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Advanced Mixed Mode Combustor for Hydrogen F-Class Retrofit

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NETL Program Monitor - Mark Freeman

Gas Power | DoE UTSR Workshop 2024

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Program Goals

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Target Engine:
GE Gas Power proposes a combustor module that can be retrofitted to an existing F-class gas turbine, capable of running at current F-class performance and emissions on high hydrogen content fuels. For this proposal, the fleet of over 900 7Fs is the target. Specifically, the 7F.03 version is assumed to be the performance base-line.

Performance Targets:
- Maintain Simple Cycle heat rate on hydrogen fuel equal to or better than current product running on Natural Gas.
- Produce less than 25ppm NOx while operating on 100% Hydrogen, with a stretch goal of 9ppm. O_2 & H_2O impacts to be removed.
- Turn down to < 20% gas turbine load while operating on Natural Gas.
- Run with 100% hydrogen, 100% natural gas, and set mixtures of both.

Technology Readiness Levels	Starting Status	Current Status	Projected Ending Status
Technology Element 1 - Hydrogen-capable Axial Fuel Staging Injector, H2AFS	TRL4	**TRL5**	TRL6
Technology Element 2 - Hydrogen-capable Axial Fuel Stage, consisting of multiple H2AFS injectors	TRL4	TRL4	TRL6
Technology Element 3 – Advanced Mixed Mode Hydrogen Retrofit Combustor (implements Mixed-Modes)	TRL4	TRL4	TRL6

How Do We Engineer Combustors for Hydrogen?

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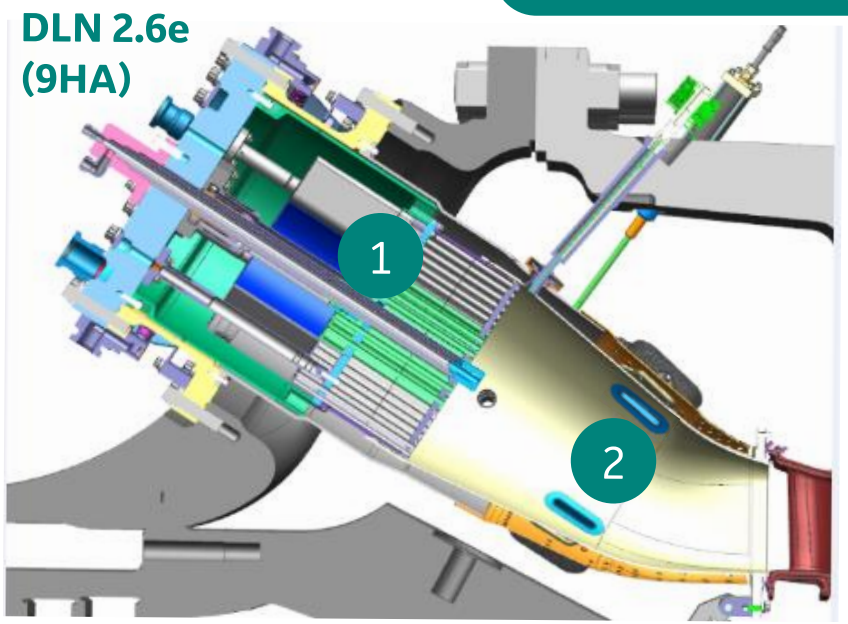
Main Focal Areas:

- Robustness: Flame Holding & Flash Back
- NO_X Emissions
- Pressure Drop
- …
- Operability, NG to 100% H_2
- H_2 Embrittlement, HEE

Key elements of High H_2 premixed systems:
1. Micro Mixer
2. Axial Fuel Staging



Premixers:

General guidance, for Micro Mixers or otherwise

- High velocities… in the right direction
- Clean flow path. Avoid steps/gaps.
- Restrict time in the premixer

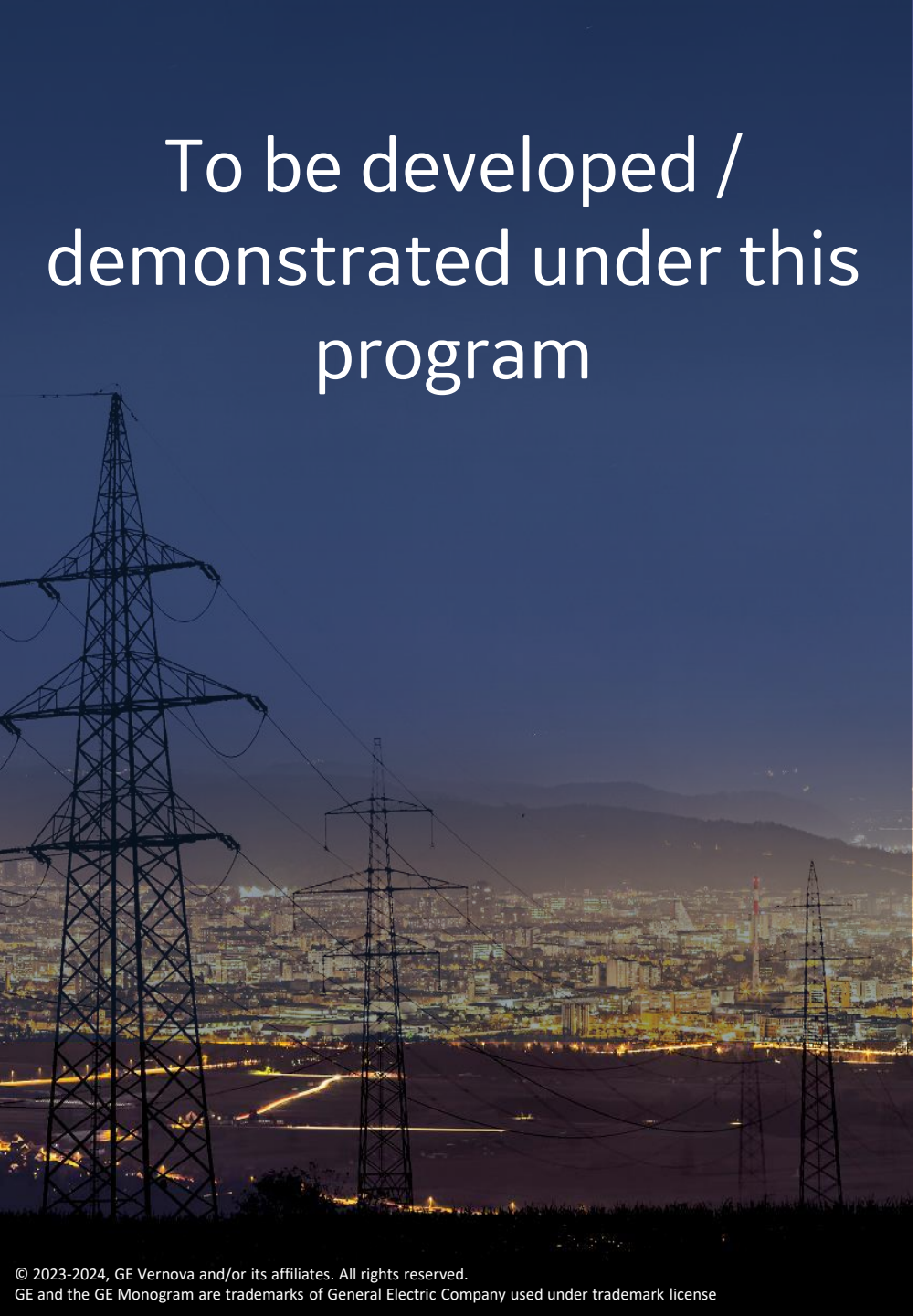
Axial Fuel Staging:

- Lowers system NOx
  Position injectors close to the exit, with a large fraction of the air & fuel.
- Spreads out heat release. dynamics benefits
- Staging options give part-load flexibility

Dynamics:

- Use of 3D acoustic finite element models
- Flame Transfer Functions (FTFs)
- Engineered air & fuel side impedances
- Dampers

To be developed / demonstrated under this program



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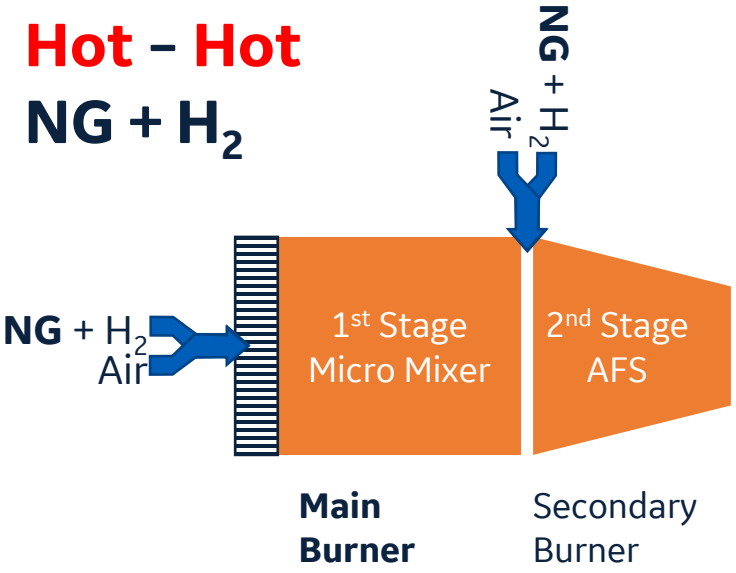
The proposed technology builds upon GE Gas Power's proven Micro Mixer and Axial Fuel Staging technologies, yet is distinguished by:

- AFS injectors (H2AFS) for high hydrogen fuels
- Cool-Hot (Mixed Mode) operating mode for high hydrogen fuels

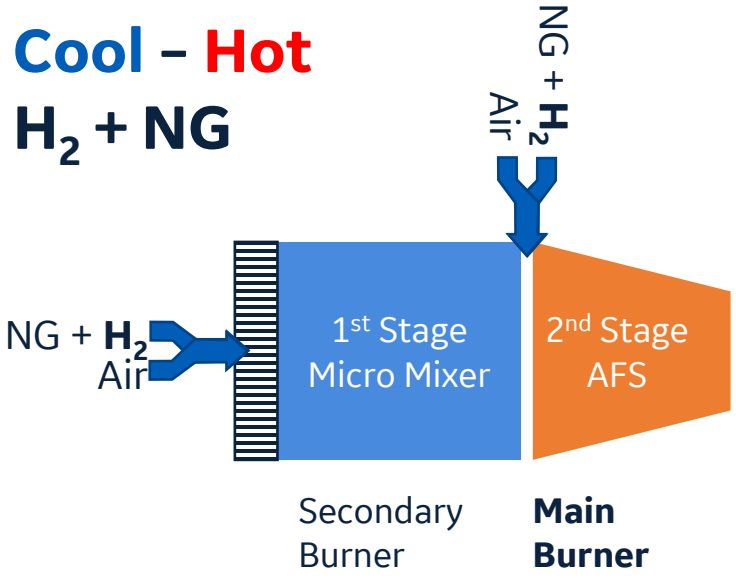
Hot – Hot

$NG + H_2$



Cool – Hot

$H_2 + NG$



Program Tasks

	Task 1	**Project Management**
	1.1	Project Management Plan
BP1	**1.2**	Technology Maturation Plan
	Task 2	**Gen I Combustor Engineering**
	2.1	Define Preliminary Test Plans
	2.2	Gen I Hydrogen Injector Engineering and Fabrication
	2.3	Gen I Subscale Hydrogen Injector Testing
	2.4	Gen I Mixed Mode Combustor Engineering and Fabrication
	2.5	Gen I Hydrogen Fuel Supply Engineering and Fabrication
	2.6	Hydrogen Embrittlement *Study*
	Task 3	**Gen I Combustor Testing** **Gen II Combustor Engineering**
	3.1	Finalize Test Plans
BP1	**3.2**	Gen I Mixed Mode Testing
BP2	**3.3**	Hydrogen Fuels Startup Study
BP2	**3.4**	Hydrogen Embrittlement *Materials Tests*
BP2	**3.5**	Gen II Combustor Engineering and Fabrication
	Task 4	**Gen II Testing, F-Class Retrofit Combustor Conceptual Design**
BP3	**4.1**	Hydrogen F-Class Performance Studies
BP3	**4.2**	Gen II Mixed Mode Testing
BP3	**4.3**	F-Class Retrofit Combustor Conceptual Engineering and Deployment Plan
	Task 5	**Final Report**

Program Details:

- 4-year program duration
- 3 budget periods (tasks 2, 3, 4)
- Started Oct 1st, 2022. ~2 years into the program.
- Budget Period 1 and related subtasks are complete.

Subtasks Zoom-in

	Task 1	**Project Management**
	1.1	Project Management Plan
Tasks Complete	**1.2**	Technology Maturation Plan
	Task 2	**Gen I Combustor Engineering**
Tasks Complete	**2.1**	Define Preliminary Test Plans
Tasks Complete	**2.2**	Gen I Hydrogen Injector Engineering and Fabrication
Tasks Complete	**2.3**	Gen I Subscale Hydrogen Injector Testing
Tasks Complete	**2.4**	Gen I Mixed Mode Combustor Engineering and Fabrication
Tasks Complete	**2.5**	Gen I Hydrogen Fuel Supply Engineering and Fabrication
Tasks Complete	**2.6**	Hydrogen Embrittlement *Study*
	Task 3	**Gen I Combustor Testing Gen II Combustor Engineering**
In-Process	**3.1**	Finalize Test Plans
In-Process	**3.2**	Gen I Mixed Mode Testing
In-Process	**3.3**	Hydrogen Fuels Startup Study
In-Process	**3.4**	Hydrogen Embrittlement *Materials Tests*
Oct '24 Start →	**3.5**	Gen II Combustor Engineering and Fabrication
	Task 4	**Gen II Testing, F-Class Retrofit Combustor Conceptual Design**
	4.1	Hydrogen F-Class Performance Studies
	4.2	Gen II Mixed Mode Testing
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	Task 5	**Final Report**

2.2 H2AFS Injector Engineering and Fabrication

- 11 injectors manufactured for full scale testing
- 15 "injectors" manufactured for subscale testing

2.3 Subscale Test Campaign

- Three phases of testing complete

2.4 Gen I Full Scale Combustor (excl. H2AFS & fueling)

- Hardware manufacturing, instrumentation, and installation is complete.

2.5 Gen I Hydrogen Fuel Supply Engineering and Fabrication

- Fuel supply hardware for Gen I testing complete

2.6 Hydrogen Embrittlement Study

- Study complete. Three areas of interest identified for testing.

3.2 Gen I Mixed Mode Testing

- Five of the planned six tests complete.

3.3 Hydrogen Fuels Startup Study

- In the brainstorming / planning phase. Testing complete EOY '24

3.4 Hydrogen Embrittlement Materials Tests

- Manufacturing material test samples now. Testing complete EOY '24

Milestones

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Budget Period	Milestone #	Title	Planned Completion Date
BP1	1.1.1	Update Project Management Plan	Completed 11/02/22
BP1	1.2.1	Create Technology Maturation Plan	Completed 12/21/22
BP1	2.4.1	Complete Design of Gen I Test Hardware	Completed 6/07/24
BP2	3.2.1	Complete GEN I Mixed-Mode Testing	9/30/24
BP2	3.4.1	Downselect Approach for Hydrogen Start	12/31/24
BP2	3.5.1	Complete Fabrication of Gen II Test Hardware	9/30/25
BP3	4.2.1	Complete GEN II Mixed Mode Testing	3/31/26
BP3	4.3.1	Complete Pre-CDR Review	7/31/26
BP3	5.1.1	Complete Final Report	9/30/26

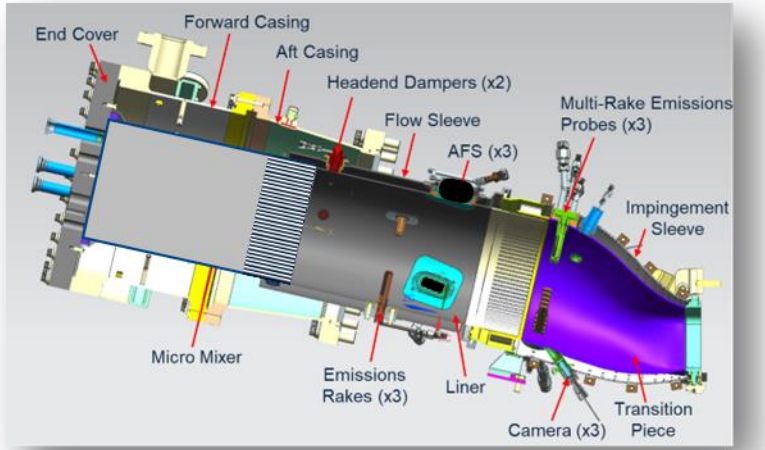
← **On-track to meet 9/30 date**

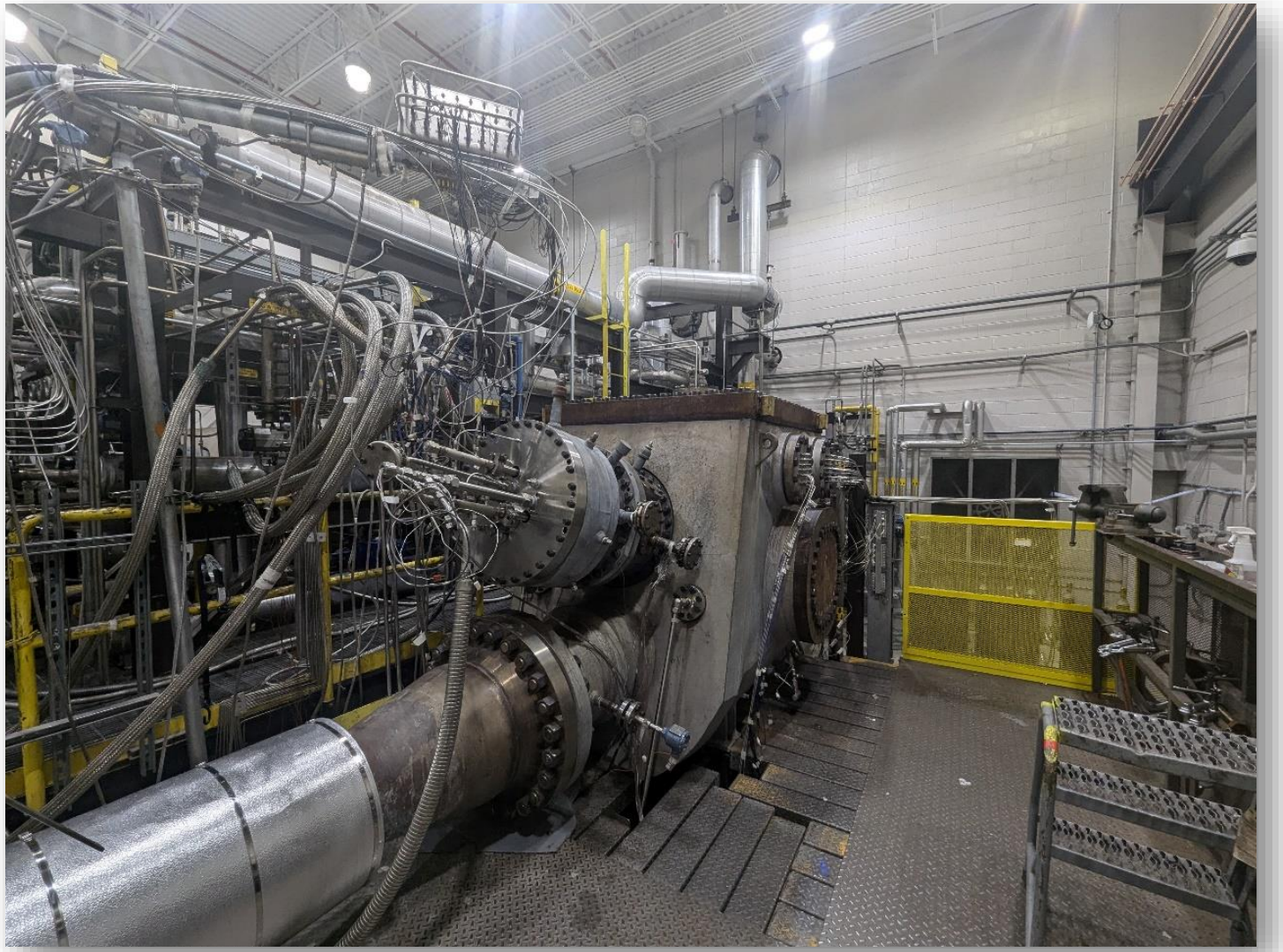
Gen I Mixed Mode Testing

First Test Completed June 20th. Everything worked well during a first test, despite the complexities. We were able to gather usable data on multiple injectors.

Since the first test, we have completed testing on four additional builds.

Test Stand Build





Test Stand Build

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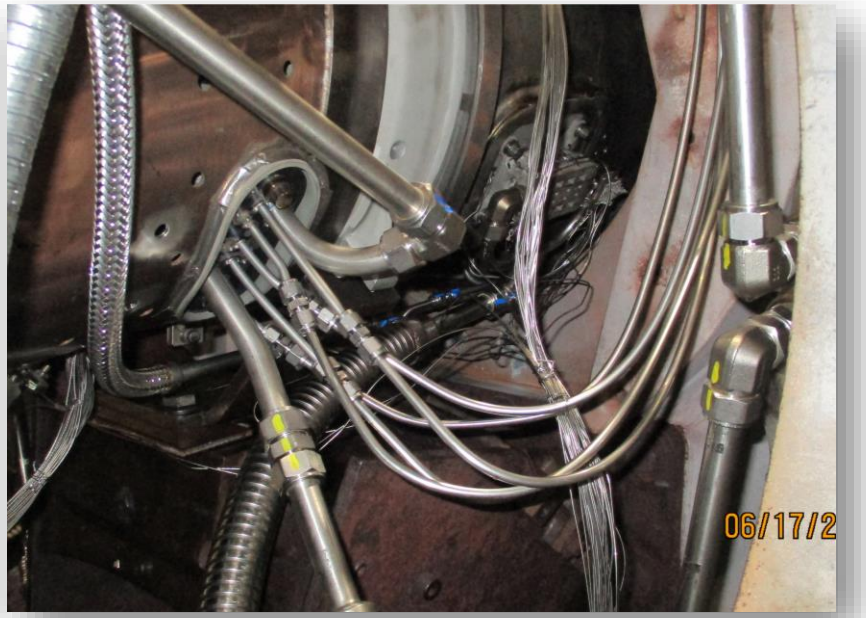
What are we looking at here?

	Standard Rake water in/out
	Standard Rake TC leads
	Standard Rake Emissions samples
3+3	Liner Rake Water in/out
3	Liner Rake emissions samples
3+3	TP Rake water in/out
3x5	TP rake emissions samples
4x	AFS Fuel Connections
4x	Dynamics pressure waveguides
3x	Camera air & video signal bundles



Supporting Equipment

5 skids in the test cell to create Hydrogen-Natural Gas blends for each of the six AFS fuel circuits.

Gen I Full-Scale H2AFS Injector Performance

May change?

Configuration	Test	Maximum Stable H_2	Maximum H_2 for robust operation*	NOx Emissions	dP/P
1	4	100%	Low	*Moderate*	Low
2	1,2,5	100%	Low	*Low*	Low
3	3	70%	Low	*Moderate*	Low
4	1	100%	Med	*High*	Moderate
5	1,2,5	100%	Med	*Moderate*	High
6	3,4	100%	100%	*Moderate*	Low
7	2,4	100%	Low	*Low*	Moderate
8	5	100%	Med	*Moderate*	Moderate
9	3,6	Last Test	Last Test	*High*	Moderate
10	6	Last Test	Last Test	Last Test	Moderate
11	6	Last Test	Last Test	Last Test	Moderate

*Full load cycle conditions

Nearing the end of the Gen I engineer / build / test cycle the team has made significant progress towards cultivating multiple concepts that operate robustly on 100% hydrogen fuel with low NO_X and dP/P. There is work to do to achieve the program goals, but we have multiple concepts that will move forward into the 2nd half of the program.

Year 3 Plans

Task 1	Project Management
1.1	Project Management Plan
1.2	Technology Maturation Plan

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Wrap up Late '24

Year 3 Focus

Task 4	Gen II Testing, F-Class Retrofit Combustor Conceptual Design
4.1	Hydrogen F-Class Performance Studies
4.2	Gen II Mixed Mode Testing
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Task 5	Final Report

Plans for year 3: Oct '24 – Sept '25:

- Wrap up embrittlement testing & H_2 startup subtasks
- Use analytical tools to look back at Gen I designs and compare with experimental data.
- Create Gen II system & H2AFS injector definition.
- Manufacture and instrument Gen II system & H2AFS injectors.

The GE team offers our sincere thanks to the NETL for supporting this collaboration, as well as numerous previous collaborations. We would not be able to do this work without your support.

Thank you!

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NATIONAL ENERGY TECHNOLOGY LABORATORY

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