DISPATCHABLE RENEWABLE ENERGY FOR A LOWER-CARBON UTILITY FUTURE

MOVE THE WORLD FORW>RD MITSUBISHI HEAVY INDUSTRIES GROUP

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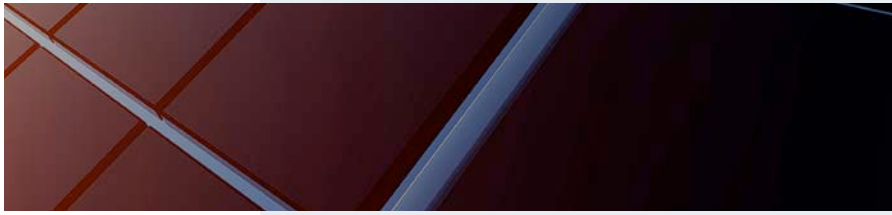
So far, the main roadblock to a fully decarbonized power system has been this: electricity supply must equal demand at all times. Significant wind and solar capacity has been built, but its output is intermittent. This has yielded considerable overbuilding to meet peak demand.

It's common for renewables to be curtailed when their output exceeds system demand; This can lead to substantial waste of renewable energy potential. For instance, the American Public Power Association noted in 2019, California "set two related but seemingly contradictory energy records. On June 1, the California Independent System Operator (CAISO) set an all-time peak for instantaneous solar generation, 11,363 MW. The previous peak, set on May 4, was 11,358 MW. In May, the CAISO also curtailed a record amount of solar and wind power, shutting off 223,195 MWh. In the first five months of the year, CAISO curtailed 630,864 MWh of wind and solar generation compared with 287,057 MWh in the same period in 2018."

Furthermore, many utilities buy renewables under long-term power purchase agreements (PPAs) to meet sustainability goals. However, those agreements may require the utility to purchase renewable output even when that requires uneconomical ramp-down of the utility's fossil fuel-powered generation assets.



When a grid is flooded with renewable power, that can cause the wholesale price of power to go negative. Recently, negative power prices meant that Germany effectively paid neighboring countries to take excess wholesale solar power off its hands. The inflexibility of some types of fossil fuel-powered generation exacerbates this problem. A recent analysis by the Dutch bank ABN AMRO noted, “The inflexibility or financial infeasibility to shut down or ramp up/down baseload power plants during hours of high renewable energy generation only aggravates the imbalance between demand and supply. It might seem counterintuitive, but in some cases paying the buyer for purchasing electricity is cheaper than turning off power plants.”

Now that coal-fired power generation is declining in some parts of the world, a power grid that is carbon-free, flexible, reliable, affordable and resilient has become the “moonshot” of the 21st century. There is increasing awareness that affordable energy storage will be the key to achieving this goal.

Lithium-ion batteries are beginning to reach an appropriate price point for short-duration storage (usually four hours or less). However, battery technology currently is prohibitively expensive for longer energy storage needs. Fortunately, new combustion technology is encouraging the development of infrastructure to produce vast quantities of hydrogen from renewable power (via electrolysis), and to store it safely. Then, stored “green” hydrogen becomes fuel to generate electricity for days, weeks or months at a time — using turbines that can burn hydrogen as well as natural gas.

Natural gas-fired turbines continue to be the technology of choice around the world for producing reliable, affordable and flexible power. Looking to future-proof their business and systems, some power producers are beginning to explore burning hydrogen, in addition to natural gas, in their turbines.

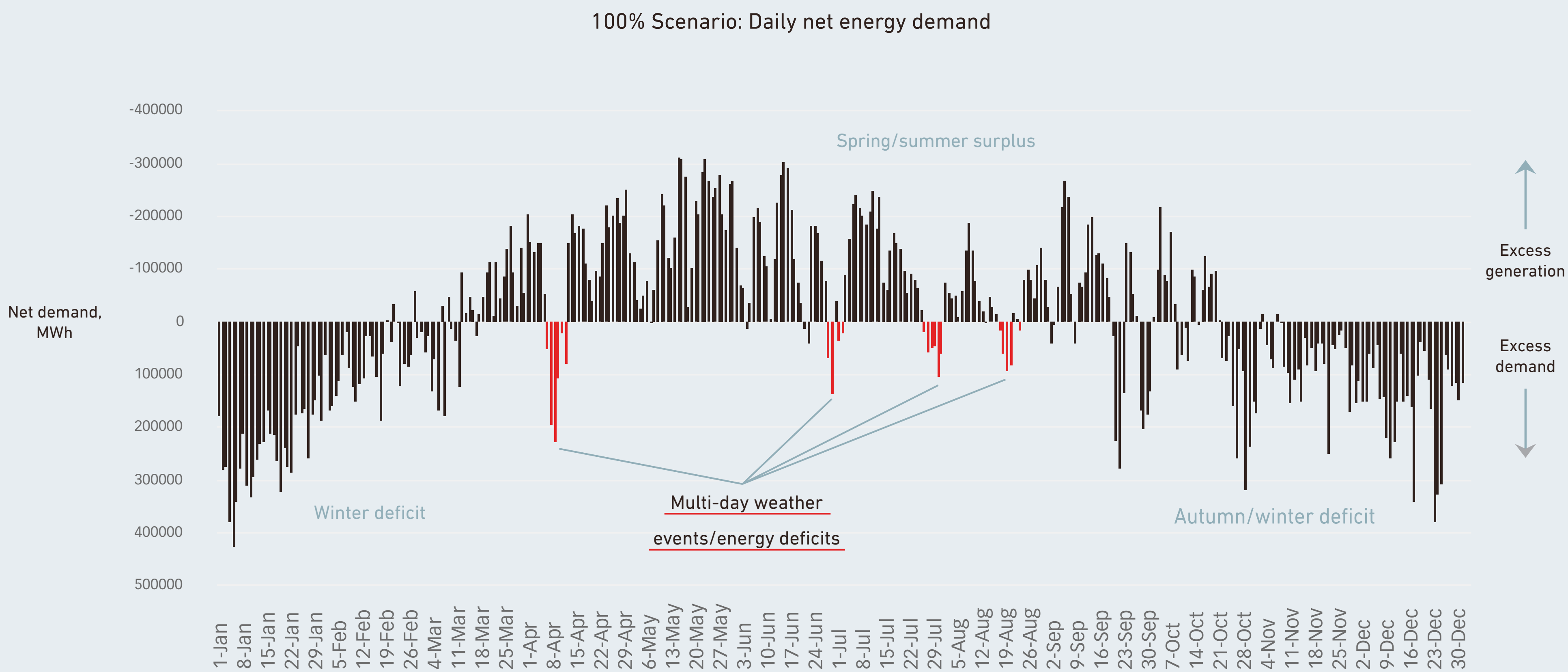
Manufacturers of large gas turbines, such as Mitsubishi Power, have developed the capability to add hydrogen to the turbine fuel mix. Eventually, this technology will be able to run on 100% hydrogen, producing zero carbon emissions. When that hydrogen is produced with otherwise "excess" renewable energy, that creates substantial potential to both decarbonize and optimize the overall power system. No longer will it be common for power producers to install extra generators that operate only a few hundred hours per year to serve peak system demand.

By providing a major new market for stored hydrogen, as well as the means to produce green hydrogen from renewable energy, the power generation industry can serve as the springboard to a new energy economy. Ultimately, the hydrogen economy could transform many critical sectors: transportation, manufacturing, agriculture, construction and more. On the path toward this goal, utilities may discover significant new business opportunities, while also leading the delivery of vital global economic and environmental benefits.

Furthermore, a green hydrogen energy economy would support better power system reliability and planning, over longer timespans. This provides an appealing utility value proposition. First, as the price for renewable power continues to drop, leveraging hydrogen can enable utilities to better control long-term fuel costs. Also, with little pressure to overbuild generation, utilities might invest their capital more efficiently, with better returns and less risk.

In a low-carbon future power system, renewable energy will no longer be intermittent. When stored in the form of hydrogen, renewable energy will be available anytime — even during extended periods when cloud cover is constant or winds are low, even for weeks or months at a time. Such "seasonal" renewable energy storage would complement shorter-term, intra-day energy storage solutions — especially battery energy storage, which provides dispatchable power in shorter bursts for other important uses (usually 2-10 hours).

PROJECTED NEED FOR MULTI-DAY ENERGY STORAGE



A renewable-reliant power system is likely to have several multi-day shortfalls per year, requiring substantial dispatchable stored energy.

Credit: CAISO Data and Strategen analysis

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CONSUMING TODAY'S AND TOMORROW'S FUELS:

Opportunities and Challenges

Many power producers are now in various stages of retiring uneconomical, emissions-heavy coal plants and replacing them with a combination of renewables and natural gas-fired plants. In the midst of this process, some are beginning to look ahead to a future beyond natural gas. This is where the business case for investing in modern gas turbines becomes clear. In addition to being cleaner and more affordable than prior generations of gas turbines, modern gas turbines (sometimes called Advanced Class Gas Turbines, or ACGTs) already can use at least some hydrogen fuel.

Today, modern gas turbines from Mitsubishi Power can use 30% hydrogen. In 2025, Mitsubishi Power plans to validate a turbine using 100% hydrogen. This upgrade could be achieved with modest modifications to the combustion and fuel handling system, during one or more regular planned maintenance outages.

"Power producers can keep using the gas turbine that they buy today. Changing the combustion system during planned maintenance will not have a significant cost impact," said Michael McManus, senior director of energy solutions at NEXT, a clean energy business unit within Mitsubishi Power Americas. "This allows companies to transition to stored green hydrogen, as that infrastructure develops and as the hydrogen economy matures. This avoids guesswork about when hydrogen might become viable in their region, or at a particular facility."

Alongside hydrogen-capable generators, battery systems and conventional spinning reserves can function as “shock absorbers” for the grid. Batteries and spinning reserves can compensate for minor system fluctuations while allowing gas-fired turbines to ramp up and down for larger and longer swings as needed.

To further reduce emissions, modern Mitsubishi Power gas turbines also have the capability to run in MHPS-TOMONI® Very Low Load (VLL) mode: the turbine essentially idles at around 20%, producing very low emissions (especially with more hydrogen in the mix) and some useful power. VLL mode maintains emissions compliance while also providing very fast ramp-up capability — an alternative to batteries and increasing spinning reserves. Until recently the lowest minimum emissions-compliant load (MECL) was around 55% of combined cycle load, at substantially higher carbon emissions.

From a business perspective, hydrogen production and storage can help power producers proactively address both curtailments and negative power prices, smoothing the overall market for renewable energy and reducing overall economic and power-system risk.

> “Changing the combustion system during planned maintenance allows companies to transition to stored green hydrogen, as that infrastructure develops and as the hydrogen economy matures.”
>
> MICHAEL MCMANUS, senior director of NEXT at Mitsubishi Power Americas

"Curtailments and negative power prices are market signals that we need energy storage," said Janice Lin, founder and CEO of Strategen, and founder of the Green Hydrogen Council. "Today, in many countries around the world, wind and solar are the lowest-cost marginal energy resources. The opportunity before us is to find ways to realize their full potential — not only to provide renewable energy, but also to make renewable energy reliable regardless of weather. Ultimately, at very high penetration levels, we will need multi-day and seasonal energy storage — an ideal application for green hydrogen. Storing renewable energy in the form of hydrogen thus can be a game changer that enables highly reliable, low-carbon grids."

The economics of large-scale electrolysis is a key consideration for adding major hydrogen generation capacity to the power system. Like turbines, electrolyzers are most efficient and economical when they consistently run near full capacity. A 2019 paper by the International Renewable Energy Agency (IRENA) noted: "Hydrogen production could help reduce curtailment in grids with a high share of variable renewable electricity. However, it likely is not possible to produce significant amounts of hydrogen using exclusively cheap or free 'otherwise curtailed' electricity if electrolyzers operate only around 10% of the time or less. ... For the hydrogen production cost to be lowered, electrolyzers should have a higher utilization rate, which is not compatible with the occasional availability of curtailed electricity. A balance must be struck between buying electricity at times of low prices and increasing the utilization of electrolyzers."

Consequently, launching the hydrogen economy is a bit of a chicken-and-egg puzzle: renewables penetration must be high enough to make electrolysis efficient enough to make hydrogen cheap enough. However, renewables development is not yet driven by a market for hydrogen. Rather, the emerging market for hydrogen energy storage is being driven by the intermittence of renewables.

"For green hydrogen to make sense, a power grid must attain high renewable penetration: greater than 40%. With that much renewable energy production, there will be longer and longer periods of surplus and deficit," McManus explained. "When renewable penetration surpasses 40%, that will considerably increase electrolyzer efficiency. At the same time, capital costs of electrolysis are continuing to fall rapidly, led by suppliers in Asia. We're investing now in hydrogen infrastructure because we believe that some of the world's power grids will soon be ready for increasingly affordable green hydrogen."

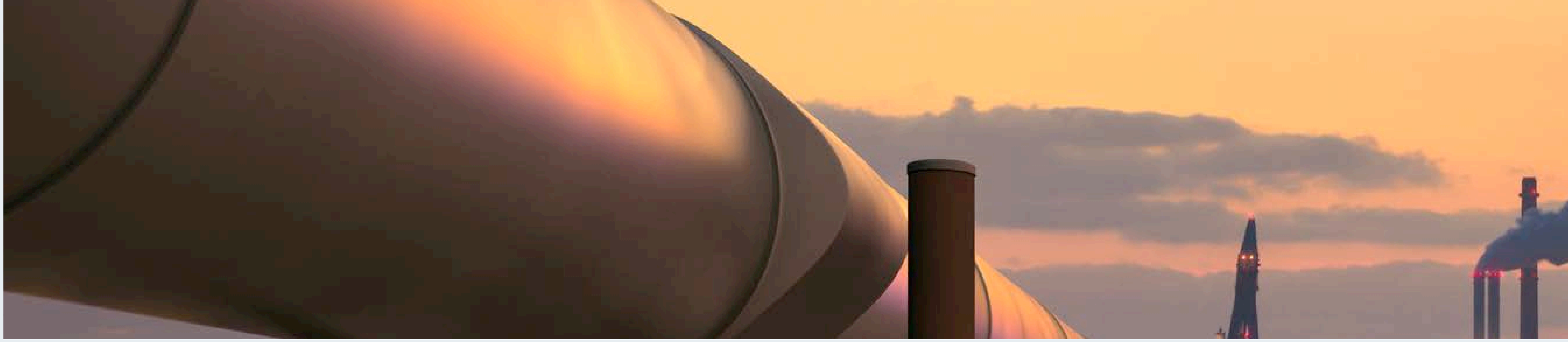
In the big picture, current technical challenges to leveraging the potential of hydrogen in the power system can be addressed.

"There are no insurmountable technical issues to green hydrogen," said Lin. "Hydrogen is a widely used commodity around the world today. There are many ways to make hydrogen. Some methods, such as electrolysis, have been in industrial use for decades. Dedicated hydrogen pipelines are in use today, and some natural gas utilities already have hydrogen in their pipeline mix."

According to Lin, the two main hindrances to utility-scale green hydrogen currently are:

- **Scale.** Applications must be identified that warrant building large enough projects to get hydrogen production costs down.
- **Market Design.** Ensuring that the benefits that green hydrogen provides are appropriately recognized and compensated.

This year, Mitsubishi Power and Magnum Development announced the Advanced Clean Energy Storage project. The project utilizes solar and wind energy to produce hydrogen via electrolysis. That hydrogen will be stored in a network of vast underground salt dome caverns beneath the desert near Delta, Utah. Each cavern will store enough hydrogen to produce 100 GWh of electricity. The project could grow to encompass 70 such caverns — more than enough storage to serve the electric grid of the entire western U.S. The Advanced Clean Energy Storage project's stored hydrogen will help fuel nearby gas turbines and solid oxide fuel cells, to dispatch generation as needed.



> "This isn't a proof of concept. The Advanced Clean Energy Storage project is a utility-scale project."
>
> MICHAEL MCMANUS

On a national scale, developing a distribution infrastructure for hydrogen would support the green hydrogen economy in regions that lack opportunities for such massive storage. Some gas utilities are injecting hydrogen into their distribution networks, much like ethanol is added to gasoline. For instance, Hawaii Gas adds 12% hydrogen to the natural gas it sells to consumers on Oahu.

"Injecting even 5% hydrogen in the gas pipeline would make a big dent in terms of taking carbon out of the gas system," said Todd Brezler, vice president of marketing, Mitsubishi Power Americas.

The Advanced Clean Energy Storage project can help shape the business side of the hydrogen economy, as well as fine-tune the technology. The business model for the Advanced Clean Energy Storage project is not yet settled, since the project is still in the design phase — but utilities are already expressing interest. According to McManus, one possible business arrangement might be to allow utilities and ISOs to contribute renewable energy to the Advanced Clean Energy Storage project, with a tolling agreement to produce and store that energy as hydrogen and deliver it back to them as needed. Alternatively, the operators of the project could offer long-term PPAs, allowing utilities to back up their renewables with hydrogen capacity.

"Essentially, this sort of infrastructure provides a 'savings account' for the power system," said McManus. "Power producers can deposit their energy, store it and withdraw as needed. That is easier than what we've been doing, which is more like trying to live paycheck-to-paycheck."

CONCLUSION

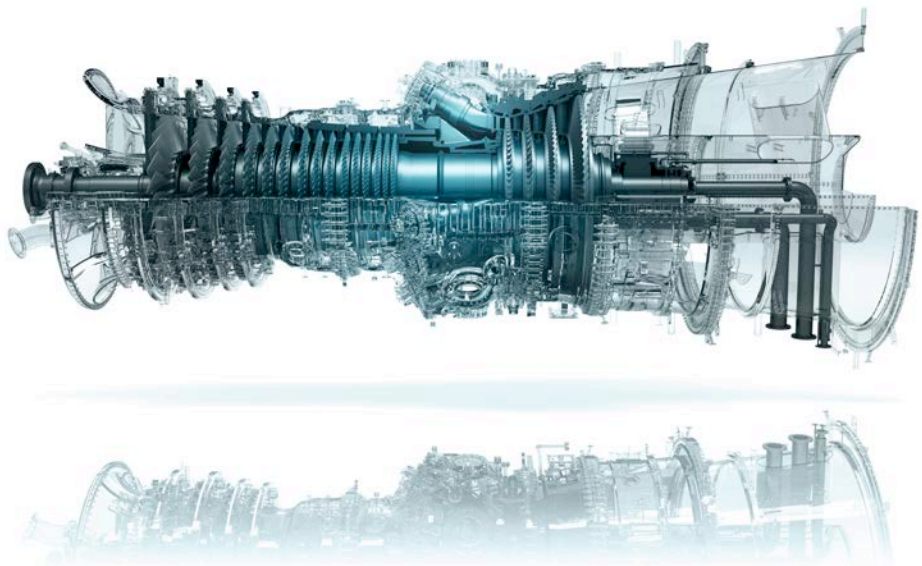
Leveraging emerging energy technologies can seem daunting, but the potential payoffs are substantial. Adding green hydrogen capacity to power systems that are ready for it can vastly reduce carbon intensity and increase the efficiency, responsiveness and performance of power plants, and of the overall power system. Green hydrogen is a necessary key contributor to realizing a cleaner, more affordable and more reliable power system.

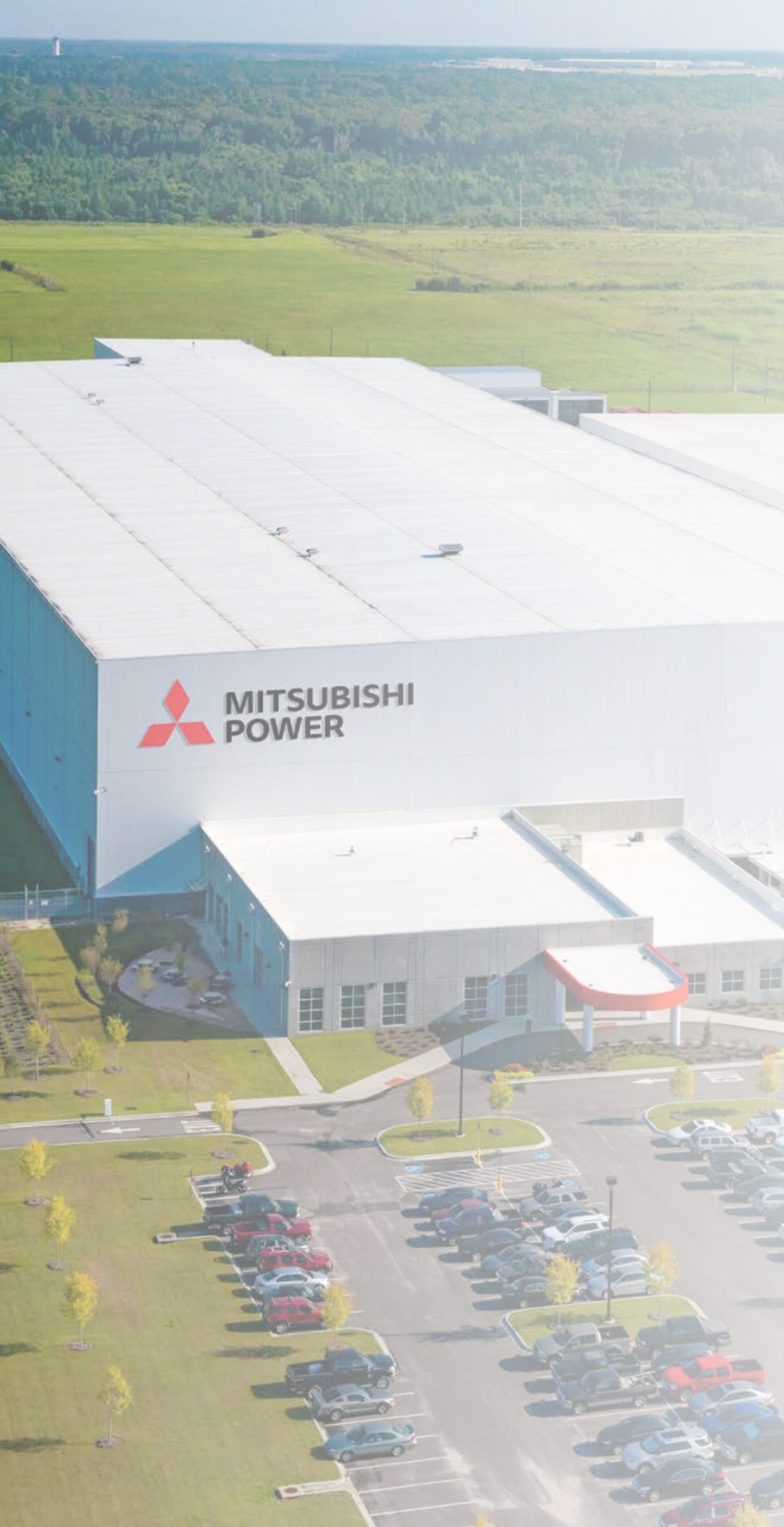
In the near term, governments might consider including green hydrogen energy storage as an option allowable under state renewable portfolio standards (RPSs) and similar sustainability mandates. Also, utilities might consider these questions regarding their own plans for decarbonization:

- What's our plan to retire baseload plants, while also adding more renewables and balancing the grid?
- As we add more and more renewable resources, how will our need for energy storage of various durations (days/weeks/months/seasons) increase?
- How might dual-fuel (natural gas + hydrogen) gas turbine technology help us adapt to changing market conditions and future-proof today's investments?

Mitsubishi Power can help utilities solve their toughest decarbonization problems and plan for the future. They have experience with more than 29 power plants using fuel with up to 90% hydrogen content, and have accumulated more than 3 million hours of operation. In fact, Mitsubishi Power is already working on their first hydrogen refueling project, by converting a 440 MW F-class gas turbine in the Netherlands to 100% hydrogen fuel.

"The transition from natural gas to green hydrogen will be gradual," said Brezler. "But eventually, this Change in Power will transform the economy, the power system and the world."





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