MOVE THE WORLD FORWARD

MITSUBISHI HEAVY INDUSTRIES GROUP

# HYDROGEN SOLUTIONS:

## TOWARDS A DECARBONIZED FUTURE

**Mark L. Peak, P.E.**
**Principal Environmental Engineer**
Mitsubishi Power

**Northwest Business & the Environment Conference**
**Track D: Climate & Fuels**
**Renewable Hydrogen: Opportunities & Challenges**
**December 10, 2024**

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# Hydrogen: Secure, Sustainable, Efficient

## THE GEOPOLITICAL LANDSCAPE

- Goal of **sustainable and secure** energy supply
- **Increasingly turbulent** geopolitical landscape
- Decarbonization occurring at vastly **different rates**

## REINVENTING A CARBON-BASED SOCIETY

- More than **100 years in the making**
- Low- or no-carbon solutions in **less than 30 years is the greatest challenge of our times**

## THE ENERGY INDUSTRY

- Leads the way with **bold action and a sense of urgency**
- Demonstrates **multiple ways to decarbonize**
- **Future-proofs** existing assets

## THE ROLE OF HYDROGEN

- **Reduce emissions,** functions as a form of **renewable energy storage**
- **Clean hydrogen** can support the rapid adoption of innovations in hard-to-abate industries such as steel, concrete, and long-haul transportation

**At Mitsubishi Power we're in a position to innovate in decarbonization,** foster new strategic collaborations and commercialize new solutions – all of which will empower the world to reach net zero goals in 2040 or sooner.

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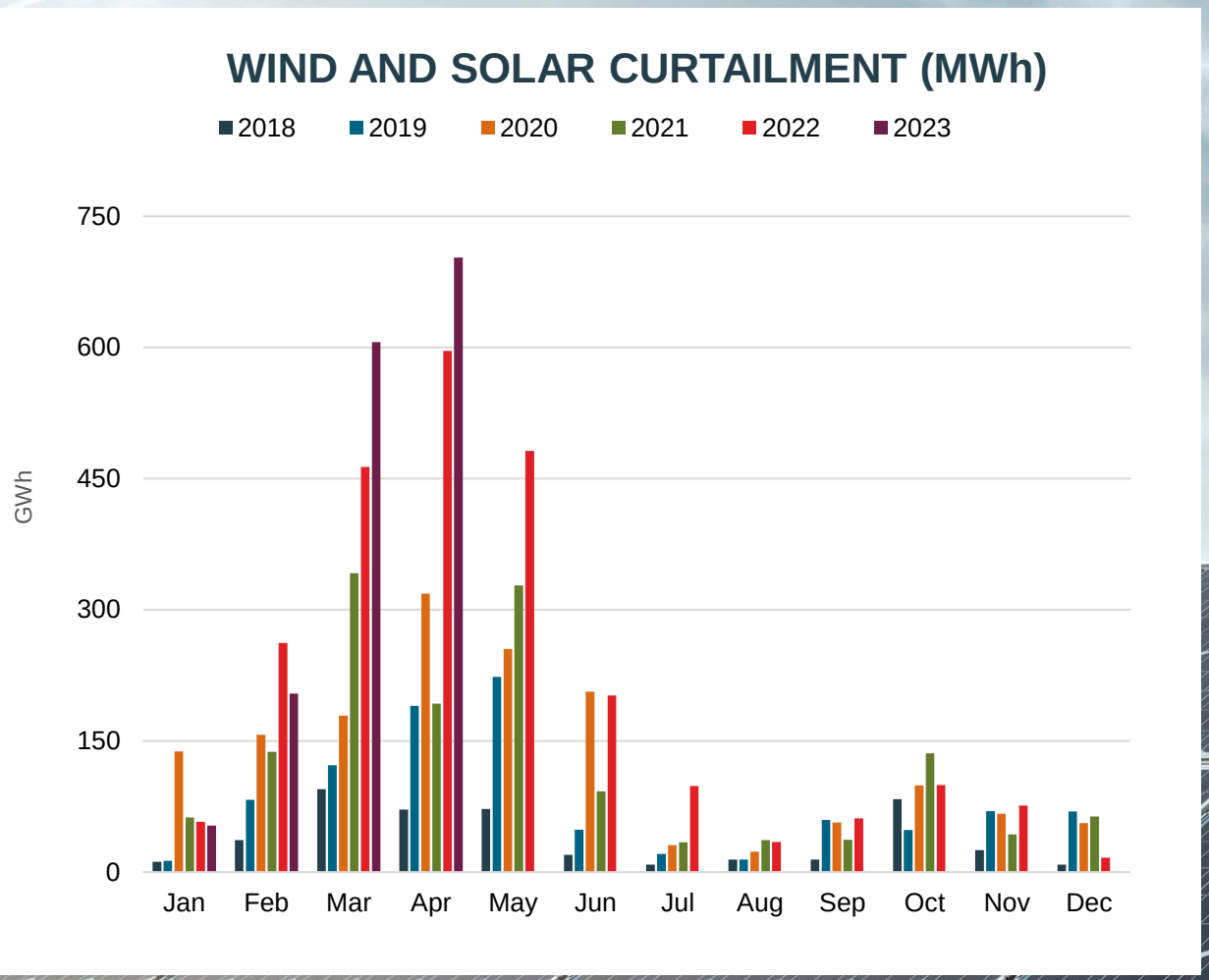
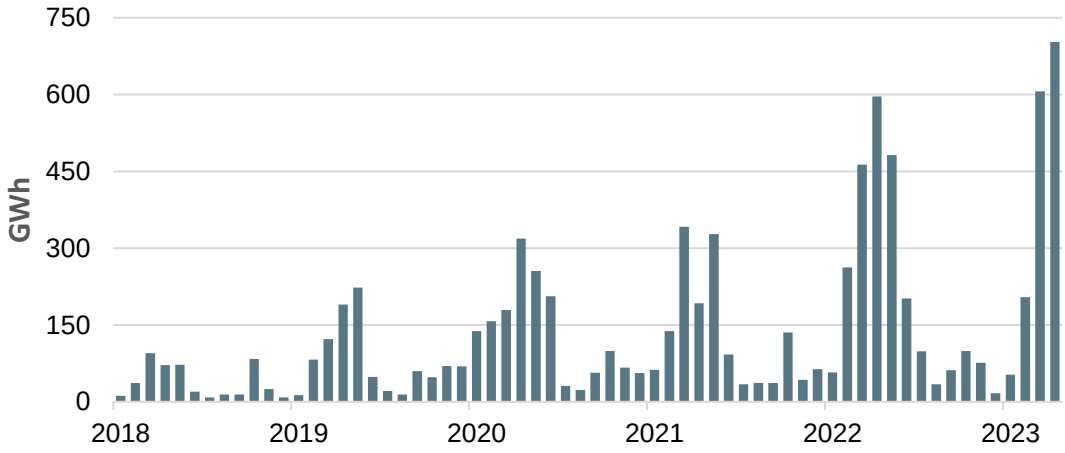
# CAISO Solar and Wind Curtailments




**Curtailments in California will increase** as the state reaches **60% Renewable Portfolio Standard (RPS) by 2030.**

Without long-duration storage, California will continue to see **massive curtailed energy.**

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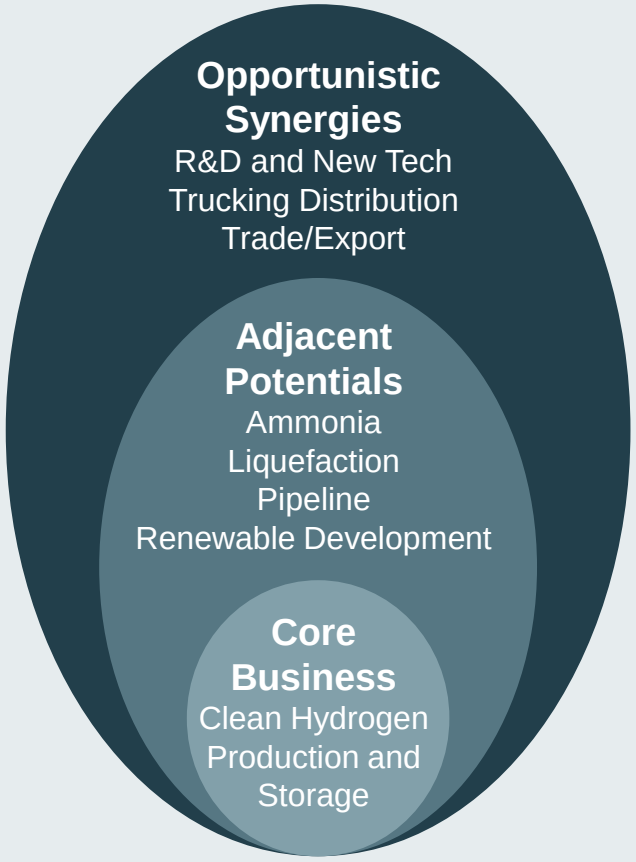
# What Uses for Hydrogen Does Mitsubishi Power Plan to Pursue?

Mitsubishi Power is focused on impactful technology solutions that we can advance and scale reliably, starting with hydrogen.




## Power Generation

We are converting and retrofitting **natural gas turbines to run on hydrogen.**

## Clean Hydrogen Production and Form of Long-Duration Energy Storage

Developing the infrastructure to store and produce hydrogen as ecosystems

- Our goal is **to develop hydrogen infrastructure** to make clean Hydrogen just as accessible as natural gas pipelines.
- As renewable generation is built out, we see **green hydrogen becoming the dominant** form, especially as a form of long-duration energy storage for the grid.
- **Hydrogen pipelines**, located along highways, will make this **clean fuel** readily accessible, expediting the transition to hydrogen-powered vehicles. CCUS can also be used to reduce emissions for any remaining fossil fuel needs.
- **Creating hydrogen ecosystems** will also enable low-cost, low-carbon solutions for utility, transportation, and industrial customers.

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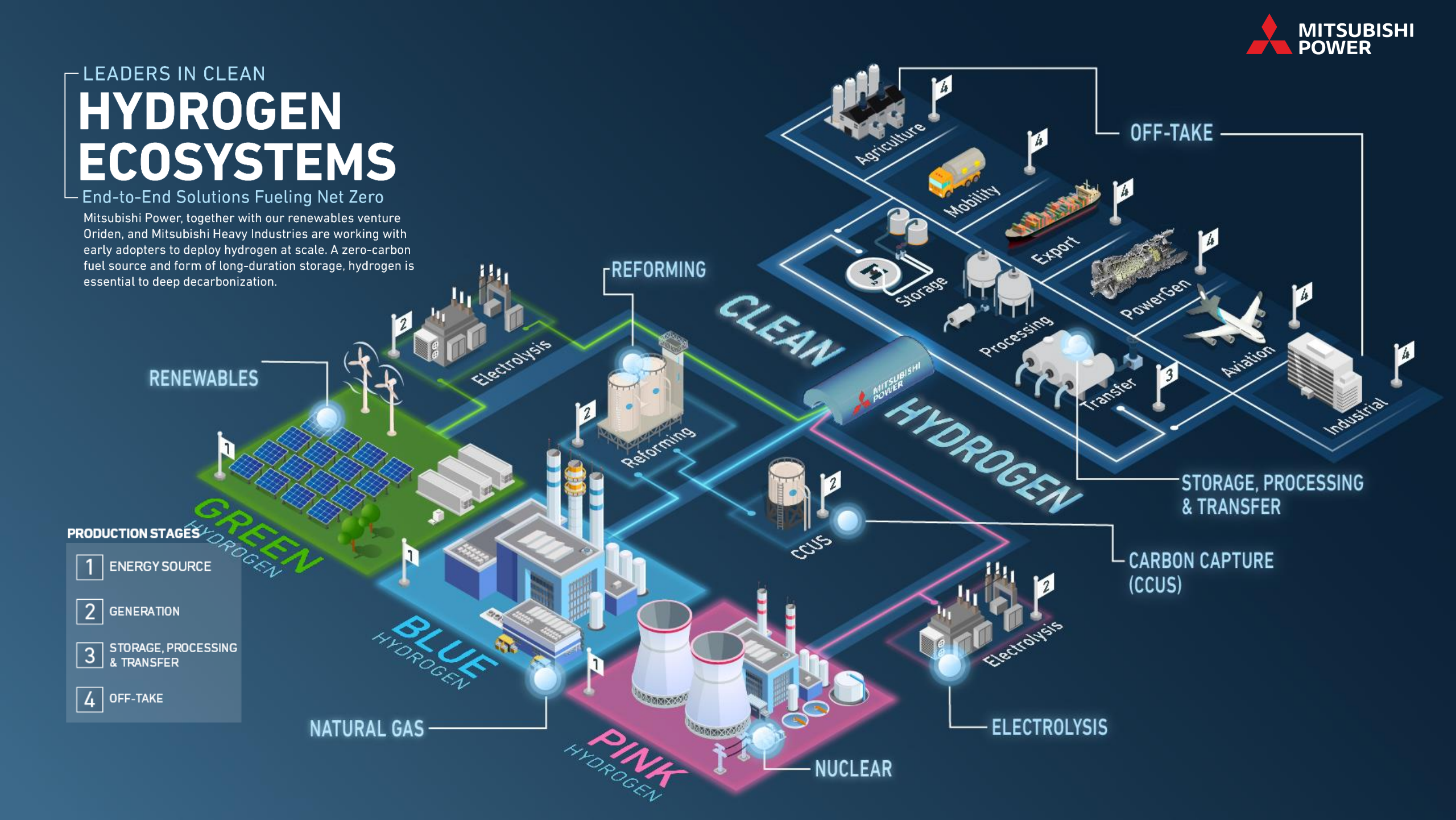
LEADERS IN CLEAN

# HYDROGEN ECOSYSTEMS

## End-to-End Solutions Fueling Net Zero

Mitsubishi Power, together with our renewables venture Oriden, and Mitsubishi Heavy Industries are working with early adopters to deploy hydrogen at scale. A zero-carbon fuel source and form of long-duration storage, hydrogen is essential to deep decarbonization.



# First In-house Hydrogen Value Chain Validation Plant in the World

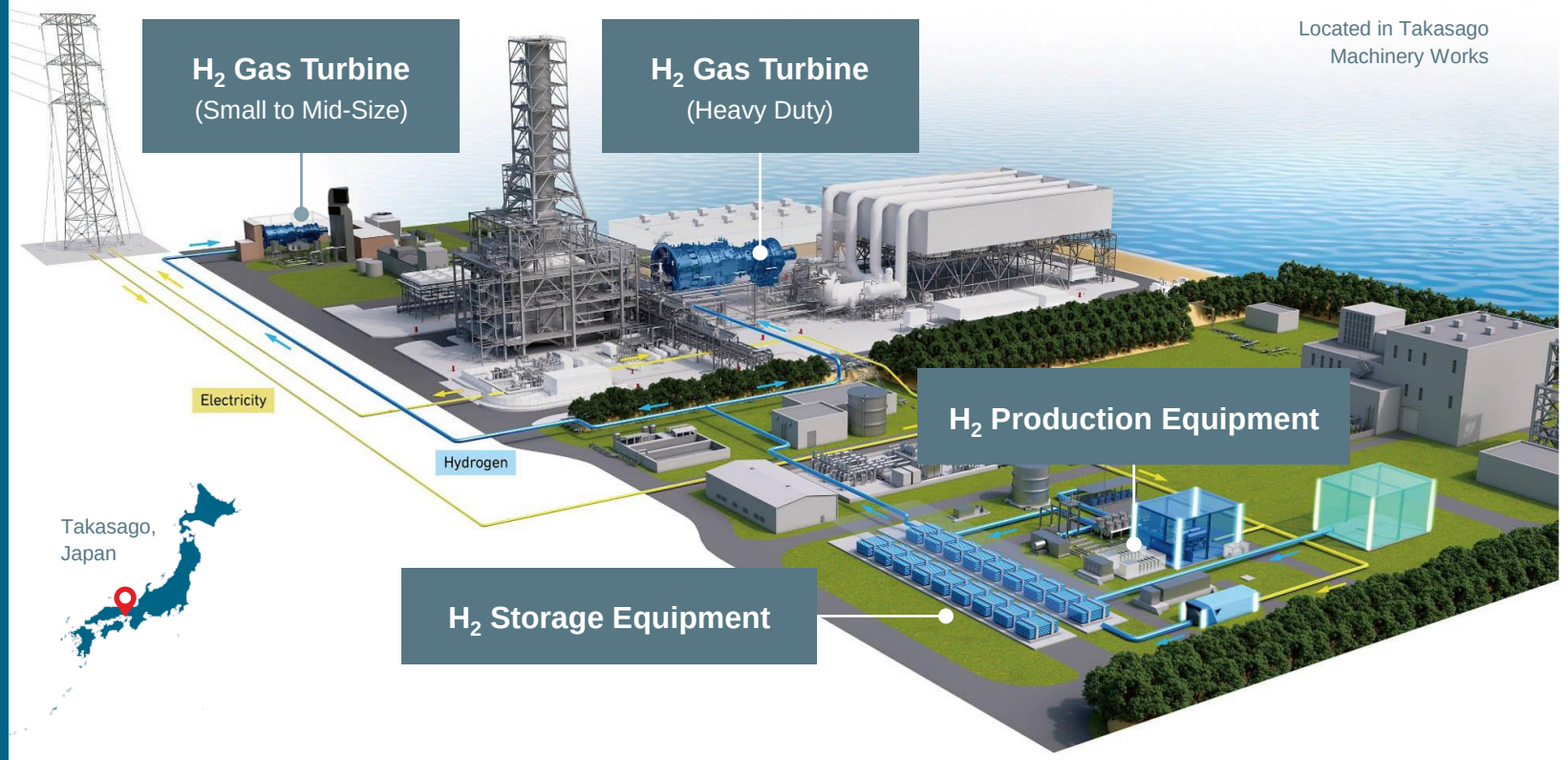
## MHI TAKASAGO HYDROGEN PARK

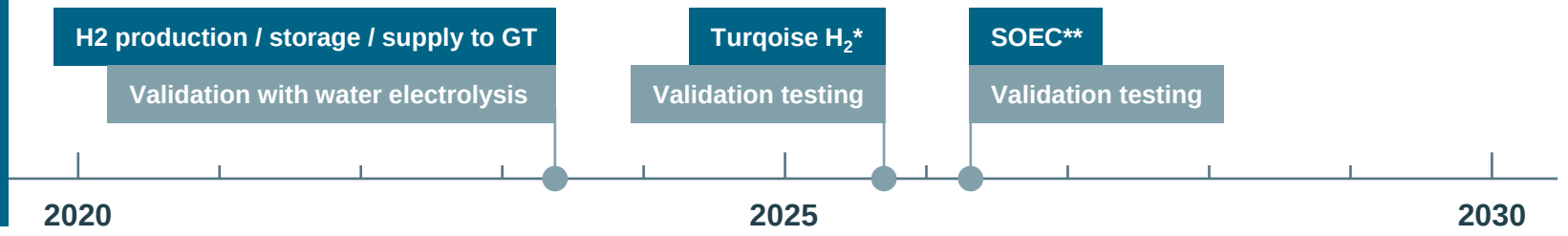
Operational in 2023

- Add hydrogen production and storage equipment to existing demonstration plant
- Validate hydrogen gas turbine technology
- Combine and evolve energy infrastructure and hydrogen technologies

* **Turquoise hydrogen:**
$H_2$ obtained through pyrolysis of methane into $H_2$ and solid carbon

** **SOEC (Solid Oxide Electrolyzer Cell):**
High temperature steam electrolysis

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# First of a Kind Market Application for Long-Duration Energy Storage

## ADVANCED CLEAN ENERGY STORAGE PROJECT

**TECHNOLOGY:** core integrated hydrogen production equipment and electrolyzers

**LOCATION:** Delta, Utah, USA

Features a single salt dome, presently in the construction phase of two caverns within the salt dome. Each cavern the size of the Empire State Building, with a storage capacity of **150 GW hours** of energy and the ability to house up to **70-100 caverns**.

**Will initially convert more than 220 MW of renewable energy to 100 metric tonnes per day of green hydrogen.**

**Significant amount of curtailments avoided with hydrogen,** a more reliable grid with greater carbon reductions and at a lower system cost

**Offtake secured by Intermountain Power Agency.** Intermountain Power Project, IPP Renewed, is an 840 MW GTCC power plant that will use 30% of green hydrogen in 2025, and 100% by 2045 or sooner.

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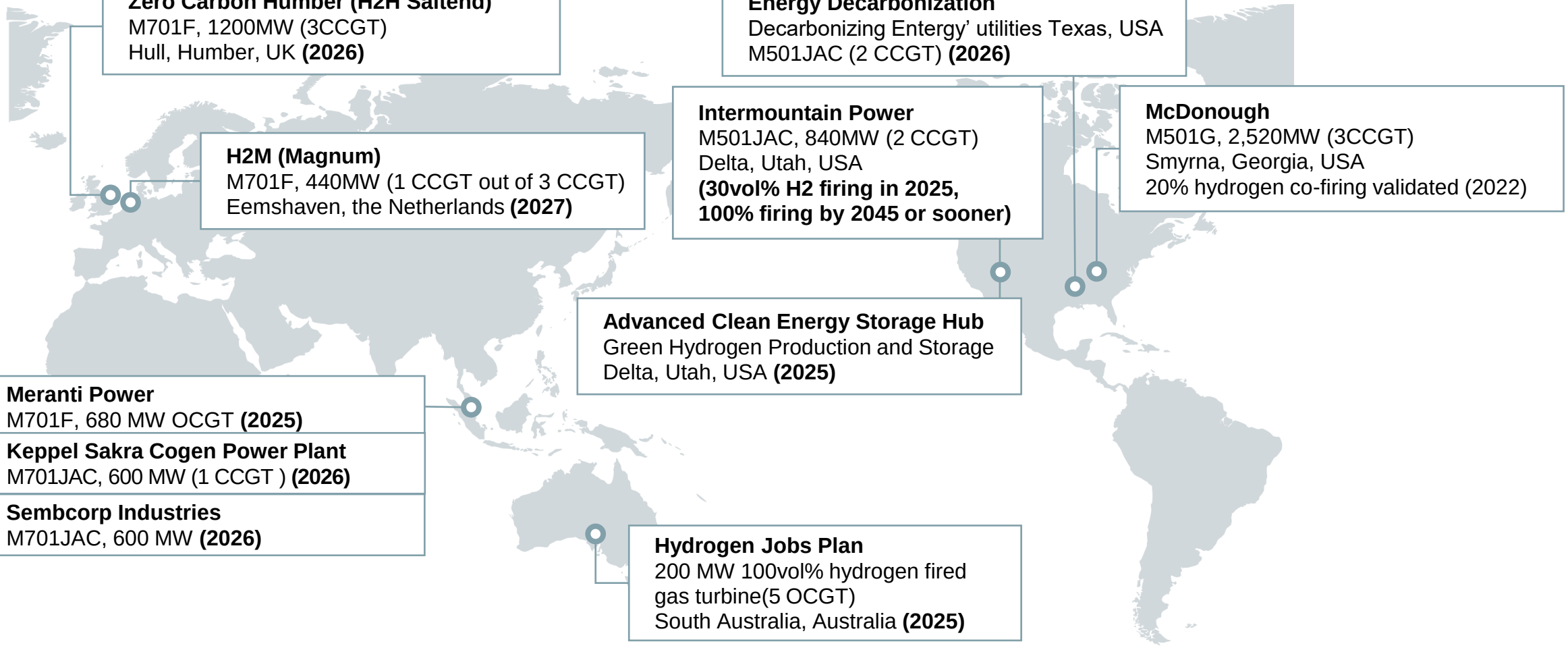
# Our Global Hydrogen Gas Turbine Projects

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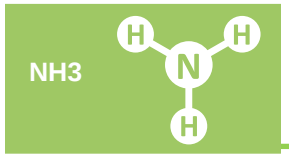
# Hydrogen and Ammonia-Fired Gas Turbines

**Natural Gas**

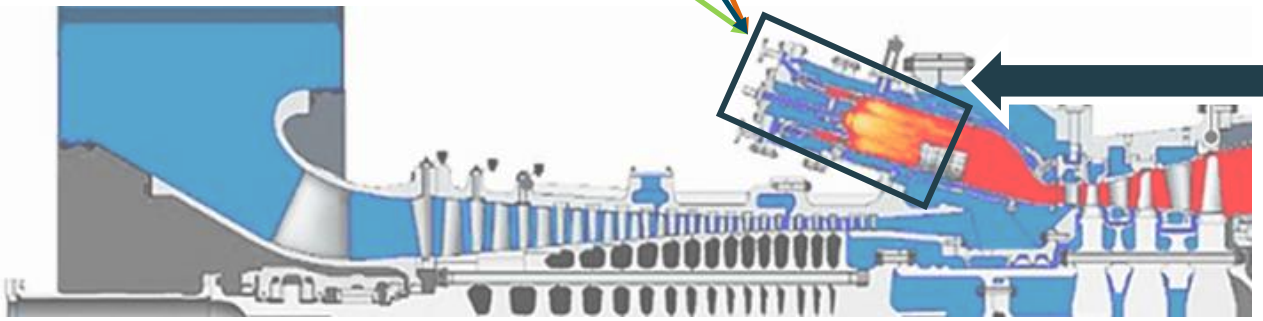
**Hydrogen**




**Ammonia**

| | | |
|---|---|---|
| **Type 1** (Diffusion) | **100% $H_2$** | **Development complete** |
| **Type 2** (Pre-mix) | **30% $H_2$ mixed firing** | **Development complete** |
| | 50% $H_2$ mixed firing | 2022: Successful combustion test for large frame GT |
| Type 3 (Multi-cluster) | 100% $H_2$ firing | Validating in lead up to 2025 commercialization |
| Type 1 (Diffusion) | 100% ammonia firing | Validating in lead up to 2025 commercial unit operation and commercialization |

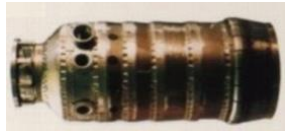
**Ready to apply to commercial facilities**



**Combustor Replacement**

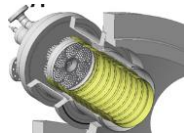
Convert to $H_2$/ammonia firing by replacing combustors and adding fuel supply system

**Type 1**



**Type 2**

**Type 3**



- Able to convert a natural gas-fired gas turbine to hydrogen or ammonia firing – and thereby achieve decarbonization – simply by replacing the combustors and adding a fuel supply system

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# Georgia Power at Plant McDonough-Atkinson

**The World's Largest** Hydrogen Fuel Blending Project on an Advanced Class Gas Turbine

The **>20%** blend resulted in a **7% reduction** in carbon emissions compared to natural gas and maintained high thermal efficiency

Successfully demonstrated in 2022 validation highest blending **20.9% hydrogen fuel** in its advanced class gas turbines to date

**The increase in hydrogen** fuel blend percentage improved turndown by lowering minimum emissions compliance load, leading to reduced emissions and operational flexibility

**"The speed at which the team designed and accomplished a 20% blend is remarkable.** It took significant commitment from many organizations, and we applied the highest technical rigor to not compromise quality, standards, or safety."

Neva Espinoza, Vice President - Energy Supply and Low-Carbon Resources at Electric Power Research Institute (EPRI)

**TECHNOLOGY:** M501G, 2,520MW (3 x 2-on-1 CCGT)

**LOCATION:** Smyrna, Georgia, USA

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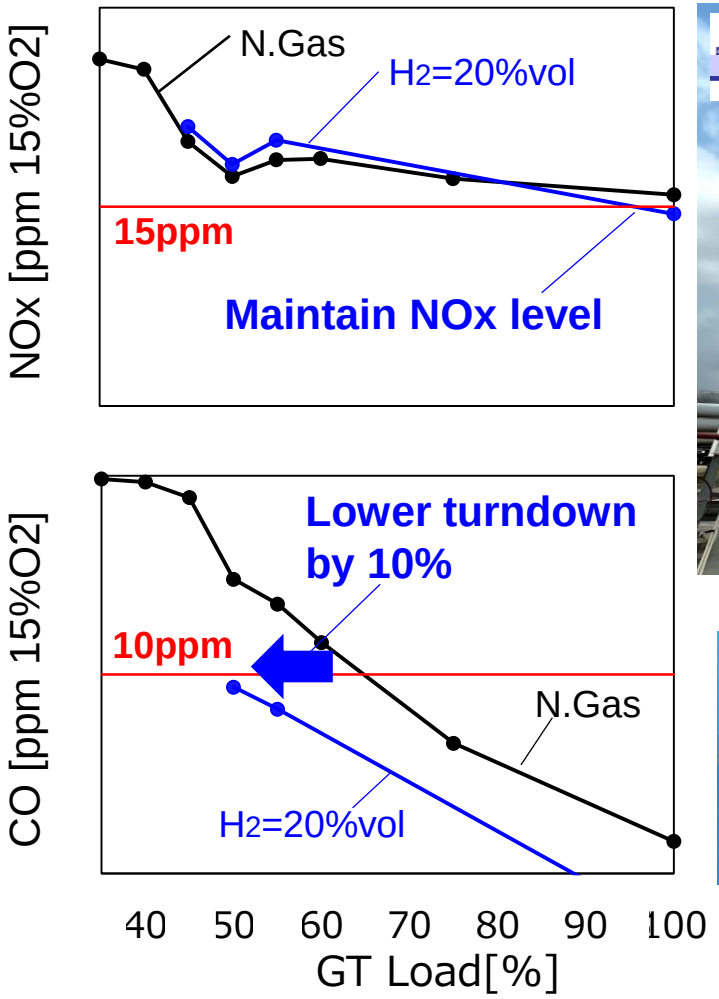
# Advanced Class GT H2 Co-firing Test with M501G at Plant McDonough

H2 20%vol co-firing demonstration of 501G equipped with DLN combustor have been done successfully on 2nd June 2022 at McDonough GT 6B.

- Base Load Hydrogen blending > 20vol% with stable combustion
- Lowered Turndown increased by > 10 percentage points
  - higher combustion efficiency ⇒lower Carbon Monoxide
- Maintain NOx level
  - Hydrogen improves combustion tuning margins
- Hydrogen fuel trip logic successfully activated
  - Prevents over firing during Hydrogen trips



DLN Combustor

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# Proposed EPA Gas Turbine New Source Performance Standard (NSPS) Revisions

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| BSER - Best System of Emission Reduction | NOx Standard is Technology Neutral | Hydrogen (H2) usage addressed |
|---|---|---|
| EPA has established combustion controls and selective catalytic reduction (SCR) as BSER in its cost benefit analysis for NOx emission reductions | While EPA has highlighted combustion controls and SCR for compliance, it does not preclude use or development of other NOx control technologies | EPA specifically addresses H2 as part of the proposed rule. Up to 30% NG/H2 blend is considered NG, over 30% is non-NG |

**Proposed rule does not change any emission limits beyond NOx**

$SO_2$ compliance will continue to be based on the use of low sulfur fuels

Proposed rule includes three base load heat input size categories for gas turbine (GT) units:

- GTs rated up to 250 MMBtu/hr (~25 MW)
- GTs rated between 250 MMBth/hr and 850 MMBtu/hr (~85 MW)
- GTs rated greater than 850 MMBtu/hr

EPA also included capacity factor (CF) ranges in alignment with the final GHG rule issued in May 2024

- Low load peaking units with a CF up to 20%.
- Intermediate load units with CF between 20% and 40%
- Base load units with a CF greater than 40%.

Heat input based on higher heating value of the fuel

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# 40 CFR 60 Subpart KKKKa Proposed Emission Limits

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| NOx Low Load Combustion Turbines – CF ≤ 20%<br>BSER:<br>New, Modified or Reconstructed - Combustion Controls | NOx Intermediate Load Combustion Turbines –<br>20% > CF ≤ 40%<br>BSER:<br>Modified – Combustion Controls | NOx Intermediate and Base Load Combustion Turbines – CF > 20%<br>BSER:<br>New, Modified or Reconstructed - Combustion Controls w/ SCR | $SO_2$ All Stationary Combustion Turbines with Base Load Heat Input > 10 MMBtu/hr<br>No changes from original NSPS |
|---|---|---|---|
| GT base load ≤ 850 MMBtu/hr<br>▪ NG: 0.092 lb/MMBtu (25 ppm)<br>▪ Non-NG: 0.290 lb/MMBtu (74 ppm)<br>GT base load > 850 MMBtu/hr<br>▪ NG: 0.055 lb/MMBtu (15 ppm)<br>▪ Non-NG: 0.150 lb/MMBtu (42 ppm) | Modified GT base load > 250 MMBtu/hr and ≤ 850 MMBtu/hr<br>▪ NG: 0.092 lb/MMBtu (25 ppm)<br>▪ Non-NG: 0.290 lb/MMBtu (74 ppm) | New or Reconstructed GT base load ≤ 850 MMBtu/hr<br>▪ NG: 0.011 lb/MMBtu (3 ppm)<br>▪ Non-NG: 0.035 lb/MMBtu (9 ppm)<br>New, Modified or Reconstructed GT base load > 850 MMBtu/hr<br>▪ NG: 0.011 lb/MMBtu (3 ppm)<br>▪ Non-NG: 0.019 lb/MMBtu (5 ppm) | ▪ You must not cause to be discharged into the atmosphere from the subject GT any gases which contain $SO_2$ in excess of 0.90 pounds per megawatt-hour (lb/MWh) gross output<br>▪ You must not burn in the subject GT any fuel which contains total potential sulfur emissions in excess of 0.060 lb $SO_2$/MMBtu heat input. If your turbine simultaneously fires multiple fuels, each fuel must meet this requirement |

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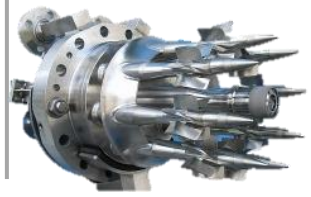
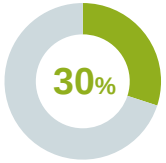
# H2 Combustion Technology Roadmap

## Large Frame Gas Turbines

| | Type | Low NOx tech | Status | $H_2$ content (volume %) | Schedule |
|---|---|---|---|---|---|
| Ready | **Type 1: Diffusion** | $N_2$ dilution, Water/ Steam injection | Available | | 1970 Cogen/IGCC → **2027 Magnum $H_2$ conversion** |
| Ready | **Type 2: Pre-Mix (DLN)**  | Dry | Available |   | 1982 DLN → **2018 30% co-firing test completed** |
| Under development | **Type 3: Multi-Cluster (DLN)** | Dry | Final Development and Validation | | **Mar, 2025 Validation completion target** |

*This presentation is based on results obtained from a project commissioned by NEDO that is a government organization in Japan. (NEDO: New Energy and Industrial Technology Development Organization)
**DLN : Dry Low NOx

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# Mitsubishi Power Heavy Duty Gas Turbine Hydrogen Fuel Line up

| | GT Model | | Output (MW)* SC | Output (MW)* CC | Combustor Type | $H_2$ (vol%) | $CO_2$ reduction* |
|---|---|---|---|---|---|---|---|
| Small & Mid-Size | H-25 | 60/50Hz | 41/41 | 60/60 | Diffusion | 100 | 100% |
| | | | | | Multi-Cluster (DLN) | 30→100 (target) | 11% / 100% |
| | H-100 | 60/50Hz | 106/116 | 150/171 | Pre-Mix (DLN) | 30 | 11% |
| | | | | | Multi-Cluster (DLN) | 100 (target) | 100% |
| Large Frame (60Hz) | M501F | 60Hz | 185 | 285 | Diffusion | 100 | 100% |
| | | | | | Pre-Mix (DLN) | 30 | 11% |
| | | | | | Multi-Cluster (DLN) | 100 (target) | 100% |
| | M501GAC | 60Hz | 283 | 427 | Pre-Mix (DLN) | 30 | 11% |
| | | | | | Multi-Cluster (DLN) | 100 (target) | 100% |
| | M501J<br>M501JAC | 60Hz | 330<br>435 | 484<br>630 | Pre-Mix (DLN) | 30 | 11% |
| | | | | | Multi-Cluster (DLN) | 100 (target) | 100% |
| Large Frame (50Hz) | M701F | 50Hz | 385 | 566 | Diffusion | 100 | 100% |
| | | | | | Pre-Mix (DLN) | 30 | 11% |
| | | | | | Multi-Cluster (DLN) | 100 (target) | 100% |
| | M701J<br>M701JAC | 50Hz | 478<br>448-574 | 701<br>650-840 | Pre-Mix (DLN) | 30 | 11% |
| | | | | | Multi-Cluster (DLN) | 100 (target) | 100% |

***Ready***

Diffusion | Pre-Mix (DLN) | Multi-Cluster (DLN) current | Multi-Cluster (DLN) target under development

*Referenced at Natural Gas firing

**All Mitsubishi Power Gas Turbines shown here are capable of at least 30% H2 co-firing straight from the factory. Only GT Combustor modification required.**