 is not subtracted from the atmosphere.

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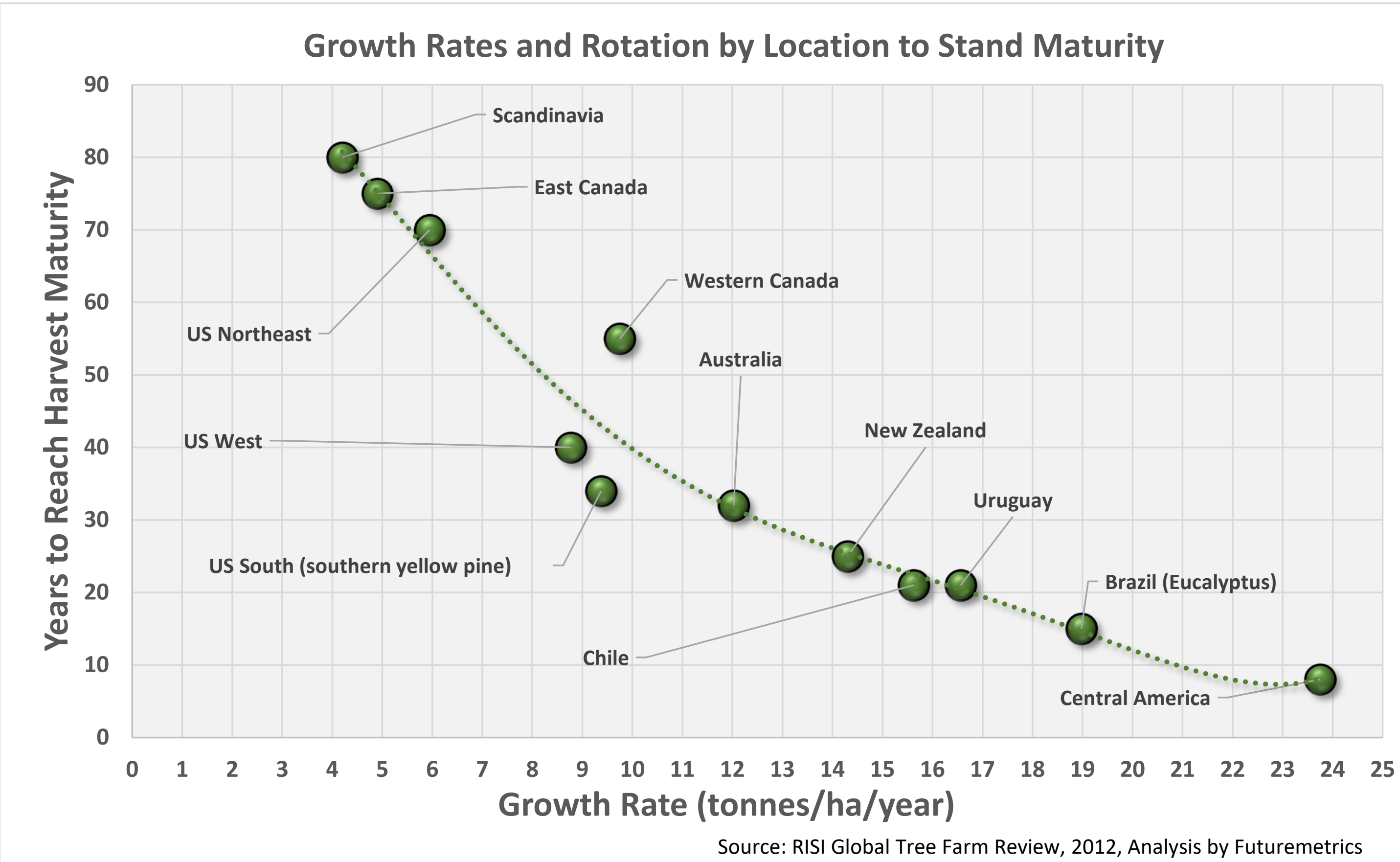
If we assume that the 300,000 hectares of working forest has an average growth rate of 10 green[9] metric tonnes per hectare per year, then the forest landscape grows 3.0 million new green tonnes per year. The chart below shows typical growth rates at different locations and the implied years from seedling to a mature tree that is ready for harvest. The rates in the chart are not necessarily representative of those locations. Growth rates vary widely by location, species, micro-climate, soil conditions, slope and exposure (north or south facing), and many other variables. In general, the farther from the equator, the slower the growth rate.



Within this stylized forest landscape, there are many different plots in may stages of growth: from seedling to mature. Every year, the mature plots in this 300,000 hectare managed forest yield 3.0 million green metric tonnes. The rest of the managed landscape is left to continue to grow and sequester carbon at a constant rate as long the annual harvest does not exceed the annual growth. The harvested mature plots then begin a new growth cycle (often called a rotation) with seedlings that will eventually grow to maturity.

The larger diameter portions of the harvested trees typically go to the sawmill. Some of the harvest, generally small branches, leaves/needles, and often stumps/roots, are typically left behind on the forest floor. Some of

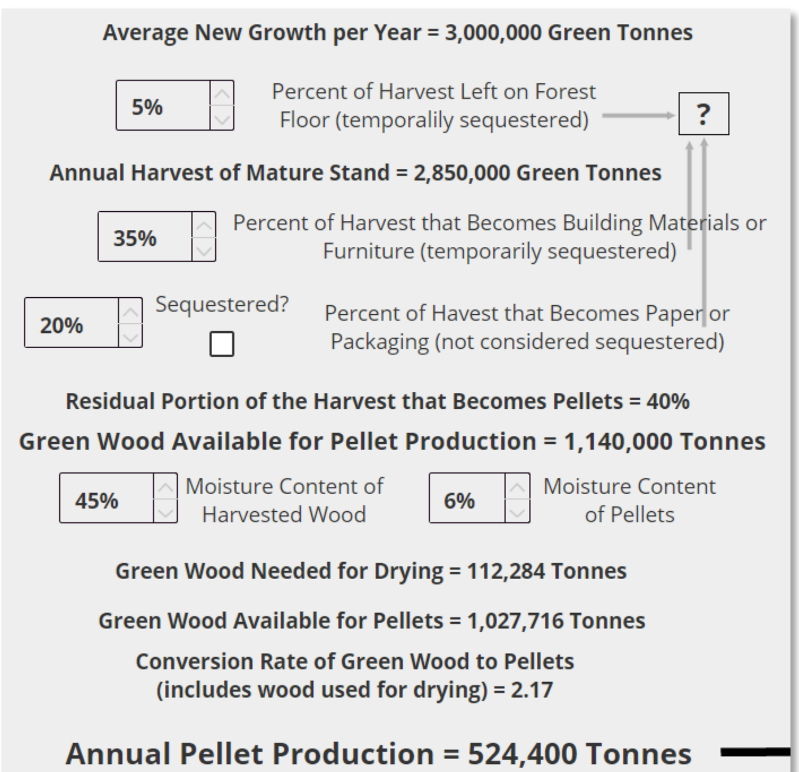
[9] Green tonnes measure the weight of the harvested wood as is. Another measure is bone dry tonne which assumes that all the water content of the raw wood is removed. In this example, the average water content is assumed to be 45%. At 45% moisture content, one tonne of green wood contains 450 kilograms of water.

the smaller diameter portions become feedstock for pulp and paper mills or other engineered building products. And some of the harvest that is not sawmill quality may find its way to a pellet mill.

In this model, and in the default settings of the dashboard, 5% is left on the forest floor, 35% becomes building materials (lumber, flooring, furniture, veneer, OSB, etc.), 20% becomes paper or packaging, and the rest, including sawdust and chip by-products from the sawmills, is available to the pellet mill. After accounting for the 5% left in the forest, of the 2.85 million metric tonnes that is removed from the mature plot, just over 1.1 million green tonnes are available for pellet production.

Note in the image below from the dashboard that there is a question mark that is referenced by three of the inputs. Hovering the mouse pointer over the question mark shows the following: “There are differing circumstances and thus differing estimations on the percentage of carbon in soil, buildings, and paper/packaging that is permanently sequestered. Biomass carbon capture and sequestration unambiguously results in the permanent removal of CO_2 from the atmosphere.”

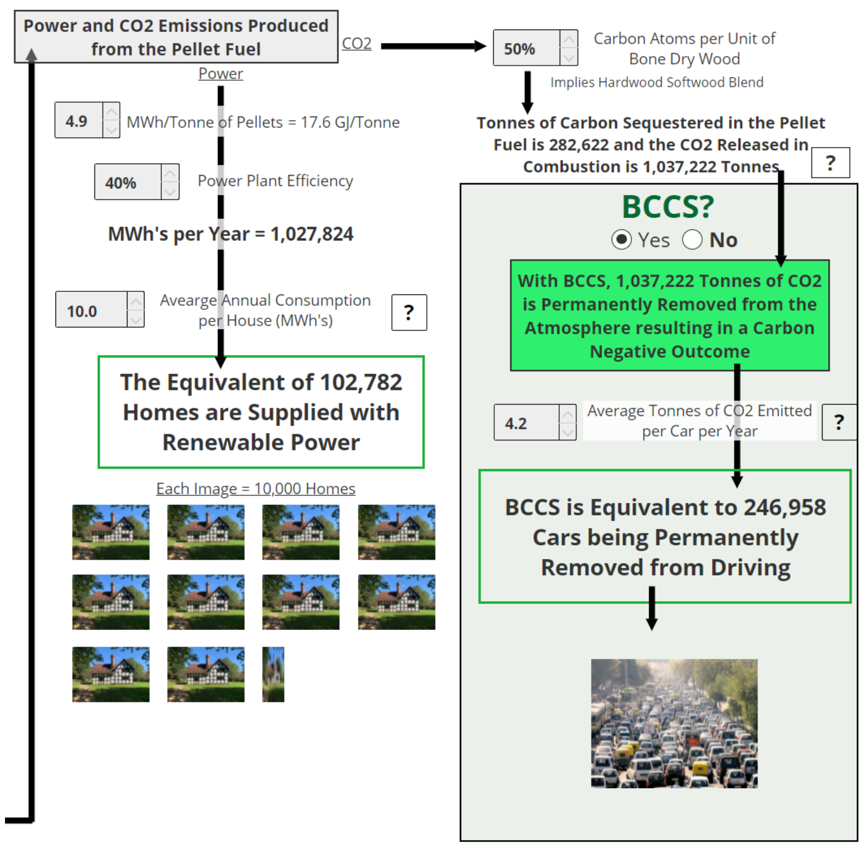
The quantification of the results of BCCS are discussed more below. For this model, it is assumed that all of the carbon on the forest floor and in building materials is sequestered at least temporarily. There is an option to have paper and packaging considered as a carbon sequestration pathway or not.



For a more detailed analysis of wood demand by pellet mills, refer to the FutureMetrics dashboard HERE that shows the relationship between green wood and pellet output for a pellet mill. Given the model’s assumed moisture content of the incoming green wood and the moisture content of the final product (and few other assumptions not shown), about 112,000 tonnes per year are need for drying energy and the rest, about 1 million tonnes, is converted into densified and dried pellet fuel for use in place of coal in a power station. The output of the pellet mill in our stylized model is about 524,000 tonnes per year.

The pellet fuel is then transported to the "power" station[10]. Power is in quotes because the station's purpose is not just for the generation of electricity. The re-purposed PC power station[11] with BCCS takes the hydrocarbons in the pellet fuel and concentrates the carbon as CO_2. The BCCS unit permanently removes the CO_2 from the atmosphere. The "by-product" of the CO_2 capture and sequestration is electricity.

The image below from the dashboard shows the pellet fuel coming into the PC power station and being converted to power and carbon dioxide.



There is a small difference in the carbon content of softwood versus hardwood and the carbon content also varies by species (45% to 57%, hardwoods to softwoods). In the model, the assumption is a blend of hardwood and softwood that is about 50% carbon. One tonne of carbon atoms produces 3.67 tonnes of CO_2.

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[10] See THIS FutureMetrics dashboard for an analysis of the carbon footprint associated the pellet fuel supply chain.

[11] As noted earlier in this paper, the cost to modify a PC power station to use pellets instead of coal while not derating the plant is modest. The design of the boilers, burners, pulverizers, the type of coal they are designed to use, and other variables impact the modification costs. The typical cost is in the range of $250 to $450 per kW of capacity. About half that is for the investment in dry storage. Using water resistant pellets will eliminate that part of the modification cost. This is significantly lower than building a new combined cycle natural gas power plant.

Thus, the 283,000 tonnes of carbon in the carbohydrate-based pellet fuel releases about 1,040,000 tonnes of CO_2 in combustion.

Without BCCS, that CO_2 is released into the atmosphere. However, the new growth in the managed timberlands absorbs all of that and more. In the model, only 40% of the annual new growth becomes pellets. Even without BCCS, the atmosphere sees no net increase in CO_2 from the combustion of pellets sourced under the constraint that the total stock of forest resources cannot be depleted.

But with BCCS, that 1,040,000 tonnes of CO_2 are permanently subtracted from the atmosphere.

The re-purposed PC power station in this model is doing the equivalent of permanently taking about a quarter of a million cars off the road. [12]

And as a valued by-product of an already valuable environmental service, under the assumptions of the model, the equivalent of almost 103,000 homes are supplied with 100% renewable electricity that, in contrast to wind and solar generation, is not intermittent or variable but is baseload.

Conclusion

Many nations are already using pellet fuel in place of coal in PC power stations to lower net CO_2 emissions. The US is a bit of an outlier with, so far, no policy that supports this proven strategy for decarbonization of the power sector. FutureMetrics expects this to change under new evolving carbon emissions reduction policies[13]. The use of pellet fuel in PC power plants sets the foundation for the strategy outlined in this paper. That foundation is already set in many nations and likely soon will be in the US as well.

As FutureMetrics has noted in earlier white papers, the evolution of power generation may eventually, over decades, make the need to generate steam to spin turbine/generators to make electricity a last resort needed only for long-tail circumstance when a grid that is based on massive energy storage is depleted.

But wind and solar generation, and perhaps nuclear generation, do not have the capacity to be used as efficient negative carbon pumps. Integrating sustainably sourced biomass-based solid fuel that is easily substituted for coal means that some of the existing PC power stations should have very long lives; not for the primary purpose of renewable power generation (which they will do) but for the purpose of efficiently lowering atmospheric CO_2 concentrations.

This is a very attractive strategy that is totally feasible with the current state of technology. It should be part of a portfolio of decarbonization strategies going forward.

The goal is to send the geologic carbon back into the depleted oil and gas formations that much of it came from.

[12] Based on data from the US Environmental Protection Administration (EPA), the average car in the US releases about 4.2 tonnes of CO2 per year. Source is HERE.
[13] See the FutureMetrics paper on Policy for the Biden Administration at the FutureMetrics website.