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Powering up sustainable energy

Can the power industry simultaneously decarbonize generation, propel the transition to electric vehicles, and keep the lights on?

Thomas Edison upended the world with his novel idea for an electric utility that would centrally power homes and industry. One hundred forty years later, the power industry has been quietly decarbonizing, even as it remains a marvel of efficiency and reliability. As economies gradually feel their way to the "next normal" that is emerging from the COVID-19 pandemic—which has curtailed commercial and industrial demand, created new volatility in markets for fossil fuels, and required operational changes to ensure employee safety—industry operators may need to recalibrate the speed and scope of ongoing efforts to curb climate change.

How far and fast they go will depend both on the rate at which the economics of renewables improve and on the advance of technologies ranging from hydrogen fuels to carbon capture, use, and storage. Also critical: an expansion of the battery industry to store power and keep the grid humming when renewables such as wind and solar power aren't, as well as to accelerate the penetration of electric vehicles.

In this compilation, McKinsey experts provide snapshots of the opportunities and challenges associated with these transitions, and Lynn Jurich, CEO of the San Francisco–based solar player Sunrun, provides a ground-level view of what it looks like to transform residential solar into a new business model for microgeneration that helps utilities manage their loads.

Fully decarbonizing the power industry

Renewables and new technologies could push power emissions to zero, but would do so in very different ways across markets.

by Jason Finkelstein, David Frankel, and Jesse Noffsinger

Renewable energy is becoming more abundant—and cheaper. But the pace and nature of its expansion will vary considerably across markets. To see how the power industry could provide cheap, reliable, sustainable power, we mapped the world into four key market types (described below), which collectively make up most of the global market, and created pathways that show the most economical way to fully decarbonize each market type by 2040. We conclude that getting to 50 to 60 percent decarbonization is not that difficult technically and is often the most economic option. Getting from there to 90 percent decarbonization is generally technically feasible but sometimes costs more. And getting to 100 percent is likely to be difficult, both technically and economically (exhibit).

'Islanded' markets

As the name implies, these are remote or isolated markets (such as Hawaii) where today's power systems are expensive—they import fuel and lack connections to other power markets. Many have sunny climates, and falling renewable prices mean that these markets could reach over 80 percent decarbonization, largely by choosing the lowest-cost power mix.

Our research suggests that climbing the ladder to 90 percent would mean sizeable new investments in solar, with battery storage for backup when solar cannot generate. That would impose some level of what the industry calls "curtailment costs"[1]—the inability to use all the renewables coming online efficiently—plus related costs of keeping underutilized thermal assets up and running as a backup. Still, this penultimate step could be achieved with lower overall system costs.

Getting to full decarbonization would require using an emerging technology known as P2G2P (power to gas to power), where renewables produce clean hydrogen fuel through electrolysis.[2] That clean hydrogen displaces fossil fuels for backup power. It's a high-cost technology now, but the price tag might be contained since use will be mostly at the margin.

Thermal-heavy, mature markets

These markets have large populations, are heavily powered by thermal facilities today, and have major interconnections to other power markets to manage loads. Examples are the

[1] Curtailment, defined as the purposeful reduction in the output to the grid of a generator from what it could otherwise produce, is a concept that is particularly applicable to renewables because they cannot be controlled like thermal plants.

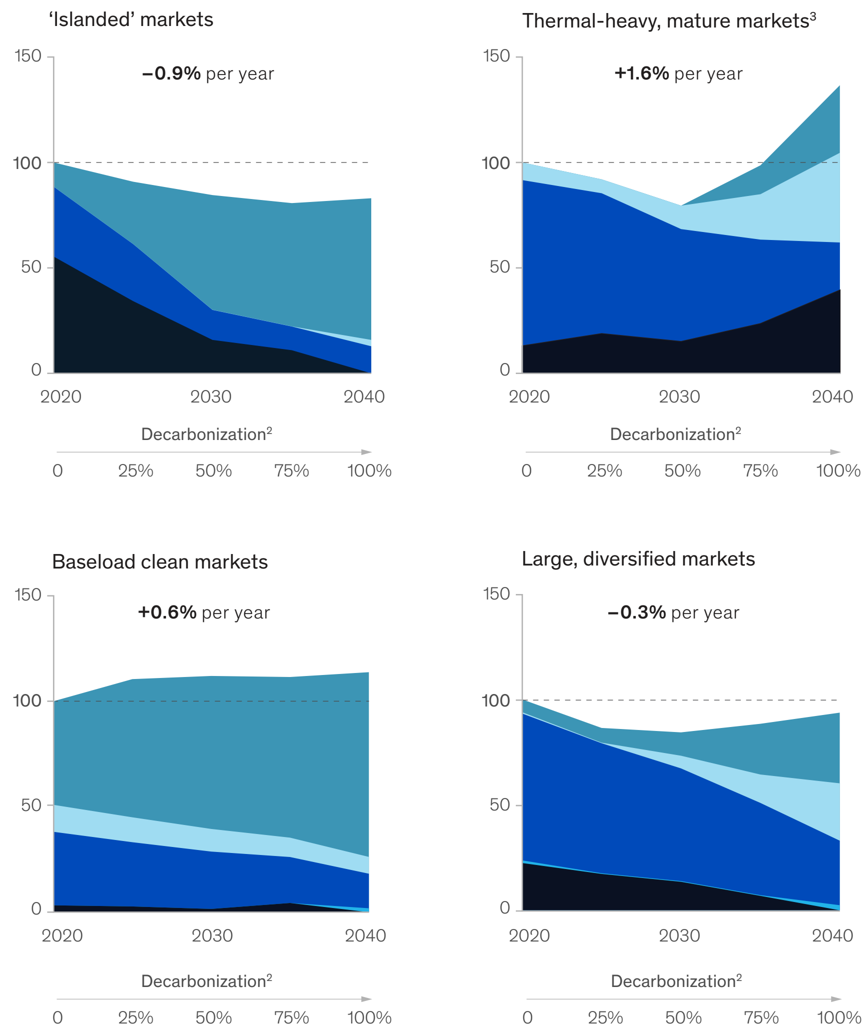
[2] In its most basic form, electric power from renewables drives a current through water to produce clean hydrogen gas.

Exhibit

The pathway and cost of decarbonization will vary, depending on the market.

Total cost of power, by technology type, indexed, real (2020 = 100)

- **Intermittent capacity:** wind, solar, run-of-river hydro
- **Clean dispatchable capacity:** reservoir hydro, nuclear, CCUS,[1] battery, pumped hydro storage
- **Fossil-fuel capacity:** coal, natural gas, oil
- **Clean fuel:** biogas, biomass, uranium
- **Fossil fuel:** coal, natural gas, oil



[1]Carbon capture, use, and storage.
[2]Net total power-sector CO_2-emission reduction relative to starting point.
[3]To achieve 100% decarbonization, fossil fuels continue to play a role via operation of gas plants outfitted with carbon capture, use, and storage (CCUS). The balance of uncaptured emissions from CCUS (~10%) are abated through bioenergy carbon capture and storage and direct air capture.

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US PJM market[3] and Germany. Getting to 90 percent decarbonization would require more wind generation and battery storage. Going the final distance to 100 percent decarbonization would likely rely on carbon capture, use, and storage (CCUS), where emissions from fossil-fuel plants are captured and stored. CCUS capital costs are high, but continuous use for power generation can temper them.

Baseload clean markets

These markets have a substantial core of baseload clean power, such as nuclear plants in France and hydroelectric facilities in Brazil and the Nordic countries. That's a hefty structural advantage: building on a zero-emissions base, they can choose the lowest-cost decarbonization option—in this case, wind—at little or no additional cost (using the base power to balance renewable intermittency) to reach 90 percent decarbonization.

These markets also would be well positioned to achieve full decarbonization through innovation in negative-carbon technologies. The combination of their clean base and renewables would create an opportunity to offset remaining emissions from the small amount of gas-fired "peaking" capacity needed (about 3 percent) with direct air capture (DAC). This technology effectively inhales CO_2 from the atmosphere and stores it underground or dispatches it for industry use. Costs are high but would be manageable in narrowcast usage.

[3] The PJM Interconnection serves all or part of Delaware; Illinois; Indiana; Kentucky; Maryland; Michigan; New Jersey; North Carolina; Ohio; Pennsylvania; Tennessee; Virginia; Washington, DC; and West Virginia.

Large, diversified markets

This market type comprises large territories, such as California, Mexico, and parts of eastern Australia, where renewables represent only a modest chunk of base power today, and substantial potential exists for additional renewables—principally solar and wind, but also river-based hydro. Our analysis suggests that the most direct path to 90 percent emissions abatement would be greater solar generation, plus storage—backed up by gas facilities to manage intermittency. Although efforts to connect renewables to the grid at large scale would impose some inefficiencies (curtailment costs), overall system costs might decrease as the costs of solar and storage continue to fall.

Getting to 100 percent decarbonization in these markets would require overbuilding of renewables and storage, which in turn would pile on curtailment costs as these new assets are cycled through the system. These markets would need to keep some thermal plants, supported by hydrogen through P2G2P technologies, to run the facilities. While expensive, P2G2P would kick in only if renewables could not produce for multiple days to supply power.

Technology advances could lower costs and accelerate the transition pathways we have described. In addition to direct air capture, CCUS, and P2G2P, advances in longer-duration storage and biomass fuel technologies could also move the needle, as could advances in more traditional areas such as nuclear generation and transmission. Significant penetration levels of electric vehicles could displace a meaningful portion of the stationary batteries that would otherwise be built. Paradoxically, however, they are unlikely to substantially affect system costs, since they do not solve the puzzle of achieving the transition from 90 percent to 100 percent decarbonization. That requires a breakthrough in storage.

The challenge, of course, is that even though the outlines of a new environment have begun to emerge, the power industry operates with time horizons in the decades. The implication is high-stakes strategic decision making under uncertainty, from utilities, regulators, and investors, and an innovation imperative that will vary considerably by market and company. Q

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For more, see "How to decarbonize global power systems," on McKinsey.com.

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Shifting the status quo in energy: An interview with Sunrun CEO Lynn Jurich

Solar power could play a vital role in decarbonizing power generation—even as it disrupts the status quo.

Shifts in consumer preferences toward sustainability initiatives and renewables could play a key role in decarbonizing the generation of power. With interest in solar power on the rise, the San Francisco–based company Sunrun pioneered a business model that enables more households to access solar panels and batteries. Since its beginning in 2007, the company has grown from two graduate students in an attic to more than 4,000 employees.

In this interview with McKinsey's Katy George, Sunrun CEO Lynn Jurich talks about the importance of creating win–win models with the utilities industry, innovating in the face of disruption, and empowering the front line.

The *Quarterly*: *The word "disruptor" is thrown around a lot, but it's certainly true of Sunrun. How did that happen?*

Lynn Jurich: It was clear to us from the start that solar was going to be the breakthrough renewable technology. We hypothesized that solar is disruptive because it can be distributed at a microlevel. When a new technology emerges, people always try to force it into the way they already do things—and, in the energy industry, that often looks like a hub-and-spoke model, where a centralized energy source is distributed elsewhere for consumption. But one of the disruptive things about solar is that it's more typically sited where the energy is actually consumed.

We wanted to go for the direct-to-consumer market, because we believed that's where you hit grid parity[1] first. It cost a lot more money than we thought it would and posed many challenges along the way. But fast-forward 13 years: we've installed nearly $5 billion worth of residential systems, have 285,000 customers, and have sold our solar service in 22 states, Washington, DC, and Puerto Rico.

The *Quarterly*: *How did you build the capabilities and culture to be successful?*

Lynn Jurich: The business model has evolved over time. We've had to make significant changes in how we attack the market. Our original plan was to own scalable pieces of the value chain. We believed there were advantages to building up a financing capability and making it affordable for people to install solar. So that's the business model we invented—delivering solar as a service. That model gives you scale from finance, reach, distribution to end consumers, and brand.

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[1] Grid parity is when the cost of generating electricity from renewable sources reaches or beats the cost of traditionally generated power.

In the beginning, we deliberately didn't handle any of the construction. That's a local business, so we partnered with local companies. It became clear, about six years in, that we needed to be involved in construction as well. That was a massive change for us. We needed to acquire a local solar installer and build out that capability. Furthermore, we were dealing with a completely different business, workforce, and set of challenges there. Not only that, but we had to convince them to take our equity before we were publicly traded.

We also had to make culture shifts—and our culture is still evolving. We primarily had a structured culture, full of people with deep backgrounds in finance and policy. Now, execution is where all the action takes place. The front line is getting more efficient, and the people who talk to our customers are the same people who handle installations. I spend a lot of time in the field myself to better understand the challenges and opportunities. We're also figuring out how to orient the business so that decision making is done locally. People are smart and want to do the right thing. Give them the right context, and the people closest to the action are going to make the best decisions.

The *Quarterly*: *You're competing with local, nimble installers, but you're also competing with utilities. How does this dynamic affect the customer?*

Lynn Jurich: There are many long-standing incumbents in this industry. Their business model is big energy flowing one way and building all the assets for peak demand. Today, it's suddenly getting expensive to maintain that system. There are massive amounts of capital expenditure going into upgrading our utility system—and climate change is making it worse.

Now we're able to sell solar electricity as a service to our customers at a lower price than the utility. Our structural advantage is increasing because our costs are decreasing. What I want to do is work with the utilities—it's not a zero-sum game to me. Instead of having both us and the utilities build infrastructure, we strive for win–win models where we say to the utility, "You have peak demands for power. Instead of powering an expensive fossil-fuel plant, let us tap into thousands of our customers' batteries, coordinate, and dispatch them." We create a response to peak demands, and the customer doesn't need to change their behavior.

I often see people misunderstand risk. The status quo *feels* safer but is actually riskier. If you're a utility commissioner, it's riskier to keep relying on those 30-year-old gas plants than to incentivize a bunch of homes to help meet that demand. Yet this is how so many people react to disruption: with fear and a desire to protect the way things are.

The *Quarterly*: *How would you describe the leadership team's culture? What is most important to you in terms of behavior?*

Lynn Jurich: It's critical that our leadership start from a place of abundance and win–win scenarios; even if those scenarios end up not being possible, it's important to get creative and think in that space. That's what it takes to move quickly and within the time frame necessary to address energy issues as urgent as climate change.

When operating from a place of abundance, we can call each other out when we're getting too attached to our own ideas, and we have a facilitating coach to help us. We make it safe to think freely and say, "What if the opposite of that could be true? Let's be curious about this for a second." You make much better decisions that way.

Also, it's crucial for us to take care of our employees, particularly the ones on the front lines with customers. If your employees are passionate about the purpose, and the company takes care of them, they're going to take care of your customers. Your customer experience is everything in this world. Q

Lynn Jurich is the CEO of Sunrun. This interview was conducted by **Katy George,** a senior partner in McKinsey's New Jersey office.

→ *For the full version of this interview, including Lynn Jurich's views on diversity in the workplace, see "Shifting the status quo in energy: An interview with Sunrun CEO Lynn Jurich" on McKinsey.com. This interview originally appeared in* Voices on Infrastructure: Workforce of the future*, December 2019, McKinsey.com.*

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Building a more sustainable battery industry

The ability to store growing amounts of renewable energy not only is critical to combating climate change but also will jump-start a range of economic activity.

by Bernd Heid, Sean Kane, and Patrick Schaufuss

The global battery industry is powering up: we estimate that uses—from electric vehicles to backup power to mobile phones and other consumer products—could increase demand for batteries 17-fold by 2030 (exhibit). That would mean big changes for the industry and could also bring huge benefits.

To understand the potential, we modeled a base-case scenario incorporating today's "industry momentum" rate of battery adoption[1] and comparing it with a high-growth "target scenario." In the latter, a "circular" value chain, new business models, and better cross-border coordination would enable faster adoption and better overall economics. How much better? By 2030, in our target scenario, batteries could contribute up to $185 billion a year in economic value[2] to the global economy. Battery-driven powertrains would replace a growing number of internal-combustion engines (ICE) in transportation and support the use of renewables to generate electricity. The resulting displacement of carbon-based fuels could contribute about 30 percent of the CO_2-emissions abatement needed to limit warming to 2 degrees Celsius above preindustrial levels. Additional progress would be needed to reach a 1.5-degree threshold.

Gearing up the industry

We expect that demand for lithium-ion (Li-ion) batteries will grow to more than 3,500 gigawatt hours (GWh) by 2030, from about 220 GWh in 2019. The structure of demand for Li-ion batteries is shifting rapidly, too. Batteries for consumer electronics could represent a much smaller part of total demand—about 2 percent in 2030, versus 18 percent today. Meanwhile, demand for Li-ion batteries for use in electric cars, trucks, and buses could rise to more than 85 percent of the total, from just 7 percent in 2020.[3] Power storage for the electricity grid would account for 13 percent of demand for new batteries.

In this high-growth target scenario, 120 new large-scale factories would be needed to produce battery cells. The required raw-material inputs would increase up to 40 times, depending on the mineral used. Production of the active materials in battery cells would rise nearly 15-fold. In parallel, a more robust circular value chain, including a network of facilities to refurbish and recycle batteries, would have to expand by orders of magnitude.

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[1] We also modeled a growth path in which the adoption of batteries was "unguided" by sustainability considerations.

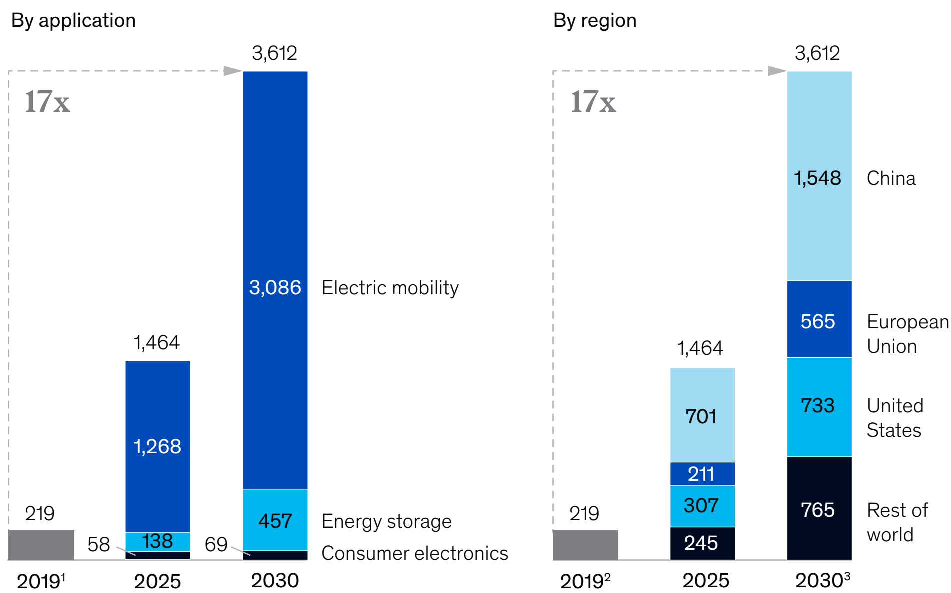
[2] See *A vision for a sustainable battery value chain in 2030: Unlocking the full potential to power sustainable development and climate change mitigation*, Global Battery Alliance, World Economic Forum, September 2019, weforum.org. We define value as global earnings before interest and taxes.

[3] That would represent nearly 25 percent of global sales of new passenger cars in 2030 and 35 percent of sales of commercial vehicles, including buses.

Exhibit

Global battery demand is expected to grow to approximately 3,600 gigawatt hours by 2030.

Global battery demand in gigawatt hours, target case



[1] In 2019, demand for consumer electronics equaled 40 gigawatt hours (GWh); for energy storage, 7 GWh; and for electric mobility, 171 GWh.

[2] In 2019, regional demand totaled 26 GWh for United States, 24 GWh for European Union, 155 GWh for China, and 14 GWh for rest of world.

[3] Figures do not sum to total, because of rounding.

Source: Global Battery Alliance; World Economic Forum; McKinsey analysis

Our research shows that progress toward circularity could improve the industry's economics, particularly for vehicles, since longer usage would increase both the value of batteries and their end-of-life value.[4] This could prove critical to the electric-vehicle (EV) manufacturers' business models, which depend on lower battery costs. A combination of circularity, expected advances in battery technology, economies of scale, and more efficient manufacturing could reduce battery costs by more than 20 percent in 2030 compared with the base case.

Taken together, the economic value of an expanded battery economy could range from $130 billion to $185 billion a year in 2030. More than half of that value would arise from new applications—for example, the growth in electric vehicles, vehicle-charging stations, power-distribution assets, and new technologies that cycle power from batteries in vehicles to the grid. The remaining value would be generated in mining and processing, the production of battery cells and packs, and an expanded recycling industry. Consumers in developing markets would also benefit: with the help of batteries, some 600 million people living in areas beyond the reach of today's power grids could gain access to electricity.

[4] We analyzed five levers in detail: electric shared mobility, smart-charging (V1G) and vehicle-to-grid (V2G) technologies, repair and refurbishment, the repurposing of EV batteries after use, and recycling.

Displacing greenhouse gases

In automobiles, the greater use of batteries could reduce CO_2 emissions by 1.3 gigatons (Gt) a year in 2030 in our target case,[5] or about 25 percent of what's needed from the sector to achieve decarbonization objectives consistent with a 1.5-degree warming pathway. By 2030, EVs are poised to deliver dramatic emissions advantages over today's ICE vehicles across the full value chain in many regions and segments. Larger passenger EVs in Europe, for example, would curb 60 percent of emissions, while smaller ones in China would perform 35 percent better than ICE vehicles. Those abatement gains would come about because batteries would be more economical to use, boosting ICE-replacement rates, and because battery manufacturing would be more sustainable.[6]

In the power sector, batteries could help abate some 7.1 Gt of CO_2 emissions annually by 2030, about 77 percent of what's needed from the sector to hit decarbonization targets for a 1.5-degree pathway. Batteries, acting indirectly, are an important tool for balancing the power grid: they allow more renewables to come on stream and replace so-called peaker plants, which run on natural gas and now cover intermittent electricity supply—for times when there is no sun or wind. We estimate that 2,200 GWh of renewable power will be added to the world supply by 2030—more than 1.5 times today's levels—and that 480 GWh of additional battery-storage capacity will be needed to accommodate the new renewables. A robust, decentralized battery-storage network would also increase the grid's resilience, since more power would be generated, stored, and distributed locally, and businesses and homeowners would play a greater role than they do now.

The way forward

Our target case assumes that the industry will operate more sustainably across its value chain, which starts with mining and refining operations for nickel, cobalt, lithium, and other minerals. Another assumption is greater reliance on renewable energy; without it, emissions from battery manufacturing could rise to eight times today's levels by 2030.

Getting to a more sustainable operating environment will demand concerted action. In mobility, for example, it would require an orchestrated rollout of charging and grid technologies, in tandem with higher EV sales; better systems for collecting batteries for refurbishment, backed by better data tracking; harmonized recycling regulations across regions; and guidelines for the responsibilities of producers. Gearing up would also take capital: we estimate that $400 billion in new investment would be needed to generate the full economic and environmental benefits. That's a sizable bet, but it would ensure that the battery economy reaches its full potential. Q

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[5] CO_2-abatement estimates reflect today's global sales of 100 million vehicles.

[6] This analysis assumes increased use of renewable energies across the battery value chain, as well as the intensified use of batteries and raw-material components through purpose-built shared vehicles and recycling. These developments would effectively spread the initial carbon footprint of batteries over a longer lifetime and greater mobility usage.