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Gas Turbine World

Hydrogen pathway for integrating gas turbines with renewables

Mitsubishi Power M501JAC at their Savannah Machinery Works facility

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Standardized pathway for integrating gas turbines with renewables

By Harry Jaeger and Junior Isles

With increasing pressure on fossil fuels, Mitsubishi Power has launched a standardized package that allows easier integration of hydrogen gas turbines, electrolyzers and storage.

Intermittent renewable capacity in the US, specifically wind and solar, is expected to almost quadruple by 2050, according to the U.S. Energy Information Administration's Annual Energy Outlook 2020.

While gas-fired, fast-ramping, combined cycle plants and simple cycle peaking units are one way of complementing intermittent renewables, their use will ultimately come under pressure in the same way as coal, as use of fossil fuels is reduced in the power generation mix.

As the world moves to net zero carbon emissions, power plant owners and energy providers are exploring how they can integrate intermittent renewable generating sources in an optimum way, while maintaining security of supply.

Hydrogen gaining traction

While batteries are an option already being employed on a growing scale, using hydrogen as an energy vector for ensuring the optimum use of intermittent renewables has been gaining significant traction. The concept taking front stage is the use of excess wind and solar to produce 'green hydrogen' by electrolysis of water.

This can then be stored for later use in the production of fertilizers or e-fuels, for example, or used directly in gas turbines for carbon-free dispatchable power. Essentially allows green hydrogen to act as a form of storage for wind and solar while decarbonizing sectors including industry, transport, electricity and buildings.

Standardizing hydrogen readiness

Several gas turbine manufacturers have therefore been making steady progress on modifying gas turbines in the power sector to use hydrogen. In September, however, Mitsubishi Power embraced the move to hydrogen with the launch of what it claims to be the world's first "standard packages" for green hydrogen integration.

According to Mitsubishi Power, its standard packages cut through the complexity that power generators and grid operators would otherwise encounter when integrating renewable power, gas turbines, green hydrogen and other energy storage technologies.

Explaining the thinking behind standard packages, Mike Ducker, Vice President of Renewable Fuels at Mitsubishi Power, said: "All the technology we are looking at right now for green hydrogen – the production of green hydrogen, the storage of green hydrogen, the use of it in gas turbines – are all mature commercial technologies. What's taking place now though is the need to scale it up for applications that historically haven't been there." The challenge is to scale those technologies and get them more rapidly into the marketplace, says Ducker.

"We've been working with customers to develop a standardized solution that will work across all of their gas-fired assets.. This will help drive costs down, which will accelerate scaling within the industry, and, in turn, lead to more rapid cost reductions and market acceptance."

How it all fits

Greater penetration of renewables makes balancing of resources on the grid more complex. Mitsubishi Power believes that while storage is a key tool in balancing intermittent renewables, combining energy storage with a gas turbine brings even more benefits in reducing these complexities.

Ducker explained: "When you run an electrolyzer to produce hydrogen, that's actually a load on the grid. So when we are over-producing solar, for example, we can run the electrolyzer to utilize that excess solar [or wind] rather than curtailing it.

"Then when the solar (or wind) production starts to fall off and additional generation is needed on the grid, we can first shut down the electrolyzers to shed load. Meanwhile, the gas turbine is quickly ramped up, burning stored hydrogen, to provide the generation needed to assure grid stability and reliability."

Integrated packaging

In terms of packaging the electrolyzer and the gas turbine, Mitsubishi Power is looking to standardize both the physical and the digital integration.

In terms of the physical integration, the company is looking into ways to use waste heat available from the gas turbine. For example, using low-grade heat for the electrolyzers to help improve start-up and operating efficiencies.

"Looking at the overall plant as well, we can get improvements in capital costs. When you look at an electrolyzer system, many of the components needed for a power plant are also there, such as a cooling water system, demineralised water system, and a lot of the electrical equipment," said Ducker.

"So we see many synergies that we can take advantage of, which will help reduce some system complexity and actually achieve some operating efficiencies and reduction of capital costs."

In a typical standardized package, Mitsubishi Power will supply the gas turbine and will act as an integrator for the other parts of the system, which come from other manufacturers.

Ducker said: "Much like the lithium-ion battery storage world, we are effectively integrators. We look at the core electrolyzer technologies; we're neutral to the various technologies available and we are working with the many different manufacturers of those pieces.

"But the key is putting all of that together. You need rectifiers, transformers, buildings, and all the other auxiliaries like the demineralised water systems, cooling systems, etc. That's what we'll be doing."

Hydaptive flexibility package

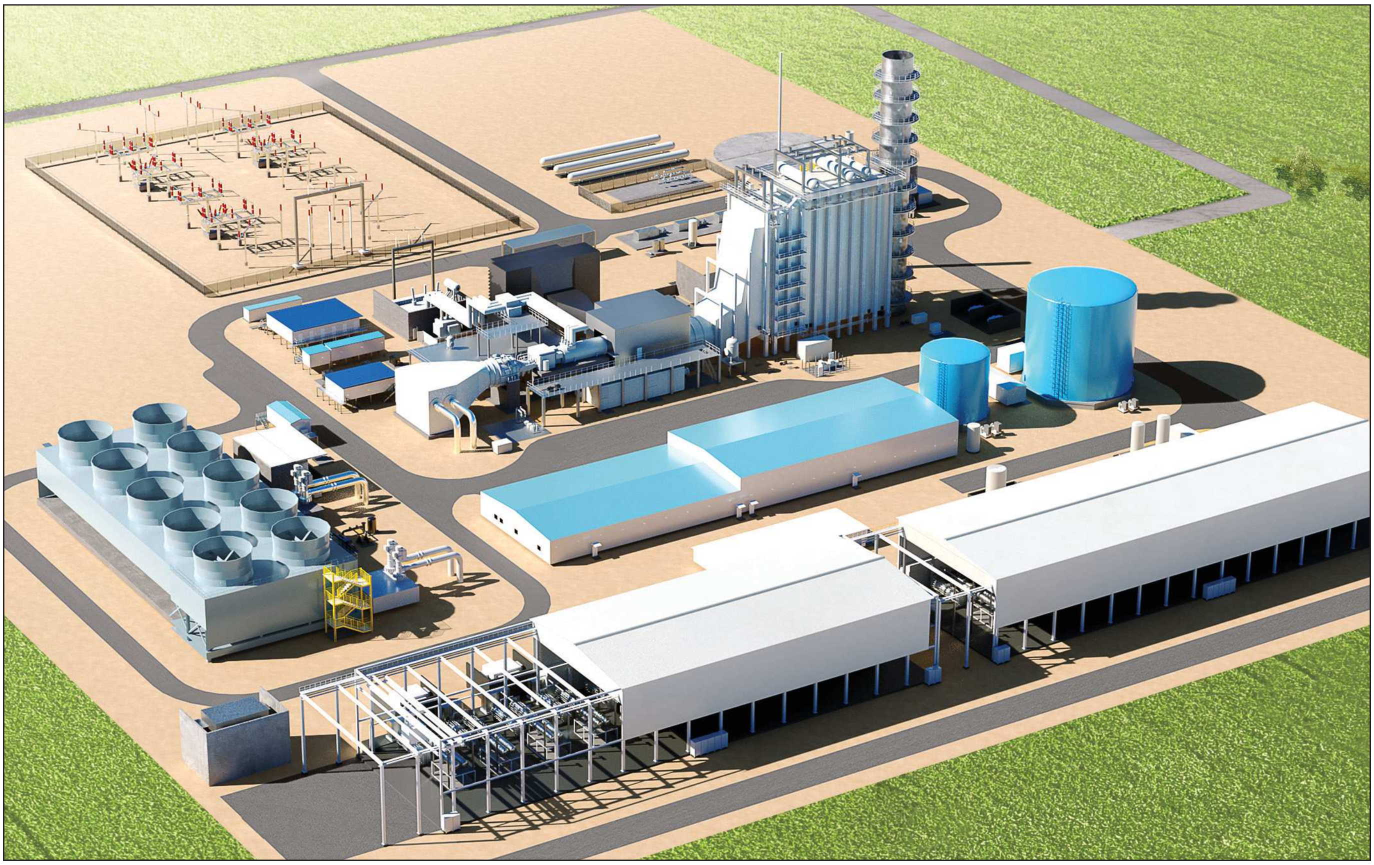
Mitsubishi Power is offering a green hydrogen solution known as the *"Hydaptive Standard Flexibility Package*". The Hydaptive package provides renewable energy flexibility by acting as a near-instantaneous power balancing resource that greatly enhances the ability of a simple cycle or combined cycle power plant to ramp output up and down to provide grid balancing services.

It integrates a mixed hydrogen-and-natural gas fueled gas turbine power plant with electrolysis to produce green hydrogen using 100% renewable power and onsite hydrogen storage. And, with Mitsubishi Power's TOMONI software and controls, enable rapid load response by integrating operations of the gas turbines and the electrolysis plants.

The Hydaptive storage package adds expanded/extended storage capability and is available for new gas turbine power plants or as a retrofit to existing plants to improve flexibility and extend asset life.

Ducker commented: "We are looking at the Hydaptive packages as the family of technologies for integrating hydrogen with our gas turbines. For the storage part of it, we're looking at both onsite storage and offsite storage. Here we can draw on our experience with the Advanced Clean Energy Storage project, where we've gained a lot of experience with hydrogen storage techniques."

The Advanced Clean Energy Storage project announced in 2019 is a 150,000 MWh renewable energy storage facility in central Utah being developed by Mitsubishi Power and Magnum Development. The green hydrogen produced will be stored in underground salt caverns. The site has room for over 100 salt cav-



Hydaptive integrated plant. Conceptual plant layout designed around a single-shaft hydrogen-enabled gas turbine combined cycle unit. Site incorporates two electrolyzer buildings (foreground), air-cooled condenser (left), hydrogen storage field (background) and switchyard.

INTERMOUNTAIN COMBINED CYCLE STATION

Site: Delta, Utah
Developer/Owner: Intermountain Power
Nominal Rating: 840MW
Major Supplier: Mitsubishi Power
EPC Contractor: Black & Veatch
Commercial Operation: 2025

The existing Intermountain Power Plant (IPP) is a relatively modern 1,800MW coal-fired power station in central Utah operating since 1986. Intermountain Power Agency (IPA) is the plant owner, while the Los Angeles Department of Water and Power (LADWP) operates the plant and purchases most of its output.

In early 2020, IPA announced that the coal plant will be retired and replaced with an 840MW (site-rated) gas-fired combined cycle facility. It was further announced that, although the new plant will start operation on natural gas, it will transition to a mix of 30% hydrogen (by volume) and 70% natural gas by 2025, the scheduled project completion date.

The plan also commits the plant owner to increasing the fuel mix to 100% green hydrogen fuel by 2045, with renewable energy to power electrolysis facilities for hydrogen production and storage at the site.

The combined cycle plant will be built around two single-shaft units equipped with an advanced technology power block supplied by Mitsubishi Power. Each power block will include one M501JAC gas turbine, a heat recovery steam generator and a steam turbine.

Each 1x1 M501JAC combined cycle is design rated at 630MW net plant output at over 64% efficiency on natural gas fuel for 59°F and sea level ISO conditions. For operation at a site elevation of 4634 feet above sea level, and summer temperatures of close to 100°F, each block is nominally site rated at 420MW.

Although the gas turbines will burn natural gas fuel when first installed, the M501JAC gas turbines are hydrogen-capable to operate on up to 30% hydrogen fuel mixture and transition to 100% hydrogen as increasing supplies of hydrogen become available.

City of Los Angeles says it will continue to purchase most of the new combined cycle station output and will rely on the Intermountain project to help meet California's target to decarbonize all retail power sales in the state by 2045.

"Our mission is to provide affordable, reliable power with a future vision of becoming a net-zero carbon energy resource," said Dan Eldredge, IPA General Manager. "The unique Intermountain Power Project site and existing regional energy infrastructure provide an ideal opportunity for accomplishing this mission."

Mitsubishi Power is also collaborating with Magnum Development on the 1,000MW Advanced Clean Energy Storage project to create a renewable hydrogen generation and storage facility next to the combined cycle station site.

Magnum owns and controls the only known "Gulf Coast" style domal-quality salt cavern formations (for hydrogen storage) in the western United States.

The project partners aim to use excess renewable energy from across the Western U.S. to generate green hydrogen via electrolysis and store it in an existing underground salt dome near the power plant.

The Advanced Clean Energy Storage Project is planning to ultimately deploy four types of clean energy storage technologies including renewable hydrogen, compressed air energy storage, large-scale flow batteries and solid oxide fuel cells.

erns which will provide weeks or even months of storage.

Extensive hydrogen capability

The integrated hydrogen packages will extend across Mitsubishi Power's entire turbine fleet – from its 40MW class H25 to its largest and most efficient 400MW-plus JAC series.

Ducker says the gas turbine product line can already use fuel mixtures of up to 30% hydrogen and aiming for 100% hydrogen capability by 2025.

"We're in the final stages of validation of that capability today," he said. "In the timeframes when we will need 100% hydrogen, from an energy storage point of view, our gas turbines will be able to support that functionality."

Mitsubishi Power reports experience of using 100% hydrogen in its gas turbines since the 1970s, with over 3.5 million operating hours on hydrogen from syngas, blast furnace gases and other industrial off-gases with high hydrogen content.

Most of those turbines used diffusion-flame combustion systems, using nitrogen or steam as a diluent to control NOx emissions, but today's gas turbines use dry low NOx (DLN) systems. In these DLN burners the fuel and air are pre-mixed before combustion to control NOx without water or steam injection. Now manufacturers are exploring use of 100% hydrogen in these DLN burners.

No major changes

"We already understand what it takes to use high hydrogen content in gas turbines; it's now really about applying it to today's combustion technologies," said Ducker.

Some properties of hydrogen, specifically its higher flame speed, lower ignition energy, and broader flammability limits compared with conventional gas turbine fuels (e.g., natural gas) increase the risk of flashback and auto-ignition.

According to Ducker, converting current gas turbines to run on hydrogen involves no "major" changes. The main focus is on the combustion system itself. The valves and piping and systems also must be adapted to handle the lighter, lower density of hydrogen versus natural gas.

"Some of those pipes need to be bigger in diameter," noted Ducker, adding, "we also need some redundancies, different flow meters, fire protection, the enclosure of the gas turbine itself, etc. But we need not complete a whole rebuild of the existing plant or touch other parts of the gas turbines like the blades and vanes; the main focus is on the combustion system."

Flashback-resistant combustion

Mitsubishi Power has been working with a new state-of-the-art DLN combustor that consists of multiple fuel nozzles and multiple air holes. The essence of this burner concept is the integration of two key technologies: rapid mixing of fuel and air for low NOx combustion and flame lifting for flashback-resistant combustion.

This multi-cluster burner provides both the advantage of the premixed combustor of low NOx combustion and the advantage of the diffusion-flame combustor of flashback-resistant combustion.

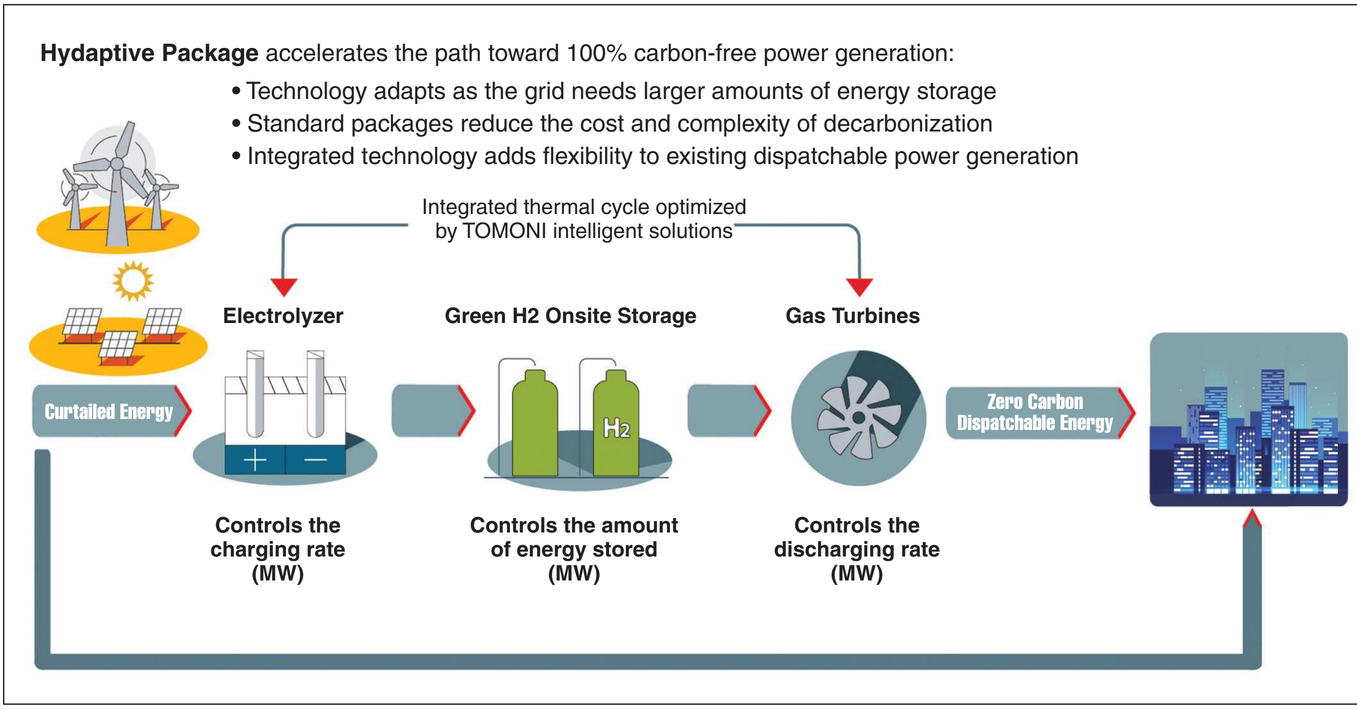
Mitsubishi Power has been testing its multi-cluster combustor on a multi-can combustor configuration at an oxygen-blown IGCC pilot plant in Japan. Ducker said: "The validation for operating on 100% hydrogen is targeted to be complete by 2025 which will correspond to a 100% reduction in CO_2 emissions."

Market needs

Commercial standardized packages will be based around market needs. As Ducker put it: "What's needed in the western part of the United States today is different to what is needed in the eastern states.

"But what all our customers recognize is that their power plants will be expected to achieve zero, or near zero, carbon emissions. So how do we provide

M501JAC gas turbine. Simple cycle gas turbine plant is ISO rated at 425MW base load output and 44% efficiency on natural gas fuel; single-shaft 1x1 combined cycle is rated at 630MW net plant output at over 64% efficiency.



the ability for these plants to continue to provide affordable and reliable energy throughout their life?"

He says the starting point is analyzing the demand or use case for hydrogen today, which is a function of market conditions: how much renewables are on the grid, and how much storage is needed.

Ducker believes one of the most fundamental aspects to understand is that green hydrogen is a form of energy storage, not a fuel. "We tell customers don't think about \$/lb or \$/MMBtu but think of \$/kWh costs: compare it to batteries. From there we've been working with our customers on setting a roadmap," he said.

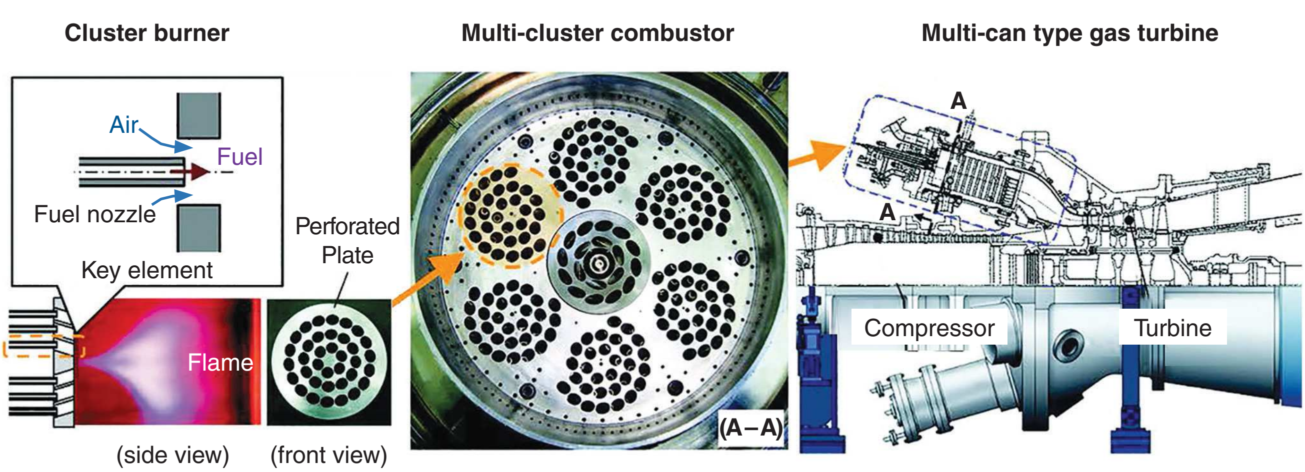
Hydrogen as a battery/fuel hybrid

"One of the best aspects of a gas turbine," continued Ducker, "is that we can start with a small blend of hydrogen, and as more renewables are added to the grid, we can increase the amount of hydrogen production and storage until, ultimately, the power plant is operating on 100% hydrogen.

"From an energy storage aspect, say for a 500MW power plant that operates on 10% hydrogen in the early years, that looks like a 50MW battery and 450MW generator. In 10 years, if we need 250 MW of storage on the grid and less generation, we can run the gas turbine plant on a 50% blend of hydrogen and natural gas to have a 250 MW of battery and a 250 MW generator.

"And in 2040, when there is a lot of renewable energy on the grid, it might need to run solely as a storage system.

State-of-the-art configuration of dry low NOx combustors for hydrogen-rich fuels. Several multi-cluster combustors, each consisting of multiple cluster burners in a can-type cylindrical liner and casing, are radially mounted at an angle to the compressor section casing.



ORANGE COUNTY POWER STATION

Site: Orange County, Texas
Developer/Owner: Entergy
Nominal Rating: 1200MW

Major Supplier: Mitsubishi Power
EPC Contractor: To Be Determined
Commercial Operation: 2026

In September 2020, an integrated energy company Entergy Corp. with a 30GW power generating portfolio, announced plans to collaborate with Mitsubishi Power under a "Joint Development Agreement" to take steps towards decarbonization of its utility businesses in Texas, Louisiana, Arkansas and Mississippi.

Together Entergy and Mitsubishi Power said that their efforts will focus on:

- developing hydrogen-capable gas turbine combined cycle facilities
- developing green hydrogen production, storage and transportation facilities
- creating nuclear-supplied electrolysis facilities with energy storage
- developing utility-scale battery storage systems enabling economic growth through partnerships with the Entergy utility customers.

Entergy has been voluntarily working to lower its carbon footprint for some 20 years. In early 2019 they announced goals to lower system-wide carbon emission rates to half of their 2000 year-end levels by 2030 and to reach net zero carbon emissions by 2050. Teaming with Mitsubishi Power is a major step toward reaching these goals.

A significant piece of Entergy's plan for implementing its decarbonization program, and most likely the first dedicated hydrogen-ready project, is the proposed 1200MW Orange County Power Station, an advanced combined cycle project being developed in partnership with Mitsubishi Power.

Mitsubishi Power has indicated that the two M501JAC gas turbines to be supplied for the project would be "hydrogen capable" and that preliminary project designs include provisions to operate on a fuel mixture of 70% natural gas and 30% hydrogen by volume upon commercial operation.

The plan is to adopt the Hydaptive standardized packaged hydrogen-fuel combined cycle plant concept for integrating electrolyzers for green hydrogen with the gas turbines – also featured in other ongoing projects, such as the 840MW Intermountain Power Project in Utah.

Significantly, Mitsubishi Power is also involved in the pioneering Advanced Clean Energy Storage project, near the Utah site, storing up to 1 GW of renewable energy as hydrogen gas, and other storage technologies.

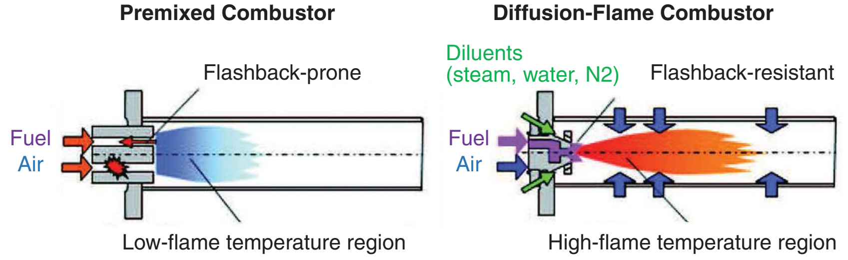
As of late 2020, a decision to proceed with the Orange County project was still pending. Once Entergy's self-build proposal is accepted by the Texas system operator and regulatory approvals are obtained, the final design would include provisions for transition to 100% hydrogen fuel once hydrogen supplies and infrastructure are established.

In announcing Entergy's plan to team with Mitsubishi Power, Paul Hinnenkamp, the company's Executive Vice President and Chief Operating Officer, said, "For two decades, sustainability has been a priority for Entergy. We have pledged to conduct our business so it is environmentally, socially and economically sustainable.

"New technologies and innovative solutions to the challenges posed by climate change present opportunities for us to significantly decrease carbon emissions from our generation portfolio while maintaining low rates.

"We are pleased to welcome Mitsubishi Power as a collaborative partner in developing strategies to integrate these new technologies and solutions that support us achieving our environmental and customer commitments."

Technology hurdles. State-of-the-art premixed combustors can achieve low NOx but are subject to flashback on hydrogen-rich fuel. Diffusion-flame combustors are more flashback resistant but diluents needed to lower flame temperature for NOx suppression reduce plant efficiency.



Then it can run on 100% hydrogen as a 500MW battery."

This approach of allowing a gas turbine to transition from a hybrid storage and generating asset to more storage over time as renewables are added to the grid, highlights the flexibility such a package can bring.

Meeting carbon targets

"Our customers are seeing the value (of this), noted Ducker, "particularly long-term resource planners who are really struggling with the challenge of not wanting to build an asset today that doesn't meet long-term goals to decarbonize.

"Similarly, they don't want to overbuild a bunch of batteries not needed today but might be 10 years from now. The gas turbine allows them to reliably and affordably meet their carbon targets through the next several decades."

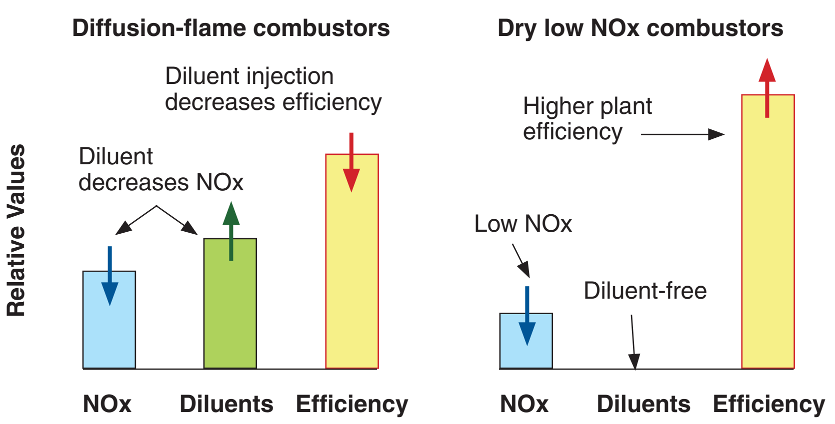
The entire operation – the digital integration between the gas turbine generating facility and the electrolyzer facility and the grid – is controlled by Mitsubishi Power's TOMONI platform.

Looking at fast ramps as an example, Ducker said: "Gas turbines can have ramp rates of 20% per minute when viewed in isolation. If tied in with an electrolyzer, the electrolyzer can be dropping its load as the gas turbine comes up, so the effective ramp rate can look almost instantaneous, or 100%. A grid operator can fine-tune that to have, say, an effective 40% per minute ramp rate."

Three projects underway

Already Mitsubishi Power has been selected as the green hydrogen storage integrator for three projects, totalling more than $3 billion that will use the new standard packages.

Comparative performance of dry low NOx combustors without injection versus diffusion-flame combustors which require water or steam injection for "wet" NOx suppression.



These projects each include JAC gas turbine power islands initially capable of operating on 30% green hydrogen, with future capability of operating on 100% green hydrogen.

- The first project is with Danskammer Energy in Newburgh, New York, with a capacity of 600MW, whose CEO, Wiliam Reid. said: "We are committed to helping New York meet its climate targets.

"We selected Mitsubishi Power's product because it would ready our facility to be a hydrogen-based zero-carbon power generator.

"By partnering with Mitsubishi Power for integrated green hydrogen generation and storage technologies, we hope to provide leadership in developing short- and long-duration energy storage infrastructure in New York State."

- The second project is being developed by Balico in Virginia, whose CEO, Irfan K. Ali, said: "Balico's fully permitted 1600MW Chickahominy Power Project is poised to deliver the critical Dominion Zone PJM market and Virginia the most efficient and reliable gas turbine technology in the world.

"We are excited at the prospect of even further environmental improvement by incorporating Mitsubishi Power's innovative renewable hydrogen based technologies."

- The third project is with EmberClear for its fully permitted 1084MW Harrison Power Project in Cadiz, Ohio, whose President and CEO, Raj Suri, said: "We look forward to the flexibility that the Mitsubishi Power technologies will provide as we ramp green hydrogen integration. We expect this plant to be the first hydrogen-capable project to reach commercial operation east of the Mississippi River.

"We also plan to use Mitsubishi Power as the green hydrogen integrator in our Eastern Pennsylvania project, which is in the early stages of development."

Explaining the status of these projects, Ducker said: "Each of them has selected us as their green hydrogen integrator. We have selected what we call the 'discharge piece', i.e. gas turbines, which are currently capable of using 30% hydrogen.

"Now we are working with them on

the charging piece, i.e. how big the electrolyzers will be and how much storage will be necessary. It's about planning for the next several decades – what do we install today, five years from now, 10 or 20 years from now."

Commercial operation for each project is expected in the 2024-25 timeframe. Mitsubishi Power says it is now working to firm-up the timing for integrating hydrogen production and storage needed for each facility.

Looking at road ahead

Looking at the key challenges ahead in developing the projects, Ducker says the technology issues are not so much of an issue; the focus will be on the market complexities.

"The market testing has to be better understood. These projects have the ability to be a hybrid storage-generating asset and we are seeing challenges in terms of how markets perceive them. How do we bid them into those regions?

"For example, how do we look at electrolyzers? They could be viewed as stand-alone across-the-fence systems and as a load with typical commercial industrial rates as opposed to being part of an energy storage ecosystem which would pay a different tariff."

While these regulatory issues are being worked out, Ducker sees integrated hybrid gas turbine-energy storage as an important part of the toolkit in the transition to a carbon-free energy sector.

He concluded: "We are putting customers on a pathway towards achieving the end goal. If you try to do it all today, you will not have affordable, reliable energy and if you do nothing today, you will not be ready to combat climate change.

"We are not saying hydrogen integrated with gas turbines is the only energy storage solution; lithium ion batteries are an important part of the solution, but hydrogen can work in tandem with batteries to solve the integration of renewables.

"It's about how we ensure there is adequate wind and solar and other decarbonized resources on the grid. All of these technologies will be necessary as we help our customers decarbonize." ■

Commitment to hydrogen-ready gas turbine portfolio

In a recent announcement on gas turbine orders in the Americas market region last year, Mitsubishi Power reported selling close to 3.3 GW of heavy frame capacity during 2020.

In keeping with the company's commitment to a hydrogen future, all of those gas turbines will be delivered hydrogen-ready, capable of operating on mixtures of natural gas and hydrogen fuel.

The orders span a variety of applications, with decarbonization and hydrogen capability emerging as key competitive advantages – and with over half of them said to include a hydrogen performance guarantee or joint development agreement in progress.

Mitsubishi Power says that it now ships all of its heavy frame gas turbines with hydrogen capability for deeper decarbonization. As-delivered, the gas turbines will be operational on a mixture of up to 30% hydrogen and 70% natural gas, which can be increased to 100% hydrogen in the future.

As hydrogen content increases, carbon emissions intensity (lbs of $CO2$ per kWh) is reduced. When a unit reaches 100 percent green hydrogen, carbon emissions intensity will drop to zero.

Last year's orders include the first combined cycle gas turbine units specified to be operational on 30% green hydrogen by their scheduled commercial startup date – which will achieve more than a 10% reduction in carbon emissions intensity.

Paul Browning, President and CEO of Mitsubishi Power, points to 2020 orders as "the culmination of a 5-year strategic plan launched in 2016" when he declared the company mission is to provide power generation and storage solutions to our customers, empowering them to affordably and reliably combat climate change and advance human prosperity.

"We started 2020 with the industry's first order for a hydrogen gas turbine, as part of the Intermountain Power Project plan to sequentially transition from coal to natural gas and, ultimately, green hydrogen. We have since received additional orders from other customers with the announced intent to transition to hydrogen."

Mitsubishi Power also has initiated a hydrogen joint development agreement with Entergy Corp. to introduce the world's first "standard green hydrogen packages" with electric utility businesses in four states and to collaborate on hydrogen production, storage and transportation facilities.