

Hydrogen + CNG (HCNG) Engine Development

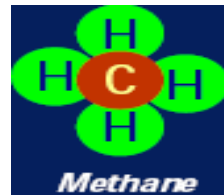


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What is HCNG ?

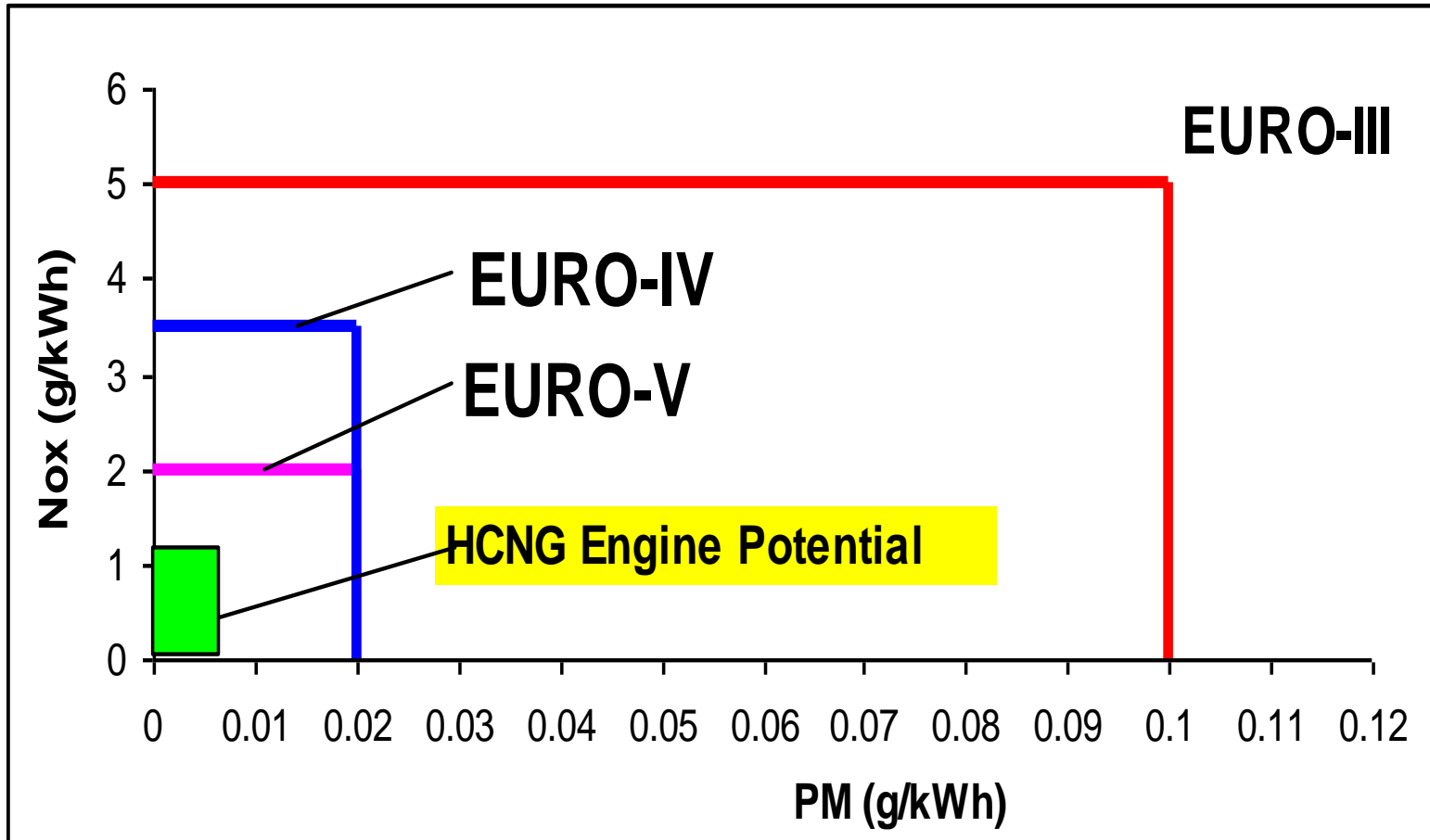
- * HCNG is a general term used to denote varying blends of Hydrogen and CNG.
- * The name “Hythane®” signifies a patented blend of Hydrogen and Methane (CNG) which is patented by Frank Lynch of Hydrogen Consultants Inc, USA
- * Adding Hydrogen, which has higher flame speed to a low flame speed fuel like CNG, improves the combustion efficiency of the HCNG blend.
- * HCNG has advantage of low minimum ignition energy and wide range of flammability limits
- * **HCNG is thus the first step for introducing Hydrogen and is considered as the transition automotive fuel**



HCNG Improves CNG properties

Properties	Hydrogen	HCNG (20 % Blend)	CNG
Flame speed	237 cm/s	120 cm/s	42 cm/s
Diffusion coefficient	0.61 cm²/s	0.25 cm²/s	0.16 cm²/s
Higher Cal Value	142 MJ/kg	92 MJ/kg	55 MJ/kg
Stoichiometric A/F	34.3:1	22.8:1	17.2:1
Flammability limits	4-75 (% vol)	5-35 (% vol)	5.3 – 15 (% vol)
Minimum Ignition Energy	0.02 mJ	0.21 mJ	0.28 mJ
Auto-ignition Temp.	858 K	825 K	813 K

HCNG Engine Emission Potential



Environmental Benefits of HCNG

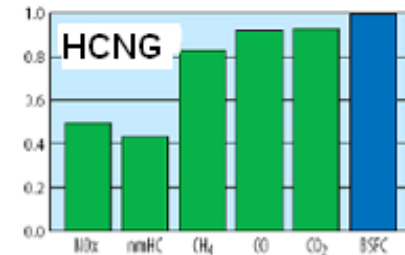
- 1) Reduction in emissions due to 20 % HCNG blend as compared to CNG is as follows *

CO reduction by 40-50 %

NMHC reduction by 25-30 %

NO_x reduction by 45-50 %

CO₂ reduction by 7-10 % * Reference: USDOE (2004)



- 2) Improvement in ambient air quality and mitigation of health problems associated with air pollution
- 3) Creation of a Hydrogen infrastructure thereby promoting the entry of a renewable fuel in the energy market

OEM Benefits of HCNG

- ★ **Engine Changes required for technology adoption of HCNG are minimum – changes in injectors, fuel lines and addition of gas leak detectors.**
- ★ **Ability to meet Euro-V norms with minimum after treatment**
- ★ **Minimal changes to operation and maintenance procedures of standard CNG Light and Heavy commercial Vehicles**



End Customer Benefits of HCNG

- 1) Fuel economy and power output of HCNG engine superior as compared to CNG providing faster return on investment.
- 2) Affordable gaseous fuel reducing dependence on non renewable fossil fuels
- 3) Familiarity with use of Hydrogen as an Auto fuel
- 4) A satisfaction of contributing to a clean environment creation



HCNG Engine Development WorldWide



**Ricardo, UK
Hydra single
cylinder HCNG**



**Yuchai, China
Six cylinder
Hythane engine**



**AVL –
Cummins Six
cylinder
HCNG engine**

HCNG Vehicles Worldwide



HCNG Bus Case Study : Cummins Westport

- **Two Hythane® fueled Sunline buses are developed and in use since 2000. No engine issues, fuel consumption is equivalent to CNG buses**
- **Improved engine and throttle response. Provides max emissions benefits with 20% vol blend of Hydrogen with CNG**
- **Hythane® cost represents a 30% premium over CNG cost of \$ 1per kg.**



HCNG Scenario in India

- **NHEB constituted by MNRE has prepared a roadmap for the hydrogen research & implementation in India.**
- **IOC with SIAM is executing the demonstration project on use of up to 30 % H₂ - CNG Mixtures in automotive vehicles.**
- **1st Public HCNG station from IOC setup in Dwarka, New Delhi**
- **Infrastructure required for HCNG includes setting up of fixed and mobile dispensing stations. The total estimated cost is around Rs 150 Crore.**



Economics of HCNG

CNG fuel cost : Rs 22 /kg

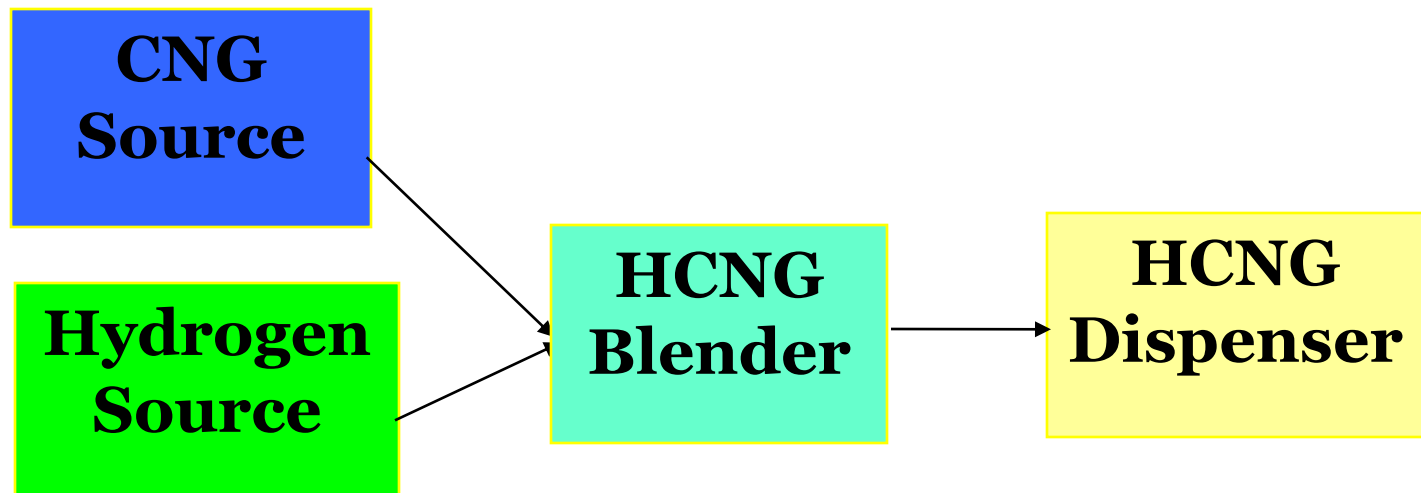
H₂ fuel cost : Rs. 100/ kg (Industrial Hydrogen cost in India)

H₂ Fuel cost: Rs. 200 /kg (Methane reforming cost as \$5 per kg)

H₂ fuel cost : Rs. 400 /kg (Electrolysis cost of \$ 12/kg)

For average 10 % HCNG blend

HCNG Cost = 22 x 0.9 + 100 x 0.1 = Rs. 30 / kg



HCNG Fuel Blending and Dispensing Facility



HCNG Combustion Approaches

* STOICHIOMETRIC

$$\lambda = 1$$

Required:

- Optimised combustion
- Accurate lambda control
- Exhaust gas recirculation
- Three-way catalyst

Advantages:

- Low CO, HC emissions
- Small combustion variability

Disadvantages:

- Lower efficiency & safety
- Higher thermal loading and heat loss

* LEAN BURN

$$\lambda > 1$$

Required:

- High spark energy
- Oxidation catalyst
- Lambda Control
- Turbocharging & Intercooling

Advantages:

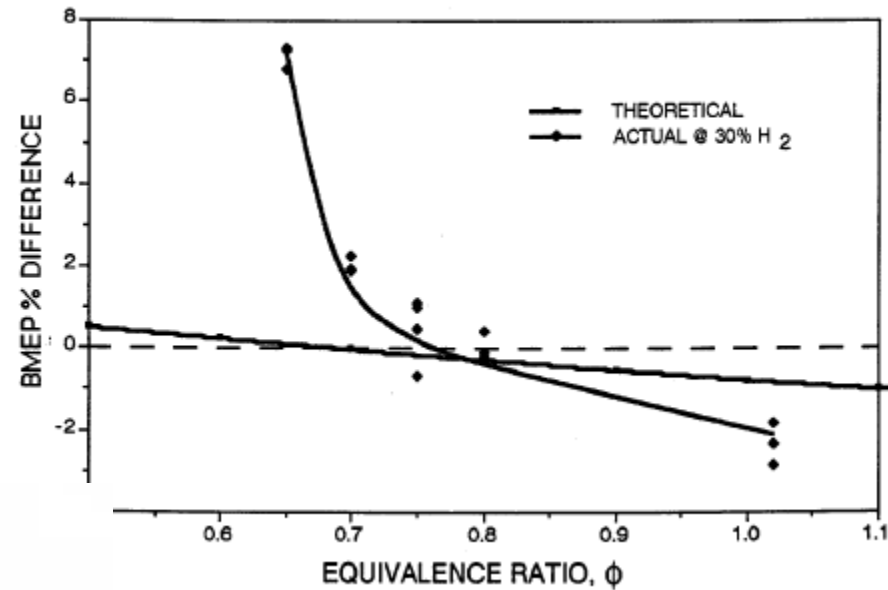
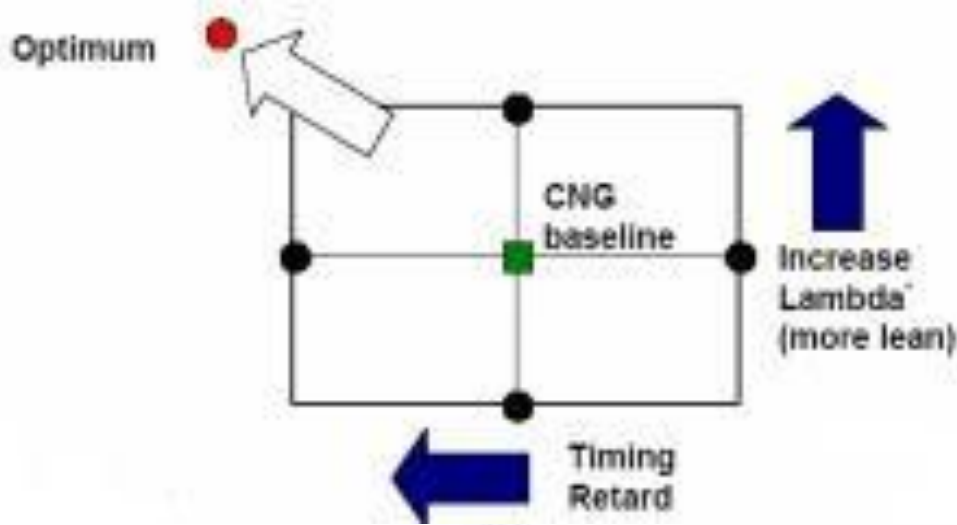
- Higher efficiency and BMEP
- Increased Safety
- Low Nox emissions

Disadvantages:

- Higher emissions
- Sensitivity to gas composition

HCNG Combustion

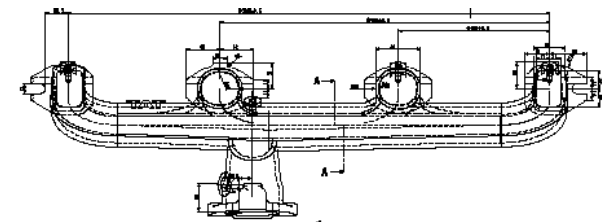
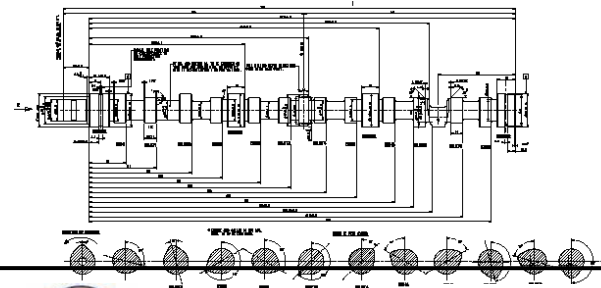
The theoretical improvement in BMEP at very lean conditions ($\lambda > 2$) is about 1% but the actual improvement is considerably more because of improvement in the CNG combustion due to hydrogen addition.



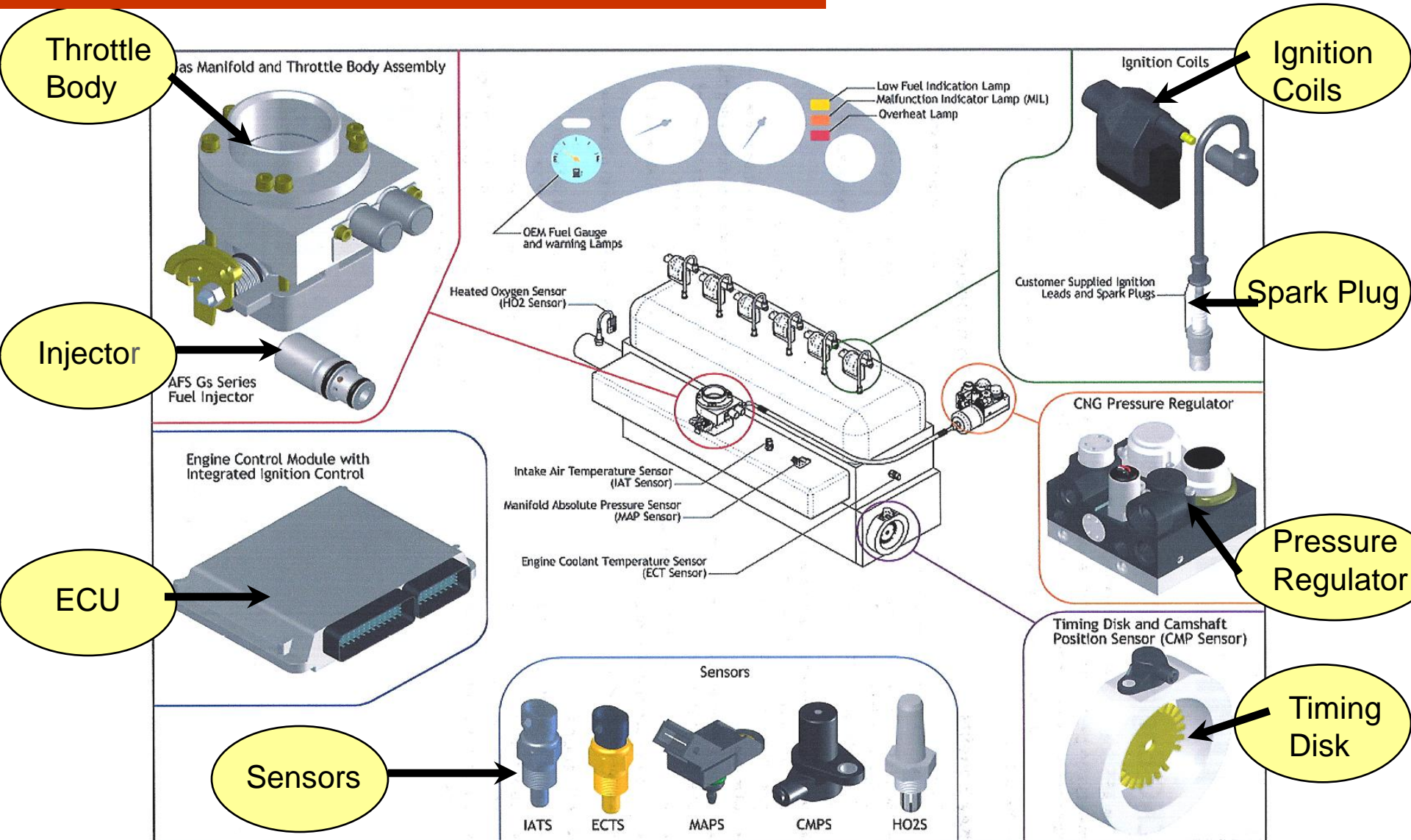
Optimised Lean Region

Base CNG Engine Modifications for HCNG Use

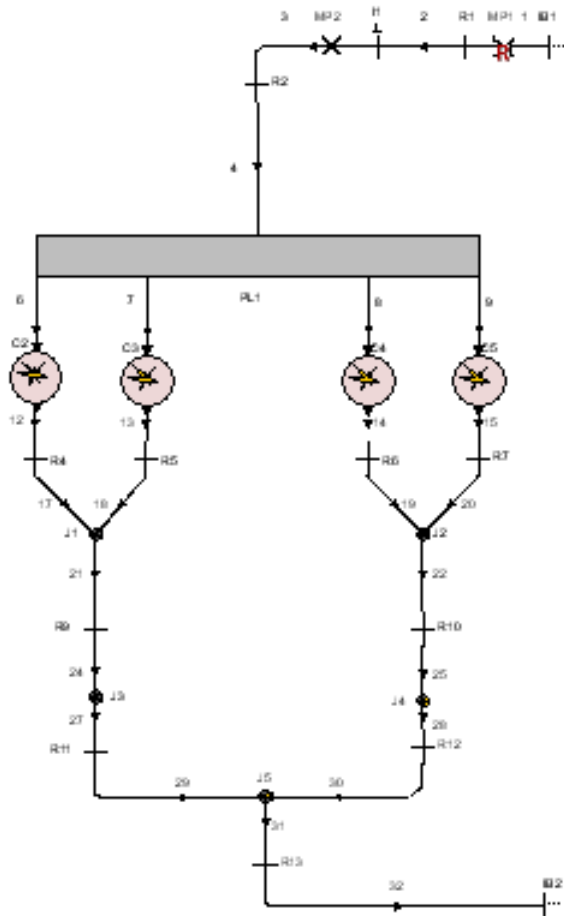
- The base CNG engine had a large valve overlap angle of 49 degrees CA, which reduced to 22 degrees for HCNG operation by designing a new camshaft.
- The combustion chamber was modified to increase the CR to 11.5 suitable for HCNG operation from 11.2.
- Based on literature guidelines exhaust manifold volume was increased to cater for the higher flame speed of hydrogen blend in order to take care of back fire and flow pulsations.
- The cylinder head was modified by way of modifying port geometry to reduce swirl.



Details of HCNG Injection Kit



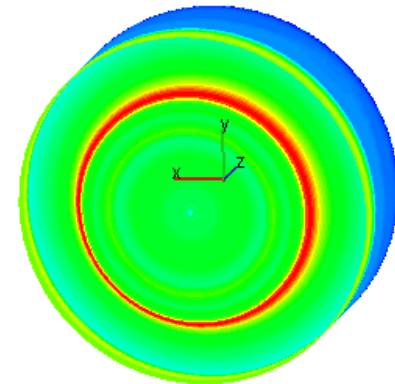
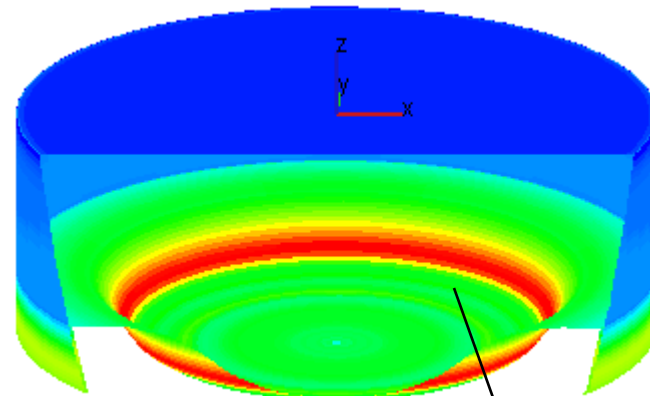
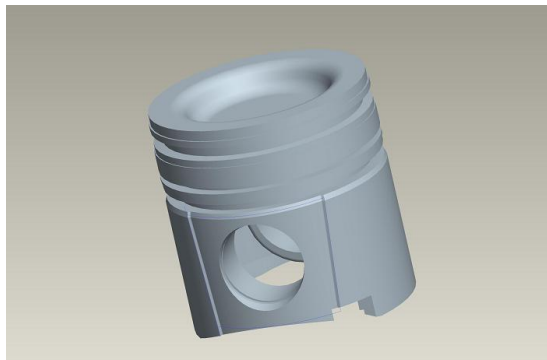
Thermodynamic Simulation for HCNG Engine



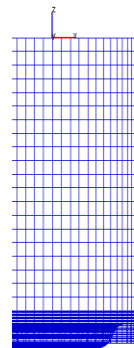
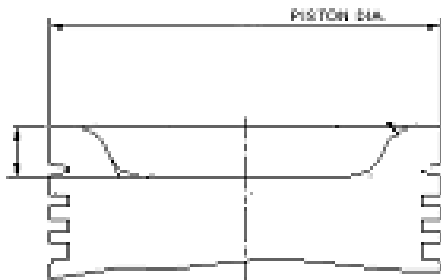
Thermodynamic modeling of HCNG Engine can be done using Boost Software.

CFD Simulation of HCNG Combustion

FIRE software can be used for CFD simulation of CNG and HCNG fuel combustion. Initially Methane (CNG) /Air mixture stoichiometric combustion can be modeled as reference.

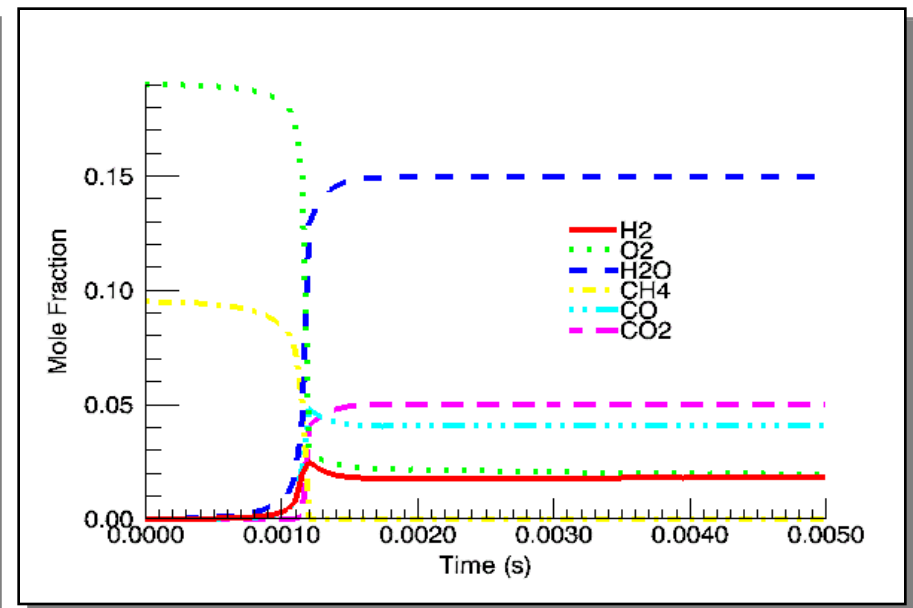
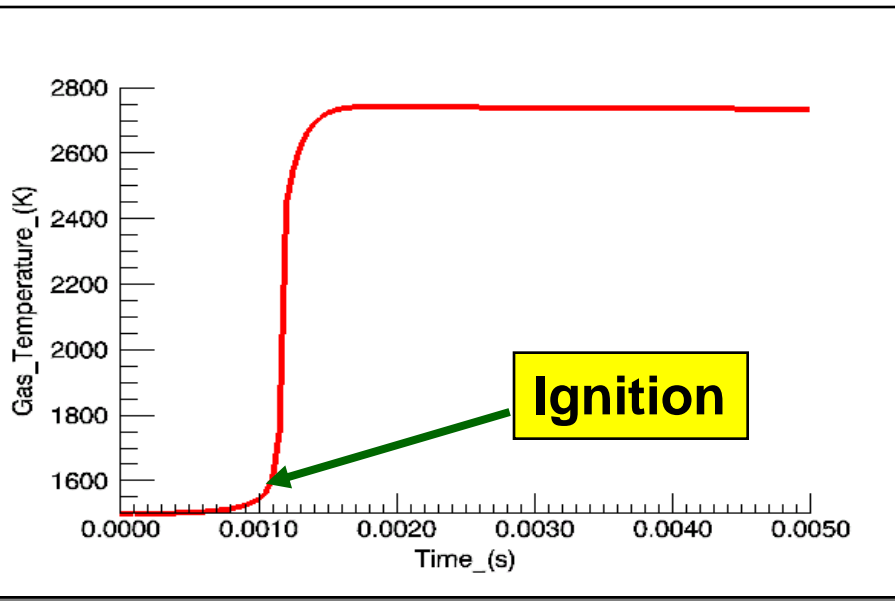


High Temperature Regions



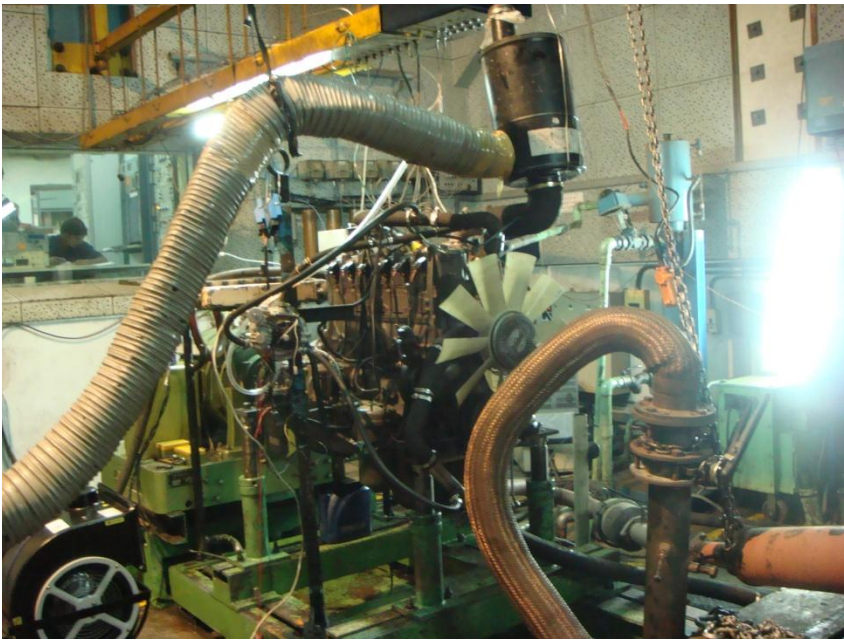
Chemkin Simulation of HCNG Combustion

Chemkin is a chemical kinetic modeling software from Reaction Design Inc. Methane (CNG) /Air mixture and HCNG/Air – stoichiometric combustion can be modeled modeled. Prediction of start of ignition, adiabatic flame temperature, peak combustion pressure, emission species prediction can be done.



ARAI LCV HCNG Engine

ARAI has developed a 4 cylinder stoichiometric LCV HCNG engine with 5 %, 10 %, 15 %, 18 % and 20 % HCNG blends



Conclusions

- **Blending of Hydrogen and CNG can reduce HC, CO and NOx emissions. Requirement of after treatment is reduced for HCNG to meet future stringent emission norms.**
- **HCNG can advantageously exploit the growing infrastructure of CNG and help introduce Hydrogen through a stepwise mechanism.**
- **Fuel economy and power output of HCNG engine superior as compared to CNG providing faster return on investment.**
- **Indian standards for HCNG need to be developed conforming to global regulations Cost of HCNG will be a deciding factor for its future use**
- **Additional safety aspects with HCNG operation to be considered**