Powering to a **LOWER CARBON FUTURE** with **GAS**:

THE USE OF HYDROGEN IN POWER GENERATION

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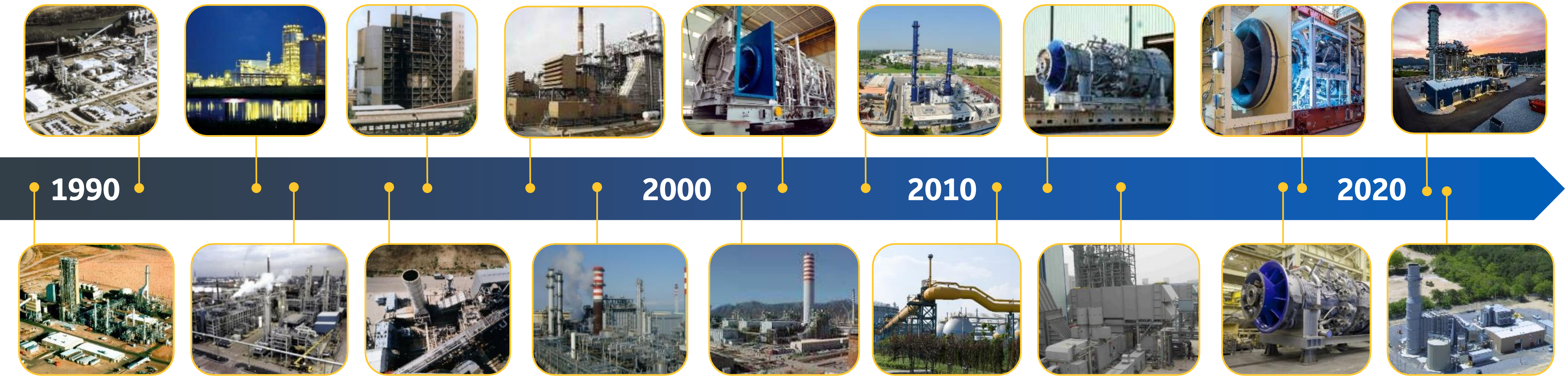
Long Ridge Energy Terminal in Hannibal, OH
485 MW 7HA.02 combined cycle plant, purpose-built to transition from natural gas to hydrogen

Outline

- Commercial experience using H_2 as a gas turbine fuel
- Technical challenges using H_2 as a gas turbine fuel
- The energy trilemma & the cost of H_2

Decades of experience with hydrogen fuel

1x7F IGCC (USA) | 1x7F IGCC (USA) | 1x6B IGCC (Europe) | 2x6F Refinery (USA) | 2x6F Syngas Refinery (Asia) | 1xGE10 High H_2 (Europe) | 2x7F Syngas coal IGCC (USA) | 2x9E Refinery (India) | 1x7HA H2 blend (US)



1x7E IGCC (USA) | 1x6B Refinery (Europe) | 1x6B Refinery (S. Korea) | 1xGT13E2 Refinery (Europe) | 3x9E Refinery (Europe) | 2xGT11N2 Steel mill (Brazil) | 2xLM2500 Steel Mill (China) | 1x7F Syngas IGCC (Korea) | 1xLM6000 H2 blend (US)

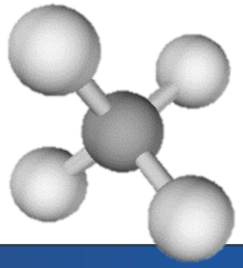
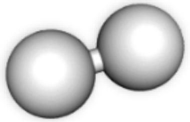
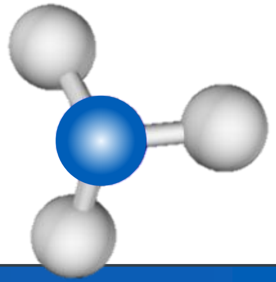
7HA Hydrogen Blending & Operation Demonstration
Long Ridge Energy Terminal, Hannibal, OH – April 22, 2022

Project highlight video available online

LM600 NYPA Brentwood Hydrogen demonstration project
Brentwood Power Station, NY

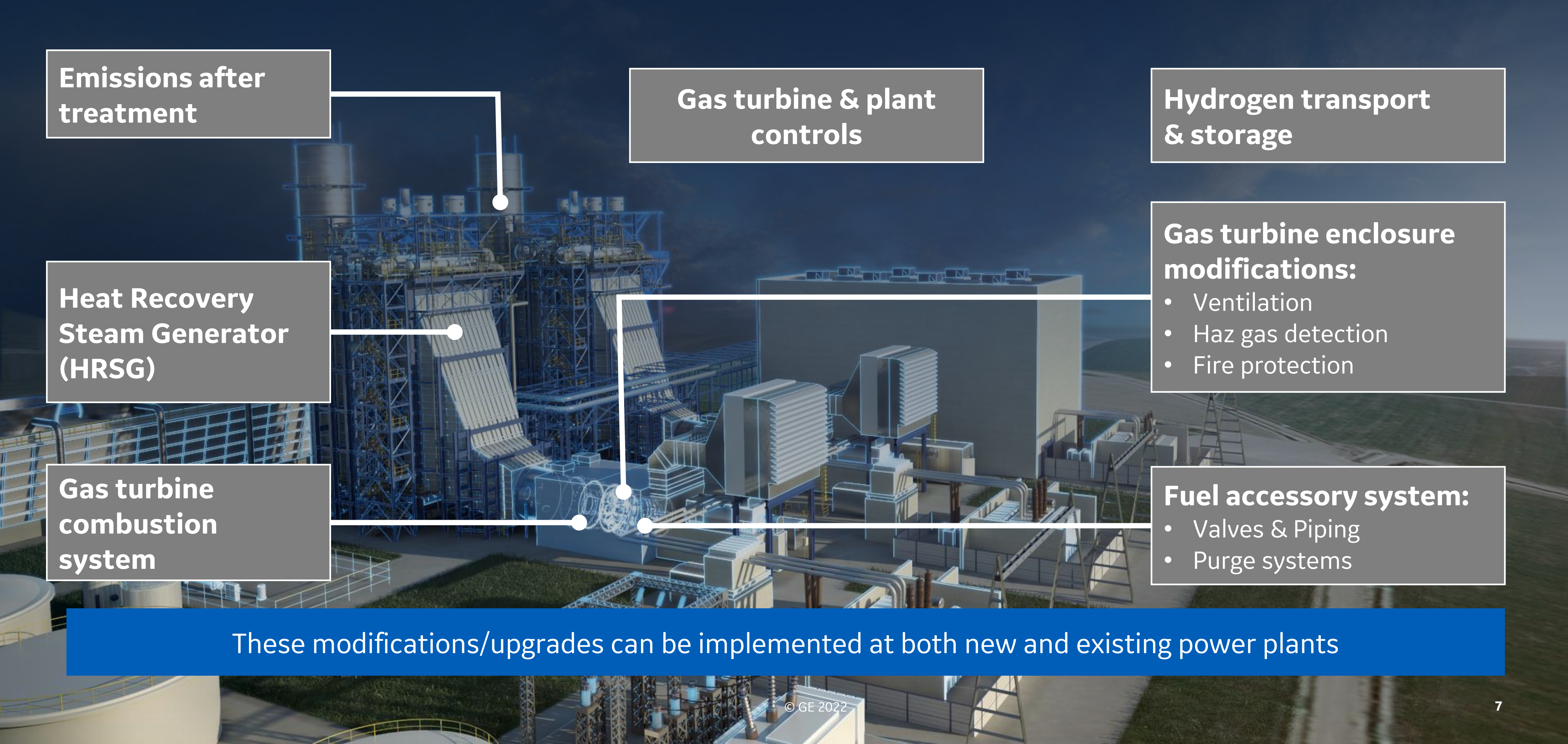
Project highlight video available online
Project executive summary available online

A tale of three molecules:
HYDROGEN, AMMONIA, & METHANE

Characteristics		Methane	Hydrogen	Ammonia
Formula		CH_4	H_2	NH_3
Molecular weight	grams/mol	16	2	17
Boiling temperature	°F (°C)	-258.7 (-161.5)	-423.2 (-252.9)	-28 (-33.3)
Lower/upper flammability limits	%	4.4/17	4/75	15/28
Flame speed	cm/sec	~30–40	~200–300	~6–7
Adiabatic flame temperature	°F (°C)	~3,565	~4,000	~3,270
Lower Heating value	MJ/Nm^3 (BTU/scf)	35.8 (911.6)	10.8 (274.7)	14.1 (360)
NO_x impact (relative to methane)			~2x	~150x

Impact of hydrogen on new and existing power plant systems



These modifications/upgrades can be implemented at both new and existing power plants

Advanced premixer technology development

2005 — 2016 — 2018

Swozzle based architectures

Target premixing and flashback tolerance for NG

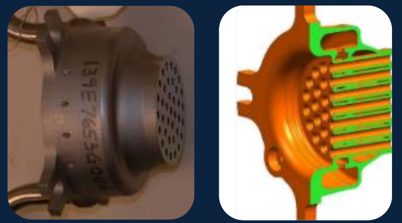
Hydrogen limits

- DLN 2.6 ~5% (vol)
- DLN 2.6+ ~15–18% (vol)

DOE High-H_2 program*

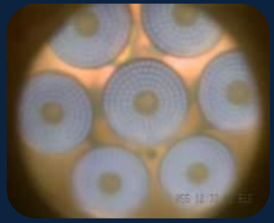
Target premixing and flashback tolerance for H_2

Small prototype

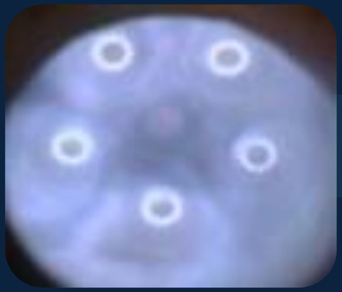


Prototype fuel nozzle

Full head end combustion test

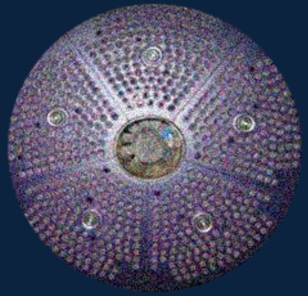


Demonstrated single digit NO_x emissions at F-class temperatures and pressures



Demo

7HA.01 TS7



DLN 2.6e commercial operation in 2021

- This technology can be applied to natural gas or H_2 fuels…decouples flashback, premixing and dynamics
- Demonstrated capability to **50%** (by vol) H_2

*US Department of Energy under Cooperative Agreement DE-FC26-05NT42564

Addressing technology challenge – advanced combustion systems

Today's options for hydrogen:

- Diffusion combustion systems which require diluent injection to meet NO_x requirements (lowering efficiency)
- Premixed combustion systems which are H_2 limited due to operability issues (flash back, flame holding)

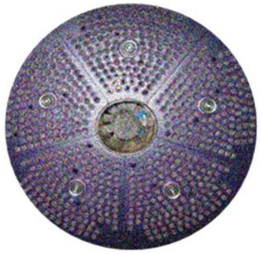
Challenges for 100% H_2:

- Flashback and flame holding
- Combustor operability
- Combustion system durability
- NO_x emissions
- Plant safety

Heavy-duty gas turbine combustion systems

Diffusion combustors
Max H_2 ~70–100%

Premixed combustors
Max H_2 ~20–30%



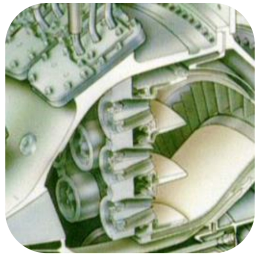
Advanced premixer
Max H_2 ~50%

Advanced premixer
100% H_2

Aeroderivative gas turbine combustion systems

Diffusion combustors
Max H_2 ~30–85%

Premixed combustors
Max H_2 ~10%



Advanced premixer
Max H_2 ~60 %

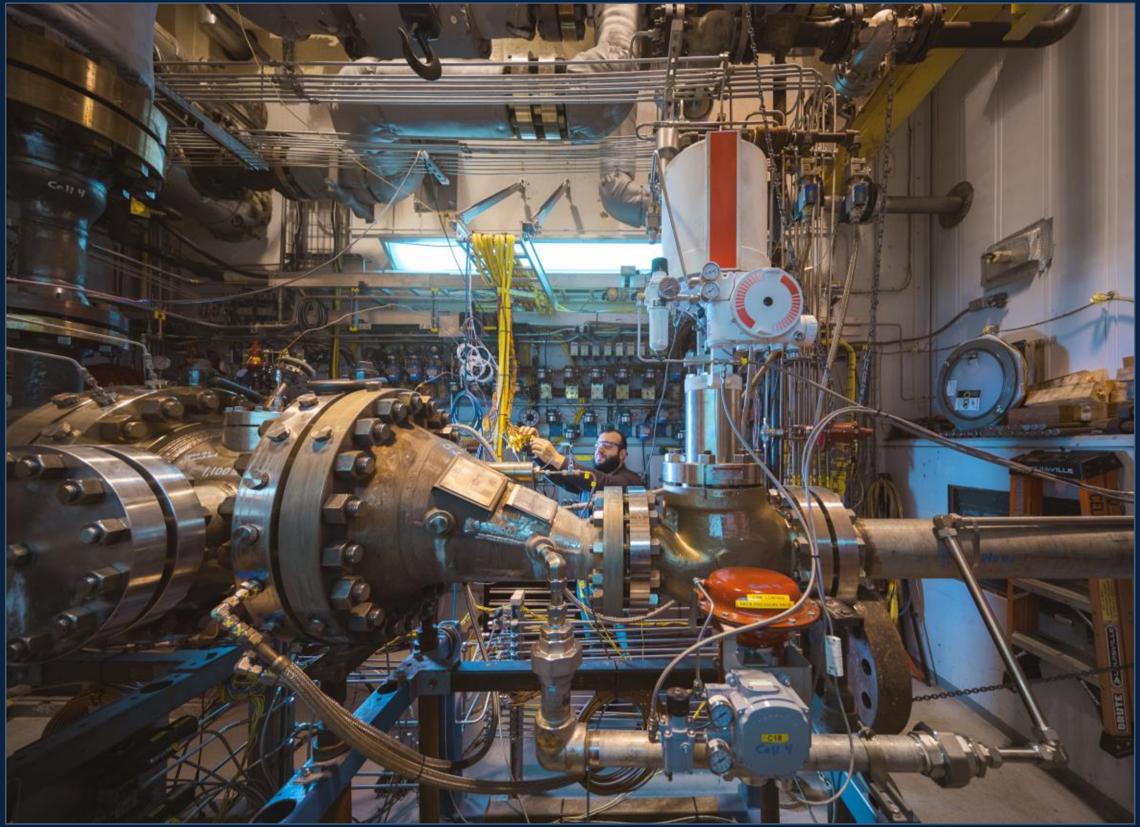
Advanced premixer
~100% H_2

Next generation combustion systems are being developed to operate on high H_2 fuels while meeting stringent emission standards

US DOE funding of GE's hydrogen combustion technology

- The US DOE has selected a GE Gas Power proposal to develop and test a retrofittable combustion module for operation with natural gas/hydrogen fuel mixtures ranging from 100% natural gas levels up to 100% hydrogen. This will project will be based on micromix and axial fuel staging technologies.

- GE's goal is to produce **< 25ppm** NOx with a stretch goal of **9ppm** NOx. (Available emissions control technology can reduce NOx from 25ppm to < 3ppm from the power plant stack.)



https://www.energy.gov/fecm/articles/additional-selections-funding-opportunity-announcement-2400-fossil-energy-based
https://www.ge.com/news/press-releases/ge-doe-accelerating-the-path-towards-100-hydrogen-combustion-in-gas-turbines

Energy Trilemma

Challenges our customers are facing for electricity generation, delivery and consumption

A mix of generation and grid solutions are required to provide the desired balance between:

- Affordability
- Reliability
- Sustainability

The balance varies significantly by region. Decarbonization actions will be determined locally.

Affordable, reliable and sustainable energy is a basic human right, critical to growing economy and fundamental to quality of life in the modern world

* Decarbonization as used herein is intended to mean the reduction of carbon emissions on a kilogram per megawatt hour basis.

Hydrogen cost conversions and comparisons

Hydrogen cost conversions

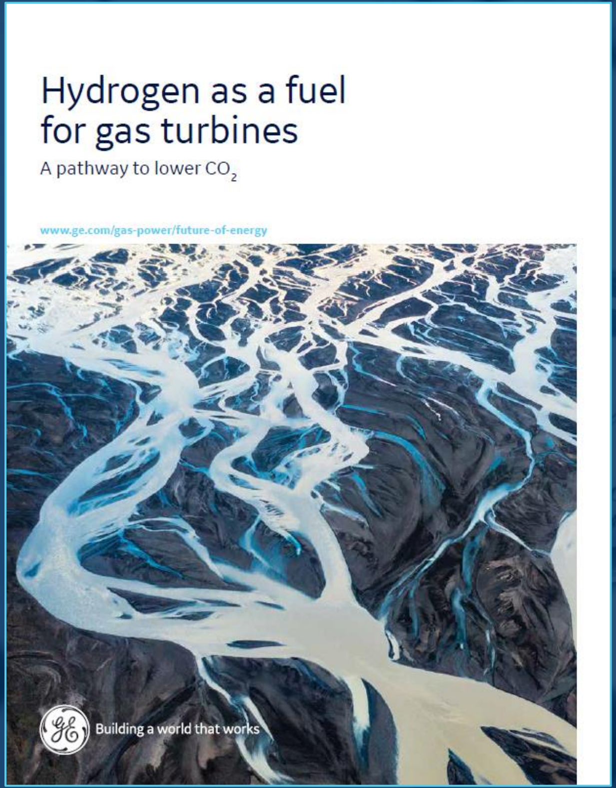
$1	$7.4	$25.2
$/KG	$/MMBTU HHV	$/MWH

Comparative fuel prices*

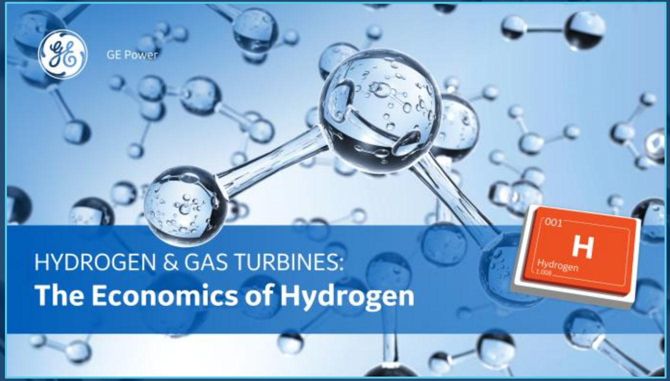
Fuel	Price ($/MMBTU)	
	~2019	2022 (Oct)
Gasoline	~26.4	~30
Jet-A (Aviation)	~11.1	~29
Natural gas (Henry Hub)	~3.8	~7.9

Externally, there is a large focus on getting (green) hydrogen to $7.4/MMBTU by 2030. This may support other industries, but it does not automatically make green hydrogen an economical gas turbine fuel

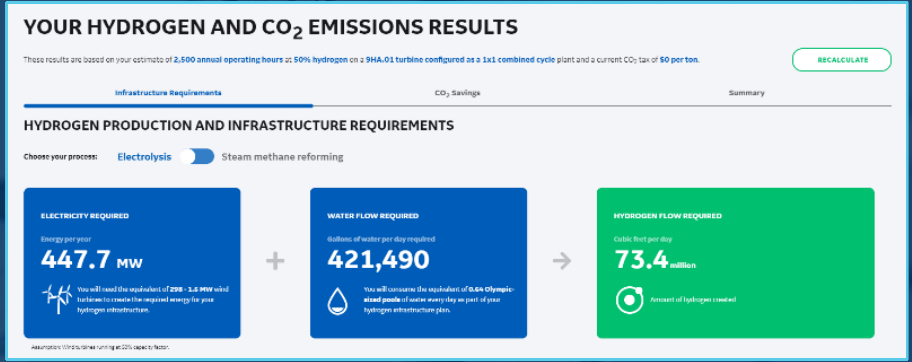
For more information: www.gepower.com/hydrogen



White paper



Webinars



Carbon emissions calculator

CUTTING CARBON PODCAST

Season 6 coming soon