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“When The Sun Don’t Shine And The Wind Don’t Blow”:

SOLVING THE INTERMITTENCY PROBLEM AND MOVING TO A ZERO CARBON FUTURE

KEN MARTENS FRIESEN

Responding to anthropogenic climate change has become the central cause of our day. The strong scientific consensus is that there is a narrowing window of opportunity to make a rapid transition to carbon-free energy to stave off the worst impacts of human-induced climate change. The world must therefore make the transition rapidly. One key element of this transition is the rapid electrification of the transport sector, which makes up nearly one-third of the current global greenhouse gas emissions. Electrified cars and trucks (and planes and trains) are much more energy efficient then their fossil-fuel powered cousins and can be powered largely on renewable energy sources.

The problem is, of course, that our industrialized world was largely built on a fossil fuel foundation and continues to thrive on it. The adoption of oil as virtually the sole source to power our transport has largely resulted in a virtual complete dependence on fossil fuels to maintain our very energy-intensive mobile lifestyle. The years since the first and second oil crises of 1973 and 1979 caused some countries to question the wisdom of relying so exclusively on fossil fuels to power their vehicles. But the United States, and many other industrialized countries, largely ignored the calls of the environmental and scientific community. They stuck to the dream of endlessly using fossil fuels to power vehicles, regardless of the increasing social and environmental cost they were obviously causing.

This dream began to crumble in the late 1990s and early 2000s. Increasing awareness of the long-term consequences of endlessly burning prodigious amounts of fossil fuels in our cars and trucks increasingly alarmed scientists and portions of the public. Western countries began to emphasize the need for more efficient engines and vehicle design to reduce the ever-increasing amounts of oil being consumed by the world every year. Inauspiciously, however, it was precisely in the early 2000s that countries like China and India began to copy the industrialized world's model of a fossil-fuel dependent energy system. Consumption and economic growth shot up. As a result, rather than slowing, fossil fuel extraction and consumption soared. While in the early 1990s global oil consumption leveled around 3.1 million metric tonnes a day, by 2005 that number increased to 3.9, and by 2015 the world was consuming over 4.3 million tonnes a day.[1] Increasingly dire warnings about the potential environmental disaster such profligate use of fossil fuels entailed were made. CO^2 levels continued to rise, surpassing 360 ppm by 1995 and 400 ppm by 2015[2], levels not seen in tens of thousands of years.

It became clear that an important component to solving the CO^2 carbon crisis would be to create a transportation system that can rapidly and sharply reduce, and eventually eliminate, the use of fossil fuels altogether. Individual countries like Japan and states like California pushed the envelope by requiring car companies to produce a certain percentage of zero emissions vehicles in order to sell cars in their region. The mandate was initially decried by the large automakers, with General Motors and others claiming there was not a technological means for them to come up with such vehicles. But then the upstart electric car company Tesla Motors, led by its founder and certain creative genius Elon Musk, demonstrated that it was possible to build an attractive and impressive zero-emission vehicle. The Tesla roadster came to production in 2008 and was an all-electric two-seater roadster capable of going 244 miles on a charge and travelling from 0-60 in 4.4 seconds. The problem, however, was cost. The $100,000 roadster was no car for the masses.[3]

Tesla's first attempt at an electric car was followed by additional models, however, namely the Model S, X, 3, and Y. The price of each succeeding generation of Tesla's vehicles fell, as did the arguments about the impossibility of creating attractive, mass-produced vehicles that were emissions free. Tesla eventually became the darling of both the automotive world and the investment world, with its stock price rocketing up in 2021 to over $800 per share, enabling it to become listed on the S&P 500 and, at over $600 billion, claim the distinction of being the most capitalized automobile company in the world.[4]

Mainstream automobile companies noticed. Even before the recent jump in Tesla share prices, other companies began making announcements about their plans to transition to electric vehicles. Motivated by a combination of a changing environmental equation, increasing governmental regulations, and seeing consumer change blowing in the wind, numerous legacy automobile companies began announcing a shift to electric. Volkswagen, burned by the Dieselgate scandal, announced that by 2030 at least 60 percent of its European sales would be electric. General Motors stated that by 2035 all its light duty vehicles would be electric and by 2040 its entire automotive manufacturing process would be carbon neutral. Likewise, Japanese automakers Toyota, Mazda, Mitsubishi, and Nissan said they would be entirely carbon neutral by 2050.[5]

The drive for zero-emissions vehicles was part of a larger global initiative to push renewable energy into the spotlight for all parts of the industrial order. Calls for a carbon-free energy system based on renewable energy became louder and louder. Countries began to reevaluate their energy mix. They passed laws requiring an increasing share of its energy consumption be fueled by renewables. Skeptics criticized the drive for renewables, citing the enormous economic and employment cost to make this transition. With fully 9.8 million jobs involved in the oil and gas industry dire predictions abounded about unemployment and government subsidies necessary to shift to renewables.[6]

But this is changing. Renewable energy is becoming an important and increasingly central part of any local or national discussion about energy and economics. While even a few years ago there was debate over the viability of renewable energy as an economic alternative to traditional fossil fuel sources of energy, the reality is that today solar and wind generation can compete head-to-head on a cost basis against coal and, increasingly, natural gas. Plummeting prices of solar panels have continued, driven in large part by the massive scaling-up of production volumes, the commodification of panels, and state and local requirements for alternative energy to form a larger percentage of the energy mix.

The United States currently has 20 percent of the electrical grid powered by renewable energy. This is up from less than 10 percent in 2010, when solar and wind were virtually absent and small and large scale hydro were the only forms of available renewable energy.[7] Looking around the world one sees similar trends. In the industrialized world the United States lags behind some of its European and Asian neighbors. Germany and Spain each produce over 40 percent of their electrical power from renewables while China, using hydro, solar and wind power, provides 26 percent of its electricity from renewables. And in all cases the year-on-year increase in renewable power is dramatically increasing.

While this is generally positive news, there is an essential renewable energy issue that lies central to the viability of transitioning to electric vehicles. In a nutshell, the problem is renewables intermittency. While renewables can, for the moment, provide increasing percentage of overall power, "the sun doesn't always shine and the wind doesn't always blow." Even if solar and wind power provides a substantial portion of renewable energy power in the coming years, there will still be significant periods when conventional fossil fuels will be required to provide the electricity that charge electric vehicles. When this occurs electric cars are, in effect, efficient but largely powered by natural gas or even by coal.

Understanding the source of electricity required to charge an electric car battery requires unpacking the myriad ways electricity is now produced and sourced in a state or country. In the case of a state like California, known for its generally progressive environmental thinking, there has been substantial progress in shifting electric power production from coal and natural gas to renewables. In 2000 56 percent of electricity production was from natural gas while 34 percent was from non-fossil fuels, mostly nuclear and hydroelectricity. In 2019 the numbers were basically reversed, with 57 percent of California's electricity generation sourced from renewables (including solar [20 percent], hydroelectric [18 percent], nuclear [7 percent], wind [7 percent] and geothermal [5 percent]), followed by natural gas (39 percent).[9] This is commendable, and shows the great strides the state has made toward moving toward a renewable energy economy. But those numbers hide two unfortunate realities relating to electric vehicles. The first is that if the numbers are disaggregated between day and night-time the challenge of renewables is plain to see. During the daylight hours in a typical spring and summer, the abundant sunshine and plentiful wind help California produce virtually all its power through renewables. At night, however, renewables provide less than 20 percent of the total electricity production. This means that up 80 percent or more of the energy produced in California during a typical spring or fall night may be generated using fossil fuels.[10] The reality that the vast majority of California's night-time electricity production is currently from fossil-fuel sources means that, electric cars, that predominately charge during the night, are, in effect, "filling up" on fossil fuel.

What is true in California is true in most U.S. states. With the exception of a handful of states like Washington, Oregon, and Idaho, where a high percentage of electricity is produced day and night from hydroelectric dams, the vast majority of electricity produced at night throughout the United States is from natural gas or coal.[11] The implication of this is that even if Americans were to suddenly transition to electric vehicles, most of their recharging would be done using electricity produced by fossil fuels. Electric vehicles (EVs) still retain their tremendous advantage over internal combustion vehicles in terms of energy efficiency. EVs convert 80 or 90 percent of the energy used to "fill up" to actually powering the car, compared with 25–40 percent of an internal combustion vehicle. Yet the goal of completely eliminating fossil fuels from fueling the transportation sector is hardly possible without tackling the question of how to create electricity from renewables twenty-four hours a day.

The question of what to do about this has naturally been of great interest to scientists and politicians alike over the past several years. If America has even a glimmer of hope of achieving its promises made by former President Obama in the 2015 Paris Climate Accords (immediately dropped by President Trump and then immediately renewed by President Biden) it must rapidly transition its vehicle fleet to electricity, and the source of that electricity must increasingly be carbon free.

The scale of this transition is daunting. One study estimated that the 133 million gallons that the United States burned by automobiles in a recent year would translate to 1,111 TWh (terawatt hours) of electricity. This is based on electric vehicles traveling an average of about 3.3 miles/kWh of electricity, and the average American vehicle traveling about 15,000 miles per year. Some worry that this alone is a reason not to switch to electric vehicles, worrying that the strain on the electric grid will be too great. Yet this is very unlikely to happen, as the actual overall increase is a relatively manageable

29 percent [12], occurring gradually over a two-decade period. In addition, the majority of this increase will take place during the nighttime when the current electric grid is strained the least.

But the fact that much of the additional generation will need to occur at night makes the question of how to generate the electricity using non-fossil fuels ever more important. There are currently several options being developed that help solve the conundrum of what to do “when the sun don’t shine and the wind don’t blow.”

Battery Storage

Lithium-Ion Batteries

Seemingly the most obvious, and the one that presently gets the most attention, are large batteries. Tesla, and now additional companies, have developed large-scale battery systems that are beginning to demonstrate the possibility of powering a small city or even a state during times when renewables are not available. In a remarkable demonstration project in South Australia Tesla used lithium-ion batteries to build a 100MW energy storage system. In this case the problem was that the Australian grid operator was paying extraordinary amounts of money for “peaker” natural gas powerplants that needed to be ready to go at a moment’s notice when electricity demand spiked. Demonstrating that this in not just a single, unrepeatable possibility, a Tesla subsidiary called Gambit Energy Storage LLC is currently building a 100 MW energy storage facility in Angleton, Texas.[13] And California’s Pacific Gas and Electric, in cooperation with Tesla, have taken over a shuttered coastal nuclear power plant in Moss Landing, California, aiming to initially make it into a 182.5 MW energy storage system, with the option of additional, even larger, systems there and in other locations.[14]

Through these installations Tesla effectively demonstrated that a renewable energy source could be used to provide the necessary on-demand power, and can do it at a very competitive price. But these remain relatively small operations in the large picture of overall electricity demand: 100MW of battery power is capable of powering about 30,000 homes for a short duration, far less than the demands of a large city trying to move away from fossil-fuels altogether. In order to truly scale up the battery technology hundreds of these facilities would need to be built in multiple locations around the United States.

Flow Batteries

A second type of battery storage that, up until now, has not received the press of Tesla's lithium-ion based battery storage, is flow batteries. Flow batteries are, in many ways, a much simpler and more straight-forward form of battery storage than lithium-ion batteries. In addition, they have an advantage over lithium-ion batteries in terms of ease of scalability. Flow batteries use a container full of a positively-charged liquid electrolyte and a container of a negatively-charged liquid electrolyte. When the flow of the two liquid electrolytes are combined in a fuel cell and electrodes use to push the positive electrolyte in one direction the ions discharge, creating electrical energy. When the flow direction is reversed, the fuel cell feeds ions into the two separate solutions and the two liquid electrolytes charge.[15] The largest flow battery currently being installed is in Dalian, China, a 200MW/800 Mwh vanadium flow battery to store and deliver energy connected with a large nearby wind farm in 2020.[16] The major drawback of the flow battery technology is the vanadium that form the basis of the electrolytes. If flow batteries prove to be a popular energy storage option the price of vanadium will likely also rise. The search is now on for a long-lived organic substitute for vanadium.[17]

Pumped Storage Hydropower

A second energy storage solution is one that has been in use for decades all around the world and yet, if modified, could provide substantial additional energy storage for use at night when solar is not available. Pumped storage uses hydropower's existing configuration of a reservoir, dam, intake pipes and a turbine to provide electricity both day and night. Once the water is past the turbines in a hydropower station it is normally not used again. But with pumped storage the traditional hydro system is combined with a second downstream reservoir. By adding this second reservoir below the turbines, part of the day's water can be channeled and stored to allow that water to be reused. A second series of pipes and turbines, powered during the day by renewable solar or wind turbines, allows the diverted water to be pumped back up to the higher reservoir, ready to be released during the night in order to provide renewable hydroelectricity for night-time use.

In theory this system could be used in areas where there is not a riverine system in operation, with the complex ecological habitat issues that must be attended to. Rather, two natural or human-created reservoirs at different elevations could provide the source of water for pumped hydro storage, with water simply recirculating and an endless supply of energy being generated both day and night from the hydroelectric plant while solar and wind provide the power to pump the water back up to the higher reservoir.

Compared to battery storage the cost of pumped storage is currently very competitive, pricing out at roughly one-quarter the cost, without the cost of the solar or wind generation factored in.[18] Pumped storage facilities have been operating around the world for several decades. In California, the Helms Project east of Fresno has provided re-circulated water between Courtright Reservoir and Lake Wishon for over three decades. In this example the water is pumped back up through the turbines in reverse when the cost of and demand for electricity is low. Helms Project electricity is only used when spikes of electricity are needed, usually during a hot afternoon. But adding solar power to the installation could create a truly dynamic addition to the existing pumped storage facility, allowing it to operate beyond a facility only used for critical need.

The largest potential example of pumped storage is emerging at one of the largest dams in the United States. Hoover Dam recently announced that it was considering spending $3 billion to create a pumping station downstream from the dam, powered by solar panels. The pumping station would pump water back up to the Hoover Dam reservoir, thereby making the dam, in effect, a "rechargeable battery." The main reason this can be considered is that today there is excess solar power in the electrical grid in the southwest. Using some of this solar power to power the giant turbines necessary to push water back up to reservoirs several hundred feet higher could help provide the basis for nighttime generation of renewable electrical energy.

Feasibility studies of pumped storage have also brought to light its serious potential limitations. The most serious one may be the lack of available sites for creating pumped storage facilities in an environmentally sustainable manner. Even in a country like Ireland, with plentiful fresh-water lakes and replenishing rainfall, only one new pumped storage site is currently being developed, a 948MW system that is forecast to cost almost one billion dollars.[19] Another study on the overall costs of pumped storage hydro forecasts that for the short term it may have a cost advantage, but in the medium to long term, the rapidly declining cost of large-scale battery storage will likely be more cost-competitive.[20]

Concentrated Solar Power with Thermal Storage

A third option for energy storage uses the power of the sun to both create energy that can be used immediately or be stored for nighttime use. Storing the heat of the sun in solutions that can include clay, brick and sandstone, or glass, aluminum and steel can provide efficient energy storage solutions. The United States' largest solar thermal plant is located in the Mohave desert of California, though there are larger plants in Morocco, Spain, India, and China. These plants take the intense heat produced by the sun to capture it and run turbines used to create electricity for immediate consumption. A more recent development is to not simply generate power during the day but to store the heat in large, insulated holding tanks for use during the nighttime hours when solar thermal energy is not available. Thermal energy storage is a relatively new development in the solar thermal industry and, as such, has not been developed on a truly industrial scale. A facility like the Ivanpah plant could potentially divert a percentage of its vast production to heat molten salt to 1,050 degrees Fahrenheit and then store the molten salt in a giant insulated tank for use at night to make steam to run a turbine.[21] Prices have fallen using this technology to less than 7 cents kWh, meaning they could be competitive with other thermal sources of energy including natural gas and coal. A thermal solar plant with storage is being constructed in the Nevada desert; its potential for success may herald a new direction in renewable energy storage systems.

Compressed Air Energy Storage

A third viable means of storing renewable energy for later use is compressed air energy storage (CAES). CAES uses enormous underground caverns like salt mines to store air that is compressed using turbines powered by excess solar or wind energy. This energy is available for use when solar or wind power is not available and can be easily tapped and the energy produced entered in the electrical grid. The compressed air can sit stable for weeks or months without worry of explosion or being transformed into a flammable or toxic substance. Though the technology is not terribly complex the use of CAES is relatively new. Until 2012 there were only two working CAES systems in the world, one in Germany and one in the U.S. state of Alabama. Both used former salt mines to store air up to 1100 pounds per square inch. The resulting electricity produced from the CAES can run 11,000 homes. Additional plants are being developed in England, Northern Ireland and Austria.[22] Though a relatively young technology, it seems promising because of its small above-ground footprint and the relatively straight-forward technology that it is based on.

Gravity Battery

Gravity batteries use suspended weights to produce electricity. The weights are either lifted high into the air or suspended in a deep mine shaft in the ground. Excess renewable energy lifts the weights to their uppermost point and, when needed, the weights are slowly lowered, turning a shaft which produces electricity. A Swiss company named Energy Vault has built a test gravity battery structure and is now in operation. The advantage over traditional battery storage system is in the ease of construction as well as environmental simplicity. Once the weights are made (usually of cement or some kind of brick) they can be used indefinitely. Both the initial construction as well as long-term viability of a gravity battery causes little harm to the environment. They also have a very low operating cost since the entire technology involves raising and lowering weights, something that can be computer controlled and requires very little human input.[23]

Small Scale Thorium Nuclear Reactors

Another fossil-fuel free option is potentially more controversial, but also potentially significantly more capable of freeing much of the world from fossil fuels. Nuclear energy, a form of energy generation that has been largely removed from debate from some prominent thinkers because of its reputation for risk, is in the unique situation of being a technology that has a proven track record of providing massive amounts of electricity for many countries around the world. Of course, Three Mile Island, Chernobyl, and Fukishima, all conjure up images of mushroom clouds and radiation poisoning that can linger for thousands of years while creating tons of radioactive waste that will also linger for thousands of years.

While each of these has its own story, the reality is that nuclear power plants have been operating for decades in dozens of countries, the vast majority of which produce carbon-free energy with few to no problems. France, a prominent producer of nuclear power, decided after the energy crises of the 1970s to transition its energy production to nuclear. It now produces over 70 percent of its entire electrical production from nuclear power. China has gone on a nuclear power building spree, adding the most nuclear power capacity of any country between 2012 and 2018. By 2020 they were projected to have over 55 GW of installed nuclear power capacity, making them the third largest nuclear power producer in the world, behind France and the United States.[24]

While not wanting to wade too deep into the shoals of nuclear energy there are several important aspects of nuclear power that need to be mentioned. New developments in nuclear power technology, termed "Generation IV" nuclear reactors, have, according to their proponents, overcome many of nuclear power's shortcomings. They use thorium instead of uranium for fuel rods, greatly reducing radioactive waste, and molten salt to cool the reactor, eliminating the threat of a nuclear meltdown.[25]

Because of these fundamental changes to the production of nuclear energy some environmentalists believe that nuclear power must be given a fresh look. They argue the reality is that without the possibility of adding nuclear energy to the mix of non-fossil fuel energy sources that will power our electric future, especially as a form of reliable base power that can be guaranteed regardless of external conditions, there is very little hope that we can come close to reaching the goals of the 2015 Paris Agreement. Some dedicated environmentalists and others seriously concerned with the potential impact of climate change argue that ramping up the use of nuclear energy may be the most realistic and much less damaging than the potential impact of nuclear power. Richard Rhodes, Pulitzer Prize winning of author of *Energy: A Human History,* argues that nuclear energy can be, "a major component of our rescue from a hotter, more meteorologically destructive world."[26]

Scaling Up

Each of the carbon-free alternatives to gas and coal could feasibly provide part of the solution to the question of intermittency and how to make electricity "when the sun don't shine and the wind don't blow." Collectively they could create the necessary energy generation potential to reduce our reliance on fossil fuels to zero. There remain enormous technical, environmental, and logistical challenges to making this transition but the consensus among energy analysts is that a transition to zero carbon emissions is possible. That said, the imminent question looming over the discussion is not whether this could happen but how quickly it could happen. The time is growing increasingly short as to when the world must wean itself off of its fossil fuel diet. Each year that fossil fuels dominate means that a more difficult and dramatic shift must occur in the future.

The transition from one primary energy technology to another has, of course, taken place in the past. One of the most preeminent energy scholars, Vaclav Smil, writes extensively on the timeline for past transitions in *Energy Transitions, History, Requirements, Prospects*.[27] He traces the transition humans made from biomass to coal to hydrocarbons. In 60 years (from 1840 – 1900) coal went from providing 5 to 50 percent of the world's energy supply, while over the same amount of time oil provided less than 40 percent and natural gas less than 20 percent.[28] The global energy production of solar and wind in 2020 was roughly nine percent. If you combine it with other renewable energy supplies including hydroelectricity and biofuels that number increases to 28 percent. But at current rates of increase the U.S. Energy Information Administration estimates that by 2050 all forms of renewables will fuel about half of the global energy demands.[29]

The problem is that by 2050 the world will have produced hundreds of billions of additional tons of CO^2, pushing us nearer to the brink of an environmental precipice. The reality is that the longer the world waits to rapidly scale up the transition to fossil-fuel free renewables the shorter the time there is to effectively complete the transition. Will we succeed? If we don't, future generations will very likely feel the brunt of our failure with a much hotter planet, coastal cities under water, a dramatic increase in wildfires, declining water supplies and reduced snowpack, and environmental migrants by the millions.

There is reason for hope. The confluence of rapid price declines for battery storage technology, increased public awareness of the crisis that we face, and the potential for international cooperation to effectively tackle climate change have increased our prospects. A significant voice in the conversation is Bill Gates. He argues that a concerted drive by government, industry and the public can push us to a deeply de-carbonized world by 2050. In practice he argues that policies like putting a price on carbon, clean electricity standards, clean fuel standards, clean product standards, and a rapid turnover of old to new carbon-free technologies can get us where we need to be in the next thirty years.[30] We will need all the help and hope we can get.

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