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Without nuclear energy, there is no large-scale decarbonization.

Clean Ambition: Nuclear Energy and Decarbonization

BLACK & VEATCH

While wind, solar and hydropower occupy critical space in our renewable energy portfolio, the limitations of each will likely prevent them — at least in the near term — from playing more than a supporting role in establishing our independence from fossil fuels. **To accelerate our arrival at a true net-zero carbon future, we'll need to rely on the only large-scale, zero-emission generation technology currently available: nuclear**.

In this first installment of our four-part eBook series, we'll dive deeper into current renewable generation capacity, energy storage technology, the realities of today's electricity market and the economics of renewable energy production.

Clean Ambition: **Nuclear Energy** and **Decarbonization**

Lately, summers are too hot, winters are too warm, rainfall is either too heavy or too scarce and climate politics are confused. The energy system is on the cusp of a massive change as it strives to eliminate the emissions of climate-forcing gases, and some promising tools are emerging to get the job done. But melding them into a system that is clean, reliable and affordable is going to be complicated and contentious, largely because the problem is so poorly understood.

It's no wonder, because the ground rules have changed. While decarbonization is the umbrella under which all energy technologies will gather, the push for a carbon-free system and the introduction of massive amounts of generation that can't be scheduled to match demand patterns are two of the factors destroying the traditional underpinnings of utility planning

Meanwhile, the lines between the sectors of the energy world increasingly are becoming blurred, as cars and trucks shift from petroleum to electricity and heating our homes, shops and offices becomes a job for electricity rather than fossil gas or oil. We will also need carbon-free energy for new or expanded purposes, like making potable water from the sea or moving water vast distances. We will need energy from new, carbon-free sources to make steel and concrete. Put these all together and we find ourselves at a crossroads with no road signs.

Renewable ≠ Carbon-Free

At least the size of the problem is clear. Today, renewable energy provides only 12 percent of total energy use, about one-third of which may not be compatible with a zero-carbon economy due to its substantial carbon footprint: biofuels such as ethanol are processed with fossil energy, and wood is harvested in a way that releases carbon dioxide from the soil. According to the **U.S. Energy Information Administration** (EIA), the other carbon-free source, nuclear electricity, provides only 9 percent of our total energy; oil, fossil gas and coal provide 79 percent.

And we have mistaken mathematical models for actual progress. Many buildings today, both houses and commercial structures, boast of being "net-carbon neutral," but there is less to that phrase than meets the eye. It means that over the course of the year, solar panels on the building generate as many kilowatt-hours as the building consumes in a year. In practice, it means that the building runs a surplus for a few hours in the

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middle of the day and dumps that on the grid. During the rest of the day, it pulls energy off the grid.

So at noon, somewhere, a natural gas plant can dial back a bit, and emit less carbon than it would otherwise release. But the building couldn't operate without somebody, somewhere, burning fossil fuel to keep it energized during non-sunny hours. Worse, it isn't setting an example for the system as a whole: If every building was net-zero, we'd have a terrific surplus at noon and a horrible shortage at 5 p.m. Clearly, a more comprehensive, balanced solution is needed.

Energy Systems

The world's energy system — which we've developed over the past 15 decades or so — needs to be revolutionized in the next three decades. We have to develop reliable, carbon-free power generation that can replace the 79 percent of the electricity system currently running on fossil fuels, and scale to roughly triple the size of the current electric system to cover what we need for transportation, industrial heat and direct use of fossil energy in buildings.

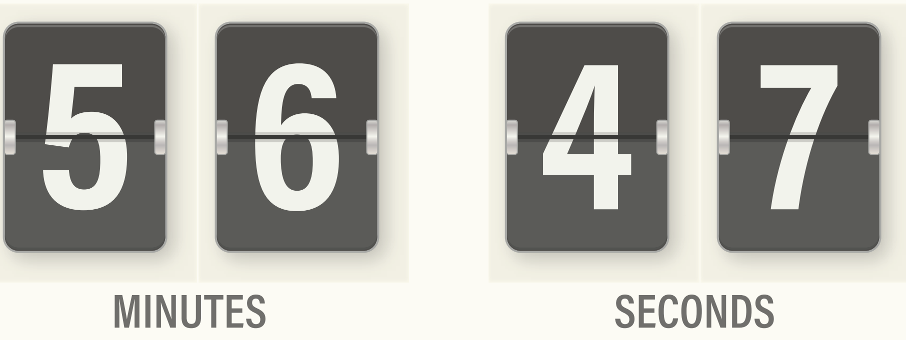
But it's more complicated than just adding generation. Nearly all the carbon-free generation added in the last few years has unpredictable production and cannot be scheduled to align with daily demand patterns. The builders call these "variable" generators; some planners call them "intermittent" generators. Without being able to schedule the production, the value of their product is highly variable, too. Sometimes, the electricity is useful and important; sometimes, it's in such surplus that it has no value — like 100 zucchini plants in your garden, all ripening at the same time.

Sometimes, because of the odd way the electricity market is structured, electricity has negative value — that is, you would have to pay somebody to take it.

The problem is exacerbated by the nature of electricity, which is more perishable than even zucchini. Production and consumption must be exactly synchronized. If they get out of sync, the precise, orderly dance of the electrons stops.

Electric power supply and demand is a problem you have to solve by the hour — which calculates out to 8,760 times per year. Actually, that's outdated. Power companies and power pools used to make the big adjustments in generation by the hour. Now, much of the system much of the system is run by independent system operators, who do it in five-minute intervals, because that's how far into the future the wind and solar producers can accurately predict their output.

If production and consumption don't align within a very narrow margin, the system collapses. More



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often, system operators unplug neighborhoods in "rolling blackouts" to ration consumption, or they shut down generators.

In a simple example, a 10-MW solar farm only produces 10MW at noon, when the sun is directly overhead. In the late afternoon, when demand for electricity is usually the highest, it will produce far less. But an entrepreneur might overbuild, putting in 20MW to get the 10MW at 4 p.m.

That may add to a surplus at noon, when the panels have to be disconnected, or the electricity dumped on the grid is in such volume that the balance of supply and demand pushes prices to zero or even below.

In Economics 101, if the price goes to zero, the producers stop producing, but in reality, some generators can't shut down without taking hours or days to re-start, meaning some coal and nuclear units will continue producing, pushing prices below zero.

While the solar farm won't lose money on fuel at noon, it does raise costs because it throws the classic economic formula out the window. That formula assumed that the product had value. (And why wouldn't it? If it had no value, you wouldn't run the plant.)

The Value of Energy

Before solar and wind, power plants traditionally divided into two categories: Expensive to build but with fuel that's cheap or free (nuclear and hydro) or cheaper to build but with a significant fuel cost (coal and fossil gas). Along come new entrants — wind and solar — and they are getting cheaper to build and have free fuel.

But their value usually is calculated by comparing their total output with their construction and operating cost. Thus, advocates of renewables will cite their declining "levelized cost of energy," which is the total cost divided by total production.

The cost equation is obviously different if some of the production is being thrown away, and if the value of the electricity during peak production hours is always depressed, because there is so much solar production.

A bigger problem is the obverse situation: It is a hot afternoon or evening. The sun is too low in the sky to illuminate solar panels, or it has set. People are returning home from work and turning on their air conditioners, microwaves and flat-screen televisions, but office air conditioners are still running.

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The solution, according to the advocates of a market system solution, is to let the price of electricity rise sharply, which will make consumers reduce their demand and will bring forth some energy storage.

But a growing body of research says that what the system needs is a carbon-free energy source that is firm and dispatchable, meaning it can be relied on and switched on and off as needed, regardless of weather.

There are four such sources in our toolkit today, either already deployed in limited amounts or on the technology horizon. They are energy storage, fossil fuel with carbon capture, green hydrogen and nuclear energy.

Storage: A Critical Component

Storage includes batteries — as in, devices that store energy — using lithium ion chemistry or something like it. It can also mean pumped storage, where you pump water to the top of a hill; heat storage, because the heat can be turned into electricity when needed; mechanical storage, including compressed air; or pushing a heavy train up a steep slope and recapturing the energy when gravity pulls it down again. Short-term storage is now practical for some specialized uses, but beyond daily storage, batteries are not practical and do not appear to be on the way to becoming practical, for reasons we will examine.

Carbon capture is understood at a lab level, but there is limited experience at an industrial level, and carbon storage is another can of worms, at least at the scale required for meaningful use of fossil fuels. Our most promising disposal method so far is using carbon dioxide to force the last dregs of oil out of old wells, but in a zero-carbon economy, there won't be much use for the oil.

Green hydrogen — hydrogen produced from the electrolysis of water powered by renewable energy — is gaining awareness in the power industry. Most often recognized for fueling transportation (e.g., fuel cell electric vehicles), process heat and power generation, hydrogen has several other applications: it can be converted to ammonia for use as a chemical feedstock, fertilizer or energy carrier; it can be used to hydrogenate toluene into the liquid organic energy carrier methylcyclohexane; and it can be used to create synthetic fuels ranging from methanol to gasoline to sustainable aviation fuel.

Nuclear energy already constitutes the largest source of carbon-free electricity in the United States, and existing plants will run for many decades to come. But new designs also are approaching commercialization. These will differ from existing plants in several ways: nearly all are modular, a characteristic that makes them easier and less expensive to manufacture and install. Most importantly, they are intended to operate flexibly, complementing the intermittency of wind and solar output.

Future eBooks in this series will explore how the elements of a carbon-free energy system, including wind, solar and nuclear, can come together to solve our climate problems in North America and demonstrate a path forward for the rest of the world.

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