भारतीय प्रौद्योगिकी संस्थान दिल्ली
Indian Institute of Technology Delhi

U.S. Department of Transport and U.S. Department of Energy Workshop

Compressed Natural Gas and Hydrogen Fuels

Lessons Learned for the Safe Deployment of Vehicles

December 10-11, 2009

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HYDROGEN VEHICLES AND FUELLING INFRASTRUCTURE IN INDIA

Prof. L. M. Das
Centre for Energy Studies
Indian Institute of Technology Delhi
INDIA

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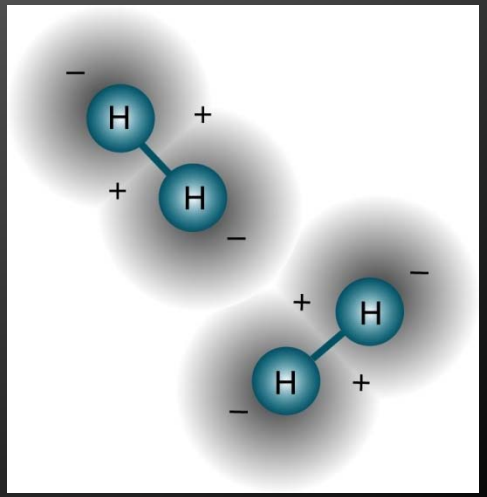
Hydrogen



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" The earth was not given to us by our parents , it has been loaned to us by our children"

Kenyan Proverb

Same feeling exists in all societies

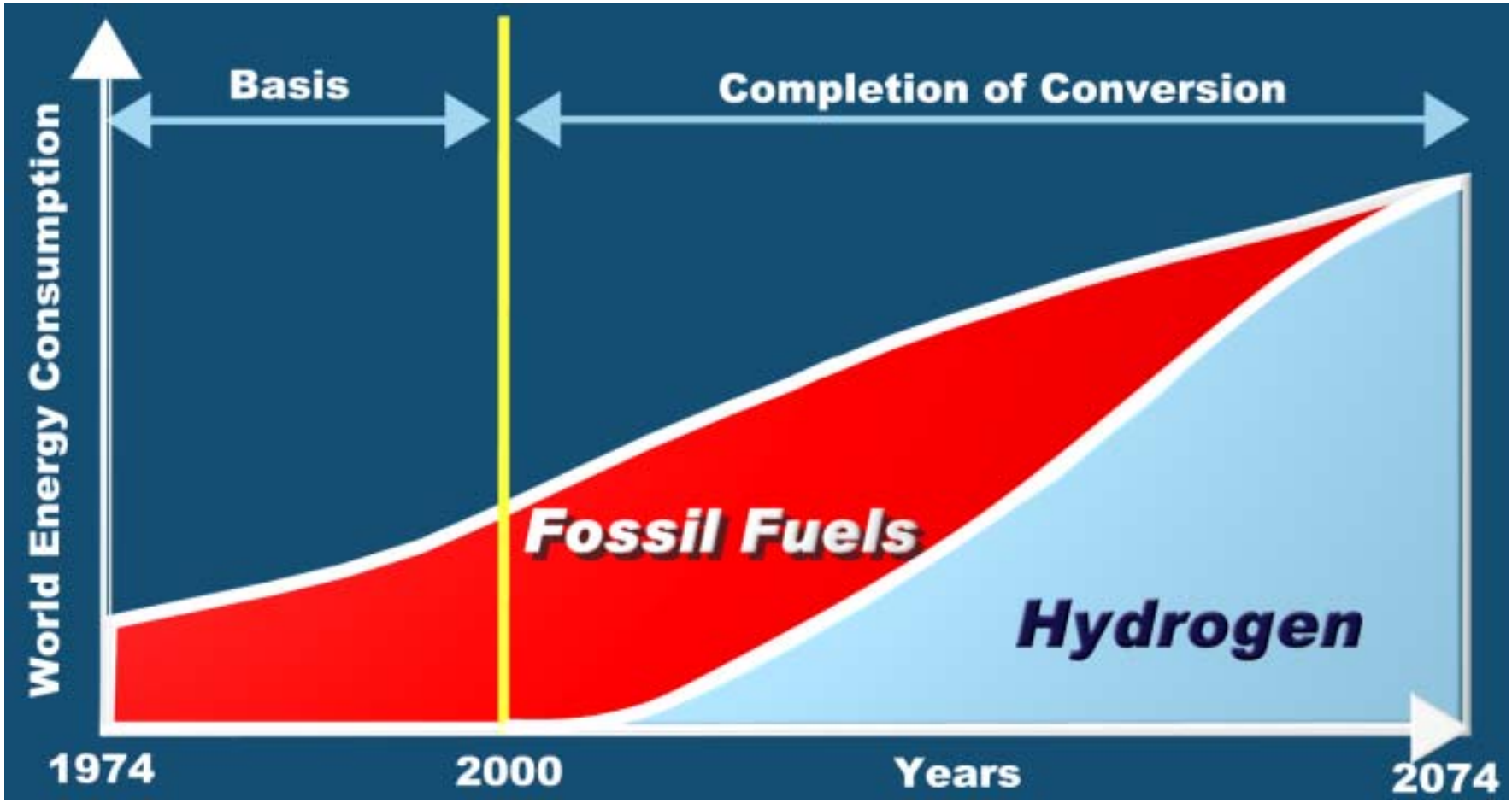
Our moral responsibility---to handover a safer earth to future generation

-:Hydrogen:-
Not a Radically New Concept

JULES VERNE
Mysterious Island
(1876)

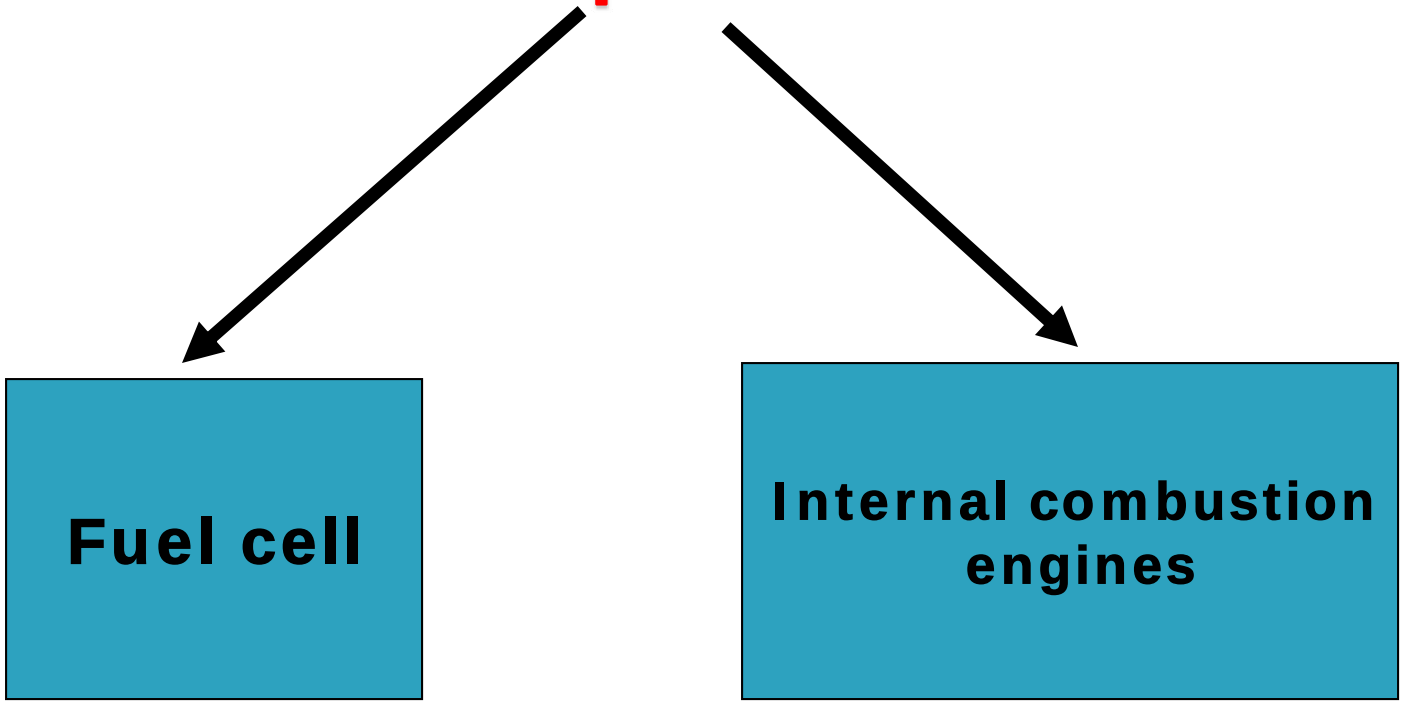
…." I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together will furnish an inexhaustible source of heat and light of an intensity of which coal is not capable……water will be coal of the future"

Building Hydrogen Energy



Source: T. Nejat Veziroglu , Hydrogen Energy Technologies, UNIDO

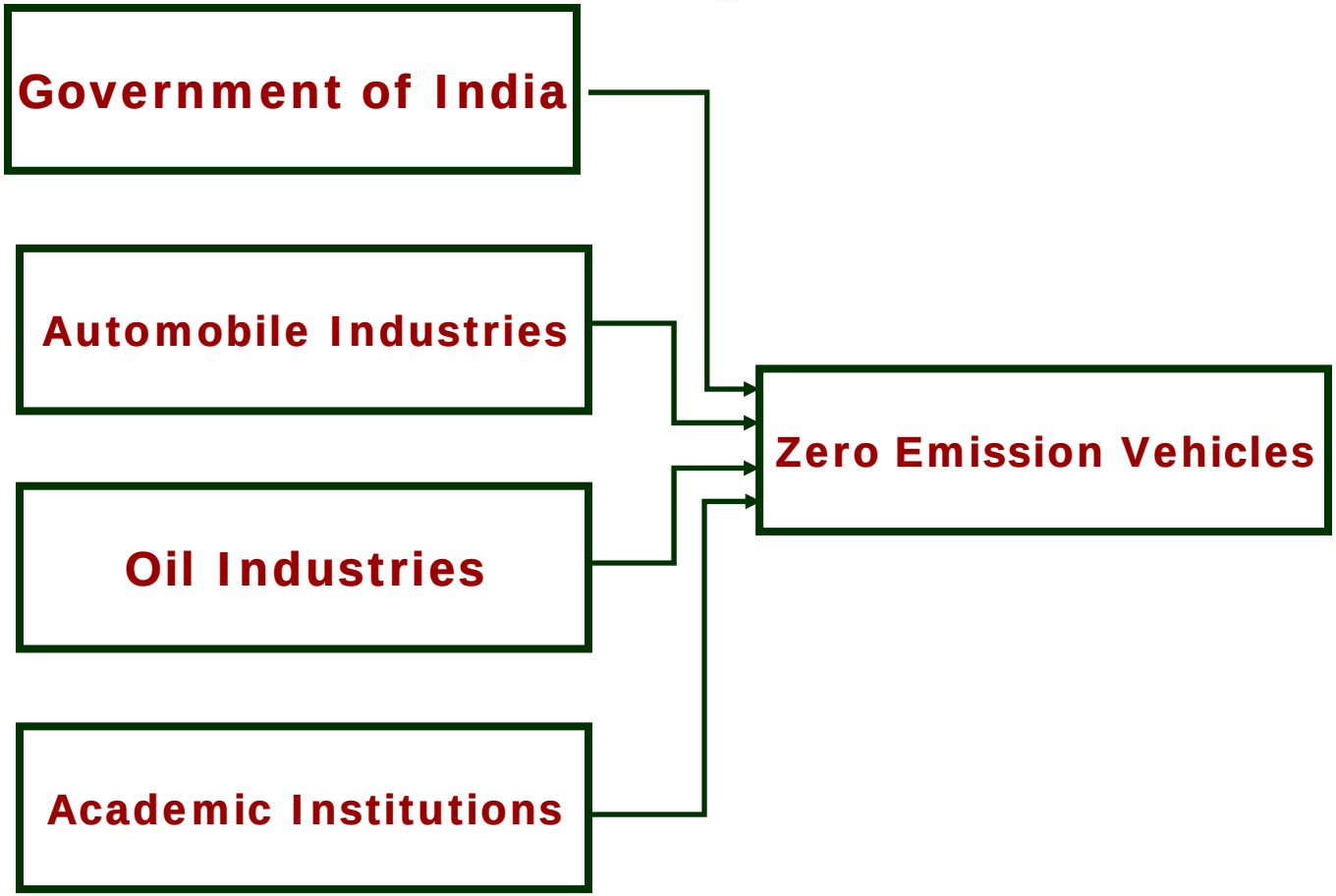
Hydrogen Utilization in Transport Sector



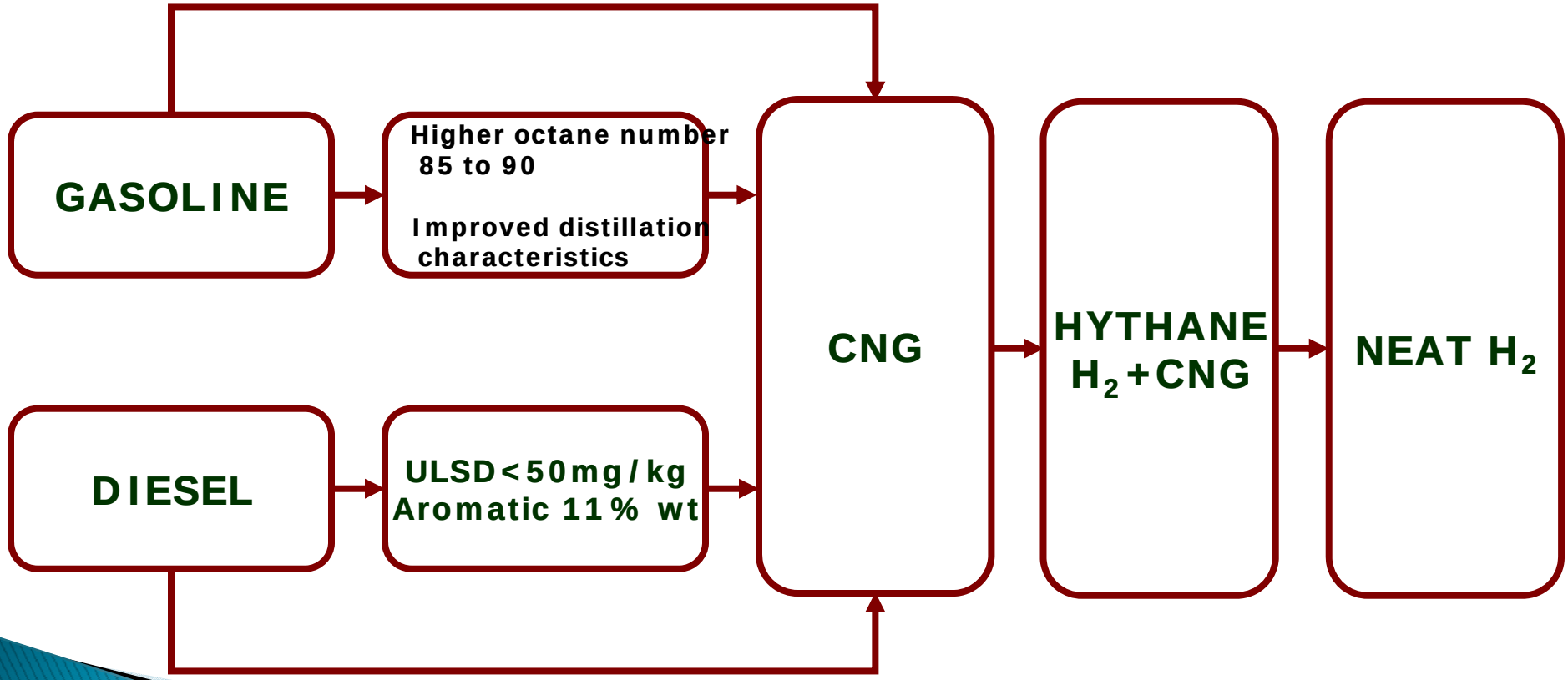
WHY INDIA WILL ADOPT Hydrogen and H-CNG

- Extreme urban air pollution -Indian Supreme Court identified 20 cities for natural gas
- Government support - funded First Public Hythane® station – Delhi 2009
- The 2006 Indian hydrogen roadmap proposes Hythane® as transitional fuel
- Natural Gas is far cheaper (per GGE) than diesel (up to 60% cheaper)
- Increasing supply of natural gas – 5Mtpa to 25Mtpa over 5 years, starting April 2009
- National rollout of natural gas pipelines
- City Gas distribution networks in 8 cities increasing to 28 medium term and 300 longer term
- 5 new City Gas licences issued in April 2009
- 2008 India adopts Hythane® as Natural Gas- regulations planned for August 2009
- Natural gas already a major vehicle fuel – GAIL plans 2000 further gas stations

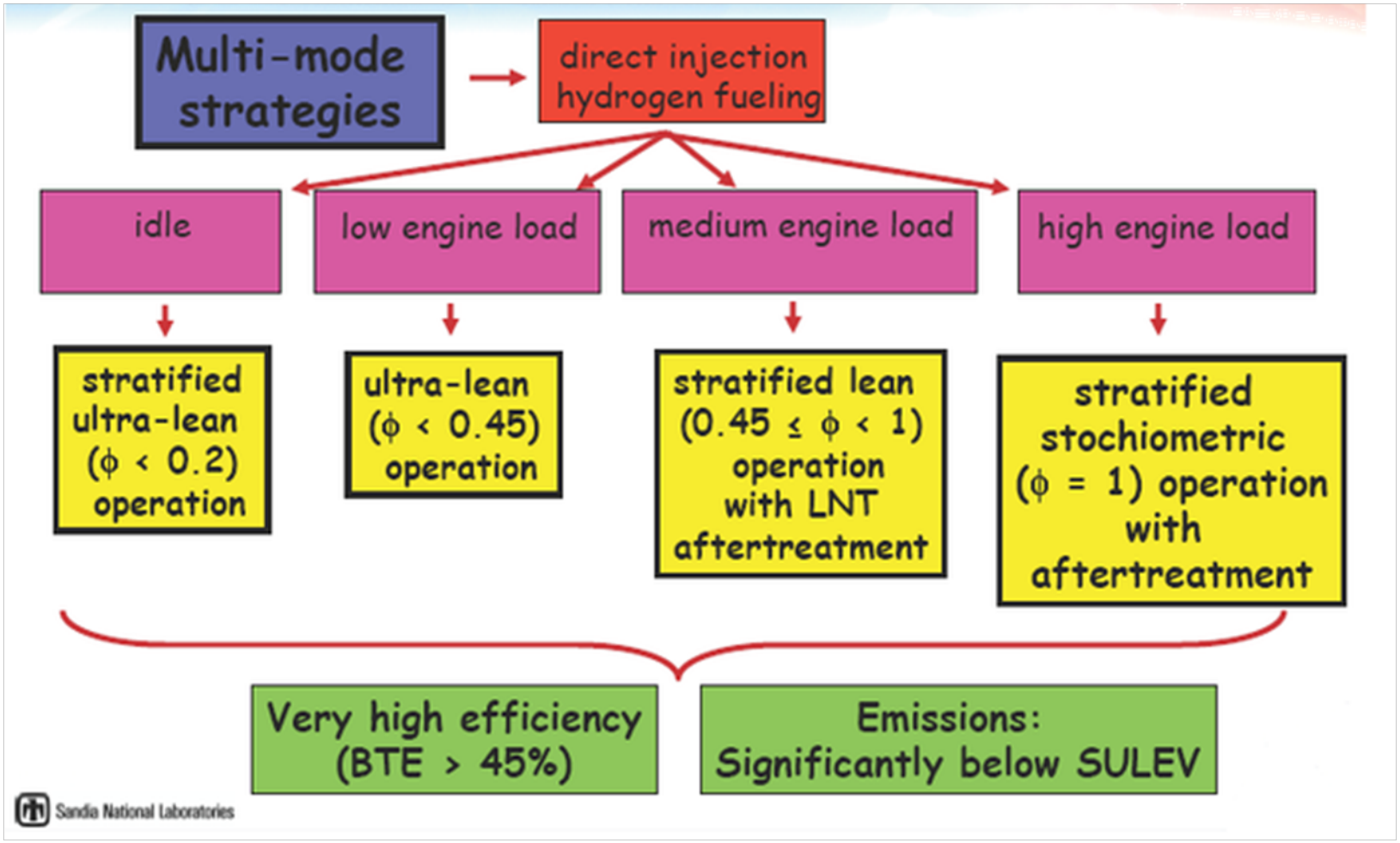
Vital players towards clean transport in India



PROGRESSIVE STEPS TOWARDS TOTAL HYDROGEN SYSTEM



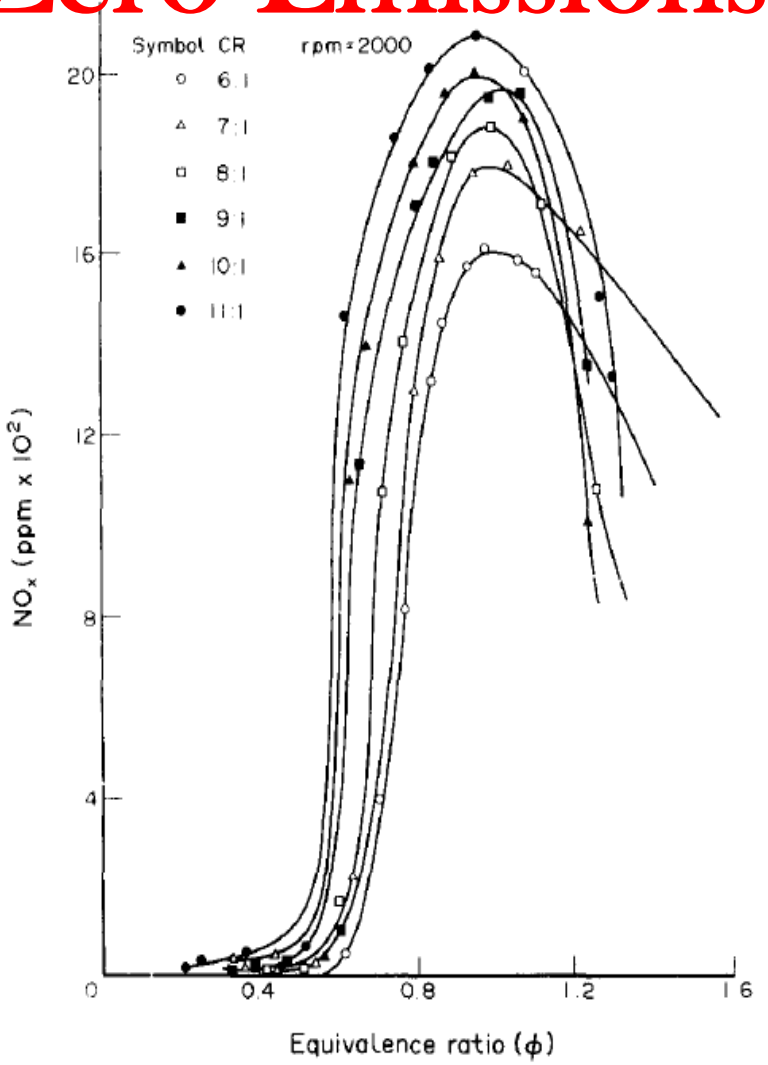
Hydrogen Fuelling



Near Zero Emissions

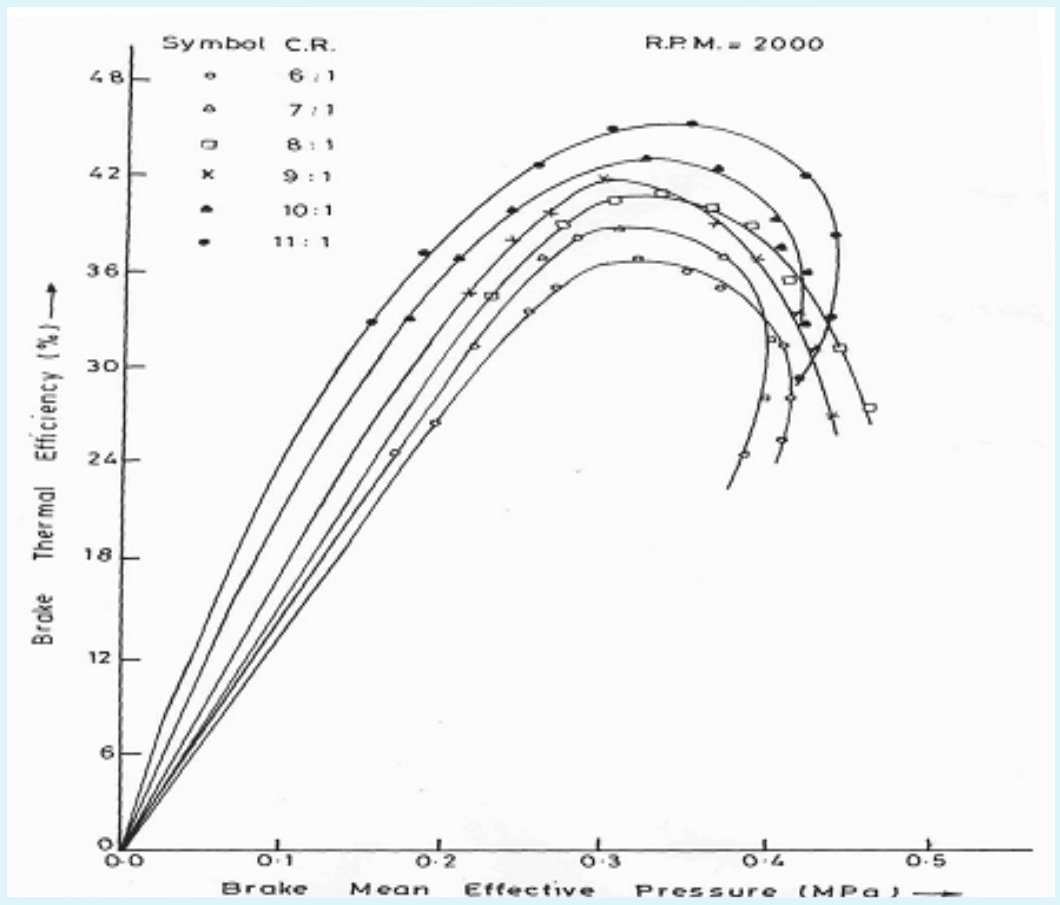
There is no

CO, CO_2, SO_2,
HC and PM emission



Ref: L. M. DAS, **EXHAUST EMISSION CHARACTERIZATION OF HYDROGENOPERATED ENGINE SYSTEM: NATURE OF POLLUTANTS AND THEIR CONTROL TECHNIQUES** *Int. J. Hydrogen Energy* Vol. 16, No. 11, pp. 765-775, 1991.

BTE vs BMEP



Maximum Thermal efficiency close to 44 % at lean engine operation

GLOBAL AND INDIAN HYDROGEN ENERGY SCENARIO

- Global production of Hydrogen was estimated to be 50MMT
- World-over Hydrogen is being produced by steam reformation of Natural Gas (48%) partial oxidation of oil(30%), Gasification of coal(18%) and electrolysis of water
- About 2.79MMT of Hydrogen is produced annually in India by fertilizer industry and Petroleum refineries for captive consumption
- About 0.36MMT by-product Hydrogen is available annually from chloro-alkali industries

Government of India Initiatives

Hydrogen in Transport Sector

•Planning Commission constituted working groups on Hydrogen

•Ministry of Petroleum and Natural Gas created a corpus fund of Rs 100 Crore for taking up hydrogen research activities with IOC R&D as nodal agency.

•***National Hydrogen Energy Board constituted by Government of India- Road map prepared***

Two Measure Initiatives on Transport and Power Generation

- **Green Initiative for Future Transport (GIFT)**
  - It aims to develop and demonstrate hydrogen powered IC engine and fuel cell based vehicles

- **Green Initiative for Power Generation (GIP)**
  - It envisages developing and demonstrating hydrogen powered IC engine/Turbine and fuel cell

HYDROGEN ENERGY ROAD MAP: GOALS AND TARGETS BY 2020-INDIA

- A. Green Initiative for Future Transport(GIFT)
  - Demonstrate One Million Hydrogen vehicles
    - 700,000 two wheelers
    - 50,000 three wheelers
    - 50,000 cars and taxis
    - 100,000 buses and vans
- B. Green Initiative for Power Generation(GIP)
  - Setup 1,000MW Hydrogen Based Power Generation capacity
    - 50MW small IC engine stand alone generators
    - 50MW stand alone fuel cell power packs
    - 400MW Gas Turbine Based Power Plants
    - 500MW Central Fuel Cell Power Plants
- C. Investment for Infrastructure and R&D: 25,000 crores
- D. To be achieved through Public Private Partnership

1 million vehicles will require about 7000 tonnes of H2 / day

Hydrogen Roadmap Proposed by National Hydrogen Energy Board (NHEB)

Estimated Hydrogen Requirement for Fueling one Million Vehicles

Sl No	Item	Bus	3-wheeler	Car	Total
1	Range, Km/day	250.0	150.0	150.0	
2	Mileage, km / kg of H2	10.0	50.0	90.0	
3	H2 required, kg / day / vehicle	25.0	3.0	1.7	
4	No. of vehicles	200000.0	400000.0	400000.0	1000000.0
5	Total Hydrogen required, kg / day	5000000	1200000	666667	**6866667**
6	Total Hydrogen required, tonnes / day	5000	1200	667	**6867**

Assumptions:

1. Cars will run on Fuel Cell only
2. 3-wheelers will run both on Hydrogen IC engines and fuel cells (50:50)
3. Buses will run on Hydrogen IC engines only

INTRODUCTION OF HYDROGEN-CNG BLEND AS FUEL IN VEHICLES

- MNRE has supported a project for demonstrating Hydrogen up to 30%) with CNG in 7 automobiles(3 buses, 2 cars and 2 three wheelers) to **Society of Indian Automobile Manufacturers SIAM**) in September, 2007
- This is first project of **public-private partnership** undertaken in Hydrogen energy
- SIAM, IOCL and OEMs(Tata Motors, **Ashok Leyland, Eicher Motors, Mahindra and Mahindra and Bajaj Auto)** are participating in the project
- Existing Hydrogen-CNG dispensing station set up by IOC at Faridabad to be used for filling hydrogen-CNG blends in the test vehicles
- Project would help in optimization of engine performance and blend ratio of Hydrogen with CNG

DEVELOPMENT OF DEDICATED HYDROGEN ENGINE

- Experience from H-CNG project to benefit in development of dedicated Hydrogen Engine and also 100% Hydrogen fuelled vehicles
- National Hydrogen Energy Road Map gives higher priority to IC Engine route in short term
- Indian Auto Industry also wants to focus initially on IC Engine route
- Switch over to Fuel cell route to be made once fuel cells become cost competitive

Hydrogen Roadmap Proposed by National Hydrogen Energy Board (NHEB)

- *Targets-2020*
  - Hydrogen cost at delivery delivery point @ Rs 60-70 / kg
  - Hydrogen storage capacity to be 9 weight %
  - Adequate support infrastructure including a large number of dispensing stations to be in place
  - Hydrogen bulk storage methods and pipeline network to be in place
  - Safety regulations, legislations, codes and standards to be fully in place

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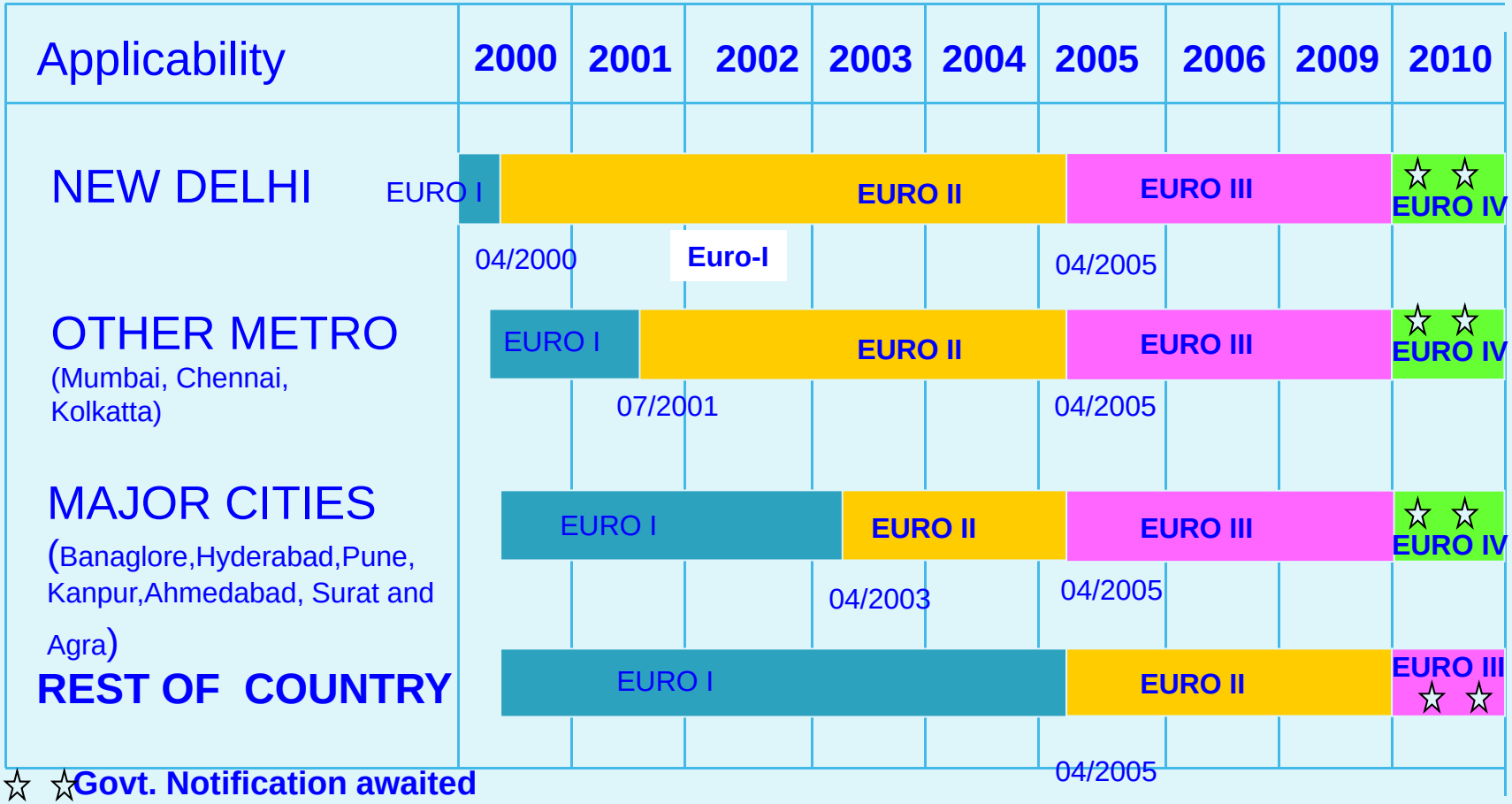
Emission Roadmap



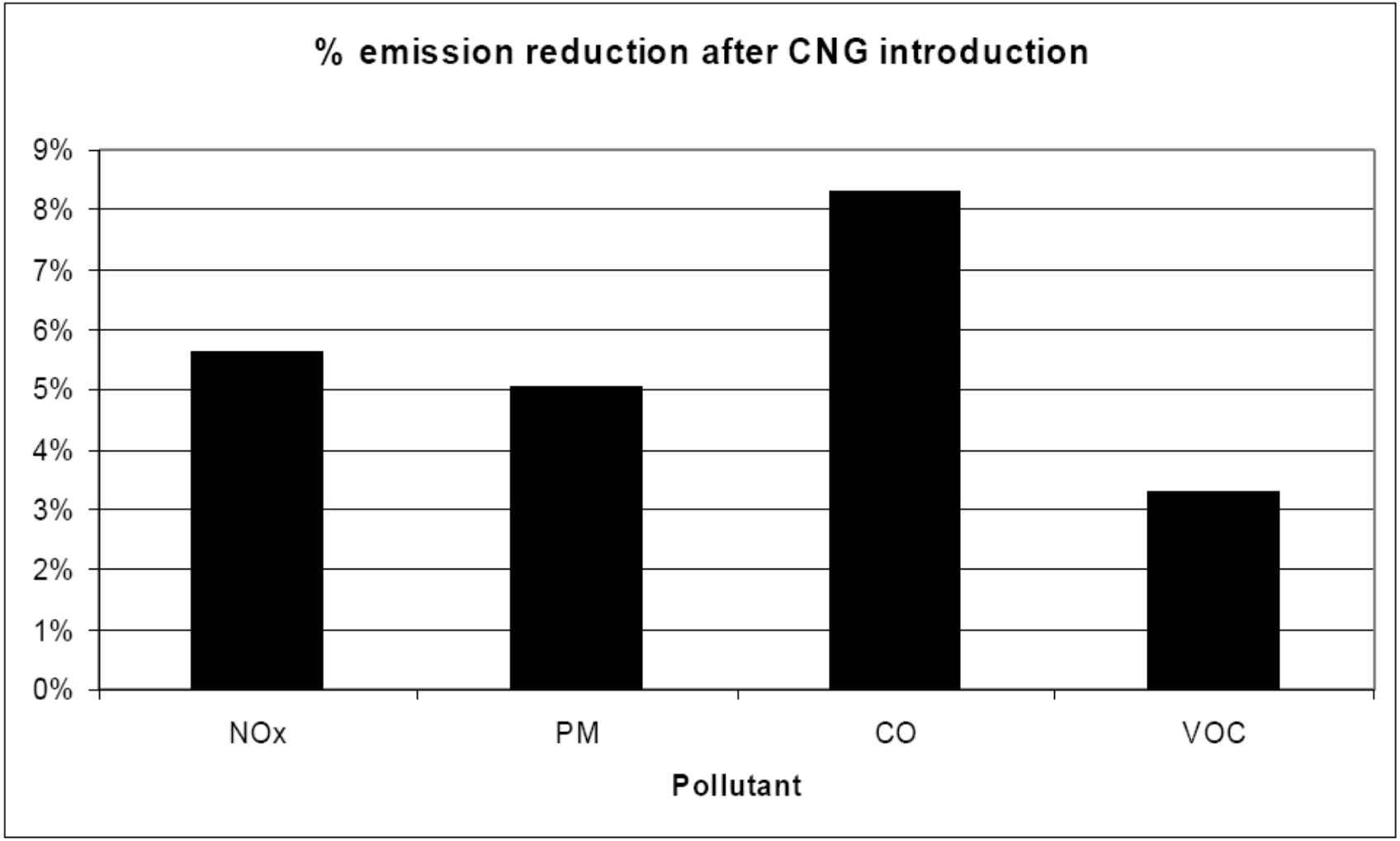
☆ ☆Govt. Notification awaited

Fuel Quality = Corresponding Europe Quality
(Except Minor Deviation)

Success story of CNG :An optimistic vision towards hydrogen

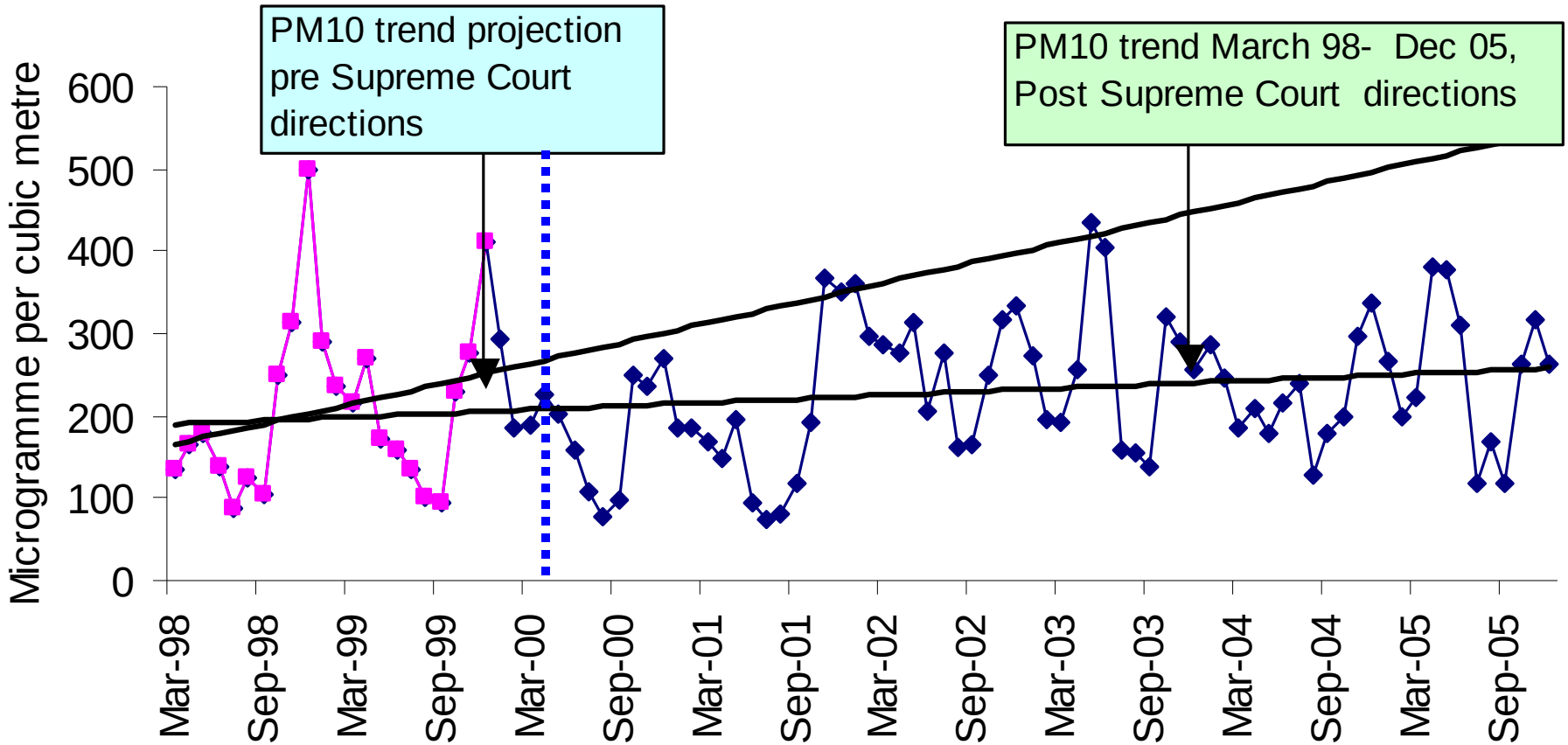
Aggressive CNG implementation in Delhi

- July 28, 1998 – Supreme Court of India orders the CNG program for Delhi
- No buses over 8 years old after 4/1/2000 except on CNG
- All buses on CNG or other clean fuel by 3/31/2001
- Financial incentives for CNG in taxis, three-wheelers etc
- Increase the number of buses to at least 10,000


% emission reduction after CNG introduction
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
NOx
PM
CO
VOC
Pollutant

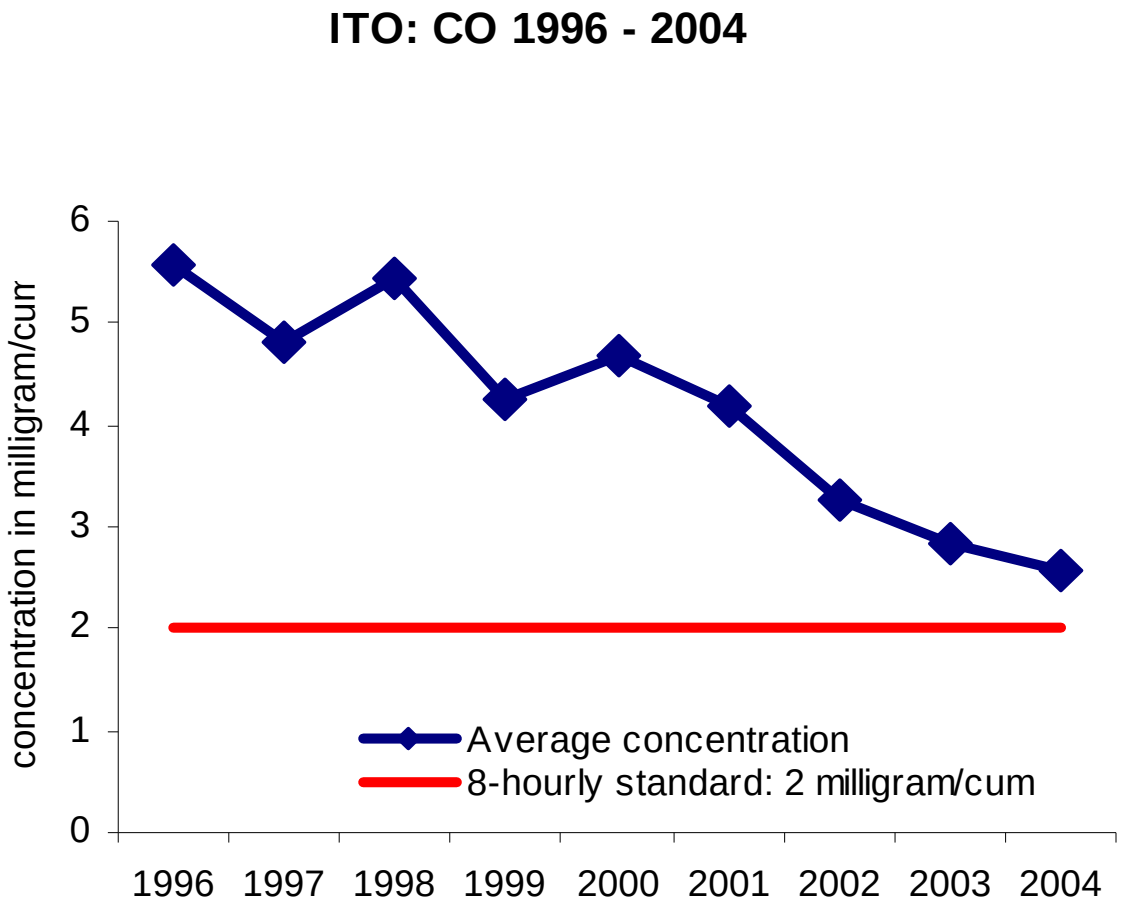
Impact on air quality
Particulate pollution stabilised

PM10 at ITO Traffic Intersection
(March 98-Jun 05)



Delhi CO levels

Lower despite vehicle growth



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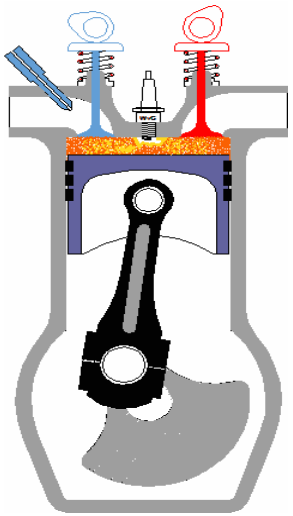
Initiatives Research

R&D Pursuits and Attainments at IIT Delhi



Engines & Unconventional Fuels Lab
Centre for Energy Studies,IITDelhi

Fuels Studied

- *Hydrogen*
- *Compressed Natural Gas*
- *Biodiesel*
- *Alcohols*
  - *Ethanol*
  - *Methanol*
- *Producer Gas*
- *Bio Gas*

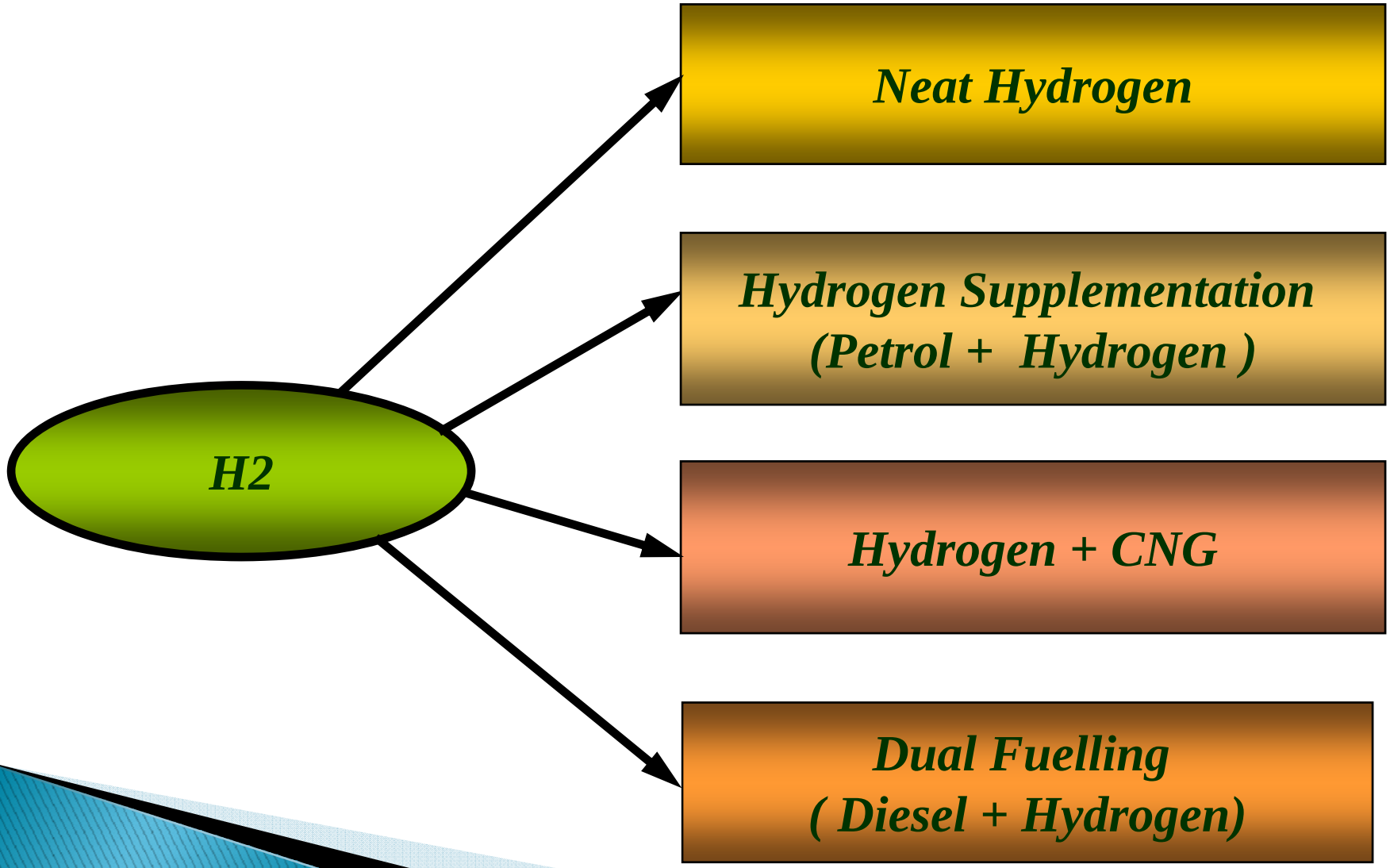
Engine Systems Investigated

- *Single Cylinder Variable Compression Ratio Engine*
- *Multicylinder Automotive Engine*
- *Single Cylinder Tractor Engine*
- *Small Horse Power Agricultural Diesel engine*
- *Small Horse Power spark ignition Engine*

R & D Focus on Hydrogen-fuelled Engine

- Mixture Strength Requirement
- Backfire– Achilles heel for hydrogen engine
- Choice of Appropriate System Configuration
- Emissions Characteristics

Exhaustive Engine Tests



Fuel Induction Techniques – IIT D

Mixture formation	Flow timings	Supply pressure	Comments
Continuous carburetion (CC)	Continuous flow	A little above atmospheric	Unsuitable for neat hydrogen but can be adopted for HANG
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

Causes of Pre-Ignition and Flashback identified through exhaustive tests

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

BACKFIRE CONTROL TECHNIQUES

- Ultra lean Operation (Limiting the Equivalence Ratio)
- Adopting Exhaust Gas Recirculation(EGR)
- Avoiding hot spots on sharp edges and protrusions and Using spark plugs with narrow gap settings
- Water Induction
- **Fuel Induction---Most effective**

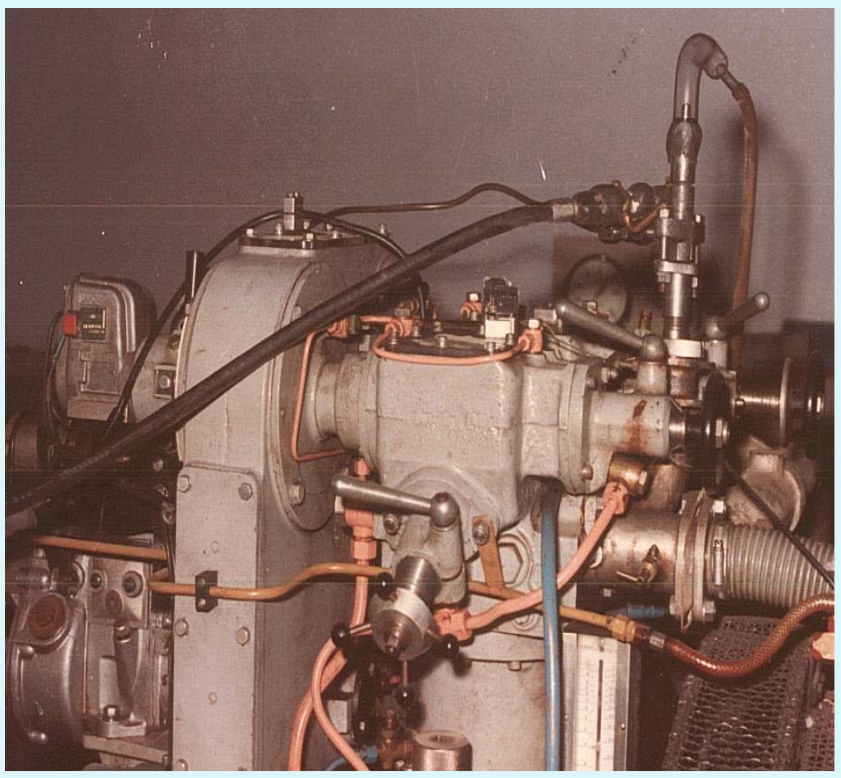
Injection Systems- Actuation Mechanism

- Hydraulically operated
- Cam –actuated
- Solenoid-actuated electronically –controlled

Exhaustive tests in lab at IIT Delhi shows that these systems eliminates undesirable combustion phenomenon such as pre-ignition, backfire & rapid rate of pressure rise.

Injection System Installed on a Research Engine – Parameter Optimization

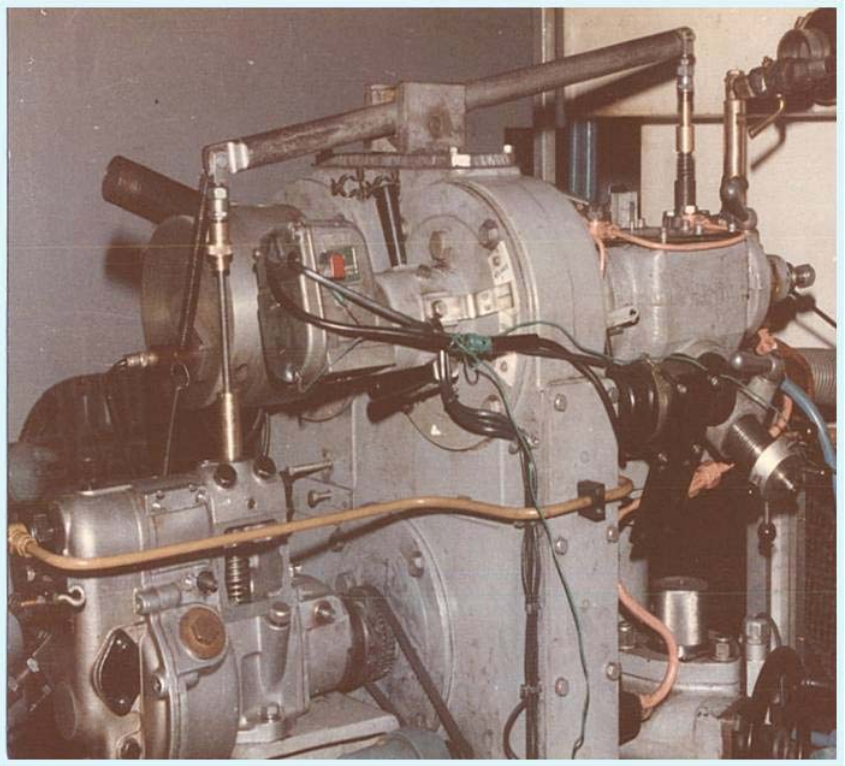
Hydraulically operated



- Diesel oil is used as hydraulic fuel
- Jerk from diesel injector forces open gas injector
- Diesel after passing through nozzle is collected back

Injection System Installed on a Research Engine – Parameter Optimization

Cam Actuated.



- Uses a lift rod moved by a cam & motion being transmitted through a specially designed linkage
- Engine control depends on response controllability, durability & fuel – feeding capacity of injector

A Hydrogen Engine Genset using Electronic Fuel Injection System

The system provided adequate flexibility to control injection timings & injection duration to provide an appropriate & desired fuel quantity at appropriate point in engine cycle operation.

Total Hydrogen Operated S.I. Engine Genset

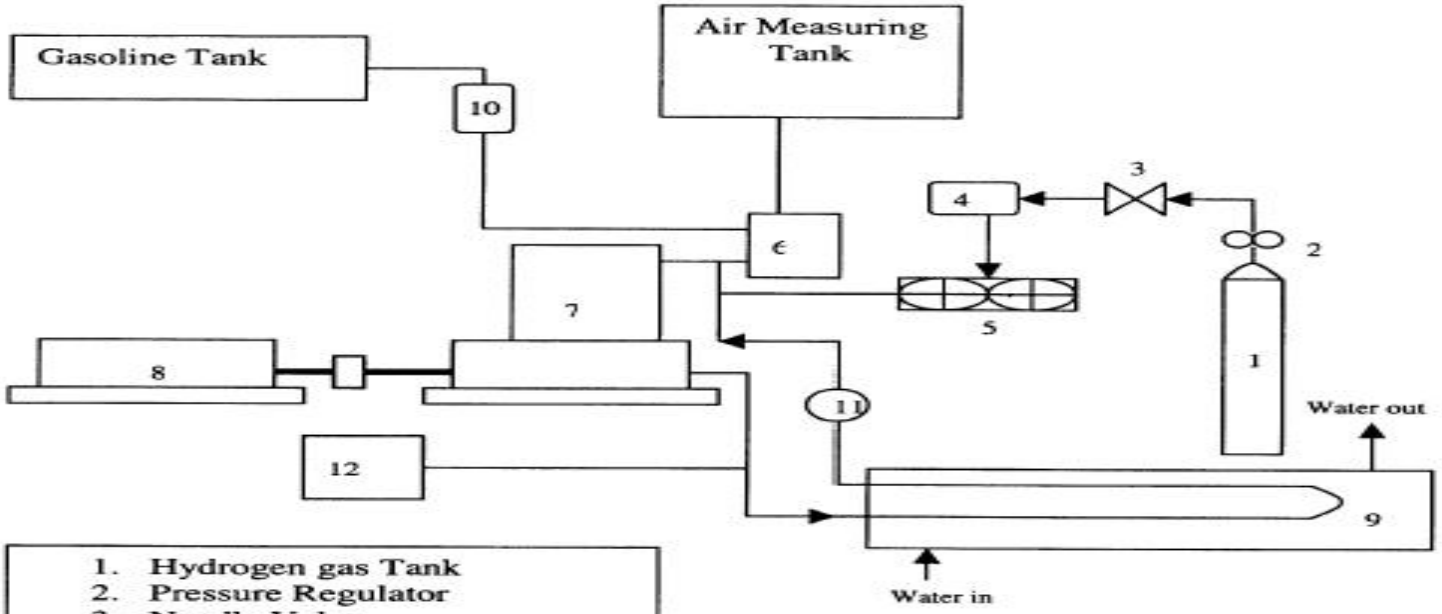
A 5HP, 1500rpm, 4-stroke single cylinder naturally aspirated spark ignition engine converted to operate with Hydrogen

An Alternator of 2.5KVA output coupled to engine

The converted engine exhibited good performance and low emission characteristics without any undesirable combustion phenomenon

Specific Hydrogen consumption of prototype about 160g/KWH

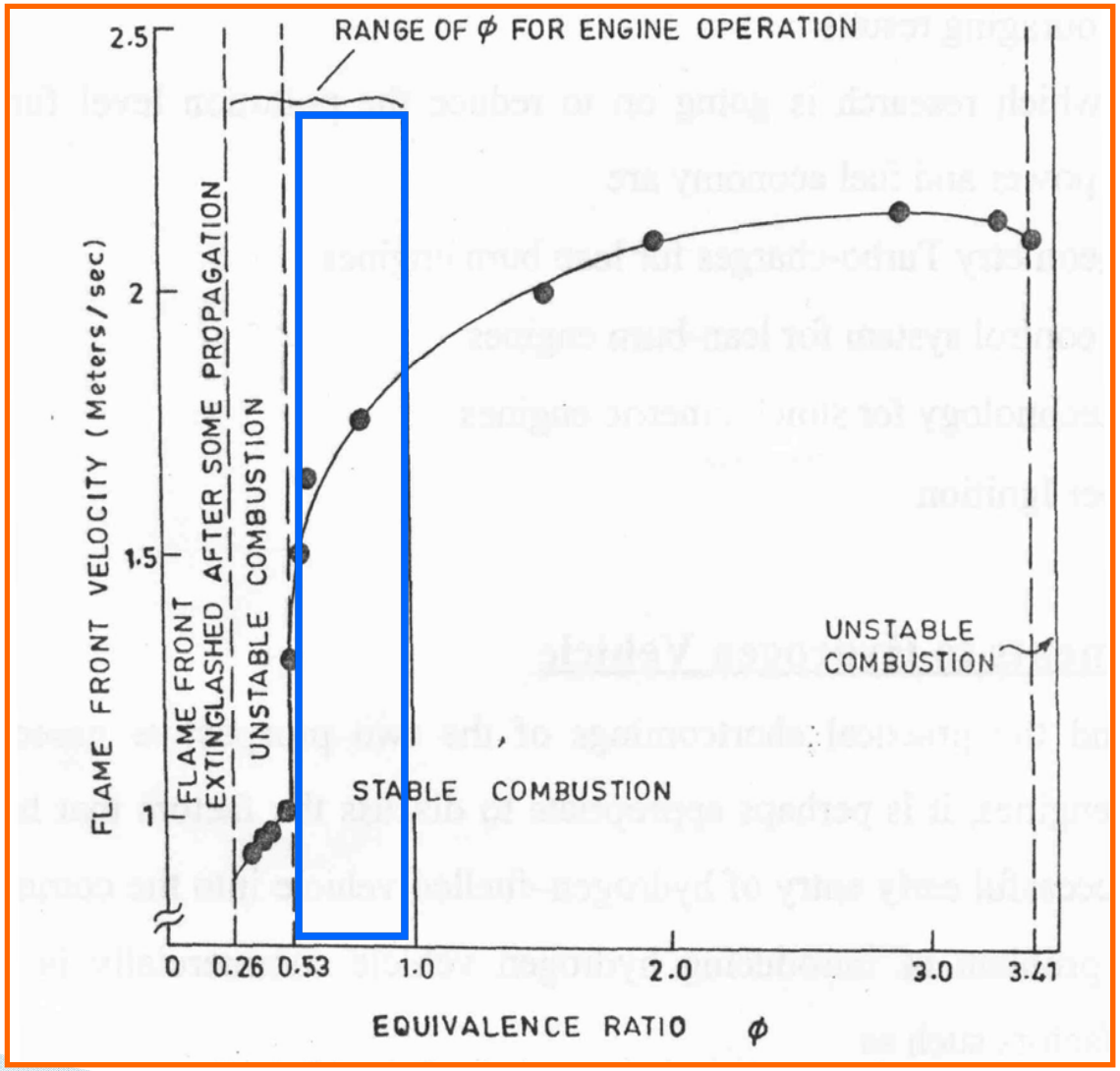
Exhaust Gas Recirculation In Automotive Engine



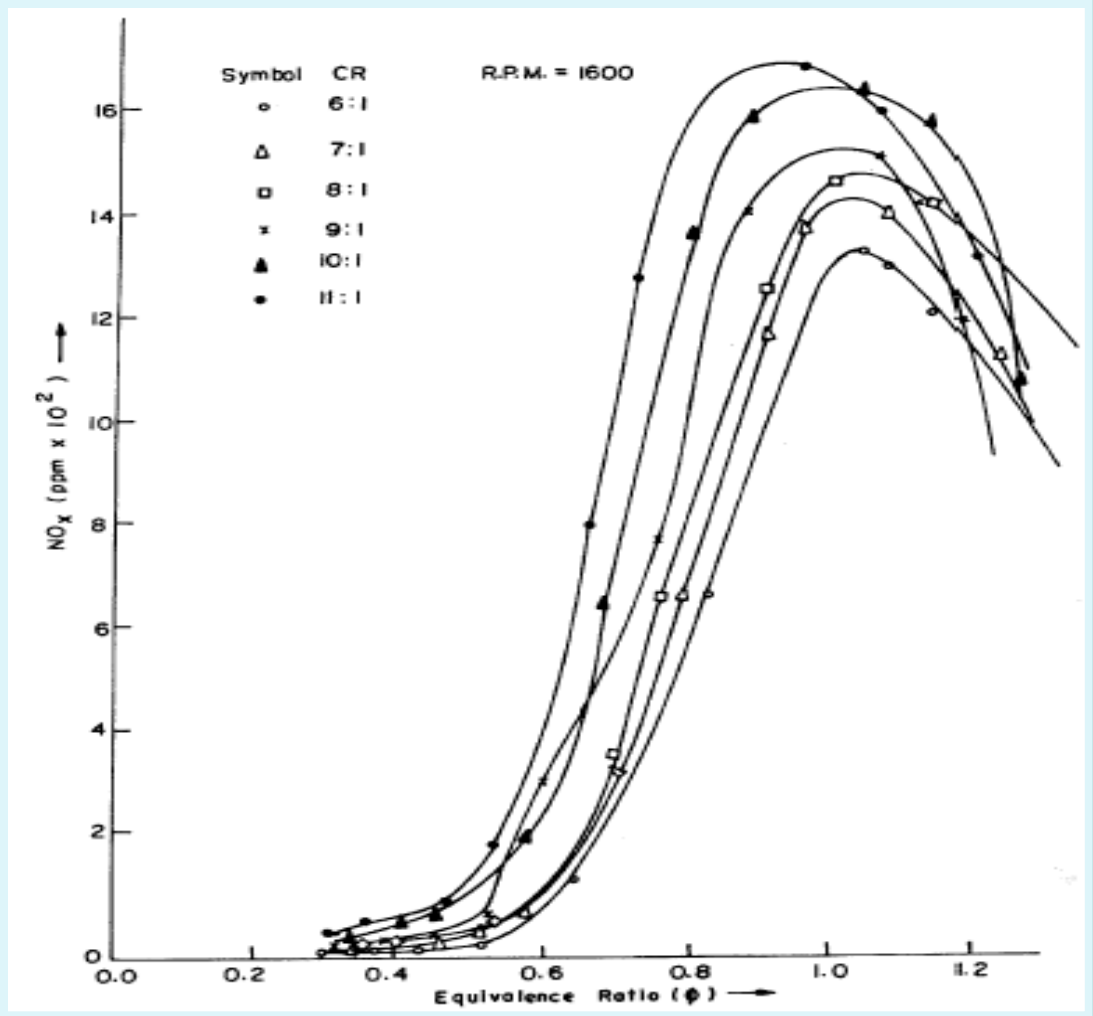
1. Hydrogen gas Tank
2. Pressure Regulator
3. Needle Valve
4. Hydrogen Flow Meter
5. Flame Trap
6. Carburetor
7. Engine
8. Dynamometer
9. Heat Exchanger
10. Gasoline Flow Meter
11. Exhaust Gas Flow Meter
12. Chemiluminescent analyser

STABLE ENGINE OPERATION RANGE

- Range of equivalence ratio for effective hydrogen engine operation in lean burn mode without showing any undesirable phenomena *
- Unstable engine operation above $\phi > 0.8$ reported #
- Combustion instability and reduction in thermal efficiency has been reported for $\phi < 0.4$

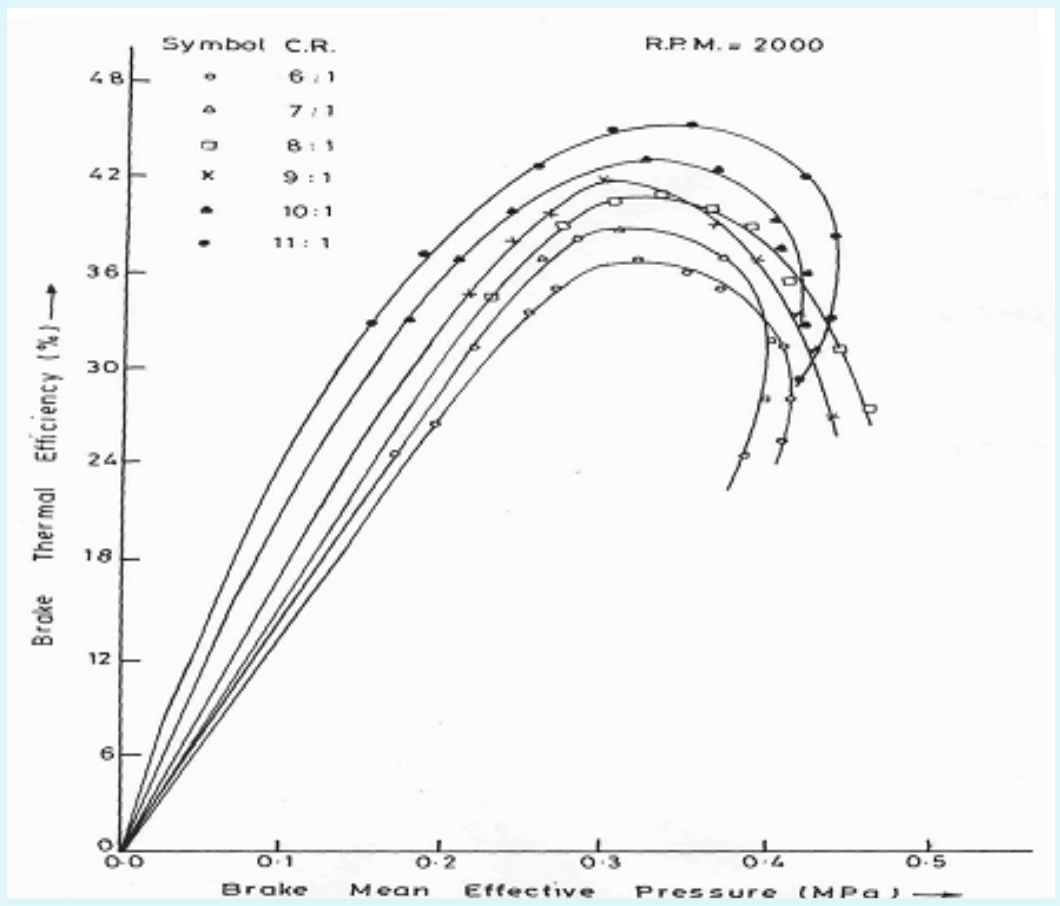


NOx vs Equivalence Ratio



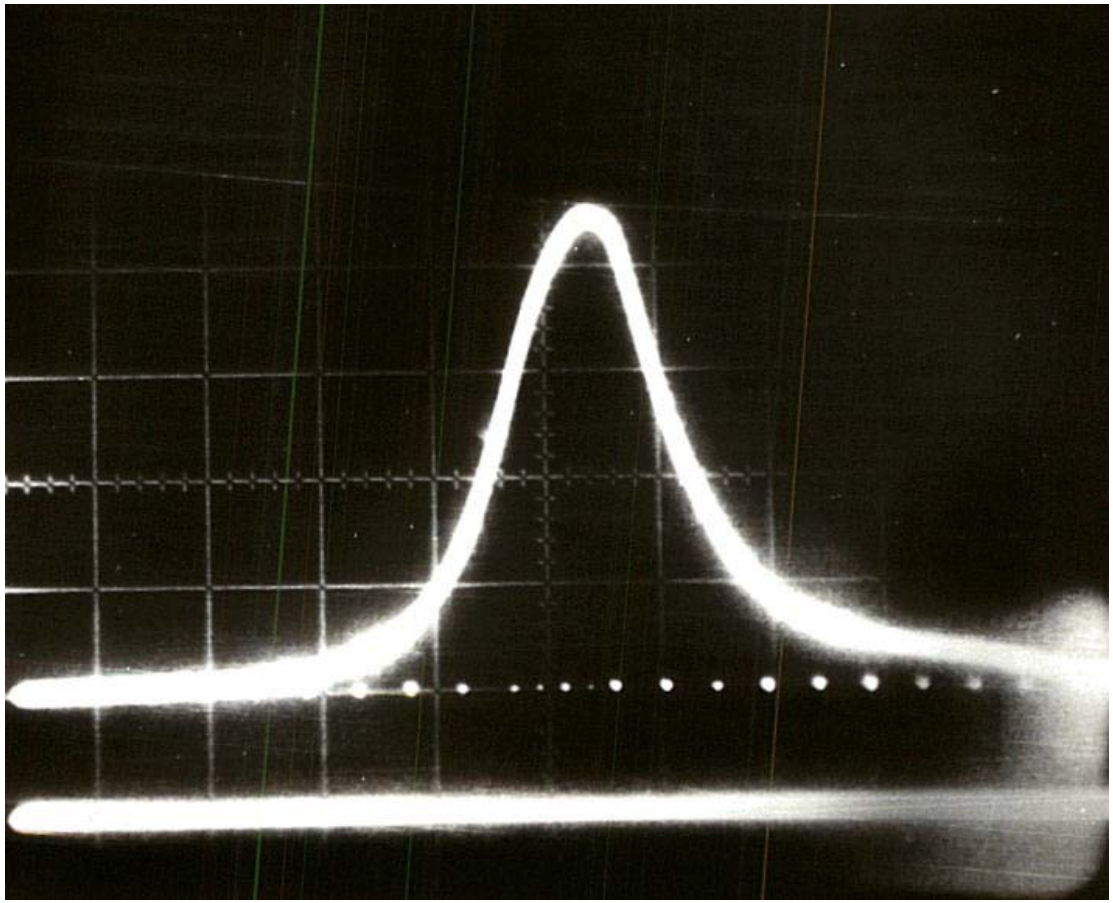
Ultra lean operation -- close to zero emissions

BTE vs BMEP

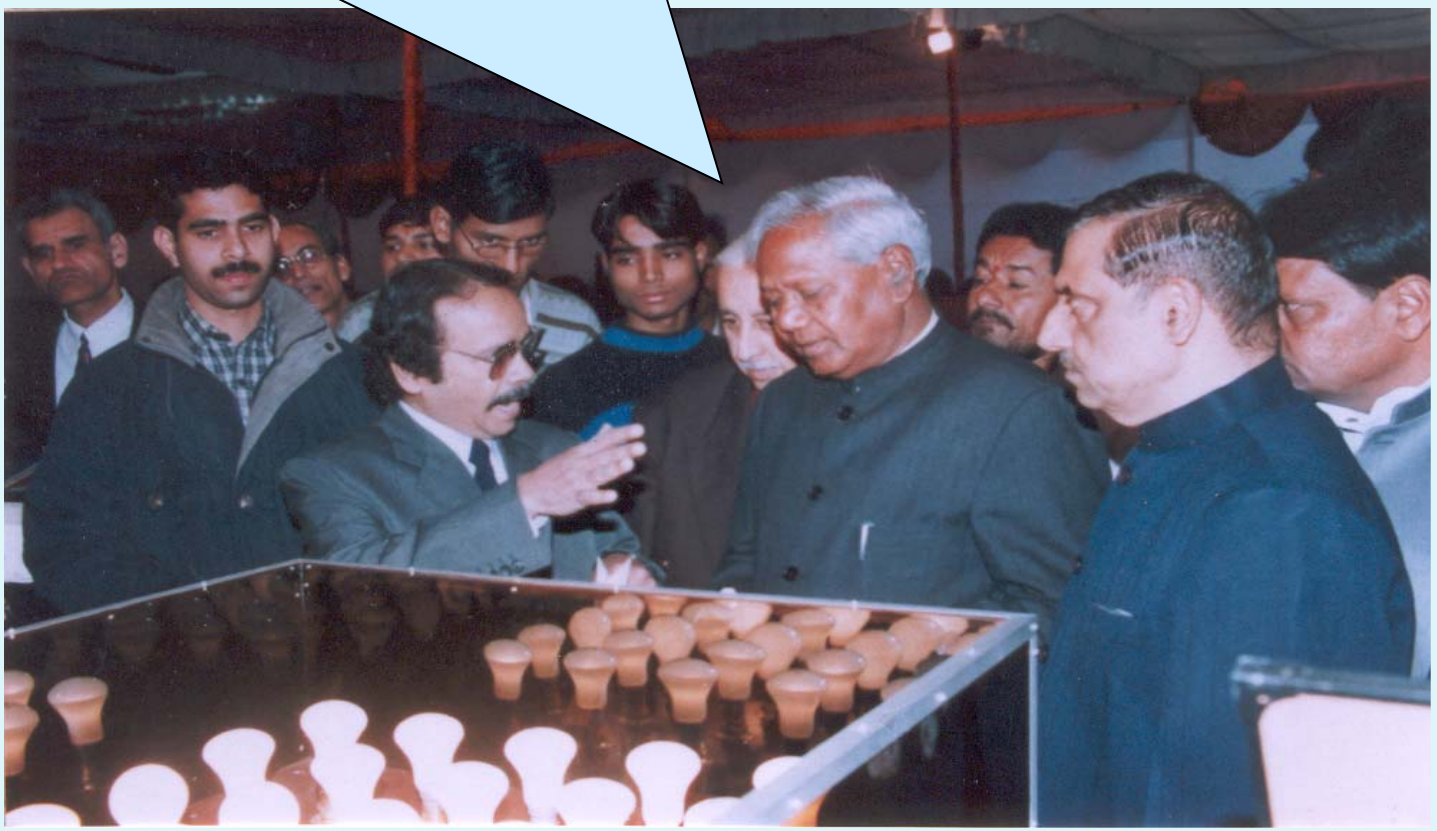


Maximum Thermal efficiency close to 44 % at lean engine operation

Pressure Vs Crank Angle -Smooth Combustion



Shri. Kariya Munda, The then Minister for Non – Conventional Energy Sources discussing about the *Hydrogen – operated S.I. Engine Genset developed at I.I.T. Delhi* during the "Demonstration of Hydrogen Operated vehicles and other systems" held at New Delhi, in Feb.2004



Prof. T. N. Veziroglu and Ms. Ayfer Kayle having a closer look at the Hydrogen-operated Genset developed in IIT Delhi

Prof. T. N. Veziroglu along with the Union Minister of Petroleum and Natural Gas and other dignitaries visiting IITD stall during the International Symposium of Fuels and Lubricants, New Delhi, India (2003)

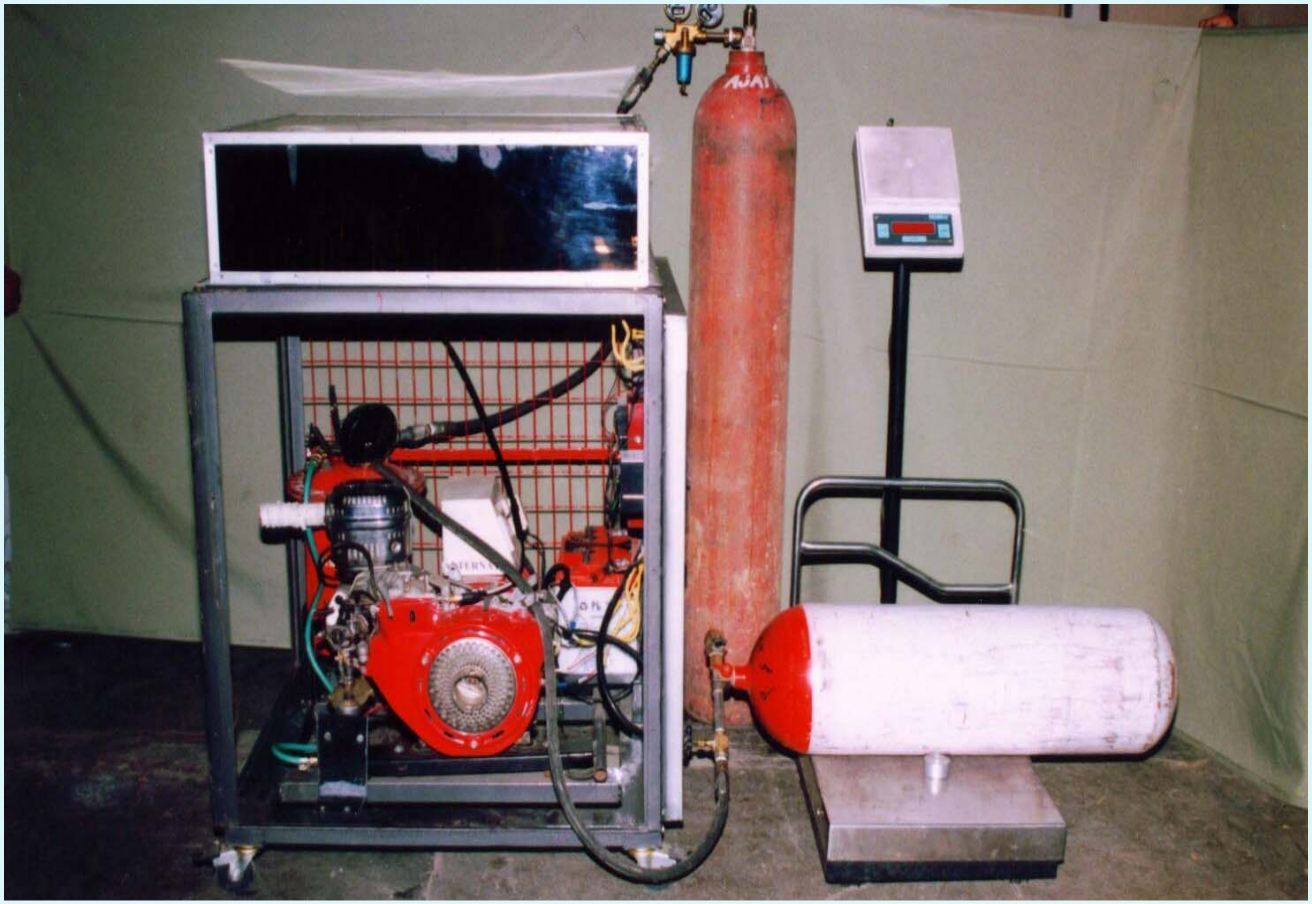
Hydrogen Utilization in Diesel Engine

- Auto ignition temperature of Hydrogen –576 C-ignition by compression alone –not possible even at a CR of 29 (Study at Cornell University)
- Prof Ikegami's work at Kyoto University
- Dual fuel operation -most practical mode of diesel engine operation using hydrogen
- Small horse power diesel engine –capable of hydrogen-diesel operation
- Multicylinder Diesel engine --- 45% Energy substitution

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

Hydrogen CNG Blend – IIT Delhi



Hydrogen + CNG Blend

HANG

Hydrogen Added Natural Gas

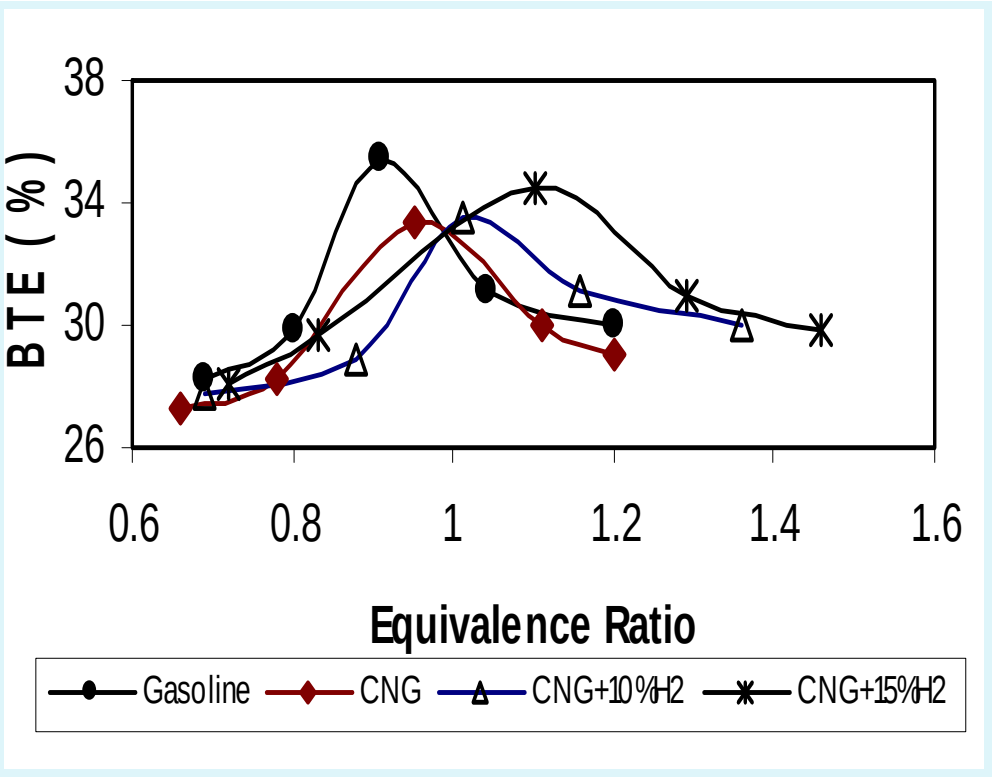
Various percentages of hydrogen added to CNG on volume basis

HYTHANE

20% of Hydrogen added to 80% of CNG by volume

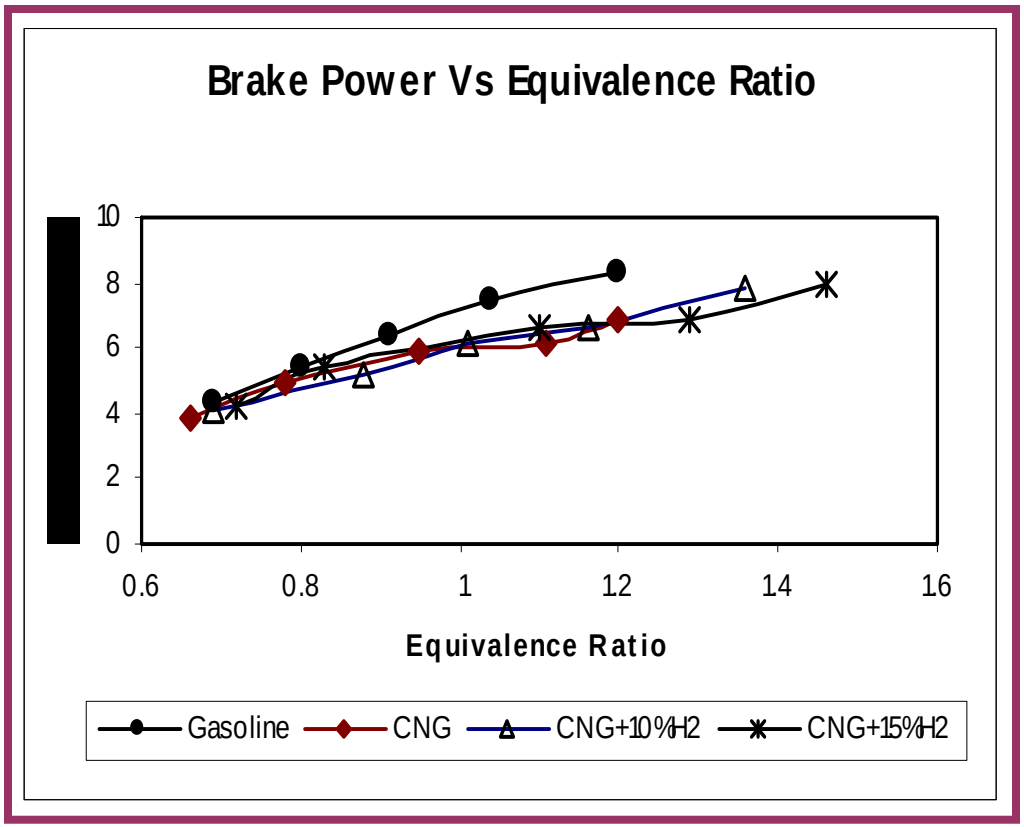
* A registered trade mark of Hydrogen Consultants Inc. USA

BTE vs Equivalence Ratio



34.5 % of BTE (max) at equivalence ratio of 1.2 for 10 % hydrogen addition

BRAKE POWER VS EQUIVALENCE RATIO



With 10% hydrogen supply the power output increased by about 5% over neat CNG operation

Hydrogen addition –very effective with lean mixtures

Three-wheelers as common reliable transporters in Delhi

Hydrogen operated Three Wheeler

- The hydrogen-powered Internal combustion engines will be one of the significant technologies being developed for automotive application.

- IIT and Mahindra & Mahindra jointly developed a Hydrogen engine system & M&M later developed a commercially viable three wheeler with which call as " HY Alpha".

Hydrogen operated Three Wheeler

This vehicle is the first of its kind in India and in abroad running with compressed hydrogen gas.

Engine Specifications & Performance

Type	4 stroke
Bore * Stroke	86*68
No Cylinder	One
Cooling Method	Air Cooled
Max Power	4.8kW @ 3600
Max Torque	13 Nm @ 2000-2200
Capacity of the engine	395 CC
Pay load	3+1
Gross vehicle weight	850 Kg
Fuel consumption	95 Km /Kg
Water Capacity	33 Liter
Weight	15 Kg
Working pressure	200 bar
H2 capacity	0.6 Kg

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DELHY-3W

(**DE**LHI **HY**DROGEN –**3 W**HEELERS)

Objective

Objective

- To introduce the most environment-friendly gaseous fuel "Hydrogen" in transportation sector.

- To reduce
  - Vehicular Emission
  - Ozone Depletion
  - Global Warming

- To bring down most of the health-related problems caused due to vehicular pollution.

Why Three -Wheelers ?

- The three-wheelers have been chosen for this project as they represent a common mode of affordable public transport in India.

- It is proposed to operate a fleet of 15 three-Wheelers vehicles powered by hydrogen in the site of New Delhi.

Three-wheelers as common reliable transporters in Delhi

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Project Partners

1. Indian Institute of Technology Delhi (IITD)
2. UNIDO-India
3. Mahindra & Mahindra (M&M)
4. Air Products (AP)
5. India Trade Promotion Organization (ITPO)

UNIDO - ICHET

- Total Budget :1,031,000.00 US $

- The International Centre for Hydrogen Energy Technologies (ICHET) of the United Nations Industrial Development Organization (UNIDO) is promoting this project.

- 500,000.00 US $ - ICHET Support: funding from Turkish Ministry of Energy


UNIDO
Development and Demonstration of
H2-fuelled three-wheelers
Launching Ceremony
12 March 2009, New Delhi
Mahindra
AIR PRODUCTS


UNIDO
Development and Demonstration of
H2-fuelled three-wheelers
Launching Ceremony

Hydrogen Fuelling Infrastructure

Infrastructure in India

- Infrastructure Players
  - Indian Oil Corporation (IOC)
  - Gujarat State Petroleum Corporation (GSPC)
  - Hindustan Petroleum (HP)
  - Bharat Petroleum (BP)
  - Reliance Group
  - Shell Hydrogen
- Pipelines tend to run in major cities and for industrial applications/buses
- Bulk delivered H2 is a problem
  - Distributed production and local delivery

Liquid and Gaseous Hydrogen Providers in India

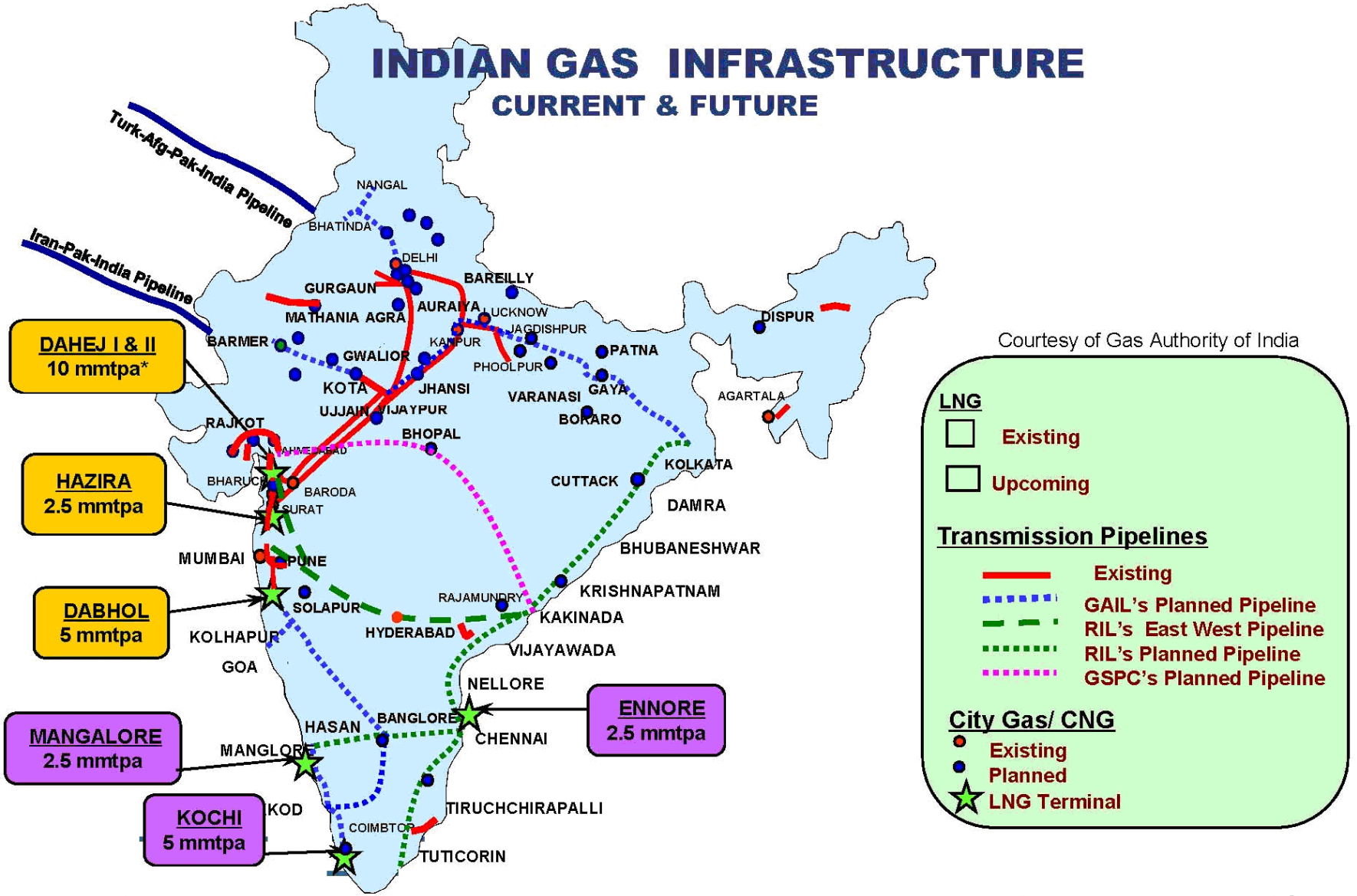
- Players
  - Inox AP (Air Products)
  - Air Liquide
  - Praxair
  - Linde presence through old BOC
  - Eden (Hythane/Hyradix/Larsen and Toubro)

- Indian Hydrogen Pathway
  - Short term Hydrogen/CNG and HICE deployments by 2012
  - Early entrants will be positioned for larger market
  - A significant fleet of HCNG/HICE/FCV by 2020

India Hydrogen Resources

- Existing Hydrogen Stations
  - IOC by AP
  - Delhi station by Hythane in progress
- Where's the early market
  - Bus areas with CNG
  - Distributed Power shortages
  - Areas with pipeline CNG
  - Hydrogen R&D centers
- Hydrogen Source
  - Chlor-alkali waste streams
  - Refinery by-product streams
  - Distributed production

INDIAN GAS INFRASTRUCTURE
CURRENT & FUTURE



Courtesy of Gas Authority of India

LNG
- Existing
- Upcoming

Transmission Pipelines
- Existing
- GAIL's Planned Pipeline
- RIL's East West Pipeline
- RIL's Planned Pipeline
- GSPC's Planned Pipeline

City Gas/ CNG
- Existing
- Planned
- LNG Terminal

INTEGRATED GRID TO LINK ANY SOURCE TO ANY MARKET

Hydrogen Fueling Stations

Location	Fuel	Project	Partners	Dates	H2 Production Technique	Specifics/ Comments	Picture
Faridabad, India	HCNG blend & pure H2	Hydrogen Fueling Station at Indian Oil Corporation Ltd's R&D Center	Indian Oil Corporation, Ltd., Air Products and Chemicals, Inc., INOX Air Products	Opened October 2005	Uses APCI's HCNG mixing unit and dual dispensing unit that can fuel vehicles with either a HCNG blend or pureH2.	Station owned by Indian Oil Corporation. First phase of India's development of its hydrogen economy.	
Delhi, India	H2/CNG	Indian Oil Corporation hydrogen station	Indian Oil Corp	To be opened by 2010	Will deliver a 20:80 percent hydrogen: CNG mix	Will be located near the Commonwealth Games Village and be capable of fueling 100 vehicles.	
New Delhi, India	N/a	Hydrogen station	ICHET, UNIDO, IIT-Delhi	Two-year demonstration to start in July 2010	Will use Air Products refueling equipment	Will fuel a fleet of 15 Mahindra & Mahindra 3-wheeled H2 vehicles that will transport visitors at the Pragati Maidan public exhibition hall.	

HYDROGEN FUELLING STATION BY INDIAN OIL CORPORATION LIMITED

- A total of 170 Hydrogen fuelling stations have been set up globally
- An electrolyser based Hydrogen production of (5mm^3/h) and dispensing station has been set up by IOCL in its R&D centre at Faridabad, near New Delhi
- IOCL is setting up one more such dispensing station in New Delhi
- IOCL intends to set up two SMR based Hydrogen production (100nm^3/h capacity each) and dispensing stations in New Delhi within next two years

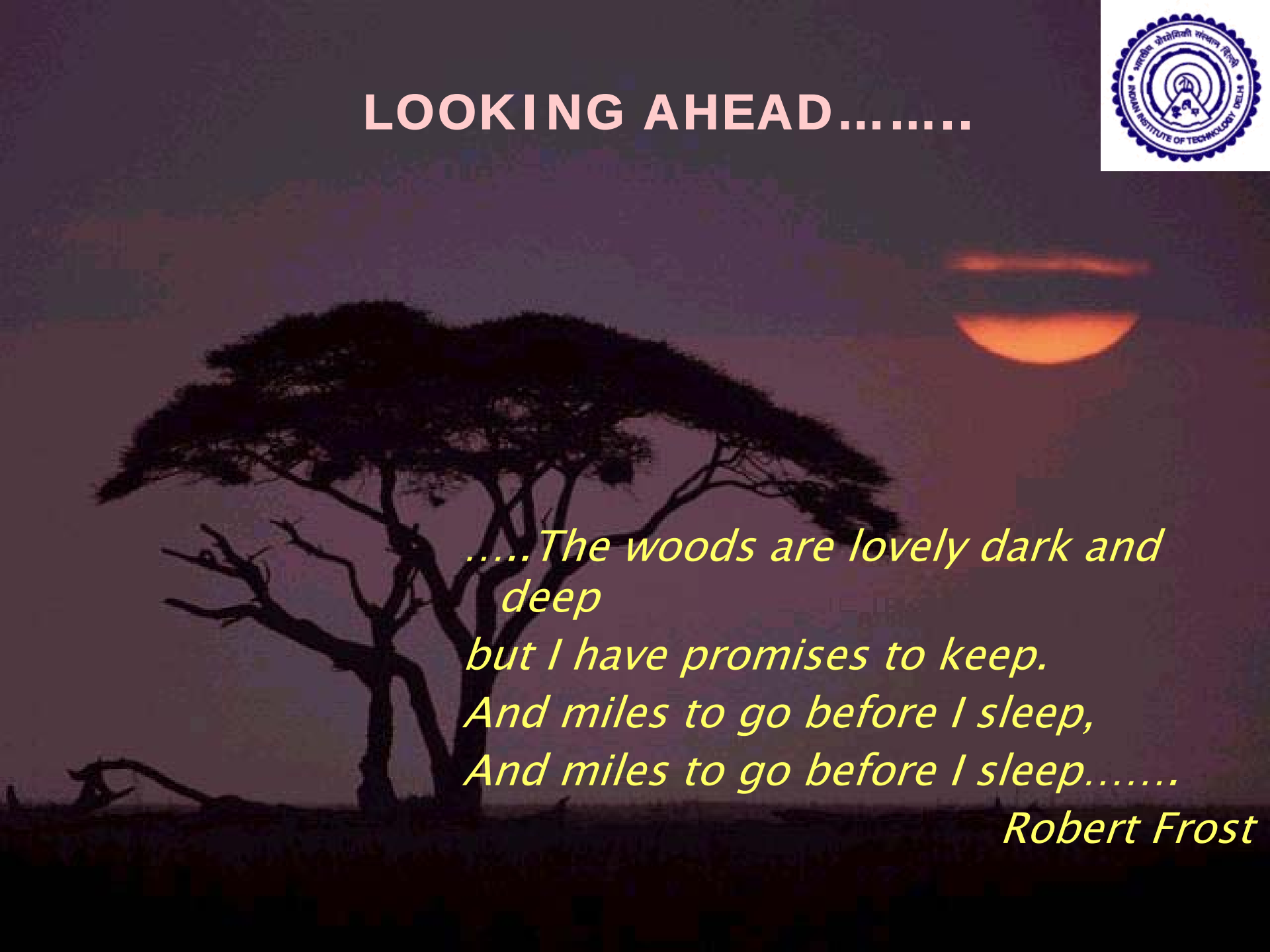
India's First Hydrogen and Hydrogen-CNG station at IOC R&D Centre, Faridabad

FIRST PUBLIC INDIAN HYTHANE® STATION

H-CNG filling station in India at Dwarka in Delhi

Indian Oil Corporation (IOC) has taken the first baby step for the country in the goal towards using hydrogen as an alternative fuel for running vehicles.-

LOOKING AHEAD……..



…..The woods are lovely dark and deep
but I have promises to keep.
And miles to go before I sleep,
And miles to go before I sleep…….

Robert Frost

भारतीय प्रौद्योगिकी संस्थान दिल्ली
Indian Institute of Technology Delhi

Thank You

Indian Institute of Technology, Delhi