Gas Turbine Technology Enhancements for Traditional and Novel Applications: Improved Fuel Efficiency, Use of Low Carbon Fuels and Low Combustion Emissions

Our Speaker(s)

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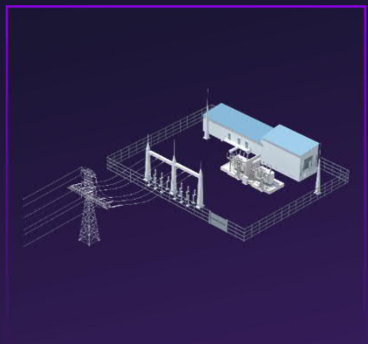
Siemens Energy covers the complete energy value chain

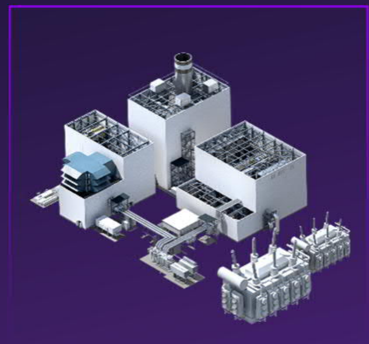
SGRE

Transmission



New Energy Business

Generation

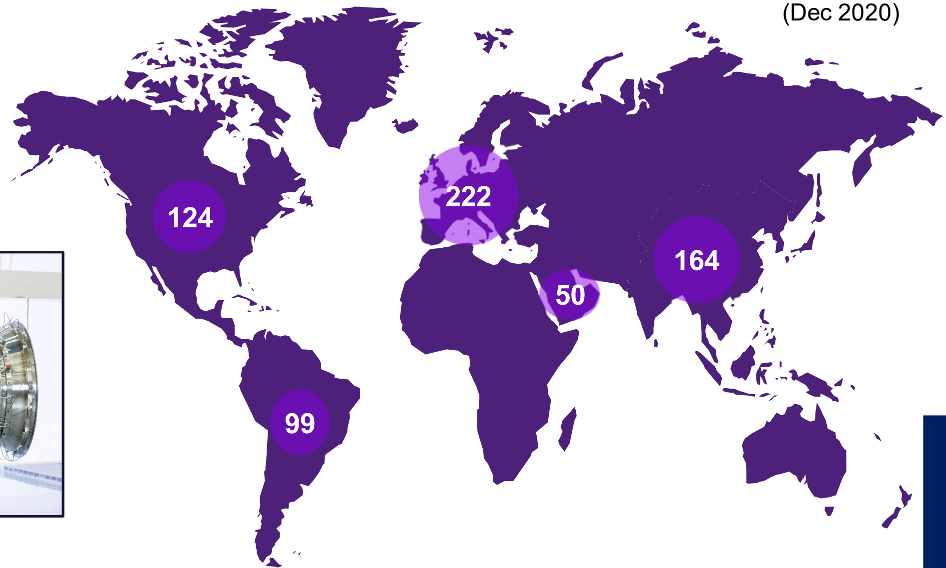


Industrial Applications

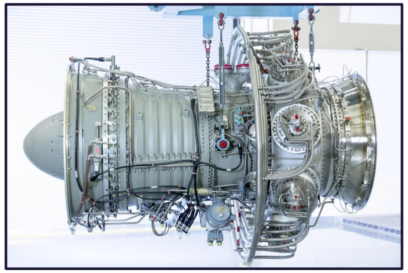
Developing Solutions for a Sustainable Future

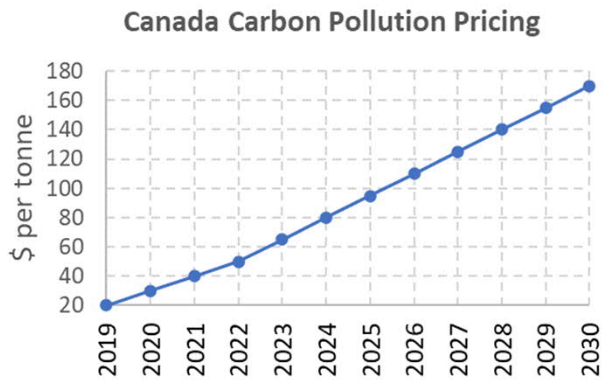
SGT-A35 Gas Turbine Installed Base
Business as Usual?

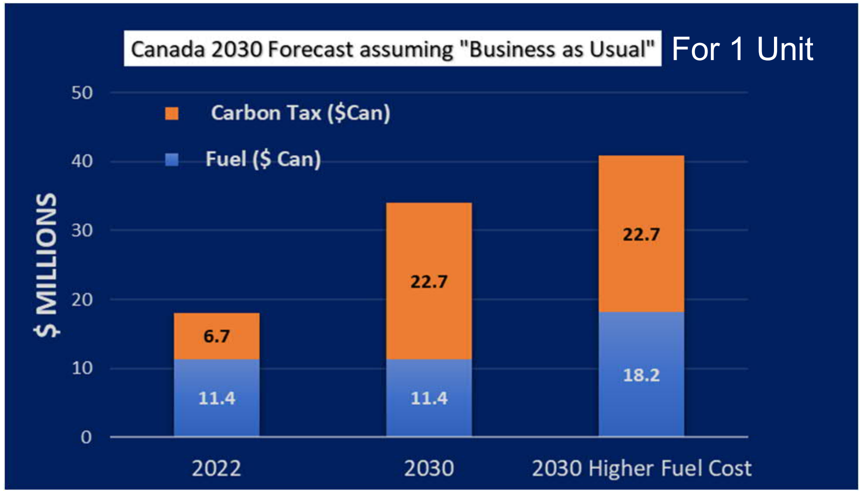
660+ A35 units sold worldwide



SGT-A35 DLE Gas Generator







Year 2030, Baseload, 8760 hrs	Per Unit	Canada	Global
Number of Units	1	91	660
Capacity	28 - 34 MW	2.6 GW	18.9 GW
CO_2 Emissions (annual)	133 000 t	12 millon t	87 million t
Carbon Price (per tonne)	$ 170 / t	$ 170 / t	$ 80 /t (indicative)
Carbon Price (annual)	$ 22.6 million	$ 2.1 billion	$ 15.2 billion

Fuel Cost $5 to $8 /MMBTU; CO2 cost $50 to $170 / tonne

How to reduce carbon emissions

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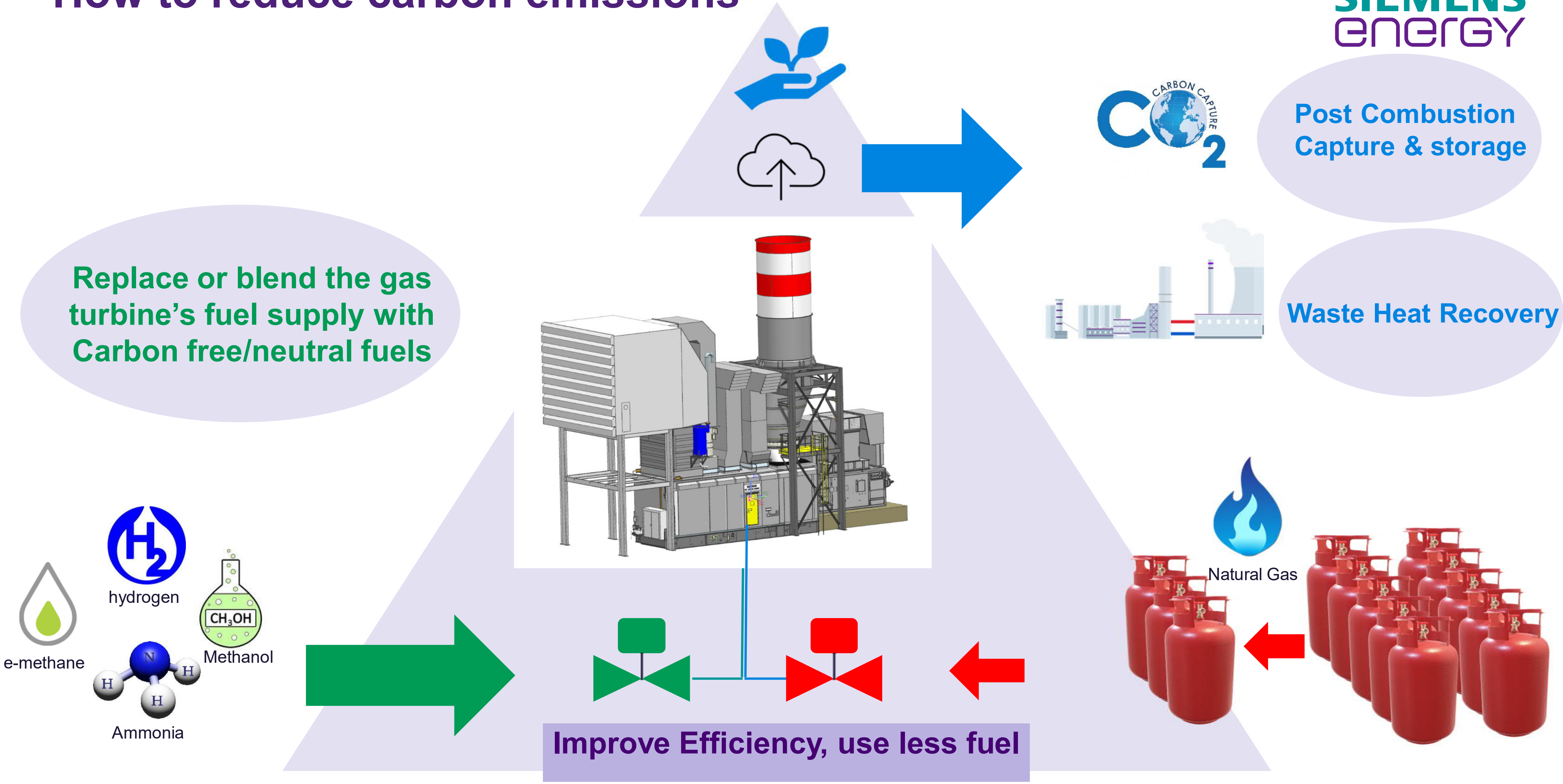
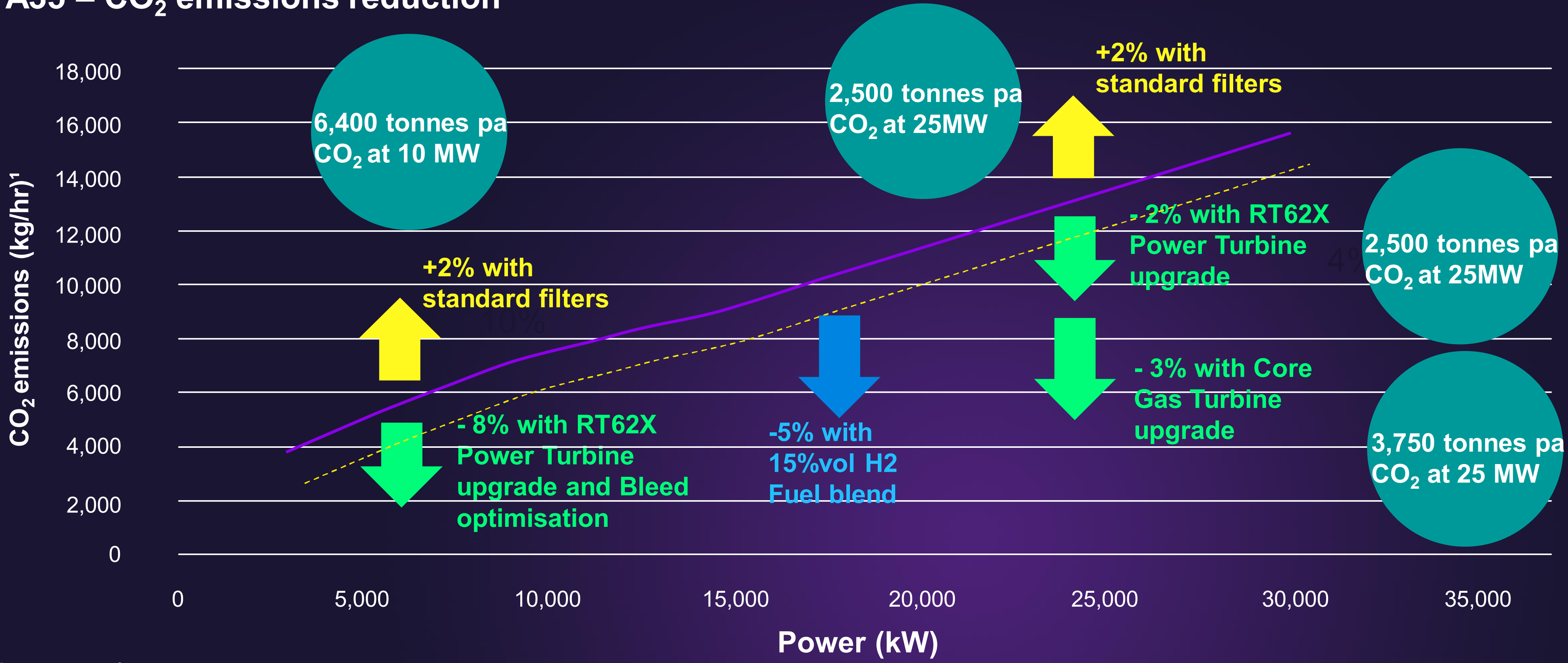


Product Efficiency Modifications
Immediately Available Solutions

SIEMENS energy

SGT A35 – CO_2 emissions reduction



[1]Methane natural gas

Renewable Liquid Fuels – Known Solutions Requiring Demonstration

Bio-fuels made from biological feedstocks such as agricultural waste, municipal solid waste and sewage

Electro-fuels made using captured carbon dioxide and hydrogen produced from renewable electricity

Examples – methanol, ethanol, bio-diesel, hydrotreated vegetable oil, sustainable aviation fuel

Optimize choice of fuel based on properties, availability and price

Demonstrations with operators and developers that are considering using green fuels

Example - Methanol

Lower carbon alternative to diesel using existing infrastructure

Bio-methanol or electro-methanol options

Established infrastructure, green production increasing

Fuel system & burner upgrade required, fire and gas system should be assessed

SGT-A20 demo at RWG in Aberdeen, UK
Coming in fall of 2022
Live stream of the test

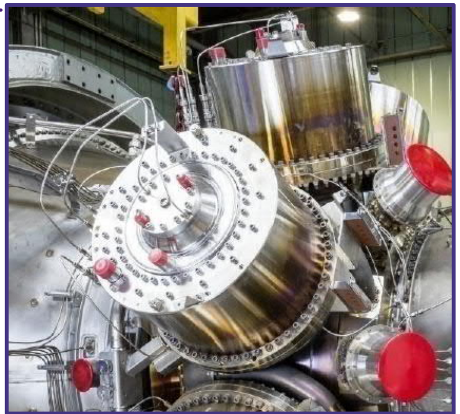
Hydrogen Capability: Aeroderivatives

100% Hydrogen firing possible today in WLE configuration

DLE burner
WLE burner
Diffusion burner with unabated NOx emission

	Gas turbine model	Power Output	H_2 capabilities in vol. %
50Hz or 60Hz	**SGT-A65**	58 to 66 MW	15 (DLE) / 100 (WLE)
	SGT-A45	41 to 44 MW	100 (WLE)
	SGT-A35	25 to 38 MW	15 (DLE) / 100 (WLE)
	SGT-A20	13 to 17 MW	100 (Diffusion)
	SGT-A05	4 to 6 MW	30 (DLE)

DLE Combustor



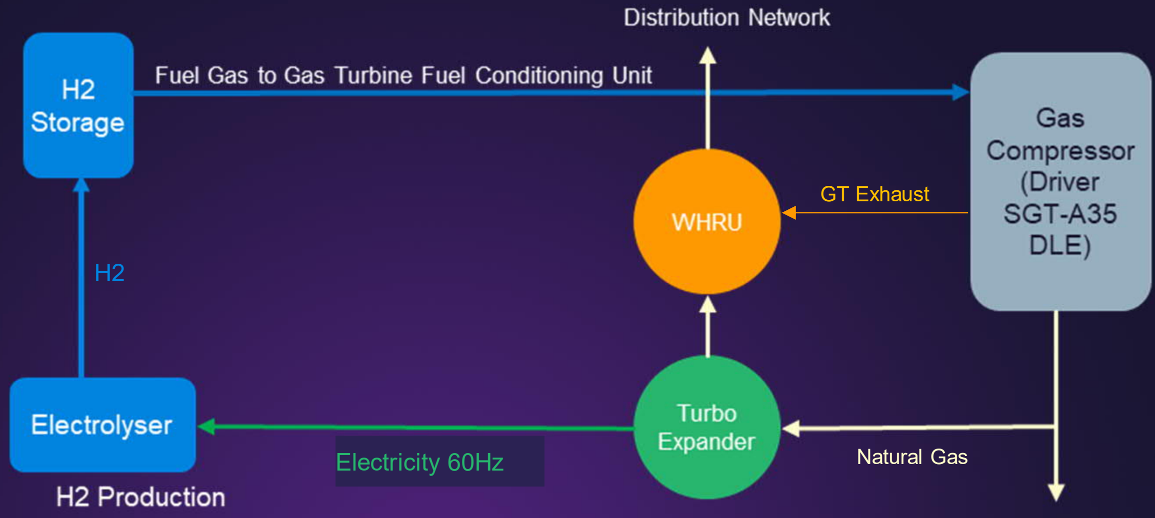
Over 250,000 hours of recorded operation since 1968 on fuel blends containing up to **80 vol% H2**

- **1968** – A20 LPG co-fired with up to 60 vol% H_2
- **1983** – A20 natural gas co-fired with up to 80 vol% H_2
- **2011** – Annular D/F 100% H_2 rig test
- **2018** – Release of 100% H_2 WLE
- 2023-24 – DLE H_2 Capability Extension Partnerships
- **2023-24** – Power-to-X - to-Power SGT-400 Hyflex Demo
- **2022-30** – DLE 100% H_2 Development and release

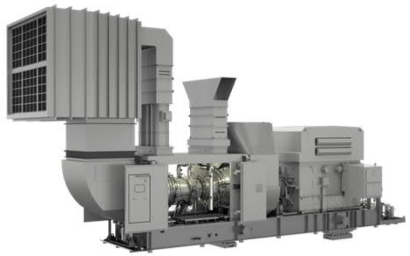
Decarbonizing Midstream Gas Compression
Feasibility Study and Preliminary Concept Design

- Siemens Energy and Enbridge Gas partnership
- Self production of H2 and blending into SGT-A35 DLE fuel at an Enbridge site
- H2 production by electrolysis, powered using waste energy recovered from existing gas pressure let down process
- Demonstrate capability of the gas turbine with up to 40% volume H2, by combustor rig test and site engine test
- Reduce CO_2 emissions by up to 17%

Hydrogen Deployment Vision for Compressor GT



SGT-A35 (34-38 MW)



SGT-A05 (4-6 MW)

Challenges	Solutions
Wide Range of Power	Scalable to 300+ MW with A35 & A05 combinations
City Location	Power dense, small footprint
Emergency Grid Backup	Very fast start (< 2 minutes) with no hot lockout Instant with batteries
Grid Capacity Limitations	Dispatchable peaker
Start & Operational Reliability	Extremely reliable with N+1 or N+2 redundancy
Fuel Flexibility	Multi fuel options with fuel changeover at power
Capable of up to 100% H2	Upgrades available 2030 or earlier
Low Operating Expenses	Low fuel and oil consumption, low maintenance

Some Combustion considerations…

Fuel Interchangeability

Fuel	NH_3	CH_4	H_2	CH3OH	Diesel
Lower heating value (MJ/kg) (MJ/L)	18.6 (11.5)	50.0	120	20 (15.6)	43.4 (38.6)
Wobbe index (MJ/m3)	18.7	48.2	40.9	[-]	[-]
Maximum laminar burning velocity (m/s)	0.07	0.37	2.91	0.45*****	0.33*****

Wobbe index

NH_3

- Uncracked NH_3 (Gaseous at SGT-A35 injection conditions) has a low WI
  => Larger Injector required (larger fuel passages)

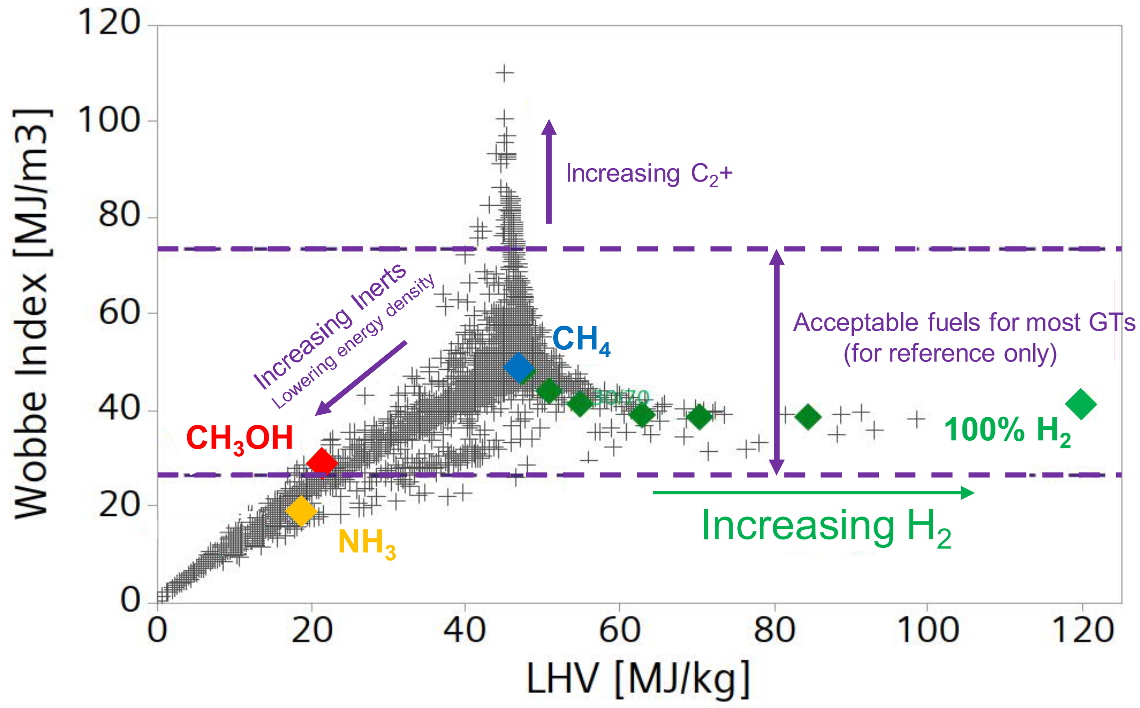
CH_3OH

- CH_3OH (liquid) has a 2.3x smaller energy density (MJ/L)
  => Larger Injector required (larger fuel passages)

H_2

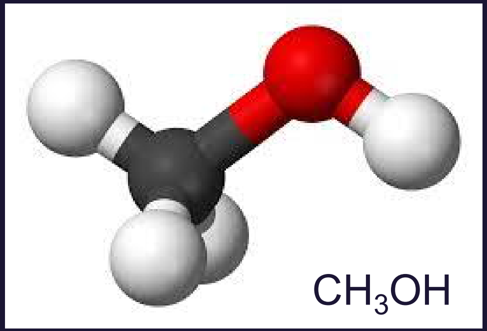
- Pure H_2 will most likely require a Larger Injector area (approx. +20%)

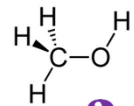
Note: that modifications to other systems will also be required



$$\text{Wobbe-index} = \frac{LHV}{\sqrt{\rho_{rel}}} \qquad \left(\rho_{rel} = \frac{\rho_{gas}}{\rho_{air}}\right)$$

Methanol:
Some Combustion considerations…
(Not exahustive!)





Why use Methanol as a fuel for land-based gas turbine application?

- Improved **heat rate*** (~+3% vs wet diesel)
- **Higher power output** at constant turbine inlet temperature (potentially as much as 10%)
- Reduced NOx emissions (potentially as much as 75 %). **Better NOx with Dry Methanol than Diesel with water injection***!
- **No soot** production – no visible exhaust
- **No Sulfur**
- **Reduced life impact** because:
  - Methanol is a cleaner liquid fuel than diesel (Hot section life)
  - Virtually no flame radiation (combustor components)
- *Infinite* shelf life
- **Power-to-X:** Potential reduction of CO_2 footprint if made from renewable (30 to 90% depending on the process used to synthesize the methanol)
- Cheaper than Diesel on a $/MJ basis**!

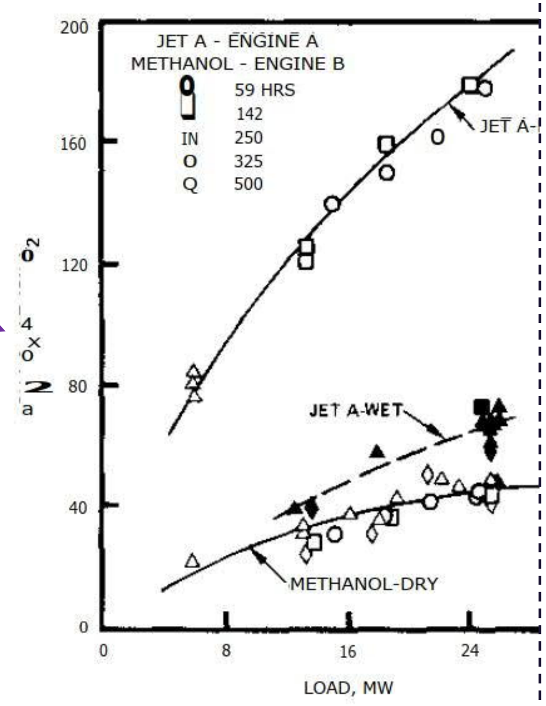
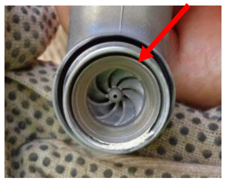


Figure 4 NOx at 15% 02 vs. Load on Methanol

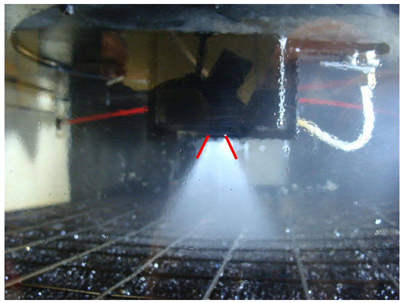
*ASME 81-GT-64: Methanol combustion is a 26 MW gas turbine
** https://www.methanol.org/ - based on European and Chinese case studies

A20 Case study

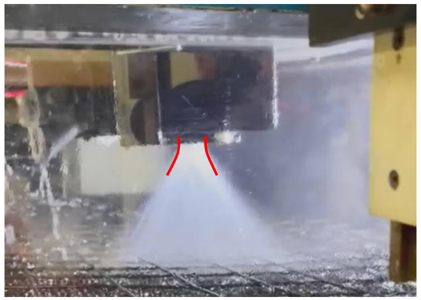
Liquid passage



Cone Angle

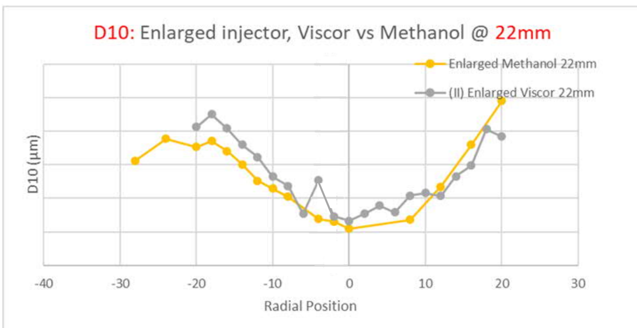


Conventional Dual Fuel Swiler Burner

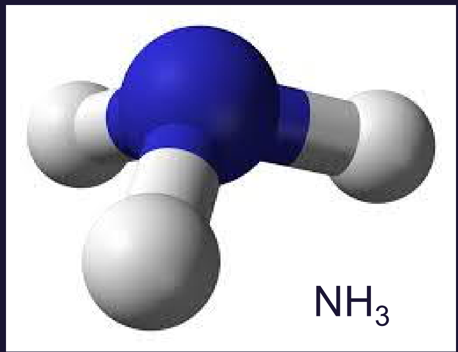


Increased Flow Capacity Dual Fuel Swiler Burner

Dropplet size



Ammonia:
Some *real* emission data…



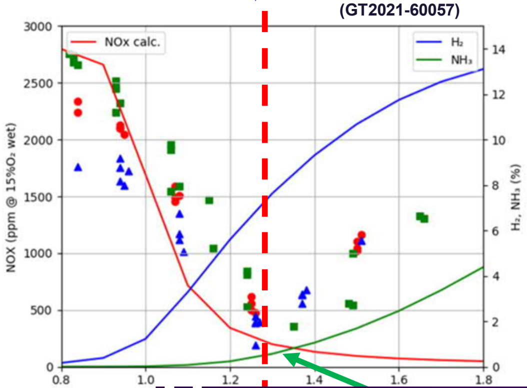
Ammonia as a fuel for land-based gas turbine application?

How to burn NH_3 in a GT?

- **Burn NH_3 directly** (unlikely due to low reactivity and major modifications to key systems required)
- **(Fully) "Crack & Burn"** (75% H_2 – 25% N_2)
- **Partially "Crack & Burn"** (mixture of NH_3, H_2 & N_2)
- **Partially "Crack & blend"** (mixture of NH_3, H_2 , N_2 & CH_4)
- **NH_3 - CH_4 blends**

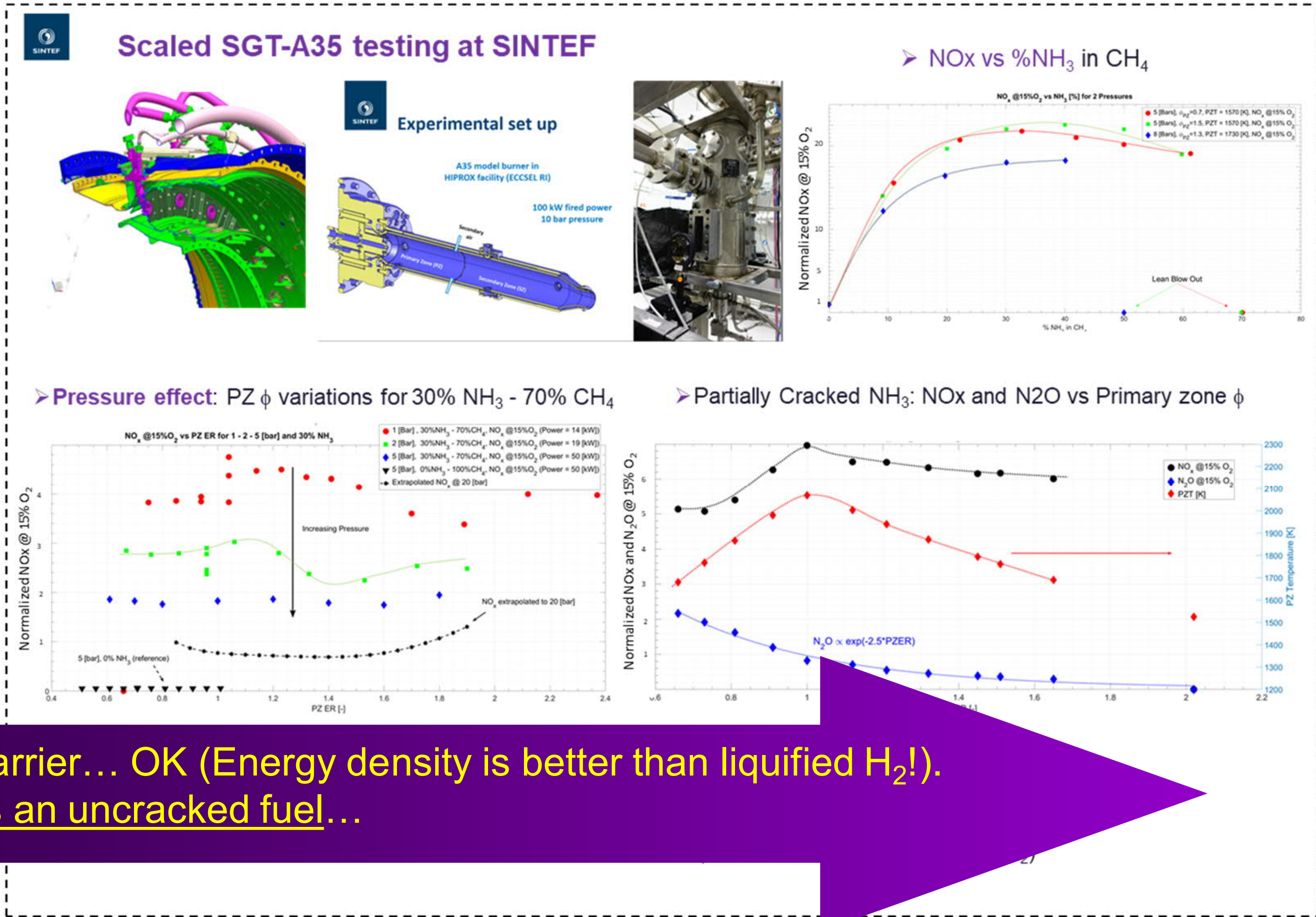
Dry Low Emission (**DLE**) or conventional (**RQL**)?

SGT 750 combustion system (GT2021-60057)



Minimum NO… f

=> Rich-Quench-Lean!?



- NH_3 as an energy carrier… OK (Energy density is better than liquified H_2!).
- <u>But more unlikely as an uncracked fuel</u>…

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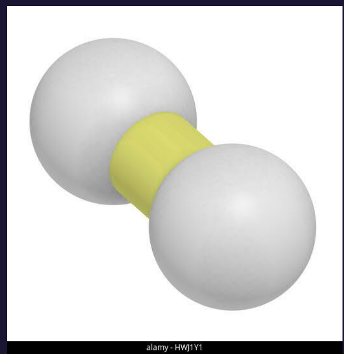
Hydrogen:
OEM Trends and basic considerations



Hydrogen as a Gas Turbine fuel…

H2 combustion physics vs. Natural Gas

Higher reactivity and flame velocity

- Increased Flashback propensity

Higher flame temperature

- Increased Thermal NO_x for higher amounts of H_2

Lower energy content per unit volume

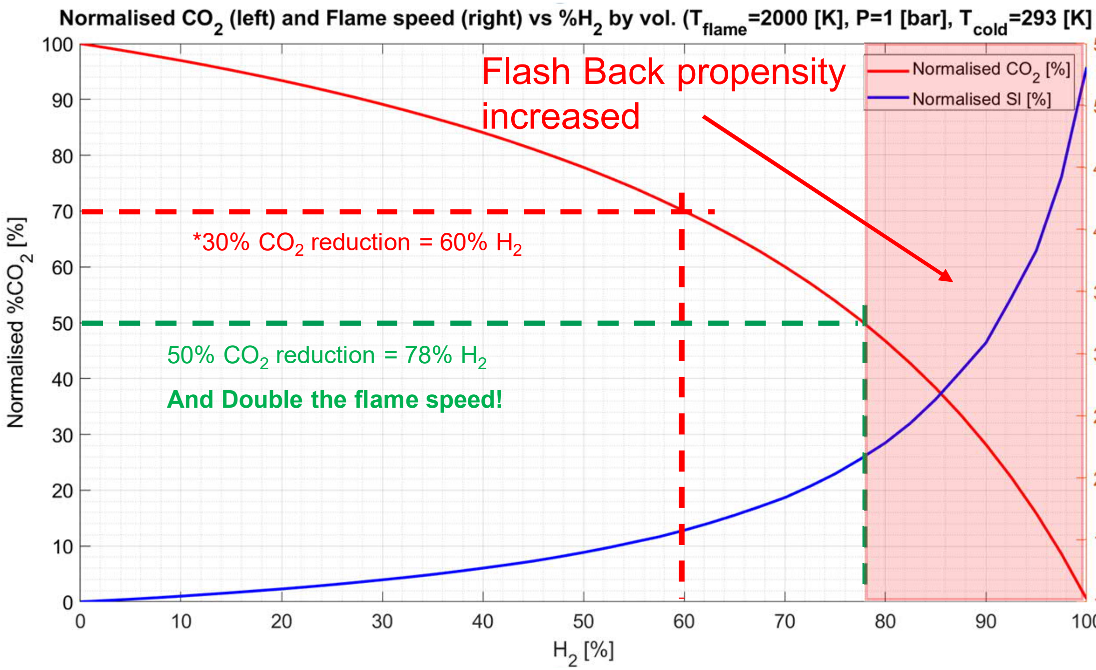
- Higher volume flow in fuel systems (+ 20%)

Explosivity characteristics

- Modifications in auxiliary protection systems and flame detection systems
- Much larger flammability limits

Thermo-acoustics

- More stable or unstable??
- Frequency changes??



- The real benefit for CO_2 is for high $\%H_2$ where **flame speed increases very rapidly**
- => NEED MODIFICATIONS TO THE COMBUSTION SYSTEM!
- … and the combustion system needs to work as well as today for pure Natural Gas, pure H2 and **all blends**

*Under the Paris Agreement, Canada has committed to reducing GHG emissions by 30% below 2005 levels by 2030

OEM trends for H_2 combustion (and why)…

H_2 has a higher flame speed, so FB is a risk for the injector's integrity…

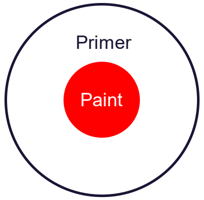
Well, what about using Non-Premixed flames?

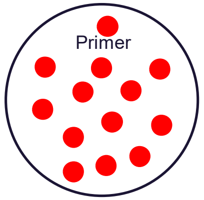
Not a bad idea, but you then need large amount of demineralised water to control NOx emissions…

Hmm… what about mixing fast in the combustor itself then (not in a premixer passage)?

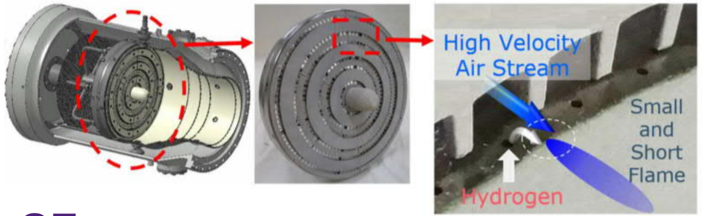
But you have a lot of air and fuel to mix, which will be a challenge!

Then lets have **smaller but more flames** to mix less fuel and air faster…

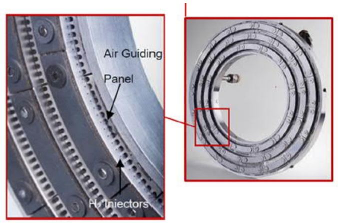




Kawsaki (KHI)

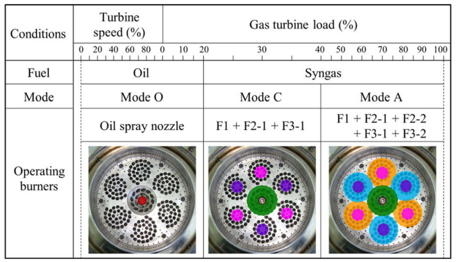


Honeywell



GE

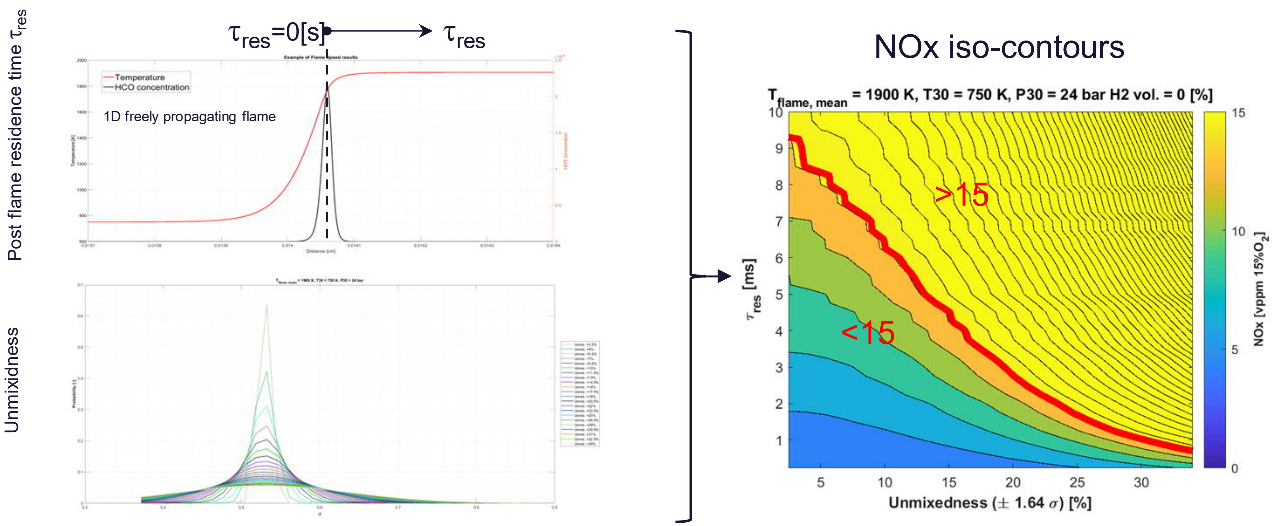
MHI

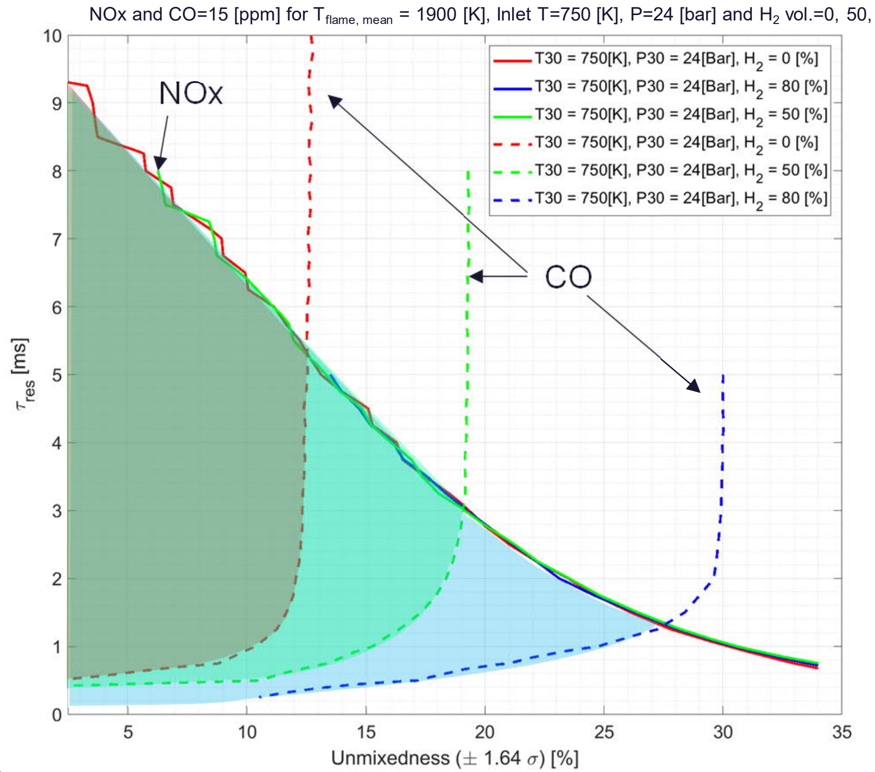


Conditions	Turbine speed (%) 0 20 40 60 80	Gas turbine load (%) 0 10 20 30	40 50 60 70 80 90 100
Fuel	Oil	Syngas	
Mode	Mode O	Mode C	Mode A
Operating burners	Oil spray nozzle	F1 + F2-1 + F3-1	F1 + F2-1 + F2-2 + F3-1 + F3-2

Micro-mixing… OK, but what about emissions?

Some considerations: theoretical frame

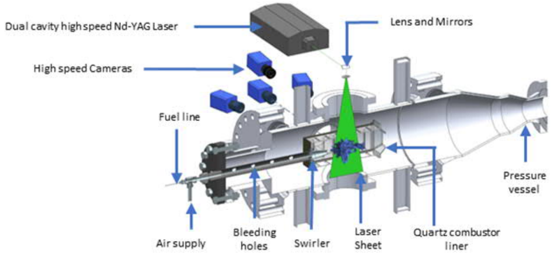




- **High Methane fuels**: **Good mixing is required** for CO, longer post-flame residence times can be tolerated for NOx
- **High Hydrogen fuels**: Lower mixing can be tolerated for CO, but **shorter post-flame residence times are required** for NOx

Collaborations with universities to address new challenges (Mission Alliance)

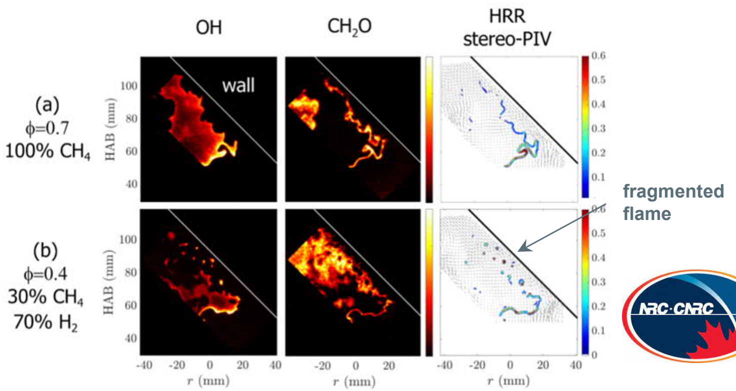
Static and dynamic stability



Combustor and optical diagnostic setup

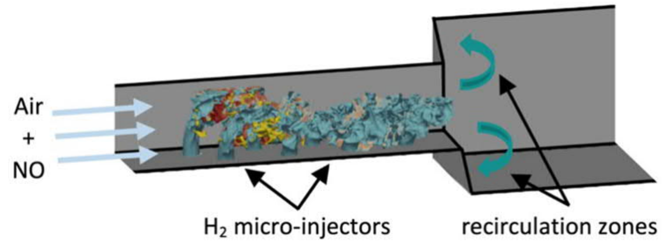
UNIVERSITY OF TORONTO

Flame-Wall Interaction



NRC·CNRC

Flame location and shape, combustion efficiency and NOx/CO emissions



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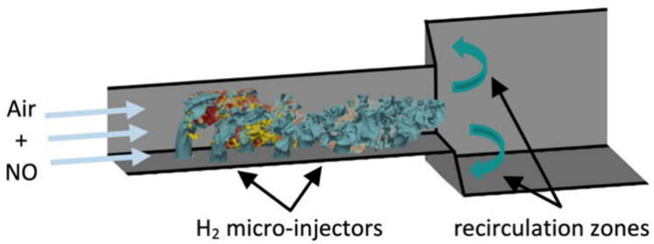
Mixing characteristics

McGill UNIVERSITY



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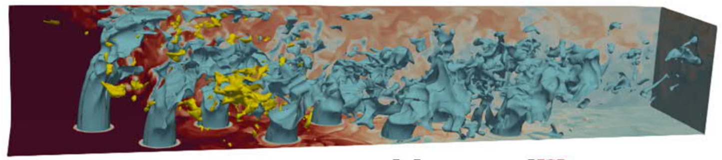
High-fidelity simulations (DNS)



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