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Ammonia as a gas turbine fuel

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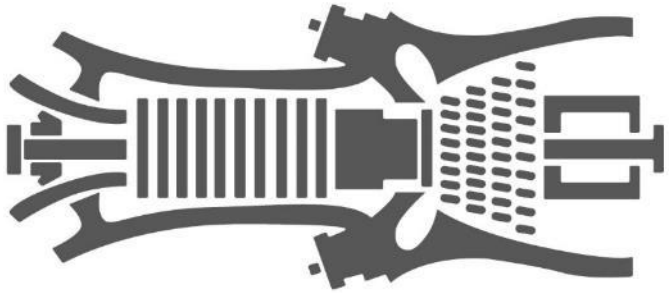
Decarbonizing gas power* … a range of options

Pre-combustion



Post-combustion

Use a zero or carbon neutral fuel

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

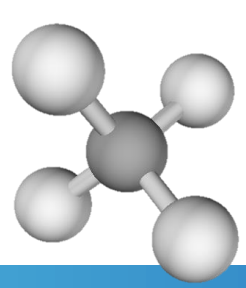
Remove carbon from the plant exhaust

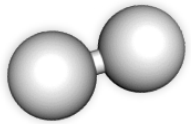
- Carbon capture (liquid solvents)
- Carbon capture (solid sorbents)
- Oxy-fuel cycles

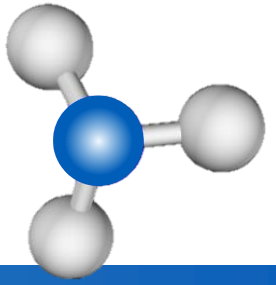
Gas turbines offer multiple options to achieve lower or zero carbon emissions

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

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





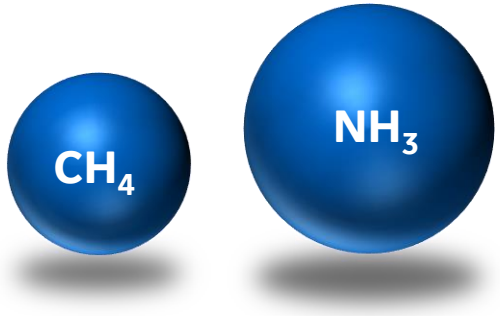


Characteristics		Methane	Hydrogen	Ammonia
Formula		CH_4	H_2	NH_3
Molecular weight	grams/mol	16	2	17
Boiling temperature	°F (°C)	-258.7 (-161.5)	-423.2 (-252.9)	-28 (-33.3)
Lower flammability limit (LFL)	%	4.4	4	15
Flame speed	cm/sec	~30-40	~200-300	~6-7
Adiabatic flame temperature	°F (°C)	~3565 (~1963)	~4000 (~2204)	~3270 (~1799)
Lower Heating value	MJ/Nm^3 (BTU/scf)	35.8 (911.6)	10.8 (274.7)	14.1 (360)

Use of ammonia as a gas turbine fuel requires system changes

Fuel System

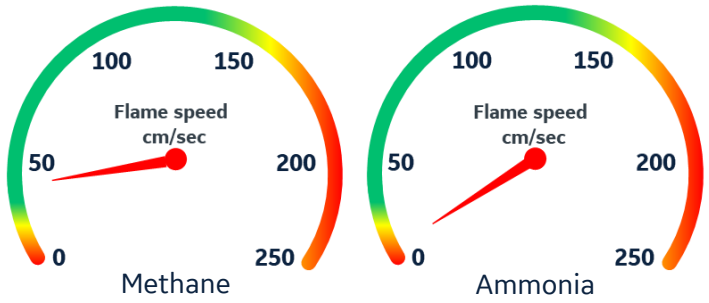
Lower heating value
Methane (CH_4): 912 lb/ft^3
Ammonia (NH_3): 360 lb/ft^3



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

Combustion System

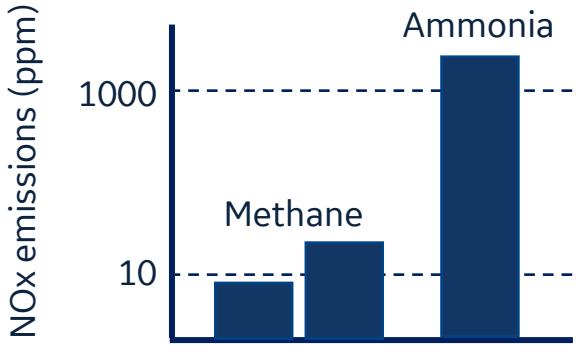
Flame speed (reactivity proxy)
Methane (CH_4): ~30–40 cm/sec
Ammonia (NH_3): ~6-7 cm/sec



A new combustor may be required to provide same operability

Emissions Aftertreatment

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



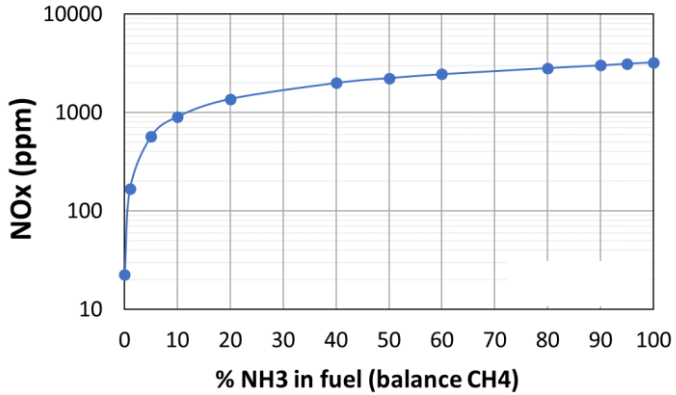
Without a new combustion system, will need to abate 100x more NOx

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

Ammonia … an alternative zero-carbon gas turbine fuel

Emissions	Zero carbon emissions (total carbon footprint of fuel will depend on source of H_2)	Ammonia is 83% N_2 by mass. Potential for 100x increase in NOx using current lean premixed combustion systems
Operability		

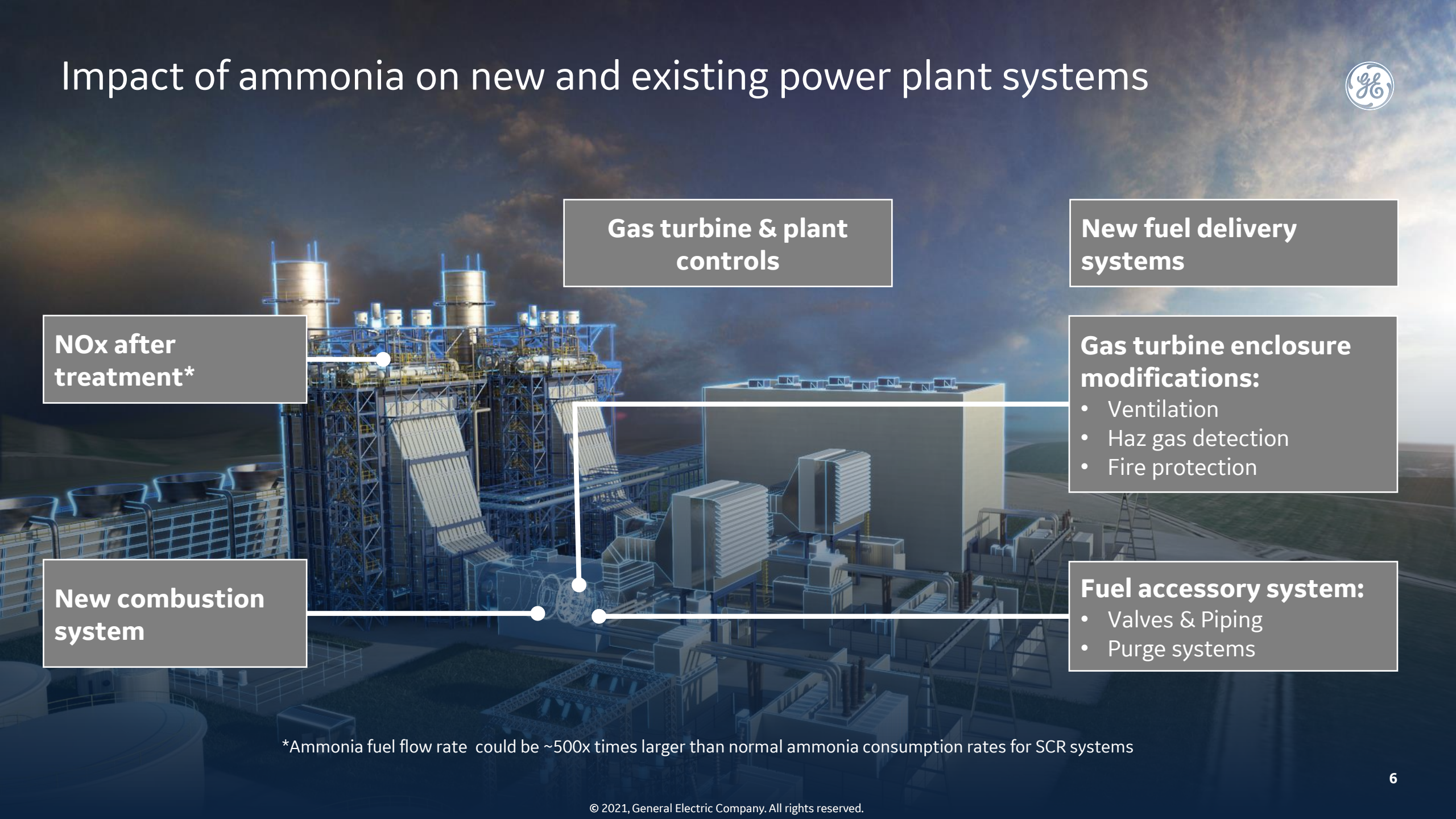
NOx as a function of ammonia blends in **methane**



NOx as a function of ammonia blends in **hydrogen**

Ammonia's viability as a gas turbine fuel will depend on upgrading power plants, developing a robust supply chain, and getting acceptance of toxicity issue

Impact of ammonia on new and existing power plant systems



Gas turbine & plant controls

New fuel delivery systems

NOx after treatment*

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

New combustion system

Fuel accessory system:
- Valves & Piping
- Purge systems

*Ammonia fuel flow rate could be ~500x times larger than normal ammonia consumption rates for SCR systems

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