What You Really Need to Know About Renewable Energy

(That the Pembina Institute Won't Tell You)

Second Release, October 2021

About

Friends of Science Society is an independent group of earth, atmospheric and solar scientists, engineers, and citizens that is celebrating its 19th year of offering climate science insights. After a thorough review of a broad spectrum of literature on climate change, Friends of Science Society has concluded that the sun is the main driver of climate change, not carbon dioxide (CO_2).

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Introduction and Overview

In August 2020, the Pembina Institute published a report titled *Renewable energy—what you need to know.*[1] The report opens with the claim that "There are significant opportunities to supply the majority of Alberta households and industries with reliable, cheap, and clean electricity," and it goes on to say that, "With the falling costs of solar and wind energy, our electricity sector has entered a new reality where renewable generation is the most economical source of new electricity generation for the province." ***Pembina's so-called "new reality" is a fantasy, and a dangerous one at that.*** Jurisdictions that have shut down reliable fossil-fueled and/or nuclear generation in favour of wind and solar have seen skyrocketing electricity prices and have faced (or at the time of this writing are facing) severe energy shortages along with consequential economic losses and, sadly, loss of life.

The authors of Pembina's report prove the old adage that a little knowledge is a dangerous thing. Most of their statements contain a modicum of truth, so many Pembina readers may have become convinced that the authors understand the physical and market operations of Alberta's electric power system. Based on *Renewable energy* and a Pembina document referenced therein titled *Baseload myths and why we need to change how we look at our grid,*[2] they clearly do not: their analyses ignore critical details, use cherry-picked data,[3] fail to acknowledge the massive and ever-increasing implicit subsidies that Albertans are providing to wind and solar generators, and ignore the crucial role played by fossil-fueled generators—the very generators that many green-energy advocates love to hate—in allowing wind and solar generators to operate in the first place.

This rebuttal of *Renewable energy* and *Baseload myths* is considerably longer than those two documents. The reason is that refuting false or misleading statements often takes more time and ink than it takes to make the statements in the first place, and that is certainly the case here. The effort is necessary, however, because Pembina receives a large amount of taxpayer and private funding, it uses that funding to produce grossly misleading reports, and then it pushes for government policies based thereon.[4] While Pembina proclaims on its website that "We provide our expertise to industry and government leaders, and we advocate for a strong, science-based approach to policy, regulation, environmental protection and energy development,"[5] science and expertise are nowhere to be found in *Renewable energy* or *Baseload myths.* Perhaps competent and objective analysis was too much to expect, given that the funders of Pembina's work were the Municipal Climate Change Action Centre, Energy Efficiency Alberta, and Environment and Climate Change Canada.[6] These entities are almost certainly biased in favour of "climate action," and they probably have little or no understanding of what it takes to operate a safe and reliable electric power system.

In addition to being somewhat lengthy, this document makes extensive use of quantitative analysis. We are well aware that math was not everyone's favourite subject in school, but real-world data and sometimes-complex quantitative analyses are essential elements in the design, construction, and operation of modern energy systems. They are also critical inputs to public policy discussions, at least if we want those policies to be rational and to serve the public interest.

It is <u>imperative</u> that we not base public policy decisions on the sort of hand-waving arguments and inept analyses contained in *Renewable energy* and *Baseload myths.* We cannot run a modern society on energy systems that depend to a large extent on the whims of the wind and the sun, no matter how much green-energy zealots would like it to be otherwise. ***The economic and social well-being of our children and grandchildren, and maybe even their lives, depend on us getting this right.***

This report consists of several parts. It will be updated when new parts become available. Please note that the final content of future parts may change a bit from what is set out here.

- In Part A, we discuss the serious flaws in Pembina's evaluation of solar energy. We explain why the number of Alberta homes that can be reliably served by solar energy alone is zero, we show that southern Alberta solar resources are not equivalent to those in Miami or Rio de Janeiro by any useful measure, and we show that paying for the energy storage needed to turn solar generation into a reliable electricity source using today's technology would put the purchase of electricity beyond the financial reach of most Alberta families.
- In Part B, we discuss Pembina's inept analysis of the simple but critical concepts of "base load" and "baseload generation," and we show that renewable generation is the cause of—not the solution to—the increasing need for more flexible (and more expensive) generation in Alberta. We explain why Pembina's views on these topics are in direct conflict with sound engineering and economic principles. We briefly introduce Pembina's seriously flawed analysis of the roles of baseload generation and renewable generation in an energy emergency event that occurred in 2017.
- In Part C (to come), we will examine Pembina's analysis of the energy emergency event in more detail. We will also review the reliability-related characteristics of various types of generation. Finally, we will discuss how the energy market, the *ancillary services* market, various automatic control systems, and the system controller work together to ensure system reliability. Not surprisingly, Pembina gets this wrong, too.
- In Part D (also to come), we will examine how wind and solar generation negatively affect other generators and drive up costs for consumers. Contrary to Pembina's claims, wind and solar are not the most economic sources of new generation for Alberta, at least if we want the lights to come on when we flip the switch.

The overall conclusion of our analysis of *Renewable energy* and *Baseload myths* is that Pembina's reports are wholly unfit for educating readers on power-system operations and reliability. Basing significant public policy decisions on Pembina's so-called expertise will almost certainly have dire social, economic, and perhaps even life consequences for Alberta families and businesses.

PART A: PEMBINA'S EVALUATION OF SOLAR ENERGY IN ALBERTA IS WRONG

Most, if not all, of the press releases we've seen for renewable energy projects make a claim that goes something like, "This project will supply enough clean electricity to power [insert number here] Alberta homes for a year." For example, Pembina's *Renewable energy—what you need to know* claims on page 1 that wind farms secured through the Alberta government's Renewable Electricity Program will generate enough electricity to power 555 000 homes. And on page 3, it asserts that 100 000 MWh is enough to power 15 700 Alberta homes for an entire year.[7] In reality, wind and solar projects can reliably power no Alberta homes at all.

A.1 Solar energy projects cannot reliably serve any homes at all.

Claims like Pembina's are examples of the half-truths that pervade green-energy advocacy. The reason they are *half*-truths is that producing a sufficient amount of energy over the course of a year solves only half the problem of providing a reliable supply of electricity. To solve the other half, the energy must be delivered when and where it is needed. To see how (obviously) critical the other half is, imagine that a meal service company promised to meet your food needs for all of last year. If it delivered way too much food in the summer, about the right amount of food in the spring and the fall, and way too little food in the winter, it might well have delivered enough food over the whole year—but in no sense did the company meet your nutritional needs, especially if it occasionally delivered no food at all for days at a time.

The obvious solution to the timing difference between the need for food and its availability is to store the summer surplus for winter use. Similarly, to provide a reliable supply of electricity for a year, solar energy must be stored for use when the sun is not shining. No one wants to live in a home that has no electricity on cloudy days or after sunset, and no one wants to be forced to cut their electricity consumption dramatically during Alberta's cold winter months. So, ***any claim that solar energy by itself can reliably serve any Alberta homes at all is simply wrong.***[8]

While Pembina acknowledges that storage is required in a "clean energy portfolio," the authors conspicuously fail to consider that the energy storage needed by solar generators today is in the form of fossil fuels and is paid for, not by those generators (as should be the case), but by Alberta ratepayers through one of several implicit subsidies that renewable generators receive. As we will discuss after rebutting Pembina's claim that solar resources in southern Alberta are equivalent to those in Miami and Rio de Janeiro, properly attributing the cost of storage to solar generators would scuttle any notion that solar is among the cheapest forms of new generation in Alberta.

A.2 Alberta's solar resources are *not* equivalent to those in Miami or Rio de Janeiro.

The Pembina report states on page 1 that "Alberta has some of the best wind and solar resources in Canada. In the southern half of the province, solar resources are equivalent to those of Rio de Janeiro and Miami." On page 2 there is a self-produced map of solar resources in Canada that shows parts of Alberta falling into what Pembina calls the "excellent" category. While southern Alberta's solar resources may be excellent in a Canadian context, they are far from excellent when considered in a broader geographic context.

Annual Photovoltaic Potential

Figure A1 is a map of the photovoltaic power potential in North America.[9] Southern Alberta's potential, which lies in the 1400 to 1600 kWh/kWp range, is well below the 1900 to 2100 kWh/kWp that is available in parts of Arizona, New Mexico, Texas, and north-central Mexico.[10] In fact, the map and its legend show that southern Alberta solar is no better than middle-of-the-pack. Pembina's own map not only misleadingly claims that southern Alberta solar resources are "excellent," it extends that claim to include a large swath of land east of Lake Winnipeg and into northwestern Ontario whose solar potential is as low as 1300 kWh/kWp, even though it excludes much of the land to the north and east of that swath that has that same potential. By doing so, Pembina exaggerates the geographic extent of the best solar resources in the country.

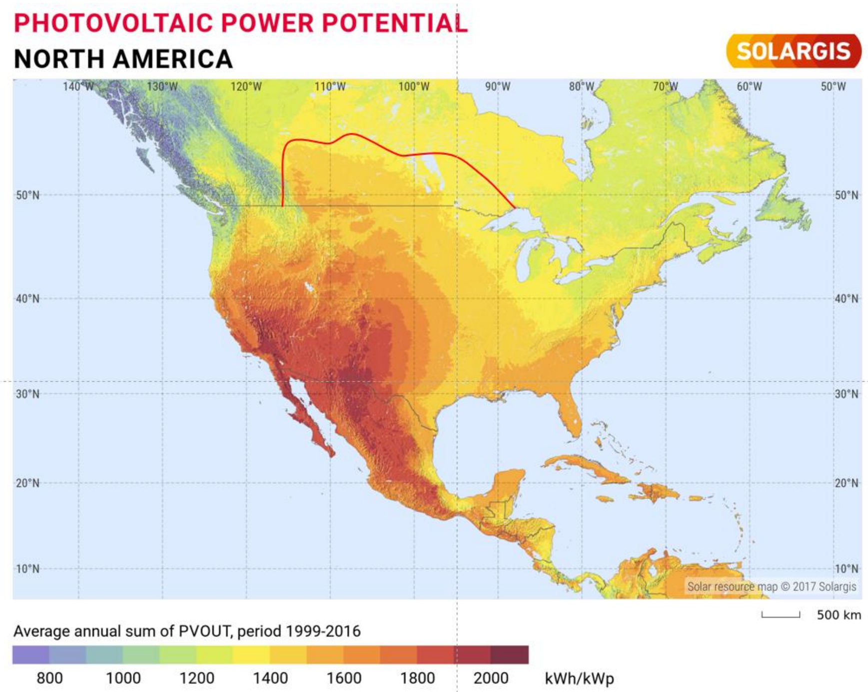


Figure A1: Photovoltaic power potential for North America. The red line, which was added by the authors of this document, shows the approximate extent of Pembina's "excellent" resources in Canada.

Rough equivalence of solar photovoltaic potential does not tell us everything we need to know anyway. With respect to Miami, many comparisons are possible because solar systems can be configured in many different ways and can be placed in many different orientations relative to the path of the sun across the sky. If we assume identical arrays with two-axis tracking,[11] a Miami system produces ~15% more energy on an annual basis than one in Medicine Hat.[12] If south-facing rooftop solar is assumed, then a Miami system produces about 25% more energy.[13] As for Rio de Janeiro, where a two-axis array produces about the same amount of energy per year as a similar array in Medicine Hat, it is simply one of thousands of middle-of-the-pack locations that southern Alberta could have been compared to. In the global context (see Figure A2),[14] most places in south-east Asia have poor solar energy potentials—despite being in the tropics—because they are cloudy much of the time. On the other hand, most of Africa, the Middle East, and Australia have far better solar resources than southern Alberta. Using the term "excellent" to refer to southern Alberta solar resources is disingenuous.

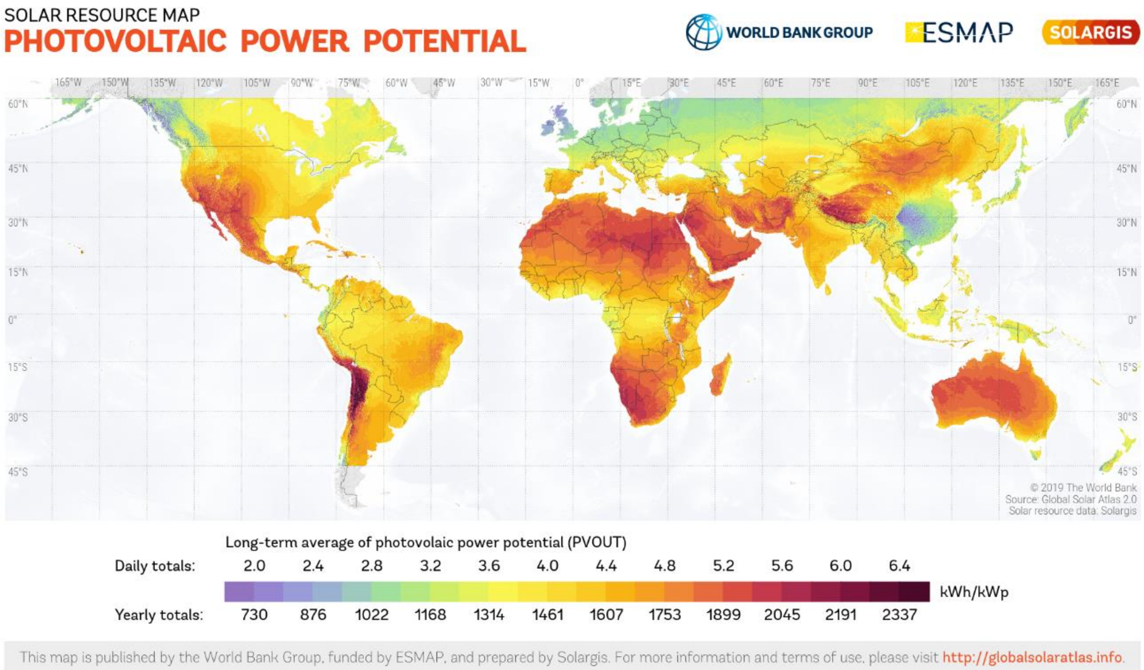


Figure A2: Global solar photovoltaic potential.

<u>Seasonal Variations in Solar Energy</u>

Even if we assume that a Medicine Hat solar energy system produces “close enough” to as much energy as an identical Miami system, we have addressed only half the supply problem. To see how large the other half is, let’s assume we want to serve a customer in Miami and a customer in Medicine Hat who each consume exactly the amount of energy produced by their own solar panels over the course of a year. To keep things simple we will assume (for now) that each customer’s consumption is the same in all 12 months. Since a 6 kW rooftop-mounted solar array in Miami produces 9312 kWh in a typical year, while the same array in Medicine Hat produces 7368 kWh,[15] we will assume that the customers use 776 and 614 kWh per month, respectively.

Let’s look at the Miami customer first (see Figure A3). In January, her solar panel produced 701 kWh, so there was an energy shortfall of $776 - 701 = 75$ kWh. (We will talk about how that shortfall was handled shortly.) In February, the panel produced 705 kWh, the shortfall was 71 kWh, and the cumulative shortfall for the first two months was $75 + 71 = 146$ kWh. In March the panel output was 887 kWh, which was 111 kWh more than usage, so the cumulative shortfall decreased to $146 - 111 = 35$ kWh. April’s 890 kWh output resulted in a surplus for the month of 114 kWh and caused the cumulative shortfall to switch to a cumulative surplus of 79 kWh. Similar calculations for the remainder of the year show that the peak cumulative surplus of 276 kWh was reached at the end of August and that energy shortfalls from September through December consumed it. By the end of December, total consumption and total solar energy both reached 9312 kWh for the year.

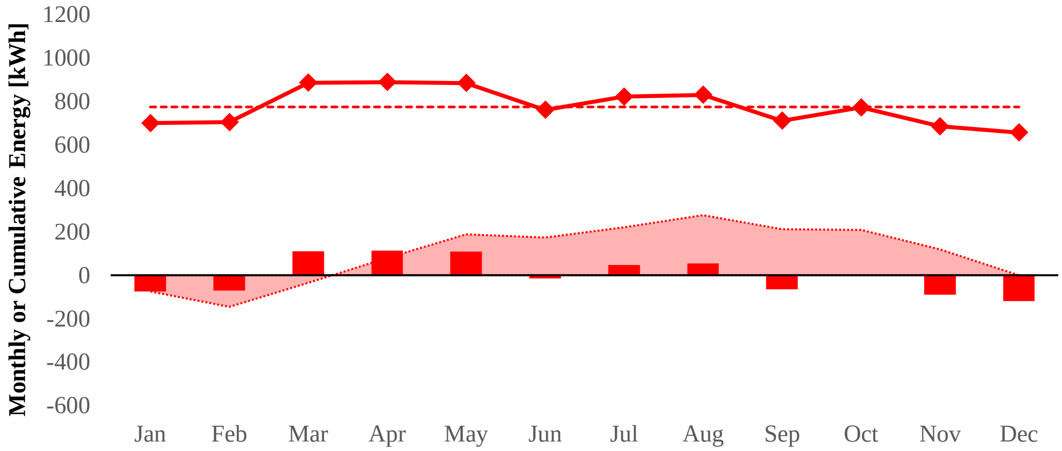


Figure A3: This chart shows: (i) monthly solar output as a solid line with markers; (ii) monthly electricity demand as a dashed line; (iii) monthly energy surplus (+) or shortfall (−) as columns; and (iv) the cumulative energy surplus or shortfall at the end of each month as a shaded area. The chart is for the Miami electricity consumer.

The Medicine Hat customer's January electricity consumption was 614 kWh, but his solar panel output was only 291 kWh (see Figure A4). His energy shortfall of 323 kWh was far larger than the Miami customer's January shortfall even though his consumption was lower. Completing the calculations for all months shows that a minimum cumulative shortfall of 560 kWh was reached at the end of February and a maximum cumulative surplus of 780 kWh was reached at the end of September. As we will see in the next section, the fact that these surpluses and shortfalls are much larger than those in Miami has huge cost implications for the Albertan. ***These differences between Miami and Medicine Hat are inescapable consequences of the greater seasonal variation of solar energy at higher latitudes, and they clearly show why simply comparing annual energy production between solar arrays in different parts of the world is meaningless.***

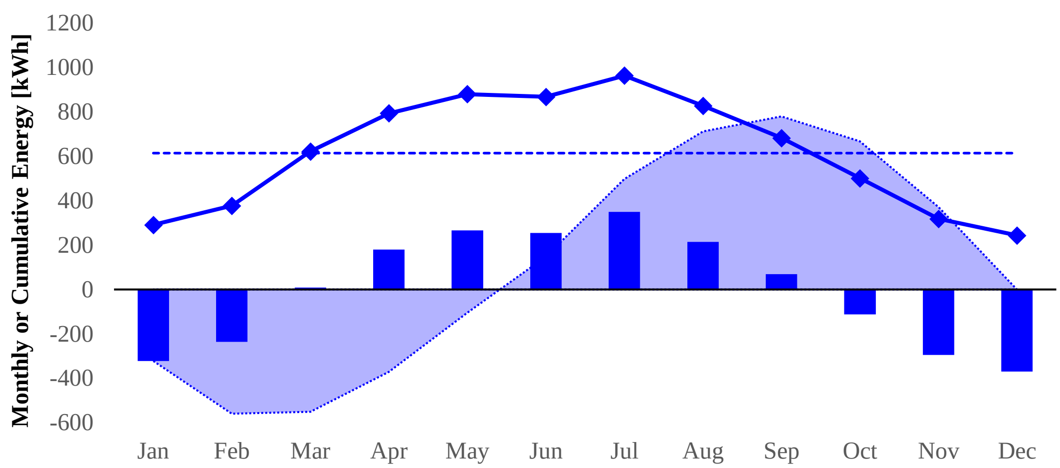


Figure A4: This chart is the same as Figure A3, except that it's for the Medicine Hat customer.

Seasonal Variations in Demand

Not only is it necessary to consider both the quantity and timing of solar energy availability when comparing locations, it is also necessary to consider the timing of demand. The sun is, of course, a major determinant of demand, since at low latitudes demand tends to peak on summer afternoons when air conditioners are running and the sun is shining, while at high latitudes it tends to peak on cold winter evenings when heating and lighting are in heavy use and the sun has set for the day. (Obviously, socioeconomic factors also play a major role.) As we saw from the much larger surpluses and shortfalls in Medicine Hat than in Miami, the more the time at which solar energy is available differs from the time at which the energy is needed, the more difficult (and expensive) it becomes to use the sun as an energy source.

Because the preceding calculations assume equal electricity use in each month, whereas residential use in Alberta is higher in the winter, the monthly and cumulative surpluses and shortfalls for Medicine Hat are underestimates. While the calculations could be re-done with a more accurate historical consumption profile, it will prove more interesting to consider the effect of eliminating the residential use of fossil fuels, which green-energy advocates tell us is necessary to save the world from climate change.[16]

The Proposed Conversion of Natural Gas Home Heating to Electrical Heating

Eliminating fossil fuels would require, among other things, that we convert home heating systems, water heaters, and cooking appliances from natural gas to electricity. Since the average Alberta home uses 100 GJ of natural gas each year,[17] the conversion would add almost 28 000 kWh per year to the average home's electricity consumption. The vast majority of the new demand will appear in the winter: based on residential natural gas usage data for 2015-2019 from the Alberta Energy Regulator,[18] December and January each account for 15% of annual gas consumption, while June, July, and August are each under 3%. These numbers translate into roughly 4200 kWh/month of incremental electricity use in the winter and approximately 700 kWh/month in the summer. Adding the monthly increments to the 614 kWh per month assumed above,[19] scaling up the solar array to 29 kW to rebalance the annual energy supply and demand, and recalculating the monthly and cumulative shortfalls gives Figure A5. The cumulative shortfall now reaches 7260 kWh, which is *13 times larger* than before the conversion, while the cumulative surplus reaches 6340 kWh, which is eight times larger than before.

There is no value in attempting a comparison between future Miami and future Medicine Hat because, as we now know, the relative timing between availability and need is critical and both are very different in Florida than they are in Alberta. Any comparison between southern Alberta and Rio de Janeiro, a city whose metropolitan area contains more than 12 million people, whose population density is ~2700/km^2 compared to Calgary's 272/km^2, and where per capita electricity use is 2400 kWh/year versus Canada's 13 085 kWh,[20] would be even less useful. And while the words "Rio" and "Miami" conjure up images of warm, sunny beaches in the minds of readers—likely as intended by the Pembina report's authors—both cities are subjected to heavy cloud and a lot of rain during their summers. The reference Pembina provides to support its Rio/Miami claim is no longer available, so we cannot comment on the basis for it. In the end, however, it is much like the one that says "this renewable plant can serve 10 000 homes:" it may be true in a very narrow sense, but it is not true in any practical or economic sense. In the end, ***Pembina's claim that solar resources in southern Alberta are like those in Miami and Rio de Janeiro is unsupported by facts, is irrelevant, and is (at best) misleading.***

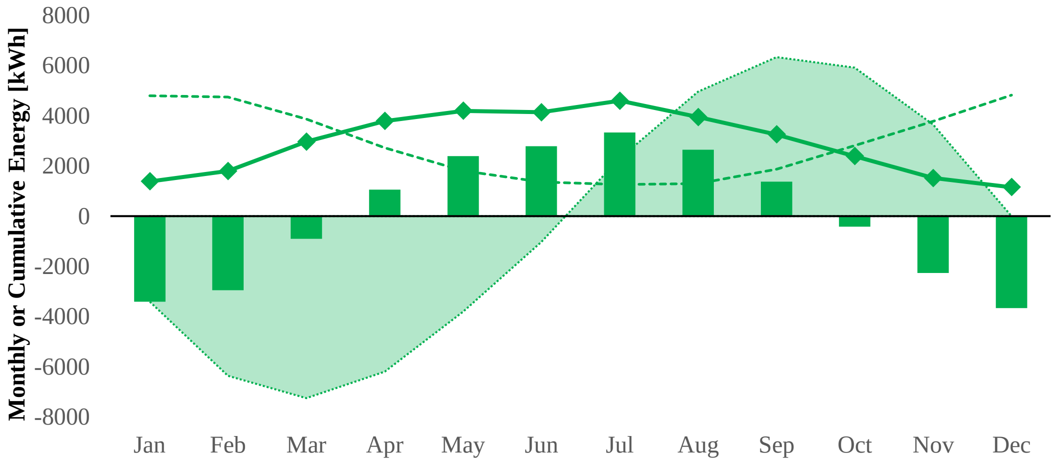


Figure A5: This chart is the same as Figures A3 and A4 except that it's for "future Medicine Hat," where the residential use of fossil fuels is assumed to have been eliminated. The anti-correlation between solar generation and electricity demand is obvious. Caution must be used when comparing this chart to Figures A3 and A4: the vertical scale here is much different than on the other two charts.

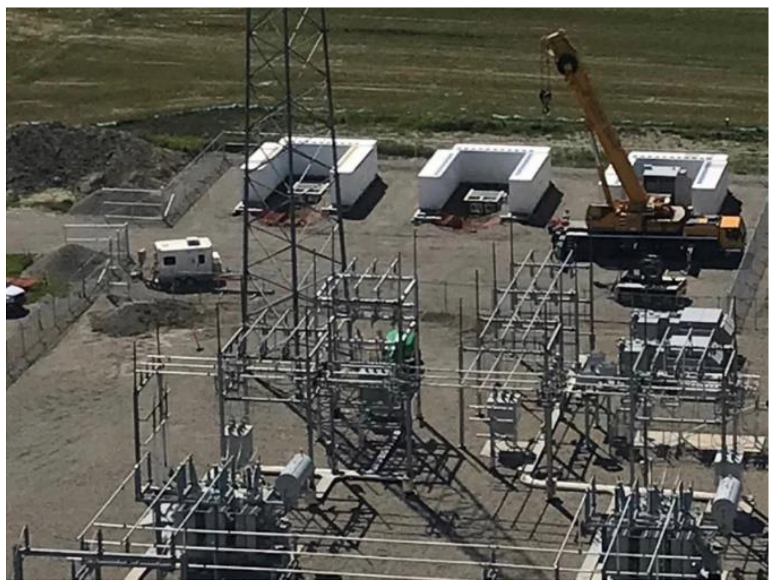
A.3 Pembina ignored the huge cost of the energy storage needed for solar generation.

Today, most consumers' energy surpluses and shortfalls are managed through connections to their respective power grids, which in both Florida and Alberta are supplied largely by fossil-fueled generators.[21] Shortfalls are covered by importing power from the grid, while surpluses are managed by exporting power to it. Now, let's assume our two customers believe Pembina's claim that solar is among the cheapest forms of new generation and decide to try disconnecting from the grid to save money and to eliminate their own use of fossil fuels. Let's also assume they decide to use batteries to supply their electricity when the sun is not shining, as many renewable energy advocates believe they can do today.

If we continue to assume a flat consumption profile for the Miami customer, her battery must be charged to 146 kWh on January 1st to avoid having an energy shortfall (i.e., lights out) period in February. With this initial charge, her August surplus increases to 276 + 146 = 422 kWh. Thus, she requires a solar-and-batteries system that can store 422 kWh, which is about 17 days' worth of consumption.[22] For the Medicine Hat customer, again using the original flat consumption profile, the battery must initially be charged to 560 kWh. It must therefore be capable of storing 560 + 780 = 1340 kWh, or about 66 day's worth of consumption. ***These numbers refute the notion that solar energy systems require only a few days' worth of backup storage to get through cloudy periods***, and comparing the two locations further negates the claim that solar resources in southern Alberta are equivalent to those in southern Florida.

So, what would it cost these customers to get their electricity from a solar-and-batteries system? The United States Energy Administration produced a report titled *Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies* in February 2020,[23] and Table 2 therein gives an estimate for batteries of US$423 (~C$550) per kilowatt-hour. Of course, utility-scale systems and residential systems are not directly price-comparable, but the number is good enough for present purposes.[24] The cost of batteries for the Miami customer would be 550 × 422 = C$232 100. (Since the cost of the solar panels is small compared to the cost of batteries, we will assume they're free.) If her system never needs maintenance, if her batteries last a rather optimistic 10 years without degradation, and if she can borrow money at zero interest, her annual cost would be about C$23 000; dividing by 9312 kWh/year, that's roughly C$2.50/kWh. The Medicine Hat customer's batteries would cost 550 × 1340 = $737 000, and under the same assumptions his cost would be $73 700 per year or $10/kWh. This compares to the ~17 cents/kWh ($1253/year for 7368 kWh) that Alberta residential consumers spend today for electricity (including energy, transmission, and distribution charges, administration fees, and taxes). The absurdity of this result hits home when we realize that, since the median after-tax income in Alberta in 2019 was $72 500, most Albertans would be unable to buy the amount of electricity they use today even if they stopped buying food. So, ***Pembina's claim that "our electricity sector has entered a new reality where renewable generation is the most economic source of new electricity generation for the province" is categorically wrong.***[25]

Some readers may be suspicious of the estimate of $10/kWh for battery storage because published values are frequently a tiny fraction of this. For example, UnderstandSolar provides an example of a battery costing $0.37/kWh, which it calls "expensive," and EnergyStorageMedia shows one costing $0.12/kWh.[26] But these calculations assume that the number of times the battery will charge and discharge over its lifetime will equal its cycle limit (which is the number of charge/discharge cycles expected before its storage capacity degrades to less than 80% of original capacity), and that assumption is way off the mark in high-latitude locations. Since the explanation is somewhat detailed, it is provided in the appendix.



The already-huge mismatch between reality and Pembina's claim will become even larger if a gas-to-electricity conversion is forced on consumers. If the Medicine Hat customer were to convert his natural gas consumption to electricity and scale up his solar array to match his annual energy demand (assuming he has the roof space to do so), rather than 1340 kWh of storage he would need 13 600 kWh. That's about 70% of the storage capacity of TransAlta's WindCharger battery facility (shown here under construction),[27] and it would cost more than $7 million at the assumed $550/kWh. But even that number is too low because we have yet to account for the batteries' round-trip energy losses and capacity degradation over time, the electrification of transportation, or the additional storage that would be needed in colder-than-average or cloudier-than-average years. As for the idea that the batteries in electric vehicles can help, most personal EVs store 100 kWh or less, a miniscule fraction of what would be needed. Figure A6 is a graphical view of the numbers we just discussed.

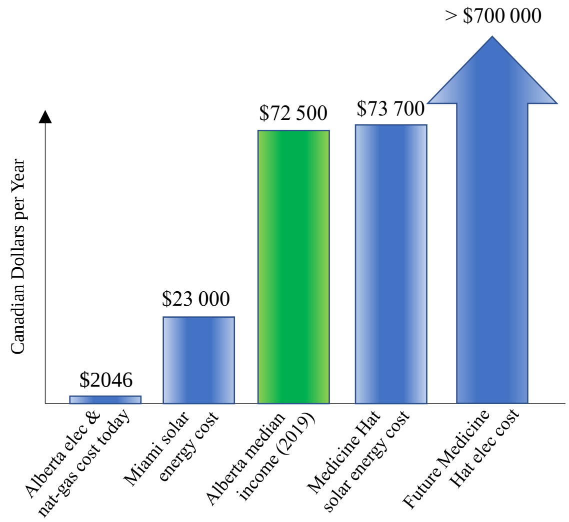


Figure A6: The cost of: Alberta home electricity and natural gas today; Miami solar & batteries electricity today; Medicine Hat solar & batteries electricity today; and Medicine Hat electricity after converting from natural gas. Alberta's 2019 median family income is shown for comparison purposes. If we drew it at full height, the rightmost column would reach to about the top of the previous page.

Now, one might argue that individual consumers won't have to provide their own energy storage because grid-scale storage options, including alternatives to batteries, will exist. That's true. However, Alberta's hydro storage potential is limited, and other options, such as compressed air energy storage, have not yet proven to be both scalable and commercially viable. Of course, consumers must ultimately pay all costs, including those for on-site and/or grid-scale storage, so even if storage costs ultimately come in at a tenth of today's battery costs,[28] none but a handful of exceptionally wealthy Alberta families would be able to afford the amount of electricity they use today.

What about Demand Management?

On page 4 Pembina states, "Combined with other technologies such as energy storage and demand-side management, wind and solar can contribute to a clean energy portfolio that can provide a reliable supply of electricity to the grid at all times." This sounds wonderful, but in the absence of much more information, it's a hollow statement. Would Pembina consider that we have a reliable grid if the cost of a wind, solar, and storage power system to the average homeowner is $10/kWh, or even $1/kWh, with the demand destruction that those prices would entail? Is using smart meters to turn off the power to tens of thousands of homes, businesses, schools, shopping centres, seniors' homes, and hospitals an acceptable form of "demand management" when storage has been exhausted, the sun has set, and wind generation is producing at just a few percent of its installed capacity?

Why is Solar Generation Being Built in Alberta?

An obvious question is, if solar generation is absurdly expensive when all costs are considered, how could it be that solar farms are being built at a fairly rapid pace in Alberta today? As we alluded to above, there are two main reasons. First, fossil-fueled generators are still allowed to exist, and they provide the energy needed when the sun is not shining (and/or the wind is not blowing) at a tiny fraction of the cost of batteries. Second, both residential and commercial solar generators in Alberta are beneficiaries of massive, growing, and mostly hidden subsidies that make solar projects economic for their owners but off-load large costs onto consumers. We explore these points in upcoming parts of our rebuttal to Pembina.

A.4 Part A Conclusions

According to many green-energy advocates, we're on a train to energy utopia, where we get our electricity from gently spinning wind turbines and glistening solar panels, we drive through pristine natural spaces in our environmentally benign electric vehicles, our homes are heated without combusting a single molecule of methane, and every worker has a high-paying job that does not involve disturbing the planet in any way. Since we are promised that the electricity to make all this happen will be "reliable, cheap, and clean," it's an easy vision to sell to governments and voters. The problem is, it isn't real.

In this Part A of our rebuttal, we focused on Pembina's errors regarding solar energy. Using the example of residential consumers in Medicine Hat and Miami, we showed the following.

1. Claims like "this solar facility can provide enough energy to serve 10 000 homes" are misleading because having enough energy, by itself, does not lead to a reliable, year-round supply of electricity for Alberta homes.

2. Pembina's claims that southern Alberta solar resources are "excellent" and "equivalent to those of Rio de Janeiro and Miami" are based on cherry-picked comparators. While solar energy is indeed more plentiful in southern Alberta than in most of Canada, it is no better than middle-of-the-pack when seen in a global context. Pembina could have, but for obvious reasons did not, compare southern Alberta to Phoenix, Arizona or El Paso, Texas. In addition, the seasonal variation of solar energy in Medicine Hat results in storage requirements that are much greater than those in Miami.

3. As we move further away from the equator, solar energy's seasonal variation gets larger and electricity demand tends to shift from summer-peaking to winter-peaking. In Alberta the winter peaks will become vastly larger if consumers are forced to convert from natural gas heating to electric heating. The changes to supply and demand that occur as we move to higher latitudes increase the amount of storage needed to turn solar generators into reliable energy sources. In Alberta, the needed storage is not just that required to get through a few cloudy days, but rather that required to get through the October-to-March solar energy shortfall. This amount of battery storage is not economically feasible for Alberta families.

In upcoming parts of our rebuttal to Pembina, we will highlight numerous other errors in its *Renewable energy—what you need to know.* Among other things, we will: (i) show that adding wind generation to a solar portfolio improves renewable-energy economics, but not by enough to make 100% renewable electricity affordable; (ii) explore the *levelized cost of electricity* and show how green-energy advocates either misunderstand it or abuse it; (iii) explain why Pembina's analysis of how renewable generators affect electricity-market prices misses critical points which, when properly taken into account, turn Pembina's conclusions upside down; and (iv) show how some of the large implicit subsidies to renewable generators arise. In the meantime, you may wish to consider *The True Cost of Wind and Solar Electricity in Alberta* and *Electricity from the Sun: Reality versus Fantasy*.[29]

In closing this Part A, we note that there is nothing wrong with Pembina advocating for its vision of the future. However, there is something *fundamentally* wrong with influencing public opinion and government policy based on statements that are poorly researched and either misleading or false. After all, public well-being in the modern world, especially in often-inhospitable climates like Alberta's, depends on a safe, reliable, and *affordable* supply of electricity. In our view, documents like Pembina's help push Alberta down a path that ends with unaffordable electricity and maybe even with draconian government-mandated restrictions on energy use. We believe that Pembina has an obligation to the public to base its advocacy on facts and complete analyses. To that end, both the Friends of Science Society and the authors of this document welcome open, honest, and respectful debate with Pembina regarding Alberta's energy future. We are prepared to share all of the data (which is public anyway) and models that support the conclusions presented in this document.

Carbon dioxide: the official plant food of Mother Nature.

PART B: PEMBINA DOES NOT UNDERSTAND THE CRITICAL CONCEPTS OF BASE LOAD AND BASELOAD GENERATION

In this Part B of our rebuttal to the Pembina Institute's *Renewable energy—what you need to know,* we discuss the authors' inept analysis of the simple but critical concepts of "base load" and "baseload generation." While these concepts are somewhat arcane and may be of most interest to readers who are directly involved in the electricity industry, our review reinforces for all readers that Pembina's authors do not understand real-world power systems and that their views on how to handle base load are contrary to sound engineering and economic principles. Fortunately, Pembina is not in charge of running our power system. Unfortunately, Pembina is quite influential with governments and media on energy and environmental policies, and Pembina's advice is leading us down a path to drastically higher electricity prices and lower reliability, which in turn could ultimately pose a danger to the public. And to add insult to injury, Canadian taxpayers have been paying for Pembina's misguidance.

B.1 What are base load and baseload generation?

The physical laws that govern electric power systems are such that the supply of electricity must match the demand for it on an almost-instantaneous basis.[30] In Alberta, the supply comes from generators located inside the province and from generators located outside the province via transmission lines that connect Alberta to Saskatchewan, British Columbia, and Montana. The demand for electricity includes the power used by Alberta consumers, the power exported to our neighbours, and the power inevitably lost as heat in the transmission and distribution lines (wires) that carry power from generators to consumers.

We can think of the demand for electricity as having a fixed or *base* component and a variable component. The fixed component is the minimum amount of electricity that is needed at all times, 24 hours a day, seven days a week. Our homes are always using electricity because, even if we turn our lights, computers, and TVs off at night, our furnaces and refrigerators continue to run. In addition, there are many industrial, commercial, and public enterprises that operate around the clock: hospitals always need a reliable and stable supply of electricity to maintain heat, lights, and life-saving medical equipment; police stations and fire stations are always occupied; traffic lights stay on for public safety; grocery-store freezers run all the time to keep food fresh; and many large industrial customers have processes that must run continuously to avoid product wastage and equipment damage.[31]

On top of the fixed component of demand, which is often called *base load,* there is a variable component. Demand varies because we use more electricity when awake than when sleeping, we use more during the week than on weekends, and we use more for heating and lighting in the winter than in the summer. Figure B1 on page 18 shows both the base component (light blue) and the variable component (dark blue) of Alberta electricity demand for the weeks beginning January 18th and May 31st, 2020. The boundary between the dark blue and the light blue marks that year's minimum hourly-average demand, that being the 7579 megawatts ("MW") that was reached between 3 a.m. and 4 a.m. on June 1st.

Baseload generation is simply generation that is intended primarily to serve base load. We're sure it won't surprise readers to learn that the best baseload generators are those designed to run steadily at or near their maximum outputs, 24 hours a day, seven days a week—ideally, from one planned maintenance outage to the next.

B.2 Pembina's understanding of base load and baseload generation is very poor.

In recent years, due mostly to the noise being made by environmental activists (including Pembina), power system operators have been forced by so-called "climate" regulations to take more and more electricity from intermittent, highly variable, and generally unpredictable renewable-energy sources like wind and solar generators.[32] On page 4 of *Renewable energy* Pembina states:

> Critics of renewable energy question if it can match steady "baseload generation" that large-scale conventional power plants can provide. However, the need for baseload is increasingly becoming an outdated concept. As consumers adopt more technologies such as electric vehicles and smart heating that can draw electricity at traditionally off-peak times (such as at night), the grid needs to become more flexible to adapt to this new demand profile. Inflexible generation from large generators such as centralized coal plants can now be a liability, because power sources need to be able to respond quickly to changes in demand. Instead, a mix of different types of generation that can be brought online as needed can better meet demand at any given time.

An endnote to this paragraph cites a blog post titled *Baseload myths and why we need to change how we look at our grid,* in which Pembina claims that baseload generation "is a meaningless concept at the least and dangerous at its worst." The authors go on to write:

> The term "baseload" was coined over a hundred years ago. When the electricity grid was first built, large, inflexible fossil fuel generators dominated and played a critical role in the Industrial Revolution. But much like many other aging technologies and approaches, baseload generation is no longer the best tool for the job. Think of it like refusing to get a DVR or Netflix because you already went through the trouble of programming your VCR. Previous understandings of the importance of baseload just aren't true anymore, but old habits die hard.

The only thing dangerous about the baseload concept is that ***Pembina's stunning lack of understanding*** of it could lead to misguided energy policies—and consequently to a very expensive and unreliable electricity supply for Albertans. In the following points, we repeat Pembina's statements (in italics) and then respond to them. We will elaborate on most points below.

- *The need for baseload is increasingly becoming an outdated concept*. We assume Pembina was referring to baseload generation, not base load, but whether that's the case or not, the authors are wrong. Since some minimum level of electricity demand will <u>always</u> exist (just imagine the consequences of cutting off the electricity supply to homes, hospitals, and fire stations at night!), there will <u>always</u> be a need for generation to serve it. In fact, if green-energy advocates like Pembina succeed in their misguided and ultimately futile quest to force Albertans to spend untenable sums to replace all fossil fuel energy systems with electric ones,[33] base load—and consequently the need for baseload generation—will grow far beyond levels we've seen in the past.
- *As consumers adopt more technologies such as electric vehicles and smart heating that can draw electricity at traditionally off-peak times (such as at night), the grid needs to become more flexible to adapt to this new demand profile*. What were the authors thinking? As even junior power-system planners know, if we shift some energy use from peak times to off-peak times, the demand profile gets flatter (i.e., base load increases and peak demand decreases),[34] and when that happens we can get by with a <u>less</u> flexible grid and overall system efficiency improves. That's the whole point of

using technologies and rate incentives to shift demand to off-peak hours in the first place. As for "smart heating," there are no off-peak heating times for homes, hospitals, and seniors' residences when it's −25 °C during the day and −30 °C at night.[35]

- *Inflexible generation from large generators such as centralized coal plants can now be a liability, because power sources need to be able to respond quickly to changes in demand.* Wrong again, on two counts. First, it is the ongoing addition of highly variable renewable generation (particularly wind and solar), not changing demand, that is causing the need for more flexible generation. Second, and as already noted, the best way to serve base load is with generators, such as coal plants and combined-cycle natural gas plants, that are specifically designed to run at or near full capacity on a 7×24 basis.
- *Instead, a mix of different types of generation that can be brought online as needed can better meet demand at any given time*. This statement is partly true, but it's also ironic. Different types of generation are indeed needed to best meet demand, but the wind and solar units touted by Pembina can not be brought on line as needed because they produce power only at the whim of the wind and the sun. Even when those generators are running, wind gusts and passing clouds can produce large changes in output that must be balanced nearly instantaneously by generators whose outputs can actually be controlled by system operators.
- *When the electricity grid was first built, large, inflexible fossil fuel generators dominated and played a critical role in the Industrial Revolution.* This is bizarre. The term Industrial Revolution refers to the transition to new manufacturing processes in Europe and North America in the period from 1760 to about 1830, long before the development of "large, inflexible fossil fuel generators."
- *But much like many other aging technologies and approaches, baseload generation is no longer the best tool for the job. Think of it like refusing to get a DVR or Netflix because you already went through the trouble of programming your VCR.* The notion that reliable, steady-output generation is an aging technology is ludicrous and flies in the face of ongoing technological developments in ultra-supercritical coal plants (some with CO_2 capture), cogeneration facilities, combined-cycle natural gas plants, simple-cycle gas turbines, and both large and small nuclear plants.
- *Think of it like refusing to get a DVR or Netflix because you already went through the trouble of programming your VCR.* The authors would have you believe that replacing stable, reliable, efficient, controllable, and mostly weather-independent baseload generators with highly variable, non-controllable, wind-and-sun-dependent generators is akin to replacing a VCR with a DVR or Netflix. This is absurd.
- *Previous understandings of the importance of baseload just aren't true anymore, but old habits die hard.* Wrong yet again. Neither the laws of physics nor the principles of economics that govern the design and operation of efficient, reliable power systems have changed. It is an affront to ratepayers and taxpayers that untold millions of dollars have been poured into organizations like Pembina that seem to believe that climate ideology can and should trump physics, economics, and the knowledge and experience of power-system engineers and operators. If Pembina succeeds, the long-term well being of Canadians will suffer.

It is deeply troubling that an organization can get huge government grants and actively influence energy policies at the municipal, provincial, and federal levels based on technically incompetent analyses. Taxpayers should be outraged.

B.3 What are the existing and future base loads in Alberta?

Figure B1 shows both the base component (light blue) and the variable component (dark blue) of Alberta electricity demand for the one-week periods beginning January 18th and May 31st of last year.[36] The daily variations in load as most Albertans wake up in the morning, go to work or engage in home-related or leisure activities during the day, and go back to sleep at night are obvious. The difference in shape between the winter "bumps" and the summer ones arises from the different daily temperature and sunlight profiles. As already noted, the boundary between the colours marks 2020's base load of 7579 MW. Figure B2 shows minimum, maximum, and average Alberta demand from 2005 to 2020. As both graphs show, base load constitutes a large fraction of total provincial demand.

The whole point of Pembina's advocacy is, of course, to prevent Albertans and other Canadians from using fossil fuels. The enormity of the conversion challenge in this province can be seen in Figure B3 on page 19, which shows the fraction of electrical energy produced by each of the major forms of generation for each day from August 1st, 2020 to July 31st, 2021. Despite favourable policies and large subsidies for renewables, fossil-fueled generation still dominates in Alberta (as it does throughout most of the world).

Even Figure B3 does not adequately convey the challenge of a "green energy transition" because it only accounts for what is already electrified in Alberta. Additional context is provided by Table B1 on page 20, which shows the percentage of the energy used in each of Canada's four largest provinces that was supplied by fossil fuels in 2017.[37] Almost 90% of Alberta's energy came from fossil fuels, and that's not counting the electrical energy that was produced by fossil-fueled generators. Lest anyone vilify Alberta for making the best use of its available energy resources, hydro-rich Quebec got more than half its total energy from oil and gas.

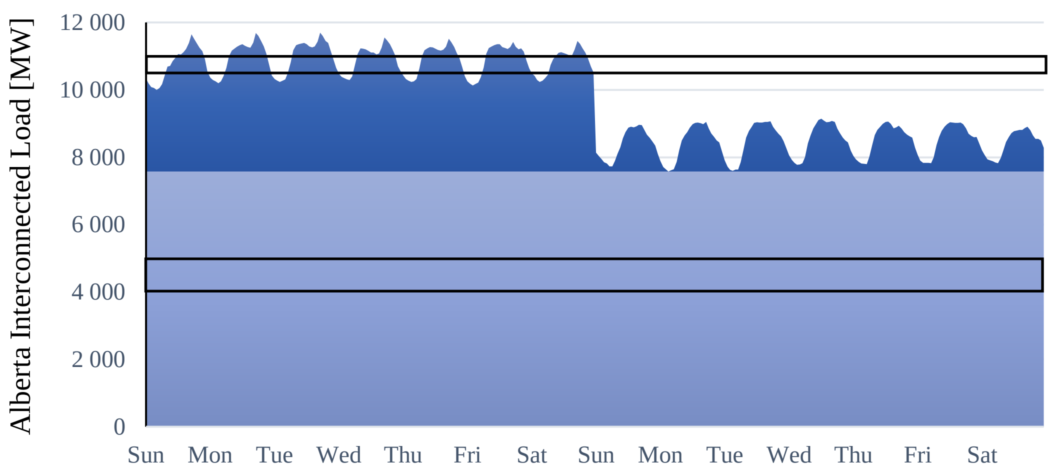


Figure B1: Alberta Interconnected Load for a winter week (left) and a summer week (right) in 2020. The annual base load is shown in lighter blue. The black rectangles will be discussed later.

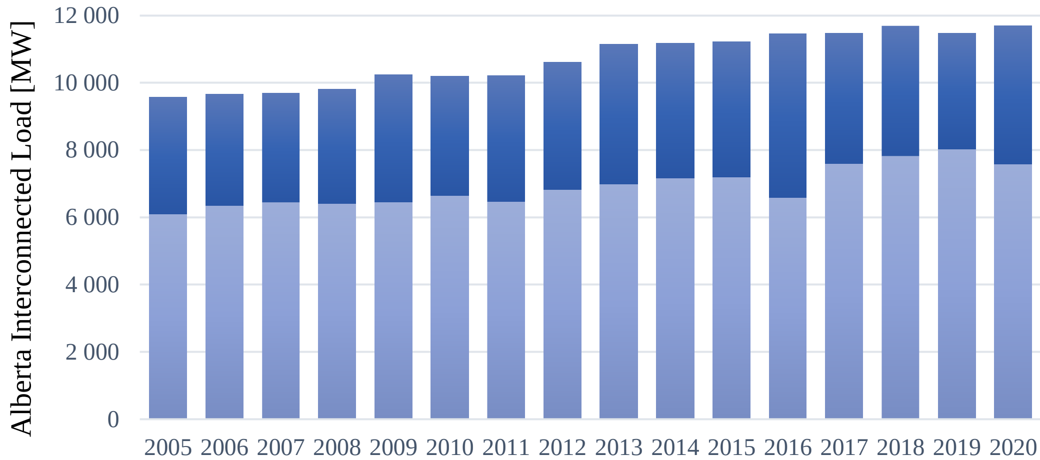


Figure B2: Minimum and maximum Alberta Interconnected Load for each year from 2005 to 2020.

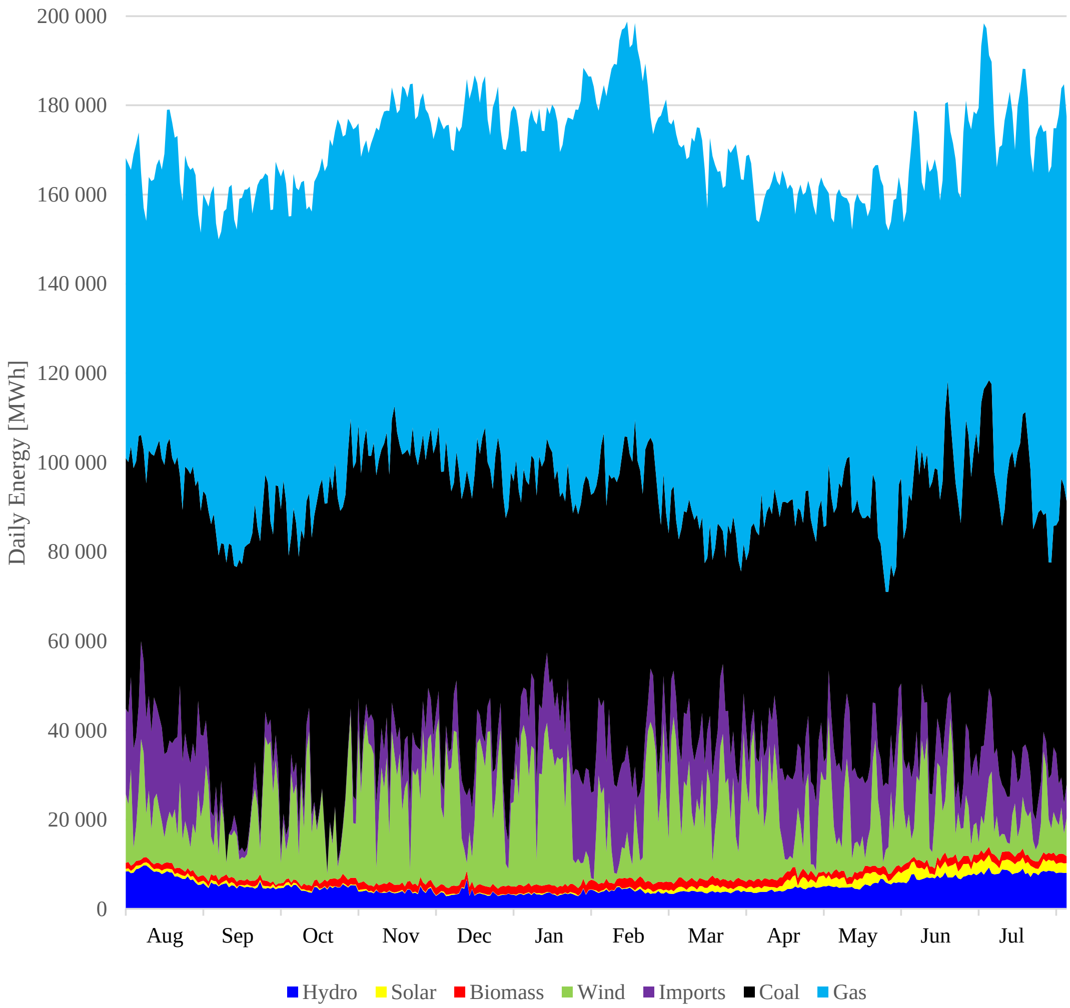


Figure B3: Daily energy (megawatt-hours) supplied by Alberta's generation types.

TABLE B1: ENERGY SOURCES IN CANADA (ALL VALUES IN TERAJOULES)

Energy Source	**Alberta**	**Rest of Canada**	**Quebec** [a]	**Ontario**	**BC** [a]
Electricity [b]	224 756	1 706 400	675 350	498 931	233 388
Natural gas [c]	1 296 721	1 729 074	268 150	894 148	276 272
Refined petroleum	560 216	2 729 750	648 821	993 224	423 688
Other fossil fuels	2 663	139 950	?	119 503	?
Total [d]	2 096 175	6 305 174	?	2 511 059	?
Fossil fuel share [e]	89.3%	72.9%	57.6%	80.1%	75.0%

a – StatsCan does not report coal/coke use or total energy in Quebec or British Columbia due to confidentiality concerns.
b – primary electricity, hydro and nuclear
c – natural gas including gas plant natural gas liquids
d – the total is not equal to the sum of the individual entries because small components are ignored here
e – this is the share of the sum of reported values, not the share of the total (due to the absence of the total for Quebec and BC)

Combining the data in Table B1 with data supplied by the Alberta Energy Regulator,[38] we can estimate the increase in average electricity demand by month that would occur if all fossil-fuel-to-electricity conversions are performed—and assuming we are not severely restricted by either prices or government diktats[39] from using the same amount of energy we use today. January's average electricity demand would rise from 8000 MW to 40 000 MW without industrial natural gas and to 57 000 MW with it (see Figure B4), which means we'd require about a seven-fold increase in transmission and distribution wire capacity to accommodate the conversions. Transmission lines are very expensive: for example, the ~217 km line from the Pincher Creek wind farms to Calgary cost approximately $2.2 billion. Base load, and with it the need for baseload generation, would increase by a similar multiple.

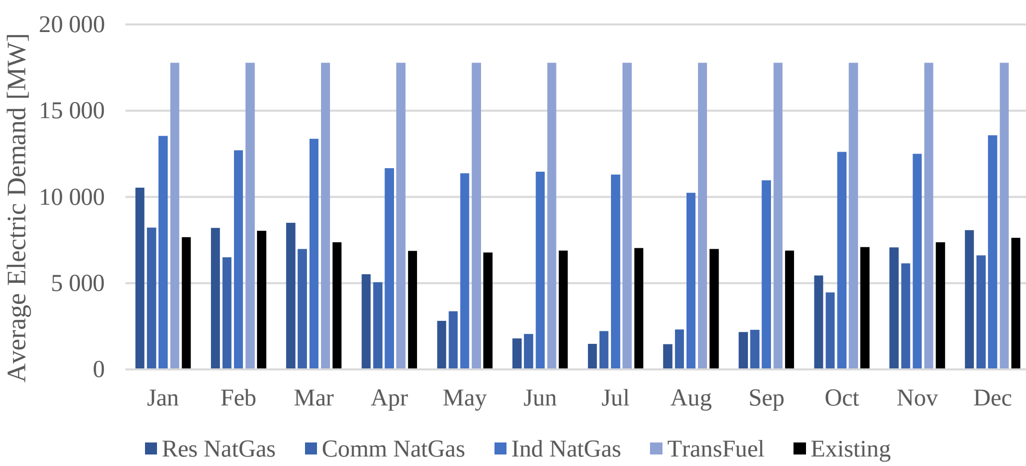


Figure B4: The estimated *increase* in average hourly electricity demand due to the proposed conversion of fossil-fuel energy to electrical energy use on an energy-equivalent basis. The five components will be additive if all conversions take place.

If Pembina's desired "green energy transition" actually takes place, Albertans will be faced with a lot more than just a gargantuan increase in generation, transmission, and distribution costs. We will also have to: pay to replace our internal-combustion-engine vehicles with electric ones; cover the cost of converting home heating, cooking, and hot-water systems from natural gas to electricity; pay higher taxes to cover similar transitions in every hospital, school, and other public building in the province; pay higher prices for goods and services, as businesses seek to cover the cost of their own forced energy-system conversions; write off billions and billions of dollars' worth of personal, government, and corporate infrastructure; replace the revenues that governments can no longer collect through oil and gas royalties and taxes; write off trillions of dollars' worth of oil and gas resources forcibly locked in the ground; and suffer further economic hardship as jobs are moved to places where energy is still reliable, abundant, and far cheaper than it will be here. Moreover, any reductions in CO_2 production in Canada will be swamped in a matter of months by increasing emissions from developing countries that have far less rigorous environmental standards and where, incidentally, most wind turbines and solar panels are made using coal-fired power. No wonder renewable energy advocates seldom talk about the cost of their favourite dystopian policies like "net zero." And on those few occasions when they do talk about costs, we need to be very worried that their analysis is of a similarly poor quality to what we find in *Renewable energy* and *Baseload myths.*

B.4 What is the economically efficient way to serve base load?

Base load in Alberta in 2020 was 7579 MW, and to serve it, we would ideally have 7579 MW of "baseload generation" that runs 24 hours a day, 365 days a year. Why? Because variability causes costs, for three main reasons: (i) when load is less than its maximum, some amount of generation capacity is sitting idle—assuming, of course, that we have enough supply to meet the peak; (ii) it causes sub-optimal generator performance; and (iii) it forces units to cycle on and off, which can lead to startup and shutdown costs along with additional maintenance costs due to extra wear and tear. Here in Part B we will focus on idle capacity (which is usually the dominant driver of variability-related costs) and the related concept of *capacity factors.* We will discuss the other two points in the upcoming Part D.

As noted by Pembina on page 3 of *Renewable energy,* in Alberta's deregulated market, the system operator chooses electricity from the lowest-price power producers first and works its way up to more expensive producers until demand is met.[40] Assume, for illustrative purposes, that generators are perfectly reliable and that their individual energy-market offers did not vary at all in 2020. If generator $\mathcal{B}$ offered to produce up to 1000 MW whenever demand was greater than 4000 MW,[41] its potential annual output was as shown by the lower rectangle in Figure B1, the area of which is (1000 MW) × (8784 hours) = 8 784 000 MWh. If generator $\mathcal{P}$ offered to produce up to 500 MW whenever demand was greater than 10 500 MW, its potential annual output was (500 MW) × (8784 hours) = 4 392 000 MWh, as shown by the upper rectangle.

Since base load for 2020 was 7579 MW, demand was always greater than 5000 MW. As such, all of the energy that $\mathcal{B}$ was capable of producing was consumed. This is reflected in $\mathcal{B}$'s entire rectangle being shaded. However, demand was only greater than 10 500 MW a small fraction of the time, and by looking at the upper rectangle we see that $\mathcal{P}$'s output varied from zero to 500 MW during the winter week and was zero at all times during the summer one. For 2020 in total, $\mathcal{P}$ produced 332 724 MWh over 1193 hours.

It is easier to see the fraction of theoretically possible output that each generator produced over the year if we sort the hourly demands from largest to smallest instead of by time. Doing so produces Figure B5. The upper boundary of the shaded area is called the *load duration curve.* If we start at the vertical axis and follow the bottom of the horizontal line at 10 500 MW (i.e., the bottom of the upper rectangle) to the right, we find that it intersects the duration curve at 1193 hours, which as we just saw is the number of hours in which $\mathcal{P}$ produced energy. Calculating the area of the shaded portion of that rectangle gives 332 724 MWh, which is the energy 𝒫 produced for the year. Consistent with 𝒫 having produced (332 724)/(4 392 000) = 7.6% of the energy it was capable of producing, only that percentage of the upper rectangle is shaded.

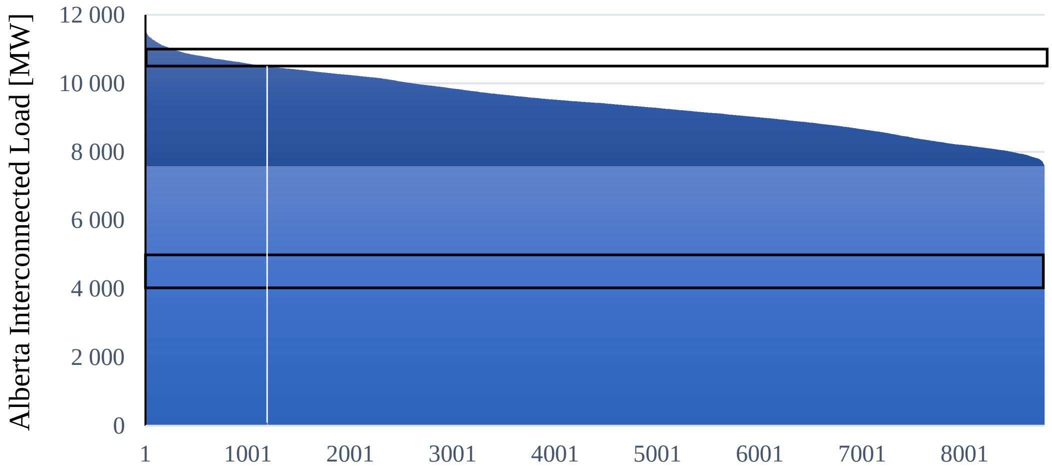


Figure B5: The demand duration curve for 2020. The rectangles are explained in the text.

The amount of energy a unit actually produces (or is forecast to produce) in a given period, divided by the amount of energy it would produce by operating at full capacity the whole time, is known as the generator's *capacity factor*. In this example, ℬ's capacity factor was 100% and 𝒫's was 7.6%. The real-world capacity factors of Alberta generating-unit types are shown in Endnote 42.

Now, let's assume we have two choices for generating units, both of which are 500 MW in size. Type I has a fixed cost of $140 million ($140M) per year and a variable cost of $30/MWh, while Type II has a fixed cost of $70M/year and a variable cost of $70/MWh. (The higher capital cost and lower fuel cost of Type I over Type II is accounted for by the inclusion in Type I of additional components [such as second-stage heat recovery steam generators that recover some of the waste heat from the first stage to produce additional electricity] that boost fuel efficiency.) Serving the baseload energy represented by the lower rectangle using two Type I units would cost $544M, while serving it with two Type II units would cost $755M.[43] Serving the energy in the 10 500 to 11 000 MW range using a Type I unit would cost $150M, while serving it with a Type II unit would cost $93M.[44] Clearly, the higher-capacity-factor ℬ should consist of two of the higher-fixed-cost, lower-variable-cost Type I units, while the lower-capacity-factor 𝒫 should consist of two of the lower-fixed-cost, higher-variable-cost Type II units. It is worth emphasizing that: (i) a combination of Type I and Type II units produces the most economically efficient outcome; and (ii) the Type II unit is a better choice for 𝒫 even though it is less fuel efficient.

Since ℬ serves base load, it is often called a *baseload generator*, and since 𝒫 serves load only during peak-demand periods, it is often called a *peaking unit* or *peaker*. The fact that economics dictates different choices for baseload units and peakers has long been understood by people in the electricity industry, which is one of the reasons why power systems have a mix of generator types. It is also why Pembina's claim that baseload generation is a "meaningless concept at the least and dangerous at its worst" is just plain wrong. We will discuss the market implications of the need for both baseload units and peakers, and will refute more misleading statements by Pembina's uniformed authors, in later parts.

As is probably already clear to readers, the above analysis is a much-simplified version of power-system economics and operations. Real generators are not perfectly reliable, of course, and when several baseload units are off line for maintenance, units that normally function as peakers can step into the baseload role. For this and other reasons there is no hard line between baseload units, peaking units, and what are sometimes called mid-range units. Offer prices can change, too, with changes in fuel costs, CO_2 taxes, labour costs, borrowing costs, and many other variables. Nevertheless, ***the fact remains that base load is best served by generators that are specifically designed to run at or near full output 24 hours a day, seven days a week, for as long as possible—hopefully from one scheduled maintenance outage to the next.***

B.5 Renewable generation, not demand, is driving the need for flexible generation.

While base load is growing, our ability to serve it with economically efficient baseload generation is diminishing. There are two main reasons, the first of which is that CO_2 taxes and oppressive (and ultimately futile) CO_2 regulations are being implemented with the specific intent of killing off fossil-fueled generation. But for Alberta, that is the only reliable, non-weather-dependent source of electricity available—other than a small amount of hydro and biomass.[45] The second reason is that those same taxes and regulations, along with massive implicit and explicit subsidies, are driving increases in the amount of electricity supplied by intermittent, highly variable, largely uncontrollable, and largely unpredictable wind and solar generation.[46] As such, the *net load*, which is the load left to be served after the renewable generation has been accounted for, is becoming ever more variable.

Figure B6 shows actual Alberta demand for a 14-day period in 2020 (the black line). It also shows net demand under the assumption that 2020's actual wind and solar generation were scaled up to meet the province's total 2020 energy requirement.[47] When wind and solar output is less than consumer demand, net load is positive (dark blue) and the system controller must assign controllable supply resources to meet it. When excess wind and solar energy is available, net load is negative (light blue) and some combination of generator curtailment, additions to stored energy, and exports must be used to maintain supply/demand balance. As Ontario consumers found out to their chagrin, having too much renewable energy can force you to pay your neighbours to take electricity off your hands.[48]

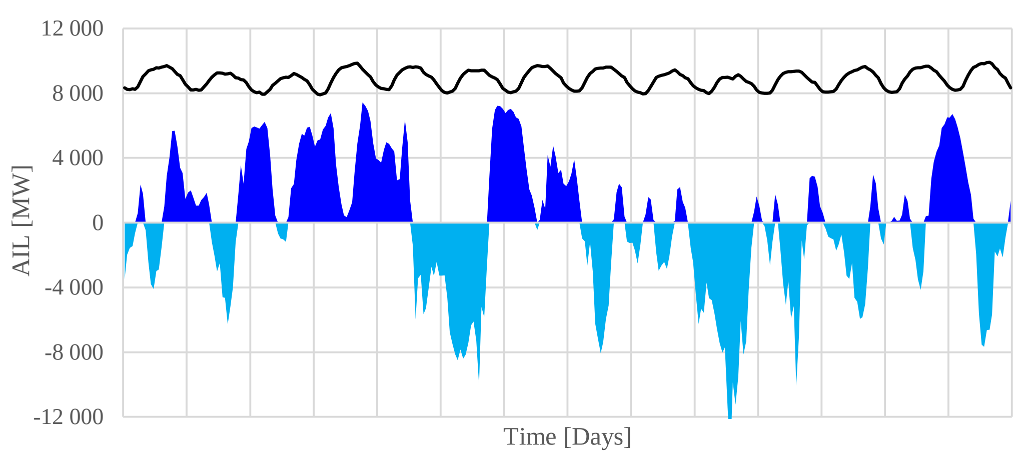


Figure B6: Net demand in a 14-day period in 2020, assuming wind and solar have been scaled up to produce the required annual energy. Dark blue represents net demand to be served by non-wind-and-solar generation; light blue represents excess wind and solar output that must be stored or curtailed (lost forever).

Pembina claims that the electricity grid needs "flexible" power sources that can respond quickly to changes in demand, but as Figure B6 clearly shows, net load changes much more rapidly than total demand as a direct result of the extreme variability of renewable generation. Thus, it is renewable generation, not consumer demand, that is increasing the need for flexible, controllable generation. Pembina also asserts that "a mix of different types of generation that can be brought online as needed can better meet demand at any given time." While a mix of resources is always needed, Pembina's statement is disingenuous because the whole point of *Renewable energy* is to tout the virtues of wind and solar generation—which can not be brought on line at will and can not be controlled to match demand.[49] In other words, ***what Pembina proposes as a solution to a problem is actually the cause of the problem.***

Because system controllers have little or no control over the amount of wind and solar generation available at any given time, controllable generators must follow net load. Consequently, the price of electricity will be driven primarily by net load, not consumer demand. As can be seen from Figure B6, at high levels of renewable generation, there is no definable net-load shape and therefore no discernible daily off-peak period. As such, prices will effectively be random through time and technologies and pricing mechanisms intended to shift demand from some hours to others will become largely irrelevant. It should be noted that, if solar dominates wind as the renewable energy source of choice, a better-defined net load shape that exhibits a large dip during the day and a large peak after sunset is likely to emerge. This shape, too, will create challenges, since solar output is drastically lower in the winter than in the summer at Alberta's high latitudes. We will discuss the reliability and market implications of the large swings in net load in Parts C and D, respectively.

B.6 Pembina's assessment of the summer 2017 energy emergency event is inept.

As if *Baseload myths* weren't already bad enough, the authors double down on ineptness when they discuss an energy emergency that occurred in the summer of 2017. They write:

> As the mercury climbed in Alberta on Wednesday, July 26, it helped bust the myth that baseload [generation] is synonymous with reliability. At 2 p.m. the Keephills 2 coal plant tripped offline, and at 3:45 p.m. a second coal plant followed. The failures were most likely a result of the high temperature, which can be problematic for coal generators. All told, by 4 p.m. roughly 2000 MW of coal was offline — almost a third of the installed coal capacity in the province.

They go on to claim that

> …if Alberta had significant solar PV generation installed this emergency could have been avoided completely. Instead of depending on the coal plants that tripped offline, the same amount of solar capacity in Alberta would have generated enough electricity to avoid any emergency alert and the threat of blackout, while keeping prices under control. For similar energy emergencies caused by high temperatures, solar — which generates most when the sun is shining brightly — is a reliable source of power. It's a pretty easy choice to make: let's work with weather, instead of scrambling to adjust to it and risk blackouts.

Pembina's suggestion that we "work with the weather" and its implicit suggestion that we would be better off with 2000 MW of solar generation than 2000 MW of coal-fired generation are absurd. Ever since humans discovered how to harness fire, one of the most important purposes of our energy use, especially in places like Alberta that have harsh climates, has been to protect us when the weather turns against us.[50] While 2000 MW of solar might have prevented this one event (which, incidentally, did not result in the loss of any firm load), it would contribute exactly nothing toward keeping us warm on the many cold winter nights Albertans endure every winter. If Alberta had to rely on the sun as its primary source of electricity, no home would be habitable because there would be no cooking, lighting, or heating for considerably longer than 12 hours at a time in the depths of winter.[51] While some argue that the solution to the sun's nightly disappearance is to install batteries, adding enough of them to make a solar-energy-only home livable would cost the average Alberta family well over $1 million (see Part A). Having 2000 MW of coal, on the other hand, would almost always provide us with close to 2000 MW when we need it.

We will provide a much more detailed analysis of this event and of the reliability implications of renewable generation in the upcoming Part C, but for now we will point out the following.

- Of all the sources of power in the province, coal produced at the highest percentage during the event. Its output averaged 65%, while Pembina's much-touted wind generation averaged a paltry 6%. (So much for working with weather-dependent resources.)
- There was too little commercial solar generation in Alberta at the time to report on its contribution, but as discussed in Part C, we can easily show that it would have under-performed coal.
- Basing resource and reliability suggestions on the (seriously flawed) analysis of a single event is irresponsible and potentially dangerous.

Following their comment about working with the weather, the authors state:

> What does this have to do with baseload myths? The need for baseload to ensure reliable electricity is often touted as the reason to not move away from fossil fuel generation to other sources like wind and solar.
>
> What happened [on July 26th, 2017] is a stark reminder that baseload isn't synonymous with reliability — it's a lot more complicated than that. Let's use this opportunity to explore some of the myths around baseload, and how our understanding of the grid has changed over the years.

The authors are correct that "it's a lot more complicated than that:" we need to consider real-time balancing, contingency reserves, generator ramp rates, and system inertia, among other things, none of which the authors discuss and none of which they appear likely to be able to address.

Since the driver for Pembina's inept analysis of solar energy's reliability is its desire to replace what was once ~6300 MW of Alberta coal-fired generation with renewable generation in order to "save the climate" from CO_2 emissions, it is interesting to note that:

- After the province passed its *Specified Gas Emitters Regulation* in 2007, the world's installed capacity of coal-fired generation grew from 1 397 234 MW to 1 790 642 MW. China's coal fleet grew from 476 374 MW to 1 004 948 MW, more than making up for all the plant retirements.[52]
- As of 2020, 199 572 MW of coal generation was under construction and another 297 829 MW was in various stages of planning.
- Over the course of a year, 2000 MW of coal-fired generation that is not hamstrung by taxes and regulations related to CO_2 emissions would produce about four times as much electricity as 2000 MW of solar generation.

In other words, the so-called "green energy transition" in Alberta is an exercise in economic self-destruction that will produce an immeasurably small climate benefit.

B.7 Part B Conclusions

Unless government diktats or astronomical prices—neither of which is as far-fetched as it should be—prevent Albertans from having access to the amount of energy they have come to rely on, base load is not going away. ***In fact, if Alberta families and businesses are forced to convert their energy systems from fossil fuels to electricity, base load will grow far beyond levels we've ever seen in this province***. The technically and economically optimal way to serve base load is to use generators that are optimized to produce at or near their maximum outputs for many months at a time, which means wind and solar generators are <u>terrible</u> baseload generators. Contrary to Pembina's inept and grossly misleading analysis, renewable generation does not address the need for more flexible generation; rather, it is the cause. And the idea that we can ensure a reliable supply of electricity to Albertans by relying on solar generation in times of system stress is both absurd and dangerous.

Millions and millions of trees, brought to you by water and carbon dioxide.

APPENDIX A: WHY THE USUAL CALCULATIONS UNDERESTIMATE $/KWH FOR BATTERY STORAGE

In the main body of this document, we showed that battery storage for the Medicine Hat residential consumer would cost about $10/kWh. That number is far higher than what is typically published. While the published numbers would be valid if the underlying assumptions held, the assumptions do not hold in the cases of most interest to Albertans.

According to understandsolar.com:[53]

Total Lifetime Storage (kWh) = (*Capacity* × *Depth of Discharge* × *Cycle Life* × *Voltage*) / 1000

Lifetime Cost ($/kWh) = (*Purchase Price*) / (*Total Lifetime Storage*)

Let's use, as an example, a 12 volt, 100 ampere-hour (Ah) battery with a life of 3650 cycles (one per day for ten years, ignoring leap years) and a 100% depth of discharge. Since (12 V) × (100 Ah) = 1200 VAh = 1200 Wh = 1.2 kWh, the purchase price would be $660 if we use the same $550/kWh capital cost we used in Section 3. The battery's lifetime storage is (100 Ah) × (100%) × 3650 × (12 V) / 1000 = 4380 kWh, so its lifetime cost is $660/(4380 kWh) = $0.15/kWh.[54] Keep in mind this is a cost for energy *storage,* not energy; batteries are net energy sinks when round-trip losses are considered.

Both $0.15/kWh and $10/kWh are correct, but under much different conditions. To demonstrate this, we can use an example in which a constant 1 kW load is supplied by a 2 kW PV array and some batteries. We will assume that both the array and the batteries are perfect: the array produces its maximum output whenever the sun is up, and the batteries are lossless and can be charged and discharged at will without affecting their performance or lifetimes. For ease of explanation, each "day" begins at sunrise.

Let's start with the case in which the PV array receives exactly 12 hours of sunlight every day. This is a good approximation for locations near the equator. During the day, consumption totals 12 kWh and solar output is 24 kWh, so battery charge increases from zero to 12 kWh. During the night, solar output is zero and consumption is again 12 kWh. The batteries make up the difference and discharge fully just in time for the next morning's sunrise. After 28 days, the batteries will have provided 28 × 12 = 336 kWh.

Now let's consider a situation more like what we find in Alberta. To limit the number of calculations, let's assume that a year consists of four seasons, each having seven days, and that it starts on the first day of summer. There are 16 hours of sunlight in the summer, 12 in the spring and fall, and 8 in the winter. Batteries labelled BA through BH each have a capacity of 8 kWh, while BI has a capacity of 4 kWh. As indicated by the empty boxes in the Day 0 column in Figure AA1, the batteries are connected to the PV array with zero charge on the last day of spring. The system works as follows.

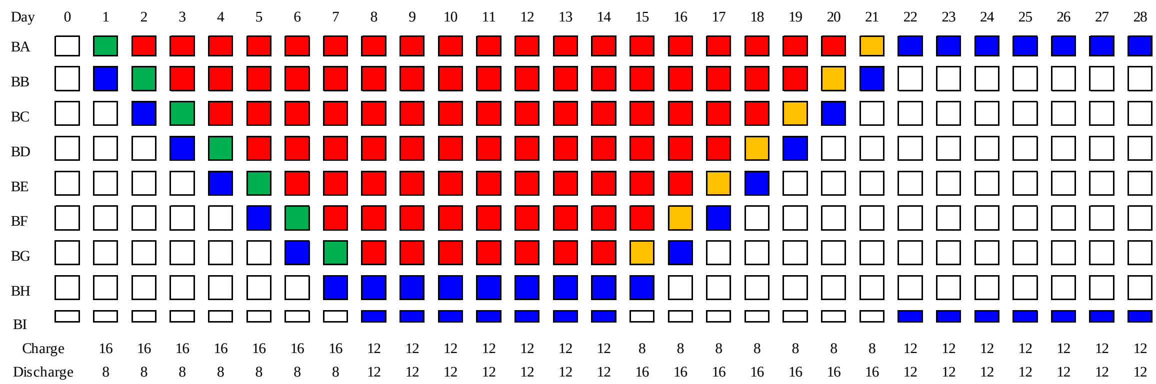


Figure AA1: A battery charge/discharge schedule for an idealized solar-and-battery power system. The colours are: white, fully discharged; red, fully charged; blue, charged and then discharged; green, charged only; gold, discharged only. At the end of each day, red and green boxes are full; blue and yellow ones are empty.

- During the 16 sunlight hours on Day 1, solar output is (2 kW) × (16 h) = 32 kWh and consumption is (1 kW) × (16 h) = 16 kWh, so the total battery charge must increase from zero to 16 kWh. During the 8 nighttime hours, solar output is zero and the load's consumption is 8 kWh, so the total battery charge must drop back to 8 kWh. These actions can be accomplished by charging BA and BB during the day and then discharging BB at night. In Figure AA1, this is shown by the green "charge only" box in the BA row and the blue "charge then discharge" box in the BB row, both in the Day 1 column.
- On Day 2, the charge/discharge cycle is the same as it was on Day 1. Since BA is already charged, as signified by the red "charged" box in the BA row on Day 2, BB and BC charge during the day and then BC discharges to supply the load at night.
- On Day 3, the charge/discharge cycle repeats. This time, BA and BB are both full (red boxes), BC gets charged (green box), and BD gets charged and then discharged (blue box). Days 4 through 7 are the same, and by the end of the latter, BA-BG are fully charged and BH and BI are available for charging.
- Day 8 is the first day of fall. During the first 12 hours, the PV array produces 24 kWh and consumption is 12 kWh, so storage must increase by 12 kWh. This is accomplished by charging BH and BI. Since the 12 daylight hours are followed by 12 nighttime hours, BH and BI must both be discharged to supply the consumer. Days 9 through 14 follow the same pattern, and since supply and consumption balance on each of those days, BH and BI charge and discharge each day while BA-BG remain fully charged.
- Day 15 is the first day of winter. During the first 8 hours, solar output is 16 kWh and consumption is 8 kWh, so the charge in BH increases by 8 kWh. At night, the consumption of 16 kWh is met by discharging BH and then BG. Since BH was charged and then discharged, its Day 15 box is blue; since BG was only discharged, its box is a gold (discharge-only) box.
- On Day 16, BG starts out empty and can absorb the 8 kWh of excess solar power during the first eight hours. For the last 16 hours, BG and then BF are discharged. By the start of Day 21, BA is charged but BB is not, so BB is charged to 8 kWh during the day and then it and BA are discharged overnight. By sunrise on Day 22, the first day of spring, storage is empty.

- On Days 22 through 28, solar production and the load's consumption are 24 kWh and 12 kWh, respectively, during the first 12 hours. The excess 12 kWh are stored in BA and BI. All of that stored energy is needed during the night, so both discharge (hence the blue boxes).
- On Day 29, the 28-day "year" begins again.

The battery charge/discharge schedule in Figure AA1 shows us several things.[55]

- Even though the PV arrays and the loads were the same in Alberta as at the equator, the equator system required only 12 kWh of battery storage while the Alberta system required 68 kWh. This is consistent with the fact that, as we saw in Section 2, more storage is needed in higher-latitude places like Medicine Hat than lower-latitude places like Miami.
- At the equator, the 12 kWh battery was charged and then discharged every day. Therefore, it used 100% of its available charge/discharge cycles and it provided 100% of its possible discharge energy (28 days × 12 kWh/day = 336 kWh). This 100% utilization factor is implicitly assumed in the above equations. In Alberta the discharge energy was the same 336 kWh, but the *available* discharge energy from 68 kWh of storage is 28 × 68 = 1904 kWh. The Alberta batteries' utilization factor is therefore only 336/1904 = 18%. Figure AA2 shows the relative cost of any device as a function of its utilization factor. and at 18% it's about six times greater than at 100% (which is consistent with 68 kWh of storage versus 12 kWh).
- Look at Day 8 in Figure AA1. It is easy to see that, had we used 91-day seasons, Day 92 in an updated version of that diagram would have 91 charged boxes (red) and 1½ charge/discharge boxes (blue) representing 92½ × 8 = 740 kWh of storage. That's 62 times as much storage as for the same perfect solar array serving the same-size customer at the equator.
- The charging (+) and discharging (−) volumes are +16 and −8 in the summer, +12 and −12 in the spring and the fall, and −16 and +8 in the winter. Total battery discharge energy for a 364-day year would be (91 × 8) + (2 × 91 × 12) + (91 × 16) = 4368 kWh (or 4380 kWh if we add one average 12 kWh day). The available discharge capacity at one cycle per day is 365 × 740 = 270 100 kWh. Therefore discharge utilization, which was 100% at the equator, is only 1.6% in this hypothetical Alberta. Given a purchase cost of $550/kWh × 740 kWh = $407 000 and discharge energy of 4380 kWh, the storage cost here works out to be about $93/kWh.

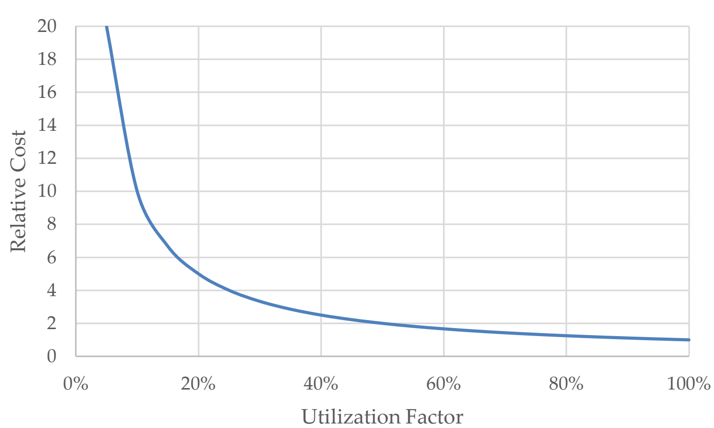


Figure AA2: The relative cost of a device as a function of its utilization factor, based on a cost of 1 unit at 100% utilization.

So what can we conclude? ***In high-latitude locations like Alberta, the storage required to make solar work as a reliable energy source is vastly greater than that required to cover a few cloudy days. Those, like Pembina, who suggest that solar-and-battery systems provide the most economic source of electricity for Alberta are horribly and dangerously wrong.***

END NOTES

All of the following hyperlinks were confirmed to be valid as of October 12, 2021.

1 Renewable energy — what you need to know | Publications | Pembina Institute

2 Baseload myths and why we need to change how we look at our grid | Blog Posts | Pembina Institute

3 For readers not familiar with the term, "cherry-picking" refers to highlighting data that supports one's case while hiding or ignoring data that does not.

4 According to Pembina's website, *Renewable energy* was made possible in part with the financial support of Environment and Climate Change Canada, the Municipal Climate Change Action Centre, and Energy Efficiency Alberta. Pembina's 2019-2020 Report to Donors shows that $5.6 million was received from granting agencies for completing specific projects and $352k was received under contracts for completing research and advisory services. About Pembina claims that "We provide our expertise to industry and government leaders, and we advocate for a strong, science-based approach to policy, regulation, environmental protection and energy development."

5 About Pembina | Pembina Institute

6 Renewable energy — what you need to know | Publications | Pembina Institute

7 These numbers imply an annual energy consumption of 6370 kWh/year. According to the Alberta Electric System Operator, the average residential consumer uses 600 kWh/month or 7200 kWh per year.

8 Wind is also incapable of reliably supplying any homes at all, as we in Part C.

9 https://solargis.com/file?url=download/North%20America/North-America_PVOUT_mid-size-map_156x138mm-300dpi_v20180611.png&bucket=solargis

10 "kWp" means "kilowatts peak," the rate at which a solar array generates power at peak performance. "kWh/kWp" refers to the kilowatt-hours of energy produced in a year for each kW of peak-output capacity.

11 Two-axis tracking allows the solar panels to track both the north-south and east-west movements of the sun across the sky, thereby maximizing the conversion of the available solar energy into electricity. However, two-axis arrays are more expensive than fixed or single-axis arrays, and tracking is not applicable for rooftop installations.

12 The US National Renewable Energy Laboratory's PVWATTS web application (PVWatts Calculator (nrel.gov)) produces a value of 8567 kWh for a PV array in Miami, assuming the default array configuration except for the use of two-axis tracking. The corresponding value for Medicine Hat is 7363 kWh.

13 With two-axis tracking replaced by the default rooftop mount with 20° tilt, the Miami value is 6209 kWh and the Medicine Hat value is 4914 kWh. (See the preceding endnote.)

14 https://solargis.com/file?url=download/World/World_PVOUT_mid-size-map_160x95mm-300dpi_v20191015.png&bucket=globalsolaratlas.info

15 These values come from PVWATTS. A few 1 kWh adjustments were made to the monthly values returned by that application to make the uniform monthly demand values into whole numbers.

16 More will be said about this subject in a later part of this response to Pembina.

[17] Natural Gas: A Primer (nrcan.gc.ca) states, "A rough approximation is that 100 GJs of energy – or 2,700 cubic meters or 94,800 cubic feet of natural gas – is required to heat a new average-sized single detached home in Canada for one year."

[18] Alberta Energy Regulator, Alberta Energy Resource Industries Monthly Statistics. ST3 (aer.ca)

[19] The effect of the natural gas conversion is so large that it makes the historical seasonal variation in electricity demand practically moot. Using the original (flat) pattern of 614 kWh/month therefore does not materially affect the new calculations.

[20] Electricity consumption per capita by country - Thematic Map - World (indexmundi.com)

[21] According to United States - U.S. Energy Information Administration (EIA), Florida's electricity comes from coal (15.6%), natural gas (64.0%), petroleum (1.1%), renewables (4.3%), and nuclear (15.1%).

[22] This number is based on the assumption of infinitely flexible batteries with no round-trip losses. In reality, losses of about 10% can be expected.

[23] Capital Costs and Performance Characteristics for Utility Scale Power Generating Technologies (eia.gov), Table 2.

[24] An internet search on June 7, 2021 provided several 12 V, 100 Ah $LiFePO_4$ batteries in the C$650 range. Since the storage capacity is (12 V)(100 Ah) = 1200 Wh = 1.2 kWh, that works out to be C$542/kWh. However, the search also revealed a 1.2 kWh battery rated for cold climates for US$1055 or US$880/kWh = C$1170/kWh. These numbers are "bare" values that do not take into account depth of discharge, inverters, installation, etc. Another cost benchmark is provided by TransAlta's WindCharger project (see endnote 27). The 20 MWh facility was built for $16 million, or $800/kWh, with that cost likely including the grid connection, battery buildings, and associated environmental controls. Tweaking battery cost estimates would not change the fact that backstopping Alberta solar generation with batteries is economically infeasible.

[25] The claim has been shown to be wrong with respect to solar generation. Later parts of this response will show that Pembina's claim is just as wrong with respect to wind generation and to the combination of wind and solar.

[26] What Are the Best Batteries for Solar Off Grid? - Understand Solar and Calculating Energy Storage Cost The Right Way - Energy Storage Media

[27] Varcoe: TransAlta set to flip switch on Alberta's first large-scale battery storage project, using technology from Tesla | Calgary Herald The project received a $7.7 million grant from Emissions Reduction Alberta using money collected through the carbon dioxide levy on industrial greenhouse gas emitters.

[28] The US National Renewable Energy Laboratory projects that, under a best-case scenario, battery costs will drop to about 40% of today's values by 2030 and to about 25% by 2050. The corresponding mid-case values are 50% and 40%, respectively. See Cost Projections for Utility-Scale Battery Storage: 2020 Update (nrel.gov).

[29] The-True-Cost-of-Wind-and-Solar-in-Alberta-FINAL-Ap-25-2021.pdf (friendsofscience.org) and Electricity-from-the-Sun-Reality-Versus-Fantasy-3.pdf (friendsofscience.org)

[30] The amount of time within which any imbalance between supply and demand must be corrected depends on the size of the imbalance. Tiny imbalances almost always exist and do not cause problems, while large ones, such as those arising from the sudden loss of a large generator or load, can lead to system instability and blackouts if not corrected in less than a second—far less time than a human would need to respond. Consequently, automated protection and control systems are necessary.

[31] For example, steel foundries and aluminum smelters must operate 24/7 between planned shutdowns or the materials harden and equipment is destroyed.

[32] We call them "so-called 'climate' regulations" because, for several reasons, they will have no discernible effect on Earth's climate for decades or longer (if ever).

[33] According to carbonbrief.org, the installed capacity of coal-fired power in China in 2000 was 199 376 MW. By the end of 2019, it had grown to 992 433 MW with an additional 99 710 MW under construction and 105 996 MW planned. By contrast, in 2017 (the last year included in Installed plants, annual generating capacity by type of electricity generation (statcan.gc.ca), Canada had about 49 700 MW of thermal generation in total. Regarding CO_2 emissions, BP's Statistical Review of World Energy reports the following (all values in megatonnes).

Source	**2000**	**2019**	**Change**
Canada	538	578	+7%
Other OECD	12 540	11 562	−8%
Non-OECD	10 770	22 217	+206%
World	23 848	34 357	+144%

[34] As a simple example, assume we have 7000 MW of load for 12 hours a day and 9000 MW of load for the other 12 hours. Base load is therefore 7000 MW. If we move 500 MW of demand from the peak hours to the off-peak ones, the load rises to 7500 MW in 12 hours and decreases to 8500 MW in the other 12. The effect is an *increase* in base load to 7500 MW and a decrease in peak load to 8500 MW.

[35] There are some forms of heating, such as radiant heating in concrete floors, that can "charge" during off-peak hours and then keep the building warm for a number of hours without using additional energy. However, such systems typically do not respond quickly enough to the large and rapid temperature swings that can occur in this part of the world. Such systems are also uncommon in Alberta and would require massive and expensive retrofits.

[36] More specifically, the graph shows what the Alberta Electric System Operator calls *Alberta Interconnected Load* ("AIL"). It includes the electricity consumed by all Alberta customers, including industrial customers who have on-site generators. It also includes transmission system losses. The relevant data can be downloaded from the Alberta Electric System Operator's *Pool Price* report at ets.aeso.ca.

[37] See Report on Energy Supply and Demand in Canada 2017 Revision (statcan.gc.ca). 2017 is the last year for which the report is available.

[38] Gas_2020.pdf (aer.ca)

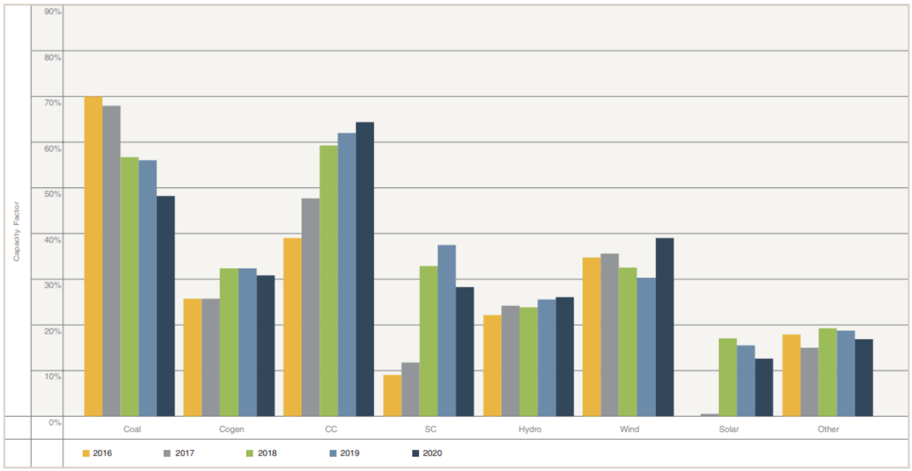
[39] Several dictionary definitions of "diktat" exist, but they all generally refer to decrees, usually harsh ones, that are imposed by those in power without popular support.

[40] Part D will contain a more detailed description of how Alberta's electricity market works. For clarity on terminology, in Alberta's market, generators make *offers* (not *bids*, as stated by Pembina) to supply a certain number of megawatts at a certain price. Loads make *bids* to stop consuming a certain number of megawatts when the price is at or above the bid price.

[41] This means that 4000 MW of generation is offered into the market at a price below $\mathcal{B}$'s price.

[42] The following chart is from the Alberta Electric System Operator's 2020 Annual Market Statistics report. "Cogen" refers to cogeneration units, typically gas-fired, which are designed to produce both electricity and industrial-use heat from a single source. "CC" refers to combined-cycle units, which use one or more gas turbines to drive generators and use the heat in the turbine exhaust to produce steam, which is then forced through one or more steam turbines to drive additional generators. "SC" refers to simple-cycle gas turbines, which are aeroderivative gas turbines whose rotating shafts drive generators. In Alberta the "Other" category includes biomass and waste-heat units. Among the reasons for the declining coal-unit capacity factors and the rising CC capacity factors is the increasing CO_2 tax, since coal units produce more CO_2 emissions per unit of output that natural gas CC units do.

FIGURE 15: Annual capacity factor by technology



[43] Fixed costs are those that are independent of the amount of energy produced by a generator. They include, but are not limited to, the payments to lenders for the capital cost of the plant, annual property taxes, and fixed operating and maintenance costs. Variable costs include fuel (if applicable) and variable operating and maintenance costs. For Type I units, the fixed cost is 2×$140M = $280M and the variable cost is ($30/MWh)×(8 784 000 MWh) = $264M, for a total of $544M. Serving the baseload energy with two Type II units would result in a fixed cost of 2×$70M = $140M and a variable cost of ($70/MWh)×(8 784 000 MWh) = $615M, for a total of $755M.

[44] For Type I units the cost would be $140M + ($30/MWh) × (332 724 MWh) = $150M, while for Type II units it would be $70M + ($70/MWh) × (332 724 MWh) = $93M.

[45] Hydro generation is, of course, dependent on water, so hydro output can be affected by droughts and by seasonal variations in water flows.

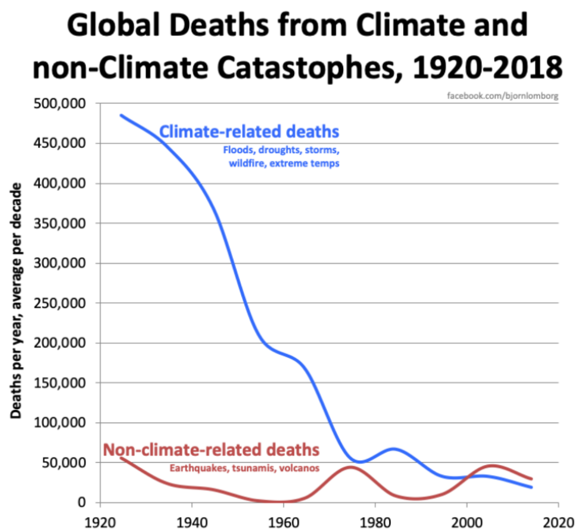
[46] In Alberta, there is no law or regulation that guarantees that wind and solar power must be dispatched by the system controller. However, wind and solar have close-to-zero variable costs, so they generally offer power into the energy market at $0/MWh and are therefore among the first generators to be dispatched. While renewable-energy advocates like to claim that this makes wind and solar the cheapest forms of generation available, they ignore the large and ever-increasing costs that wind and solar generators impose on consumers and other generators. We will discuss this at length in Part D.

[47] Excel's Solver function was used to optimize the amount of wind and solar generation based on minimizing the amount of energy storage that would be needed to maintain supply/demand balance in all hours. For the data used here, the optimized installed capacities were 1.69 times peak demand (19 769 MW) for wind and 0.71 times peak demand (8306 MW) for solar. Actual levels will be determined by investors and the electricity market.

[48] In section 3.05 of its annual report, Ontario's Auditor General wrote:
[I]nvesting in conservation does not necessarily mean saving money during periods of surplus because energy savings from conservation efforts can add to Ontario's surplus, contributing to an oversupply of electricity that means increasing exports and/or curtailing production. Since power is exported at prices below what generators are paid, and curtailed generators are still paid even when they are not producing energy, both of these options are costly. From 2009 to 2014, Ontario had to pay generators $339 million for curtailing 11.9 million MWh of surplus electricity; during the same period, Ontario exported 95.1 million MWh of power to other jurisdictions, but the amount it was paid was $3.1 billion less than what it cost to produce that power. In 2014 alone, 47% of Ontario's total power exports were related to surplus generation, with low-cost and low-carbon-emission energy, such as hydropower and nuclear-generated electricity, being exported. As well, from 2009 to 2014, there were also almost 2,000 hours in which the Hourly Ontario Electricity Price was negative, and Ontario paid exporters a net total of $32.6 million to take our power.

[49] The system controller can force wind and solar generators to produce less power than the available wind and sun would allow, but he cannot force them to produce more.

[50] It is highly informative to look at the number of climate-related deaths over time. Modern infrastructure, including (but not limited to) homes and related energy systems that shelter people from extreme weather and satellite-based storm warning systems, have contributed to a dramatic decrease in such deaths over the last 100 years. Bjorn Lomborg's related Facebook post, which is discussed at [Inverse Hockey-Stick: climate related death risk for an individuals down 99% since 1920], presents the following graph. Notably, cold kills far more people than heat, as discussed at [Heat Wave Versus Cold Wave Deaths in The U.S. and the Pacific Northwest].



[51] In Fort Chipewyan in northern Alberta on December 21, 2021, the sun will rise at 9:15 am and set at 3:30 pm. That makes the day 6h15m long and the night 17h45m long. The times for Milk River in southern Alberta are 8:20 am and 4:32 pm, giving 8h12m of day and 15h48m of night.

[52] Since the province passed its *Specified Gas Emitters Regulation* in 2007, the world's installed capacity of coal-fired generation has grown from 1 397 234 MW to 1 790 642 MW. China's growth alone, from 476 374 MW to 1 004 948 MW, more than made up for all the plant retirements. As of 2020, CarbonBrief reports that another 199,572 MW of coal generation is under construction and 297,829 MW of coal generation is planned. See [Mapped: The world's coal power plants in 2020 (carbonbrief.org)] and Figures E1 and E2 following these endnotes.

[53] [What Are the Best Batteries for Solar Off Grid? - Understand Solar]

[54] Understandsolar.com (see preceding endnote) provides the following example (verbatim):
You spent $1,000 on two 300 amp-hour, 6 volt batteries. Each of these batteries last 1,500 cycles if you limit discharge to 50% of their capacity. You connected these in series to increase your battery system's voltage to 12 volts. First, let's figure out their total lifetime storage:

300 * 50% * 1500 * 12 / 1000 = 2,700 kWh of total lifetime storage.

Now, let's figure out the cost per lifetime kWh:

$1,000 / 2,700 = $0.37 per kWh.

That's an expensive battery, but you get the point! Having the $/kWh cost allows you to compare the cost-effectiveness of any battery, regardless of technology, size, cycle life, and DoD. Yes, you should feel empowered!

[55] In the real world, an optimization program might change the order in which the batteries charge and discharge. For example, on Day 8, it could charge BH and then discharge BA. However, rearranging the charge/discharge cycles can change neither the storage capacity required nor the amount of energy supplied by batteries over the lifetime of the system.