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A Perspective on Solar Energy Storage

Solving the Challenges of Balancing the Power Grid During the Transition to a Decarbonized Future

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As climate change impacts become more frequent and severe, even those countries with short-sighted policies will soon begin the transition away from a high carbon power sector. Fossil fuels used for power generation will eventually be history. Wind and solar generated electricity will provide a significant proportion of power in that decarbonized future. But wind and solar power are not always providing energy when needed. In other words, wind and solar are not dispatchable. The solution to that challenge is energy storage.

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. That variable demand has been met with hydro power (where possible) and thermal generation powered by fossil fuels.

The decarbonized grid of the future will still have baseload, but it will also have a large amount of power generated from wind and solar that are fed into the grid when the wind is blowing and the sun is shining. The solution for the variability and intermittency of wind and solar generated power is energy storage. Perhaps there will be a solution to grid -level energy storage based on large batteries in the future. Today and in the foreseeable future, there is no conceivable battery solution that can provide the megawatt-hours of power sufficient to keep the grid energized for more than very short periods if the gap between demand and insufficient supply is persistent. Natural gas plants are the typical solution today. But natural gas is a fossil fuel that emits CO_2 when burned.

There is a sustainable non-carbon emitting energy storage solution that can play an important role in the transition from now to a future in which most power generation does not emit CO_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 reliable and economically feasible transition to a decarbonized future.

The World's Largest Solar Battery

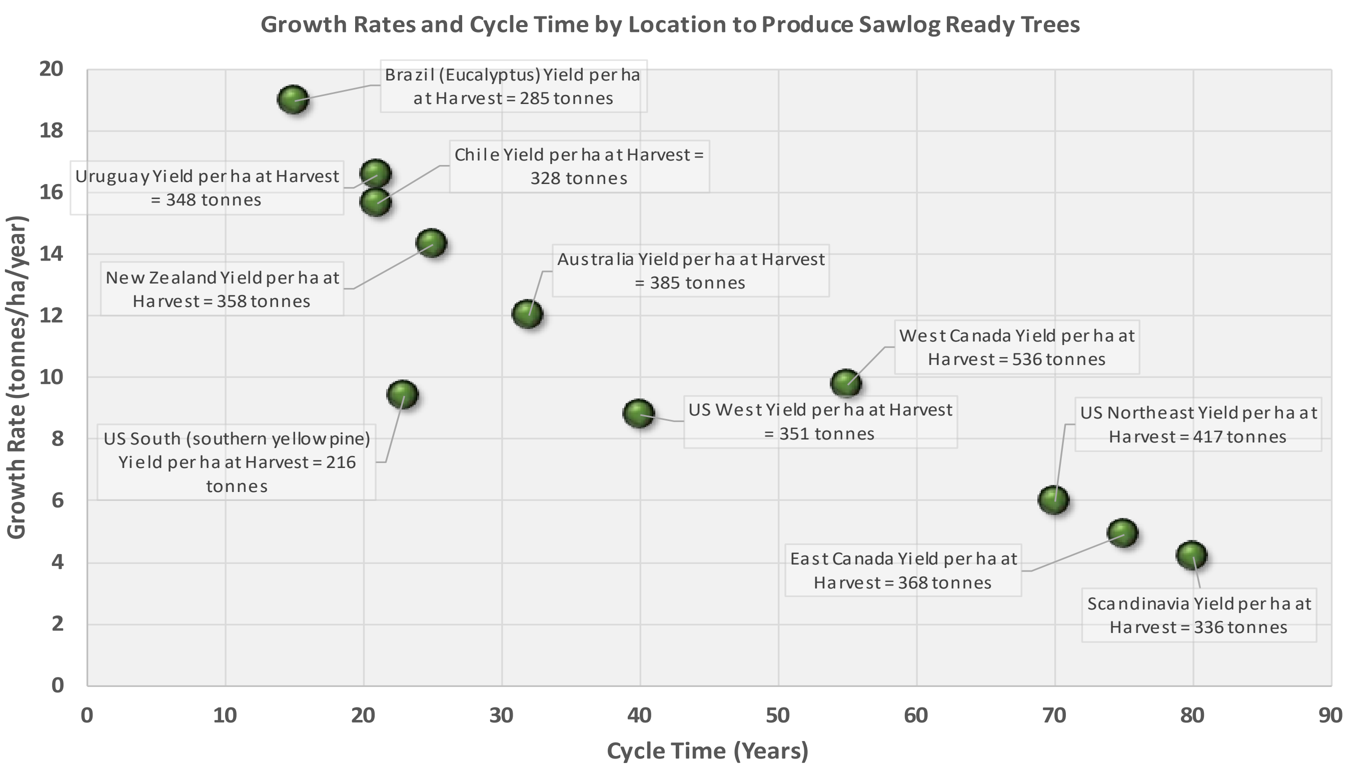
Every year about 5.7 x 10^{24} joules of solar energy irradiates the earth's surface[1]. That solar energy is an essential part of our planet's ecosystems. Plants and photosynthetic organisms utilize that energy to convert large amounts of CO_2

[1] Source: FAO http://www.fao.org/docrep/w7241e/w7241e06.htm#TopOfPage

into $C_6H_{12}O_6$ (glucose)[2]. The chemistry of plant growth transforms the glucose into other 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.

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[3] of forests are managed and cultivated to continuously produce logs for lumber, and wood chips for pulp and paper and engineered wood products. These managed "working" forests are in effect tree farms. These tree farms cycle through stages of regeneration, growth to maturity, and harvest. The growth rate and therefore the cycle time between harvests depends on the climate and species of trees.

The chart below shows the time from planting to harvest at selected locations. In general, the nearer to the equator, the shorter the time to grow a tree that is ready to be harvested. The yields per hectare at harvest do not vary greatly. Harvests are more frequent in more temperate regions.



Source: RISI Global Tree Farm Review, 2012, Analysis by Futuremetrics

The average growth rate is about 12 metric tonnes per hectare per year. In northern climes it is less and in some tropical locations with fast growing tree species, it is more than 20 tonnes per hectare per year.

2 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.

3 One hectare = 2.47 acres.

Forests cover 31 percent of the world's land surface. That is about 4 billion hectares. Assuming an average growth rate of 12 tonnes per hectare per year and an average energy content per tonne of about 8.64 gigajoules (GJ)[4], the world's forests store about 415 billon GJ or 115,000,000 gigawatt-hours (GWh's) per year. The total electricity produced by solar arrays across the world in 2016 was about 333,000 GWh's. The total produced by wind turbines was 956,000 GWh's[5]. The forests capture about 90 times as many GWh's per year as all solar and wind combined.

But almost all of the power generated by solar panels and wind turbines is consumed as it is produced. Without battery storage, solar and wind power are not dispatchable. Whereas the solar energy captured by the world's forests is stored. The forests are nature's solar battery.

Grid Balancing in a Decarbonized Power Grid Will Require More than Electric Battery Storage

Battery storage in 2016 was able to deliver about 5 GWh's of power. By 2030, global battery storage is expected to double six times to about 300 GWh's[6]. On April 23, 2018, the US electrical energy consumption was 329 GWh's[7]. If all of the forecast global battery storage for 2030 was deployed in the US on April 23, 2018, it would keep the lights on in the US for less than 24 hours. While it is unlikely that battery storage will have to carry the full load, there is little doubt that by 2030, as the world is well into a transition away from fossil fuel power generation, wind and solar with battery storage will not be sufficient to fill the gap between power demand and persistent insufficient power supply during peak demand periods.

Perhaps the vision for distributed battery storage from electric vehicles smartly connected to the grid will provide a larger battery storage buffer over the next decade[8]. Of course, if that scenario plays out, demand for electricity will also increase. But given the finite and relatively small capacity of battery storage with respect to the total grid demand, on-demand power generation other than battery storage will be needed to maintain voltage stability and the overall reliability of the power grid.

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 industry. The proportion of total forested land that is managed and what is available to sustainably supply[9] raw materials varies by country.

[4] The gross energy content per tonne is based on wood with a moisture content of 50%.
[5] From BP Statistical Review of World Energy 2017.
[6] From Bloomberg New Energy Finance, November 20, 2017.
[7] EIA real time grid status https://www.eia.gov/realtime_grid/?src=data#/status?end=20180426T03
[8] The vision is that owners of EV's will allow some portion of the charge in their EV to flow into the grid. For example, if the EV has a range of 200 miles but the owner only needs to go 50 miles that day, they will allow perhaps 50% of the charge to be taken back from the EV to carry some of the grid's peak demand.
[9] 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 and the stock of carbon held by the forest is not reduced.

Canada and the United States are the world's first and second largest producers of forest products and have a combined 650 million hectares of forests.

Most of Canada's forestland is regulated by the government. Canada has strict guidelines for setting the annual allowable cut. In 2016 the Canadian forest products industry harvested about 780,000 hectares with an average volume of 118 m^3 per hectare[10]. At an average weight of 1.5 metric tonnes per cubic meter, that is about 138 million tonnes. Despite the continuous annual flow of wood from the forests to supply sawmills and other mills that use primary woody feedstock, the Canadian forest cover has remained stable. From 1990 to 2015 the area went from 348.3 million hectares to 347.1 million hectares: a change of -0.34%.

Similar statistics can be shown for US working forests. US forest inventory in jurisdictions that have traditionally relied on the forest products industry has increased between 2000 and 2014[11].

It is important to distinguish between the activities of tree farming and deforestation. Forest land that temporarily has no trees after a harvest or a forest fire is still considered a forest. A new crop of trees will grow back and in 10 to 70 years will again be harvested. Deforestation is the permanent clearing of forest to make way for a 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. 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 wood pellets which can be used to fuel dispatchable power generation with a net zero of carbon emissions from combustion. Producing dispatchable power from the carbohydrates[12] produced from solar energy is already being done at large scale with densified solid fuel provided by industrial wood pellet factories.

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. In plantation grown forests, there may be a few rounds of thinning to promote better quality timber and higher productivity per hectare. Those thinnings may find their way to pellet plants. 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[13]. Last in the pecking order of the ability to pay for woodchips are pellet mills.

[10] Source: Natural Resources Canada.
[11] http://www.theusipa.org/Documents/USSouthWoodSupplyTrends.pdf
[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] Oriented strand board and medium density fiberboard. https://en.wikipedia.org/wiki/Oriented_strand_board https://en.wikipedia.org/wiki/Medium-density_fibreboard

The part of the wood pellet sector that produces "industrial" pellets for use as a substitute for coal is already regulated by strict sustainability rules that disallow the use of wood pellets that do not come from sustainably managed forests[14].

Industrial pellet producers in the developed world understand that their social and legal license to operate is based on using only feedstocks that are proven by independent audit to be sustainable[15]. Industrial wood pellets must come from landscapes that are growing at least as fast as they are being harvested. If the forest landscape is shrinking due to deforestation, the basis for carbon neutrality in combustion is voided.

How Many MWh's can the Biomass Storage Battery Sustainably Generate

Currently a very small proportion of the total annual harvest finds its way into wood pellet production. The feedstock for pellet production is a by-product from other forestry activities: both sawmill by-products and the by-products of sawlog tree farming and harvesting. For example, in the US Atlantic and Gulf regions, 3.7 million tons of wood went into pellet production in 2014. That same year 117.6 million tons went to the other demanders of forest products[16].

The US southeast and western Canada have been and continue to be the major suppliers of industrial wood pellets to the world. Depending on a variety of parameters such as the strength of the housing markets, the competitiveness of north American pulp and paper producers, and the finite size of the maximum annual sustainable harvest from managed working forests, there is a limit to how many millions of tonnes per year of pellets can be produced.

Currently, north American has the capacity to produce about 12 million metric tonnes per year of pellets. Credible planned projects will add another 5.2 million tonnes. Within a few years, capacity will be over 17 million tonnes per year.

North American Industrial Pellet Production
Nameplate Capacity in Metric Tonnes

	US	Canada	Total
Operating Now	8,375,000	3,545,000	**11,920,000**
In Development	3,616,000	1,535,000	**5,151,000**
Total	**11,991,000**	**5,080,000**	**17,071,000**

source: Argus Direct, April 23, 2018

[14] The policies in the major importing countries such as the UK, the Netherlands, Belgium, and Denmark do not allow power stations to consume wood pellets that do not pass rigorous independent audits to prove that they are sourced sustainably. Otherwise, the utility will fail to participate in the policy support that allows the use of pellet fuel for carbon emissions mitigation.

[15] Policy in the EU and UK that supports industrial wood pellets also requires that the power producer be in compliance with sustainability criteria. Policy in Japan and South Korea will codify similar requirements in 2018.

[16] Source: Forest to Market report on Wood Supply Trends in the US South, http://www.theusipa.org/Documents/USSouthWoodSupplyTrends.pdf

At an energy density of about 18 GJ per tonne of pellets (about 5 MWh's per tonne) and assuming a 41% power plant efficiency and a pellet factory capacity factor of 90%, 17 million tonnes of nameplate production capacity for pellet fuel can produce about 31,500 GWh's. As noted above, the forecast for global electric battery storage in 2030 is about 300 GWh's; or about 100 times less than then energy contained in the annual output of north American wood pellet fuel by current and developing pellet factories[17].

All of the industrial wood pellets produced in the US and Canada are exported to power stations in countries that have already embarked on a decarbonization transition strategy[18].

While it is unrealistic to project that all of north America's current capacity will go into US power stations, **the analysis illustrates the potential significant benefit to grid stability of responsibly using the solar energy capture and storage systems that already exist naturally via the use of wood pellets.** The same solar energy that powers silicon cells that will feed large battery storage stations also enables the capture and storage of energy that ends up in the by-products of forestry that are used to produce pellets. Using this strategy can provide some of the on-demand non-fossil fuel power needed when solar, wind, and battery are insufficient to meet demand.

What are the Limits to Growth?

There are always limits to growth. The carrying capacity of any system is defined as the maximum level of demand on that system that can be sustained indefinitely.

How many wood pellets can the world produce and not violate the carrying capacities of regional forest systems? While we do not know the answer to that question, we expect that if credible long-term demand for industrial wood pellets develops, there can be many many times more wood pellets produced than there are now. In many jurisdictions, the low-grade wood left over from a harvest that has no value for traditional forest products industries is left behind in "slash" piles (and in some locations burned in the open air!).

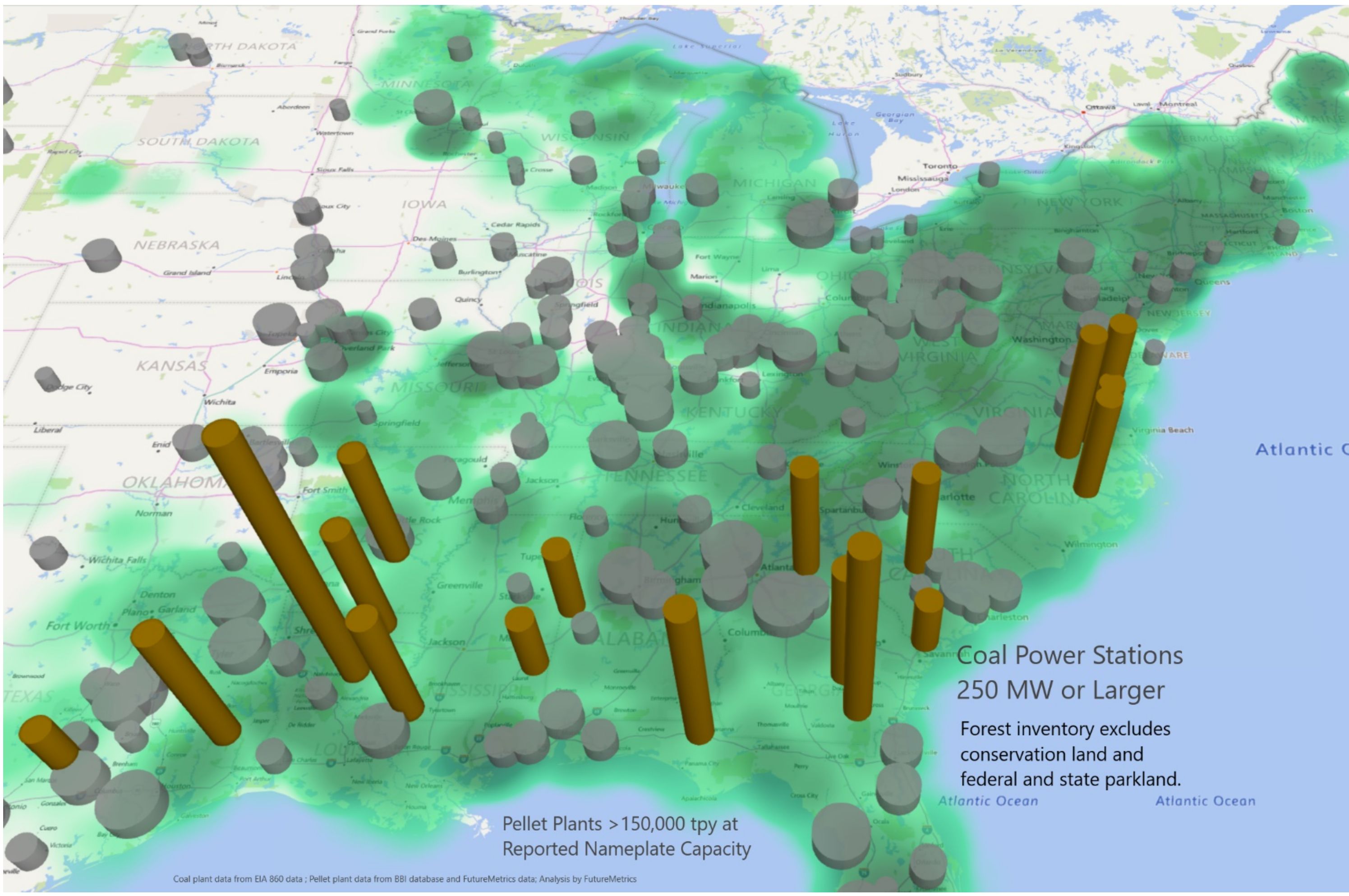
Guiding the growth of the pellet sector is the requirement that the maximum production boundary in every jurisdiction must be defined with strict sustainability rules that are measurable and strictly applied. The use of pellets for power cannot be an excuse to deforest the landscape.

Can north America can produce more than 17 million tonnes per year and not be in violation of good forestry stewardship practices? The limits to the size of the pellet industry depends on many factors. For example, will the pulp and paper industry's demand for wood chips decline or increase in the future? While demand for printed media has declined, demand for packaging and tissue has increased. Will housing demand remain robust so that lumber

[17] Battery storage MWh's can be discharged very rapidly. The MWh's in pellet fuel must be converted to energy in a thermal power plant. 17 million tonnes per year of pellets equals about 46,500 tonnes per day or about 86.3 GWh's. If the US's share of the forecast global battery storage in 2030 is 29%, then US battery storage in 2030 would equal about 86.3 GWh's; the same quantity of power that could be continuously produced every day by pellets in this scenario.
[18] One power station in the UK, the Drax station, generates about 3% of the UK's daily baseload from wood pellets imported mostly from north America.

production and the sawmilling by-products that are used by pellet mills continue to grow? Will OSB and MDF factories crowd out the potential for new pellet plants?

We think opportunity still exists in the US for growth. The chart below shows the existing industrial wood pellet factories, the density of forest cover, and the locations of coal power plants. There are three take-aways from the chart.



The height of the columns is based on the size of the pellet mill. The diameter of the coal plant circles is based on MW's. The shading indicates the density of forest cover.

First, the industrial wood pellet plant locations are based, in part, on the necessary availability of a continuous supply of sustainable feedstock <u>and</u> transportation infrastructure to get the pellets from the mills to a port for export. So, most are close to deep water ports or have direct rail to the ports. As the market for wood pellets grows, new sites for pellet production will be developed.

Second, clusters of coal power stations are located in areas that do not produce industrial wood pellets and in which the markets for sawmill residuals and the secondary low-grade wood not used by sawmills is lacking. If policy in the US evolves, as we think it will in the 2020's, those coal plants may be modified to use renewable pellet fuel that is produced right in their backyard.

Third, Maine, which has lost over 3 million tonnes per year of softwood wood chip demand due to numerous pulp mill closures and has three deep water ports, sits on an abundant and now underutilized sustainable wood supply with no industrial wood pellet production.

Just over the border from Maine, there are similar conditions for the development of industrial wood pellet production in New Brunswick and Quebec. Sawmills in both provinces are looking for solutions to sawmill residue disposal problems. Wood pellet production turns a "waste" into a feedstock.

Western Canada has vast resources that can support growth. Several new industrial pellet mills that will export to Europe, Japan, and South Korea are planned in Alberta and British Columbia and others will be built as demand grows.

And then there are emerging areas such as Brazil and Chile which have large forest products sectors. Brazil is moving into pellet production and Chile, which is a major exporter of wood chips to Asia, may follow. Australia, Tasmania, Vietnam, and other areas which already grow trees for lumber, furniture, and produce wood chips for pulp and paper are entering the sector. The vast and mostly untapped resources of eastern Russian forests could increase global supply significantly if infrastructure and legality challenges are solved.

In all cases, credible independent auditing to prove that the renewable fuel is renewing has to be applied.

Conclusion

The future of our planet's environment is a stake. Most of the world's leaders have recognized the impact of releasing massive amounts of CO_2 in to our atmosphere from fossil fuel combustion. Those that have not, will soon as the impacts of climate change become increasingly obvious and costly. Removing fossil fuels from the transport, power, and heating sectors is the long-term goal. 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.

The pathway to decarbonizing the electricity generation sector is clear. Wind power and solar power will produce an increasing proportion of demand. However, as that proportion grows and dispatchable fossil fuel generation is reduced, energy storage becomes an essential part of balancing the grid.

Battery storage will play a 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 supply is relatively small.

By expanding our perspective of energy storage to include the biomass that is produced every day by solar energy and 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 keep the grid balanced by drawing upon the nature's solar battery.