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Nature's Natural Solar Energy Storage

Quantifying the use of the forest products industry's residuals to supply on-demand green power

Complimented with a new interactive dashboard described in this paper

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Fossil fuels used for power generation will eventually be history for two reasons: (1) They are a finite depleting mineral resource that will become increasingly scarce within several generations, and (2) the combustion within a span of centuries of hydrocarbons that were produced by natural processes over millions of years is overwhelming the earth's systems with carbon dioxide[1].

Transitioning off of fossil fuels requires a rational and pragmatic strategy. This transition is even more challenging now in the power generation sector given the rapid growth in the demand for electricity[2].

This white paper describes how the solar energy captured by plants and converted into and stored as energy rich carbohydrates should be part of how we achieve a rational, pragmatic, reliable, sustainable, safe, and economically feasible transition to a decarbonized future[3].

There are technological solutions for converting solar energy into stored energy (primarily battery storage). But there is also a natural solution that can complement the transition to a decarbonized future. Remember, carbohydrates created by plants using solar energy were the precursor to all fossil fuels (hydrocarbons)!

This white paper is complimented with a new interactive dashboard that tells the story of how some of the megawatt-hours (MWh's) of captured solar energy can be used to make green electricity.

The Challenge

Traditionally, the electric grid has been composed of a foundation of baseload power stations that provide steady power day and night, and a peaking or grid balancing set of power stations that provide power as needed to match demand variations above the baseload. The variable demand above baseload has been met with hydro power (where possible) and power stations powered by fossil fuels (primarily natural gas and coal). Nuclear generation is limited to baseload.

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[1] See the FutureMetrics white paper, "*Unless the Costly Consequences of Depleting Fossil Fuels and Increasing Carbon Emissions are Recognized, The Future Will Not be What We Want it to Be*".

[2] See the recent FutureMetrics white paper "*The Growing Mismatch between US Electricity Demand and US Electricity Supply*".

[3] There are a number of whitepapers and dashboards at the FutureMetrics website that describe how a utility scale power generation unit that uses coal can be easily modified to use solid fuel produced from sustainably sourced biomass. Many of the papers and some of the dashboards show how the use of that fuel produced from renewing feedstock is carbon neutral in combustion.

The power grid of the future will still need baseload. The rapidly growing demand from AI hyperscalers needs baseload. However, the power grid of the future will have a large amount of power generated from wind and solar which is fed into the transmission and distribution systems when the wind is blowing and the sun is shining.

The solution for turning the variability and intermittency of wind and solar generated power into predictable and controllable supply is energy storage. Today, and probably for a few decades at least, there are insufficient technological energy storage solutions that can provide the terawatt-hours of power sufficient to keep the grid energized during times when the gap between peaking demand and insufficient wind and solar supply is persistent.

In addition to limited but growing battery storage, new natural gas (NG) fueled power plants are the typical solution today for following variations in power demand. NG can and will play a role in powering the grid. But natural gas is a depleting fossil fuel that emits geologically stored CO_2 when burned. It is not a sustainable solution for the medium to long run from both economic and ecological perspectives. Nor is it a solution that can be quickly implemented[4].

For corporations that have pledged to be carbon neutral in the future, adding NG generated power is counter to their mission and their message. This is particularly challenging for large AI/datacenter developers with green credentials that need to be nurtured on a global scale.

There is a sustainable non-carbon emitting energy storage solution that can play an important role in the transition from now to a decarbonized future; and it can be part of the decarbonized future. Even with massive technological energy storage solutions, there will be so-called "long-tail" periods in which on-demand generation will be needed. And the solution can be implemented with almost no lead time.

The solution leverages nature's natural solar energy storage.

Nature's Natural Solar Energy Storage

Every year about 5.7 x 10^{24} joules of solar energy irradiates the earth's surface[5]. That solar energy is an essential part of our planet's ecosystems. Plants and photosynthetic organisms utilize that energy to convert large amounts of CO_2 into $C_6H_{12}O_6$ (glucose)[6]. The chemistry of plant growth transforms the glucose into other carbon based molecules such as sugars (hemicelluloses), cellulose, lignin, and other plant matter. Every year solar energy and photosynthesis converts billions of tonnes of CO_2 and water into plant matter and oxygen.

A portion of that plant matter is trees. While some forests are not used and should not be used to supply the forest products industry, many millions of hectares[7] of forests are managed and cultivated to continuously produce logs for

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[4] Rapidly increased demand for combined cycle natural gas units has resulted in a 5 to 7 year backlog for delivery and significantly higher capital costs. See HERE.
[5] Source: FAO http://www.fao.org/docrep/w7241e/w7241e06.htm#TopOfPage
[6] Photosynthesis can be described by the simplified chemical reaction $6H_2O + 6CO_2 + \text{energy} \rightarrow C_6H_{12}O_6 + 6O_2$. Source: Wikipedia.
[7] One hectare = 2.47 acres.

lumber, wood chips for pulp and paper/packaging/tissue, and engineered wood products such as oriented strand board (OSB) and medium density fiberboard (MDF) [8].

These managed "working" forests are in effect tree farms. These managed forests cycle through stages of regeneration, growth to maturity, harvest, and then again regeneration. The growth rate and therefore the cycle time between harvests depends on the climate, geography, the species of trees, and other factors.

Forests cover 31 percent of the world's land surface. That is about 4 billion hectares.

An average managed forest will contain about 350-400 tonnes per hectare at maturity and will have grown at an average rate of about 12 tonnes per year per hectare. The average energy content per tonne of wood is about 8.64 gigajoules (GJ)[9]. Therefore, the world's forests store about 415 billon GJ or 115,000,000 gigawatt-hours (GWh's) per year. Total solar and wind generation in 2024 was about 4,625,000 GWh's[10]. That is, the earth's forests captured about 25 times more energy in 2024 than what was produced by wind and solar generation in 2024.

Almost all of the power generated by solar panels and wind turbines is consumed as it is produced. Without intermediate energy/battery storage, solar and wind power are not dispatchable (dispatchable means the power can be supplied when needed). Whereas the solar energy captured by the world's forests is stored. Forests are nature's natural solar energy battery. And just like wind and solar, some of those forests can be a perpetually renewing resource.

Can We Sustainably Use the World's Largest Energy Storage System and Supply On-Demand Carbon Free Power?

Not all of the 4 billion hectares of global forested land is used to produce the primary feedstocks for the forest products industries. The proportion of total forested land that is managed and what is available to sustainably supply[11] raw materials to the forest products industries varies by country and by region.

> It is important to distinguish between the activities of managed forest harvests and deforestation. Areas within a managed forest that temporarily have no trees after a harvest or a forest fire are still considered forest. A new crop of trees will grow back and in 10 to 70 years and they will again be harvested. Deforestation is the permanent clearing of forests to make way for new non-forest land use such as commercial development or agriculture.

As was shown above, forests are continuously capturing solar energy as they continuously grow.

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[8] Oriented strand board and medium density fiberboard. https://en.wikipedia.org/wiki/Oriented_strand_board https://en.wikipedia.org/wiki/Medium-density_fibreboard

[9] The gross energy content per tonne is based on wood with a moisture content of 50%.

[10] Source: HERE.

[11] Sustainable forest management guarantees a renewing resource. The baseline necessary condition is that annual removals (harvest) can never exceed the annual new growth. If that fundamental and necessary required is met, the forest inventory, the stock of carbon held by the forest, and the energy stored in the biomass is not reduced. It is a continuously renewing resource.

However, it would not be possible nor ecologically responsible to consider all forests as a source of stored solar energy. But some portion can be responsibly used to produce coal-replacement solid fuel (in the form of wood pellets) which can be used to fuel dispatchable power generation. As long as removals do not exceed growth within the managed forest (the basic necessary condition for this entire strategy to make sense!), the atmosphere sees a net of zero new CO_2 from combustion.

Producing dispatchable power from the carbohydrates[12] produced from solar energy is already being done at large scale with densified solid fuel. One example is England's largest power station, Drax[13], which will produce about 14 TWh's of carbon beneficial electricity in 2025 from 100% wood pellet fuel. That station was once England's largest coal fueled power plant and the largest CO_2 emitter in the UK power grid. The wood pellet fuel used to produce 14 TWh's in 2025 contains part of the solar energy captured by sustainably managed forests in 2025.

It is important to understand that only a portion of the primary harvest becomes fuel suitable for coal replacement in utility scale power stations.

The wood pellet manufacturing sector uses the by-products of lumber production and the parts of the harvested tree that are not suitable for making lumber. The portion of the tree that is suitable for making lumber always has the highest value and almost always goes to a sawmill. If there are pulp and paper mills or engineered wood products factories in the region, some of the remainder of the tree in the form of wood chips will turn into paper, packaging, tissue, or building products such as OSB and MDF.

Pellet manufacturers provide a valuable value-adding outlet for the by-products of sawmills. Some 35% to 55% of the incoming wood to a sawmill does not become lumber or flooring, or cabinetry, etc.

Wood pellet producers are "bottom feeders" taking up the scraps. And, like many bottom feeders in other ecosystems, pellet factories' demand for the low value woody biomass leftovers plays a valuable role in the overall forest products ecosystem.

How Many Megawatts of Generation Capacity Can a Managed Forest Support?

The use of coal-replacement fuel produced from upgraded woody biomass garners a lot of misguided criticism around the idea that forests are being destroyed in the process of producing the fuel. Yet those same critics do not fret about how lumber or cabinets or packaging or toilet paper is produced.

As noted above, and in many FutureMetrics white papers over the years, they all come from the same source: forests that are continuously renewing so that the mills that depend on them have a non-depleting supply of raw materials every day and every year.

[12] Carbohydrates (a biomolecule made of hydrogen, carbon, and oxygen) and hydrocarbons are similar. Hydrocarbons used to be carbohydrates in the distant past. The primary difference is that hydrocarbons have lost the oxygen atoms and thus have a higher energy density.

[13] See HERE.

A depleting raw material supply in the forest products sector is counter to any rational business model that starts with an investment of hundreds of millions of dollars and requires a long life to justify the investment (for example, lumber mills, pulp and paper mills, and pellet mills).

Managed forests not only continuously renew the supply of materials to make lumber, etc., they also continuously capture solar energy. A portion of that renewing captured energy can be used to replace a non-renewable and depleting resource, coal, for power generation.

Let's quantify that…

To do so, FutureMetrics has created an interactive dashboard. The dashboard is free to use at the FutureMetrics website. The dashboard tells the story of an area of forest that is managed to produce the wood needed by mills that convert it into boards, paper, cardboard, tissue, flooring, etc. The "scraps", i.e., the leftovers from the initial harvest that have no higher value use, find their way to a pellet factory.

The dashboard shows the area, in square kilometers, of the managed forest. The growth rate of the forest and year of harvest determines how many gigawatt-hours of solar energy are stored in the biomass. The portion of the annual harvest that is not used for higher value products determines how much of the stored solar energy turns into upgraded coal-replacement solid fuel.

Finally, the dashboard's story is completed in the bottom right corner where the user can see the size of the power station that can be supported by the area that is harvested each year in this particular area.

The image on the next page is a screenshot of the dashboard when opened. The interactive controls allow the user to experiment with different input assumptions.

Based on the default assumptions, a 20,000 hectare area of a managed forest will store enough gigawatt-hours of solar energy per year to support a 500-megawatt generating unit.

Is 20,000 hectares (200 square kilometers) a lot? Click on the "Is this a lot" button to see that the 20,000-hectare area is just 0.021% of the managed forest land in the US state of Georgia and is 0.009% of the managed forests in British Columbia, Canada.

The harvest is set at 32 years for the Georgia scenario (the dashboard user can change that assumption). That means that the total area needed to supply to sawmills, pulp mills, and pellet mills drawing on the managed forest landscape is 32 times 200 square kilometers = 6,400 square kilometers or about 6.7% of all the managed forest in Georgia.

This strategy fits comfortably into the existing large forest products sector in Georgia (and BC).

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Nature's Natural Solar Energy Storage - Quantifying the Use of Sustainably Sourced Biomass to Make On-Demand Green Power

Start with the Size of the Forested Area that is Ready for Harvest

Size of the Managed Area = 20,000 Hectares

?

200 sq km

The managed area will fit into square that is 14.1 km's (8.8 miles) on each side.

Is this a lot? Click here

350 Tonnes of Wood per Hectare of a Mature Plot

4.7 MWh's per Dry Tonne of Wood

45% Average Moisture Content of Pellet Factory Feedstock

The harvest is typically made at the growth year which maximizes yield/revenue versus operating costs.

Use this slider to adjust the assumed timing of the plot's rotation from mature trees to seedlings.

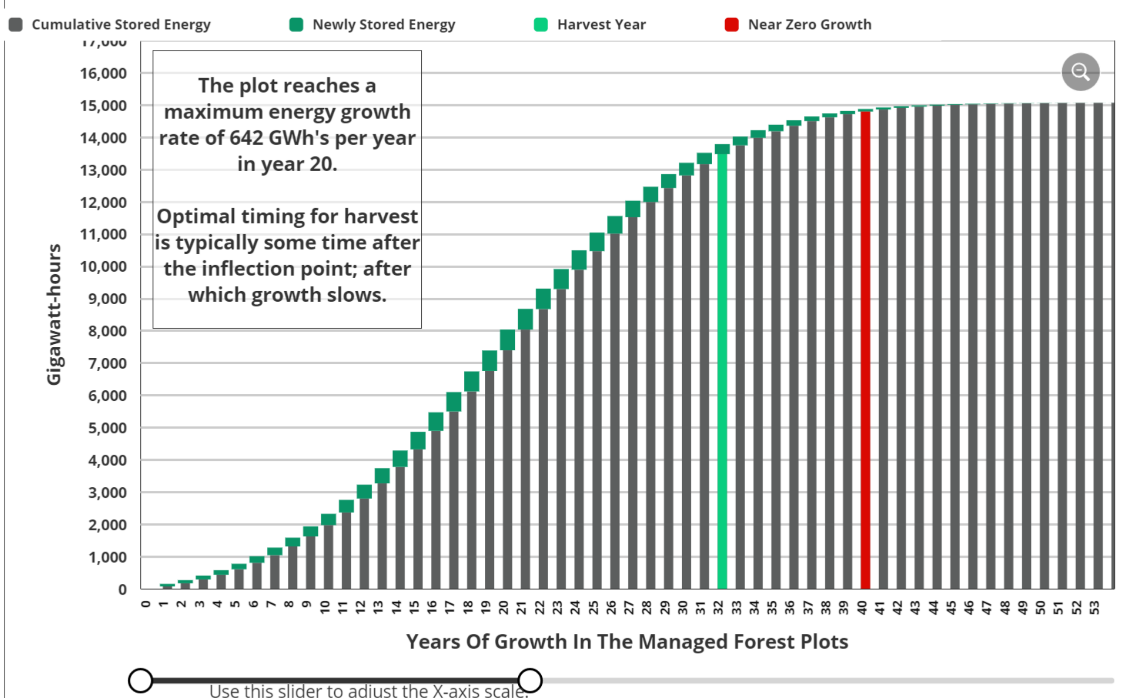
Harvest is at 80% Percent of the Area's Maximum

<== (Faster Growing) Tropical - Temperate - Boreal (Slower Growing) ==>

Natural mortality approximately equals growth in year 40 and there is only a marginal increase therafter in the stock of biomass and stored energy.

Dashboard created by FutureMetrics

Stored Gigawatt-hours For A 20,000 Hectare Area Of Managed Forest



13,485 Total GWh's Stored in the Wood at the Time of Harvest

The primary use of the wood is for the production of lumber, furniture, flooring, paper, packaging, tissue, etc.

Use this slider to change the asssumption of what proportion of the harvested wood is used to make coal replacement solid fuel (wood pellets).

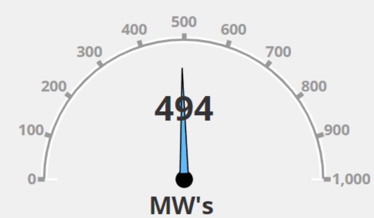
Percent of the Harvest that Becomes Pellet Fuel = 40%

5,394 Total GWh's in the Pellet Fuel

Supported Size of a Generating Unit

Generating Unit's's Capacity Factor = 50%

Unit's Efficiency 40%



Print | + Add scenario | View all scenarios

This is a stylized model. Actual maximum MWh's available will very by tree species, geography, and climate.

FutureMetrics Website

Conclusion

There are limits to the application of this coal-replacement strategy. The carrying capacity of any system can be defined as the maximum level of demand on that system that can be sustained indefinitely by natural renewal. Solar energy captured by forests that is available for sustainable power generation is limited to the size and growth rates of the managed forest resource. Respecting the growth/removal ratio boundaries and nurturing the resource are essential.

But within those constraints, there are significant opportunities.

Most energy sources begin with sunshine! Fossil fuels are the concentrated result of millions of years of solar energy capture. Fossil fuels are the foundation of modern civilization. We need energy. But we need to internalize the consequences of depending on a depleting resource whose use is sending the planet toward a climate tipping point.

Using those millions of years of energy stored in energy dense carbon-based molecules over a few hundred years is releasing massive amounts of CO_2 into our atmosphere. Independent of climate change concerns, the stock of fossil fuels on the planet is finite; so any responsible strategic plan for the future has to consider a point at which there is increasing scarcity of a depleting resource, and social and economic consequences that result.

A baseload of nuclear power plus wind and solar power will supply an increasing proportion of demand. However, as the proportion of wind and solar generation grows and dispatchable fossil fuel generation is reduced, energy storage becomes an essential part of balancing the grid.

Utility scale and distributed battery storage will play an increasing role. But battery storage, for the foreseeable future, can only keep the grid energized for a limited time even if the gap between electricity demand and insufficient electricity supply is relatively small. This reality is underlying the overwhelming demand for natural gas combined cycle generating units.

By expanding our perspective of energy storage to include the biomass that is produced every day by solar energy powering the chemistry of plant life, we see that there is a way to help fill that gap. Energy responsibly produced from that portion of new growth that comes with sustainable forestry which is converted into wood pellets can be a part of the solution for keeping the lights on.

In other words, we can support keeping the grid balanced by drawing upon nature's natural solar battery.