Notes to accompany talk by Jan Galkowski titled "Choices."
Talk scheduled for 9th November 2020, in the evening.

Slide 1. Thank you to the Walpole Greens for hosting this meeting and inviting me to speak. My name is Jan Galkowski, a resident of Norfolk County, in Westwood. I have a Masters in EE & CS from MIT, specializing in Artificial Intelligence (1976), additional graduate work in Maths, signal processing, numerical linear algebra, geology, and coursework in biology, geophysics. I have a Bachelors in Physics and took Botany as well.

"Choices." What's this about? This talk is about controlling your economic future, quite possibly your own, but certainly that of Walpole and Norfolk County. There are inexorable economic changes coming regarding the cost of energy. These changes are driven *primarily by technological innovation*, **not** by concern about climate disruption. To the degree businesses and households are aligned with those changes, and aligned now, they'll have some control over how this plays out. Otherwise they won't. And in those cases no government, no activist group will be able to push back against the economic onslaught.

Now I need to try to convince you that this hyperbolic hypothesis is true.

Slide 2. *Keeling Curve*. Concentration of Carbon Dioxide, or CO_2, in atmosphere, here shown as a series of monthly averages. This is MLO but this same chemical procedure is done a few times a day at each of a dozen and half stations around the world, including Antarctica. Now also measured using different techniques by satellites. Developed by Dr Charles David Keeling, and continued by many, including his son, Dr Ralph Keeling.

Currently at 415 ppm CO_2 ... this is humanity's legacy.

Note the sawtooth pattern on the curve. That's a feature highly pertinent to this talk. I don't have a close-up in this slide deck but this zigzag has a low in October and a high in April-May, corresponding to rough beginning of Autumn, Northern Hemisphere, and Spring. This is interpreted to be the effects of the Northern Hemisphere forests – *All* of them. Beginning with growth in the Spring, they take in CO_2 from April through October and then give it back. Note the inexorable climb in concentration. Note how small the contribution is from all northern forests. Suppose the number of trees and ecosystem was doubled. Yes, the sawtooth swings would be roughly twice as big in amplitude. But the steady increase would still dwarf these.

Sure, if the doubling was newly planted, there would be some decrease in the slope of the curve … For about 60 years. Then it would continue to climb as it does now, assuming Carbon-based greenhouse gas emissions didn't increase.

By the way, this is the contribution from the *northern* forests because there is more land there, a bigger Temperate zone.

And note, too, there are no inflection points corresponding to political changes anywhere, or to approval of the Paris Agreement. There's just steady, accelerating climb of concentrations.

Slide 3. Where does CO_2 come from? Primarily combustion primarily of fossil fuels. There's a chunk that comes from producing clinker while making cement. There's a chunk that comes from agriculture … Not tractors or processing or transport, just agriculture. Rice cultivation, for example, produces a lot of methane (CH_4).

We know these are the sources of the excess CO_2 because of its isotopic chemistry and that of the isotopic chemistry of fossil fuels themselves.

But here, on this slide, looking at *life cycle emissions* of various energy sources, not just direct emissions. So, a natural gas combined cycle plant has steel, concrete, and is fed gas by pipelines or trucks. The latter need to be built, so the emissions attending them are part of its life cycle emissions. Gas is mined, cleaned, and the drilling, fracking extraction, and what all else, including pumping it along pipes, all produces emissions. And pipelines leak, and sources of natural gas also leak. CH_4 is also a byproduct of oil drilling and development. It's often burned off by flaring.

Note the comparison for various energy sources, dominated by fossil fuels. Also note N_2O, or Nitrous Oxide. Note, too, that contrary to misinformation you can find on the Web, the idea that solar PV and wind turbines have life cycle emissions bigger than fossil fuels is ludicrous.

Life cycle emissions are not limited to energy production. Comparing plastic bags with paper bags, the life cycle emissions of the paper are much worse, not only in manufacturing, but in transport. Paper bags are heavier.

Slide 4*.* Combustion of fossil fuels has other consequences. Consequences for human health and natural systems. Here a forest has been killed by emissions from a coal-fired electricity plant. In greater Boston there are a lot of leaks from natural gas pipelines. These emissions kill trees and other vegetation. High concentrations of CO2 in atmosphere cause extreme ocean acidification, and changes to climate. 1-2 billion people use fish and shellfish as their primary source of protein. Increase CO_2 in atmosphere to 1000 ppm or higher, and even if emissions are then stopped entirely, that'll be enough CO_2 that will dissolve in oceans and will kill most fish.

But this is not a climate talk. I can do a climate talk, but not tonight. That needs more time. What should be noted is that many state governments are committed to limiting emissions of greenhouse gases, and invariably this entails electrifying the energy sector top-to-bottom. That sets the landscape.

Slide 5*.* As mentioned, CO_2 is our legacy. Not commonly appreciated is its persistence in the climate system. It remains in atmosphere a long time, and even when drawn down into oceans, it remains in equilibrium with atmosphere. This chart shows calculations of the following experiment. Put a pulse of 480 ppm CO_2 into the atmosphere instantaneously. ("Instantaneously" means in less than 100 years.) Then stop. Baseline was 288 ppm.

This takes a long time to come down, and the first 200 years of it is some of the CO_2 going into oceans. That going into oceans is reversible, because if someone figured out how to extract CO_2 from atmosphere separately and artificially, it would come back out of the oceans, at least if it was left there for any time shy of 1000 years.

We are less than 50 years away of having concentration of CO_2 be 750 ppm. Literal concentration of CO_2 may be 415 ppm at present, but actually it's more like 500 ppm. That's because there are other Carbon-based greenhouse gases in atmosphere like CH_4. These eventually convert to CO_2.

An interesting perspective is that if there were a scientifically advanced civilization elsewhere which could observe Earth from a distance, they could tell by the building of CO_2 in atmosphere what was going on, and it would be seen as a signature of "intelligent life". That's because while natural processes can dump CO_2 into atmosphere – end-Permian mass extinction, for example – they generally take several centuries to do so.

Slide 6*.* Carbon accounting. Will present about sequestration of Carbon by trees, and not CO_2. CO_2 is just the way Carbon gets into trees.

So need to go from CO_2 to Carbon. To get an amount of Carbon from a given amount of CO_2, multiply it by 0.273. To get an amount of CO_2 from a fixed amount of Carbon, multiply by 3.67. See, each CO_2 weighs 44 units, a Carbon atom weighs 12 units, and an Oxygen atom weighs 16 units.

Humanity emits 15 billion tonnes of Carbon each year. A "tonne" means a *metric* ton, or 1000 kilograms. That comes from emitting 55 billion tonnes of CO_2 each year.

Of the 15 billion tonnes of Carbon, 2-3 billion tonnes per year come from agriculture. That's not tractors or transport or processing, that's just growing. Rice cultivation, for example, produces a bunch.

Of the 15 billion tonnes 2.2 billion tonnes are produced per year while creating cement.

All natural processes … plankton in oceans, trees and plants on land … grab just 2 billion tonnes, and most of it gets released eventually. (Plankton for the most part don't have annual cycles like northern temperate forests do.)

Slide 7. Forests and oceans sequester Carbon, but slowly by human time scales. They keep things in equilibrium if the sources of CO_2 are steady, natural ones. But they are incapable of keeping up with 450 ppm increases over a couple of centuries.

Measurements show that Old Growth Forests ("OGF") sequester 2 tonnes/acre/year of Carbon. An OGF is 180-200 years old, and is *undisturbed*. For example, put a trail through an OGF, and none of the soil under the trail and the forest for a couple of meters to either side of it stops sequestering. Indeed, it becomes a CO_2 *source*.

Young Growth Forests ("YGF") do some sequestration in their above-ground biomass, and some in soils, but the next effects depend when they are measured. For example, if a YGF is growing back after a felling of OGF trees, or if an OGF is burned in a wildfire, the YGF will grow back, but for decades it will be a CO_2 source since the Carbon sequestered in soils by the OGF is now oxidizing. Soils sequestration depends upon action by fungi and microflora in soils. Disturb them or their diets, and they get replaced by another set of microflora who are interested in other things than Carbon sequestration.

Slide 8. Thinning of OGF suffices to shut its Carbon sequestration down. Also, clearing downed trees turns an OGF into a YGF, at least in the vicinity of the clearing.

Infections of forests by Woolly Adelgid suffices to shut Carbon sequestration down.

The Fisher Street forest is evidently a YGF. This is a direct measurement from recently downed, *big* trees.

Slide 9. Electricity production in Massachusetts and its sources over time. Note growth of natural gas as a source of production. Solar and wind are still minor. The Massachusetts Global Warming Solutions Act ("GWSA") says need to achieve emissions reduction so only putting out 20% of 1990 emissions by 2050.

This is challenging. Will hear more from the Baker administration and its EEA about this in mid-December. Long way to go.

This slide covers nothing about transport or heating. But the solution here – and in most places – is they they will try to electrify everything. There is some interest in solar thermal and geothermal as heating sources, but these are not universally available.

And even if that only partly succeeds, they who control the cheapest electricity control everything, at least from an economic perspective.

Slide 10. Not hard to see why solar take-up is slow. There have been aggressive incentives for residents and businesses to put solar on their roofs for most of the last decade. People with great roofs for it don't want to invest in solar PV. The incentives are now tapering. Why? Because on the face of it, investing in solar PV on your roof or in your yard is a profit-making choice. DPU and utilities feel that if people haven't jumped on this with the incentives there for so long, they are reluctant to do so for other reasons. They obviously don't want a positive stream of income.

Of course, residents and businesses still use electricity. And with EVs and other electrical appliances growing, they'll need more. The GWSA implemented by Massachusetts E.O. 569 expects to electrify all retain transportation and all home heating.

Slide 11. Fossil fuel power plants are located in poorer towns than many of the towns that consume a lot of electricity. Emissions harm locals but provide them with great views of belching smokestacks. Fair is fair. But I'll quote a resident of Maine later to convey what I think about this.

Slide 12. This is the Fisher Street solar PV proposal. If you look north of it, there are two or three developments nearby, but 200 feet away through woods. Let's look at those.

Slide 13. This is north of the Fisher Street proposal. These are large homes. Some have pools. Forest needed to be cleared to provide the land for development. Obviously, people need to live somewhere. But as noted earlier, there are plenty of incentives for people to put solar PV on their excellent roofs. But they don't.

Slide 14. This is east of the Fisher Street proposal. Smaller homes, east of North Street. *Some* have solar PV! Indeed, this is a trend. In Massachusetts, if someone has a large home, they are less likely to have solar PV. There are exceptions … including Dave Green's home in Dover, and …

Slide 15. This home east of North Street, at 1260. Note the stacking of panels. Stacked panels need less overall land area for the same production, but suffer higher wind loads because they are taller. Note 1260's panels *can be seen from North Street*.

Slide 16. Norfolk County solar project. Kearsarge. The North Street 5 MW site removes essentially no trees. Fisher Street 1 MW proposal does. I judge production at 200 MWh/acre/year. That's estimated from specifications of other utility scale projects.

Some clarification about units. MW or kW is a unit of *power*. That is energy-per-unit-time. Accordingly to get energy, you multiply by time, and you get MWh or kWh. MW is megawatts, or 1000 kilowatts. MWh is a megawatt-hour or producing at 1 MW for an hour. 1000 kWh is 1 MWh.

Estimates of emissions are 0.112 tonnes Carbon per MWh for Eversource electricity. Using the estimates for sequestration of Carbon in OGF and YGF, can convert these into how many MWh per acre per year get offset by a forest of the indicated type. Since a solar PV array emits nothing in its operations, and there is an energy estimate of 200 MWh/acre/year can make a direct calculation of how many days of operation of a PV array per year it takes to match the sequestration of a forest of the indicated type.

Slide 17. Renewable energy on land does not need to be its only purpose. Also it's possible to put PV arrays on ponds. Agrivoltaics works if people are trained to do it. Farmers appreciate the income that comes in as a steady stream. Same with wind turbines which, in upstate New York at least, often coexist with dairy cattle and other grazers.

Some crops actually do better growing under solar panels than in direct sun.

Slide 18. Now the Commonwealth has its GWSA and E.O. 569. Reduction of emissions was supposed to come from electrification and converting electricity generation almost completely to zero Carbon sources. The package was originally supposed to be wind+solar+hydropower. Land wind has not developed as much as sought, except in a couple of places, due to opposition. While rooftop solar has developed some (80,000 homes) and is considered an important and useful energy source by ISO-NE, need utility scale solar. Alas utility scale solar is running into opposition, like the opposition in Walpole and in Westwood.

Cannot get to Massachusetts clean energy goals by just going all rooftop solar without land based wind or utility scale solar. There isn't enough industrial land or brownfield to do it either. So all that's left is offshore wind and hydropower. The hydropower is to come from Quebec and New York State.

Unfortunately, hydropower needs to be brought here. An attempt to run it through NH was rejected by its residents. There is an active plan to bring it through Maine that's won government approvals, but also an active opposition. There is an attempt to mount a second referendum to repeal authorization to build the CMP line through Maine.

Slide 19. The updated plan is supposed to be revealed by EEA in mid-December 2020. Briefings I've attended indicate it means doubling the amount of offshore wind to be constructed, and also doubling the amount of hydropower from Quebec. This means, in addition to tapping the entirety of one existing dam, two more will be built. This will fell hundreds of square miles of forest and wetlands, by having reservoirs behind the dams which drown them.

Nick Bennett, staff scientist at Natural Resource Council of Maine recently summarized a view with which I agree: "Part of the problem here is that Massachusetts has been real slackers in terms of building wind [and utility scale solar] in their own state. They need to build onshore and offshore wind [as well as utility scale solar] and top exporting responsibility for generating their own clean energy to other people."

Slide 20. Well, there are potentially other options. There is a possibility that small modular nuclear reactors based upon a new design could serve. NuScale is a company which is building trial reactors of this design in Idaho and in Utah. Two such reactors would power all of Norfolk County, even with EVs and other new draws, like air-source heat pumps. The space footprint is not large. They don't need to be necessarily seen. They combine clean baseload electricity with small visual impact.

Slide 21. Alas this hasn't been built yet. The promise of NuScale and the other modular nuclear reactor designs was that construction costs would be significantly less per MW than conventional nuclear power, and time-to-build significantly shorter. But, as of this last week, the Utah project has slipped schedule for 3 years and seen its costs increase 50%.

Slide 22. And this appears to be continuing the pattern that all nuclear power everywhere has shown: A negative learning curve. What I mean is that if you build many things of roughly each the same kind, you'd think that you'd get better at it, and the *n*th copy would be cheaper than the earlier ones, and be built faster. But this is exactly the opposite of what happens in nuclear power. This chart shows this, and the costs have been adjusted to take out effects of increased safety, environmental regulations, and reviews.

Slide 23. So, back to other clean energy sources. By 2030 wind and solar with battery storage will have a *cost of construction* per kWh which is cheaper than the *cost of operation* of fossil fuel electricity.

Slide 24. Moreover, by 2030 the cost of construction of wind and solar with battery storage will be appreciably less than the *cost of transmission* from utilities. Think of what that means: Building wind or solar nearby to power your business or factory will be cheaper than plugging into the grid. And, once built, cost of operation of wind+solar with batteries is essentially zero, especially for solar.

Slide 25. Intermittency. Not enough time here to go into this in detail. Solved by overbuilding beyond need and limited battery storage. This works and it has important economic consequences. Even in New England, for a good many days, it means such power facilities will generate electricity *with a negative price*.

Slide 26. I'm planning on teaching a course in Summer 2021 on how all of this can be done for the world, based upon Professor Jacobson's new book.

Slide 27. A lot of people have worked hard to protest fossil fuels. But it's clear we need energy, and if it isn't natural gas, it has to be *something*. There's also a direct conflict between the MA GWSA and some national sentiments. There may be little help from there.

Slide 28. Thank you. This is the solar array at Walt Disney World. This one consists of 500,000 solar panels. WDW is planning to become completely self-sustaining with zero Carbon energy. They are planning to build another. Note they needed to cut down trees.

But I gotta tell ya, this is a good example of what might be coming. Sure, Disney effectively owns all their own property, but if you had a company, like Medtronic or something comparable which, in 2030, wants to generate all their own electricity independent of the grid because it's 6X cheaper and needed land to build it on, what do you think they would offer for a couple of forests?