Improved Fuel Efficiency and Low-emission Characteristics of Hydrogen Engine for Sustainable Transport

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HYDROGEN

It's abundant, clean, efficient, and can be derived from diverse domestic /non-fossil resources.

Biomass
Hydro
Wind
Solar
Geothermal

Nuclear

Oil

Coal

Natural Gas

With Carbon Sequestration

HIGH EFFICIENCY & RELIABILITY

ZERO/NEAR ZERO EMISSIONS

H_2

Transportation

Distributed Generation

Hydrogen :Some Temperamental Properties

	Hydrogen H_2	Gasoline	Diesel Fuel	Methanol CH_3OH	Propane C_3H_8	Methane CH_4
Ignition energy (mJ/kg)	20	250		200	250	300
Flame. limits (%)*	4-75	1-8	1-7	6-26	2-10	5-15
Auto-ignition temp.(°C)	580	400	220	380	490	650
Flame speed (m/s)	2.7	0.35	0.3	0.5	0.4	0.4

Striking Features of Hydrogen-Specific Engine

Hydrogen –Fuelled Engine has the Potential for

(i)very high engine thermal efficiency

(ii) Extremely low emissions

Efficiency Improvement: Unthrottled Lean-burn Operation

Typical combustion property of hydrogen such as Wide flammability range permits

"Quality Regulation" which

(i) Reduces Throttling losses

(ii) Enables ultralean operation

Quality regulation consists of controlling power by varying the fuel rate without throttling flow of intake air

In a hydrogen-air mixture the equivalence ratio(over which the mixture is flammable) is not sufficient to adopt quality governing.

Efficiency Improvement : Fuel Injection and Higher compression ratio

(i)Hydrogen engine efficiency can be further improved by adopting higher compression Ratio

(ii) Higher compression Ratio can be used by using Fuel Injection system instead of carburation

Fuel Injection system also eliminates the problem of "backfire" (which has been the major stumbling block for the development of hydrogen engine)

- Low minimum ignition energy
- Wider flammability range

Ultra lean operation

- Higher thermal efficiency
- Lower NOx emissions

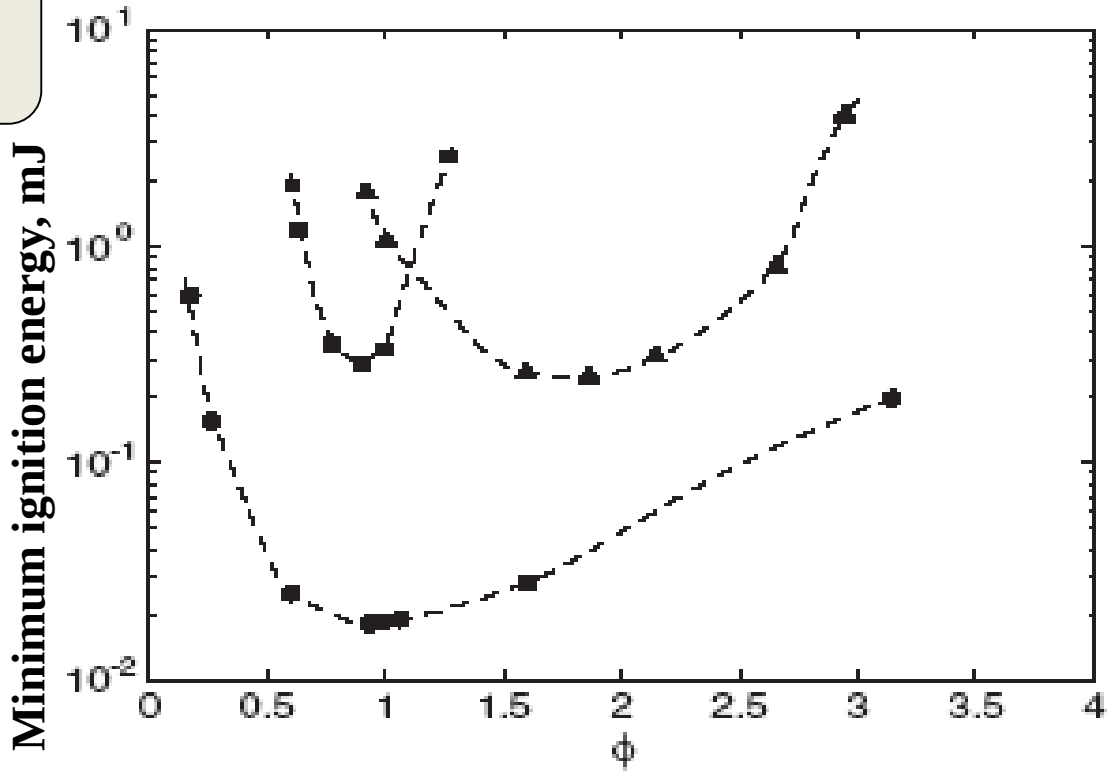
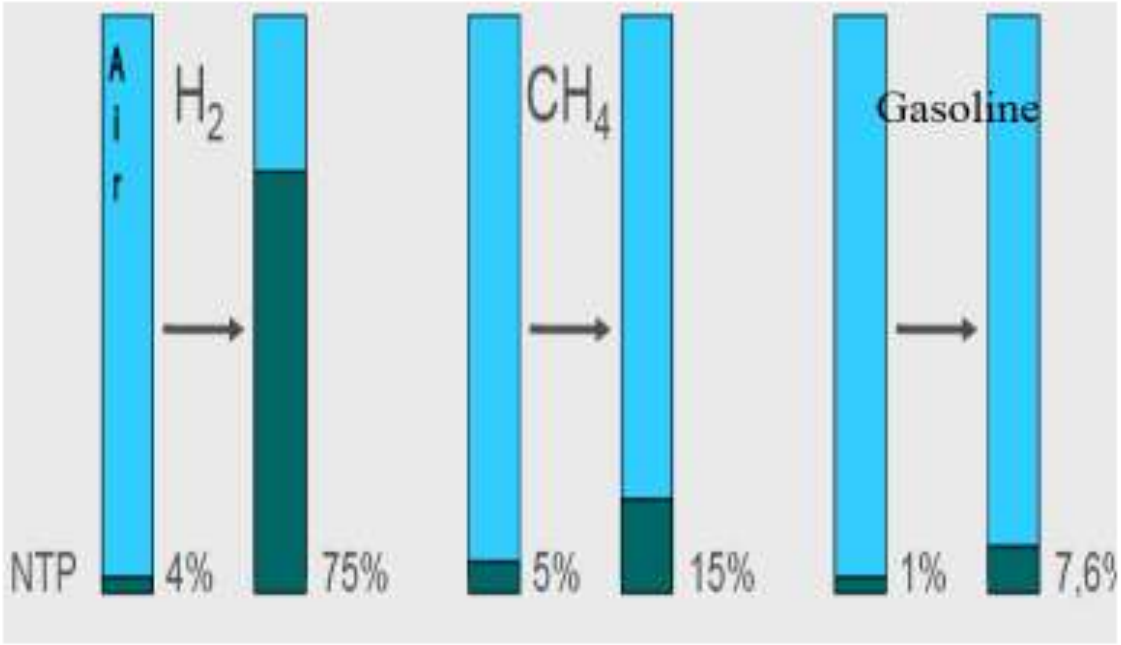


Fig 1. Minimum ignition energy of (·) hydrogen – air, (■) methane – air and (▲) heptane – air mixtures in relation to ø at atmospheric pressure(3).

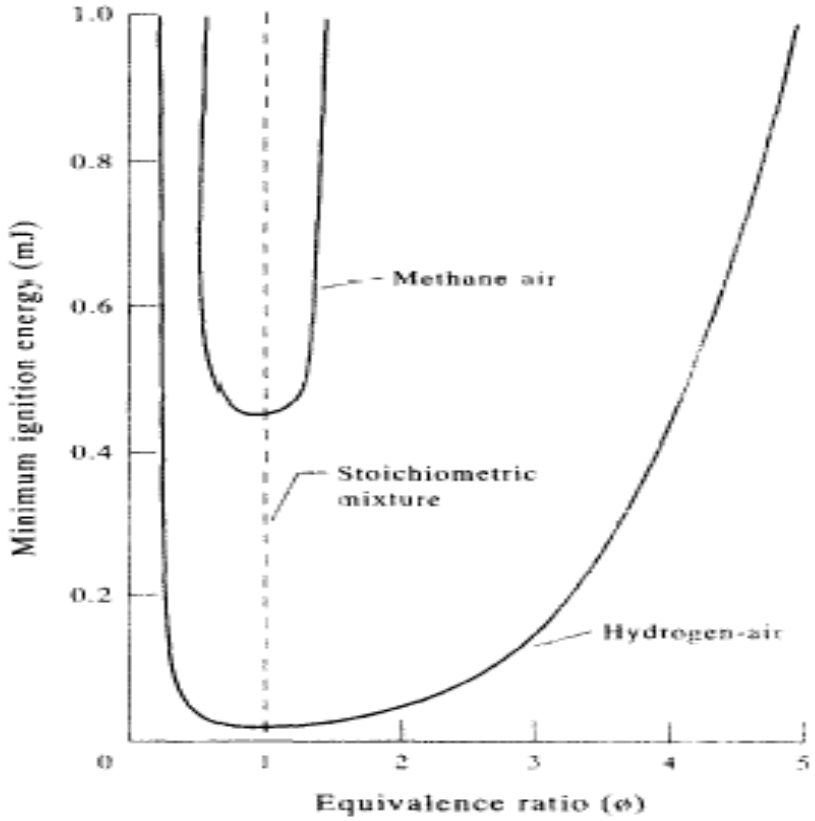
P.C.T.De Boer, W.J. McLean and H.S. Homan "Performance and Emissions of Hydrogen fueled internal combustion engines" Int. J Hydrogen Energy, 1976; 1(2):153-172.

Flammability range

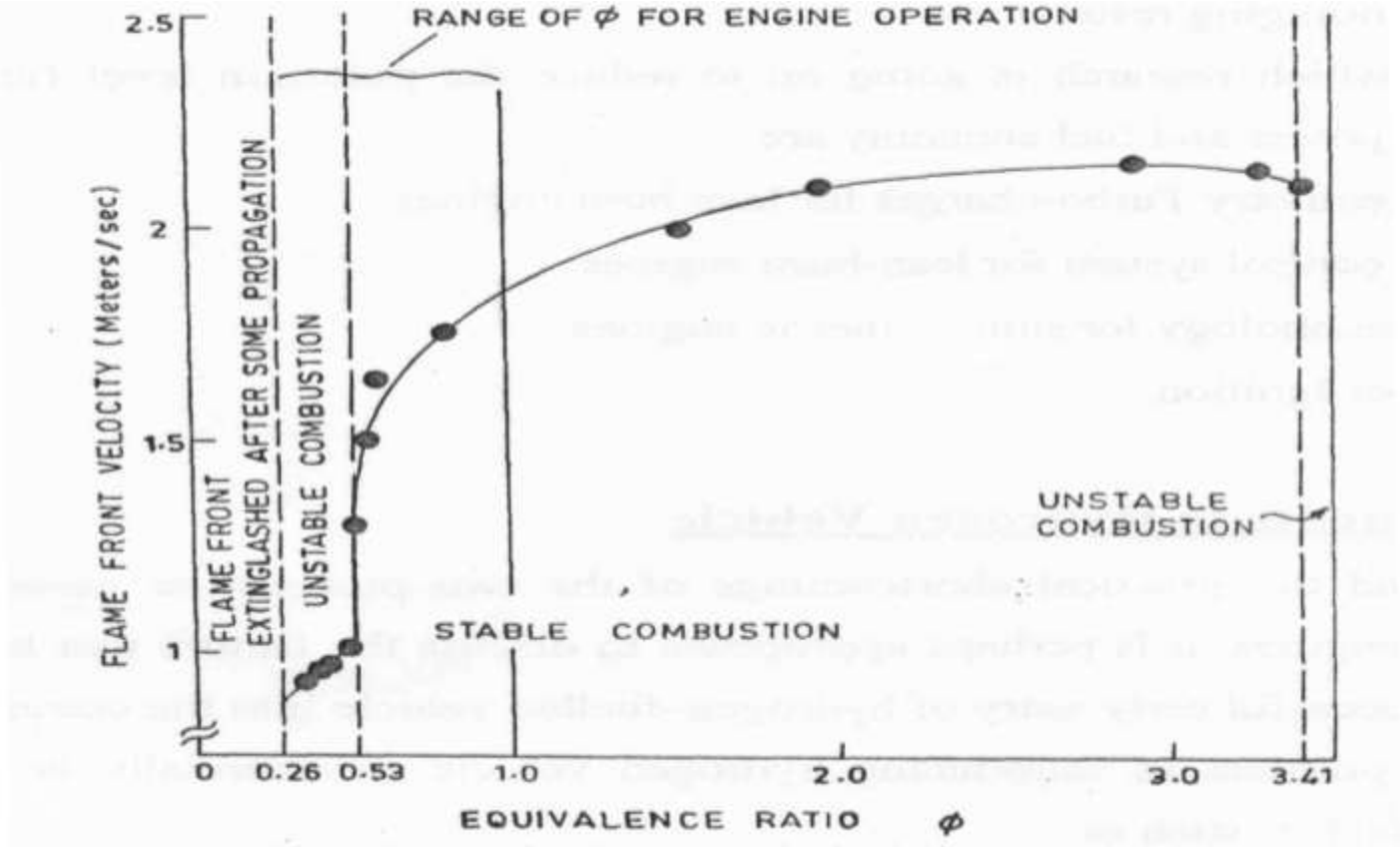
Comparison



Minimum Ignition Energy as a Function of Equivalence Ratio for Hydrogen and Methane



Flame Front Velocity



Undesirable combustion Phenomena

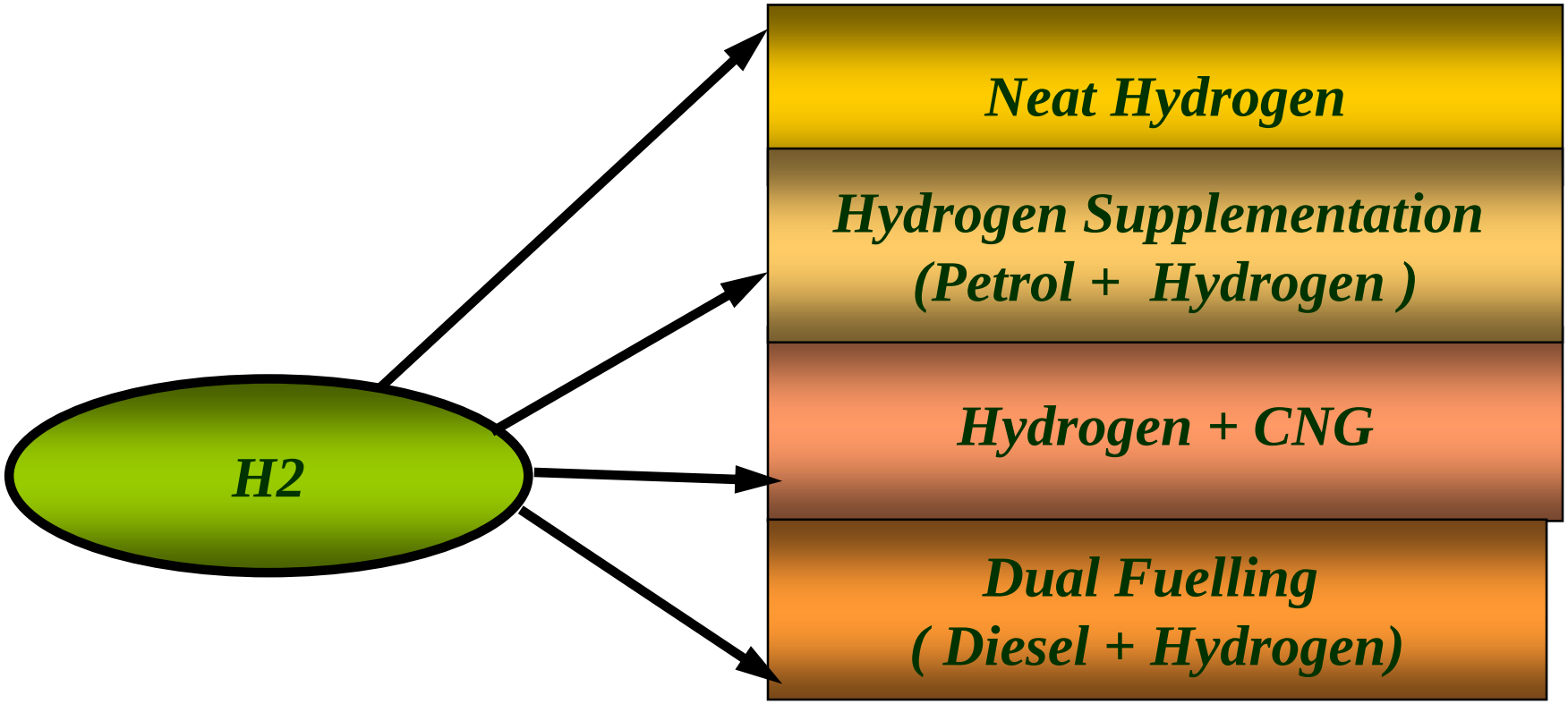
Potential of high thermal efficiency and low emission characteristics are often eclipsed by the Undesirable combustion phenomena such as

- Backfire
- Pre-ignition
- Rapid rate of pressure rise
- Rough combustion (knocking)

Backfire: Achilles Heel for Hydrogen Engine

- *Presence of Hot Particles in the Cylinder*
- *Hot Spots on the Spark Plugs and on the Cylinder Walls*
- *Particulate matter in the residual from the oil*
- *Communication of fresh charge with burning exhaust gases from another cylinder*
- *Very lean operation with the presence of still-burning gases from the previous cycle—when the intake valve opens*

Hydrogen Utilisation in IC Engines



Relevance of Fuel Induction Technique :Solution to Backfire

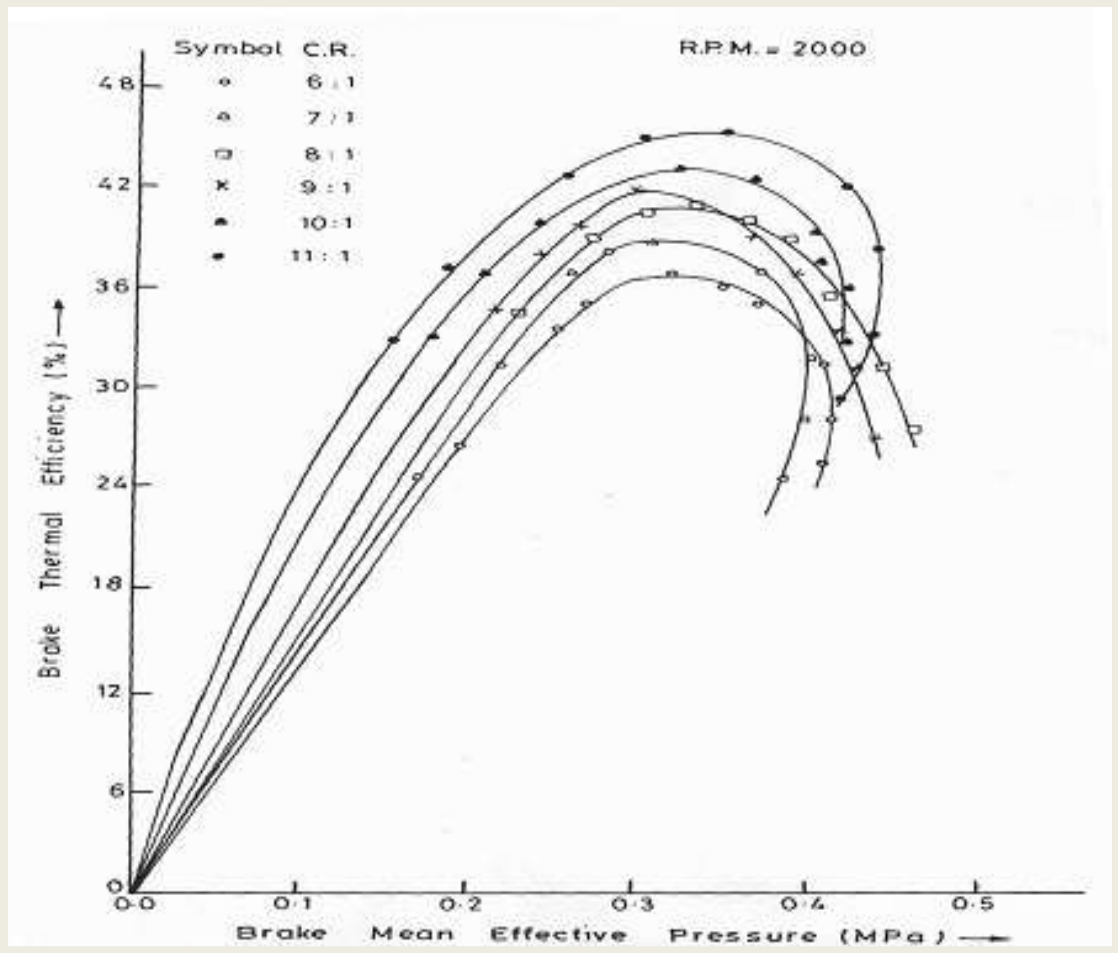
Mixture formation	Flow timings	Supply pressure	Comments
Continuous carburetion (CC)	Continuous flow	A little above atmospheric	Unsuitable for neat hydrogen b
Continuous manifold injection (CMI)	Continuous flow	Slightly greater than atmospheric	Not essentially different from CC
Timed manifold injection (TMI)	Flow commences after the opening of the intake valve but completed prior to IVC	1.4 - 5.5 kgf/cm^2	Most appropriate
Low pressure Direct cylinder injection (LPDI)	Flow commences after the intake valve closure and is completed before significant compression pressure rise	2.0 - 8.0 kgf/cm^2	Requires tough thermal environment
High pressure Direct cylinder injection (HPDI)	Flow commences at the end of the compression stroke	Abnormally high pressure	Uncontrolled combustion

An appropriately designed Timed Manifold Injection System embraces the benefit of both the Spark Ignition Engine as well as the Diesel Engine

It possesses the unique capability of adopting diesel-like quality governing and match the thermal efficiency of a diesel engine while developing the specific output of a Spark ignition engine

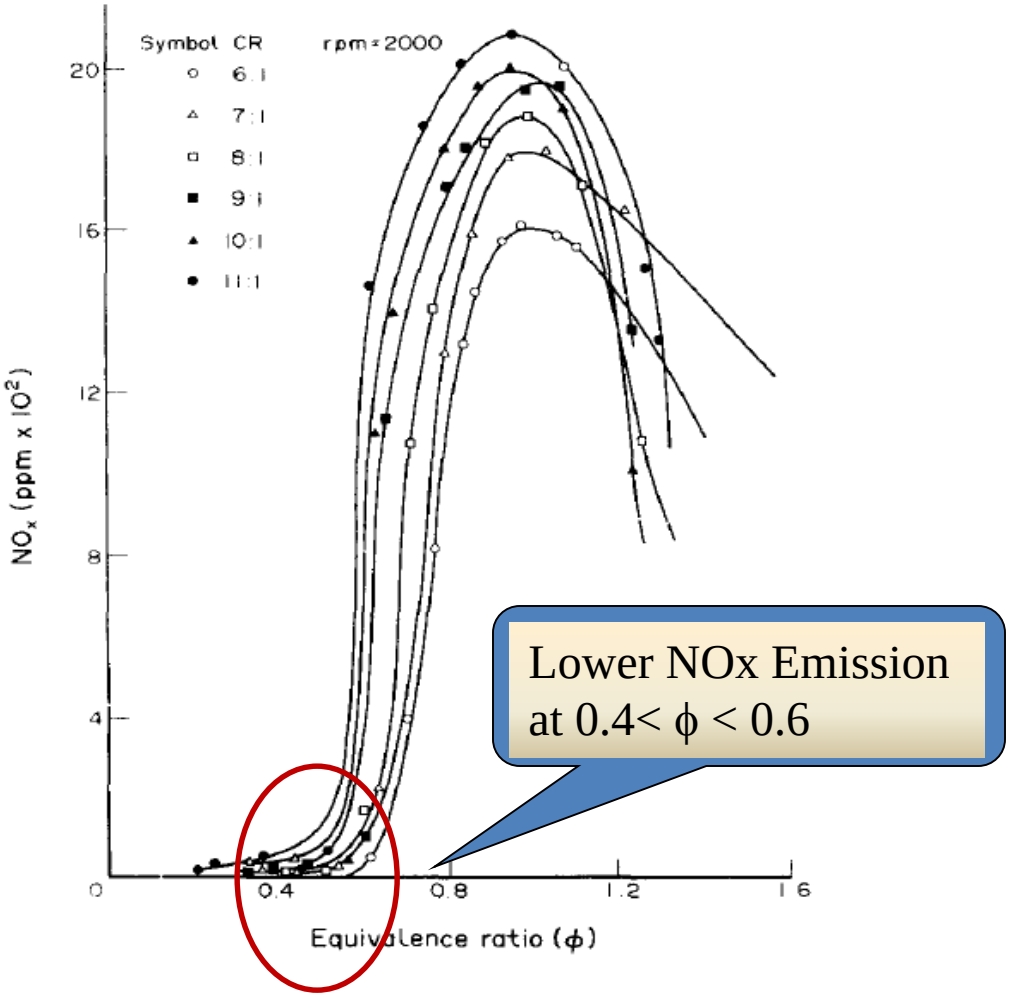
Brake Thermal efficiency Vs BMEP

IITD



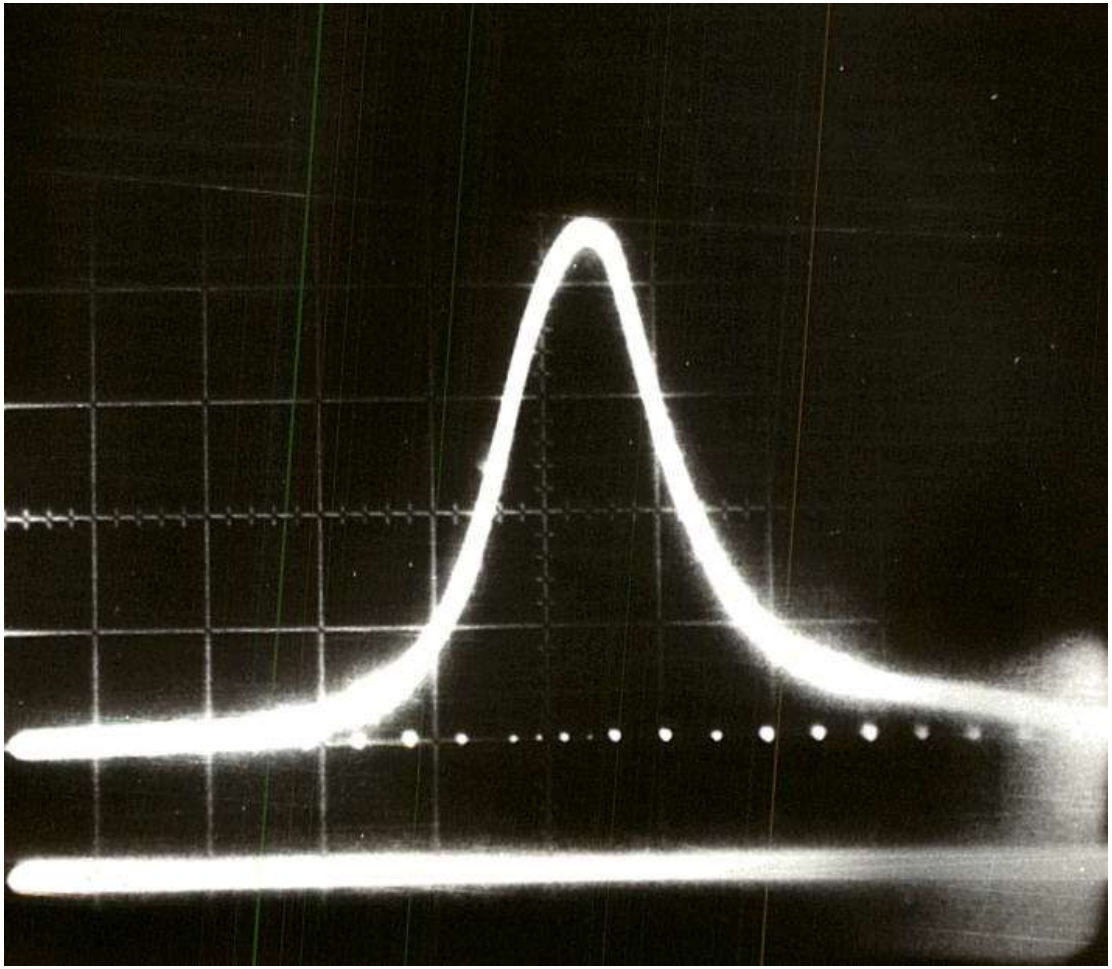
Maximum Thermal efficiency about 44 % at lean engine operation

Near Zero Emissions



Reference: L.M.Das, Exhaust Emission Characterization of Hydrogen-Operated Engine System: Nature of Pollutants and Their Control Techniques, Int. J. Hydrogen Energy Vol. 16, No. 11, pp. 765-775, 1991.

PRESSURE CRANK ANGLE DIAGRAM-H_2



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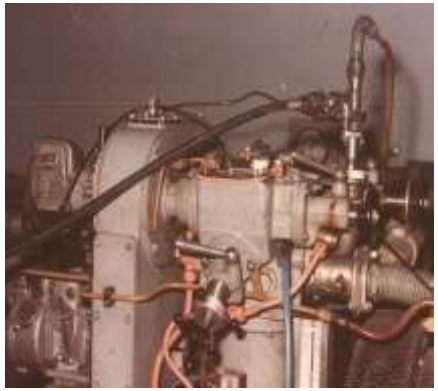
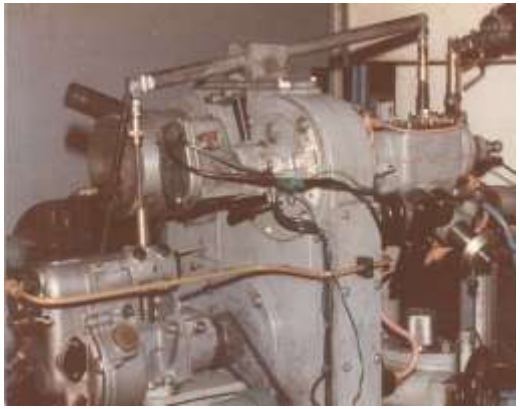
HYDRAULICALLY OPERATED INJECTION SYSTEM



CAM-ACTUATED INJECTION SYSTEM



Neat Hydrogen-fuelled S.I. Engine Genset

TOTAL HYDROGEN S.I. ENGINE GENSET USING ELECTRONIC FUEL INJECTION SYSTEM

SIX CYLINDER HYDROGEN – DIESEL DUAL ENGINE GENSET – (Ashok Leyland Engine)

HYDROGEN FUELLED DIESEL ENGINE

A picture from a video which compared fire from a leak in a gasoline engine car and the same kind of leak from a hydrogen car. The pictures are taken at one minute after ignition

The hydrogen flame has begun to subside, the gasoline fire is intensifying. After 100 seconds, all the hydrogen was gone and the interior of the car was undamaged. The gasoline car continued to burn for a long time and was totally damaged.

[Dr. Michael R. Swain 2001]

Hydrogen in Diesel Engines: Off-road applications

Operation of CI engine on neat hydrogen as a fuel requires major engine modifications/design changes.

(a) such as use of very high compression ratios or

(b)incorporation of combustion triggering devices like spark plug/glow plug and use of gaseous fuel injection/ induction system, etc.

SMALL HORSE POWER PORTABLE HYDROGEN-DIESEL DUAL FUEL GENSET UNIT

Compact portable Hydrogen diesel genset unit has been tested for long running hours

Upto 38% full load energy substitution without any abnormal combustion

MULTICYLINDER HYDROGEN – DIESEL DUAL ENGINE GENSET

Multicylinder high horse power diesel engine modified to hydrogen diesel dual fuel mode of operation.

Hydrogen substituted upto 45% on energy basis

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Development and Demonstration of H_2-Fuelled Three-Wheelers in New Delhi

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Mahindra

AIR PRODUCTS

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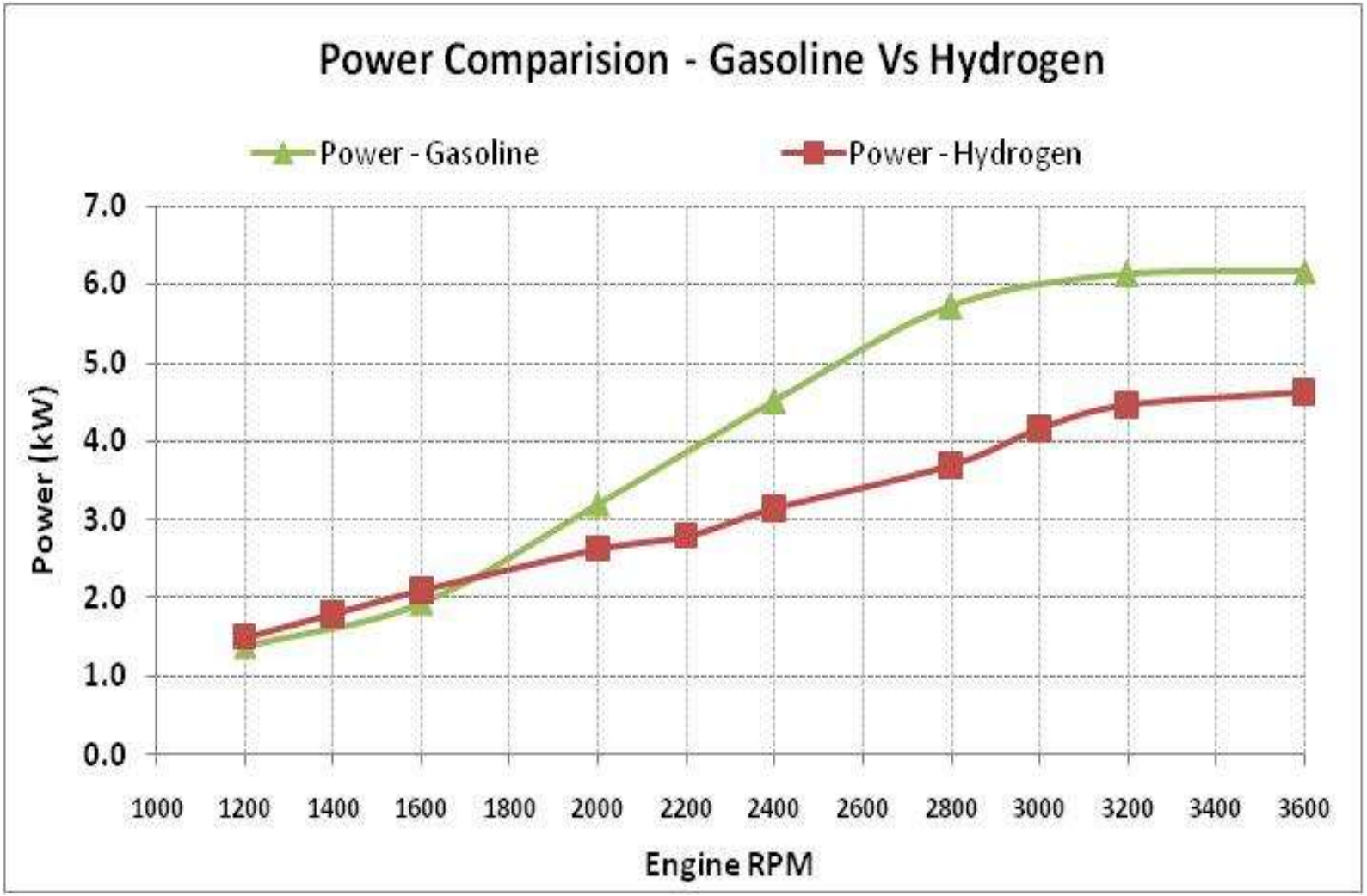
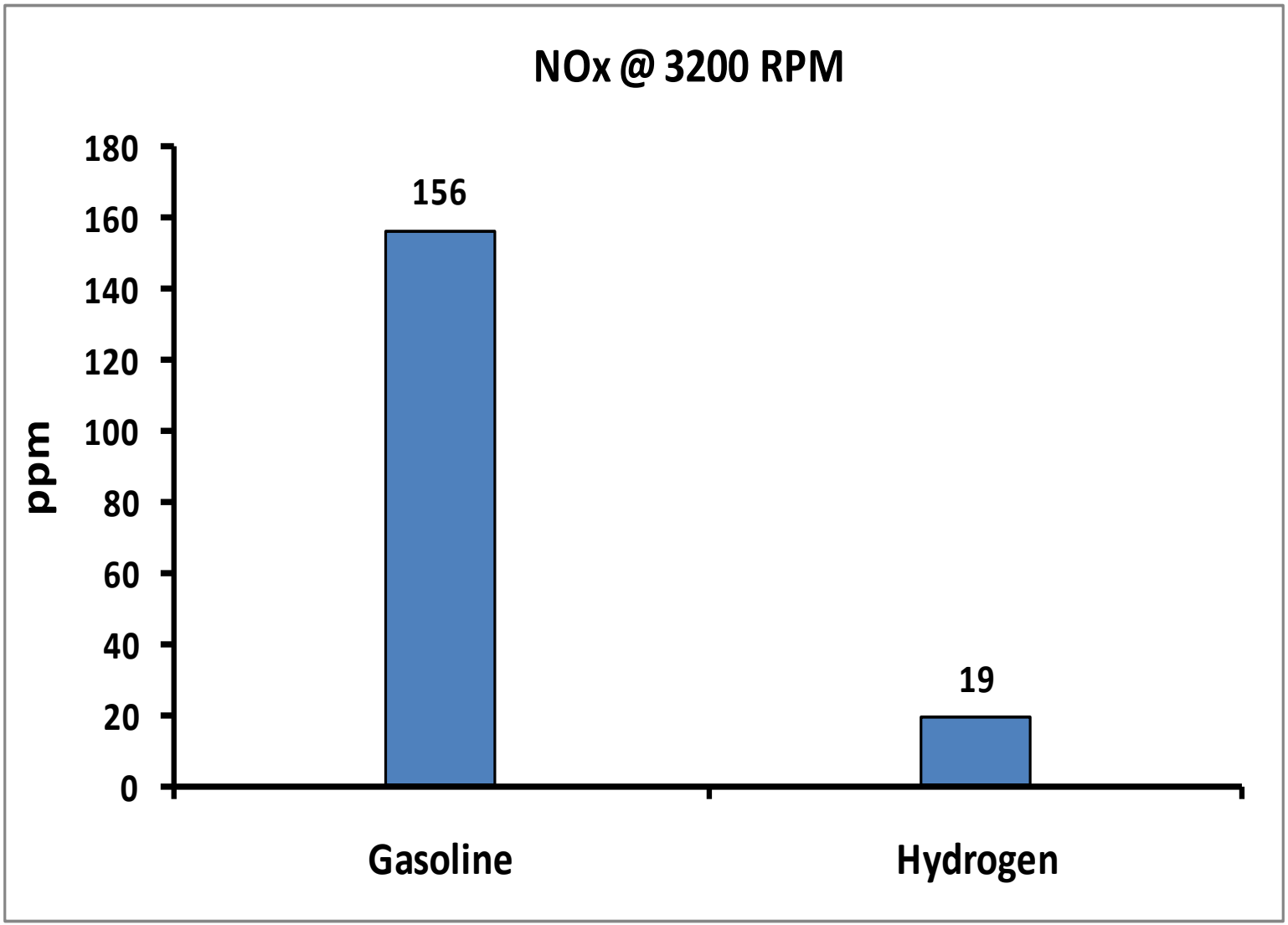
Hydrogen Vehicle: On Road Application Auto expo 2012

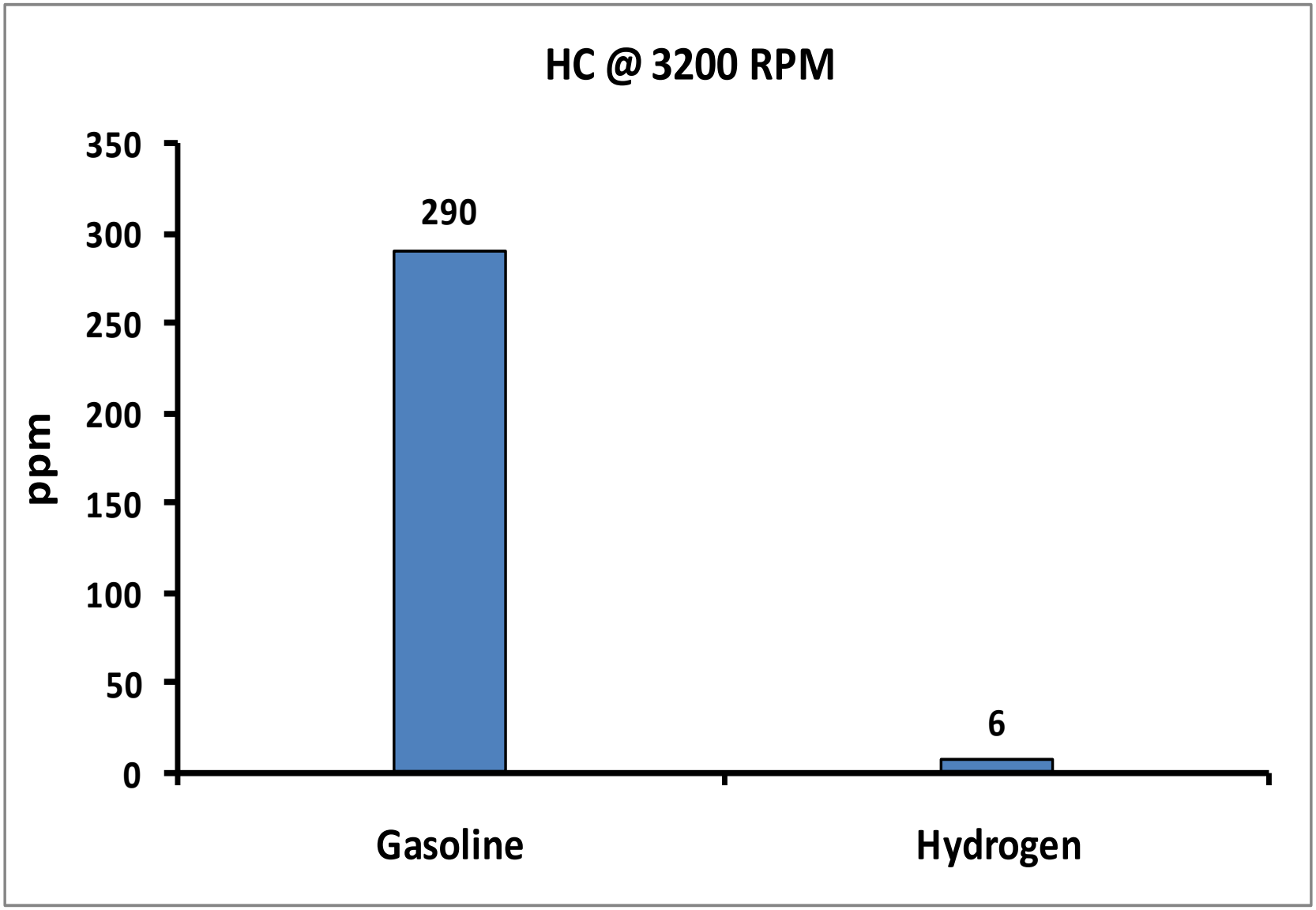
Dr. K. Yumkella, Director General of UNIDO having joy Ride in DELHY 3W

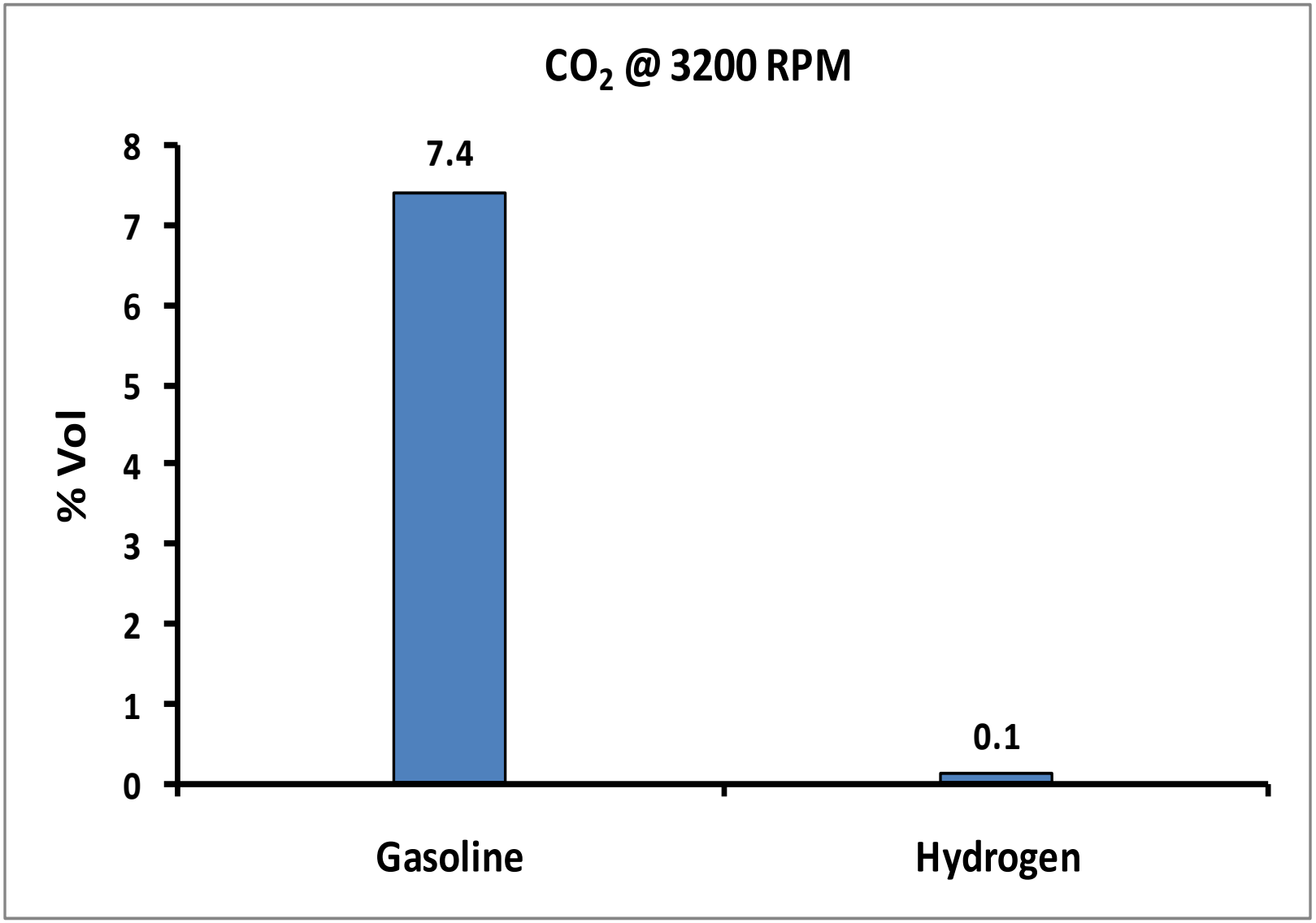
Hydrogen Cascade Cylinder for Dispenser

FUELLING STATION IN PRAGATI MAIDAN


Power Comparision - Gasoline Vs Hydrogen
Power - Gasoline
Power - Hydrogen
Power (kW)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
Engine RPM


NOx @ 3200 RPM
ppm
180
160
140
120
100
80
60
40
20
0
156
19
Gasoline
Hydrogen


HC @ 3200 RPM
ppm
350
300
250
200
150
100
50
0
290
6
Gasoline
Hydrogen


CO_2 @ 3200 RPM
% Vol
8
7
6
5
4
3
2
1
0
7.4
0.1
Gasoline
Hydrogen

Hydrogen-fuelled Minibus: On going Mission Mode Project

Sponsored by MNRE

Indian Institute of Technology Delhi ⟷ **Mahindra & Mahindra Ltd**

1) Coordinating
2) Optimization of the engine for better performance and emissions without any symptoms of undesirable combustion phenomena
3) Dissemination

1) System specification & simulation, CFD
2) Engine Controller Development
3) Components developments, Engine and vehicle integration , Safety
4) Develop two Hydrogen vehicles (4 cylinder Engine)
5) Field trials


Dynamometer Controller
Hydrogen Injection Fuel Rail
ECU
ENGINE
Eddy Current
Dynamometer
INTERCOOLER
Air Cleaner/Air In
Cu piper water cooling Arrengement
for Pressure measurement

Hydrogen Powered Mini Bus Developed

IITDelhi in collaboration with Mahindra & Mahindra :Project Sponsored by MNRE