DOE Advanced IGCC/Hydrogen Gas Turbine Program at General Electric

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GE Power & Water

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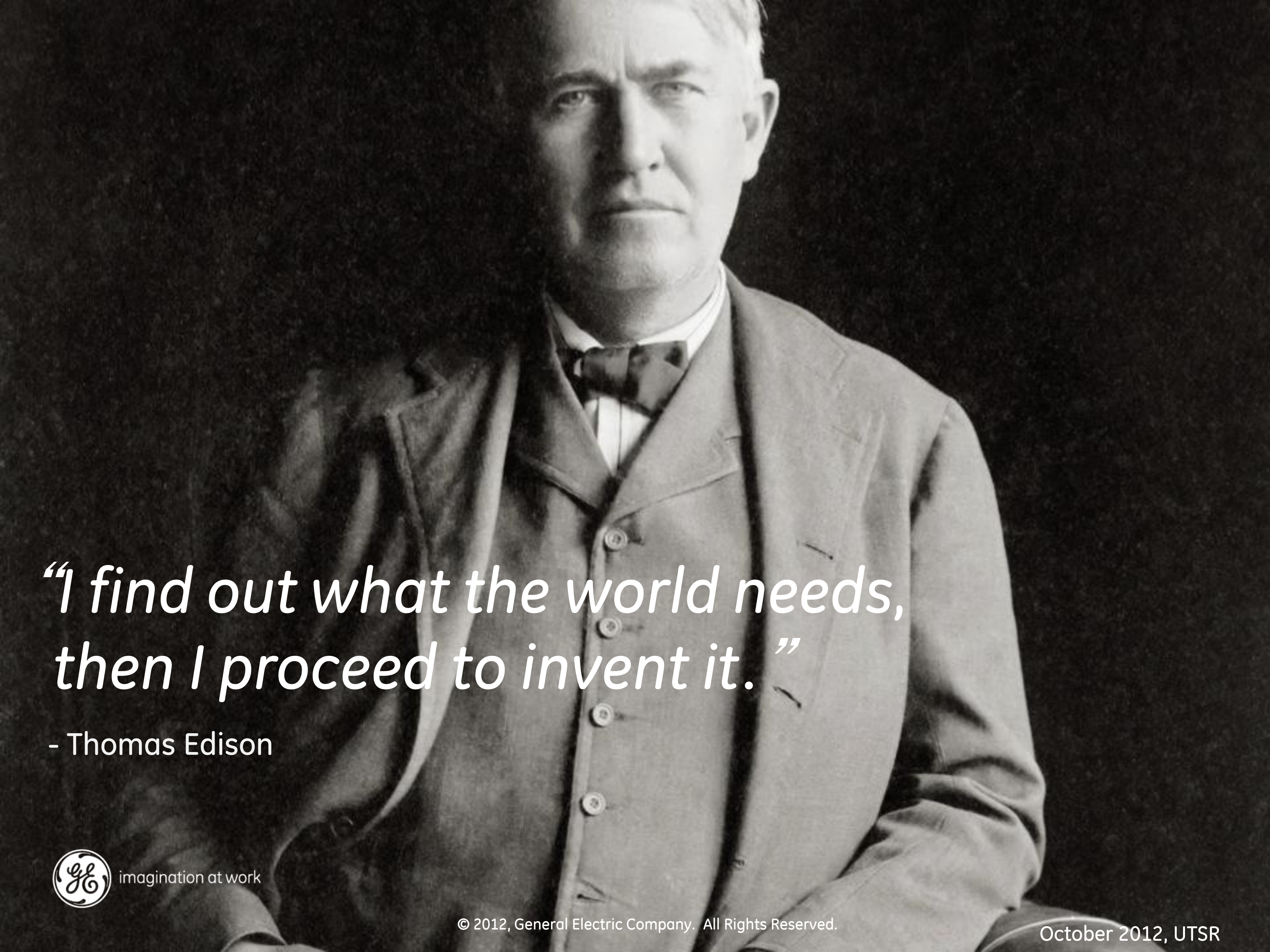
October 2012, UTSR



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Gas Turbines
– A Technology Driven Product

First U.S. Electric Utility Gas Turbine
OG&E, 3500kW - 1949

GE FE50
510MW, 61%

Fundamentals . . .

Innovation . . .

Validation . . .

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DOE Advanced H_2/IGCC Gas Turbine Program

DOE goals

✓ **Performance:** +3 to 5 % pts efficiency

✓ **Emissions:** 2 ppm NOx by 2015
Fuel flexibility – Syngas & H_2

✓ **Cost:** Contribute to IGCC capital cost reduction

Program timeline

'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	2015	TBD

IGCC /CCS – H2 GT (7F class)
- **Phase I** – Conceptual
- **Phase II** – Component Validation & Development
- **Phase III** – (Not currently awarded)

IGCC/CCS for smaller Industrial Apps (6FA class)
- **Phase II - ARRA** – Acceleration, Application, and Adaptation

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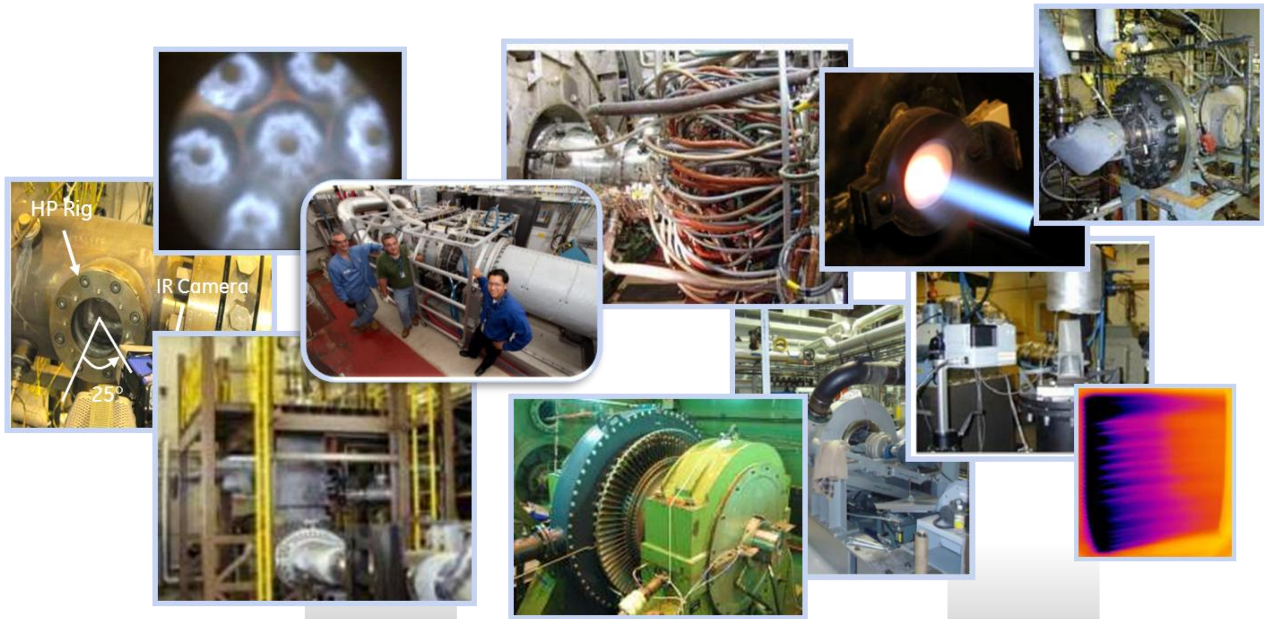
Technology Advancement

	emissions	efficiency	output	cost
• Combustion	✓	✓	✓	✓
• Turbine	✓	✓	✓	✓
• Materials	✓	✓	✓	✓
• Systems	✓	✓	✓	✓



IGCC-CCUS Industrial

IGCC-CCUS Power

NG Combined Cycle

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Validation --- Test & Learn

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Pre-Mix H2 Combustion . . . 6+ yr Journey

(many said it could not be done)

Challenge

NOx

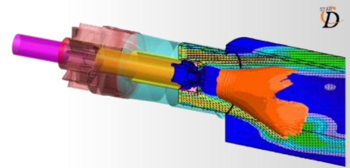
Flashback

Dynamics

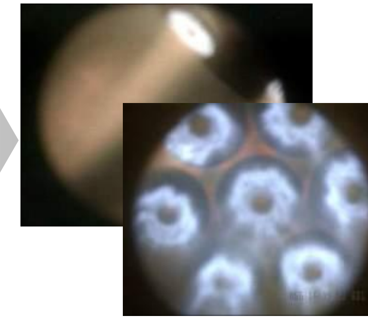
Fuel Flexibility

H2 Fundamentals

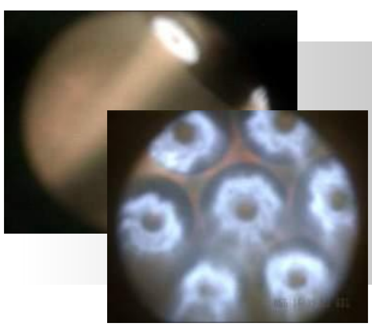
Sub-Component



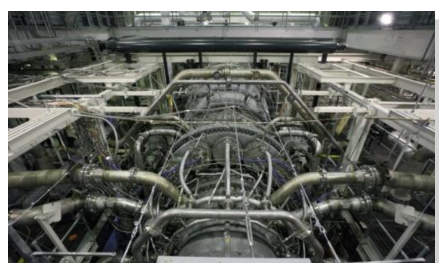
Subscale Test



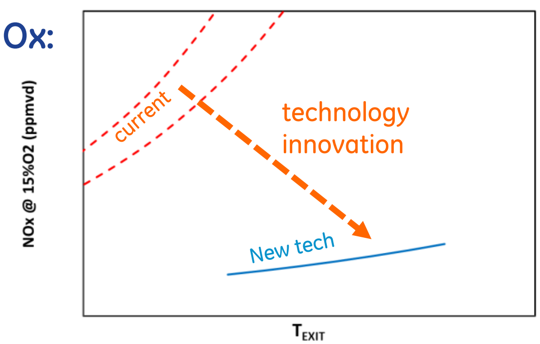
Full Size Test



Engine Test



NOx:



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Approaches to Hydrogen Combustion

- Diffusion combustion systems with diluent for NOx abatement – Current approach for GT syngas and high-H2 combustion systems.
- Swirl-based lean premixed systems – Cheng (2008), Brunetti et al. (2011)
- Lean direct injection (distributed diffusion) systems – Marek et al. (2005), Weiland et al. (2011)
- Distributed lean premixed systems – Funke et al. (2011), Asai et al. (2011), Lee et al. (2009), Hollon et al. (2011)

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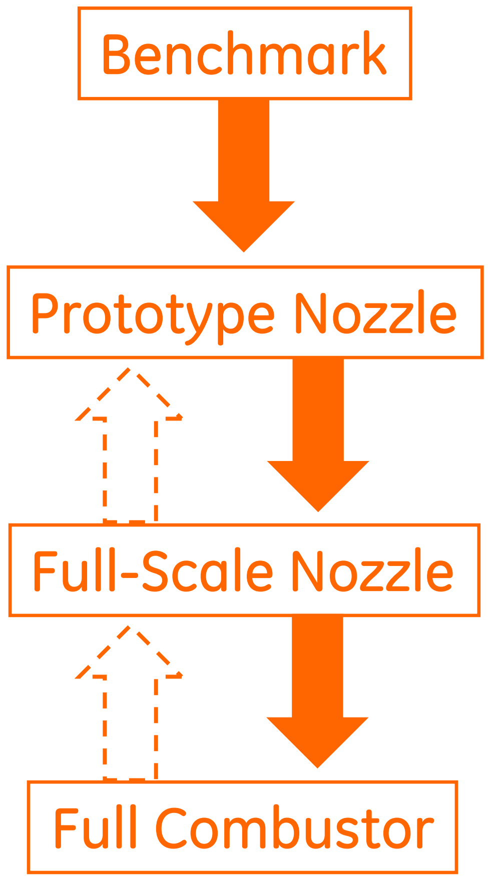
Experimental Facilities Overview

Entitlement Emissions Rig - Perfectly-premixed NOx emissions

Small Single Nozzle Rig – Operability (flashback), emissions

Full-Scale Nozzle Rig – Operability, emissions, flame holding screening (optical access)

Full-Can Rig – Multi-nozzle operability and emissions



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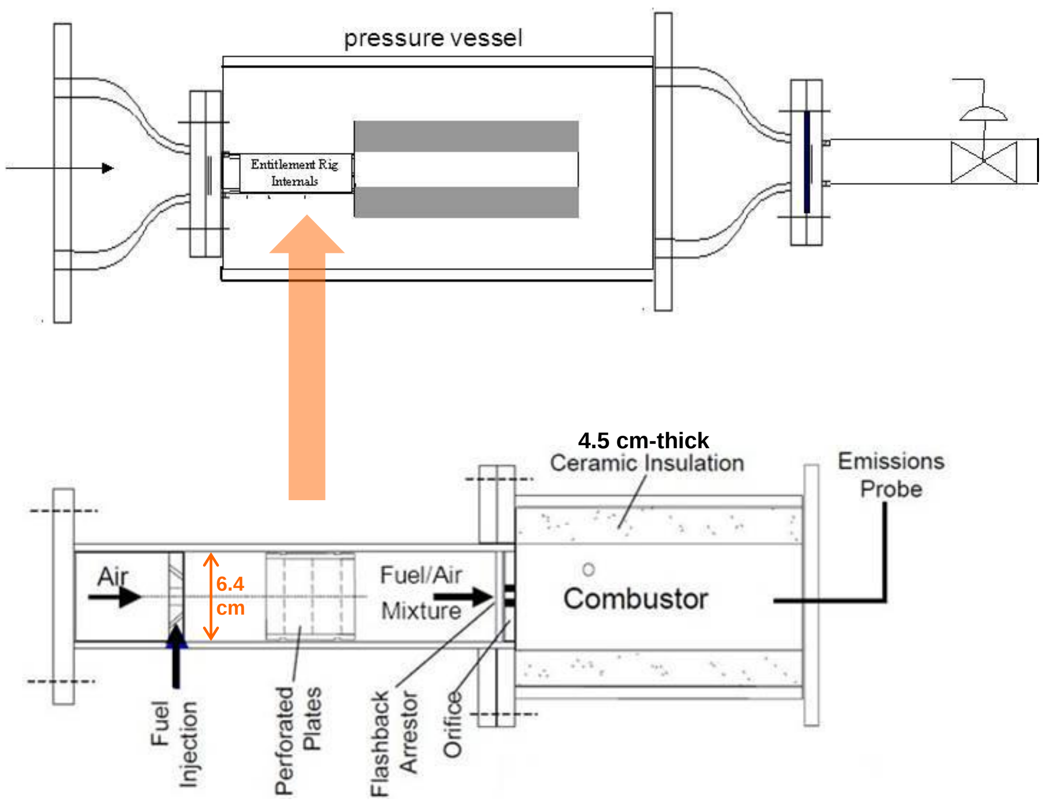
Entitlement Emissions Rig

Measured emissions from perfectly-premixed combustion in small rig (capable to P=20 atm) with orifice plate and dump combustor.

Varied flame temperature, pressure, residence time, and fuel composition.



Emissions Measurements:

- Two water-cooled sample probes immersed at combustor exit
- One probe capable of traversing exit
- Concentrations of NOx, CO, CO2, O2, and UHC continuously measured
- Uncertainty analysis: NOx ± 0.3 ppmVd with 99% confidence interval.

Flame Temperature Measurements:

- Calculated from measured O2 concentration in exhaust (local and area averaged)
- Within 15K of adiabatic calculations based on fuel and air flow rates.

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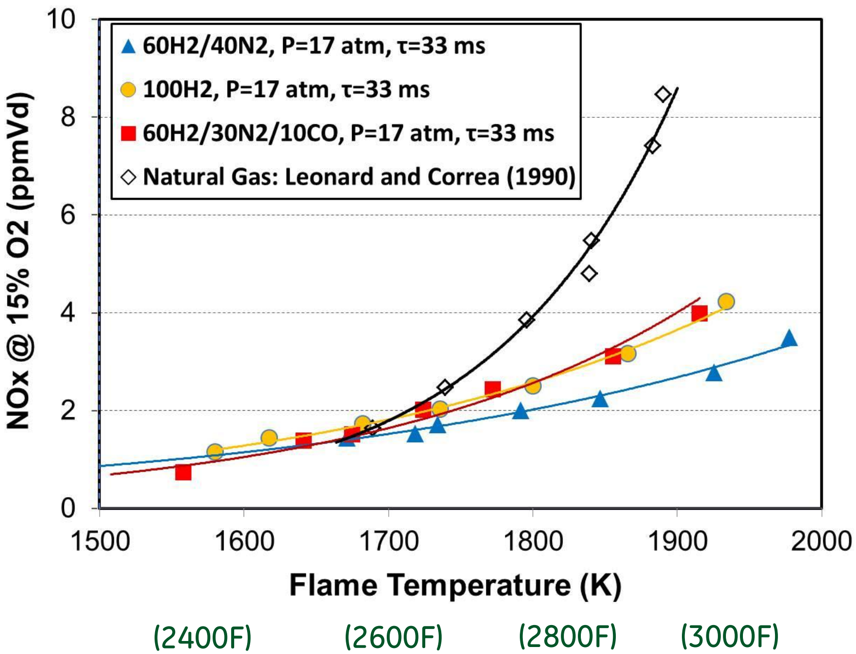
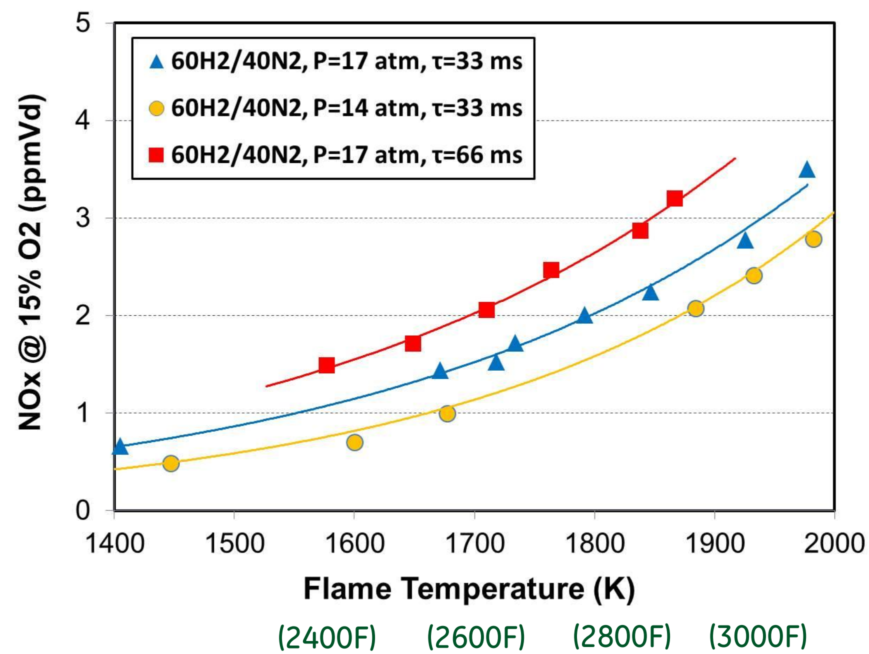
Entitlement Emissions

NOx emissions from perfectly-premixed combustion of high-hydrogen fuels

Effect of Fuel Composition



Effect of Pressure and Residence Time



Fundamentals

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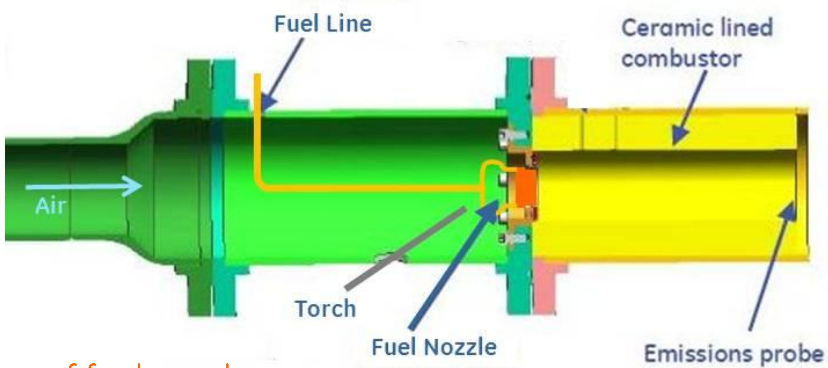
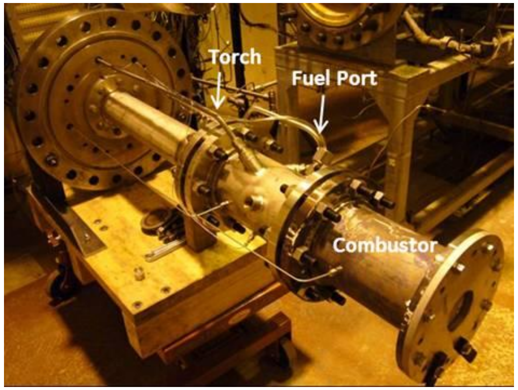
Single Nozzle Rigs

Small rig for prototype nozzles

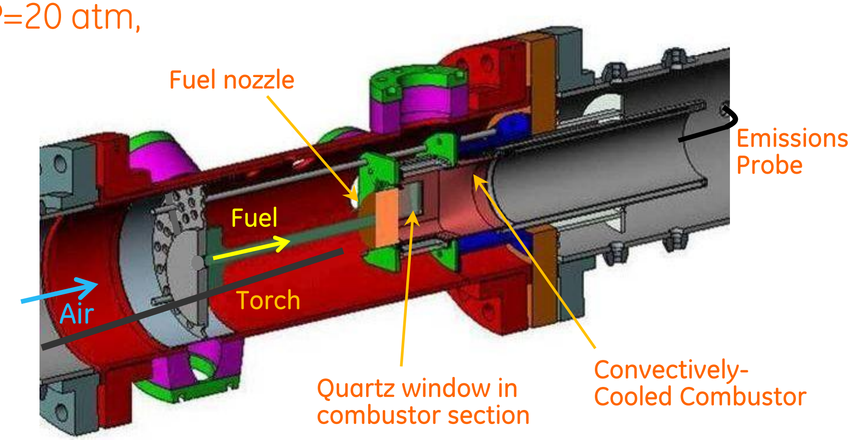


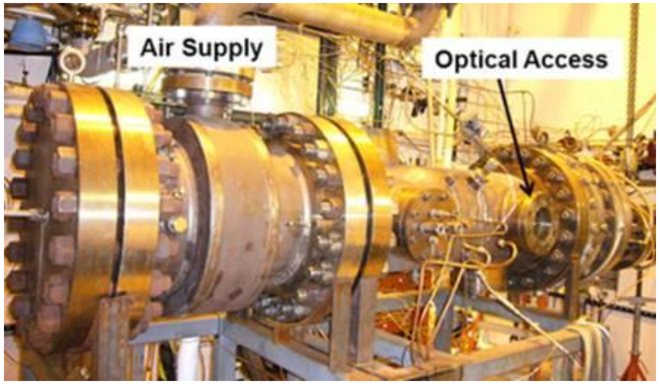


Torch installed upstream of fuel nozzle used for light-off and flame holding tests

Full-scale nozzle rig with optical access

Capable to P=20 atm,
T_{in} = 730K





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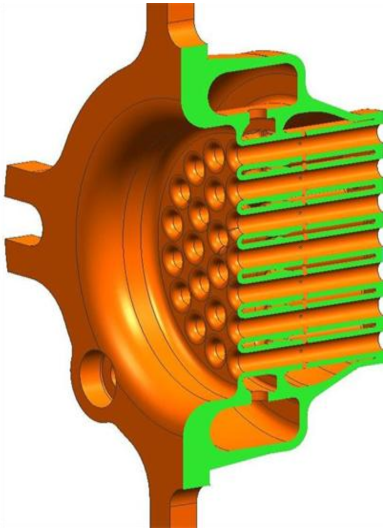
Multi-Tube Mixer

The multi-tube mixer is a distributed, premixed approach to combustion of high-hydrogen fuels.



- Jet-in-crossflow mixing of fuel and air in millimeter-scale, straight tubes.
- Multiple fuel holes at one axial location per air tube.
- Air velocity above flame speed, with reasonable pressure drop.
- Mixing length (L_{mix}/D) may vary based on fuel and conditions.

Small prototype MT Mixer

Multi-tube mixer is easily scalable without changing fundamental geometry and adaptable to range of fuels.

Larger scale MT Mixer Nozzle

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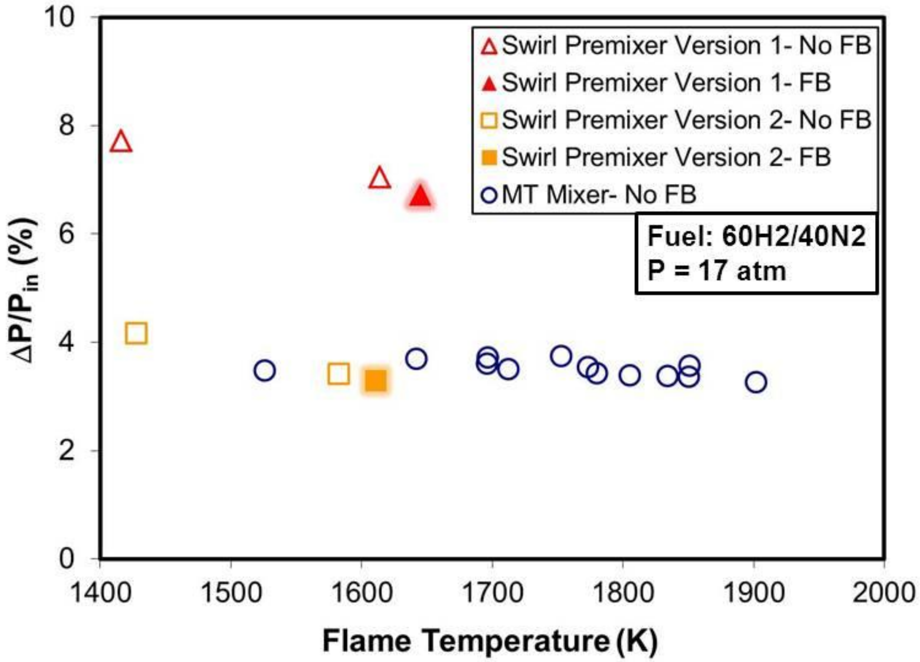
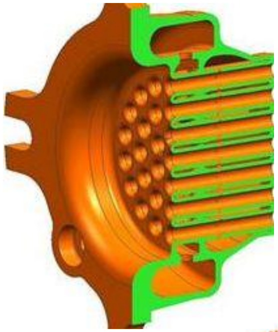
MT Mixer Flashback Resistance

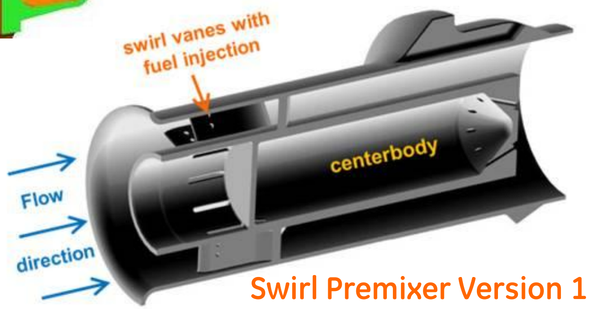
Multi-tube mixer tested in small single nozzle rig for flashback on H_2-N_2 fuel.

- Fix air flow rate, inlet T and P, then increase fuel flow to increase flame temperature.
- Four thermocouples embedded in nozzle near face detect a flashback event.



(2400F) (2600F) (2800F) (3000F)





MT mixer tested above 1900K on hydrogen fuel with a reasonable pressure drop, and no flashback was observed.

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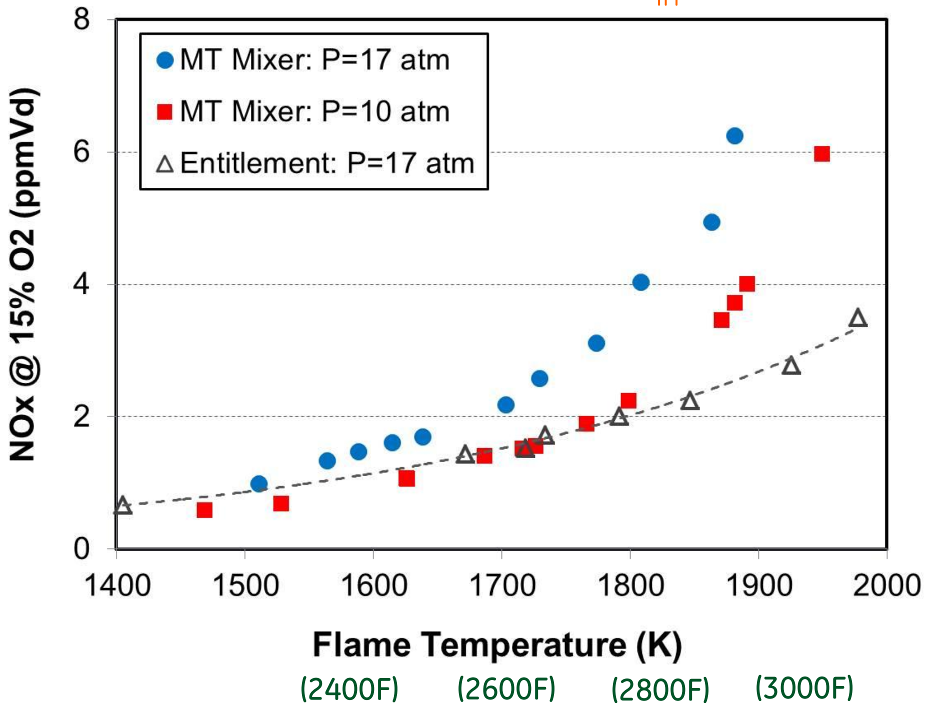
MT Mixer Emissions

NOx emissions measured with prototype multi-tube mixer in small single nozzle rig with H2-N2 fuel

Fuel: 60% H2 – 40% N2, T_{in}=650K



Low single-digit NOx emissions, but above entitlement – a trade for robust high-hydrogen operability.

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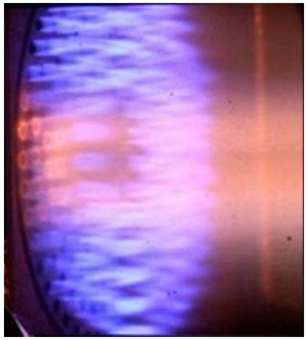
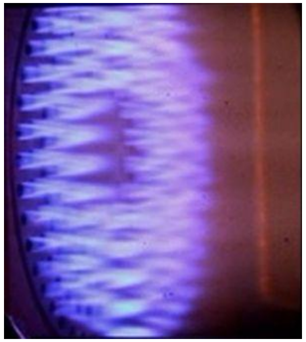
MT Mixer Flame Holding Testing

The flame holding test is more aggressive than flashback screening and is used to assess premixer robustness; Flame holding depends on internal fluid dynamics.

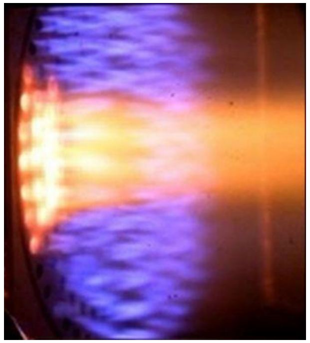
- Upstream H2 torch ignited for ~3 seconds to send flame through premixer, then extinguished.
- Flame holding (failed test) indicated by camera observation and multiple thermocouples.
- Studied effects of "minor constituents" in the fuel (CH4, CO, CO2)

Upstream torch on

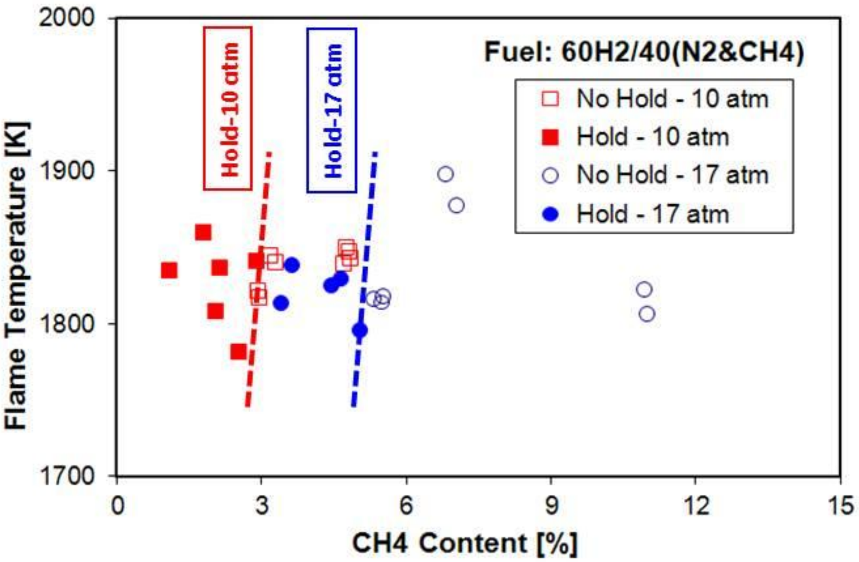




5 s after torch off
No Flame Holding



5 s after torch off
Flame Holding



Only a few percent methane in the H2 fuel affects flame holding.

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Full Can Rig Demonstration

Multi-tube mixer technology incorporated into full-can (multi-nozzle) combustion system in GE Energy Gas Turbine Technology Laboratory.

- New combustion system optimized for high-hydrogen fuel (residence time, heat transfer)
- > 10 MW combustor (energy conversion rate)

Operating experience:

- Over 20 rig tests on high-hydrogen fuel at full F-class gas turbine conditions.
- Over 100 hours with > 90% H_2 in fuel reactants by volume (balance was CH_4 or CO)
- Over 20 hours with pure H_2 fuel diluted with N_2
- Explored effects of fuel-side and air-side N_2 dilution

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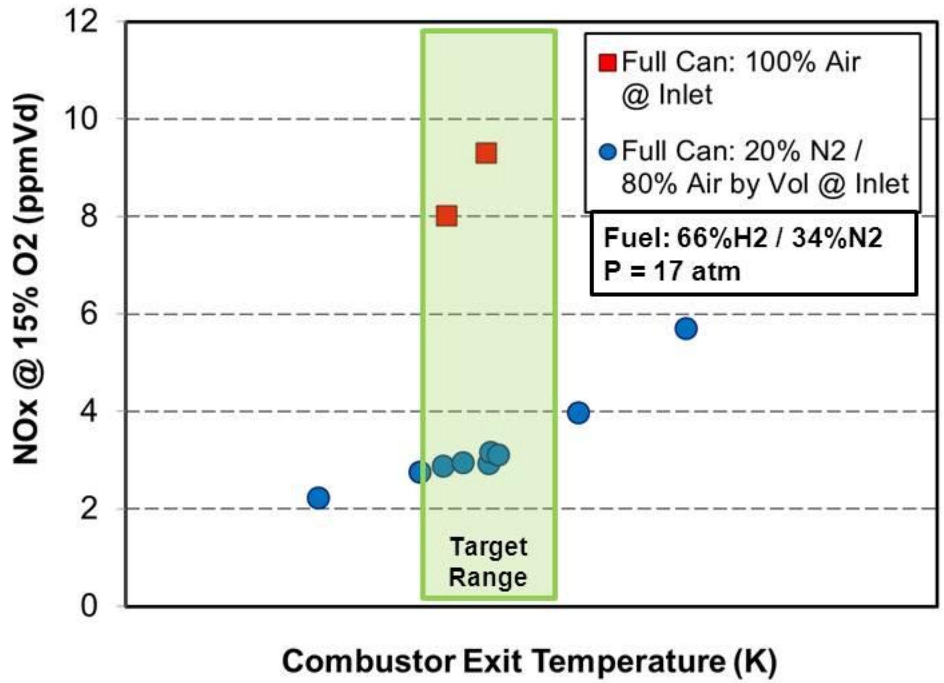
Full Can Rig Results



- Single digit NOx (corrected to 15% O2) over target temperature range with hydrogen-nitrogen fuel
- Below 3 ppm NOx (corrected) with 20% of inlet air replaced with pure nitrogen.

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Conclusions

- Single nozzle rig testing used to evaluate high-H2 operability and emissions.
  - Low single-digit NOx (ppm), but above entitlement.
  - Flashback-free operation to high flame temperatures.
  - Passed aggressive flame holding test with small amount of methane.
- Scale up to full can (multi-nozzle) combustor was successful, with >100 hours of high-H2 operation and single digit NOx measured at F-class conditions.
- The multi-tube mixer is capable of providing reliable, low-NOx combustion for advanced high-hydrogen and syngas turbines.

Published at Turbo Expo 2012 . . . GT2012-69913

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Gas Turbines
– A Technology Driven Product

First U.S. Electric Utility Gas Turbine
OG&E, 3500kW - 1949

GE FE50
510MW, 61%

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Acknowledgements

Special thanks to the US Department of Energy National Energy Technology Laboratory and their support on the DOE/GE "**Advanced Hydrogen Gas Turbine Development Program**"

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1. This material is based upon work supported by the Department of Energy under Award Number DE-FC26-05NT42643

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