GE Gas Power – Hydrogen Technology

BofA Securities Hydrogen Conference

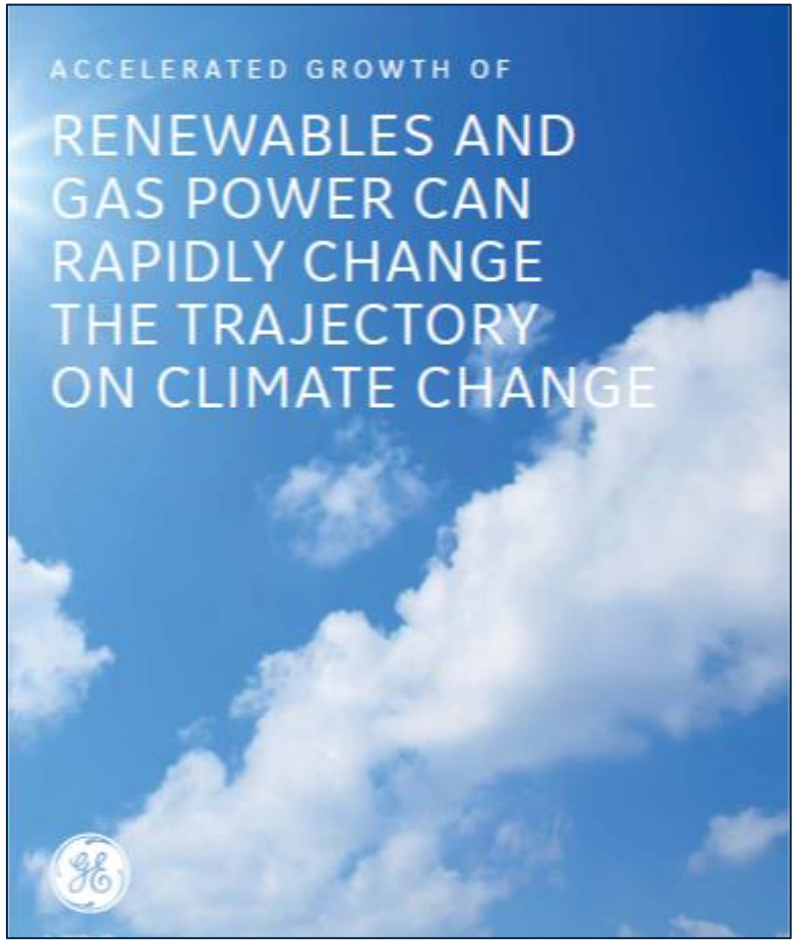
June 24, 2021

Jeffrey Goldmeer, Ph.D., Emergent Technologies Director– GE Gas Power

“**Just as energy is a human right**, so is ensuring a stable and healthy climate for each of us and for **all** future generations. We can **and must** act now.”

SCOTT STRAZIK
CEO, GE POWER

Reuters Global Energy Transition
June 22, 2021

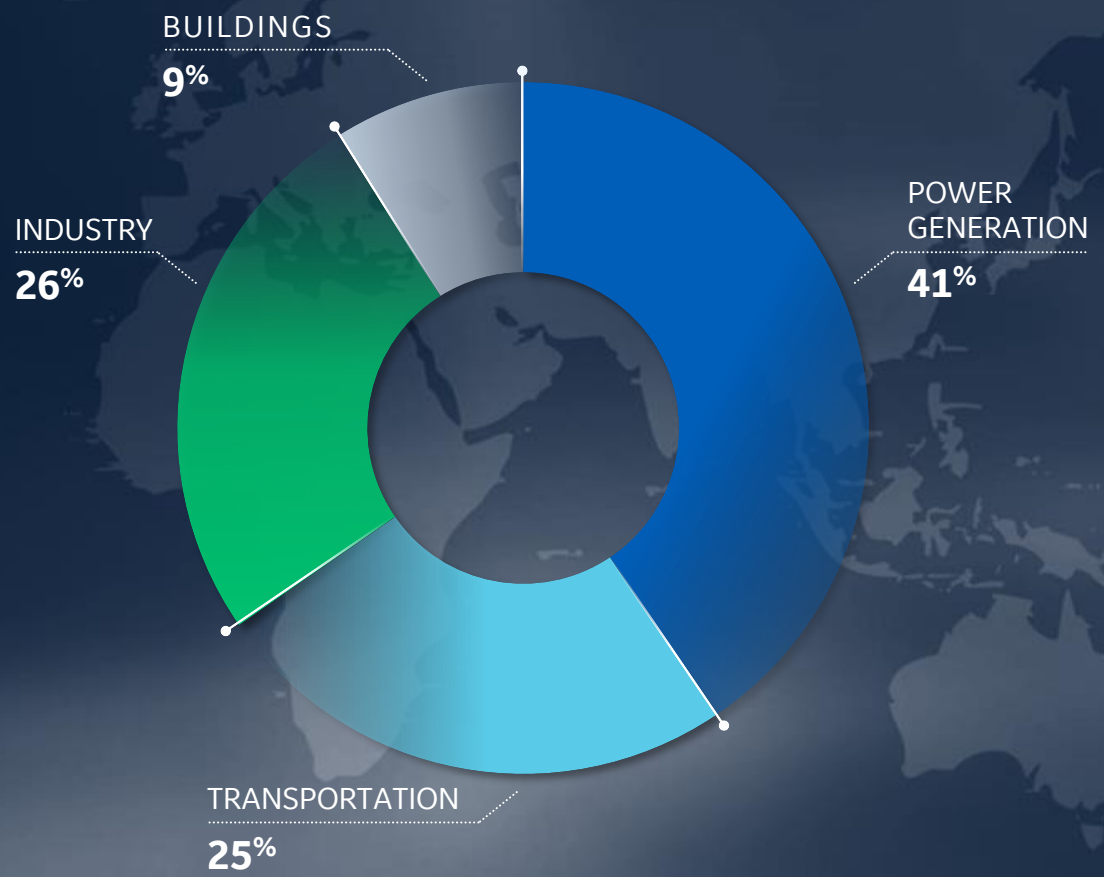


A white paper that provides GE’s view on the role that renewables and gas power can play, working together, in decarbonizing the power sector.
www.ge.com/power/future-of-energy

The world today

Global CO_2 emissions

(33.7 gigatons)



Global electricity generation

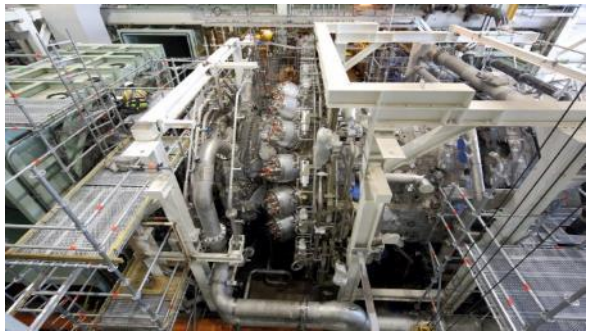
27k TWh *of electricity*

770M people *w/out power*

13.7 *gigatons CO_2*

Decarbonization* of the power sector and electrification of **ENERGY-USE SECTORS** will have the most substantial impact on global carbon emissions

*Decarbonization as used herein is intended to mean the reduction of carbon emissions on a kilogram per megawatt hour basis | Source: IEA WEO 2020



Gas turbines are integral to our power system today & will continue to provide a significant percentage of global electricity for decades

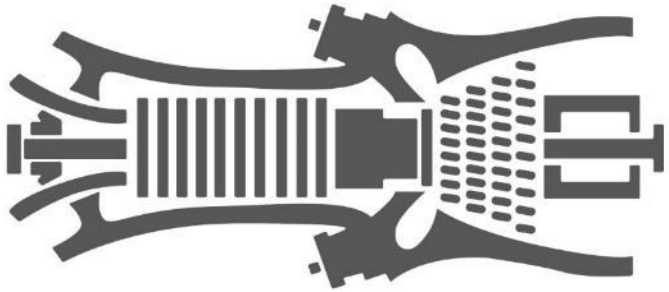
Gas turbines offer multiple technical pathways to lower and zero carbon emissions

GE is the most experienced OEM in hydrogen and similar low BTU fuel operations*

*Per McCoy Power Reports, 1980-2019

Decarbonizing gas power* … a range of options

Pre-combustion



Post-combustion

Use a zero or carbon neutral fuel

- Hydrogen (blue, green, pink)
- Synthetic (renewable) methane
- Biofuels
- Ammonia

Remove carbon from the plant exhaust

- Carbon capture (liquid solvents)
- Carbon capture (solid sorbents)
- Oxy-fuel cycles

Gas turbines are a destination technology … multiple options to achieve lower or zero carbon emissions

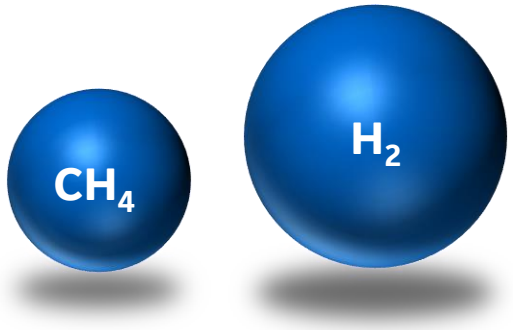
*Decarbonization as used herein is intended to mean the reduction of carbon emissions on a kilogram per megawatt hour basis

Technical pathways: hydrogen

Use of hydrogen as a gas turbine fuel requires system changes

Fuel System

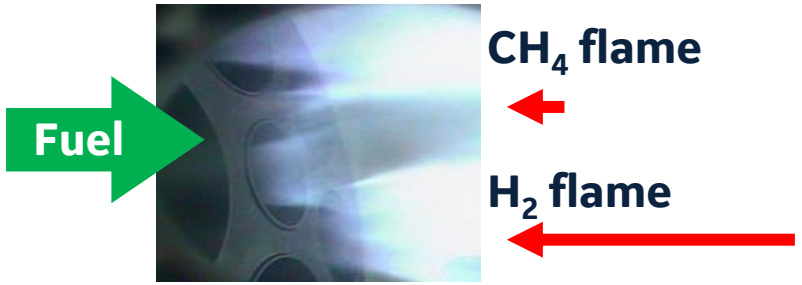
Methane (CH_4): 912 lb/ft^3
Hydrogen (H_2): 275 lb/ft^3



To deliver the same energy content, hydrogen requires 3X more volume flow

Combustion System

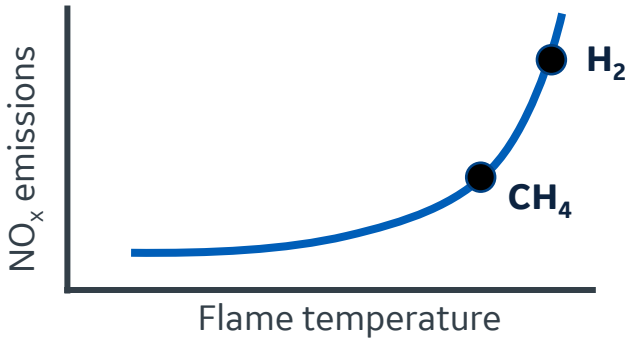
Methane (CH_4): ~30–40 cm/sec
Hydrogen (H_2): ~200–300 cm/sec



Hydrogen flames may increase risk of damage to combustion hardware

Emissions Aftertreatment

Methane (CH_4): ~3,565 °F
Hydrogen (H_2): ~4,000 °F



Operating on hydrogen may increase NO_x emissions

Operating a gas turbine on blends of hydrogen on 100% has been successfully demonstrated; may require changes to key power plant systems

Decades of experience with hydrogen and similar low BTU fuels

100% Hydrogen
GE-10 gas turbine at Enel's Fusina Power Station

Aeroderivative
2xLM2500 operating on steel mill gases with ~**58%** H_2

20+ years of operation
6B operating on high H_2 (**70-95% H2**) with more than 180k hours

F-class
4x7F gas turbines operated on a ~**5**% blend of H_2 and natural gas

More than 450 TWh of operational experience on hydrogen and similar low BTU fuels

Commercial projects using hydrogen…updates

Long Ridge Energy Terminal (USA)

- Long Ridge Energy intends to begin blending hydrogen in their **new 7HA.02** gas turbine later this year
- The owner's plan is to transition the plant to 100% hydrogen in 10 years

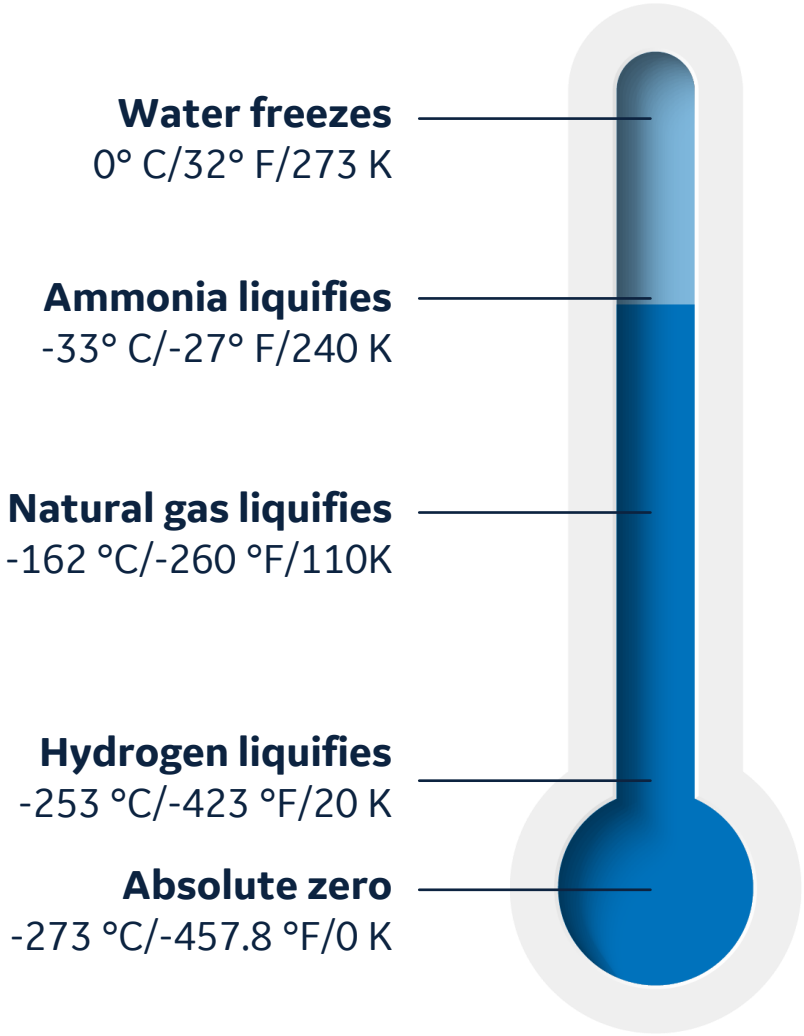
Tallawarra B (Australia)

- EnergyAustralia intends to begin blending hydrogen in their **new 9F.05** gas turbine starting in 2025
- This will be the first 9F gas turbine to operate on a blend of hydrogen and natural gas

Additional demonstration projects in development

Technical pathways: ammonia (NH_3)

The advantages and challenges of ammonia



Advantages for ammonia … transportation

- Due to extremely low temperature for H2 to liquify, new liquid hydrogen (LH2) carrier ships are required and only one of these ships exists today
- Ammonia condenses at much warmer temperatures
- Ammonia is already a global commodity that can be easily shipped at temperatures warmer than LNG

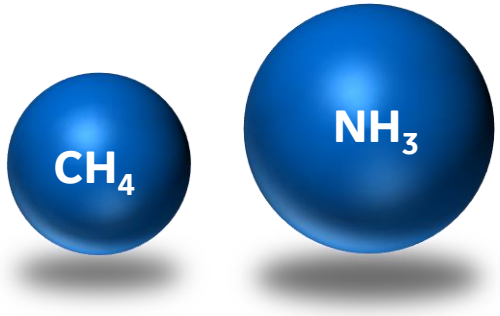
Challenges

- Ammonia can be highly toxic
- Very different chemical & combustion properties (relative to natural gas)

Use of ammonia as a gas turbine fuel requires system changes

Fuel System

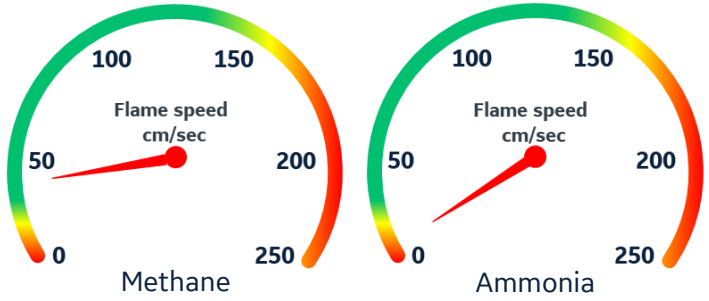
Lower heating value
Methane (CH_4): 912 lb/ft^3
Ammonia (NH_3): 360 lb/ft^3



To deliver the same energy content, ammonia requires **~2.5X** more volume flow

Combustion System

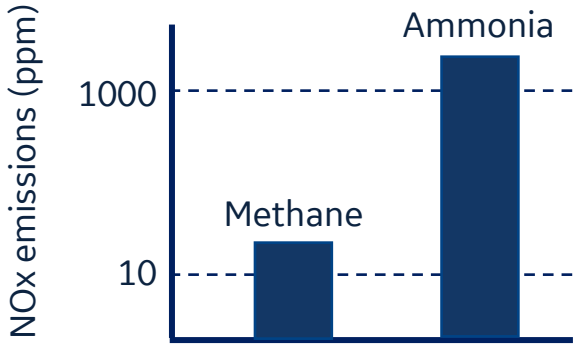
Flame speed (reactivity proxy)
Methane (CH_4): ~30–40 cm/sec
Ammonia (NH_3): ~6-7 cm/sec



Ammonia is ~**5x** less reactive than methane. A new combustor may be required to provide similar gas turbine operability

Emissions Aftertreatment

Nitrogen content:
Methane (CH_4): ~0% N_2
Ammonia (NH_3): ~83% N_2



Without a new combustion system, will need to abate **~100x** more NOx

Operating a gas turbine on blends of ammonia or on 100% ammonia will require changes to key power plant systems

GE/IHI MOU on ammonia

GE and IHI will collaborate to define an ammonia gas turbine business roadmap.

The goal for both GE and IHI is to determine the feasibility of reducing carbon emissions from both new and existing gas turbine power installations.

Together, GE and IHI will collaborate on feasibility studies that focus on possible innovative approaches to use (carbon-free) ammonia as a viable fuel option for power generation.

The power generation industry is in transition...
growing capacity to meet expanded future demands while targeting low-to-zero carbon emissions

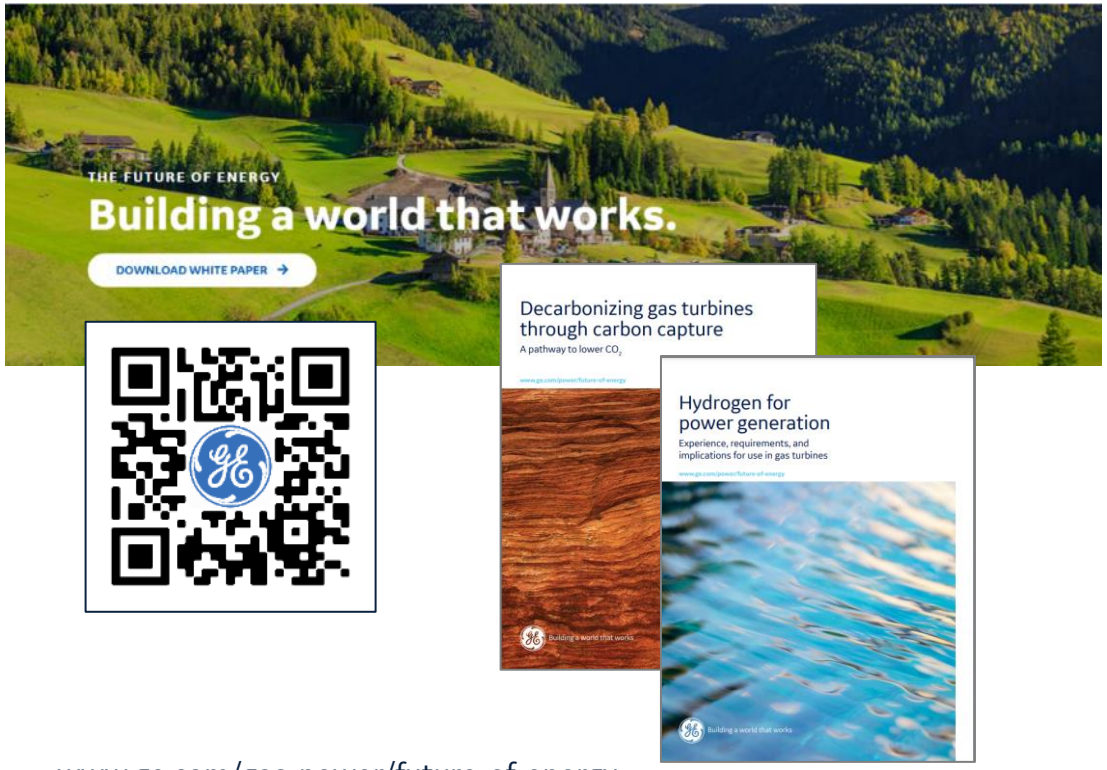
Gas turbines, which are integral to our power system today,
offer multiple technical pathways to lower and zero carbon emissions to help meet this challenge

Focusing on hydrogen, GE is the most experienced OEM
in the use of hydrogen and similar low BTU fuels*

*Per McCoy Power Reports, 1980-2019

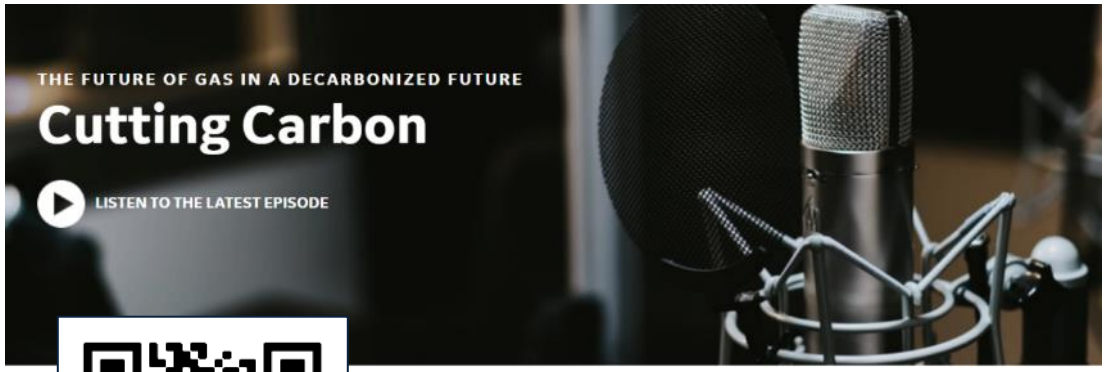
Additional information available to continue the learning…

The Future of Energy … building a world that works



www.ge.com/gas-power/future-of-energy
www.ge.com/gas-power/future-of-energy/hydrogen-fueled-gas-turbines

Cutting Carbon: a conversation about our energy future



Apple Podcasts
Spotify
Google Podcasts
amazon music
Amazon Music

www.ge.com/gas-power/future-of-energy/cutting-carbon

Building a world that works