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Power Generation in the Future

Wind, solar, and battery need help in the transition to a more decarbonized power generation sector

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Introduction

Strategies and policies for reversing the impacts of climate change are needed now more than ever[1]. To get from where we are today to future goals for lowering carbon dioxide (CO_2) emissions will require a portfolio of complementary solutions.

That future is typically seen as relying on electricity generated from wind turbines and solar farms. This white paper will show that deploying more wind turbines and solar farms will require massive battery storage at a scale that is difficult to imagine as achievable. As this paper will show, grid level battery storage sufficient to support the reliable supply of electricity in a decarbonized power sector is probably decades (or more!) away. One strategy for maintaining grid reliability during this long transition from where we are today to a 100% carbon free generation portfolio is discussed on the final section this paper.

This white paper continues with a discussion about how a carbon tax can facilitate that transition to a decarbonized future.

The final section of this paper looks at the United States' coal fueled power plant fleet and how a select number of existing units could be put to work lowering the carbon intensity of electricity generation.

The evolution of the power sector toward a goal of zero carbon

For the power generation sector, the expected pathway to decarbonization is via the use of wind power and solar power supported by grid-scale battery storage. The storage is needed to solve the variability and intermittency of those sources. But there are very challenging hurdles in that pathway. Grid-scale battery storage sufficient to meet the reliability standards[2] of our power grids is probably decades or more away. This is illustrated over the next few pages of this white paper.

The chart below shows the power mix for England (UK) for one week in August 2020. The arrow shows a period in which both wind and solar generation were very low. The difference between demand and supply

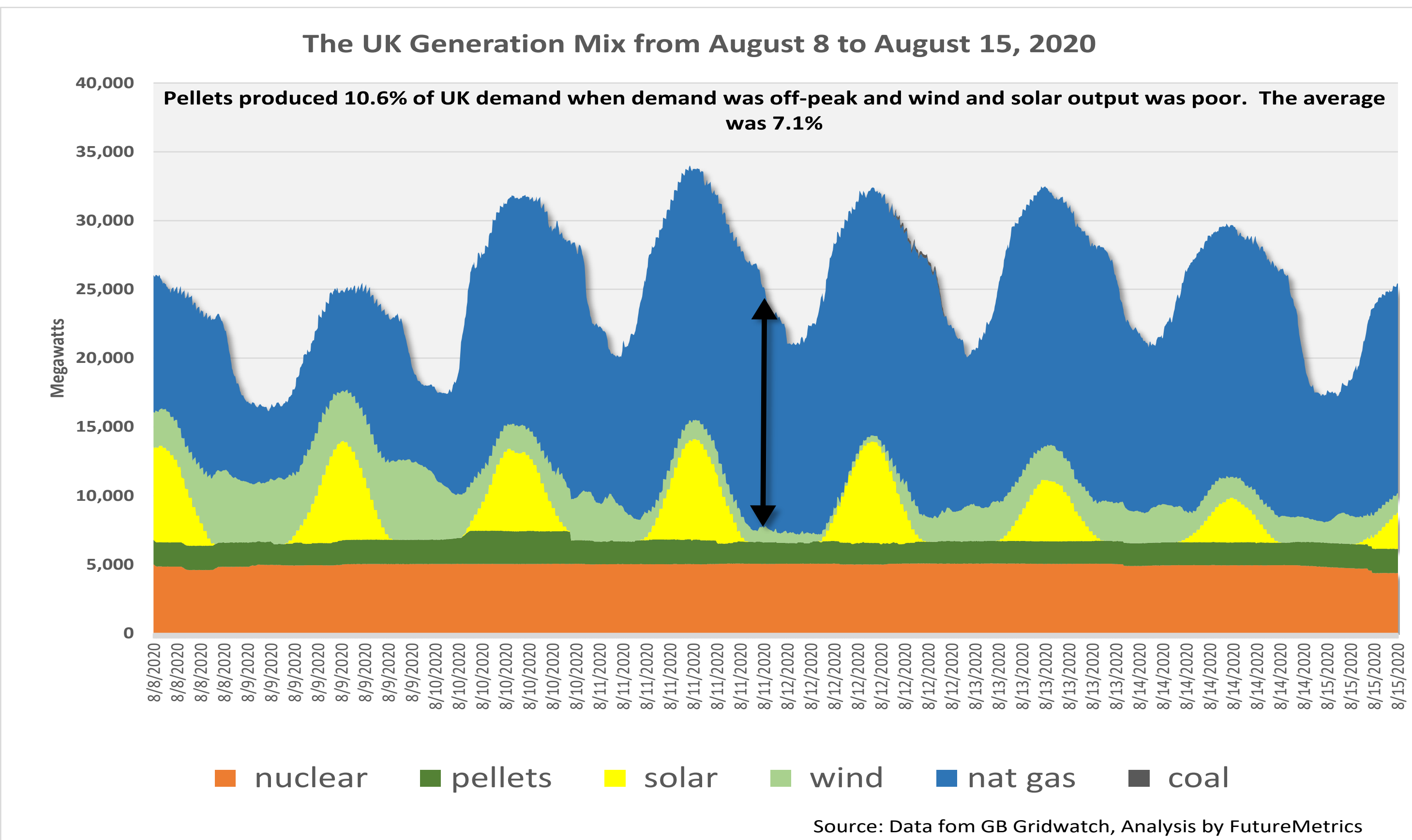
[1] See the recent FutureMetrics white paper on CO_2 emissions and climate change HERE.
[2] Utilities are expected to hold a more or less constant voltage for all users even as demand constantly fluctuates. As is quantified later in this paper, wind and solar need massive energy storage solutions to be capable of independently and reliably powering a stable grid.

from the low-carbon baseload generation (nuclear and wood pellets) plus what wind and solar added to the stack was about 19,400 megawatts. That gap was satisfied with natural gas.

Battery storge would not only have to supply some 19,400 megawatt-hours for many hours but it would have to depend on being charged up during other hours. There is no time in the chart or anywhere in the UK's history where there was more power from wind and solar than there was total demand. In other words, it is not possible unless a lot more wind and solar generating capacity is installed, and very large battery systems are deployed.

The potential for prolonged windless days and the certainty of long winter nights adds to the capacity contingency needed for grid reliability.

The UK is used as an example because another characteristic of the UK mix is the steady reliability of power generated by two large generating stations that use wood pellets rather than coal and the significant proportion of the UK's total demand that is produced using wood pellets[3].



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[3] Used in two large power stations: Drax https://www.drax.com/ and Lynemouth https://www.lynemouthpower.com/. See a number of FutureMetrics white papers about the net CO_2 benefits of substituting pellets for coal at www.FutureMetrics.com.

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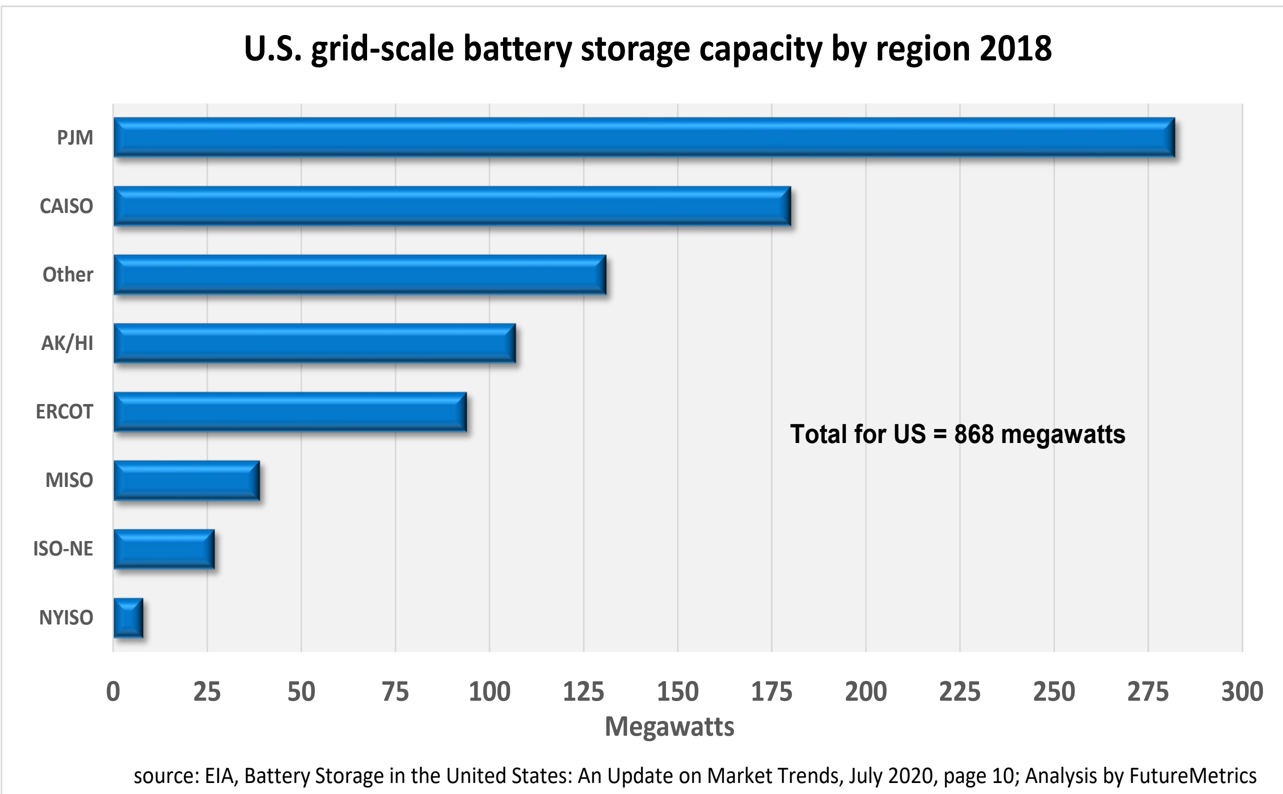
Deploying wind and solar generation is easy to envision. It is the necessary energy storage component that presents a challenge.

The concept of having a large stock of stored power in batteries that can supply power when wind and solar cannot is easy to envision. But there is a vast gap between where we are today and a system that can provide reliable power based on energy storage.

In north America, the regional transmission organization (RTO[4]) with the largest battery storage capacity is PJM[5]. The chart below shows this. The PJM region covers all or parts of 13 states in the US northeast.



Even though PJM leads in the deployment of battery storage, the PJM region still has an exceptionally long way to go to solve the problem of how to replace fossil fuels with wind and solar and battery.

Fossil fuels add well over 50,000 megawatts to supply (see chart below). Wind and solar average output in the period in the chart were 2,836 MWs; far insufficient to recharge the massive and as yet unbuilt 50,000 MWs of battery capacity while simultaneously powering the grid.

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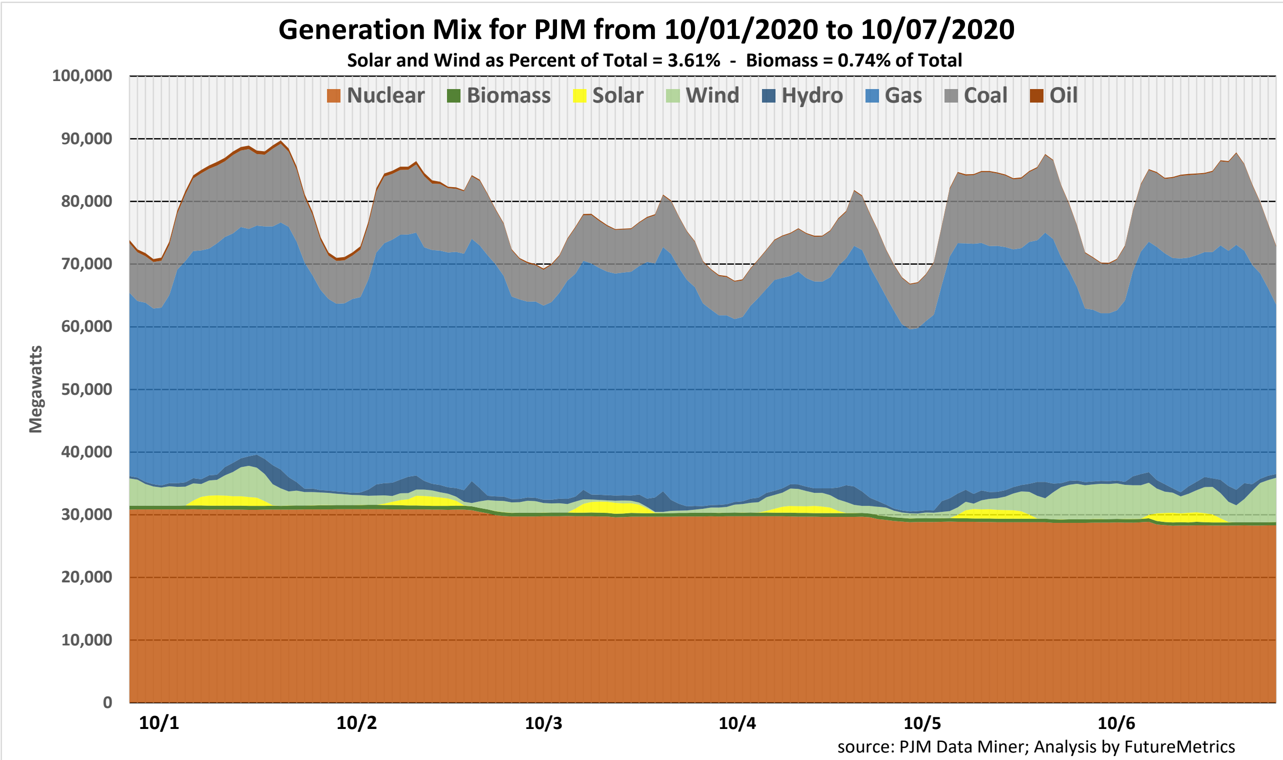
[4] https://en.wikipedia.org/wiki/Regional_transmission_organization_(North_America)
[5] PJM territory served https://www.pjm.com/-/media/about-pjm/pjm-zones.ashx?la=en



It is megawatt-hours (MWh's) that define how long the batteries can provide power. The MWh's stored in the batteries are not from the instantaneous generation of electricity from the conversion of other forms of energy (such as coal, wind, etc.) into electricity. Thus they deplete and have a limited amount of time they can supply power. In the US in 2018 there was 868 MWs of instantaneous grid level battery storage that held about 1,236 MWh's of energy capacity[6] (about 1.4 times the rated instantaneous power capacity). Batteries deplete rapidly when the load is substantial.

PJM's battery storage in 2018 was about 282 megawatts. Assuming that the batteries have to carry most of the load other than the other non-fossil fuel generation (nuclear and, if daytime, solar and, if the wind is blowing, wind), and assuming MWh's = 1.4 x MWs, then 282 MWs of battery will last between 23 and 44 **seconds** depending on if the demand is during peak or off-peak. If the wind is not blowing and it is night, it would be a even less. If all of the 868 MWs of US grid dedicated battery storage that was in place in 2018 were supplying the PJM area they would last between 1.4 and 2.3 minutes (peak or off-peak).

The US Energy Information Administration (EIA) forecasts that the US will have 1,623 MWs of grid-scale battery storage by 2023[7]. If all of that battery capacity were dedicated to PJM and required to keep the lights on if there were no fossil fuel generated power, it would last about 2.6 or 4.3 minutes at current peak

[6] https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf
[7] See HERE.

and off-peak demand. This is assuming that nuclear continues to generate at around 30,000 MWs and wind and solar are generating at the average output that they produce now.

And then the batteries would require recharging even though there is no excess power after what is still generating tries to satisfy demand.

But the system could not satisfy demand. Once the batteries are depleted, if there were no fossil fuel generation, the lights would go out in large areas.

There is a long way to go to be 100% dependent on wind and solar (and nuclear).

Note that PJM's total biomass generation (primarily waste-to-energy) was less than 1.0%. Coal was about 11.8% during the period in the chart above.

The coal fired generating units in the PJM RTO and in the rest of the US (and the world) offer a real potential to supplement baseload power with low carbon generation that is there when it is needed. The experience in the UK, illustrated in the grid mix chart above, and in other jurisdictions that use pellets in what were once 100% coal burning power plants, proves that a strategy for substituting sustainably produced wood pellets[8] for coal is technically feasible.

To make it economically feasible requires that the external costs of CO_2 emissions be internalized into how energy is priced. That is, policy that recognizes the costs of carbon pollution and prices carbon emissions, as discussed in the next section of this white paper, is necessary.

Carbon Taxes!

Most economists agree that taxing carbon emissions is the most efficient and potentially most equitable way to incentivize a transition away from fossil fuels.

Carbon trading schemes such a "cap and trade[9]", can also be effective. A trading scheme sets a limit on the quantities of CO_2 that can be emitted and the regulator issues permits that allow a specific quantity of emissions. The price of carbon is set by trading carbon credits in the markets and that price will vary with supply and demand. This is more or less the opposite of a carbon tax scheme where the price is set by policy and the businesses work out the profit maximizing (or loss minimizing) quantities of CO_2 emissions. Both can be effective, but a carbon tax is a more direct instrument that clearly places the costs of carbon pollution on the polluter while generating easy to define revenues.

In many conversations about policy, suggestions of raising any tax is a "third rail[10]". However, as in all cases with any tax policy, the revenues from the taxes are used to fund government spending. So what matters is

[8] Sustainability is a fundamental and necessary requirement to gaining a carbon benefit. Rigorous certification schemes such as the Sustainable Biomass Program https://sbp-cert.org/ certify that the fuel is sourced so that the combustion of the fuel does not add net new CO_2 to the atmosphere.
[9] https://en.wikipedia.org/wiki/Emissions_trading
[10] https://en.wikipedia.org/wiki/Third_rail_of_politics

how the funds are spent, and who within society benefits and who pays. Taxes are a necessary and fundamental component for supporting and maintaining social well-being if the spending programs they support are defined with social welfare as the primary objective.

A well-crafted carbon tax phased in over several years will obviously result in a net positive to social and environmental welfare in the long term; but it can also be a net positive in the short term as well.

With a carbon tax, it is not so simple that only the polluter pays. There will be negative social welfare impacts from the higher cost of using fossil fuels. For example, lower income households tend to spend a higher proportion of disposal income on energy (transportation, electricity, heating fuels). Furthermore, increased in the cost of production and transportation will likely increase the cost of some final goods. Thus, without an equitable strategy for how the carbon tax revenues are spent, a carbon tax would be regressive in the short term.

In a study from 2015[11], it was calculated that a $40 tax per short ton[12] of CO_2 equivalent emitted would add about $0.36 cents to price of gallon of gasoline (about $0.095 per liter). A $40/ton tax, based on the same 2015 paper, would be expected to add about $0.02/kWh to the average price of electricity. Changes in the power grid's generation source mix since 2015 will likely lower that impact in 2021 (more natural gas, more renewables, and less coal). But there will still be an impact on power costs that, for lower income households, would be a real burden.

Using the substantial revenues from a carbon tax[13] for rebating lower income households based on a measure of per capita income could reverse the regressiveness. Lowering income taxes for some could also be part of an equitable policy.

And some of the revenue could be dedicated to R&D in critical technologies for lowering atmospheric CO_2 concentrations such as energy storage, to facilitate more wind and solar, and biomass carbon capture and sequestration (BCCS)[14].

If well-crafted, and not distorted by special interests, a carbon tax will not harm economically vulnerable households and will accelerate decarbonization.

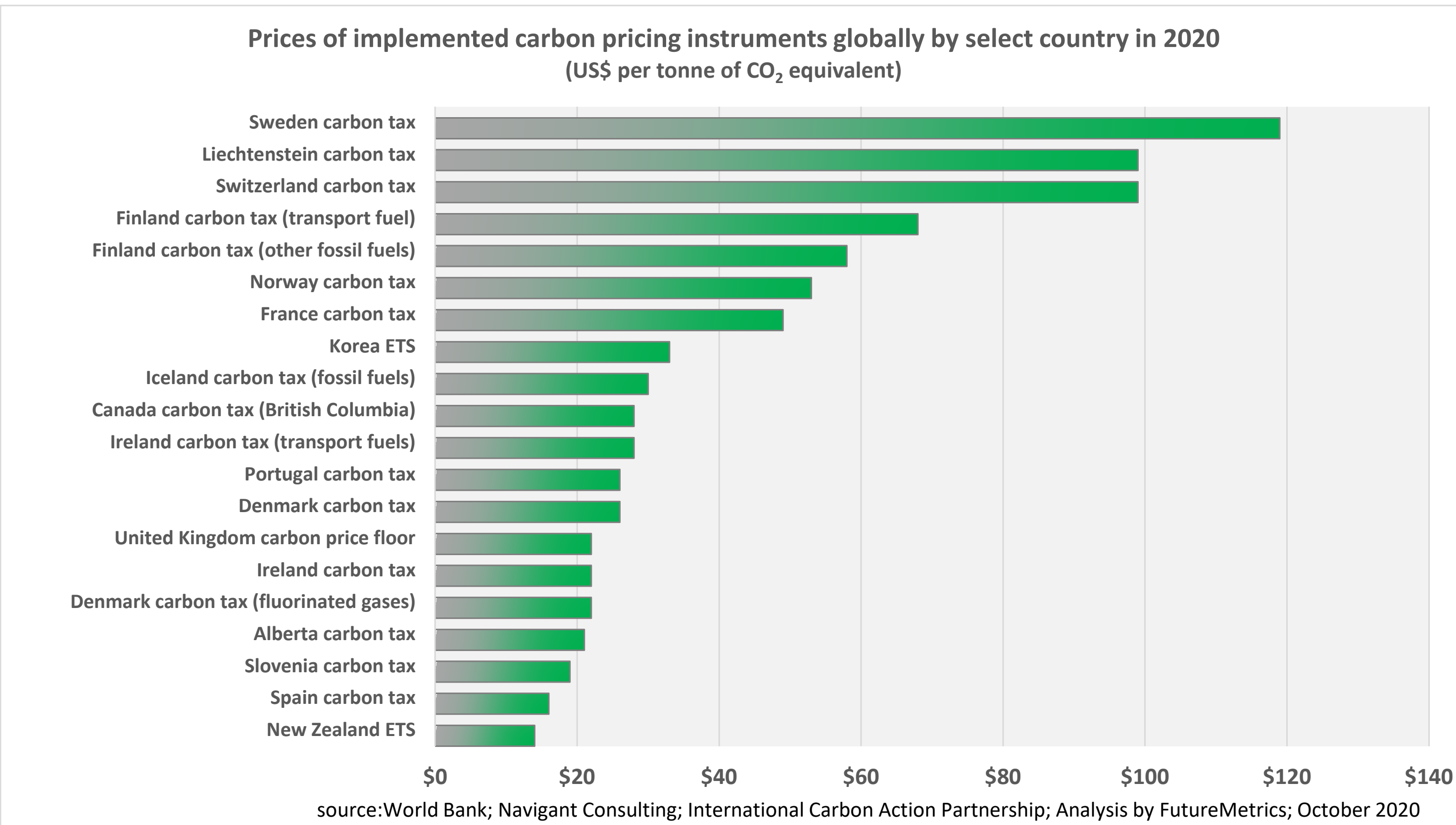
The fundamental purpose of the tax would not change: Polluters would still pay, and the use of fossil fuels would be gradually reduced. How energy is produced and used for manufacturing, transportation, and

[11] "Carbon Taxes and Corporate Tax Reform", Marron, Donad, and Toder; from *Implementing a US Carbon Tax*, pages 141-158.
[12] A short ton is 2000 pounds and a metric tonne is 1000 kg.
[13] In December 2016 the US Congressional Budget Office estimated that starting at $25/ton in 2017 and increasing the tax by 2% over inflation over 10 years would raise nearly $1 trillion in new revenue after accounting for some lost tax revenues. See HERE. By way of comparison, the US GDP in 2019 was about $21.4 trillion.
[14] BCCS is carbon negative while also generating baseload power for the power grid. https://www.nap.edu/resource/25259/Negative%20Emissions%20Technologies.pdf

heating will evolve. The efficiency of energy use will improve. The amount of energy a household needs for a decent standard of living will evolve[15].

If anthropogenic CO_2 emissions are to be curbed, a carbon tax is the most practical, effective, and equitable option for guiding meaningful action soon enough to matter.

Carbon taxes or carbon trading schemes are already in place in many countries that are taking climate change seriously. The chart below shows the most recent data (the US is notably missing).



[15] See "Providing decent living with minimum energy: A global scenario" from Global Environmental Change, November 2020, HERE

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<u>How some existing coal power stations can be part of the transition – Focusing on the United States</u>

This white paper has shown that a simplistic view of wind, solar, and battery as an easy pathway to decarbonization does not capture the real challenges of supplying sufficient and reliable renewable power.

A proven, low cost, and ready to deploy solution is to substitute sustainably sourced biomass solid fuel[16] for coal. FutureMetrics and many others have documented the efficacy of this strategy.

Globally in 2019 about 43,730,000 MWh's of baseload electricity will be produced by wood pellets[17]. The comparison with battery capacity of about 2,272 MWh's in the US in the year 2023 is meaningless.

Every tonne of coal that is replaced by wood pellets lowers net CO_2 emissions by at least 85% in most locations[18] and each tonne of pellet fuel supplies about 4.8 MWh's of continuous renewable on-demand energy.

When (not if!) the US creates policy that will support this well-proven strategy, there are a number of coal stations in the US that could benefit from co-firing or, in selected locations[19], conversion to 100% renewable carbohydrate-based fuel instead of hydrocarbon-based fuels mined from the earth.

This existing fleet could continue to supply on-demand power to balance the grid as wind and solar generation increases. The carbon intensity of the power would be proportionally lowered as the ratio of pellets to coal is increased. That on-demand reduced carbon intensity generation can contribute to goals for lower CO_2 per MWh of electricity while transitioning to that day out in the future when grid-level battery storage is sufficient.

The chart on the next page shows the age distribution of all 529 of the US coal power generating units (some power plants have more than one coal fired unit).

There are 41 units that are less than 15 years old. There are at least three decades of life left in these newer high efficiency units representing about 22,000 MWs of capacity.

Some of these assets can be used rather than discarded to contribute to a lowering of carbon emissions in the power sector.

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[16] Currently this is primarily wood pellets. But in the future biomass solid fuel suitable for large pulverized coal power units may also be produced from other suitable woody and agricultural biomass residues. In some locations, dedicated short cycle energy crops may also provide a low carbon fuel source.
[17] Based on 24 million tonnes being consumed, an average power plant efficiency of 40%, and with an average power station capacity factor of 80%.
[18] See the free FutureMetrics CO_2 footprint dashboard HERE.
[19] There are some regions in the US where coal powered units are located in an area with an abundance of low-grade woody biomass that is sustainably available and well suited for conversion into pellets. These are locations that do not have good logistics solutions for pellet export and thus are not currently considered viable for industrial wood pellet production.

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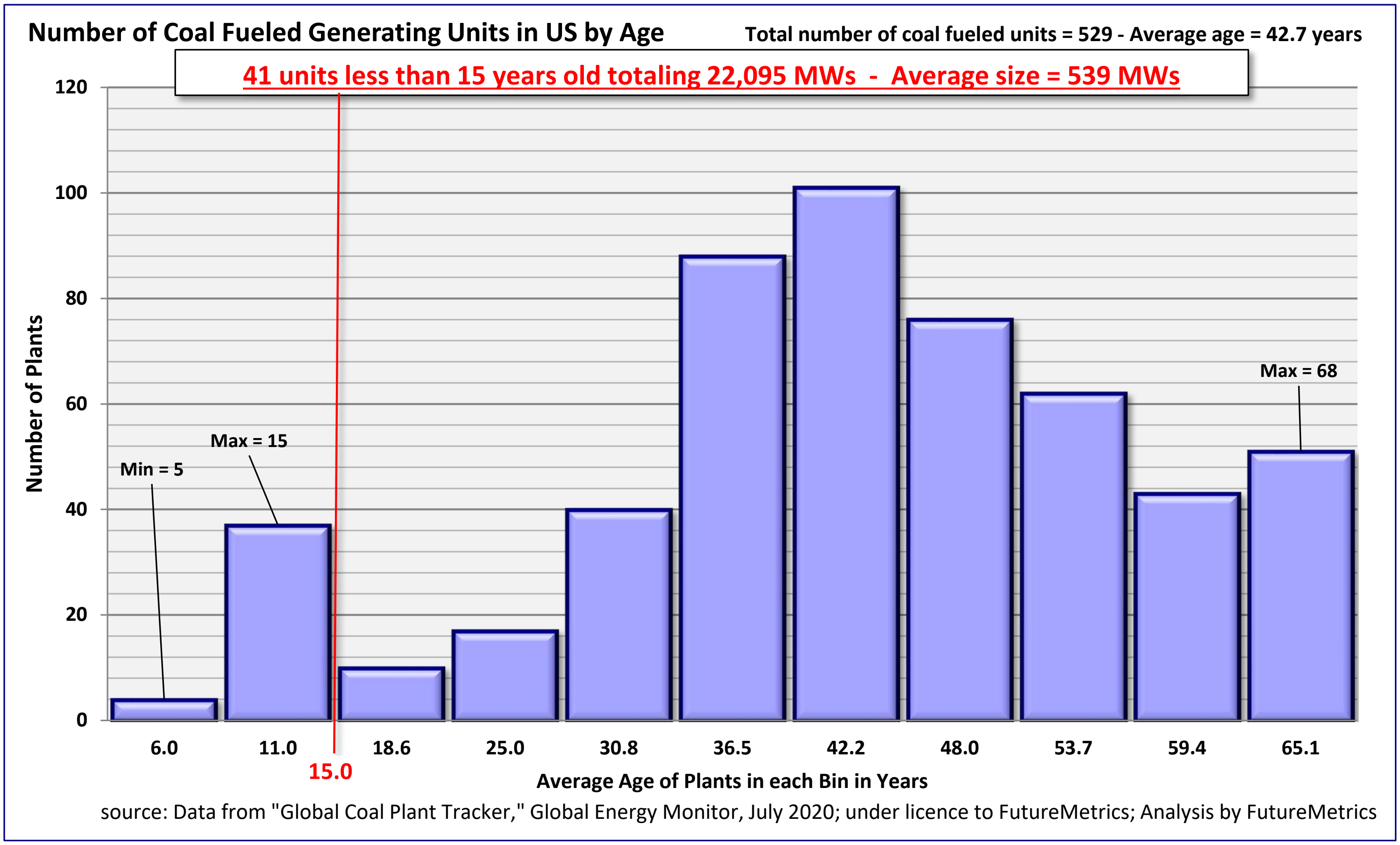


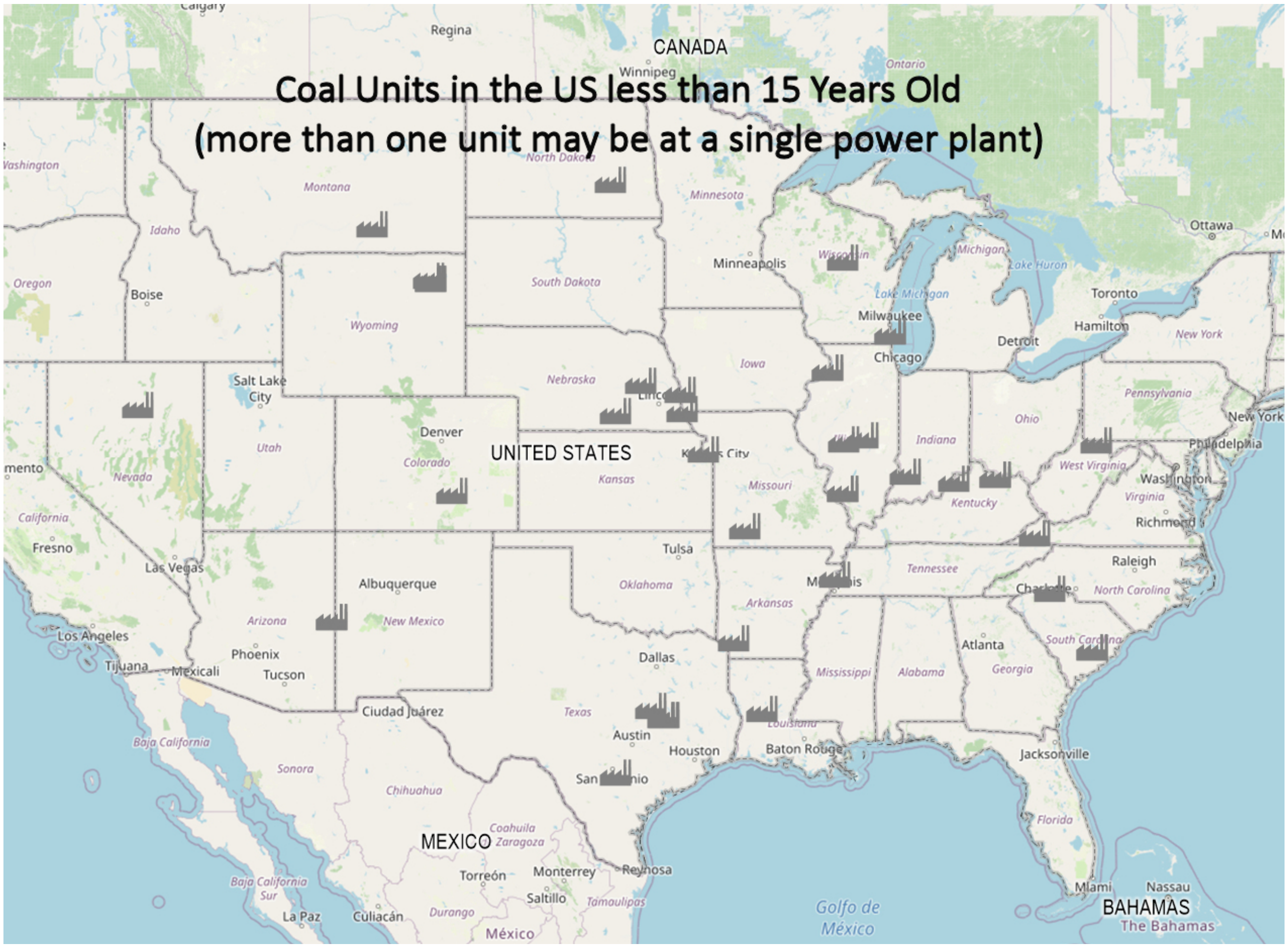
The map on the next page shows the locations of the 41 newer units. Some are in areas with an abundance of otherwise non-merchantable by-products from forestry operations. But those area are too far from ports and/or have no rail or barge options for moving pellets to an export terminal. In other words, there are areas around existing relatively new coal power stations in parts of the US that are capable of producing perpetually renewing biomass based solid fuel for power generation.

If the concentration of available sustainable wood is close enough to the power station, there is no need to make pellets first. Pellets are a way to maximize the energy density in a cubic meter of space to minimize the cost to transport the energy they contain to the power plant. If transport distances are short enough within the wood supply region to the power plant, a processing plant can be located directly next to the power station. Waste heat from the power station can be used for drying the wood and then it only has to be milled to the small particle size that the pulverized fuel system[20] needs for combustion. Pulverized fuel systems are typical in most of the large-scale utility power boilers in coal generating units.

Under that scenario, without an investment in full sized pellet factory, without the operating costs associated with densifying milled dried wood into pellets, and without transport costs for moving pellets to a power plant, the cost of that sustainable fuel will be significantly lower than pellet fuel from farther away.

[20] https://en.wikipedia.org/wiki/Pulverized_coal-fired_boiler

The supply chain carbon footprint of the pellets will significantly lower yielding reductions in CO_2 emissions versus coal of more than 90%.

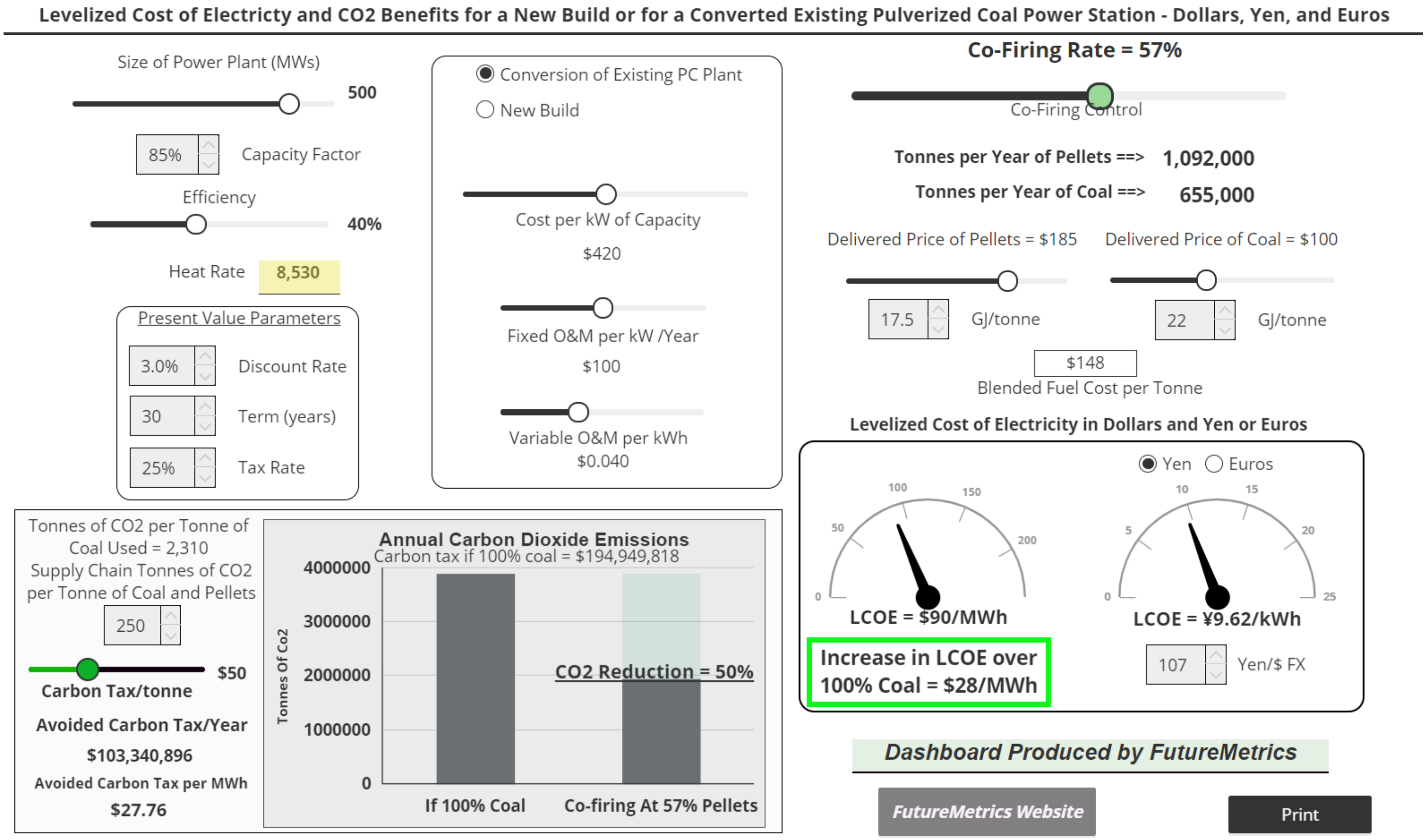


A Google maps version is [HERE]() where you can zoom in on a satellite image of any individual station.

There is no question that currently the cost per unit of energy (gigajoule per metric tonne or BTU per pound) for coal is less than it is for wood pellets. But, as in those jurisdictions that are using pellets for power production (primarily western Europe, the UK, Japan, and South Korea) there is policy in place that compensates the generator for the higher cost of pellet fuel and/or allows them to avoid costs associated with CO_2 pollution.

A combination of policy instruments are used in those countries to compensate the utilities. Feed-in-tariffs (FiT), contracts for difference (CfD), and carbon pricing are common.

The image below[21] shows that if a 500 MW coal station is modified to co-fire pellets, based on the other assumptions in the dashboard including a co-firing ratio sufficient to lower the units CO_2 emissions by 50%, the increase in the cost of generation versus 100% coal is about $28/MWh or less than three cents per kWh.



If only a carbon tax is used, at a rate of about $50 per metric tonne (about $55 per short ton) or higher, the power station would have better cash flows co-firing by avoiding the carbon tax it has to pay on the coal it is consuming. That is, the increase in the levelized cost of electricity (LCOE[22]) versus using 100% coal is fully offest by the avoided carbon tax.

The reader is invited to use the dashboard to experiment with different combinations of inputs including 100% pellet fuel and a significantly lower delivered "pellet" price as a proxy for the scenario described above in which the pellet production component of the conversion from wood to fuel suitable for a pulverized fuel unit is eliminated.

[21] From the free FutureMetrics dashboard HERE.
[22] https://en.wikipedia.org/wiki/Levelized_cost_of_energy

The benefit of a carbon tax is that the revenues, which in the example above would be based on the 655,000 tonnes of coal still being used, will pay for programs described in the opening section of this white paper.

Conclusion

Business-as-usual (BAU) in the case of CO_2 emissions will result in unimaginable negative changes to the world that we and the rest of living things have evolved in. To change that trajectory in time to prevent catastrophic outcomes, effective and meaningful policy has to make change happen in the near term.

Policy is needed because changing is more costly than business-as-usual. Although as the FutureMetrics white paper referenced on page one of this white paper suggests, the increasing frequency and severity of climate change consequences are making BAU more costly anyway. That dynamic will support policy that makes CO_2 pollution costly.

A world powered by wind turbines and solar farms is possible. But not without massive investments in generation capacity and major investment and advances in battery technology. It will likely happen but most likely not in the next decade or more.

Sustainably using the natural solar energy collectors (growing trees and other plants) that convert that energy into carbohydrates and other organic molecules that can be used for many purposes, including energy production, is a solution that is already deployed in some places.

Sensible carbon reduction strategic planning in the US and elsewhere will take a serious look at the ideas in this white paper. Then they should be incorporated into policy.