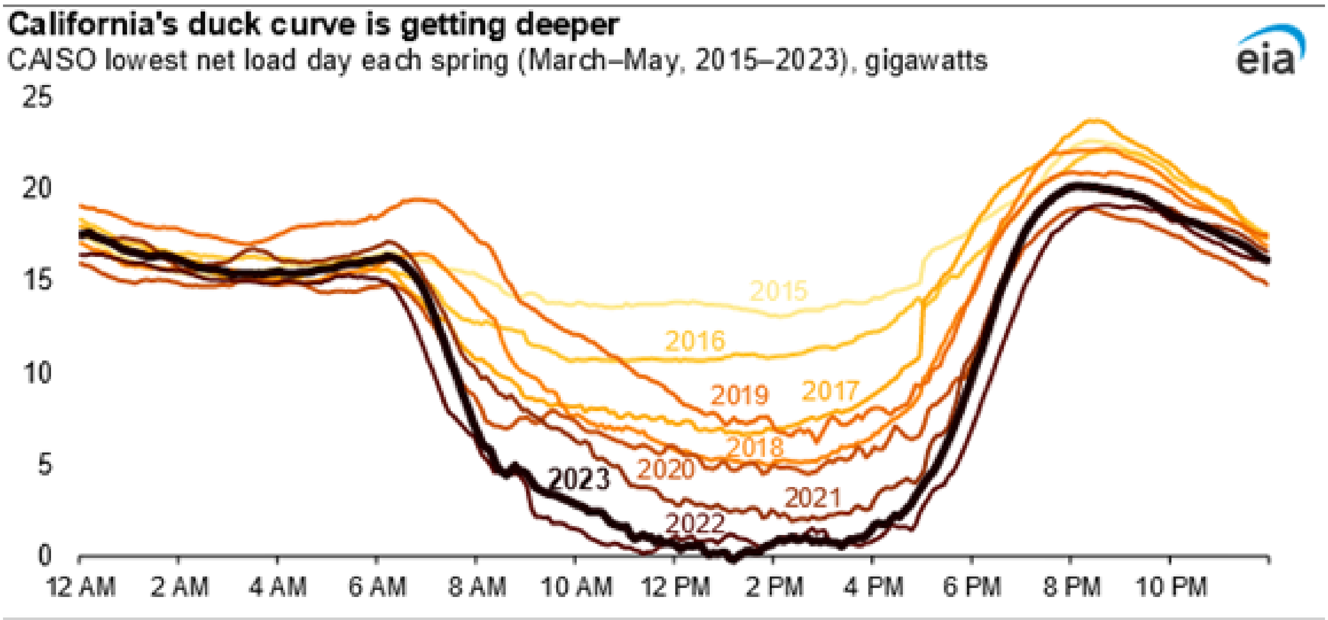
The California Duck Curve gets deeper – the challenges of high levels of intermittent variable renewable energy

A recent article caught our eye – "*Stanford study warns against overnight charging of electric cars at home*" in California. This study noted that most electric vehicle (EV) owners tend to charge their vehicles at home during the evening or overnight (which should come as no surprise to anyone), leading to significant costs for the electricity grid as California relies more and more on solar energy. It projects the rapid growth of EVs and their reliance on nighttime charging could lead to a 25% increase in peak electricity demand within a little over a decade. This study's solution, get people to shift towards daytime charging at public charging stations or workplaces. It goes on to explain that "*if more people charged their vehicles during the day at work or public charging stations, it could reduce greenhouse gas emissions (*presumably by avoiding gas usage at night*) and avoid the added costs of generating and storing electricity*".

Source: istockphoto.com

This is the beginning of an awareness of what happens when you rely too much on intermittent variable renewables for your electricity needs. It forces you to use the electricity when the sun shines (in this case) or the wind blows, which is not necessarily when you actually need it.

California has had this issue for years. Due to a rapidly increasing amount of solar electricity, the net load on the system (total load less renewables) reduces rapidly in the morning when the sun comes up and solar power comes online, then increases again as the sun goes down and solar drops off. This has come to be known as the "Duck Curve", as the shape of the curve looks like a duck! What we see below is that the depth of the curve has continued to get deeper over the last eight years as California adds more and more solar power.



Source:
https://cleantechnica.com/2023/07/07/california-duck-curve-getting-deeper-with-solar-growth/

Don't get us wrong, we like solar especially in sunny locations like California. Generally, solar plants produce about 15 to 20% of the time depending on location (based on the level of sunshine). Well, in very sunny California, the average capacity factor for solar is just over 28%. Excellent for this type of generation. This clearly has an important role to play in the generation mix.

But we also see that too much of a good thing can create new challenges. The cost to the system of being able to accommodate this rapid change in load when the sun comes up and again when it goes down is large. Storage and other dispatchable sources of electricity (likely gas) are required to meet the needs the 70% of the time the sun is not shining. The duck curve also reduces the amount of time dispatchable conventional power plants operate, reducing their revenues, making them less economic to operate in the California market. If these plants are then retired without replacement, it becomes even harder to meet the needs of the system.

The other issue is grid stress. Grid operators need to drastically ramp up non solar generation as the sun sets, a very difficult thing to do. In the past, when we considered how big of a single generating plant a system could accommodate, we often used a simple rule of thumb that no unit should be larger than 10% of the entire system. Larger than that, the ability of the system to manage a unit outage would be compromised putting system reliability at risk. That is what solar has become in California. While you may think that there are many solar units in place, due to their intermittency, they operate on the system as one extremely large plant. They all come on at the same time when the sun comes up and they all go off at the same time when the sun goes down. What is the system to do?

We had a wonderful vacation in southern California this past July. Spent some time in Palm Springs where the temperatures were on the order of 45 to 47 degrees Celsius (~115 degrees Fahrenheit). I can assure you that we needed air conditioning as much at night as during the day.

Now imagine what would happen without having the back up needed. Storage is part of the solution but requires a huge overbuild of daytime capacity to both meet the day's energy needs while also filling storage for other times. And mostly current storage technology is good for hours, not days or weeks creating issues for when the weather is simply not cooperating (two weeks of continuous rain for example) or to meet seasonal load changes. The result is a growing consensus that firm dispatchable capacity also needs to be an essential part of any clean energy solution.

The Diablo Canyon nuclear plant in California produces energy about 90% of the time, in other words each MW of capacity of California nuclear produces more than 3 times the amount of energy in a year than the equivalent capacity of solar. That is what builds a resilient system.

I don't have an electric vehicle yet, but when I do, I will definitely feel better knowing I can leave home in the morning with a full charge.

Achieving net zero requires building all low carbon technologies including lots of nuclear

In its 2022 report on the role of nuclear power in fighting climate change, “*Nuclear Power and Secure Energy Transitions*”, the International Energy Agency (IEA) says “***Nuclear energy can help make the energy sector’s journey away from unabated fossil fuels faster and more secure***.”

It goes on to clearly lay out why nuclear power is so important to a clean energy future noting that achieving net zero globally will be **harder** and **more expensive** with less nuclear.

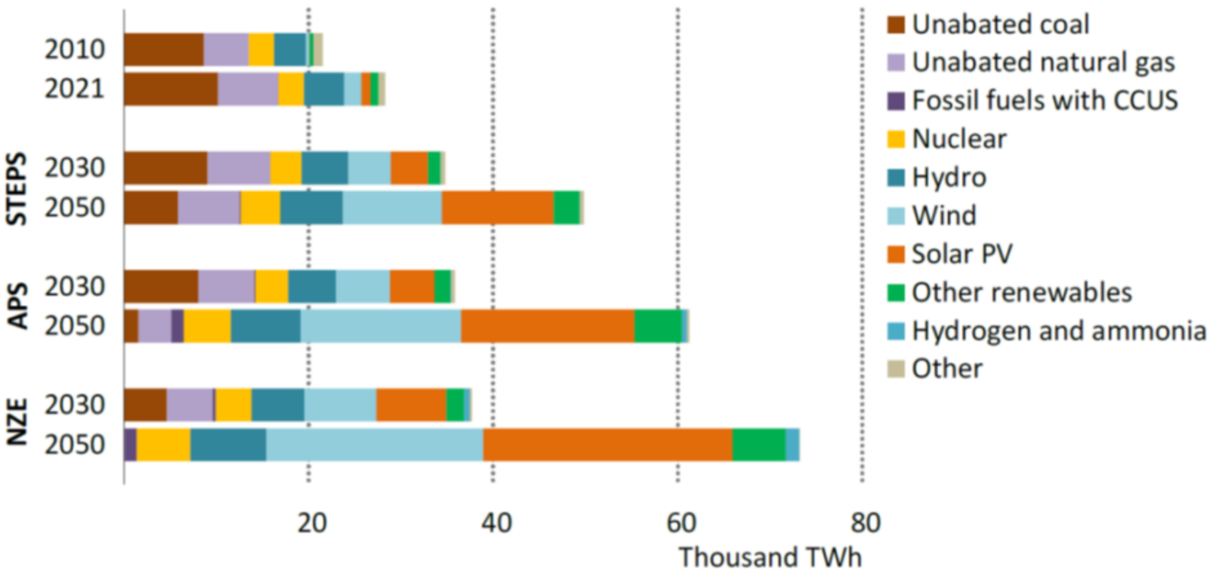
Source: Pexels.com

The report also notes there are challenges to further nuclear deployment emphasizing the importance of continuing to reduce costs and ensure projects are built to cost and schedule. These are indeed justifiable issues and there is no doubt the industry must perform for long term success.

While the IEA may say nuclear is important for net zero, this has not resulted in projections for a large new nuclear program. Rather, as is shown in the 2022 World Energy Outlook (WEO 2022) just released from the IEA, the role for nuclear remains modest. Yes, there is a doubling of nuclear capacity to 2050, but because of continued electricity demand growth the nuclear share falls from 10% of global electricity supply to only 8% in its Net Zero Scenario.

On the other hand, renewables are projected to account for the majority of capacity additions over the outlook period (to 2050). In the base STEPS scenario, wind and solar PV together set new deployment records every year to 2030 and then continue with increased annual growth through to 2050. For the IEA Net Zero scenario, wind grows by a factor of 12 and solar even faster with 27 times more solar in 2050 than in 2021. The assumption when it comes to renewables growth is that there are no limits. No concern about land use, or volume of critical materials required, or how storage technology will develop to support increasing the share of renewables from its current 28% of electricity supply to 88% of a larger global electricity system. Yet we know from experience in Germany, California and others where variable renewables have successfully achieved a relatively high share of electricity supply, that system reliability suffers, often requiring fossil fuel back up to support their intermittency.

Figure 6.7 ▷ Global electricity generation by source and scenario, 2010-2050



Electricity generation from unabated fossil fuels peak by 2030, as low-emissions sources ramp up and renewables dominate electricity supply in all scenarios by 2050

Note: Other renewables include bioenergy and renewable waste, geothermal, concentrating solar power and marine power.

Notes: STEPS (Stated Policy Scenario), APS (Announced Policy Scenario), NZE (Net Zero Scenario)
Source: IEA World Energy Outlook 2022

To be fair, we don't blame the IEA for their views. Based on recent experience in western countries with little ongoing nuclear new build and projects that have gone over budget and schedule, it may be difficult to see a path for more rapid nuclear growth. But that certainly doesn't mean there shouldn't be a challenging goal. Just look at China that has built over 50 GW of nuclear capacity in the last 20 years and has approved 10 new large reactors this year alone. In the west we have examples as the US built about 100 units and France built a fleet of 59 units in less than 30 years. Twenty years ago, there was little confidence in the ability of renewables to scale and here we are today, now assuming almost unlimited growth given their success. Just as with renewables, increasing the scale and pace of nuclear new build as we have achieved in the past is also possible given the political will.

There is an international study that considers a more balanced growth for all the clean technologies. UNECE (United Nation Economic Commission for Europe) has recently released its report "*Carbon Neutrality in the UNECE Region Technology Interplay under the Carbon Neutrality Concept*" which takes a fresh look at how to use a broad range of technology, both existing and new to meet its net zero challenge.

This report finds "*there are achievable pathways for governments to design and implement a carbon-neutral energy system through technology interplay.*" In its carbon neutrality innovation scenario, UNECE considers the potential of three innovative low- and zero-carbon technologies: a new generation of nuclear power, CCUS, and hydrogen – to deliver on carbon neutrality. In this scenario nuclear grows to 3.4 times its current base in the region by 2050 (as opposed to 2x by IEA*) and reaches 27% of energy supply (compared to 8% by IEA*). It also notes challenges with all technologies. For example, it predicts 4,430 TWh of solar power in the region by 2050 (compared to the 27,000 TWh globally in the IEA net zero scenario) and notes this requires 7 million utility scale panels covering an area equal to 2.8 million football pitches equal to the entire surface area of Belgium.

There is little doubt the challenge of achieving net zero emissions in our energy systems by 2050 is enormous. Given the view to electrify everything, electricity use will at least double. To meet this growth, it has been generally accepted that nuclear power has a critical role to play, but the size of that role remains in question. Concerns about the industry's ability to deliver has limited its potential in many studies such as the IEA WEO 2022. However, UNECE has taken a different approach and explored a more rapid expansion of all low carbon technologies, rather than assuming wind and solar can do all the heavy lifting. This seems a more viable model. Get all technologies growing as fast as possible to ensure the primary goal of carbon neutrality is achieved. We only have one world, and we need to build all low carbon technologies as quickly as we can if we really want to reach our climate goals.

* *It should be noted the UNECE projects are limited to the UNECE region and the IEA projections are global.*

Keeping the lights on is of critical importance for a prosperous future

We previously talked about energy security and the impact on global energy markets resulting from the crisis in Ukraine. In that post we discussed energy security from the traditional perspective of risk of disruption in global energy flows as a result of geopolitical issues. Today we will expand upon the concept of energy security to go beyond the political and address the technical issues that impact our ability to deliver energy reliably to consumers. For society to truly prosper, we need strong **reliable** and **resilient** energy systems.

Source: pexels.com

System reliability – means a system (or grid) where electricity flows can be counted on to be available when required – i.e., customers need confidence that when they flip the switch, the lights come on, and stay on. Given that electricity supply and demand must be always in balance, our very reliable electricity grids are nothing short of an engineering marvel. Expert planners design systems where supply adjusts to changes in demand as needed, and that can tolerate most supply disruptions (outages – both planned and unplanned) without impacting customers. Some simple rules of thumb (actual system design is quite complex) suggest no single generating station should be larger than 10% of the capacity of the total system and grids should have 15% or more excess capacity to accommodate outages.

Somehow, over the past years, attention to this very important objective seems to have been diluted as the focus shifted to emissions reduction and market deregulation. Therefore, in some jurisdictions, system reliability has suffered due to a too rapid increase in intermittent variable renewable generation that needs dispatchable back up, and poorly designed electricity markets that focus on cost above all else with real time energy markets.

Renewables present two major challenges to system planners. First, their intermittency and reliance on weather complicate system design to ensure there is sufficient back up supply for when the sun doesn't shine, and the wind doesn't blow. We have seen, as stated in an article by Robert Bryce, where an excessive focus on renewables just doesn't make sense. For example, in hot climates like Texas, the times when you need the most energy are also going to be the times when you have the least wind. That's just how the weather works.

And the other, less talked about issue is that even though there may be large numbers of solar panels or wind turbines in operation within a given jurisdiction, they actually behave on the system as one very large super plant. Hence the famous "duck curve" in California where all solar panels come on at once when the sun rises in the morning and then all go off when the sun sets. This causes additional stresses for reliability planning as the system tries to respond to these large sudden changes in supply.

We talked about the issues with deregulated market pricing in a previous post noting that least cost does not necessarily mean most reliable. And now as we did then, we will recommend reading Meredith Angwin's book, "*Shorting the Grid*."

System resilience – which is related to how well the system can withstand external events that may cause it to go down such as extreme weather or other man made events. This concept took hold post 9/11 when the concern was how to harden power plants against potential terrorism. More recently the issue has been extreme weather such as hurricanes, tornadoes and wildfires that have forced systems down and damaged them to the point of disaster. The unfortunate thing is that the same jurisdictions we listed above, Texas and California are also suffering from these kinds of extreme weather events, that are challenging the ability of their systems to operate reliably.

This is where nuclear power can play an important role. Nuclear power's high energy density, low carbon emissions, highly reliable operations and built-in resilience can provide the stable energy source we need. It is one of the reasons law makers in California have provided overwhelming support for a bill to keep the Diablo Canyon nuclear plant operating at least another five years, once thought impossible.

Having reliable affordable access to abundant energy is one of the tenets of a prosperous society. Our lives are much better for it. A public threatened with losing this reliable access will not respond well. We have become so used to having a reliable grid that we now take it for granted. However, assuming it will always be, misunderstands how complex an electricity grid actually is. It's time to go back to basics and ensure that system reliability and resilience are the cornerstones of our energy systems. Given the need for a stable baseload 24/7 supply, nuclear power has an important role to play.

The Energy transition requires a huge increase in mining of critical minerals

When considering the sustainability of future low carbon energy sources, the focus tends to be on where the energy comes from. Renewable energy is seen as environmentally sustainable in that it is both low carbon and the resource unlimited; energy from the sun, wind and water will never run out. But, as with everything in life, nothing is perfect. All these energy sources require a variety of critical minerals for their manufacture. This means mining – a lot of mining. The issue is so important to the energy transition, the International Energy Agency (IEA) recently (May 2021) released a World Energy Outlook Special Report, "*The Role of Critical Minerals in Clean Energy Transitions.*"

Source: istockphoto.com

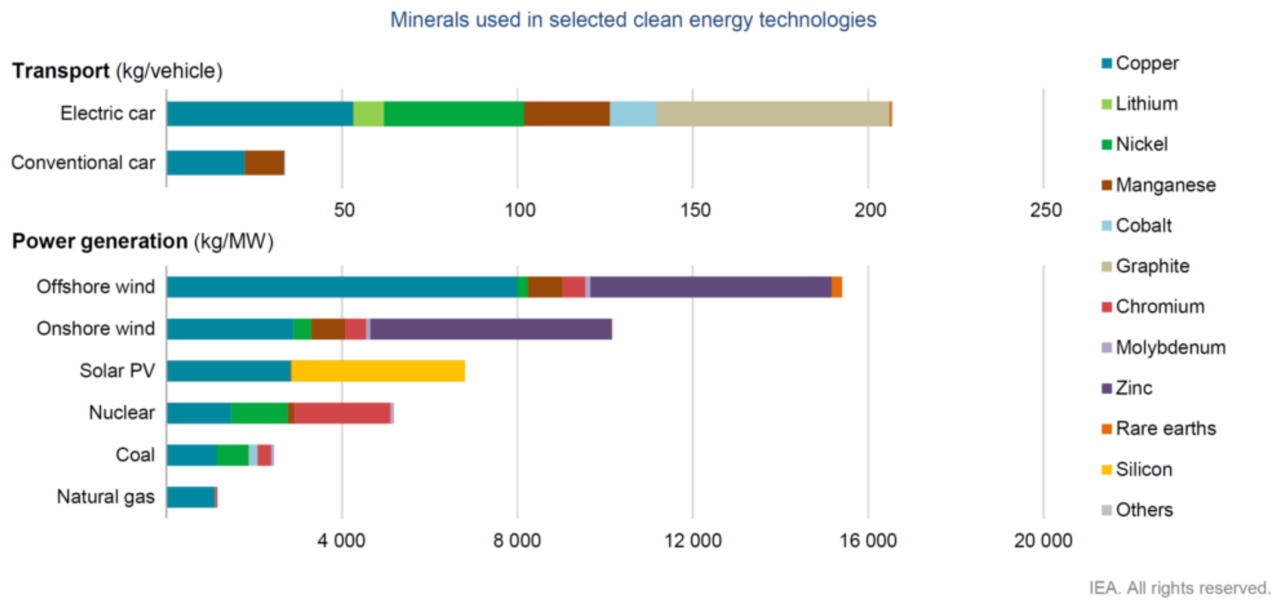
As stated by IEA Executive Director Fatih Birol, *"Today, the data shows a looming mismatch between the world's strengthened climate ambitions and the availability of critical minerals that are essential to realising those ambitions."*

Reading this report, one thing is for certain – **demand for minerals goes up, way up.** [all numbers in the next paragraphs come directly from the IEA report.]

An energy system powered by solar, wind and electric vehicles (EVs) requires more critical minerals than today's fossil fuel-based generation and transport. An electric car requires six times the critical mineral inputs of a gas fuelled car, and an onshore wind plant requires nine times more mineral resources than a gas-fired power plant. Since 2010, the average amount of critical minerals needed for a new unit of power generation capacity has increased by 50% as the share of renewables has risen.

And this is going to increase even faster going forward. To hit net-zero *globally* by 2050, would require six times more critical minerals in 2040 than today. Examples of the magnitude of this growth would see critical mineral demand for use in EVs and battery storage grow at least **thirty times** to 2040.

This represents dramatic change. Prior to the mid-2010s, the energy sector represented only a small part of total demand for most minerals. Now, clean energy technologies are becoming the fastest-growing segment of demand. In order to meet the Paris Agreement goals, clean energy technologies' share of total demand rises significantly by 2040 to over 40% for copper and rare earth elements, 60- 70% for nickel and cobalt, and almost 90% for lithium. EVs and battery storage have already displaced consumer electronics to become the largest consumer of lithium and are set to take over from stainless steel as the largest end user of nickel by 2040.



This rapid increase in demand and the world's hunger for these critical minerals will also change the geopolitical landscape. In the past, much of the world was concerned about security of supply of fossil fuels, primarily oil. Policy makers will now have to consider the challenges with security of supply and prices from a different set of resources which are mostly concentrated in a small number of countries.

And of course, with expanded supply, comes the issues of expanding waste volumes as these new sources of energy reach their end of life. In 2016, IRENA (International Renewable

Energy Association) estimated there would be up to 78 million tons of used solar infrastructure to look after by 2050. However, this assumed solar panels would all stay in service to end of life. But newer better solar panels have people replacing their panels early so that this number can increase by 2.5 times if the current trend continues. To date there is no clear path as to who will pay for this disposal and/or recycling.

With massive projected growth in renewables as they become the main source of energy replacing fossil fuel in the IEA scenarios, we can see the impact of their low energy density and relatively low resource availability. In other words, while these technologies produce very low carbon renewable energy, they do not use minerals very efficiently.

This is where nuclear power shines. It is extremely energy dense and operates at very high-capacity factors. The IEA report notes that nuclear has comparatively low mineral requirements. But the figure above is deceptive. Comparing on a MW capacity basis does not reflect the true nature of the mineral use as 1 MW of solar does not produce the same amount of energy as 1 MW of wind which does not generate the same amount of energy as 1 MW of nuclear. So, while it may look like solar uses 40% more and wind double the materials used in nuclear from the figure, this is not the whole story. Solar generates energy less than 20% of the time (when the sun shines) and wind about 35% of the time (when the wind blows), much less than nuclear that operates more than 90% of the time. And the average life of a solar or wind farm is 30 years or less while a nuclear plant lasts 60 years or more. In other words, a nuclear plant will produce between 10 and 15 times more energy per kg of critical materials used over its life than a solar panel or a windmill making nuclear plants much more mineral efficient. And, given the long life of a nuclear plant, this also greatly reduces the future mineral waste burden.

We often write about nuclear being a low carbon, reliable and economic source of electricity. Now we can add another important environmental attribute, it uses much less critical minerals than renewables per unit of energy produced. Therefore, increasing the share of nuclear power in the future energy mix will greatly reduce the burden on the mining industry (and the planet) as it tries to keep up with a rapidly growing critical mineral demand.

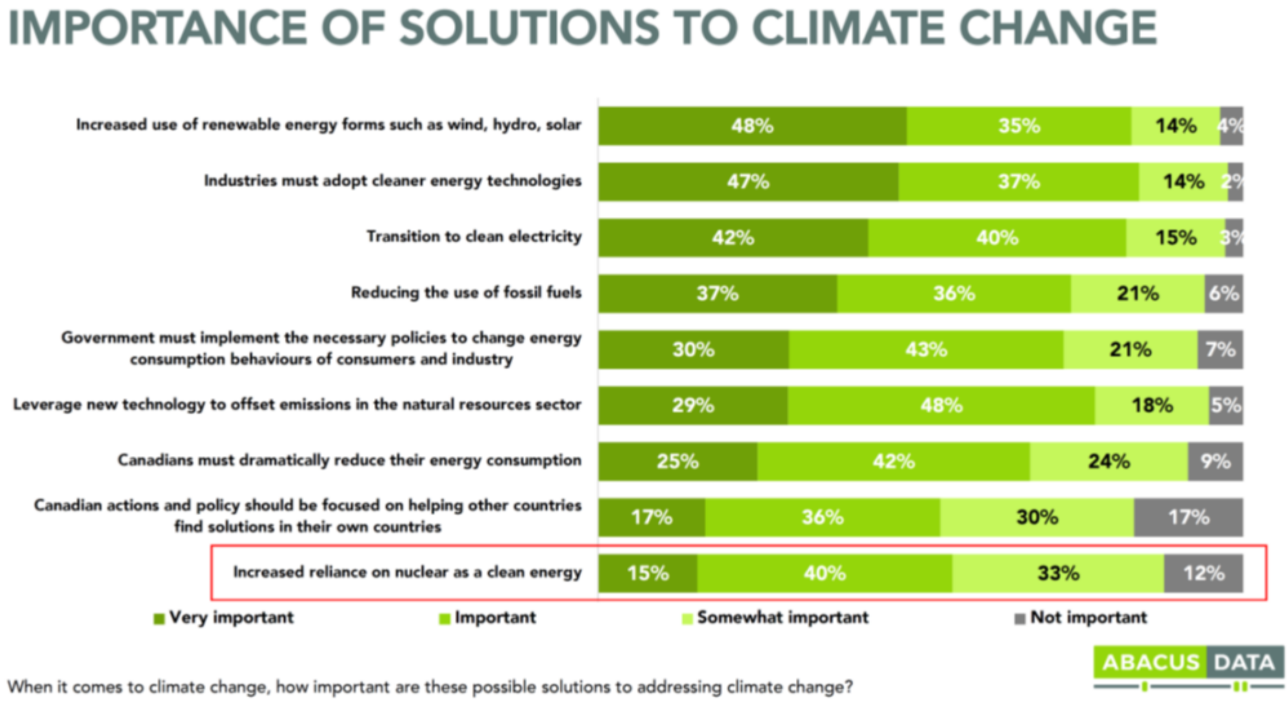
Forget about public acceptance for nuclear power – it's time for public enthusiasm!

Nuclear power can provide almost limitless economic, reliable, low carbon electricity to power the world, yet it continues to struggle to achieve the respect it so desperately seeks. For 40 years we have been hearing the same thing – that for nuclear power to achieve its potential we must work harder on securing public acceptance. This is seen as a one of the main impediments to future nuclear growth. As technocrats, we often think that if we can just educate the public on the technology, they will see the light and come to accept us. After years of effort and somewhat limited success, the time has come to refocus and set the bar even higher. Let's forget about trying to convince people to "accept" nuclear and strive to create true public enthusiasm for a technology that has the potential to solve the issues they care about most.

And we won't get there until we focus on the right things. After all, why should anyone even think about nuclear power, never mind come to love it? It is definitely not by explaining all the reasons they shouldn't worry about it; where it really starts is by having a clear understanding of the issues that are top of mind.

So, what are people concerned about?

A recent study from the Canadian Nuclear Association suggests that climate change continues to be a top of mind issue, with concerns not falling even though we are in the midst of a global pandemic. The large majority (82%) of Canadians are somewhat, very, or extremely concerned about climate change. Almost 8 in 10 (76%) feel that climate change or global warming are issues we currently face that are at least "serious" and a majority (57%) rate that the impact of climate change or global warming on themselves or their loved ones has been "Extremely/Very much".



The challenge is that even with these concerns most people are completely unaware that nuclear power can be a solution. 68% of Canadians had no idea that nuclear power is the country's second largest source of low carbon electricity (15% of total generation) after hydro power. This is then re-enforced as nuclear is at the bottom of the list in solutions to solve climate change (although support remains strong). Keep in mind that Canada is a very nuclear-friendly nation with more than 60% of the electricity in the province of Ontario and more than 30% in New Brunswick coming from nuclear. So, it should be of no surprise this lack of awareness is not unique to Canada. A similar recent poll in the US showed that nuclear power is a very unpopular form of electricity generation, second only to coal. And even in the country with the most nuclear power in the world, France, most think nuclear contributes to, rather than is a solution to, climate change.

We first discussed how we need to take back the narrative from nuclear opponents in August of 2019. The industry has been complicit (although well intentioned) by endlessly trying to defend nuclear by explaining ad nauseum how safe it is and why people shouldn't be worried about nuclear waste. This strategy has failed because the more time spent talking about why people shouldn't worry about these things, the more they understand there must be something to worry about. Rather, the priority should be on the important benefits nuclear brings – **reliable, economic, low carbon electricity in vast quantities to fuel an energy hungry world – and the many high-quality jobs and the positive economic impact to communities that support nuclear power plants.** This is what can get people excited, and only then, will they be willing to have a discussion on those aspects of the technology where they have concerns.

And yes, we are making progress. It is becoming clear that renewables alone cannot fuel a decarbonized world and that nuclear power is an important option to help meet the energy needs of the future. It has been recognized by global institutions like the International Energy Agency and most recently, Holland, with its single operating nuclear power plant, has joined the growing list of countries expressing interest in considering nuclear for the future.

Here in Canada, the Minister of Natural resources has been extremely clear – reaching net zero carbon emissions without nuclear is simply not feasible.

But this is not enough. People love the idea of renewables and strongly support them as THE solution to climate change (although they may feel somewhat different when a wind project is promoted in their backyard – but that is another story.) Many are eager to spend their hard-earned money to install solar panels on their roofs or buy electric vehicles even if they are expensive. This is because they know they are doing good in the battle for the planet and they accept and support that these technologies are the future.

While it is common to express concerns with nuclear power such as asking about nuclear waste for example, these questions are never considered when talking about renewables. Solar waste?

Low energy density land use? Variable generation dependent upon resource availability requiring not yet available storage solutions, mining of rare earths and other needed minerals? These are just silly questions that get in the way of environmental progress. Smart people will solve all. This is the strength of “knowing” that going down a given path is simply right. We don’t want to hear about challenges for solutions we believe in, while we are happy to question those options we are suspicious of.

The world can only close its eyes to the truth for so long. As more people start to accept that renewables cannot be the sole solution, support for nuclear is rising as its potential as a low carbon option is being better understood. However, it is important that nuclear be considered because it is an excellent solution to climate change as well as providing reliable economic energy to society, not because the favoured options are falling short, forcing us consider this less desirable option of last resort. Accepting nuclear should never be like taking your bad tasting medicine. You accept it may be good for you, but you hold your nose while taking it and wish you didn’t have to.

And positive change is in the air. We see many amazing groups, primarily a new generation of younger people who are making the positive case for nuclear power. There are pronuclear demonstrations, funny videos explaining nuclear on YouTube and even a pro nuclear rap song. If you are part of a group that is driving support for nuclear, please let us know in the comments below.

We live in a time where there are many that question technology with some causing more fear than others. We are in a horrific pandemic yet fear of vaccines is making many worried about taking one when available. There are even people who think 5G mobile technology is causing covid. Therefore, after decades of anti-nuclear activism, it should come as no surprise that many are concerned about nuclear technology. And while more and more environmentalists are now seeing the opportunity to fight climate change that nuclear brings, many are still fundamentally opposed. Here in Canada, famed environmentalist David Suzuki said “I want to puke” in response to the Minister’s support for new nuclear.

We live in a time of both science skepticism and a lack of belief in facts. But we should not be daunted as both the facts and the science are clear. We have a great story to tell. Nuclear power is AWESOME and can help to save the world. So, let’s stop talking about public acceptance and all work together to generate a real sense of public enthusiasm to support this technology as a path to a better world where energy is economic, reliable, abundant and has little impact to the environment.

Saving the planet step 1 – Keep the nuclear fleet operating as long as possible

On the cusp of the United Nations Climate Action Summit in New York where there was a collective outrage at the slow pace of decarbonization in the world, we lost another operating nuclear plant before its time as Three Mile Island Unit 1 closed after 45 years of operation. It made the news because of its more famous (or infamous) sister plant, TMI Unit 2 that had the USA’s worst nuclear accident 40 years ago. Of course, only the nuclear industry continues to talk about an accident that harmed no workers and had absolutely no impact on the public – other than fear. Certainly nothing to talk about after 40 years, and more so, should be a point of pride if this is the worst nuclear accident that ever happened in the US. But that discussion is for another day.

Today we want to focus on the importance of keeping the current nuclear fleet operating as long as possible. Once again, we go to the IEA report issued in May, "**Nuclear Power in a clean energy system**". It notes the "*failure to expand low-carbon electricity generation is the single most important reason the world is falling short on key sustainable energy goals, including international climate targets*."

Probably
the most important point made in this IEA report is about the absolute failure
of renewables to make a dent in carbon emissions on their own. As stated, "*Despite the impressive growth
of solar and wind power, the overall share of clean energy sources in total
electricity supply in 2018, at 36%, was the same as it was 20 years earlier
because of the decline in nuclear. Halting that slide will be vital to stepping
up the pace of the decarbonisation of electricity supply.*"
That's right.
Spending vast sums of money on renewables and closing another major
source of low carbon electricity at the same time is a losing proposition. This is not progress, it is lunacy.

Earth’s oceans and frozen spaces paying price for ‘taking the heat of global warming

To

put this in perspective, TMI Unit 1 that was closed last week produced 819 MW

of electricity. For example, the Solar

Energy Generating Systems (SEGS) in California, which is rated at 354 MW (or

let’s say half of the TMI unit for simplicity) is one of the world’s largest

solar thermal power plants with a total of 936,384 mirrors and covers more than

1,600 acres. Lined up, the parabolic mirrors would extend over 229 miles. With a solar capacity factor of about 20%,

there would be a need for 10 of these gigantic solar farms to generate the same

amount of electricity as the single TMI unit 1.

And, as this electricity is not continuous, it requires gas to back it

up when the sun is not shining. On the

other hand, the TMI unit operated continuously for 709 days before its final

shutdown on September 20. Now, no one is saying not to build solar farms, but having to build 10 massive ones to replace a single nuclear unit and not achieve a single ton of carbon reduction is an exercise in futility.

In the US, the challenge to keeping plants open is generally economic. Cheap gas in de-regulated markets is making it impossible to use any form of generation economically other than gas. On the other hand, gas is a significant carbon emitter and shutting down low carbon plants to burn more gas is not in line with environmental imperatives. So, what do governments do? They subsidize both solar and wind and balk at doing the same for nuclear. Back to TMI unit 1, its license was valid for another 15 years of operation and a subsidy of 1 cent a kWh would have kept it open, half of the subsidy provided to renewables. No one is suggesting that all plants should be kept open irrespective of its economics as there will always be cases that just don't make sense, but on average, keeping plants open is way better for both system costs and the environment.

In fact, Staffan Qvist (co-author of the excellent book "**A Bright Future**") presented a study at the WNA Annual Symposium in September for Sweden, which from a resource perspective is in a better position than most to achieve 100% renewables. Yet the results of his modelling about 20 different scenarios for full decarbonization always come out the same; in every scenario the most cost-effective system has continued long-term operation of existing nuclear. (We will have more to say on this topic in a future post.)

In the US it's economics that are the driving force behind potential early closure. Much worse are the many other countries (with very successful nuclear programs) that want to close plants early simply on outdated antinuclear policies. From nuclear France closing Fessenheim when it is still operable for another decade to early closures in Belgium, Germany and host of other European countries; to South Korea’s new found dislike of nuclear power, shutdowns in Japan and early closures in Taiwan, the world is doing itself no favours in meeting its carbon targets.

However, change is in the air. Many states in the US have implemented policies to keep plants open. Sweden, Switzerland and France have delayed plans to close some plants and others like Belgium may soon realize they have no other viable options to meet their electricity needs unless they move in the same direction. In Korea the public is much more supportive of keeping nuclear power than its government and in Taiwan, a referendum that succeeded in demonstrating public support to keep nuclear is being ignored. And we all know that Germany is failing in its Energiewende as it delays coal closures to make up for shutting nuclear plants early. While it is acceptable to have a conversation about which technologies should be used in the future to best make progress on reducing carbon emissions, it is unfathomable to imagine why safe reliable low carbon plants would be closed before their time to make the already immense environmental challenge ahead even larger.

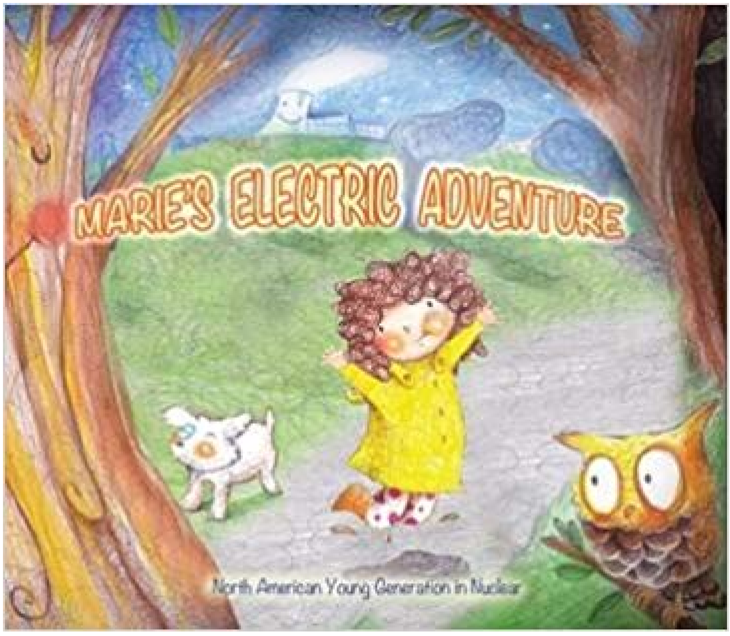
After all, the IEA report is clear. “*Lifetime* *extensions of nuclear power plants are crucial to getting the energy transition back on track*”. It concludes with a Policy recommendation to governments, ”authorise *lifetime extensions of existing nuclear plants for as long as safely possible*”.

Or as stated by Greta Thunberg in her comments to world leaders, “*How dare you continue to look away and come here saying that you’re doing enough when the politics and solutions needed are still nowhere in sight*”. Well hopefully world leaders listen and stop making decisions that only put them further behind when it is so urgent to move ahead.

It’s time to take back the narrative and rewrite the nuclear story

The facts are clear. Nuclear power is a critical part of our global low carbon electricity generation system. It provides abundant, reliable and economic low carbon electricity needed to power our energy hungry economies. Yet, as stated in the recent IEA report, **Nuclear Power in a Clean Energy System**, even though the use of nuclear power has reduced carbon dioxide (CO_2) emissions by over 60 gigatonnes over the past 50 years, (nearly two years’ worth of global energy-related emissions), nuclear power has begun to fade in advanced economies, with plants closing and little new investment made, just when the world requires more low-carbon electricity.

One issue that puzzles many in the nuclear industry is why we struggle to communicate our many merits to the public, unable to overcome the fear of nuclear that drives much of its opposition. The answer is simple. We talk in facts and figures, but people think in stories with emotion. As stated by Yuval Harari, in his newest book, **21 lessons for the 21st century** (make sure you also add his previous books, Sapiens, and Homo Deus to your to-read list), "*Humans think in stories rather than in facts, numbers or equations, and the simpler the story the better.*" It is therefore time to ask – what is the nuclear power story?



Marie's Electric Adventure: A Children's Book About Nuclear Energy, a book by NAYGN

For an example of a positive story, we only need look as far as the renewables industry, with their compelling story that the world can be
powered by nature using energy from the sun and the wind. These energy sources are limitless (after
all, we will never use up all the sun and the wind) and have no negative environmental
impact because they come from nature. Obviously,

we need to increase their use until they meet 100% of our energy needs.

This powerful story resonates with the public well beyond environmental groups to the point where many governments are fully supportive and are putting policies in place to realize this utopian dream. The fact that making this dream a reality is proving much more difficult than its supporters expected (as can clearly be seen in places like Germany and California), doesn’t seem to phase any of the believers. They love their story and they know with absolute certainty that any technical impediments can be solved with time and effort and that wasting time on any other energy source is a foolish diversion from what is really important. This is in spite of the fact that you can’t change the laws of physics or make the sun shine or the wind blow more than they do. But the faithful know they are on the right path and will not be dissuaded from their goal.

Why does this work? As discussed by Harari, facts often get in the way of a good story. A story not anchored in facts requires faith, and faith is a very powerful motivator.

On the other hand, the nuclear story has been dominated by those that oppose the technology. The story, based on extreme fear of radiation, is the technology is so dangerous that when it goes wrong (not if, but when) it may actually destroy all of mankind. Even many who support nuclear power believe the industry is made up of smart capable people who are safely managing doomsday machines. The fact that nuclear is by far the safest form of energy generation gets lost in the story that while the probability is low, the consequences of a big accident are unimaginable. Yet the reality is we have had big accidents and while the impact has been significant, they have proven that people can indeed be protected from harm – the most recent big accident at the Fukushima plant in Japan has resulted in zero deaths from radiation, but nobody believes it – it is inconsistent with this nuclear story.

The companion to this story is that even without accidents we have to fear nuclear waste. It is told that it's so dangerous that we need to bury it deep underground and protect society from it for thousands of years, the time it takes to decay away. This is a good example of how stories are made. All other toxic waste streams remain toxic forever. Therefore, the fact that nuclear waste eventually decays away should be a positive, or alternatively just assume it is bad forever like every other waste stream. But somehow, the fact that nuclear waste takes a long time to decay has been woven into a story of absolute fear of what we will do to the environment somehow making many believe that this waste is much worse than all other forms of waste. (This does not consider the fact that this waste is in solid form and in very low quantities – because who wants the facts anyway?)

After hearing these negative stories for so long, the industry is constantly on the defensive trying to fight the stories with factual arguments; in effect becoming part of the very stories we are trying to change. Well, the time has come to take back the narrative and re-write the nuclear story.

One position taken recently to try and shake things up is the story that wind and solar just aren't enough to meet all our energy needs reliably due to their low energy density and intermittency. We explain that storage at the levels required to make up the difference is very unlikely meaning that the 100% renewables goal only serves the fossil industry as gas and coal are needed to back up these unreliable energy sources. We then say that if we want to decarbonize and quickly, we need nuclear as it is the only large-scale low carbon dispatchable generating source. Or as said in this recent article, "*even if we don't love it, nuclear is the only carbon-free generating source that can provide backup power at the scale required*." The article then goes on to tackle all the anti-nuclear stories talking about safety and waste. The problem with this approach is that we are telling a story that is not a happy one – it is the story that while we may all agree we don't like nuclear; we need it. It is always hard to get people to stand behind things they don't like by telling them they are good for you. And in our experience, being the option of last resort (we wish we had other options, but we don't) is never a good strategy. Because as shown in Germany who had 30% of their generation from nuclear and is now phasing it out as they try and decarbonize at the same time; eventually fear becomes fact and as long as there seems to be an alternative, it will be taken (sometimes even when it is not working).

We need to keep the opening part of this story, i.e. that we need to reduce carbon to address climate change, and that wind and solar are simply not up to the task – as this is the path to getting those concerned about climate and energy issues to consider other options. But once we get those opposed to nuclear to reconsider because they see the need, we must then tell them a positive story they can embrace, rather than ask them to reluctantly accept something they don't like. Some think that this is too late – that people can't change their thinking. But going back to Harari, he notes that individuals can "*knit revolutionary personal changes into a coherent and powerful life story: "I am that person who was once a socialist, but then became a capitalist; I was born in France, and now live in the United States; I was married, and then got divorced; I had cancer, and then got well again.""* So why not I was once against nuclear but now I support it?

Well then – what is our nuclear story? How about an optimistic story about an exciting prosperous future where we all benefit from abundant, reliable, economic energy; raising millions of people out of poverty, all while also protecting the environment? And the best part is that nuclear can actually deliver. Now that is a story I would want to tell my grandchildren. What do you think the nuclear story should be?

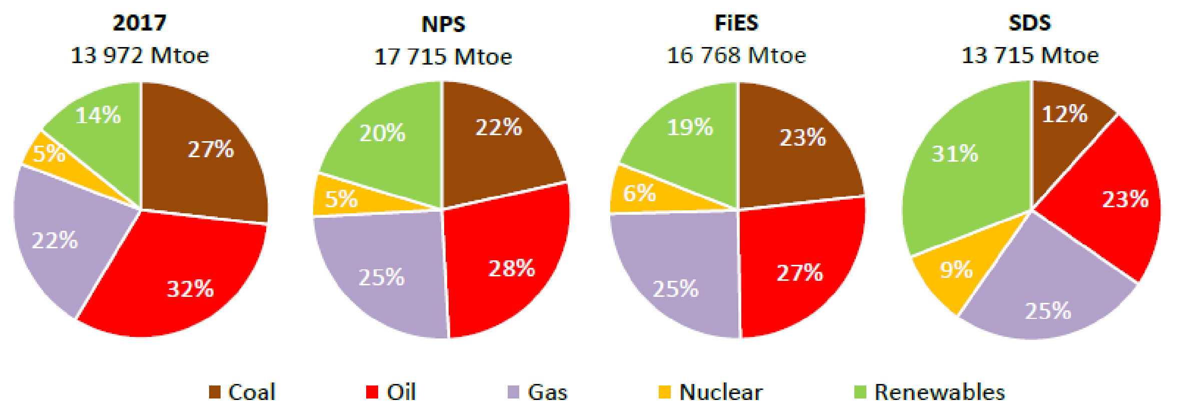
International Energy Agency (IEA) says we need nuclear

The International Energy Agency (IEA) plays an important role in looking at the global energy scene. Every year it publishes the World Energy Outlook (WEO) providing important information and analysis to countries to support their development of energy policy. Over the years, the focus of the WEO has been to consider alternative scenarios to business as usual to provide guidance on what is needed for the world to decarbonize. In various iterations of its report, it called this scenario the 2 Degree scenario, the 450 scenario (for 450 ppm) and now the Sustainable Development Scenario (SDS). Every year the IEA states the importance of decarbonizing our energy systems, and every year it laments how difficult this will be.

Yet, it rarely talks much about the role that nuclear power currently plays and must play in the future to achieve this decarbonization goal. Rather the analysis generally focuses its attention on massive increases in renewables which does reduce the fossil footprint but not nearly enough as fossil fuels remain more

than half of global
energy supply in 2040. The only path to
meet its scenario emission targets then requires policies that reduce energy
demand. Consider the following figure
from the 2018 WEO that shows renewables doubling, coal being cut in half while
gas retains its position as an important fuel in the SDS scenario – with the
balance of the carbon reduction due to reduced demand in 2040 for this scenario
– 2% less than 2017 and much less than currently projected in the New Policy
Scenario (which projects a 26% increase to 17,715Mtoe). Do we really think that the world will use
less energy in 2040 than it does today?

Figure 10.15 ▷ Shares of fuels in world primary energy demand today and in 2040 by scenario



Promoting energy security is an important policy consideration; electrification, together with energy efficiency and other alternative fuels, can help achieve this goal

Note: NPS = New Policies Scenario; FiES = Future is Electric Scenario; SDS = Sustainable Development Scenario.

Source: World Energy Outlook 2018

But that was then, and this is now. At the Clean Energy Ministerial (CEM) meeting in Vancouver last month, the IEA issued a report "**Nuclear Power in a Clean Energy System**" and the message is unequivocal. The IEA is stating that to decarbonize our energy systems, WE NEED NUCLEAR!

The report notes that “*lifetime extensions of existing nuclear power plants are crucial to getting the energy transition back on track*.” And “*that without nuclear investment, achieving a sustainable energy system will be much harder*.” In fact, “*a collapse in investment in existing and new nuclear plants in advanced economies would have implications for emissions, costs and energy security*.”

Of more importance it says that “*achieving the clean energy transition with less nuclear power is possible but would require an extraordinary effort*.” And even though it talks about the economic challenges facing nuclear power, both existing and new, it also notes that “*offsetting less nuclear power with more renewables would cost more*” and that “*taking nuclear out of the equation results in higher electricity prices for consumers*.”

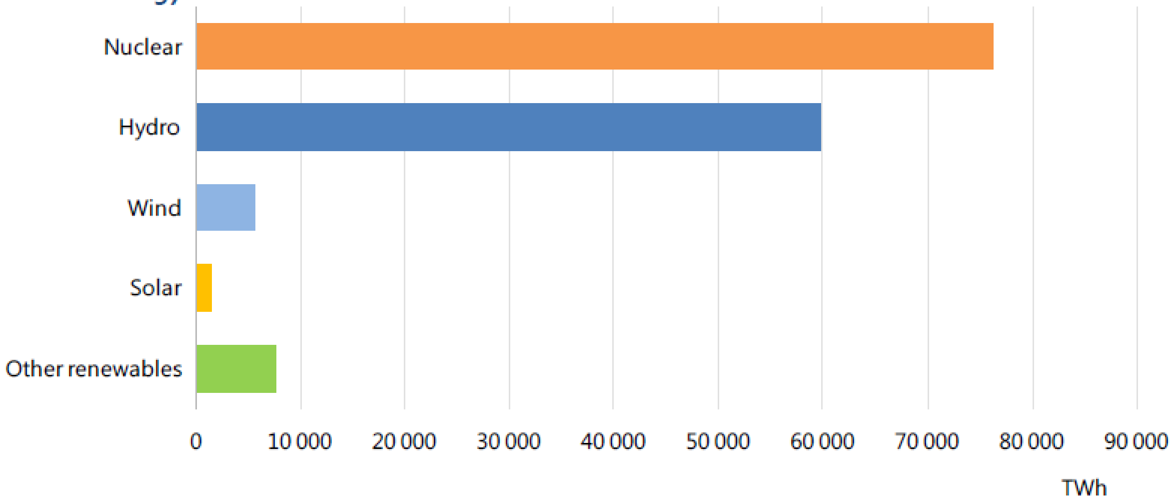
Finally, it concludes with a message to world governments, “*strong policy support is needed to secure investment in existing and new nuclear plants*.”

This is the strongest support given to nuclear power by the IEA in memory. Even back in 2014 when it had 3 chapters on nuclear in the WEO, it was a reluctant supporter. At that time it noted that “*Nuclear power is one of the few options available at scale to reduce carbon-dioxide emissions while providing or displacing other forms of baseload generation”,* but also started its discussion with “*Provided waste disposal and safety issues can be satisfactorily addressed,”* while never discussing the challenges that other forms of energy face.

To their credit, in this new report, there is no discussion of these traditional nuclear bugaboos with the focus clearly on why nuclear is needed, why we are better off with nuclear in the system and then suggests policy options for government to make this happen going forward.

The report shows the role nuclear power plays in mitigating carbon emissions is nothing new as over the last 50 years it has displaced more carbon than any other electricity source. Yes, that's correct. No other electricity source has displaced as much carbon as nuclear. So, just imagine what can be achieved in the next 50 years.

Figure 3. Cumulative low-carbon electricity generation in advanced economies by source, 1971-2018



Nuclear power and hydropower account for 90% of low-carbon electricity since the 1970s.

Source: Nuclear Power in a Clean Energy System . IEA 2019

This IEA report is a turning point in the global discussion. As one government official said, this is the kind of report that moves the world. I am not sure how far – but it is definitely a very important step in the right direction. Because one thing is now absolutely clear – if the world wants to decarbonize, the quickest and lowest cost option is to ensure an increasing role for nuclear energy.

Nuclear Power provides the performance we need

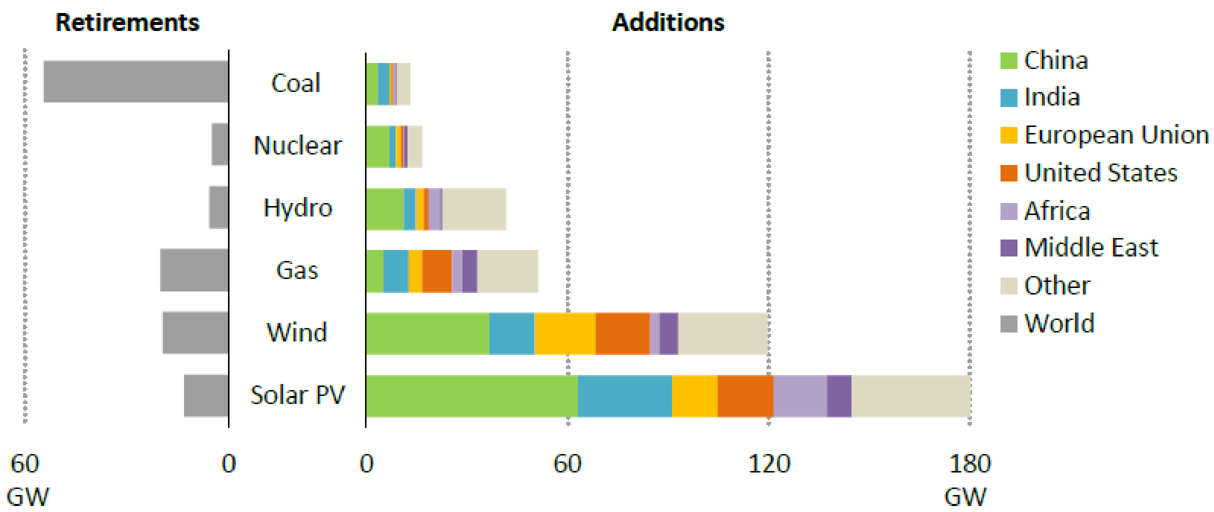
We often speak about the incredible energy density of nuclear fuel; a pellet the size of the end of your finger can deliver as much energy as a ton of coal. In addition to producing a large amount of energy from a very small amount of resource, the plants themselves offer another important benefit, their exemplary operating performance. They operate at very high capacity factors (the amount of energy produced / the total energy that would be produced if the unit ran nonstop) meaning they provide us with a reliable 24/7 energy source to support our energy hungry economies.

In fact, even as the global fleet ages, it just keeps on getting better. In 2018, the US fleet produced the most energy ever, exceeding the previous peak from 2010 even though 7 units have been retired and only two new ones have come on stream. The annual capacity factor in the US for 2018 was 92.3%. This should come as no surprise since the US fleet has operated around 90% CF for the past 20 years. This is a testament to the technology and its robustness. Not only does nuclear operate extremely well, it does so at all times during its very long life. It has no early life breaking in period and no end of life deterioration in its performance. It just continues to provide the energy we need day after day, year after year.

Let's contrast this with the world's most talked about generation sources, wind and solar. Not only are they intermittent, because the wind doesn't always blow and the sun doesn't always shine, but on average they produce relatively small amounts of energy from a given plant, i.e. a low capacity factor. Wind farms usually operate about 35% of the time and solar only about 15% of the time. Not only does each generator produce a relatively small amount of energy, it can't be called upon to produce it when it is needed.

This is why it is frustrating and frankly, deceptive, when supporters tout how much capacity of new renewables is being added to the grid, without mentioning the inconvenient truth of how little energy they are really contributing. The following figure shows how much capacity is expected to be added to the global grid in the World Energy Outlook (WEO) 2018 Sustainable Development Scenario.

Figure 9.24 ▷ Global capacity additions and retirements by technology and region in the Sustainable Development Scenario, 2018-2040 (average annual)



Solar PV and wind provide the lion's share of new capacity, while coal sees the most retirements

Source: IEA World Energy Outlook 2018

At first look, it seems like wind and solar are leading the charge to decarbonize the world energy system – 180 GW of new solar, 120 GW of new wind and only 17 GW of new nuclear.

But now let's transform these capacities into energy. The WEO assumes that nuclear runs about 80% of the time, wind 30% and solar 15%. So, what does this mean? Building 10 times the amount of solar and about 7 times the amount of wind as nuclear results in only about TWICE as much energy being produced from these sources as from new nuclear. Yes, you heard that right. Building 180 GW of solar running 15% of the time produces only about double the energy in a year as building 17 GW of nuclear plant that runs 80% of the time.

And to top it off, the nuclear energy is also reliable and predictable. Of more importance, it also means that there is a need for much more land to place all these wind and solar plants, a huge increase in the materials mined to manufacture them, a much larger and more complex transmission system, and a storage system that is not yet technologically feasible to accommodate their intermittency (or more likely gas generation to back them up); all leading to higher costs of energy, less system reliability and more carbon emissions.

A successful narrative has been created that renewables are a good way to meet all our energy needs, but it is based on how they make us feel, not on science. Who doesn't like the sound of harnessing nature and getting our energy from the wind and the sun? In reality, we simply cannot make the wind blow or the sun shine. We cannot imagine our way to a clean energy future with solutions that sound good but are incapable of giving us the result we so desperately need. In fact, the WEO bases its low carbon scenario on implementing large efficiency gains to reduce demand as a massive renewables new build program alone cannot meet the carbon reduction targets.

Looking at these numbers, should we be investing in these enormous quantities of renewables (and the back up / storage needed to accommodate their intermittency) or is there a better path to a lower cost decarbonized energy system. Nuclear power delivers what we need when we need it – large quantities of economic, reliable and low emission energy.

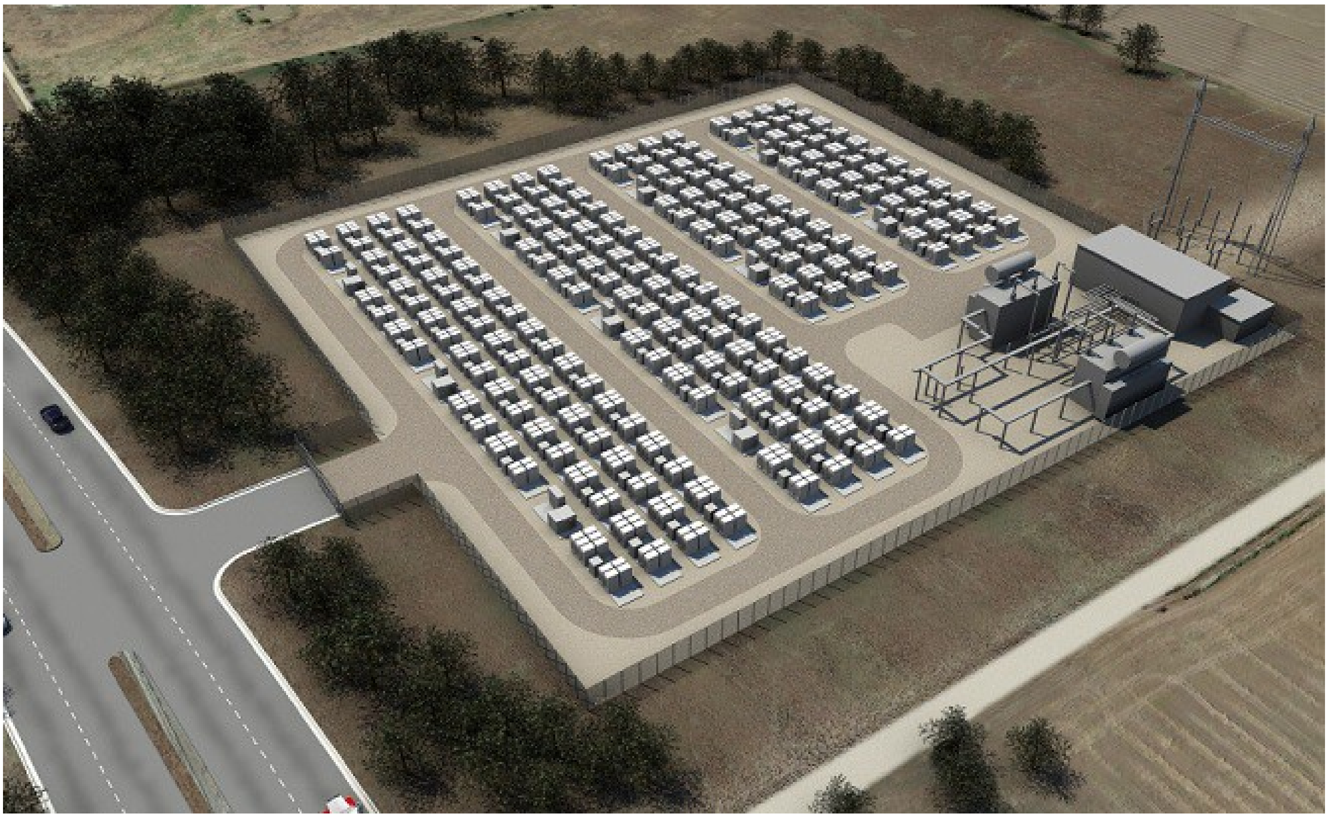
We already have the perfect energy storage – nuclear fuel

If decarbonizing global energy systems is a priority; it seems obvious that all low carbon options should be considered as part of the solution. Yet, a year and a half after 21 prominent scientists ***disproved*** the Jacobson paper that claimed a 100% renewables electricity system is feasible in the USA by 2050, it remains a challenge for many people to move on to more sensible solutions. Hence the Green New Deal that says this 100% renewable dream can not only be achieved, but in half the time. In reality, it still just won't work.

Imagine a world where the electricity system works like the battery in your cell phone. You depend on your phone and worry the battery will run out just as you need it most. To make things worse, even though there is an electrical outlet available, you can't charge your phone because these outlets don't work all the time. To keep your anxiety in check, you must always carry spare batteries with you to make sure your phone doesn't die at the least opportune moment. Assuming you make it through the day, you would like to charge your phone while you sleep so it is fully charged when you wake up ready for a new day. Unfortunately, you can't charge it at night because your charger only works during the day at the same time you most use your phone. Planning to keep your

phone charged becomes a
constant pre-occupation as you go about your daily business.

This is the challenge with an electricity system based on variable intermittent renewable energy sources.
We know that if we want to rely on wind and solar for all our electricity needs, that wind only produces about 30 to 40% of the time, and
that solar panels only produce about 15% of the time. After all, we can't make the sun shine, or
the wind blow more than they do. Therefore,
we need to find a way to save the energy produced when it is available using
some type of storage – like the extra batteries for your cell phone – that will
allow it to be used later when it is needed.



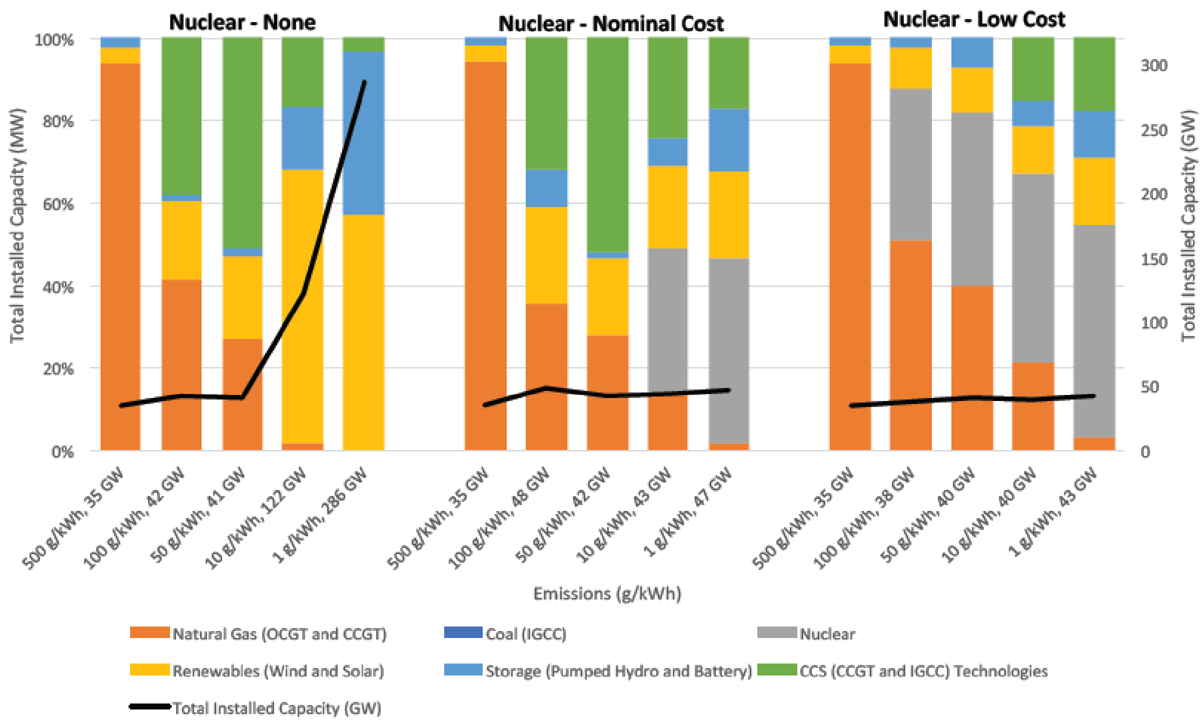
Southern California Edison 20 MW battery storage project
So how do you make sure you have enough energy to meet electricity
demand reliably in this scenario? The only
way would be to build lots and lots and lots of wind and

solar, way more than
you need at any given time and do your best to store this large amount of excess
energy for later use. In other words, the intermittency of these resources
means you have to build a HUGE amount of capacity coupled with a large amount
of storage to get the same amount of energy you could otherwise get from a readily
dispatchable resource that is available whenever you need it, (which is why the
fossil industry loves this scenario because they know the most likely option is
using gas plants to meet the demand when renewables cannot.)

An MIT study "*The Future of Nuclear Energy in a Carbon – Constrained World*" published last year looks at what is needed to fully decarbonize a system both with and without nuclear energy. As can be seen below, replacing fossil fuels without nuclear means having to build a system that is an **ORDER OF MAGNITUDE** larger that what is currently in place. Yes, that is right. Without nuclear, you need to build a system of renewable energy and storage that is on the order of 10 times larger than what you have in place today to try and make sure you will always have enough energy available to meet demand. After all, it would be hard to imagine a future where our economies accept that it's OK to run out of energy until the next time the sun shines or the wind blows.

For example, as can be seen from the figure, to eliminate the emissions from a 500g/kWh system in New England without nuclear power would require increasing the size of the system from **35 GW** to **286 GW** to replace gas with renewables and storage. (*About 500 g/kWh is an average carbon emission for many systems around the globe today. This study looks at what it would take to bring that close to zero.*) The figure also shows that decarbonizing by replacing gas with a combination of nuclear and renewables (or “nuables”) results in a system with little change in size to what is in place today, and at much lower cost. (For New England, the cost would be about half of a fully renewable system.) The MIT study looks at many regions. Achieving the same result for the UK means increasing the system size from **58** to **478 GW** while Zhejiang China would need to increase the size of its grid from **78** to **1515 GW** to get off fossil fuels without using nuclear power.

Figure 1.6: Optimal capacity mixes for New England



Source: MIT Study “The Future of Nuclear Energy in a Carbon – Constrained World”

We have seen this in action.

To date as part of the Energiewende, Germany has doubled its system capacity
to replace some of its nuclear with a massive amount of renewables all to deliver
the same amount of energy to consumers with almost no impact to its carbon
footprint, and at higher cost; all while still relying on coal as its most
important form of generation.

This also bursts the fantasy that a fully renewable system is local and environmentally friendly as the electricity system (the grid) needs a huge amount of investment to support ten times as much capacity, not to mention the very large amounts of land needed to place these wind and solar collectors, and the huge amount of materials like steel and rare earths needed to build them and then all the waste when it comes time to dispose of them at their end of life.

As for storage, the task ahead is enormous. As stated in a recent article touting the benefits of battery storage from the IEA, "*Today, pumped hydro storage systems account for the majority of storage capacity (153 GW, equivalent to about* ***2% of total power capacity worldwide****, while battery storage systems total around 4 GW. However, while pumped hydro storage is projected to grow in the next decade, the technology deployment is largely constrained by the location of suitable sites.*" This article then goes on to say battery storage can reach 400 to 500 GW by 2040, but this is still a drop in the bucket compared to what would be required. With the storage requirements for New England alone being about 100 GW, the global requirement would be in the many thousands of GWs to reach the levels required by a fully renewable system. And let's not forget today's batteries provide only short-term storage with technologies for long term storage nowhere near ready to meet a challenge of this magnitude.

Energy is most efficiently stored in fuel, like coal, gas or uranium, and then burned exactly when it is needed. And which fuel stores the most energy?
Uranium. A single pellet of enriched nuclear fuel about the size of the end of your little finger, has the same

amount of energy as one ton of coal. Or
to put it another way, uranium produces about 3 million times more energy from
a kg of U235 than coal does from a single kg of coal.

Uranium fuel pellet

Now that is what I call energy storage. This little bit of fuel can produce a huge
amount of energy and it is accessible to us when we want it. If we need to decarbonize our energy systems,
and we want to do it relatively quickly, what makes more sense? Building a system that is ten times larger
than we currently have to produce the same amount of energy we produce today,
with all the materials and land that goes along with that, or building nuclear
plants that can produce huge amounts of energy from a small amount of resource? I know which option would let me sleep at night – and would give me the best chance my phone alarm would actually work in
the morning.