MOVE THE WORLD FORW>RD MITSUBISHI HEAVY INDUSTRIES GROUP

TMCES 2026 Hydrogen Update

Todd Carlson

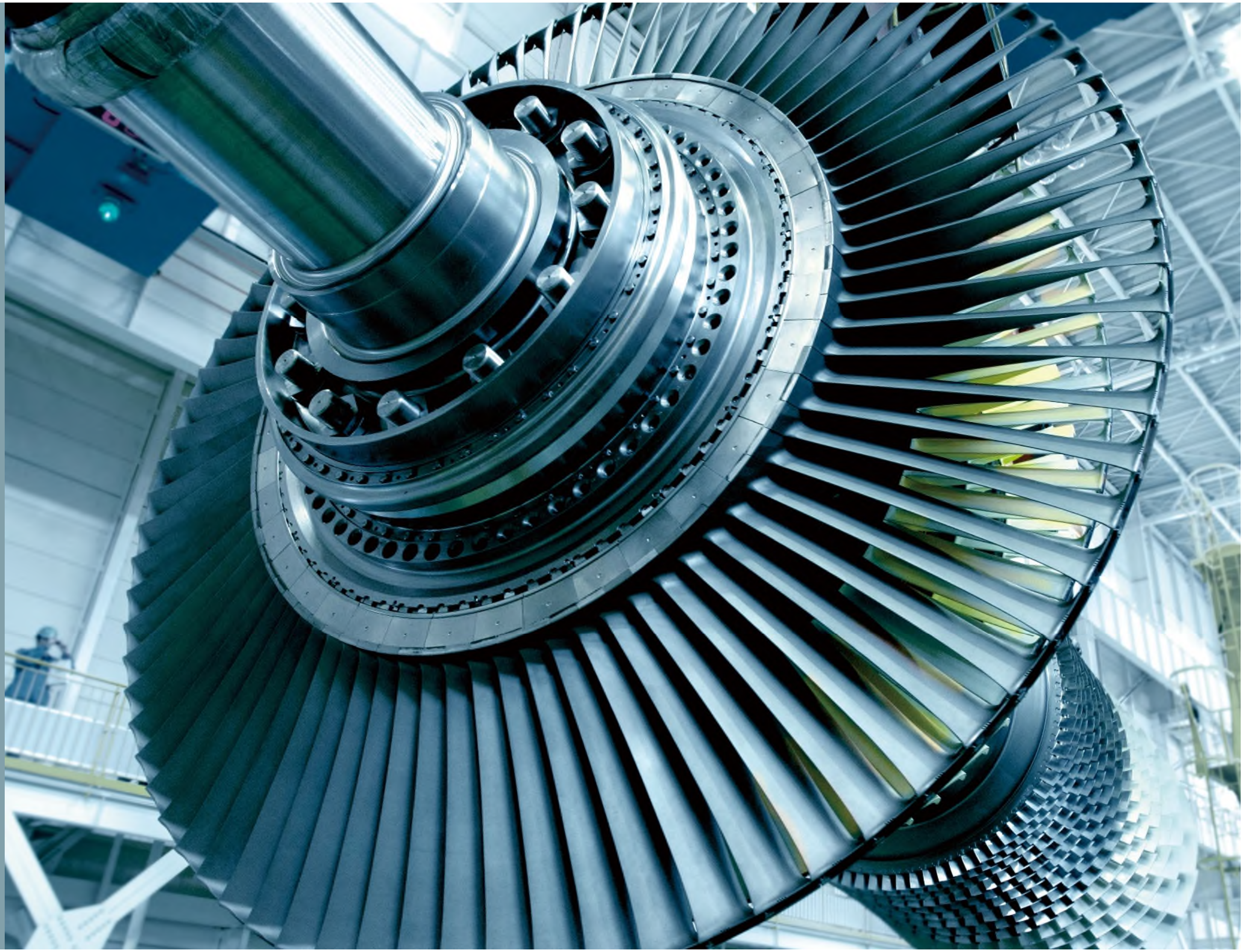
System Owner, GT Air Systems

Hydrogen Product Engineer

Mitsubishi Power Americas, Inc.

7/30/2026

This document contains CONFIDENTIAL and PROPRIETARY information of Mitsubishi Power Americas, Inc. (“Mitsubishi Power”). Neither this document, nor any information obtained therefrom is to be reproduced, transmitted or disclosed to any third party without first receiving the express written authorization of Mitsubishi Power.



Mitsubishi Power is a power solutions brand of Mitsubishi Heavy Industries.

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

MITSUBISHI POWER

Why hydrogen co-firing Demonstration at McDonough?

Decarbonization

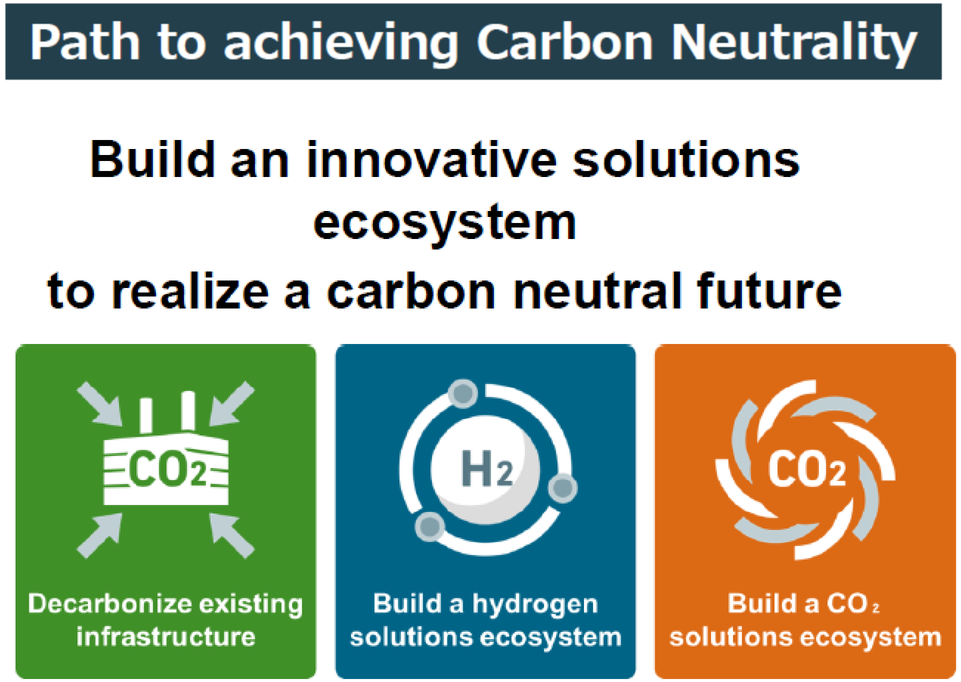
- Reduced carbon emissions with respect to pure natural gas
- Aligned with MHI's 2040 Carbon Neutrality Declaration

Grid Flexibility

- Hydrogen can improve turndown which allows units to stay online during low demand
- Avoids renewable curtailments by enabling hydrogen production & storage during low demand

Technology Verification

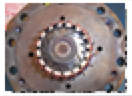
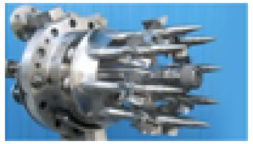
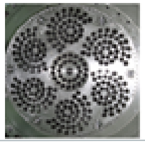
- Demonstration delivers practical data and operational experience to guide future hydrogen retrofits and fuel-blending strategies for large-scale power generation



© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

Technology Roadmap & Validation

MITSUBISHI POWER

	Combustor type	Low NO_x technology	Turbine inlet temperature	H_2 density (volume %)	Schedule: 1970 / 2020 / 2025 / 2030 year
Ready	**Type1** **Diffusion** 	N_2 dilution, Water/ Steam injection	1200~1400ºC class CC efficiency 50%	100%	MHI has over 50 years (3.5 million hours) experience in Hydrogen firing 1970  Hydrogen 82%(1989-)
Ready	**Type2** **Pre-mix** 	Dry	1650ºC class CC efficiency 64%	30~50%	Natural gas; 2018; 2022 2023 30%H_2 co-firing test 20%H_2 co-firing operation in Large Frame GT (G class) 30%H_2 co-firing operation in Large Frame GT(T-point 2) 30~50%H_2 co-firing Commercial operation
Ready		Small amount water injection	1650ºC class CC efficiency <64%	50%	Natural gas; 2022; 2025 50%H_2 co-firing test 50%H_2 co-firing operation in Large Frame GT (G class)
Under development	**Type3** **Multi-cluster** 	Dry	1650ºC class CC efficiency 64%	100%	Future 80%H_2 co-firing test completed (Small-Middle frame) (Large frame) 100%H_2 firing Commercial operation

Type1 **100% H_2 firing** **Ready/Development completed**

Type2 **30% H_2 co-firing** **Ready/Development completed** → **Will be operated at commercial plants in 2026**

50% H_2 co-firing(dry) **To be verified in actual engine**

50% H_2 co-firing(Water injection) **To be verified in actual engine** → **Completed demonstration at commercial plants in 1Q 2025 (G class)**

Type3 **100% H_2 firing** **Ready after 2025**

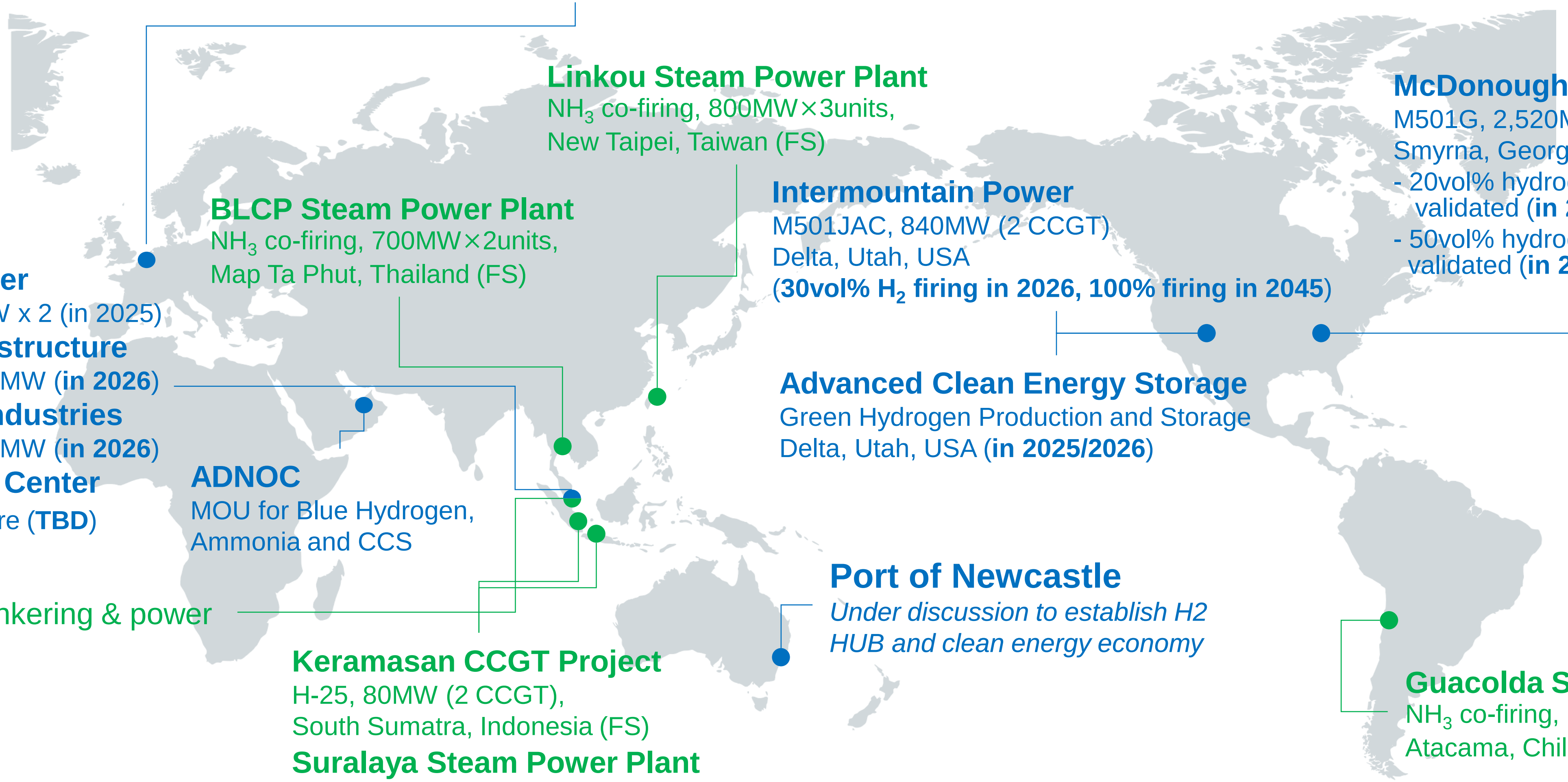
© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

Mitsubishi Power H2/NH3 Power Generation Projects

MITSUBISHI POWER

Hydrogen related projects

Ammonia related projects



Magnum
M701F, 440MW (3 CCGT)
Eemshaven, the Netherlands (**TBD**)

Linkou Steam Power Plant
NH_3 co-firing, 800MW×3units,
New Taipei, Taiwan (FS)

McDonough
M501G, 2,520MW (3 CCGT)
Smyrna, Georgia, USA
- 20vol% hydrogen co-firing validated (**in 2022**) M501GAC
- 50vol% hydrogen co-firing validated (**in 2025**)

BLCP Steam Power Plant
NH_3 co-firing, 700MW×2units,
Map Ta Phut, Thailand (FS)

Intermountain Power
M501JAC, 840MW (2 CCGT)
Delta, Utah, USA
(**30vol% H_2 firing in 2026, 100% firing in 2045**)

Meranti Power
M701F, 340 MW x 2 (in 2025)

Keppel Infrastructure
M701JAC, 600 MW (**in 2026**)

Sembcorp Industries
M701JAC, 600 MW (**in 2026**)

Keppel Data Center
CCGT Singapore (**TBD**)

Advanced Clean Energy Storage
Green Hydrogen Production and Storage
Delta, Utah, USA (**in 2025/2026**)

ADNOC
MOU for Blue Hydrogen, Ammonia and CCS

EMA/ MPA
Ammonia bunkering & power generation

Port of Newcastle
Under discussion to establish H2 HUB and clean energy economy

Keramasan CCGT Project
H-25, 80MW (2 CCGT),
South Sumatra, Indonesia (FS)

Suralaya Steam Power Plant
NH_3 co-firing, 600MW×3units,
Cilegon, Indonesia (FS)

Guacolda Steam Power Plant
NH_3 co-firing, 150MW×5units,
Atacama, Chile (FS)

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

Plant & Unit Overview (50% co-firing H2 test plant)

M501GAC		
Compressor	Number of Stages	17
Combustor	Number of Cans	16
	Cooling Method	Air Cooled
Turbine	Number of Stages	4

- Plant McDonough-Atkinson owned by Southern Company / Georgia Power in the heart of Atlanta. COD in 2012.
- Three 2-on-1 Combined cycle natural gas power blocks producing over 2,700MW
- Prior 20% Hydrogen Co-firing success in 2022
- In 2024, one block was converted from M501G (steam cooled) to M501GAC (air cooled) enabling higher H_2 blends and faster cold starts.
- M501GAC Advanced Gas Turbine
  - 283,000kW ISO rating
  - Dry low NOx Air-cooled combustion system
- Project Team:
  - Georgia Power, Mitsubishi Power, Southern Company, EPRI, Certarus

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

Technology Development

Two Development steps from the 20% H_2 benchmark:

30% H_2 Dry:

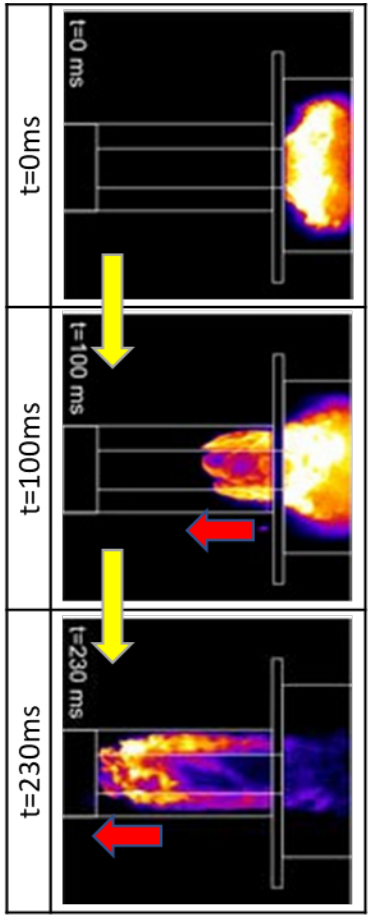
- Steam-Cooled to Air-Cooled Combustor (GAC Conversion)
- Design features to reduce flashback risk
- Validated on T-point M501JAC

50% H_2 Wet:

- 100% H_2 to Pilot zone
- Water injection added for NOx control
- Single combustor rig test to confirm flashback and emissions
  - Enabled commitment for McDonough demonstration

Test Facility

High Pressure Combustor Test Rig



Flashback

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

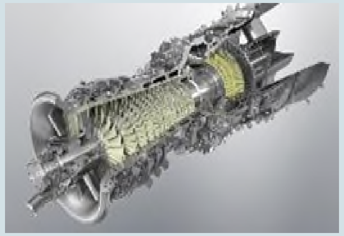
Hydrogen Demonstration Architecture

Gas Turbine
- M501GAC Advanced Class Gas Turbine
- Pre-mixed Air-cooled Combustor

Hydrogen Supply
- 2 hydrogen fuel lines sized for >10,000lbs/hr total flow rate
- 4 pressure reduction units
- 11 storage trailers with up to 20,000lbs of high pressure H_2 gas inventory on site at any given time
- 4 Refuels needed for test program (4 days each)
- Overpressure Protection
  - Tandem regulators (worker/monitor) pressure regulating valves
  - Trip stop valve
  - PSV sized for leakage

NOx Abatement
- Single stage Water injection
- Pump Skid
- Water Demineralization skid
- Water Storage Tank

Utilize **Pre-Mixed Combustor**



M501GAC (283MW)
Advanced gas turbine

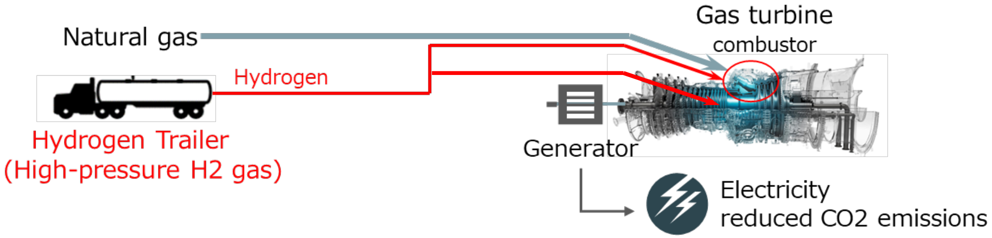


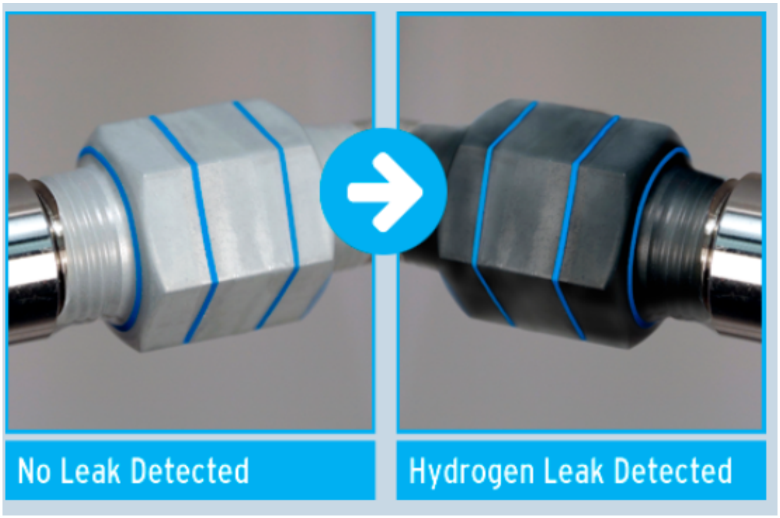
Fig. Diagram of Hydrogen Installation

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

Safety Engineering & Field Controls

Safety Controls

- HAZOP & Facility Siting reviews
- Leak testing with Helium – Nitrogen blends
- Hydrogen sensitive tape
- Restricted access and signage
- Use of “Spark-free” hand tools (bronze aluminum or copper titanium)
- Pre-brief & debrief around each test day to reinforce emergency actions plans and lessons learned
- Radio (I.S.) protocols to ensure clear efficient communication



Explosion Controls

- Hydrogen 25% of LEL detectors (personal and fixed)
- Purge with inert gas prior to fuel introduction and between each test
- Electrical grounding, bonding across flanged connections
- Devices rated for Class 1, Division 2, Group B hazardous locations
- Forced ventilation of enclosures
- Hydrogen storge units equipped with fire protection system
- Engineering controls for auto-ignition for inactive fuel stages based on research performed in collaboration with University of Central Florida

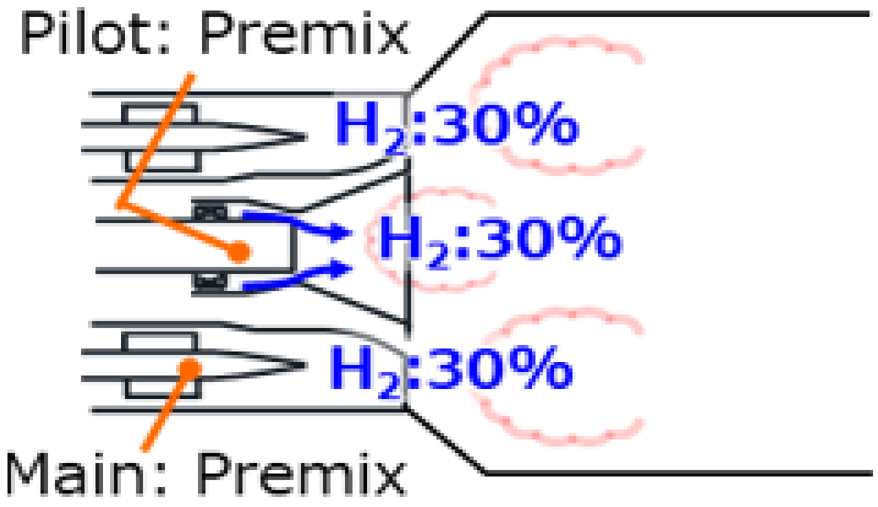
© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

Hydrogen co-firing concept

Two hydrogen co-firing modes were demonstrated at McDonough.

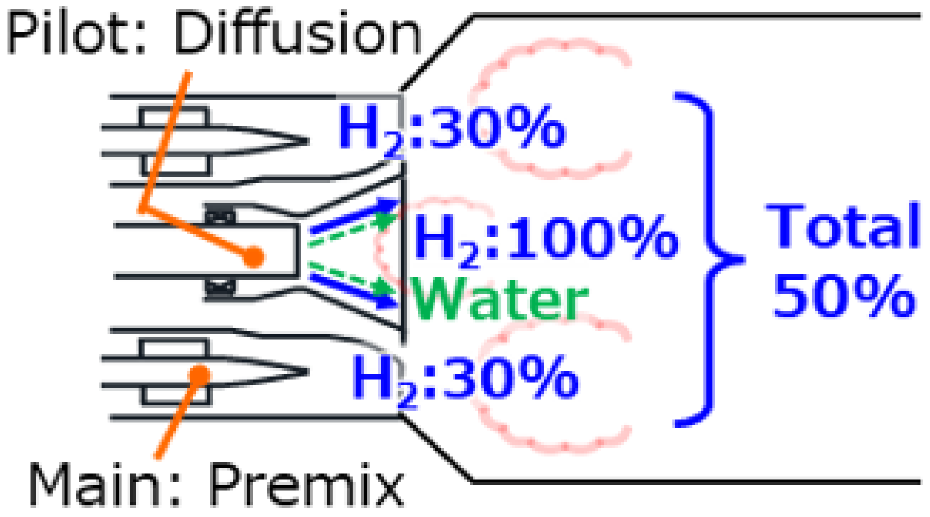
30% H_2 Dry:

- Pre-mixed 30% H_2 to all nozzles
- Design features to reduce flashback risk
- Validated in MHI`s verification facility (T-Point)



50% H_2 Wet:

- 100% H_2 to Pilot zone
- Pre-mixed 30% H_2 to Main zone
- Water injection added for NOx control

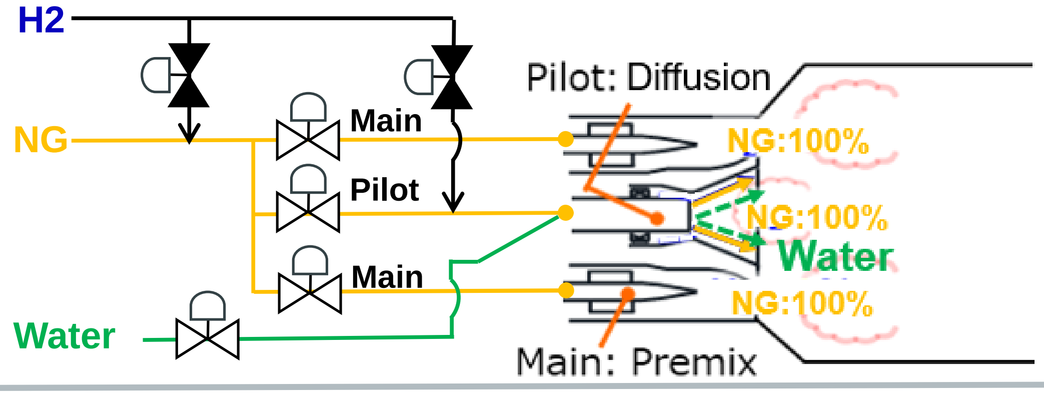


<Ref.> Development and Verification of Hydrogen / Ammonia Gas Turbines for Power Generation, MHI technical journal, Vol. 62 No.3 (2025)

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

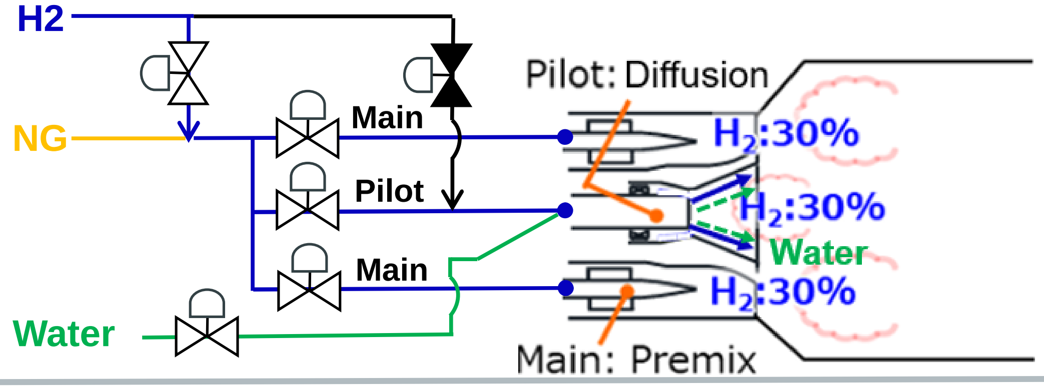
Operation Sequence

STEP-1



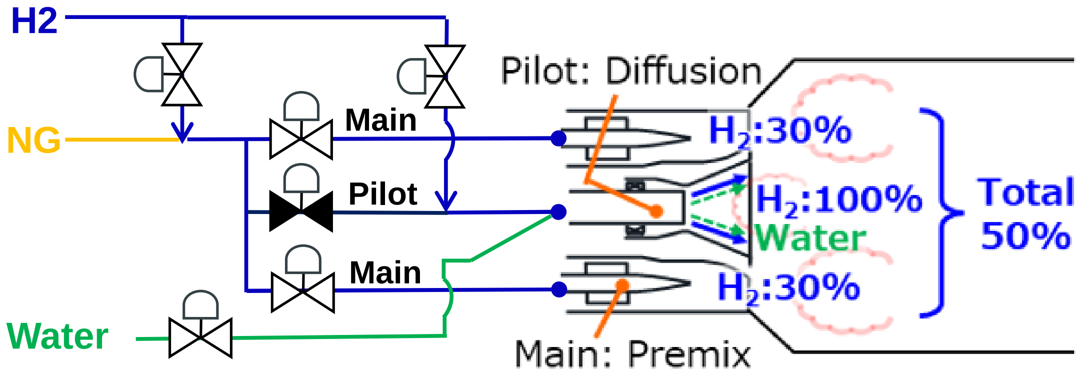
- Introduce water injection before hydrogen in-service

STEP-2



- Hydrogen in-service to main line and start to supply 30% H2 blending gas

STEP-3



- Replace 30% H2 blending gas in the pilot system with 100% H2 by switching the supply line, resulting in an overall 50% H2 gas-blending.

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

<Ref.> NEDO Hydrogen and Ammonia Results Report Meeting 2025, No.B1-13, Research and Development of Gas Turbine Power Generation Equipment Co-Firing with Over 30 vol% Hydrogen for the Realization of a Low-Carbon Society

Demonstration Results

50.2%
Wet mode H_2 co-firing ratio at base load

10,073
Pounds of H_2 per hour during 50% H_2 base load test

30%
Dry mode H_2 co-firing ratio at partial & base load

35%
Minimum environmental compliance load enabled by H_2 co-firing

25,902
Pounds of H_2 consumed during testing

172,026
Pounds of CO_2 emissions avoided during testing

<15ppm
NOx

<10ppm
CO

2025-6-16 press release *https://power.mhi.com/regions/amer/success-stories/mcdonough*

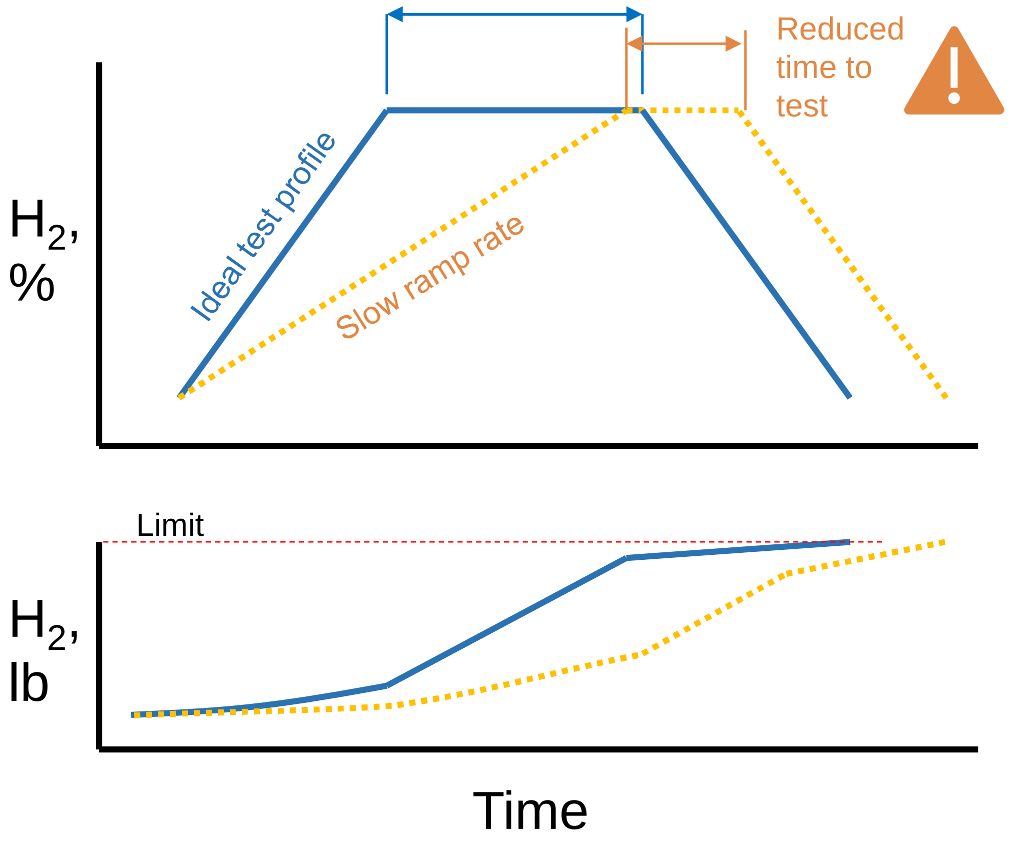
© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

Test Planning

MITSUBISHI POWER

Hydrogen Consumption Plan

- Limited hydrogen supply for each test → critical to manage usage.
- Each H_2 ramp-up point before 50% H_2 is a first-time operating condition for the GT.
- Uncertainty in tuning durations (combustion, water injection, pressure regulation) and troubleshooting.
- Test plan detailed minute-by-minute with hold points, tuning, and ramp rates.
- Operators made real-time adjustments to test step durations based on hydrogen tank feedback during testing.



Testing Organization & Preparation

- ~20 additional personal supporting testing
  - 3 in Control Room
  - 10 monitoring in adjacent room
  - 7 stationed at hydrogen and water injection equipment
- Critical to align all testing and plant personnel with plans and commissioning procedures via advance walkthroughs.

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

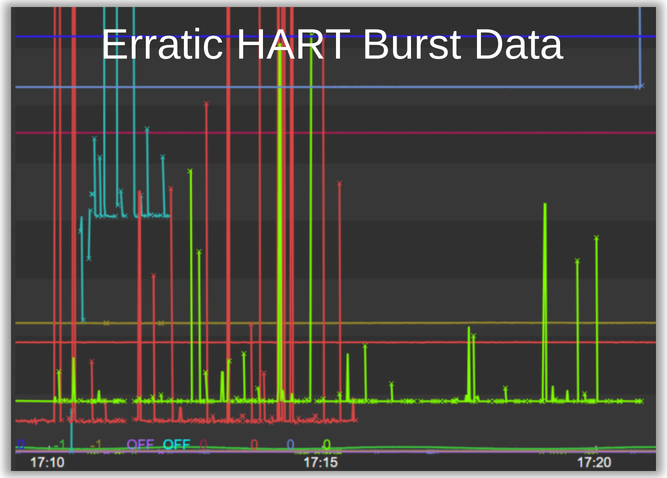
Obstacles overcome during testing

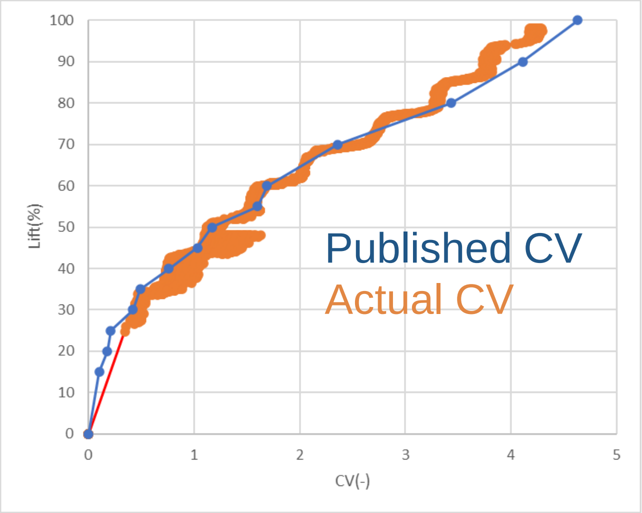
Hydrogen Flow Meter
- Erratic HART Burst Digital Data from Flow Meter Transmitter
- Tested well in static condition, but unreliable in flowing condition
- Analog signals recommended for future testing

Water Injection Flow Control
- Anti-cavitation flow control valves selected for high differential pressure operation
- Stepped CV curve discovered in testing, made flow control difficult
- VFD on pump used instead, new control logic developed
- Recommend to review cage design with supplier
- Recommend shop flow testing with more travel points than provided by the supplier

Self-Contained Hydrogen Pressure Regulators
- A sudden shutoff in flow can compromise seat tightness
- Pressure overshoots during filling
- Solar load increases pressure in static condition
- Recommend additional features to vent off pressure when constrained by downstream design pressures

Delays
- Lighting strikes
- Grid electricity demand required low trip risk operation
- Unplanned BOP maintenance





Water Injection Valve Flow characteristics

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

Conclusions

- Successfully demonstrated co-firing up to **50% hydrogen** on a commercially operating GT at baseload.
- Quantified **turndown emissions improvements** achievable with **30% hydrogen dry co-firing**.
- **Applied best practices** from the 2022 20% hydrogen demonstration at a larger scale **with success**.
- **Minute-by-minute** hydrogen consumption **planning** and monitoring **ensured test completion** within limited supply.

Special Thanks to Southern Company, Georgia Power, and EPRI for supporting this demonstration.

© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

Q&A

Mitsubishi Power is a power solutions brand of Mitsubishi Heavy Industries.
© 2025 Mitsubishi Power Americas, Inc. All Rights Reserved.

MITSUBISHI
POWER

MOVE THE WORLD FORWARD

MITSUBISHI
HEAVY
INDUSTRIES
GROUP