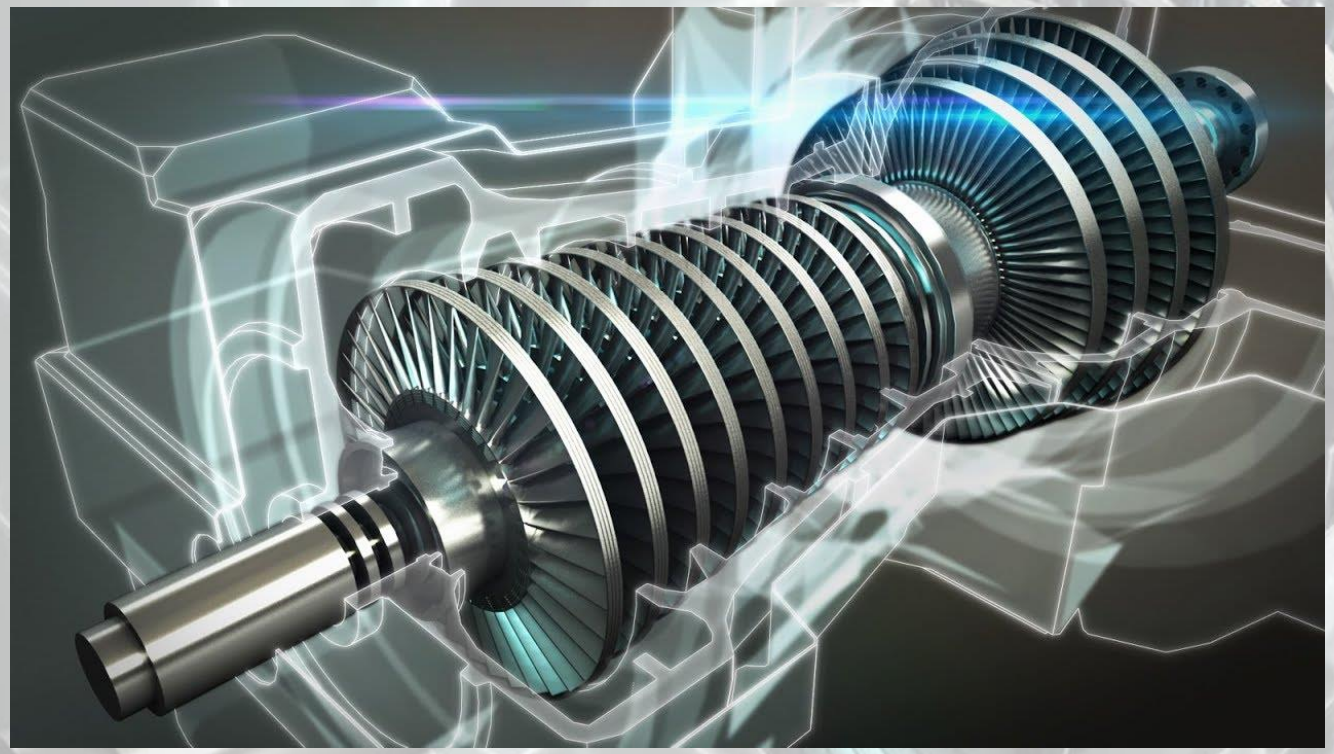
National and Regional Gas Turbines Market

Opportunities and Challenges towards a hydrogen economy



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Drivers – Hydrogen Economy in India

Environmental policy

Mitigate CO_2 emissions
(Indian CO_2 emissions = 2.53 Gt (2019) 7.32% of world)

Improve air quality
(Delhi AQI > 15 times WHO guidelines)

Reduce fossil fuel imports
(India imports >83% Crude Oil & 50% NG)

Energy independence

Avoiding dependence on imported Battery Technology

Energy Density / kg (fuel)
H2 = 33.4 KWh
Gasoline = 12.7 KWh
CNG = 13.88 KWh

Technology development

CCS developments

Cost reduction in renewable electricity
0.04 $/kWhr
(through bidding)

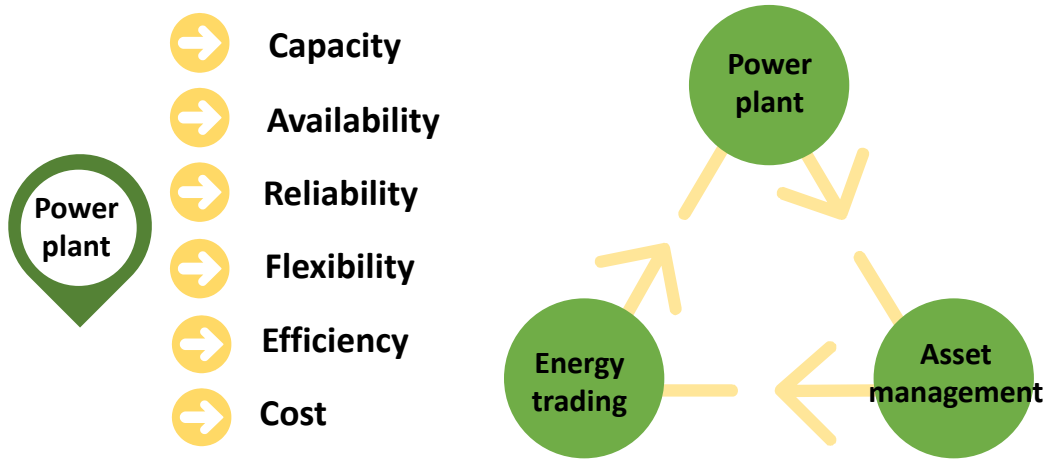
Versatility

Applications in all end use sectors (chemical / transport / energy)

- Hydrogen is a chemical - can be stored like Oil & Gas
- Energy content remains stable over long time unlike electricity stored in batteries
- Overseas trade of hydrogen is much easier relative to electricity

Energy revolution and policies

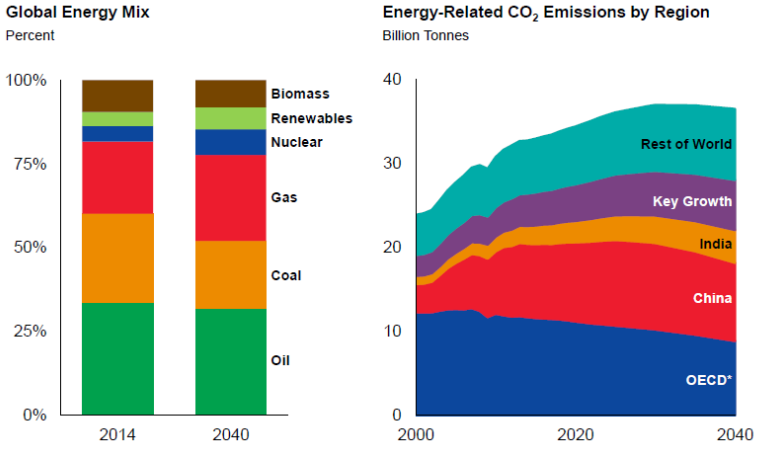
Need for flexible and reliable back-up capacity
Capacity Mechanisms to support security of supply



Low carbon gas regulatory and policy considerations

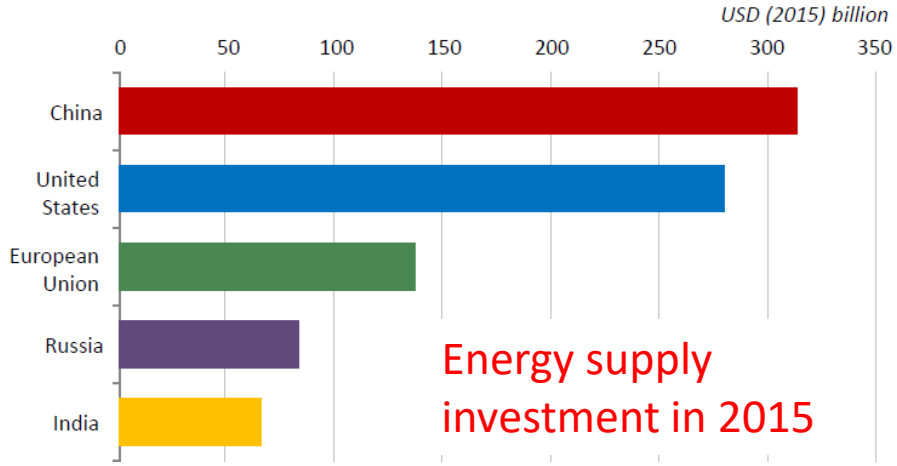
- Gas markets
  - Gas quality standards (including the H2 blending and bio-methane)
  - Certification system (=market) for low-carbon gas (industry, NG grid, mobility etc)
  - Compatibility of gas based solutions with the (electricity) market models
  - Potential impact of storage on the generation capacity market and integrated development of that market (including the various P2G applications)
- Electricity market
  - Long term investment models for all technologies
  - Investigate capacity market schemes
  - Creation of an improved model for balancing and for demand side flexibility
  - Discussion on pricing models and reforming the network tariff structures to take into account the increasing variability of generations
  - Reinforce the governance framework, (incl. distributed generation (RE), storage, smart technologies etc)

Energy Mix shifts to lower-carbon fuels



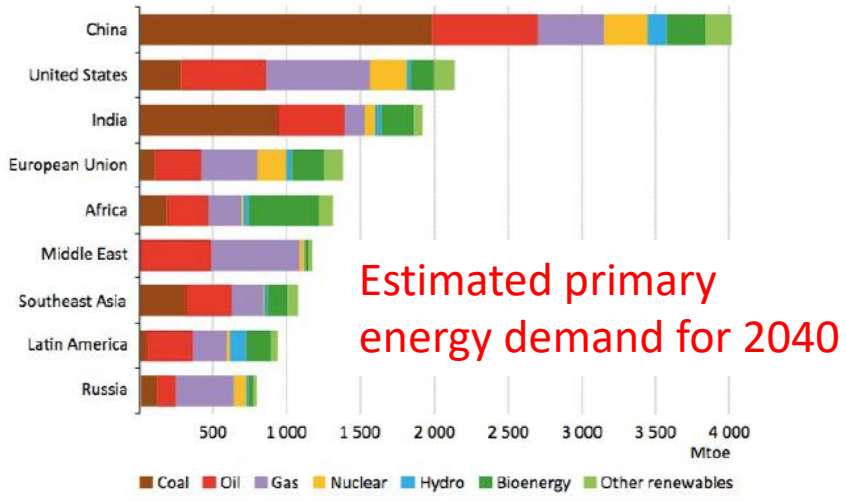
Source: Exxon Mobil

Top Five market comprised over half of global energy supply investment



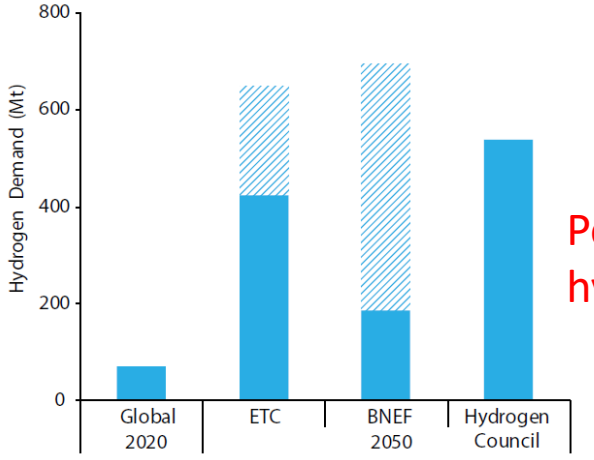
Energy supply investment in 2015

Source: IEA



Estimated primary energy demand for 2040

Source: IEA



Potential scale of hydrogen demand

Source: TERI analysis based on (ETC, 2018; BNEF, 2020; Hydrogen Council, 2017). Shaded bars represent the range of forecasts

Hydrogen mission in India

"India is committed to the rapid expansion of the hydrogen economy, ensuring the cost effective deployment of low carbon hydrogen technologies across the transport, industry and power sectors by 2030"
Hon'ble PM of India emphasized that India will be leading Green H2 exporter by 2030

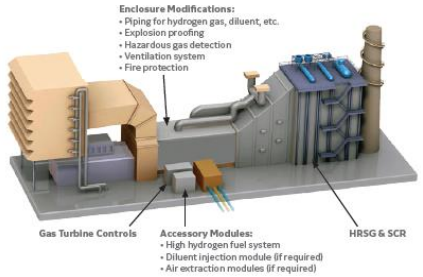
- Clear recognition of hydrogen's **cross-economy role,** with outlines for scaling-up use in transport, industry and power
- Commitment to **update existing regulations** to permit the safe use of hydrogen, at high pressure, across a number of end-use sectors
- **'Make in India' policy support** to maximise domestic manufacturing content across all parts of the value chain, including joint ventures with multinational companies
- **Champion electrolyser manufacturing and commercialisation,** realising their suitability to the Indian market and significant potential for emissions reduction
- Significant increases in existing hydrogen **R,D&D spending,** to support demonstration projects in the steel and power sectors, as well as the commercialisation of more mature Technologies
- Policies to create a **guaranteed market** for hydrogen technologies, where they are not yet at cost parity with fossil-fuel equivalents, for example in the steel sector
- Meaningful engagement in **international collaborations** on developing hydrogen technologies, including Mission Innovation and the Clean Energy Ministerial.
- Mandate for Use of Green hydrogen (GHCO) for captive consumption in Refineries and Fertilizer Industry

IndianOil's Hydrogen Initiatives

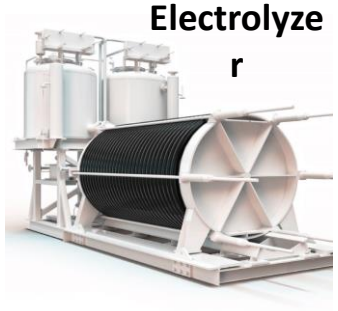
Applications and Demonstrations

HCNG (18 % Hydrogen) –India's 1st tryst with Hydrogen Economy

Green Hydrogen Initiative



HCNG Usage in Turbine at Refinery

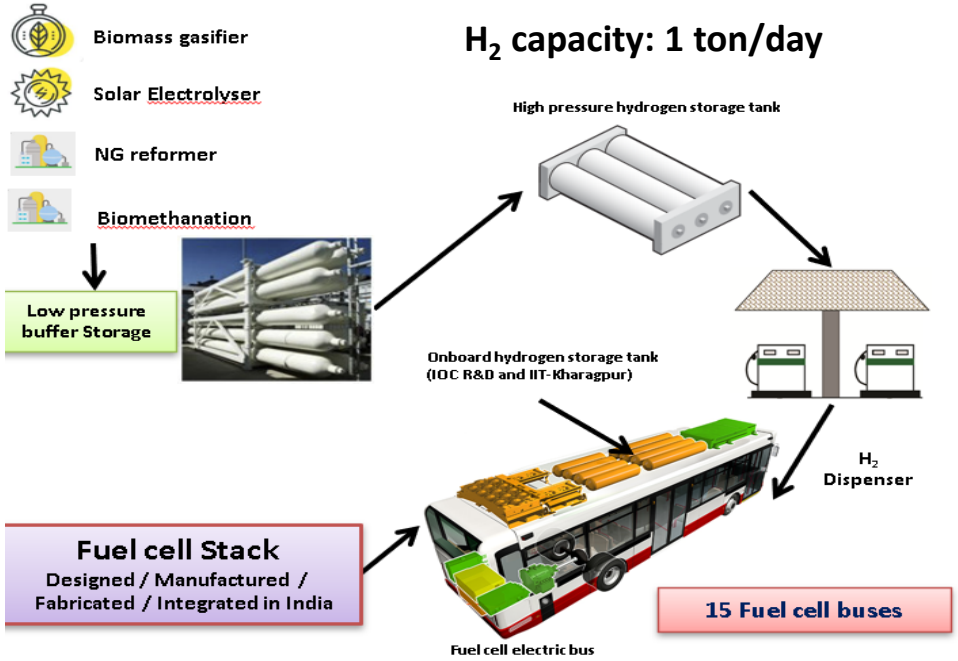


Electrolyzer

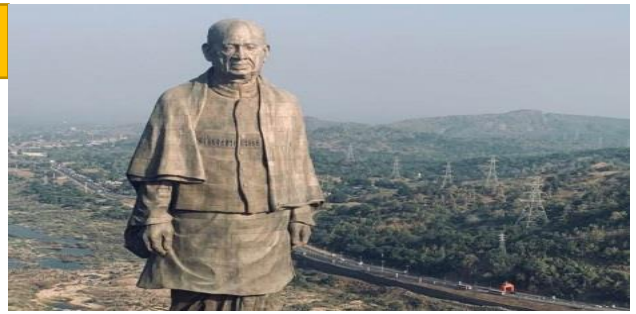
HCNG Usage in NG Pipelines

52 TMT Green H_2 in Mathura Refinery
(Entire H_2 requirement of Mathura / 8 % of IOC requirement)

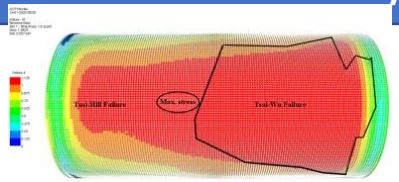
1st Hydrogen Fuel cell Mobility Initiative at R&D Campus

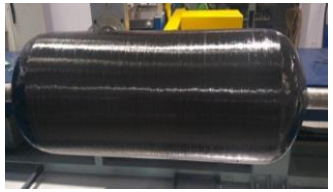


Fostering Green H2:
Solar/Wind electrolysis – 2 HRS (600 kg/day)
10 Fuel Cell buses on Iconic Route: Delhi to Agra



Turning Blue - Leveraging Hydrogen from IOC Refineries 1.5 ton/day
CCUS for EOR at ONGC
25-75 Fuel Cell buses on Iconic Route: Vadodra to Statue of Unity





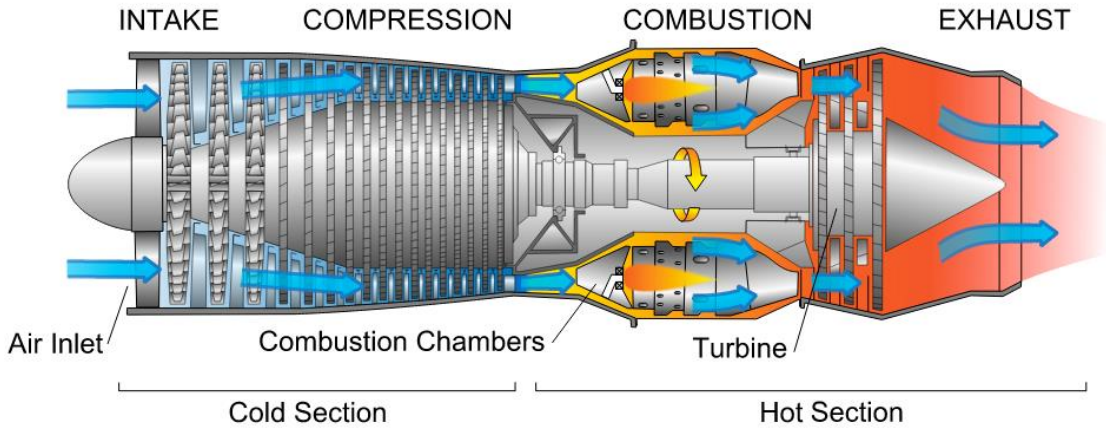
1st Indigenous Type 3 hydrogen cylinder

IndianOil – 1st Indian O&G PSU to be inducted to World Hydrogen Council

Gas turbines

It is often said that gas turbines can burn (**almost!**) any combustible gas:

- ❑ Natural gas
- ❑ Landfill gas, sewage gas, digester gas
- ❑ Syngas from coal, biomass and wastes
- ❑ Steelworks gases: Coke oven gas, blast furnace gas
- ❑ Very high hydrogen gases and blends (such as refinery gases)
- ❑ And more….



Changing conditions for power generators

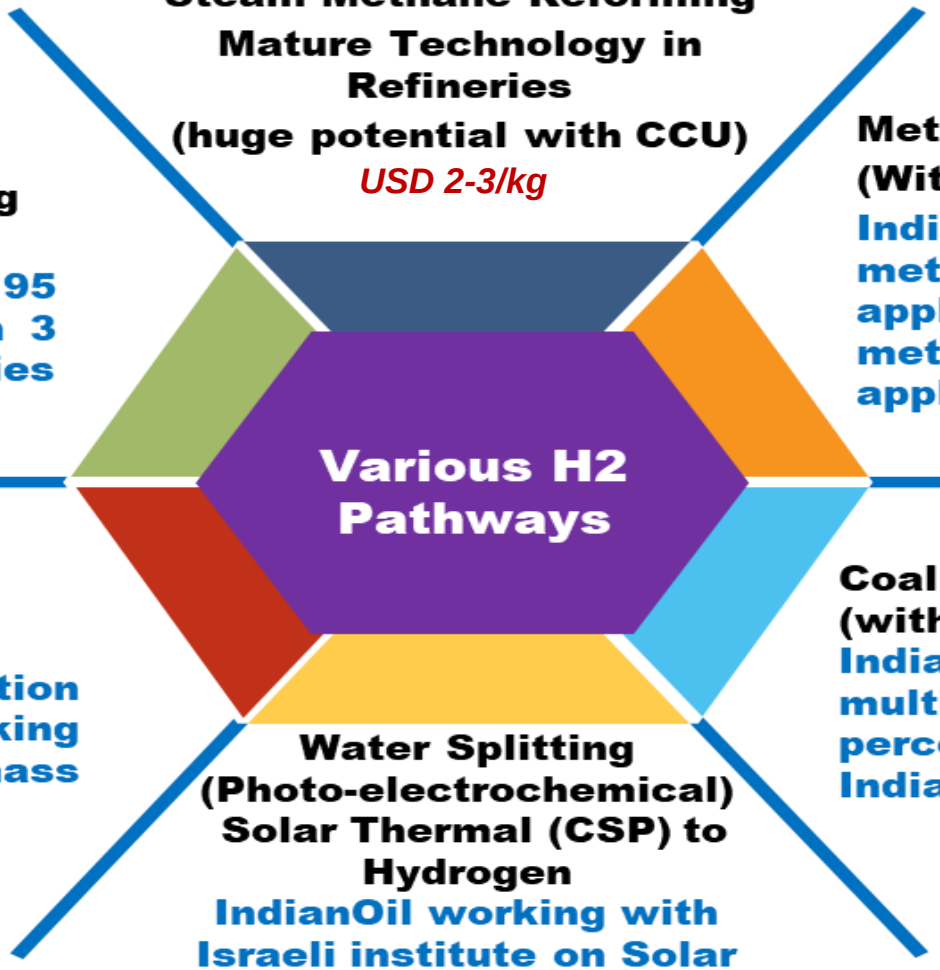
- Changing fuel composition (within current delivery specification)
- Widening delivery specifications, Operational flexibility
- Power to Gas (P2G), Emissions legislations
- Opportunity fuels (waste gases: refinery gases, process gases, gasification gases etc)

Challenges :

- NG price – Economic Constraint ----------
- Gas Allocation not there for power sector in India ---------- **Hydrogen production and usage with CNG or neat can be the Answer**
- ***E****ach individual gas turbine can only tolerate limited changes in gas composition and properties depending on the gas turbine design & some gases may have an adverse impact on component life.*
- *Each OEM need to assess based on metallurgy*

Hydrogen Supply Opportunities

Developing multiple indigenous cost-effective Hydrogen production pathways



Steam Methane Reforming
Mature Technology in Refineries
(huge potential with CCU)
USD 2-3/kg

Electrolysis (PEM/Alkaline/SOEC) using Solar PV/ Wind Energy
IndianOil setting up 95 Nm3/hr facilities based on 3 electrolyser technologies powered by Solar Energy
USD 5-6/kg. Target $2-$2.5/kg

Methanol reforming
(With Water; With Water & CO2)
IndianOil developing monolith methanol reformer for portable appl. and Aqueous phase methanol reformer for stationary applications
USD 4-4.5/kg

Biomass gasification
(IndianOil In collaboration with IISc., Bangalore working on Oxy-steam biomass gasification)
Target USD 1.5-2.5/kg

Coal gasification (with CCUS)
IndianOil pursuing Integrated multi-feed gasification of coal / percoke and biomass (US/EU and Indian patent granted)
USD 3-5/kg

Water Splitting (Photo-electrochemical) Solar Thermal (CSP) to Hydrogen
IndianOil working with Israeli institute on Solar CSP for H2 production

Enhancing scale for Hydrogen activities through its integration with Govt of India's initiatives like:

SATAT – Biomethanation to Hydrogen
Promoting Gas based economy - with CCUS
Waste to energy – Agro Residue / Biomass Gasification to Hydrogen
Solar Mission – Solar to Hydrogen through Electrolysis

Challenges in H2 based Gas turbines

Combustion of Hydrogen-containing gas

NG Network Exists in India over 600 GAs Awarded for CGD

Potential for firing Natural gas-hydrogen mixture

Power to gas (P2G) – use of excess renewable electricity to produce hydrogen as an energy storage medium

- diffusion systems tolerate high levels of H2 : **upto 100%vol**
- lean premix specifications range from **"trace" to 20%vol+**
- wide range of operational, integrity and safety concerns if H_2 added to gas network

Variation in Wobbe index and fuel composition

- Increasing NO_x with increasing wobbe index
- Flame stability issues with changing wobbe index (leading to dynamics and part load CO problem)
- Increases in dynamics with increasing C2+ or changes in wobbe index
- Flashback damage

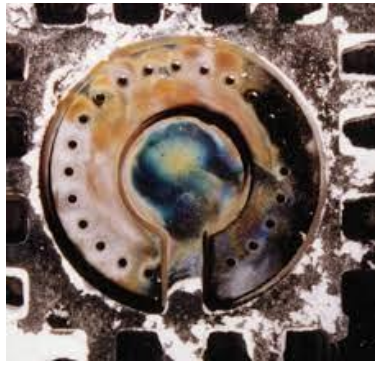


Fig. Flashback damage due to high level of C2+

Mitigation measures

- Combustion system re-design
  - Has effectively eliminated most flashback issues
  - Improvements in stability, emissions and dynamics
- Measurement of fuel composition and compensation through GT control
  - Issues with speed of composition measurement
  - Effective in controlling high C2+ in sequential combustion system
- Measurement of Wobbe index and compensation through fuel heating

Fig. Damage due to high dynamics

Development needs and possibilities

Solving the problem of variable pipeline gas quality for industrial end users

Sulphur (H_2S)

H_2S removal using selective absorbent

Trace metals

Arsine removal using selective absorbent

NG+ H2

Biogas / landfill gas

Associated gas

Shale gas

LNG

The number of sources for natural gas is increasing with emergence of LNG, biogas, landfill gas, etc in addition to the traditional source. New sources bring with them new challenges for users of natural gas as a fuel.

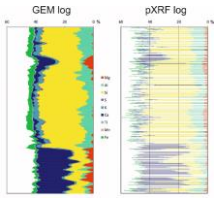
Industrial gas users

Domestic gas users

Gas fueled vehicles

Catalytic de-richment
Consistent feed
$C_nH_{2n+2} + (n-1)H_2 \rightarrow nCH_4$

Composition variability



Changing considerations for future Power Plant design

F
Lexibility
ast response
requent cycling
uel switching

Development needs

- ❖ Robust fuel combustion system
- ❖ Improved automatic tuning
- ❖ Improved hot corrosion resistant
- ❖ Full range operation on high inert fuels
- ❖ Hydrogen tolerant GTs
- ❖ Generate low cost retrofits of new solutions

Conclusions

- Govt of India mandate is to increase NG from current 6 to 15% by 2030
- Lot of Opportunity as NG network being expanded all across the country
- Hydrogen is one of the Enabling factor
- Multiple sources to produce hydrogen Locally
- Reduction in renewable electricity enables green and economically viable hydrogen.
- O&G companies can play complimentary role by supplying hydrogen for blending
- Power sector can be one of the starting points to adopt hydrogen both as HCNG and neat for electricity production The past decade has seen significant increases in grid fuel variability
- OEMs have developed more robust systems, automatic tuning systems and other mitigation measures.
- Cost of upgrades and implementation of mitigation measures remains an issue in the competitive power generation market

Gas/HCNG/ Hydrogen can be a Bridge between Fossil fuel and Environmentally friendly Renewables