The energy system must change. So what happens next?

Nuclear & the Zero-Carbon Energy System

BLACK & VEATCH

The truth is clear and conclusive: On their own, current and near-future wind and solar technologies can't replace fossil fuel-generated electricity. But the next generation of nuclear reactors … smaller, safer, easier to build and maintain … offers the promise of power that is clean, reliable and "dispatchable" according to demand.

In this final installment of our eBook series on nuclear power, we look at the complementary roles nuclear, solar and wind energy can play within the grid of the future, and how they can work together to help address our climate crisis and demonstrate a path forward for the rest of the world.

Nuclear & the **Zero-Carbon** Energy System

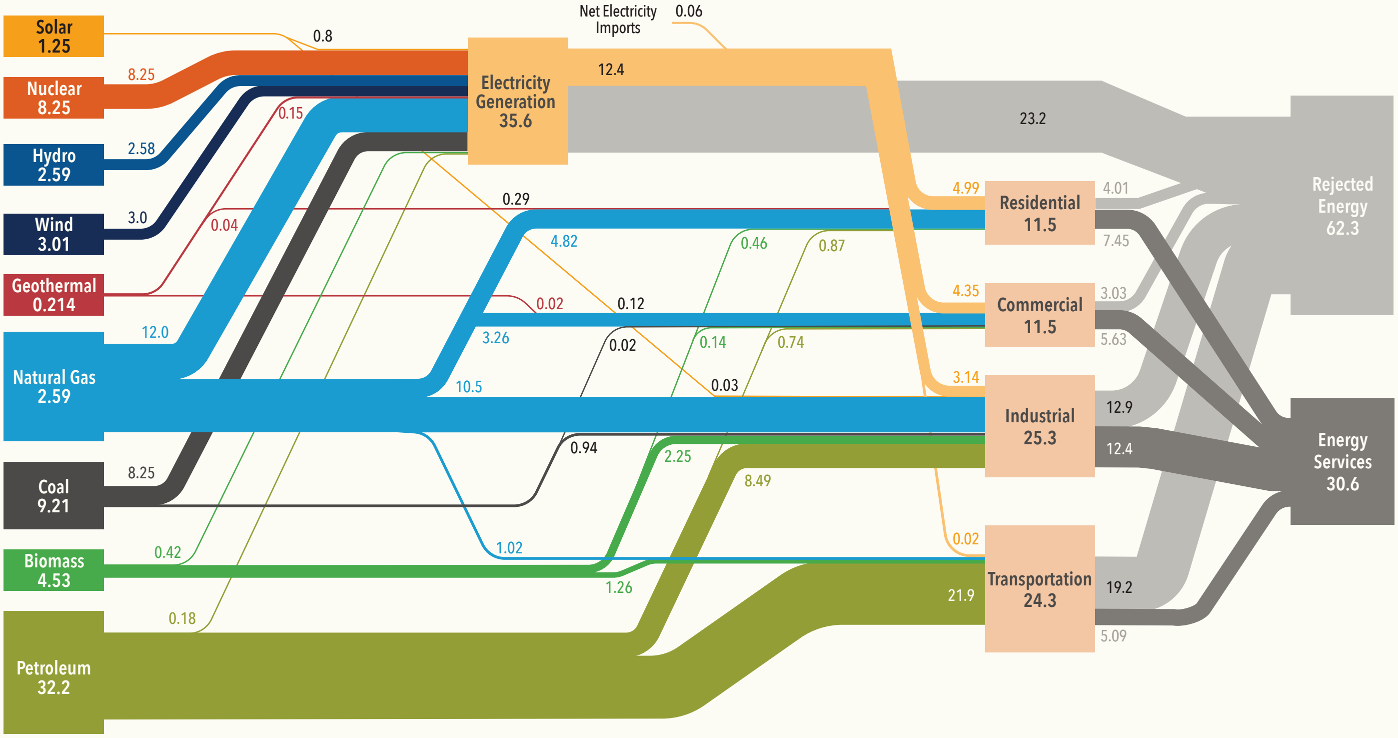
It is difficult to see the full energy picture, but every year the U.S. Department of Energy (DOE) publishes a chart that gives it a try, showing all the inputs — coal, oil, fossil gas, nuclear, falling water, wind, solar and biomass — and where they go (commercial, industrial, residential and transportation consumption) after they are converted into various forms, including electricity, motor fuel, jet fuel and process heat.

The chart below looks like a multi-colored octopus run over by a steamroller, but it is extremely informative.

This chart is slowly shifting and will shift more as we decarbonize. Fossil fuels will have to shrink and the share of carbon-free energy that passes through the form of electricity, now 38 percent, will have to rise.

Today, about 38 percent of all primary energy is turned into electricity before it goes to the ultimate consumer. In the future, that percentage will have to rise sharply, as the energy for highway transportation, space heating, chemical processing and other forms now met by fossil fuels will be met with electricity instead.

Estimated U.S. Energy Consumption in 2020: 92.9 Quads



Source: LLNT March, 2021. Data is based on DOE/ETA MER (2020). Credit: Lawrence Livermore National Laboratory and the Department of Energy. .

The push for a **carbon-free system** and the introduction of **massive amounts of generation** that **can't be scheduled** ... are two of the factors that are **destroying** the traditional underpinnings of **utility planning**.

Some inputs to electricity generation are carbon-free, like hydro, nuclear, wind and solar, or can be made carbon-free if used to make electricity, like a fossil-fueled generating station with carbon capture. Wind and solar farms and nuclear reactors must take the place of oil wells, coal mines, gas fracking operations and maybe even some biomass plants.

With the shift in the chart, the octopus' arms will re-route and meld paths as some energy markets that used to be distinct merge together. Home heating, transportation and electricity used to be mostly stovepipes; now energy will be fungible among them.

The Many Pathways to Energy

Some of the pathways are obvious; e.g., electricity will charge vehicle batteries. Some are not so obvious; e.g., nuclear reactors will provide process heat, which can be used to displace fossil gas in industrial use, or used to split water into hydrogen and oxygen for use in industry or transportation.

Hydrogen can be made by splitting water using electricity of any source, but if the water is first heated to high-temperature steam, it takes two-thirds as much electricity. Side note: Nuclear is the only carbon-free source that creates steam, unless carbon capture from coal and fossil gas plants can be commercialized.

The produced hydrogen gas can be pushed through the same distribution system that carries methane, the main component of fossil natural gas. That will convert gas-using devices, like power plants, into carbon-free machines. By the way, the "gas" in gas turbines is usually methane, but gas turbines can be made to run on other gases or fuel oil. Some utilities are requiring that all new gas turbines be capable of running on hydrogen, which presents as a gas at room temperature.

As an interim step, carbon-free hydrogen can displace the fossil fuel currently used in oil refineries and can replace the fossil gas in fertilizer production. Longer term, it may be sent to a chemical plant, where it can be combined with carbon dioxide captured from burning fossil fuels to form methanol and other hydrocarbon compounds.

The resulting synthetic molecules, long-chain hydrocarbons, are liquid at room temperature, easily transported, and can be dispensed from corner filling stations to substitute for gasoline, diesel, or even jet fuel. Aviation can become carbon-free, with a push from nuclear or from coal or fossil gas with carbon capture.

Hydrogen from carbon-free sources can also be used to process iron into steel, a job now done with coal. Today, steel mills use carbon monoxide, CO, produced by the partial burning of coal, to scavenge excess oxygen from iron, but when the CO molecule grabs that oxygen atom, it becomes carbon dioxide, CO2 which is not desirable. When hydrogen grabs the molecule, it becomes H2O, pure water.

Sometimes the **electricity is…in such surplus** that it has **no value** — like **100 zucchini plants** in your garden, all ripening at the same time…that is, **you have to pay somebody to take it.**

Process heat from carbon-free sources can also be used to make clean steam that will run chemical plants, a job now mostly done with fossil gas.

All this work will have to be done on a grid that is far more complex than the one we have now, because most of today's energy sources can be dialed up or down at will. Grid operators don't control demand, but they do control generation. Or, they used to.

The Renewable Conundrum

In the future, most generating capacity will come from renewable sources. Proponents call them "variable renewables," while skeptics call them "intermittent renewables;" in any case, their output cannot be dispatched, and can only be imperfectly predicted.

The grid will continue to be essential, but harder to manage. The trick is to find a use for all the energy — no matter when it is needed, at the moment it is produced.

California is providing an early indication of the problem. Grid dispatchers must often "curtail" solar and wind generation — literally unplugging generators because there is no place for the electricity to go. The cost for a solar or wind farm is the same whether it operates or not, forcing a major capital investment in an asset that is sometimes useless, like paying a mortgage on a house no one can occupy.

These curtailments are highest in spring, when sunshine and wind are strong, but air conditioning demand is low. In California, curtailments in March, April and May 2021 jumped to 862,000 megawatt-hours, which is enough to run almost 1 million homes for a month, with a rise of nearly 13 percent over the previous year. The increase would have been larger except for a fall-off in hydroelectricity production brought on by drought. And solar and wind installation continues across the West, ensuring that this issue will only continue.

In other words, the current system is throwing away carbon-free electricity while it continues to burn fossil fuels for electricity, transportation, space heating and industrial use. Relying on weather-dependent generation for electricity production when the weather varies by season means that if we build enough renewable energy to get through lean times, like short winter days, we will have a surplus at other times.

The problem isn't just throwing away energy. More often, the price of energy is depressed by surpluses, making solar panels or wind turbines less valuable. In June 2021, the DOE estimated that when solar or wind reached 20 percent of generation, the value of the electricity from those farms fell 30 to 40 percent below the value of a generator that ran 24/7. The more energy from solar or wind at the peak production hours for those technologies, the more the price is depressed, and the worse their economics become.

Redirecting some of the energy — and merging the energy markets — is essential if the penetration of variable renewable generators is going to increase.

Understanding Energy

But the merger is a big job. The first step in understanding what's involved is to reduce all forms of energy to a common measure — and that is heat.

The DOE's chart counts heat in the British Thermal Unit (BTU), which is the amount of heat needed to raise the temperature of 1 lb of water by 1-degree Fahrenheit. It's a small amount — for example, 1 gallon of regular-grade gasoline has about 116,000 BTUs.

The DOE measures by quadrillion BTUs. A quadrillion is one thousand trillion, i.e., the number "1" followed by fifteen zeroes. But engineers and government bureaucracies love abbreviations, and the quantity is usually referred to as a "quad."

Reduced to a common term, we see that the zero-carbon contribution in 2020 was 15.3 quads, out of 92.9 quads consumed. This figure excludes the 4.53 quads of biomass, mostly ethanol, whose production has a substantial carbon footprint through use of nitrogen fertilizers on corn, and fossil gas used in processing.

The problem is somewhat more severe than the 2020 statistics show, because consumption that year was depressed by the pandemic; the record was 101.2 quads in 2018. Economic growth pushes consumption higher, but efficiency improvements — better lighting, better windows, higher-mileage cars, the increased use of public transportation, improvements to freight rail — can push energy needs back down again.

And the future is full of wildcards: For example, will 3D printing reduce the need for shipping small objects around the world, the way fax and then e-mail reduced the need for first-class mail?

Conclusion

Sure, it's complicated, but the broad outline is clear: To reach a zero-emissions economy, carbon-free sources must increase by a factor of six or seven. And depending on the state of energy storage technology, production may have to increase substantially, because a fair portion of renewable production will be wasted as surplus.

Some surpluses can be stored but a key concept for storage and generation is that energy hardware from capital-intensive projects, like renewables, nuclear and batteries, only works financially if you can get a lot of use out of it.

Wind or solar is a difficult investment because you end up throwing away energy during the best hours of production, e.g., when wind and solar create a surplus. Nuclear plants can load follow to integrate with renewables, but nuclear plants would prefer to be baseloaded, or running 24/7.

Nuclear plants can adjust their production to fill in the gaps between renewable production and total demand, but as with solar or wind farms, reactors are capital-intensive investments and their economics work best if they can run as many hours of the year as possible. But if they do not come close to running 24/7, they may still be very valuable because they are dispatchable; that is, they can be turned on when energy is scarce from other sources, and prices are high.

And batteries can be useful if they are charged and discharged very often — e.g., charging on midday sunshine and discharging during peak consumption hours later in the same day. Think of it as cost per day of use; the price of a pair of blue jeans is spread over many more wearings than the price of a tuxedo.

The problem calls for a flexible energy system. Reactors, for example, may be making electricity when demand is high and when wind and solar output is low; during other hours they may turn to interruptible jobs like using their heat to make potable water or hydrogen, both of which can be stored. Keep in mind, the equipment to make hydrogen or drinking water must be of modest price, or else it will have to run all the time to operate economically.

A zero-carbon energy system can work. But it will have to operate as a cohesive system to be operationally efficient and affordable.

Previous eBooks in the series are available **here**, and examine nuclear power's role in decarbonization, the current state of reactor design, and the other technologies and components that will be necessary to build, integrate and maintain a successful net-zero-carbon energy structure.

bv.com/nuclear

BLACK & VEATCH