THE ENERGY STORAGE CONUNDRUM

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The Global Warming Policy Foundation
Briefing 61

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Introduction and Executive Summary

Advanced economies – including most of Europe, much of the United States, Canada, Australia, New Zealand, and others – have embarked upon a quest to 'decarbonise' their economies and achieve 'Net Zero' emissions of carbon dioxide and other greenhouse gases. The Net Zero plans turn almost entirely on building large numbers of wind turbines and solar panels to replace generation facilities that use fossil fuels (coal, oil and natural gas) to produce electricity. The idea is that, as enough wind turbines and solar panels are built, the former coal, oil, and gas-burning central stations can gradually be closed, leaving an emissions-free electricity system.

But wind and solar facilities provide only intermittent power, which must be fully backed up by something – fossil fuel generators, nuclear plants, batteries, or some other form of energy storage – so that customer demand can be matched at times of low wind and sun, thus keeping the grid from failing. The governments in question have then mostly or entirely ruled out fossil fuels and nuclear as the backup, leaving some form of storage as the main or only remaining option. They have then simply assumed that storage in some form will become available. Their consideration of how much storage will be needed, how it will work, and how much it will cost has been entirely inadequate.

Energy storage to back up a predominantly wind/solar generation system to achieve Net Zero is an enormous problem, and very likely an unsolvable one. At this time, there is no proven and costed energy storage solution that can take a wind/solar electricity generation system all the way to Net Zero emissions, or anything close to it. Governments are simply setting forth blindly, without any real idea of how or whether the system they mandate might ultimately work or how much it will cost. The truth is that, barring some sort of miracle, there is no possibility that any suitable storage technology will be feasible, let alone at affordable cost, in any timeframe relevant to the announced plans of the politicians, if ever.

This report seeks to shine a light on the critical aspects of the energy storage problem that governments have been willfully ignoring.

Section 1 shows that full backup is indispensable in an electricity grid powered mainly by intermittent generation. Without it, there would be frequent blackouts, if not grid collapse. It doesn't matter if one builds wind and/or solar facilities with capacity of ten or one hundred or even one thousand times peak electricity usage. On a calm night, or during days or weeks of deep wind/sun drought, those facilities will produce nothing, or close to it, and only full backup of some sort – that is, backup sufficient to supply all of peak demand for as long as it takes – will keep the grid from failing.

Section 2 sets out realistic estimates, for several major countries, of the amount of energy storage required to get through the inevitable periods of insufficient generation from intermittent sources. These calculations do not require any kind of fancy degree or engineering expertise to understand. Rather, they are a matter of basic arithmetic. And yet somehow, blinded by their zeal to pursue decarbonisation of the energy system, government planners in essentially all developed countries have pushed forward with Net Zero plans without setting out these fundamental figures. The task has thus been left to independent analysts, often people who are retired and generally uncompensated, who have donated their time and skills to provide the basic information that the public, on the hook for the vast cost and risks of these schemes, has a right to know.

Section 3 looks at the current plans for acquisition of energy storage in some of the countries that say they are on the path to Net Zero. In all cases, the capacity that will be delivered by the 2030s is trivial – typically from around 0.1% to at most 0.2% of the amount that is necessary if Net Zero is to be achieved.

Section 4 considers the cost and feasibility of acquiring battery storage on the scale required to deliver Net Zero. We review recent government reports on the current and projected cost and capabilities of battery technologies that have been seriously proposed for grid backup in the absence of fossil fuels. Even on the most optimistic assumptions, the cost could be as high as a country's annual GDP, thus rendering the entire Net Zero project an impossibility. On less optimistic assumptions, the capital cost alone could be 15 times annual GDP. In addition, it is not just costs that render the goal infeasible, but also practical limitations. Current battery technologies provide about four hours of discharge at maximum capacity, but weather patterns mean that grids need batteries that can store as much as a month's demand, and then discharge that energy over the course of six months or more. Such 'long duration' batteries have not yet been invented.

Section 5 examines the proposed alternative storage medium of 'green' hydrogen, produced by electrolysis of water. The best that can be said for the idea is that it is somewhat less absurd than grid backup with batteries. Hydrogen does offer a potential solution to the problem of long-term (months rather than hours or days) storage of large amounts of energy. However, green hydrogen is very costly, particularly if the electricity used comes from the wind or sun; and once produced it is inferior to natural gas in every way as a means to power the economy: it is much less energy dense, more dangerous, subject to explosions, and more difficult to handle and to store. While exact costs of a green hydrogen system are unknown because of the lack of any existing model, calculations based on reasonable assumptions indicate that electricity from a combination of solar panels and green hydrogen would be at least 5 and more likely 10 or more times as expensive as electricity from natural gas.

Section 6 looks at the studies that have calculated a so-called 'levelised cost of storage' and have suggested figures in a range that would be expensive but potentially affordable. It shows that the studies in question rely on assumptions about battery charge and discharge rates that are inapplicable to the problem of gridscale storage.

Section 7 discusses the truly shocking fact that politicians and governments have committed their people to Net Zero goals without any kind of demonstration project that shows that the goal can be achieved technologically, let alone at reasonable cost. To date, no such project has achieved Net Zero emissions through intermittent renewable generation and energy storage backup; nor is there anything close to it. Half-hearted efforts to build such demonstration projects have incurred unaffordable costs, without getting close to the Net Zero goal, leaving no reason to think that such a system can ever succeed.

The push toward Net Zero without a fully demonstrated and costed solution to the energy storage conundrum is analogous to jumping out of an airplane without a parachute, and assuming that the parachute will be invented, delivered and strapped on in mid-air in time to save you before you hit the ground. Now, before our advanced economies are destroyed, it is time to demand from our politicians and energy planners that they level with the public about the huge costs and the likely impossible technical requirements of the goals to which they have committed us.


REFHYNE

1. The problem of energy storage

In recent decades, an intense political campaign in Europe and the English-speaking countries has brought forth a moral fervour, calling for 'saving the planet' through the elimination of carbon dioxide from the burning of hydrocarbons, often called fossil fuels. In response, many governments have adopted legally binding targets for rapid emissions reductions. In recent years, the goal of eliminating all or nearly all carbon emissions from the energy economy has come to be known by the term 'Net Zero.'

Among the leaders in this regard have been the governments of Germany (with its *Energiewende* of 2010), the UK (Climate Change Act of 2008 and subsequent related statutory instruments), California (SB 100 of 2018), and New York (Climate Leadership and Community Protection Act of 2019).

In the US, Congress has not yet adopted any legally binding emissions-reduction targets for the nation as a whole. However, on April 22 ('Earth Day'), 2021, President Joseph Biden on his own authority issued a press release announcing emissions targets for the country of 'a 50–52 percent reduction from 2005 levels…in 2030', and 'net zero emissions economy-wide by no later than 2050'. The goal for 2030 effectively requires full decarbonisation of the electricity sector by that date.

These jurisdictions, and many other European countries, numerous American states, Canada, Australia and New Zealand, have all embarked on what they assert to be a path toward net zero emissions from electricity generation. The universally accepted strategy is to construct large amounts of generation facilities based on weather-dependent intermittent 'renewables'. But unfortunately, wind and solar do not produce at full capacity most of the time. Typical capacity factors (in the US) are about 35–40% for wind turbines, and 20–25% for solar panels, all coming at times outside the control of the grid operator.

The need for full backup

For an electrical grid to function, there must be a very close match between power supplied and power demanded, on almost a minute-by-minute basis. Unlike fossil fuel plants, wind and solar generators cannot be adjusted to meet demand. Solar arrays produce nothing at night, and very little on overcast winter days. Wind turbines produce nothing when the air is still. A system based on solar panels and wind turbines produces very little on overcast and calm winter days, and absolutely nothing on calm nights.

As a result, no amount of wind and solar – even with facilities with nameplate capacity ten, or a hundred, or even a thousand times peak demand – can ever power an electrical grid on their own. A predominantly wind/solar generation system needs full backup from some other source. In other words, that source needs to be capable of stepping in to provide 100% of the power demanded by customers until the sun starts shining or the wind starts blowing.

There are only a few options. Fossil fuels can obviously do the job, and they are currently in widespread use for this purpose. But the whole idea of Net Zero is that fossil fuels are to be mostly or completely eliminated. Nuclear is a second possibility, but is very challenging to apply as backup to intermittent generation, and, in any event, development of new facilities has been rendered all but impossible in most places by regulatory obstacles.

The only remaining option is energy storage of some sort. The concept is to build enough wind and solar capacity to meet full demand when averaged over a year. This will produce large surpluses at some times, and deficits at others. If surpluses can somehow be stored, they can be drawn down in times of production deficit.

The lack of a plan

In designing such a system, there are three principal aspects of storage that require attention:

- *Amount of storage* needed for full backup. A detailed calculation must be performed, based on historical weather patterns and wind/solar production, of the amount of storage capacity that must be provided to enable a given grid to get through a year without ever finding itself with the storage empty and the wind and sun not blowing.
- *Cost* of the amount of storage that has been calculated as needed.
- *Technical feasibility* of deploying the proposed storage devices. There are several considerations, including their ability to store energy for the required period, how quickly they can discharge energy, and their own energy use (e.g. for temperature control), and so forth.

Remarkably, none of the jurisdictions currently embarked on crash programs to implement Net Zero through wind and solar facilities has paid much attention to the energy storage problem.

All appear to assume that one only needs to build enough wind turbines and solar arrays, and perhaps a few batteries of unspecified amounts along the way, and the fossil fuel facilities can just gradually be retired and emissions will fade away. As we will see, the energy storage problem is enormous, it is critical, and it is far from being solved.

2. The storage capacity required

Many researchers have estimated how much energy storage will be needed to back up an electrical grid powered entirely by either wind turbines, solar panels, or a combination of the two. The examples highlighted in this section have been chosen because the researchers have made their work and their assumptions public, and that work has been reviewed and appears to be competent. Other calculations can be found, some coming to lower storage requirements, but we have either not managed to get hold of all the calculations and assumptions specified, or have determined that the assumptions are unreasonable or even incorrect.

Some estimates consider only what is required to get through a worst-case sun and wind drought, such as multiple consecutive days in mid-winter with near zero production from intermittent generators. Such a calculation is a matter of basic multiplication. For example, if the worst-case sun/wind drought is assumed to last five consecutive days of zero production, then that translates to a storage requirement of 120 MWh (24 hours × 5 days) for each megawatt of average demand.

Others model a system for a full year, based on actual historical patterns of production from existing wind and solar facilities, extrapolated to produce enough power to match demand over the year. A spreadsheet is created, where days of excess wind and solar production have energy added to storage, and days of deficit production see energy withdrawn from it. These calculations, which have been prepared for several different countries, suggest that 500 to more than 1000 MWh of storage is required per megawatt of average demand.

For many reasons, the estimate of 500 MWh, or even 1000 MWh, of storage required per megawatt of average demand may well not be sufficient to assure reliability of a grid over a longer period, such as multiple years. For example, wind output in one year may turn out to be significantly less than the wind output in the year that was used for the calculation. This only serves to emphasise the need for a working demonstration project to show how much storage it will take to achieve Net Zero over a period of multiple years.

Storage required for a lack of sun

An outline of such a calculation, for a worst-case sun drought, was produced by David Wojick at PA Pundits International on January 20, 2022,[1] and was then applied by Roger Caiazza of Pragmatic Environmentalist to the case of New York State in a post on January 24, 2022.[2] Wojick addresses the question of how much solar generation capacity and energy storage will be needed to provide 1000 MW of firm power through a five-day sun drought in the winter, followed by two sunny days, followed by another five-day sun drought. Here is the calculation:

> For simplicity let us first assume 8 hours of full sun and full power every [sunny] day. Clearly we need 16 hours of storage every night. That is 16,000 MWh of battery storage. We also need another 2,000 MW of generating capacity to charge the batteries every day…
>
> How many successive days of dark cloudiness to design for is a complex question of local and regional meteorology. Here we simply use 5 days but it easily could be more. Five dark days certainly happens from time to time in most states…
>
> The required battery capacity is simple. Five days at 24 hours a day is 120 hours. To supply a steady 1,000 MW, that is a whopping 120,000 MWh of storage…
>
> It is vital to get the dark days' batteries charged before the next dark days arrive, which in some cases might be very soon. This too is a matter of meteorology. To be conservative, we here first assume that we have two bright sunny days to do the job.
>
> Two days gives us 16 hours of charging time for the needed 120,000 MWh, which requires a large 7,500 MW of generating capacity. We already have 3,000 MW of generating capacity [for fully-sunny days] but that is in use providing round the clock sunny day power. It is not available to help recharge the dark days' batteries. Turns out we need a whopping 10,500 MW of solar generating capacity.
>
> This 10,500 MW is a lot considering we only want to reliably generate 1,000 MW around the clock.

Thus the calculation is that to provide a firm 1,000 MW of power using only solar panels and battery storage, and to reliably get through a worst-case scenario of a 5-day sun 'drought' followed by two sunny days and then another 5-day sun 'drought,' will require 10,500 MW of solar panels and 120,000 MWh of battery storage. The math is not complex and is all there in that one excerpt, so readers can check it to see if it is correct.

Storage for a full year: Germany and California

In a post at the website Energy Matters on November 22, 2018, Roger Andrews provided calculations of the energy storage capacity that would be needed to completely back up a wind/solar generation system over the course of a full year for two cases: Germany and California.[3] For his calculations, he used daily average data (rather than hourly or minute-by-minute) for the year 2016 for Germany and 2017 for California. For the years in question, average demand was about 50,000 MW in Germany and about 35,000 MW in California.

Andrews calculated that for either case, if Germany or California had supplied all of their electricity using wind and solar facilities with the intermittency patterns of their actual wind and solar facilities in those years, either would have needed approximately 25,000 GWh of storage to avoid blackouts. The 25,000 GWh of storage would have represented about 714 MWh of storage per megawatt average use for California (29.75 days of average use), or 500 MWh of storage per megawatt average use for Germany (21.83 days of average use).

This annual storage requirement calculated by Andrews is a large multiple of the requirement estimated by Wojick for a one-time worst-case multi-day wind/sun drought. This is because of the seasonality of wind and solar generation and consumption. In both Germany and California, the wind and solar facilities produce much more power in certain seasons than others – sun more in the summer and less in the winter; wind more in the spring and fall, less in the summer and winter. That phenomenon leads to a seasonal sine-wave pattern in charging and discharging the storage facility (Figure 1).

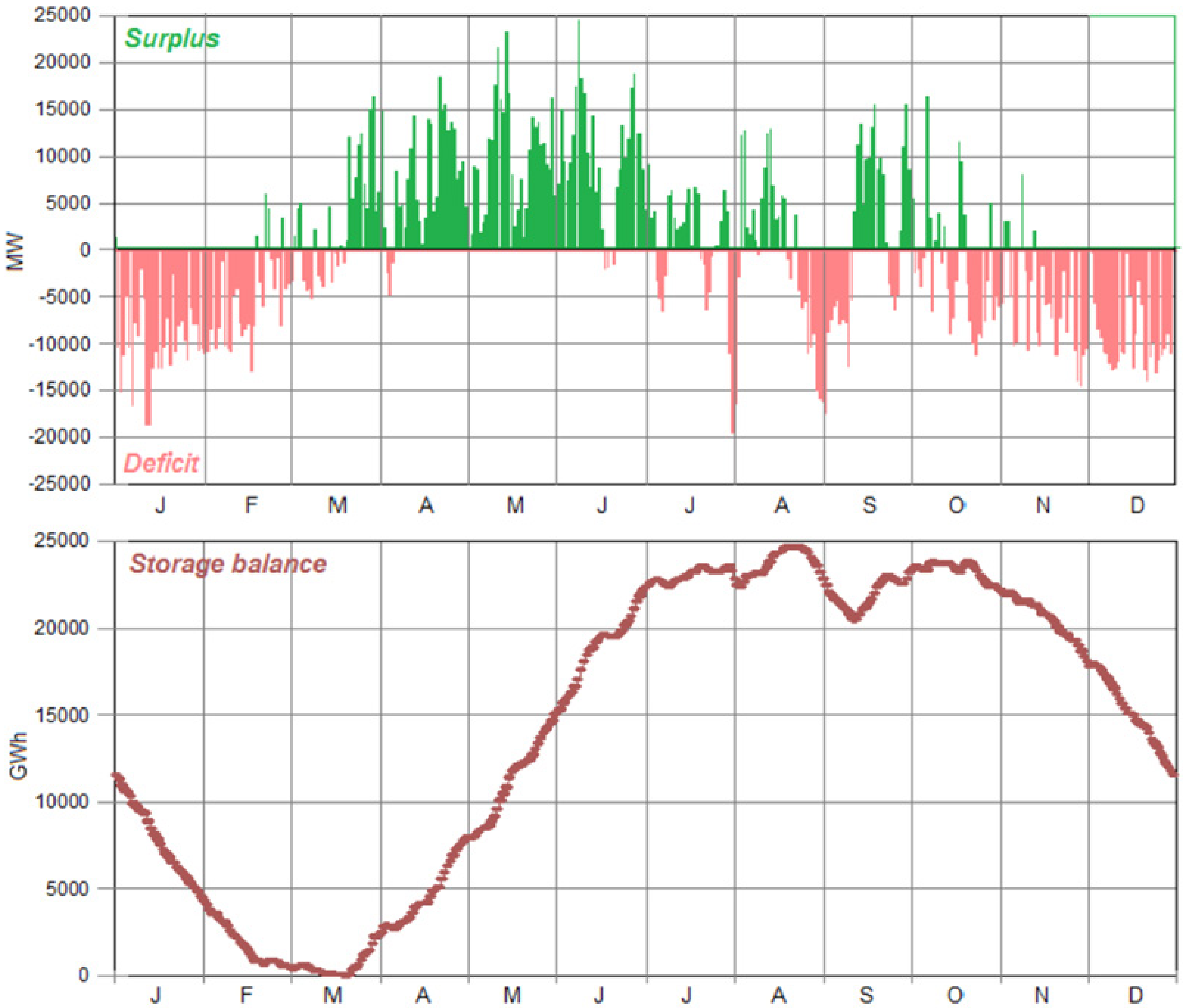


Figure 1: The seasonal charging and discharging sine wave.

The surpluses in the spring and early summer, and the deficits in the autumn and winter, are obvious. The result is that it takes storage of almost a full month's average usage to get through the year without a blackout.

Andrews further notes that since his calculations are based on actual data for a particular year, another year could turn out to require even more storage. Also, his calculations assume a 100% return of energy stored when called upon for use, even though the seasonal pattern means that the energy has been stored for periods of up to a full year before use.

Storage for a full year: USA

A similar calculation for the lower 48 states of the USA has been prepared by Ken Gregory.[4] His methodology is very similar to that of Andrews. Hourly data for electricity demand and production from existing wind and solar facilities was obtained, this time for 2019 and 2020. However, Gregory differs in two important respects:

- He considers seven different scenarios for getting to Net Zero, five of which involve substantial retention of fossil fuel electricity generation, but with putative carbon capture and storage technology applied.
- For the no-fossil-fuels scenarios, rather than assuming that the US goes to a system based entirely on generation from the wind and sun, he assumes that existing non-fossil-fuel generation – hydro, nuclear, and biomass – is left in place.

Two of Gregory's scenarios consider storage requirements in a world where wind and solar generation replace all fossil fuel generation for the lower 48 US states.

- In Case 1, wind and solar generation are set to be exactly equal to the fossil fuel generation replaced, but with a small amount of extra capacity to correct for the expected turnaround losses.*
- In Case 2, additional wind and solar facilities are built. At times of high sun and wind, there is a substantial surplus of electricity, which has to be discarded.

It turns out that Case 2 is actually the less expensive case, although not to any degree that is meaningful to the issue of feasibility.

Gregory also considers additional cases (Cases 3–7) that involve continued use of fossil fuel power generation with carbon capture and storage. These scenarios are not considered here because they involve ongoing substantial emissions that are inconsistent with Net Zero ambitions.

The bottom line of Gregory's Case 1 calculation is an annual energy storage requirement of approximately 233,000 GWh for

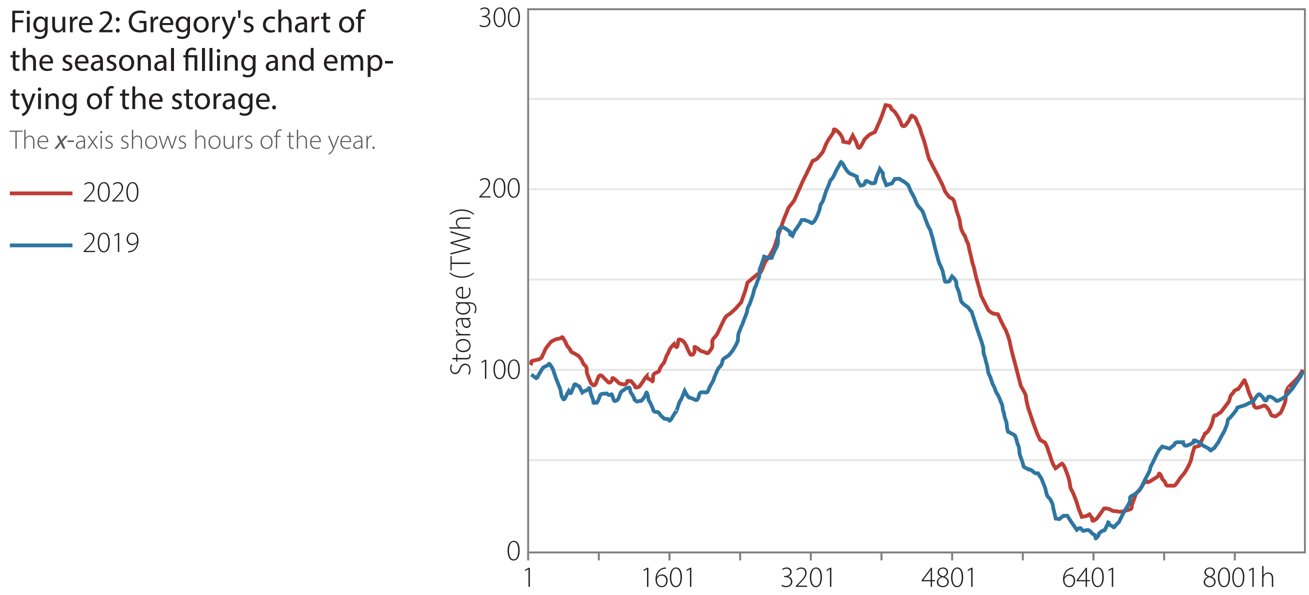
* No storage medium is ever 100% efficient. There are always energy losses along the way. The percentage of the input energy that is lost (in batteries, as heat) is referred to as the turnaround loss.

the full US (lower 48). Since the assumption is that we are replacing current fossil fuel usage, which in 2020 was an average of 305 GW, plus another approximately 10 GW for battery losses, that comes to a need for storage of about 740 hours, or 30.8 days of average usage. Gregory's Case 2 calculation, with substantial over-building of wind and solar facilities, comes to an energy storage need of some 25.4 days of average usage.

Figure 2 reproduces Gregory's chart showing the annual cycle of additions to and withdrawals from energy storage for the US for 2019 and 2020, assuming that the existing wind and solar facilities were scaled up to produce 100% of the electricity demanded, and that they operated with the exact same patterns of intermittency as the actual patterns experienced for those two years.

Figure 2: Gregory's chart of the seasonal filling and emptying of the storage.

The *x*-axis shows hours of the year.



Gregory states that he assumed a 80% return on stored energy from the batteries (as opposed to the 100% return assumed by Andrews).

Again, a different year could lead to a higher or lower storage requirement, depending on the weather.

233,000 GWh of energy storage is truly an enormous amount. To give the reader an idea of the scale involved, there is currently under construction in Queensland, Australia a massive lithium-ion battery installation intended for grid back-up, with a storage capacity of 150 MWh. Figure 3 shows a rendering of the facility from its developer, Vena Energy.

150 MWh is 15% of one gigawatt hour. In other words, 233,000 GWh of storage would require some 1.55 million of the facilities pictured in Figure 3, assuming that these facilities even have the capabilities of storing and discharging energy over the periods of time needed.

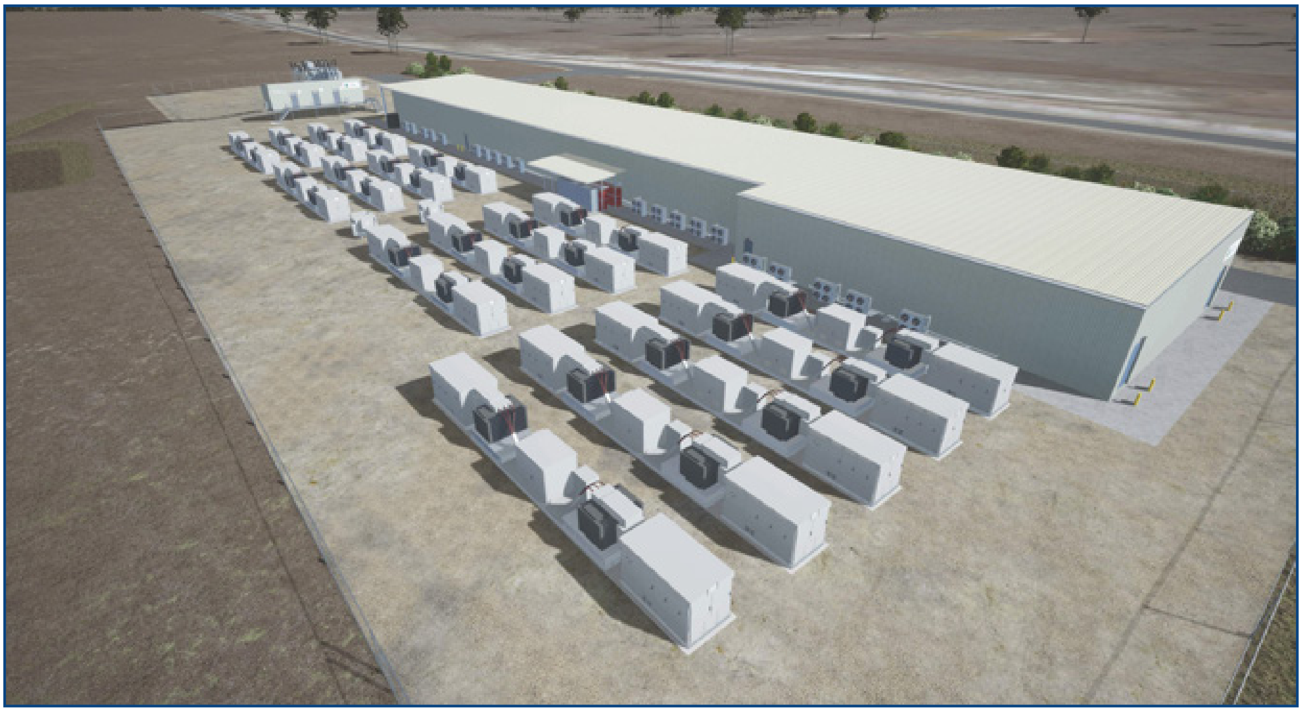


Figure 3: Digital rendering of Vena Energy's battery facility in Queensland.

Another full-year calculation for Germany

In late 2021, two German economists, Oliver Ruhnau and Staffan Qvist, published at *Econstor* a paper with the title 'Storage requirements in a 100% renewable electricity system'.[5] The paper deals only with Germany, and takes a somewhat different approach to that taken by Andrews for the same country. For example, Ruhnau and Qvist used hourly data for consumption and for production from the existing wind and solar facilities, in contrast to the daily data used by Andrews. They also assumed substantial overbuilding of wind and solar facilities, in an attempt to reduce the cost. Nevertheless, they calculated a storage requirement of 56,000 GWh, which is of the same order, but substantially higher than, the 25,000 GWh calculated by Andrews. Their result represents some 1,120 hours of average use, or almost 47 days.

3. Existing plans for electricity storage acquisition

Jurisdictions claiming that they intend to achieve Net Zero have their heads in the sand as to the amount of energy storage they will need. Existing plans call for just a tiny fraction of the capacity required. It is hard to avoid the conclusion that the people planning the Net Zero transition have no idea what they are doing.

For example, on April 11, 2022 consulting firm Wood Mackenzie issued a report on the plans of various European countries over the next decade to dramatically ramp up their energy storage capacity on the path to Net Zero. The title is *Europe's Grid-scale Energy Storage Capacity Will Expand 20-fold by 2031*.[6] But this seemingly massive increase in capacity will still leave these countries with less than one-one thousandth of the storage capacity needed to back up their grids without fossil fuels.

In the case of Germany, Wood Mackenzie states that the planned energy storage capacity for 2031, following the 20-fold expansion, is 8.81 GWh, compared to the Andrews estimate of approximately 25,000 GWh, or the Ruhnau/Qvist figure of approximately 56,000 GWh. In other words, the amount of energy storage that Germany is planning for 2031 is between 0.016% and 0.036% of what it actually would need. This does not qualify as a serious effort to produce a system that might work. With the closure of its coal and nuclear plants, Germany has thus made itself totally dependent on natural gas from Russia as the backup for its wind and solar generators.

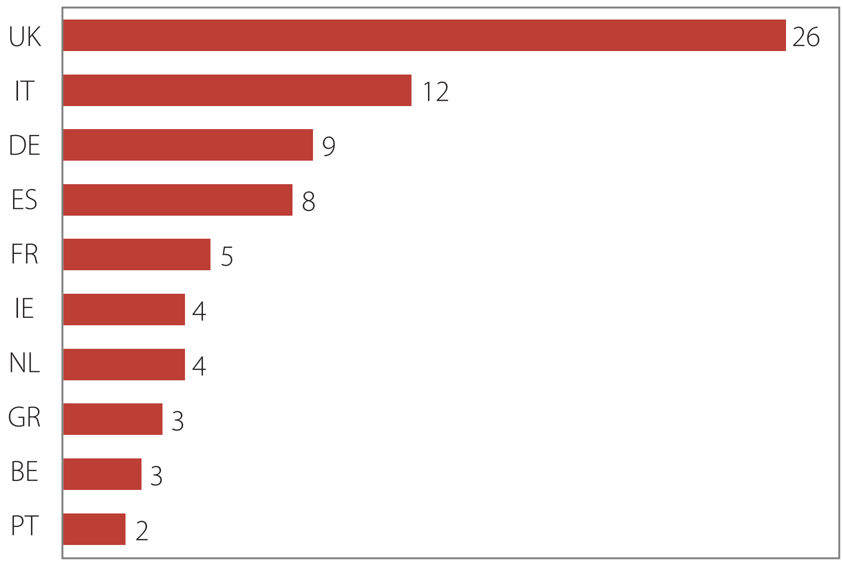
The Wood Mackenzie report also covers the plans of the other major European countries (Figure 4). Although it describes the plans in excited terms as representing a massive expansion of existing energy storage, without exception, fulfillment of the plans would still leave all of the countries with less than 0.1% of the energy storage they would need.

The planned amounts of storage capacity range from about 2 GWh to 26 GWh, against requirements that would be in the range 5,000–50,000 GWh per country. These storage procurements may well be useful or even necessary as wind and solar generation increases, in order to balance the grid within one day, as well as to synchronise the erratic wind/solar generation to the regular pattern of alternating current. However, the amounts are trivial relative to what would be needed for full backup in the absence of fossil fuels.

The US states planning rapid transition to Net Zero are similarly astoundingly deficient in their consideration of energy storage requirements. For example, of all the states, New York has the most aggressive target. Based on the calculations above for places like California and Germany, New York's energy storage requirement to achieve Net Zero at current consumption levels

Figure 4: New capacity in European gridscale storage

Figures in gigawatt hours.
Source: Wood MacKenzie.



would be in the range of 10–15,000 GWh. However, its plans also include the rapid electrification of the economy, leading to an approximate tripling of electricity consumption, and a commensurate approximate tripling of the storage requirement to 30–45,000 GWh. Yet on April 12, 2022, a service called Utility Dive reported that New York is 'forging ahead' with a goal of some 6 GW of energy storage by 2030.[7] The units in the piece are given as gigawatts rather than gigawatt hours. However, the storage that is planned is mainly, if not entirely, of the lithium-ion technology, which can deliver at most approximately 4 hours of discharge at full capacity. That means that the 6 GW of storage capacity would translate to at most about 24 GWh. Once again, this is less than 0.1% of what would be needed to achieve the goals that have supposedly been set.

California also has barely begun to address the energy storage issue. On April 6, 2022 Utility Dive reported that California had, as of that date, 3.1 GW of energy storage installed on its grid.[8] It stated that 'nearly all' of this is of the lithium-ion technology, meaning that this figure translates to at most about 12.4 GWh, compared to a requirement to fully back up a wind/solar generating system of at least some 25,000 GWh, and potentially a multiple of that, as additional sectors of the economy become electrified.

As to plans for the next few years, Utility Dive's piece reported that the California Public Utilities Commission had ordered the state's power providers to collectively procure some 11.5 GW of new storage resources to come online by 2026. Only 1 GW of that is to be so-called 'long-duration' storage, that is, with capacity going beyond 4 hours of discharge. However, the technology for the long-duration storage has not been specified, and remains to be invented. The additional 10.5 GW of lithium-ion storage capacity, translating to at most about 42 GWh, would take California all the way to about 0.17% of the energy storage it would need to fully back up a wind/solar generation system.

4. Cost and feasibility

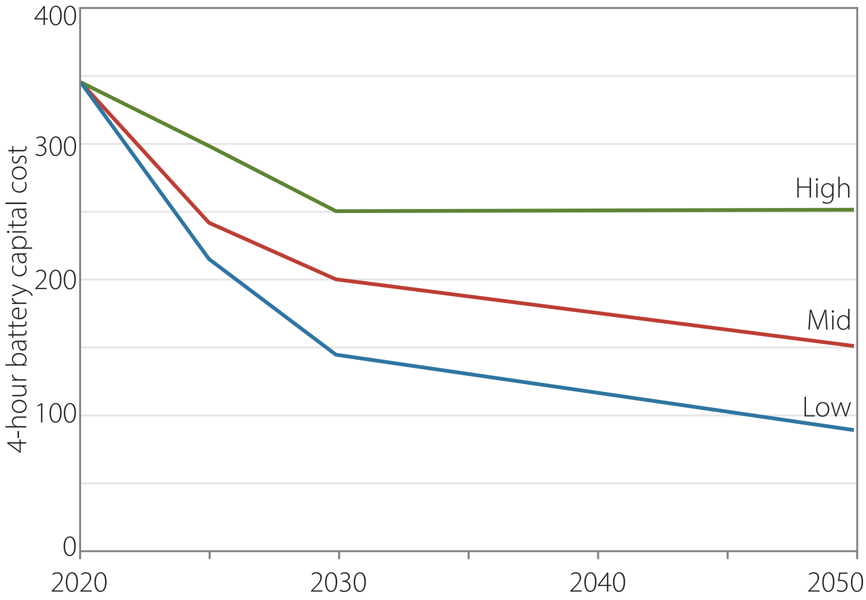
Cost

Any plan to power an electrical grid with wind and solar generators must address the cost and feasibility of the storage needed. As indicated in the preceding sections, the only battery technology that is widely available for gridscale storage is lithium ion. This is almost exclusively what is being procured in the jurisdictions discussed in this report, including Germany, California and New York.

The federal government's National Renewable Energy Laboratory produces periodic reports as to the current and projected costs of utility-scale batteries of the lithium-ion type. The most recent edition, from June 2021,[9] gives the current average cost as approximately $350/kWh. It projects declining costs, at first

Figure 5: Cost of gridscale batteries

$2020 per kilowatt hour for lithium ion battery. Source: NREL.



relatively rapidly but then diminishing over time. Three cost projections are shown – high, mid, and low – depending on the rate of decline (Figure 5). The projected costs for the year 2050 range from just under $100/kWh for the 'low' case to about $250/kWh for the 'high' case (in 2020 prices).

These figures may prove accurate, or they may be wildly optimistic. An April 12, 2022 piece from Utility Dive reports that battery storage costs in New York have recently surged by more than 20%, as the state pushes forward with its goal of procuring all of 6 GW of lithium-ion storage.[10] Utility Dive attributes the rapid cost escalation to '[c]rimped supply chains, rising demand for batteries and higher costs of lithium,' and notes that 'experts' foresee further steep increases ahead. In 2020–21, the average cost for utility-scale lithium-ion battery installations in New York was $464/kWh; but in 2022 the price for contracts actually awarded has increased to $567/kWh.

Multiplying these costs by the backup storage requirement for each jurisdiction yields truly astounding numbers. For the full United States, assuming the storage requirement of 233,000 GWh and the very lowest price for lithium-ion batteries of $100/kWh gives a bill of some $23.3 trillion – which is more than the annual GDP of the US. If you assume the electrification of currently non-electrified sectors of the economy, that figure could triple to $70 trillion. If you further assume that the cost could be closer to $500/kWh than $100, then the total price for the storage could go to $350 trillion. By comparison, the full annual US GDP is less than $25 trillion. And lithium-ion batteries only last a few years, and would then need to be replaced.

Calculations for the other places considered in this paper – including Germany, California, and New York – give similar results. At current demand levels and with the lowest assumed prices for lithium-ion storage, the cost would be commensurate with annual GDP. With full electrification of the economy and battery storage costs closer to $500/kWh, the one-time capital cost would be up to 15 times GDP, in each country.

Alternative battery technologies appear to be no cheaper. In 2019, the US Department of Energy issued a report entitled *Energy Storage Technology and Cost Characterization Report*.[11] It does not appear to have been subsequently updated. It considers, not just lithium ion, but also five other battery technologies that have been proposed for grid storage to back up intermittent wind and solar power: sodium-sulfur, lead acid, sodium metal halide, zinc-hybrid cathode, and redox flow. The report provides then-current (2018) costs for each of the six technologies, and also projected costs for each for 2025. It attempts to be comprehensive in considering all applicable costs for each technology, including such things as power conversion (AC to DC and back), construction, commissioning, and 'balance of plant.' Of the six technologies considered, lithium-ion proves to be the cheapest, both currently and in 2025, at which point it is projected to have fallen to $362/kWh. The other technologies have 2025 costs ranging from $433/kWh for zinc-hybrid cathode to $669/kWh for sodium-sulfur and sodium metal halide. Obviously, these costs are so high as to these technologies completely impractical as a back-up for a predominantly wind/solar powered grid.

Feasibility

Lithium-ion batteries are unequal to the task of backing up an electrical grid, which is nothing like a cell phone, or even an electric automobile, where four hours of stored energy can be used during a day and then recharged overnight. Rather, as shown in the charts in Figures 1 and 2, the intermittency patterns of wind and solar electricity generation have not only wide hourly and daily swings, but also a broad annual sine-wave pattern. Batteries to back up such a grid must have the capability of storing energy from the windy and sunny parts of the year (spring and summer), to be drawn down over the course of the autumn and winter.

None of the battery technologies set out in the US Department of Energy report, for all their huge costs, has anything like the capabilities needed to meet these requirements. They are only usable for about four hours of discharge at full power. The report does not even consider whether any of these technologies might be capable of handling the six-months-of-charging-followed-by-six-months-of-discharging that a wind/solar-powered grid would demand.

Batteries that can discharge over more than just a few hours are known as 'long-duration' batteries. At this point, there are only the first glimmerings of realisation that such things will be absolutely essential to make a grid work where the predominant sources of the power are the wind and sun. Research on possible technologies is at the earliest stages, and nobody has any real idea what, if any, technology might work or how much it might cost. The US Department of Energy has a program called the Energy Storage Grand Challenge, which provides grants to entities doing research into such potential technologies. The department has been seeking funding to erect a research facility and they hope it will be ready by 2025.[12] Meanwhile, they are providing some $18 million of funding in grants to four separate companies to investigate varieties of so-called 'flow' batteries. A further article in *Energy Storage News* on April 7, 2022 reported that a Canadian company called E-Zinc had raised $25 million in private funds to research a zinc-based long-duration battery technology.[13] However, the article stated that the hope is that the technology, if successful, could provide storage for 'half a day to five days,' but also that the technology 'is yet to move beyond the pilot stage.'

Barring some sort of miracle, there is no possibility that any battery technology suitable for gridscale storage will be feasible in principle, let alone at any remotely affordable cost, in any time frame relevant to the announced plans of the politicians – if ever.

5. Misleading with the levelised cost

In addition to the studies of cost and feasibility of energy storage cited above, there are others that calculate something called a 'levelised cost of storage', or LCOS, for various types of battery. LCOS, when calculated, is typically quoted in units of dollars per megawatt hour, or cents per kilowatt hour. Examples of such LCOS studies include a January 2019 paper in the journal *Joule* by authors Oliver Schmidt, et al., entitled 'Projecting the future levelised cost of electricity storage technologies';[14] and an April 2022 study from investment bank Lazard entitled 'Lazard's Levelized Cost of Storage Analysis – Version 7.0'.[15] In the more recent Lazard study, the calculated levelised costs range from $55 to $785/MWh, which would convert to 5.5 to 78.5 cents per kilowatt hour. Even these figures are high relative to current consumer costs of electricity (which range from about 10 cents to 35 cents per kilowatt hour all in, depending on the jurisdiction).

Advocates of battery storage as backup for wind and solar electricity often cite such levelised cost figures, because they appear to be in a range that is potentially affordable, particularly if further cost decreases for battery storage are assumed. But unfortunately, levelised costs are irrelevant to the question of determining the cost of fully backing up an electrical grid for a modern city or country without using fossil fuels.

For example, the Lazard study describes situations in which the study is relevant.† Each involves a battery with one or a few hours of discharge capacity, which is more-or-less fully charged and discharged on a daily basis, similar to the battery of a cell phone or an electric vehicle in normal usage. Thus the battery goes through large numbers of these cycles in a year, each discharge getting added to the denominator for a division in the levelised cost calculation. An example of a situation considered

† See p. 17.

by Lazard is a battery used to arbitrage electricity rates, enabling the owner to buy electricity at low rates at night and sell back during peak hours in the late afternoon, repeating this cycle hundreds of times per year.

Full backup of an electrical grid powering a city or country does not work like that. Without fossil fuel or other backup, batteries must be procured to cover all worst-case wind/sun droughts and also seasonal lows of wind and solar output, which could persist for months. As shown above, that means enough to cover 20–30 days of average usage, which may then be fully charged and discharged only once per year.

Citation of levelised cost of storage calculations, of the type in the Lazard and Schmidt et al. studies, in the context of gridscale seasonal electricity storage is incorrect and misleading. That advocates continue to do so only points to the need for the public to demand a working demonstration project, from which the real costs could be definitively shown. It would immediately reveal the inappropriateness of the levelised cost of storage metric.

6. Hydrogen

Some Net Zero proponents – perhaps recognising the impracticality of battery storage as the backup for a wind/solar generation system – have put forward hydrogen as an alternative. For politicians and activists, who see no need to concern themselves with issues of practicality or cost, hydrogen seems like the perfect means to cut carbon entirely out of the energy cycle; just make the hydrogen by electrolysis of water, store it until you need it, and then burn it to make electricity. Water would be the only by-product.

Unfortunately, the practicality and cost issues of hydrogen are such that it is highly unlikely to ever be the solution to the energy storage conundrum. Hydrogen is currently produced at relatively low cost from natural gas, using a process called steam reformation. However, this produces carbon dioxide as a by-product, and therefore offers no benefits in terms of reduced carbon emissions over just burning natural gas. If the goal is decarbonisation, then the hydrogen must be derived from some non-carbon source, of which water is the only real alternative. In environmental activist circles, hydrogen derived by electrolysis from water is referred to as 'green' hydrogen.

To date, there has been almost no commercial production of green hydrogen, because electrolysis is much more expensive than steam reformation of natural gas, and is therefore uneconomic without government subsidy. The JP Morgan Asset Management 2022 Annual Energy Paper states that 'Current green hydrogen production is negligible…'[16]

There are almost no prototype green hydrogen systems operational at present, but enough is known about the processes of producing and distributing it to know that the problems are substantial and the costs likely to be huge. The bottom line is that it is much more expensive to produce than natural gas, but inferior in every respect as a fuel for running the energy system (other than the issue of carbon emissions, if you think those are a problem). Hydrogen is far more difficult and costly than natural gas to transport, to store and to handle. It is much more dangerous and subject to explosions. It is much less dense by volume than natural gas, let alone gasoline or jet fuel, which makes it notably less useful for transportation applications like cars and airplanes.

Consider first the cost. In December 2020, Seeking Alpha put the current price of green hydrogen at $4–6/kg.[17] That translates to a price of $32 to $48 per million British Thermal Units (MMBTU; the units in which natural gas prices are normally quoted). By comparison, US natural gas prices[18] have been under $5/MMBTU for almost all of the last decade; and after a recent spike to about $9/MMBTU in early 2022, have now fallen back to about $6/MMBTU. Thus green hydrogen currently costs 5–10 times as much as natural gas.

And in that cost comparison, the green hydrogen has been produced with electricity that itself came mainly from fossil fuels. What would the cost of green hydrogen be if the electricity to produce it was required to come only from the wind or sun? For this calculation, no data from an existing production system are available, since no such thing currently exists. However, we can get an idea how enormous the costs would be by considering known capabilities of existing generation systems.

The following calculation is derived from a similar one that appeared in the same December 2020 piece at Seeking Alpha linked above.[19] Consider a jurisdiction with steady electricity demand of 288 MW. This number has been selected because General Electric produces a widely-used natural gas-fired turbine with that capacity, and also says that it can produce a version of the turbine that will operate using hydrogen fuel instead. The electricity needs of our jurisdiction can be fully supplied by burning natural gas in the plant. But now suppose we want to use solar panels to provide the electricity and/or hydrogen for the plant sufficient to supply the 288 MW firm throughout the year. What capacity of solar panels must we build? Here is a calculation:

- Over the course of the year, the jurisdiction will use 288 MW × 8760 hours = 2,522,880 MWh of electricity.
- We start by building 288 MW of solar panels. We will assume that the solar panels produce at a 20% capacity factor over the course of a year. (Very sunny places such as the California desert may approach a 25% capacity factor from solar panels, but cloudy places such as the Eastern US and all of Europe get far less than 20% of capacity; in the UK, typical annualised solar capacity factors are under 15%). That means that the 288 MW of solar panels will only produce 288 × 8760 × 0.2 = 504,576 MWh in a year.
- Therefore, in addition to the 288 MW of solar panels di-

rectly producing electricity, we need additional solar panels to produce hydrogen to burn in the power plant sufficient to generate the remaining 2,018,304 MWh.

- At 80% efficiency in the electrolysis process, it takes 49.3 kWh of electricity to produce 1 kilogram of hydrogen. GE says that its 288 MW plant will burn 22,400 kilograms of hydrogen per hour to produce the full capacity. Therefore, it takes $49.3 \times 22{,}400 = 1{,}104{,}320$ kWh, or approximately 1,104 MWh of electricity to obtain the hydrogen to run the plant for one hour. For the 1,104 MWh of electricity input, we get back 288 MWh of electricity output from the GE plant.
- Due to the 20% capacity factor of the solar panels, we will need to run the plant for $8760 \times 0.8 = 7008$ hours during the year. That means that we need solar panels sufficient to produce $7008 \times 1104 = 7{,}736{,}832$ MWh of electricity.
- Again because of the 20% capacity factor, to generate the 7,736,832 MWh of electricity using solar panels, we will need panels with capacity to produce five times that much, or 38,684,160 MWh. Dividing by 8760 hours in a year, we will need solar panels with capacity of 4,416 MW to generate the hydrogen that we need for backup.
- Plus the 288 MW of solar panels that we began with. So the total capacity of solar panels we will need to provide the 288 MW firm power using green hydrogen as backup is 4,704 MW.

Or in other words, to use natural gas, you just need the 288 MW plant to provide 288 MW of firm power throughout the year. But to use solar panels plus green hydrogen backup, you need the same 288 MW plant to burn the hydrogen, plus more than 16 times that much, or 4,704 MW of capacity of solar panels, to provide electricity directly and to generate sufficient hydrogen for the backup.

Cost comparisons can only be approximations, but still they are stunning. In March 2022, the United States Energy Information Administration issued a report entitled *Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2022*.[20] A table gives what is called the 'Base overnight [capital] cost' of 'Combined-cycle – multi-shaft' gas turbine generators as $1,062 per kilowatt of generation capacity; and the same metric for 'Solar photovoltaic with tracking' of $1,327 per kilowatt of generation capacity.[‡] That would put the cost of the 288 MW General Electric turbine power plant at around $305 million, and the cost of the 4,704 MW of solar panels at around $6.25 billion.

So let us compare the cost of generating 288 MW of firm power using solar panels and hydrogen backup, or using just the GE plant burning natural gas:

- In the hydrogen scenario, we need the 288 MW plant cost-

‡ See their p. 2.

ing $305 million, and 4,704 MW of solar panels costing $6.25 billion, giving a total capital cost of $6.6 billion. There is no additional cost of fuel.

- In the natural gas scenario, we need the 288 MW plant costing $305 million, plus natural gas to keep it going. As a rule of thumb, at times of normal natural gas prices the fuel is about two-thirds of the cost of producing electricity, so would be the equivalent of about $600 million additional capital costs, for a total of around $900 million.

On these numbers, the green hydrogen scenario is 7.3 times more expensive than the natural gas scenario. Since the numbers are very approximate, and could vary significantly as prices fluctuate, it would be appropriate to say that the green hydrogen scenario is likely to be somewhere in the range of 5 to 10 times more expensive than the natural gas scenario.

It is hard to imagine that any jurisdiction will actually head down this road once they have done this arithmetic. And in addition, there are other major and unsolved issues of practicality of using hydrogen as a storage medium, all of which add large, but currently unknown and unquantifiable, potential costs, as follows.

- Making enough green hydrogen to power the world means electrolysing the ocean. Fresh water is of limited supply, and is particularly scarce in the best places for solar power, namely deserts. When you electrolyse the ocean, you electrolyse not only the water, but also the salt, which then creates large amounts of highly toxic chlorine, which must be neutralised and disposed of. Alternatively, you can desalinise the seawater prior to electrolysis, which would require yet additional input of energy. There are people working on solving these problems, but solutions are far off and could be very costly.
- Hydrogen is only about 30% as energy dense by volume as natural gas. This means that it takes about three times the pipeline capacity to transport the same energy content of hydrogen as of natural gas. Alternatively, you can compress the hydrogen, but that would also be an additional and potentially large cost.
- Hydrogen is much more difficult to transport and handle than natural gas. Use of the existing natural gas pipeline infrastructure for hydrogen is very problematic, because many existing gas pipelines are made of steel, and hydrogen causes steel to crack. The subsequent leaks can lead to explosions.
- Hydrogen-powered vehicles need either specialised hydrogen engines or alternatively fuel cells, adding yet more costs.

On any realistic view, it is no wonder that the amount of green hydrogen being produced today is negligible. Any attempt to build a green hydrogen project on a substantial scale is highly likely only to result in making the high cost and technical infeasibility painfully clear to all, with full loss of investment by anyone foolish enough to have funded the project.

7. Two attempts at Net Zero systems

The unsolved, and potentially unsolvable, challenges of energy storage in a grid predominantly supplied by intermittent generation are quite obvious. One does not need to be a highly credentialed scientist or engineer to understand the magnitude of these issues, or to see that solutions are critical if such a grid is to be made to work without fossil fuel backup. And yet politicians across the world have committed their peoples to achieving full decarbonisation without any demonstration project to show that the target can be met in practice, let alone at reasonable cost.

Historically, major innovations in provision of energy have begun with demonstration projects or prototypes to establish the feasibility and cost, before any attempt at widespread commercialisation. In the 1880s, when Thomas Edison wanted to start building power plants to supply electricity for his new devices, such as incandescent lightbulbs, he began by building a prototype facility in London under the Holborn Viaduct, and followed that with a larger demonstration plant on Pearl Street in Lower Manhattan, which supplied electricity to only a few square blocks. Only after those had been demonstrated as successful did a larger build-out begin. Similarly, the provision of nuclear power began with small government-funded prototypes in the late 1940s and early 1950s, followed by larger demonstration projects in the late 1950s and early 1960s. Only in the late 1960s, twenty years into the effort and after feasibility and cost had been demonstrated, were the first large-scale commercial reactors built.

But somehow our politicians have now become so filled with hubris that they think they can just order up a functioning wind and solar electricity system and assume that backup energy storage devices will magically be invented, that it will all work fine, that it will not be financially ruinous, and that all this will be achieved by some arbitrarily-imposed date in the 2030s.

There is today no such functioning electricity system based on wind or solar or a combination of the two that is free of fossil fuels and fully backed up by energy storage. There have only been two half-hearted attempts at delivering such a thing, both of which have been, and continue to be, abject failures, only serving to demonstrate how unlikely the whole Net Zero endeavour is ever to come to fruition.

The most significant of the two is a facility called Gorona del Viento on the Spanish island of El Hierro, one of the Canary Islands. El Hierro is a mountainous volcanic island with a population of about 10,000. The Gorona del Viento project consists of five large wind turbines and a pumped storage system to provide the backup. The wind turbines have sufficient capacity to fulfill 100% of the electricity demand of the island when the wind blows at full strength – the nameplate capacity is 11.5 MW, versus an average demand of 5.1 MW and a peak of 7.6 MW. When the wind blows and demand is low, the electricity can be used to pump water from a lower reservoir to an upper storage reservoir built in an extinct volcanic crater. The water then can be released through turbines to provide electricity at other times when the wind is not blowing.

The concept of the planners of the El Hierro project was that they would demonstrate how to do a 100% renewables/storage electricity system. The project launched in 2014, and on August 20, 2015 the Spanish daily *El Pais* reported that the island 'aspires to energy self-sufficiency to provide light and water from 100%-renewable sources'. However, apparently nobody bothered to do the simple arithmetic to be sure there was enough wind capacity and storage to make it work. The project has consistently fallen far short of its goal, as anyone who had done the arithmetic could have easily shown before they started. Fortunately, the island retains a secondary backup system, based on diesel generators, with a capacity of 11.2 MW, and which is therefore capable of exceeding peak demand on its own.

The most important shortfall of the Gorona del Viento system is that it has only a small fraction of the storage capacity needed to get through frequent daily and seasonal wind droughts. Roger Andrews calculated that the storage capacity would have to be 40 times bigger to see the island through a full year without the diesel backup. Unfortunately, the existing reservoir is the only suitable site on the island for pumped storage, and it cannot be made bigger. Even if a suitable site did exist, it would be of little to no relevance to the rest of the world, where sites for pumped storage on the scale required are essentially non-existent.

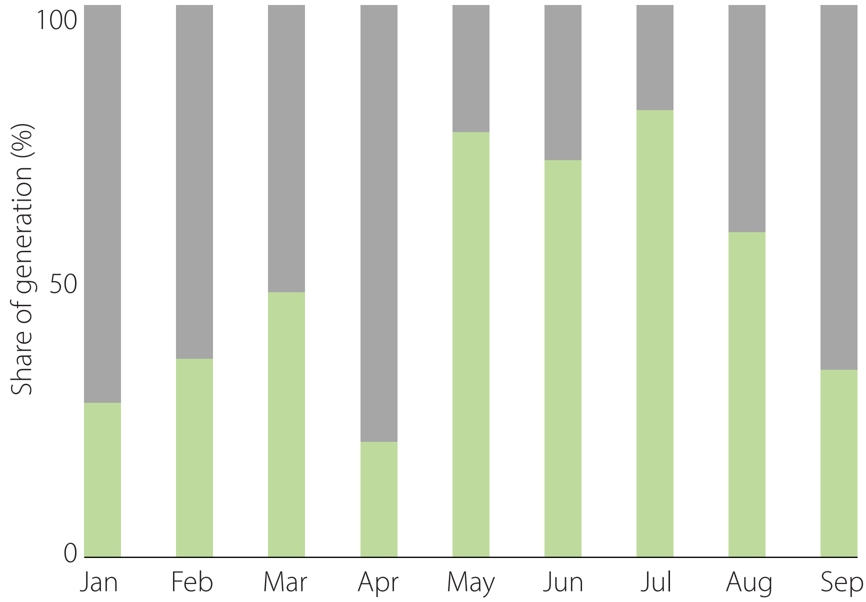
A second problem is that, although El Hierro has wind turbine capacity to supply average electricity demand more than twice over when the wind blows at full strength, the wind does not often do so, and therefore the installed wind turbines are insufficient to keep even the existing pumped storage reservoir full for when it is needed.

Gorona del Viento publishes monthly data on how much of the electricity for the island came from the wind/storage system and how much from the diesel generators.[21] The most recent data are from September 2021 (Figure 6). These make clear how very seasonal the wind power is, with far more in the summer than the winter. Data for earlier years show that the Gorona del Viento system has produced somewhat more than 50% of the electricity for El Hierro in some years of operation, but then fallen back well below half in other years, depending on the weather.

The bottom line is that El Hierro has wind turbines for more than double average demand, pumped storage for more than double average demand, and also diesel generators for more

Figure 6: Gorona del Viento generation by month

Grey, diesel; green, wind/storage. First 9 months of 2021 only.



than double average demand – three separate and redundant systems, all of which must be paid for, yet they struggle to get half of their electricity from the wind/storage system, averaged over the year. So the island must retain 100% diesel backup, fully maintained and ready to go, for the regular times, even in the windiest months, when the wind fails to blow. Estimates of the cost of the electricity produced by the Gorona del Viento system put it at around 80 euro cents per kilowatt hour, although most of that is subsidised by the Spanish government or the EU and thus hidden from the El Hierro ratepayer.

In summary, the El Hierro model, in return for electricity costs around four times the European average and seven times the US average, is not remotely capable of achieving Net Zero. It is a disaster that no other jurisdiction can or should attempt to follow.

After El Hierro, the next closest thing in the world to a Net Zero demonstration project is on King Island, part of the state of Tasmania, Australia. King Island is much smaller than even El Hierro, with a population of only about 1500 people. In fact, it never claimed that it was attempting to get all the way to Net Zero, but it did build substantial wind, solar, and battery storage facilities to attempt to get at least a large part of its electricity from these sources. However, like El Hierro, King Island retains 100% backup in the shape of a diesel generator system as well.

Roger Andrews did a detailed study of the results of the King Island system in a post on October 16, 2018.[22] He concluded that King Island did not provide sufficient data to enable a precise calculation of how much of its electricity comes from renewables and storage, and how much from the diesel backup. However, he made an estimate of about 60% from the wind, solar and batteries over the course of a year. He also calculated that to attempt to get to all the way to Net Zero without the diesel generators for a whole year, the island would need at least 100 times more storage, in addition to more wind and solar capacity.

Thus, as a model for how to get to Net Zero emissions from the generation of electricity, King Island must also be rated a total failure. All that it has shown is that you can't get much beyond 50% of electricity from renewables without vastly more energy storage capacity than anyone can afford.

8. Conclusion

Politicians throughout the developed world, urged on by environmental activists, talk with utmost earnestness about their plans for Net Zero, and have committed and are further committing their citizens and taxpayers to tens and hundreds of billions of dollars of spending to achieve this goal. Yet from their heads-in-the-sand approach to the energy storage conundrum, one would have to conclude that the entire effort is either wholly unserious or breathtakingly incompetent.

It is abundantly clear that no jurisdiction can get anywhere near Net Zero on the current path of just building more wind and solar generators and paying little to no attention to the problem of energy storage. Down that path one quickly comes to the current predicament of Germany, which has plenty of wind and solar generation capacity to supply its needs on a windy and sunny day, but almost no storage for when the night comes and the wind stops blowing. Germany has thus made itself dependent on fossil fuel backup, mostly in the form of Russian natural gas. And now, with the Ukraine war and the shutdown of the Nord Stream 1 and 2 pipelines, it has hit the Net Zero wall. With winter approaching, there is no time to acquire batteries to serve as backup, even if any existed that could technically do the job. Moreover, fully replacing natural gas backup with battery storage is a multi-trillion-dollar project, likely costing a multiple of the country's GDP, and thus completely infeasible. Realistically, Germany will never build any amount of storage that is meaningful relative to the scope of its problem. It is only a question of time until it gives up its Net Zero quest, with the other fantasist countries shortly to follow.

Notes

1. https://papundits.wordpress.com/2022/01/20/unreliability-makes-solar-power-impossibly-expensive/.
2. https://pragmaticenvironmentalistofnewyork.blog/2022/01/24/scoping-plan-reliability-feasibility-renewable-variability/.
3. http://euanmearns.com/the-cost-of-wind-solar-power-batteries-included/.
4. The original post appeared on December 20, 2021 https://blog.friendsofscience.org/2021/12/21/the-cost-of-net-zero-electrification-of-the-u-s-a/. It was substantially reproduced at the WattsUpWithThat blog https://wattsupwiththat.com/2022/01/12/the-cost-of-net-zero-electrification-of-the-u-s-a-blog-post/. This paper considers a revised version of Mr Gregory's article that appeared on August 23, 2022 at https://friendsofscience.org/pdf-render.html?pdf=assets/documents/Cost-of-Net-Zero-Electrification-of-the-USAv2.pdf.
5. https://www.econstor.eu/bitstream/10419/236723/1/Ruhnau-and-Qvist-2021-Storage-requirements-in-a-100-renewable-electricity-system-EconStor.pdf.
6. https://www.woodmac.com/news/opinion/europes-grid-scale-energy-storage-capacity-will-expand-20-fold-by-2031/.
7. https://www.utilitydive.com/news/new-york-battery-storage-costs-rise-interconnection-queue-12-gw/621954/.
8. https://www.utilitydive.com/news/brand-new-problem-california-grid-operator-long-duration-storage/621637/#:~:text=Around%203%2C100%20MW%20of%20energy,Commission%20(CEC)%20workshop%20Tuesday.
9. https://www.nrel.gov/docs/fy21osti/79236.pdf.
10. https://www.utilitydive.com/news/new-york-battery-storage-costs-rise-interconnection-queue-12-gw/621954/.
11. https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf.
12. https://www.energy-storage.news/us-doe-puts-us18m-into-long-duration-energy-storage-manufacturing-rd/.
13. https://www.energy-storage.news/e-zinc-raises-us25m-to-begin-commercial-pilot-production-of-long-duration-storage/.
14. https://www.sciencedirect.com/science/article/pii/S254243511830583X.
15. https://www.lazard.com/media/451882/lazards-levelized-cost-of-storage-version-70-vf.pdf.
16. https://assets.jpmprivatebank.com/content/dam/jpm-wm-aem/global/pb/en/insights/eye-on-the-market/2022-energy-paper/elephants-in-the-room.pdf. See p. 39.
17. https://seekingalpha.com/article/4392471-hydrogen-vs-natural-gas-for-electric-power-generation.
18. https://www.eia.gov/naturalgas/weekly/.
19. https://seekingalpha.com/article/4392471-hydrogen-vs-natural-gas-for-electric-power-generation.
20. https://www.eia.gov/outlooks/aeo/assumptions/pdf/table_8.2.pdf.
21. https://www.goronadelviento.es/en/statistical-information-and-data/.
22. http://euanmearns.com/an-update-on-the-king-island-renewable-energy-integration-project/.

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