GE Gas Power – Hydrogen Technology

Bank of America/Merrill Lynch future of Hydrogen Energy Economy

December 17th, 2020

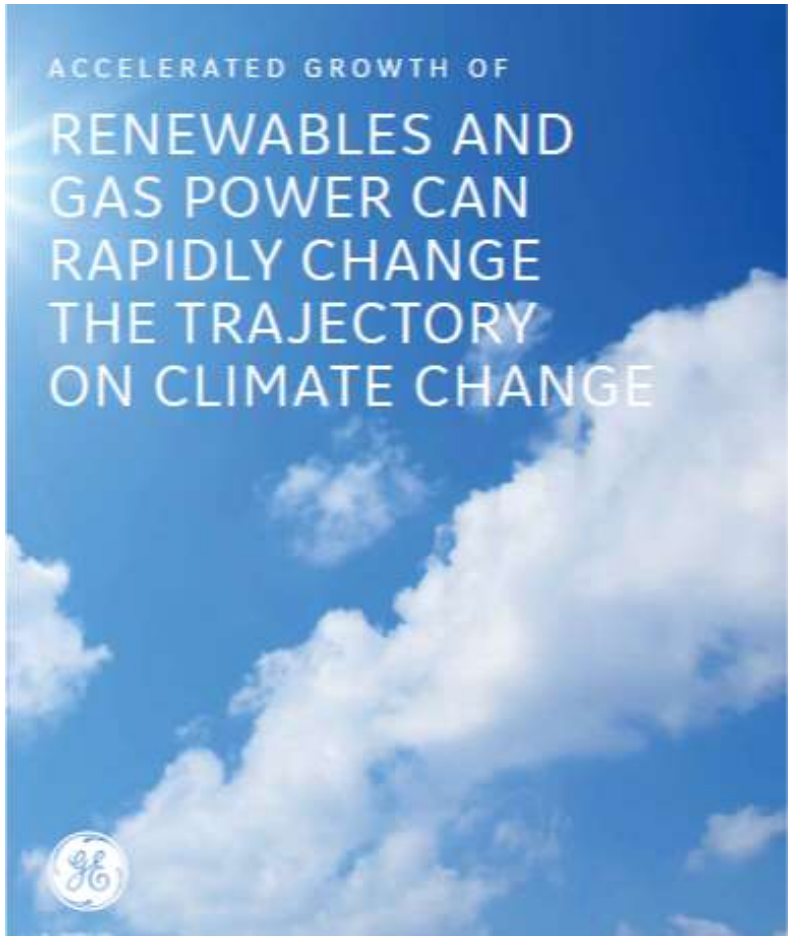
Jeffrey Goldmeer, Ph.D., Emergent Technologies Director – GE Gas Power

"Addressing climate change is an urgent global priority and one that we think we can do a better job of accelerating progress on—starting now—not decades from now.

We believe there are critical and meaningful roles for both gas power and renewable sources of energy to play, advancing global progress faster today with coal-to-gas switching while continuing to develop multiple pathways for low-to-zero carbon gas technologies in the future."

- Scott Strazik, CEO, GE Gas Power

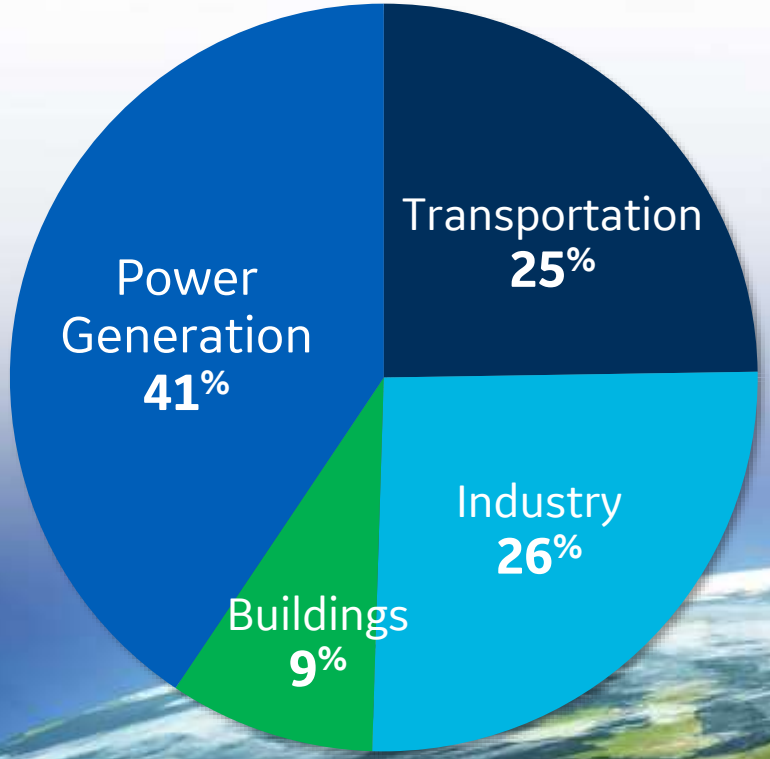
https://www.ge.com/power/future-of-energy



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.

The world today … less than ¼ of carbon budget remains

Global CO_2 emissions
(33.7 gigatons)



Global electricity generation

27k TWh *of electricity*

770 M 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 in this presentation is intended to mean the reduction of carbon emissions on a kilogram per megawatt hour basis | Source: IEA WEO 2020

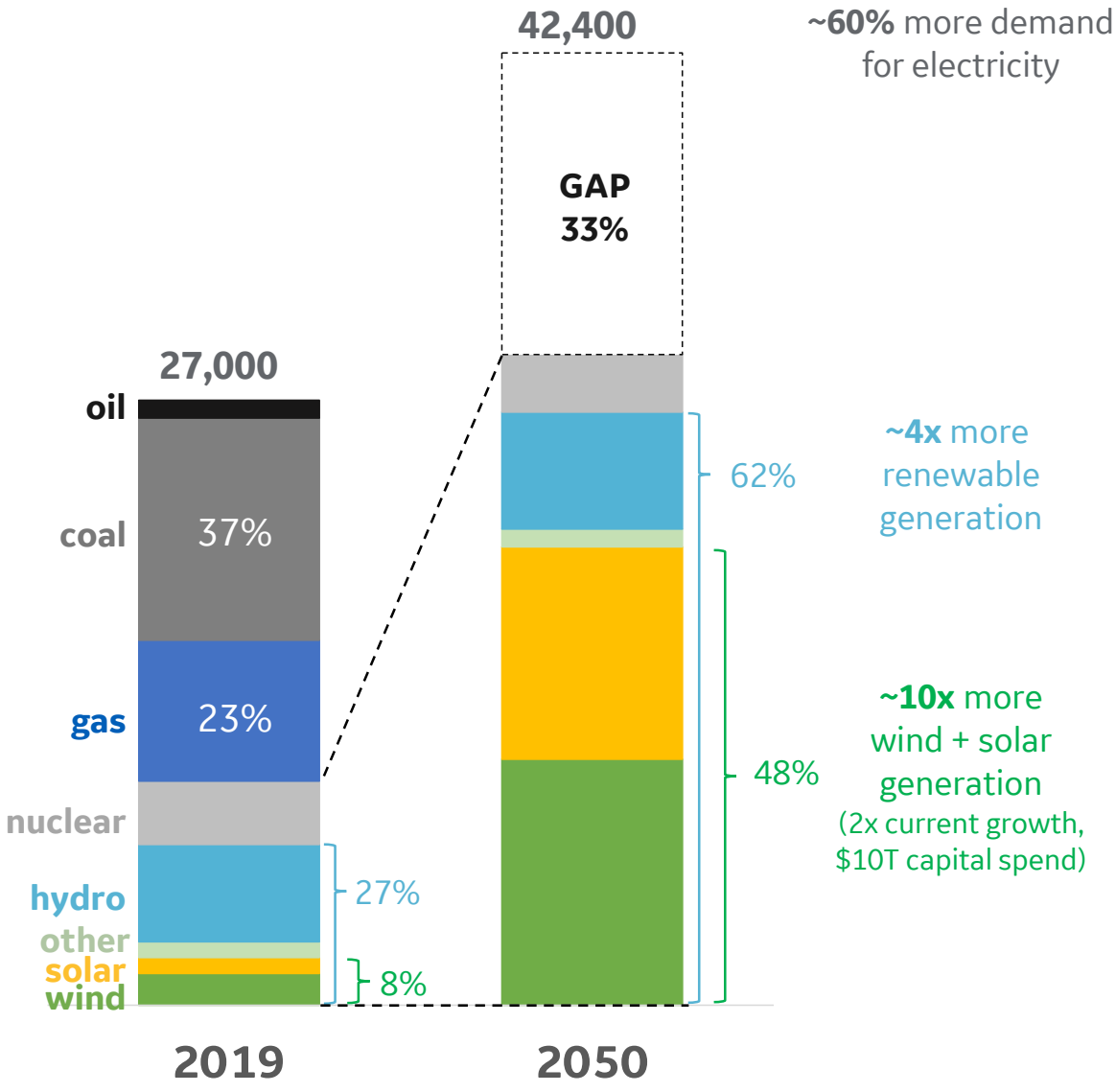
DO WE NEED GAS?

YES. THERE IS NOT ENOUGH ZERO CARBON ENERGY TO MEET FUTURE DEMAND

Even with aggressive renewable growth such as wind and solar growing at 2X the current rate

We can fill gap with gas and reduce power sector carbon emissions by >50% vs. today… with pathway towards zero

ELECTRICITY GENERATION (TWh/y)



Sources: IEA World Energy Outlook 2020 for 2019 actuals, BNEF NEO 2019 for 2050 projections (with fossil fuel generation removed)."

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

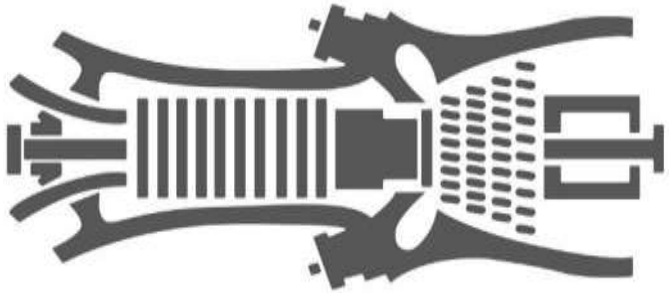
Gas turbines offer multiple technical pathways to lower and zero carbon emissions

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

Remove carbon from the plant exhaust

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

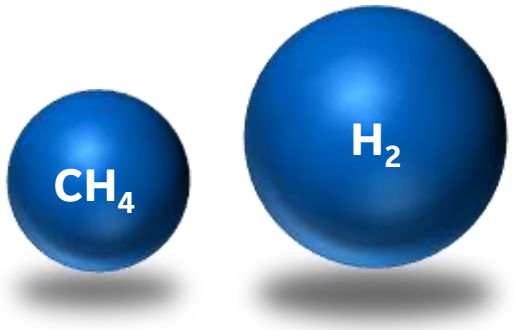
Gas turbines offer multiple options to achieve lower or zero carbon emissions

Technical Pathways: Hydrogen

Use of hydrogen as a gas turbine fuel requires system changes

Fuel System

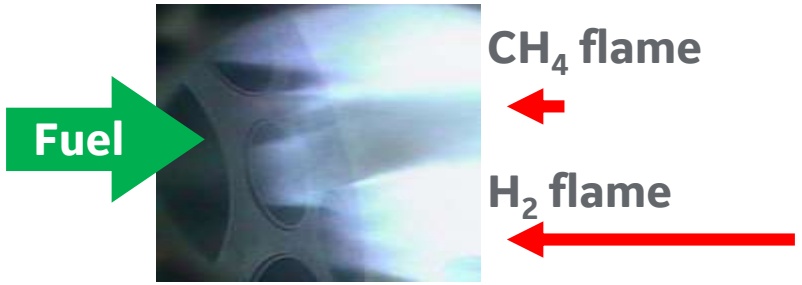
Methane (CH_4): 912 lb/ft^3
Hydrogen (H_2): 275 lb/ft^3



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

Combustion System

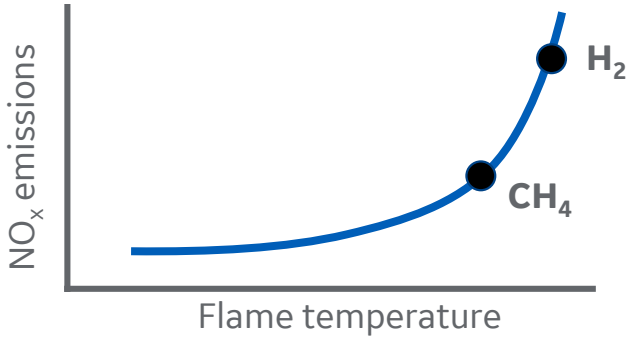
Methane (CH_4): ~30–40 cm/sec
Hydrogen (H_2): ~200–300 cm/sec



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 or on 100% hydrogen may require changes to key power plant systems, but this has been successfully demonstrated

Decades of experience with hydrogen and similar low BTU fuels

1x7F
IGCC (USA)

1x7F
IGCC (USA)

1x6B
IGCC (Europe)

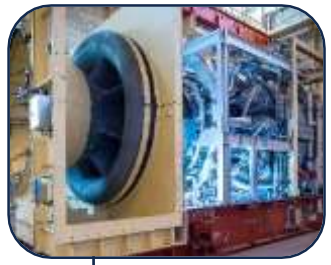
2x6F
Refinery (USA)

2x6F Syngas
Refinery (Asia)

1xGE10 High H_2
(Europe)

2x7F Syngas
coal IGCC (USA)

2x9E
Refinery (India)



1990 **2000** **2010**

1x7E
IGCC (USA)

1x6B Refinery
(Europe)

1x6B
Refinery
(Korea)

1xGT13E2
Refinery (Europe)

3x9E
Refinery
(Europe)

2xGT11N2
Steel mill (Brazil)

2xLM2500
Steel Mill (China)

1x7F Syngas
IGCC (Korea)

More than 75 gas turbines with more than 6 million operating hours

Commercial projects using hydrogen

Existing units are capable of operating on H_2 blends

- Four GE 7F gas turbines operated on a **blend** of **hydrogen** with natural gas
- Post blending, the fuel contained ~ 5% (by volume) hydrogen

High H_2 fuel commercial operation

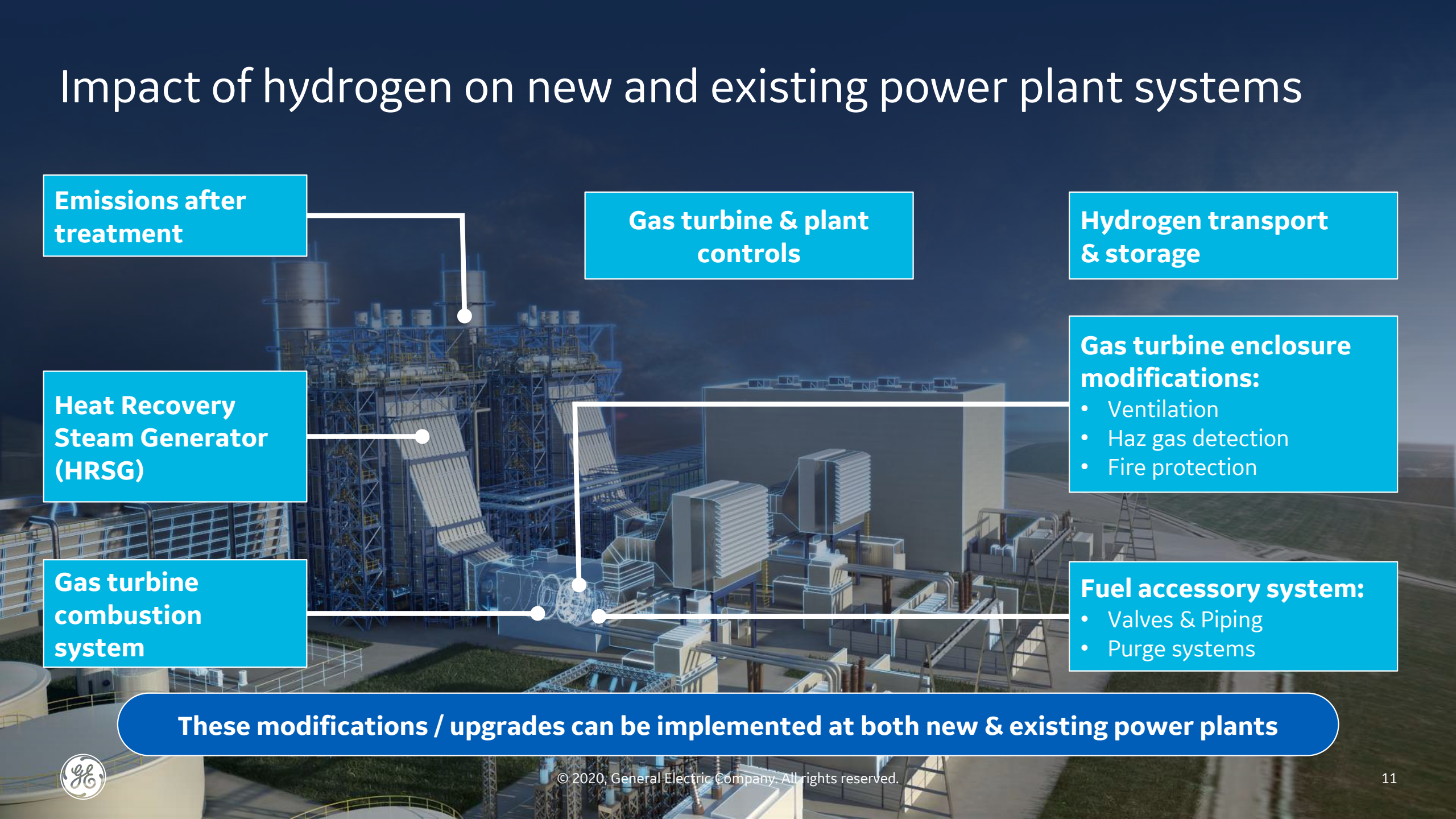
- A 6B gas turbine has been operating for 20+ years on a high-hydrogen fuel
- The hydrogen composition has varied from **70%** and **95%** (by volume)

Utility-scale gas turbine operation on H_2

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

Gas turbines (both new and installed units) can be configured to operate on hydrogen

Impact of hydrogen on new and existing power plant systems



Emissions after treatment

Gas turbine & plant controls

Hydrogen transport & storage

Heat Recovery Steam Generator (HRSG)

Gas turbine enclosure modifications:
- Ventilation
- Haz gas detection
- Fire protection

Gas turbine combustion system

Fuel accessory system:
- Valves & Piping
- Purge systems

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

Advanced hydrogen combustion technology development

F and HA DLN 2.6, 2.6+ combustion systems

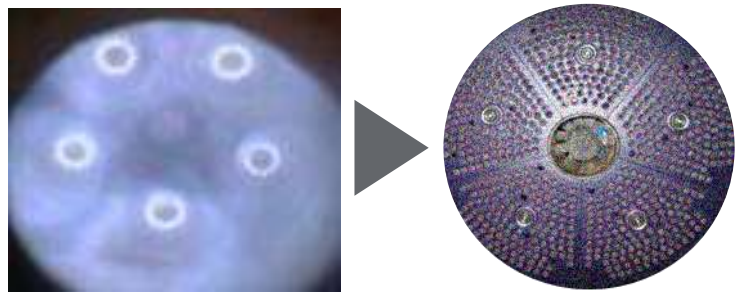
First commercial use: 1996
Fuel nozzles: 6
H2 limits: ~ 5 to ~18% (by volume)

US DOE High Hydrogen Turbine Program

Program dates: 2005–2012

GE Gas Power developed a combustion system targeted at operation on high H_2 fuels

50% Hydrogen capable combustor for HA gas turbines



First commercial operation: 2021*
Fuel injectors: > 500
H2 limits: ~ 50% (by volume)

*COD expected in 2021 on 100% natural gas

Development of a new combustion system capable of operating on high hydrogen fuels has been ongoing for 15+ years

Considerations to make hydrogen a competitive power gen fuel

Competitive cost
Inline with alternatives

Production
at scale

ENABLING THE HYDROGEN ECONOMY

Infrastructure
Transportation and storage

TODAY
70M tons of H_2 produced/year
> 99% is **grey** hydrogen

FUTURE
2050 forecast for **green** and **blue** hydrogen for power generation is ~3X more than all hydrogen produced today*

- **Grey:** Reforming natural gas
- **Blue:** Reforming natural gas + CCUS
- **Green:** Electrolysis of water with renewable power

Using hydrogen as a gas turbine fuel requires solving the trilemma of affordability, reliability, and sustainability

*bp Energy Outlook, Hydrogen, https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/demand-by-fuel/hydrogen.html

The Decarbonization Journey

GE … a key player in decarbonization

Rising to the challenges of the energy transition

Published on October 15, 2020

Larry Culp fluencer
Chairman & CEO at GE

Setting a New Goal of Carbon Neutrality

Today, GE is setting a goal of achieving **carbon neutrality for our own operations by 2030.** With over 1,000 facilities across the globe including factories, test sites, warehouses and offices, the scale of GE's industrial manufacturing footprint means that achieving our

Uniper partners with GE to decarbonize gas plants in Europe

They have signed an agreement to explore, assess and develop technology options and produce a detailed decarbonisation roadmap by early 2021

https://www.energylivenews.com/2020/07/22/uniper-partners-with-ge-to-decarbonise-gas-plants-in-europe/

Long Ridge Energy Terminal Partners with New Fortress Energy and GE to Transition Power Plant to Zero-Carbon Hydrogen

October 13, 2020

HANNIBAL, Ohio, Oct. 13, 2020 (GLOBE NEWSWIRE) -- Long Ridge Energy Terminal ("Long Ridge"), located in Hannibal, Ohio, announced plans to transition its 485 MW combined-cycle power plant to run on carbon-free hydrogen. In collaboration with New Fortress Energy ("NFE") and GE, Long Ridge intends to begin providing carbon-free power to customers as early as next year by blending hydrogen in the gas stream and transition the plant to be capable of burning 100% green hydrogen over the next decade.

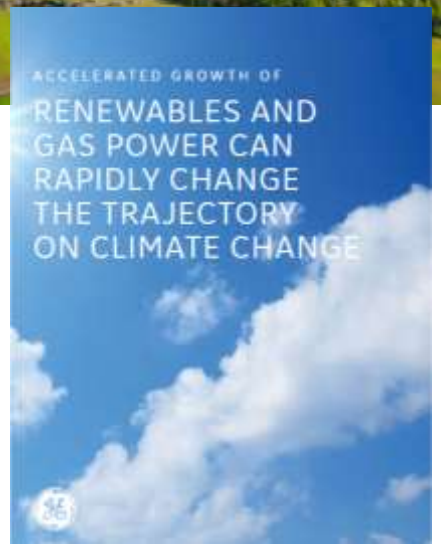
With commercial operations planned for November 2021, Long Ridge will be the first purpose-built hydrogen-burning power plant in the United States and the first worldwide to blend hydrogen in a GE H-class gas turbine. The plant utilizes a GE 7HA.02 combustion turbine, which can burn between 15-20% hydrogen by volume in the gas stream initially, with the capability to transition to 100% hydrogen over time. Long Ridge has engaged Black & Veatch to

Long Ridge power plant under construction in Hannibal, Ohio. Photo courtesy of Kiewit.

https://www.longridgeenergy.com/news/2020-10-13-long-ridge-energy-terminal-partners-with-new-fortress-energy-and-ge-to-transition-power-plant-to-zero-carbon-hydrogen

GE is excited about the future and the role that gas turbines will play in decarbonizing our society

The Future of Energy … building a world that works



Cutting Carbon: a conversation about our energy future

Apple Podcasts

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Building a world that works