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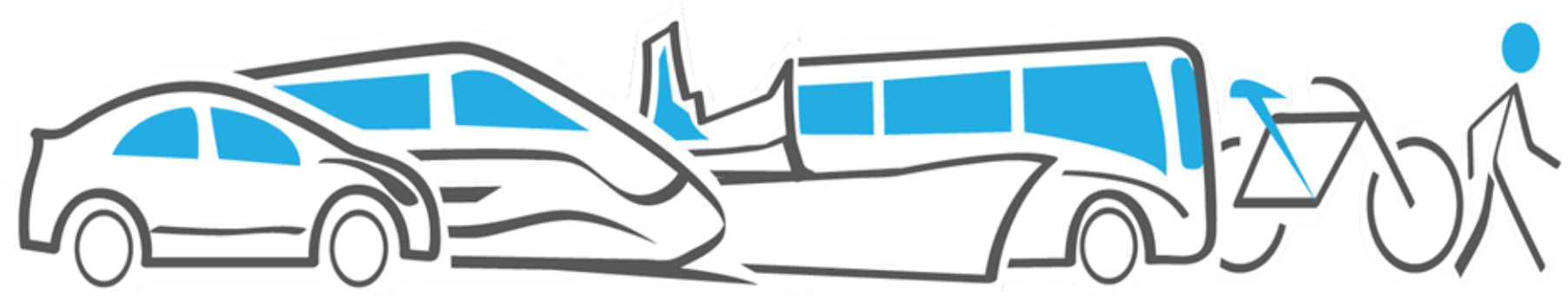
Indian Institute of Technology Delhi

Potential of Hydrogen as a Zero- emission Renewable Fuel for transport sector

L

L.M.Das



Hydrogen :Not a Radically New Concept Emerged from application in oceans

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"

ENERGY CRISIS

7

…."With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom, so that the first car driven by a child born today could be powered by hydrogen and pollution-free"…..

George Bush On Freedom Fuel

(Environmental Degradation)

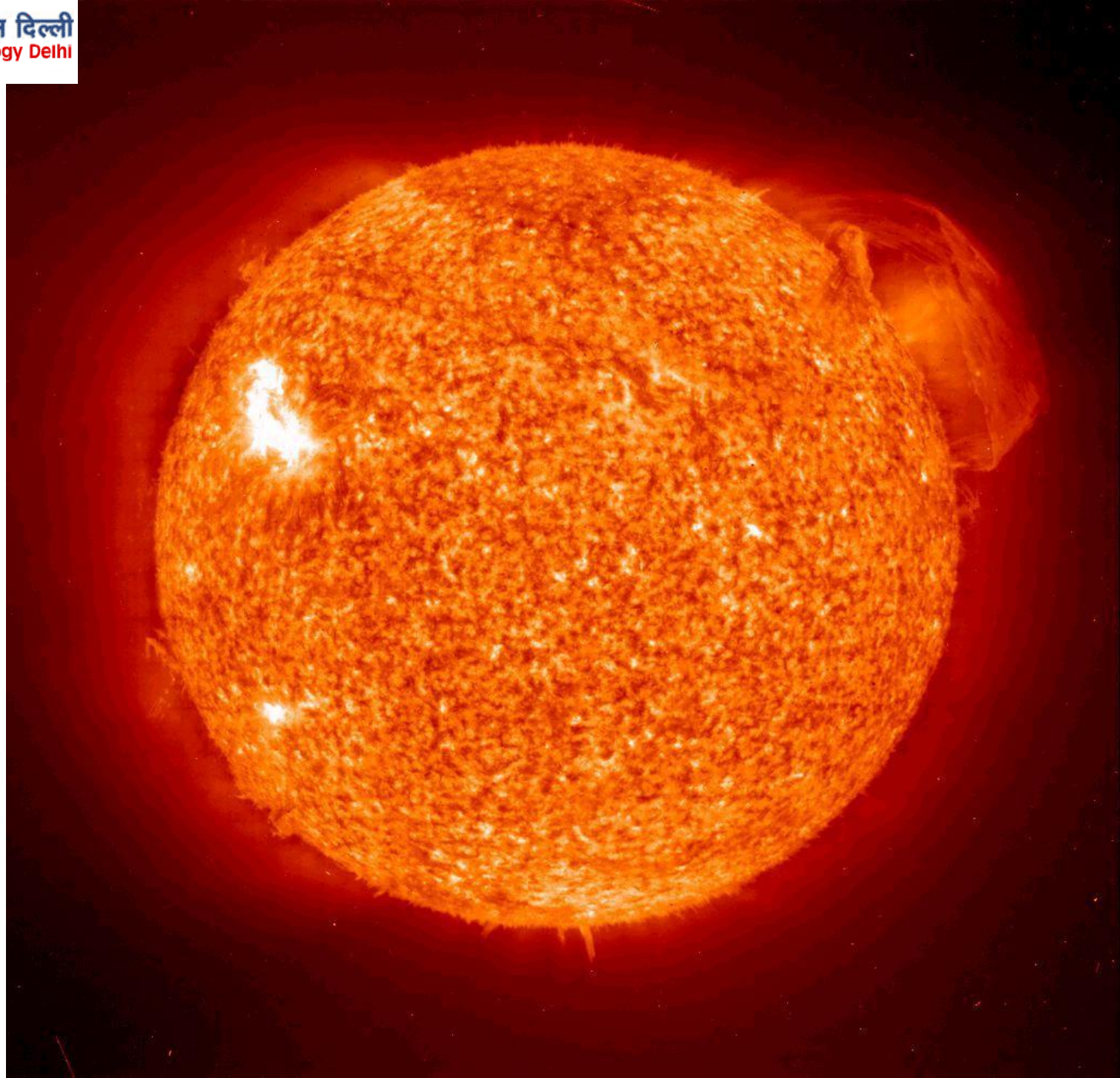
Relevance Of Hydrogen today

- Available from water using non petroleum fossil fuel/renewable energy resource
- Recycles rapidly and cleanly from hydrogen to water
- Clean burning- potential environmental benefits
- Provides high efficiency energy conversion process
- Compatible with all energy uses

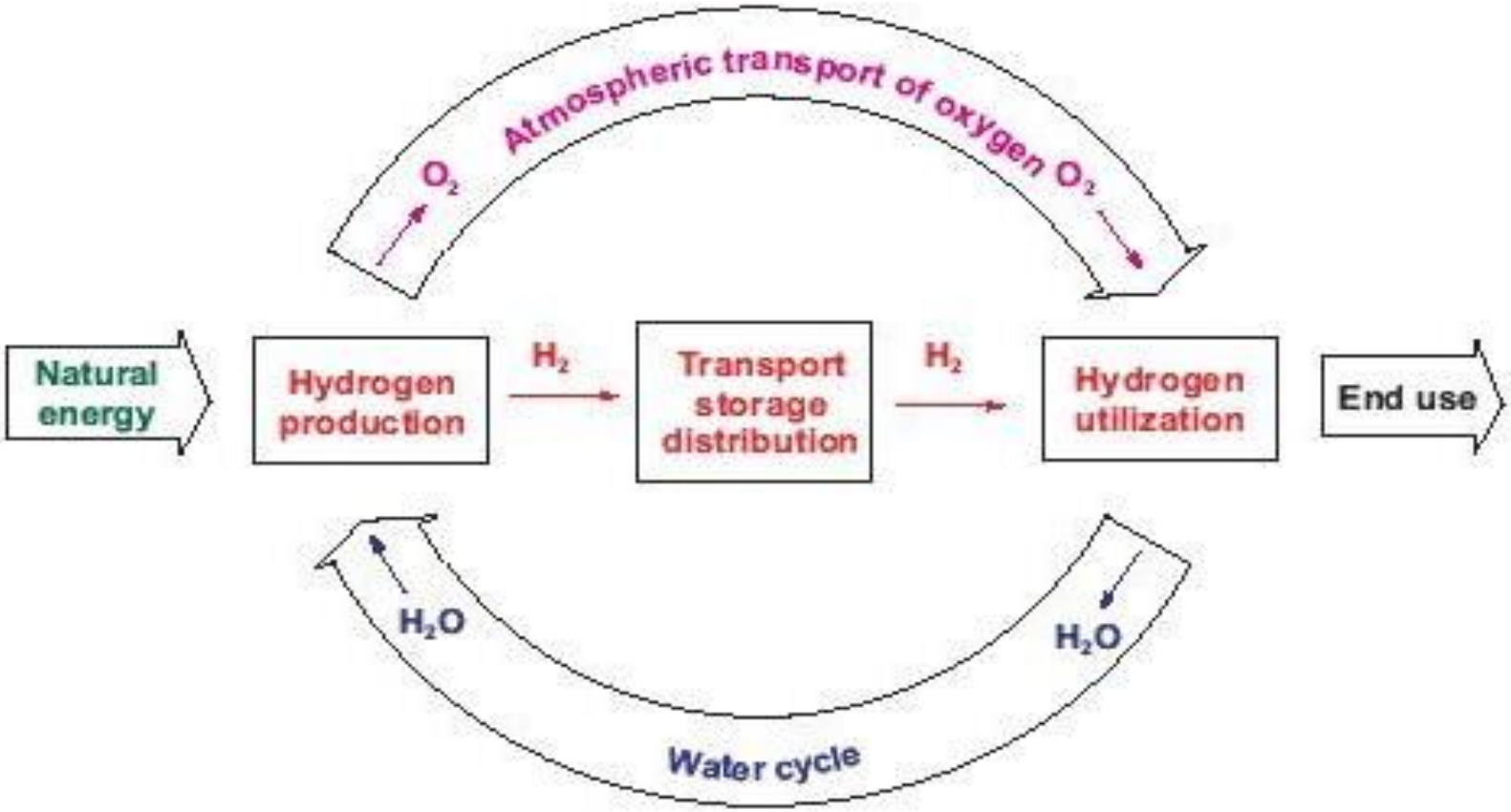
The SUN

Source of all Energy

Produces Energy from H2



THE HYDROGEN CYCLE



How to make Hydrogen

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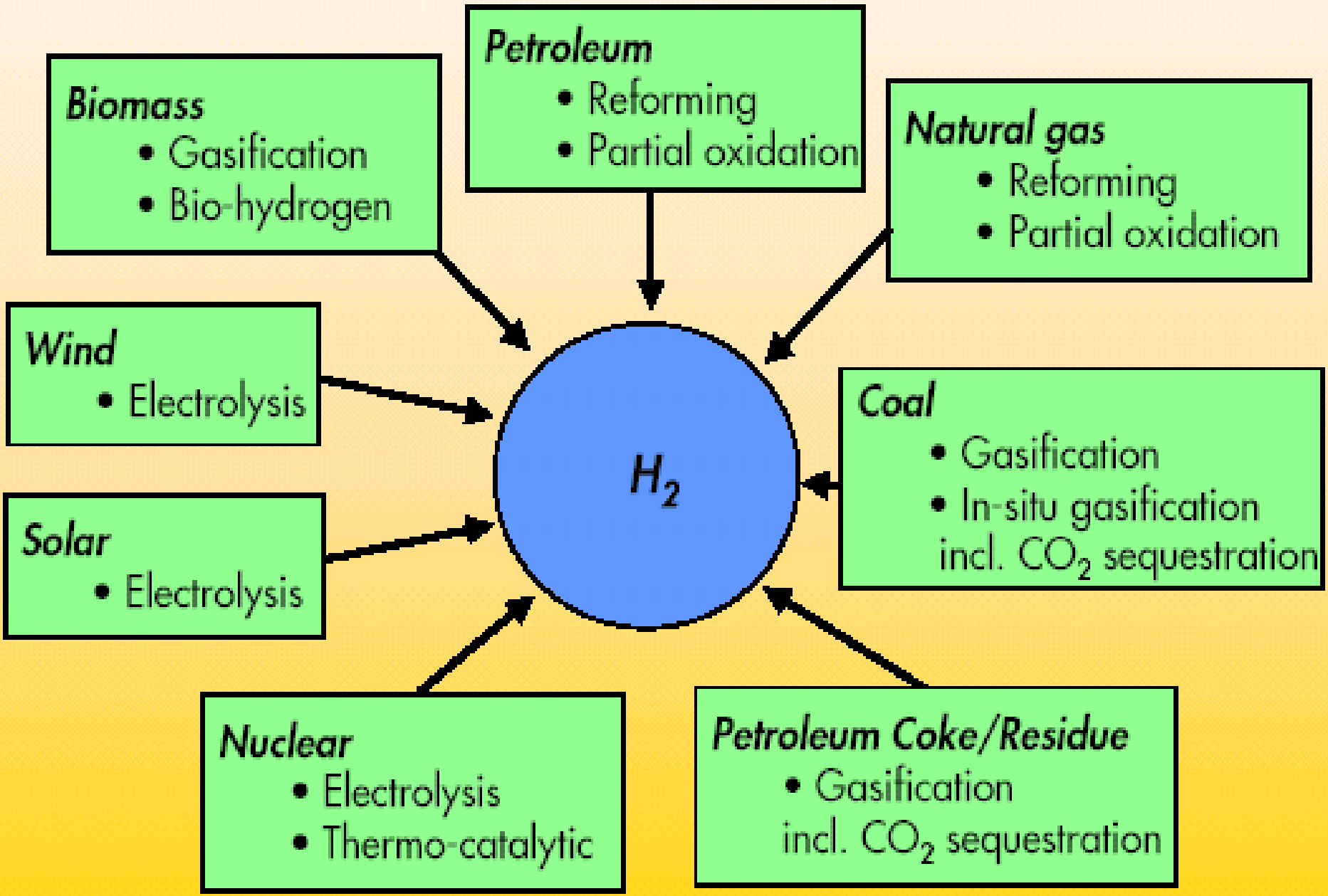

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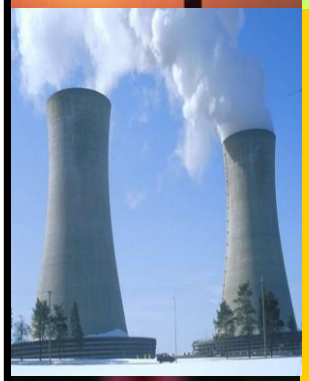
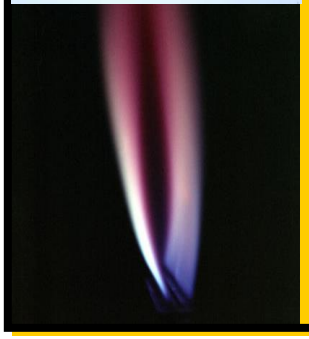
HYDROGEN

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 – SOURCES

Hydrogen

- Can be made from a variety of sources
- Sources and processes can offer CO_2-free hydrogen supply
- Create a freedom in the use of energy

Temperamental Combustion Properties Of Hydrogen

	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

Temperamental properties related to safety

- Minimum Ignition Energy
- High flame speed
- Wider flammability range
- Invisible flame

These properties are dangerous if liberally handled.

However a lot of benefit could be obtained from a hydrogen-specific system if these properties are optimally used

- Buoyancy and diffusivity are beneficial

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]

Broad Areas of Application

Hydrogen as an energy carrier can be used instead of fossil fuels for virtually all purposes

- **Hydrogen powered automobiles with I C Engines** and Fuel cells
- **Marine application** of Hydrogen
- Hydrogen powered airplanes
- Hydrogen Application in Electricity generation (Gensets)
- Hydrogen Application in Buildings

Modes of Transportation System

Land (auto vehicles such as Bus, Car, Scooter, Three wheelers, Truck , tractors etc)

Air(airplanes, helicopters, airships, gliders, paramotors hot air balloons.

Sea (Watercraft, also known as water vessels vehicles used in and on water, including boats, ships, hovercraft, and submarines)

Space : Several space crafts (flyby,,Orbitor Lander etc)

Land Transport sector: Worst victim of Energy-environment Crises

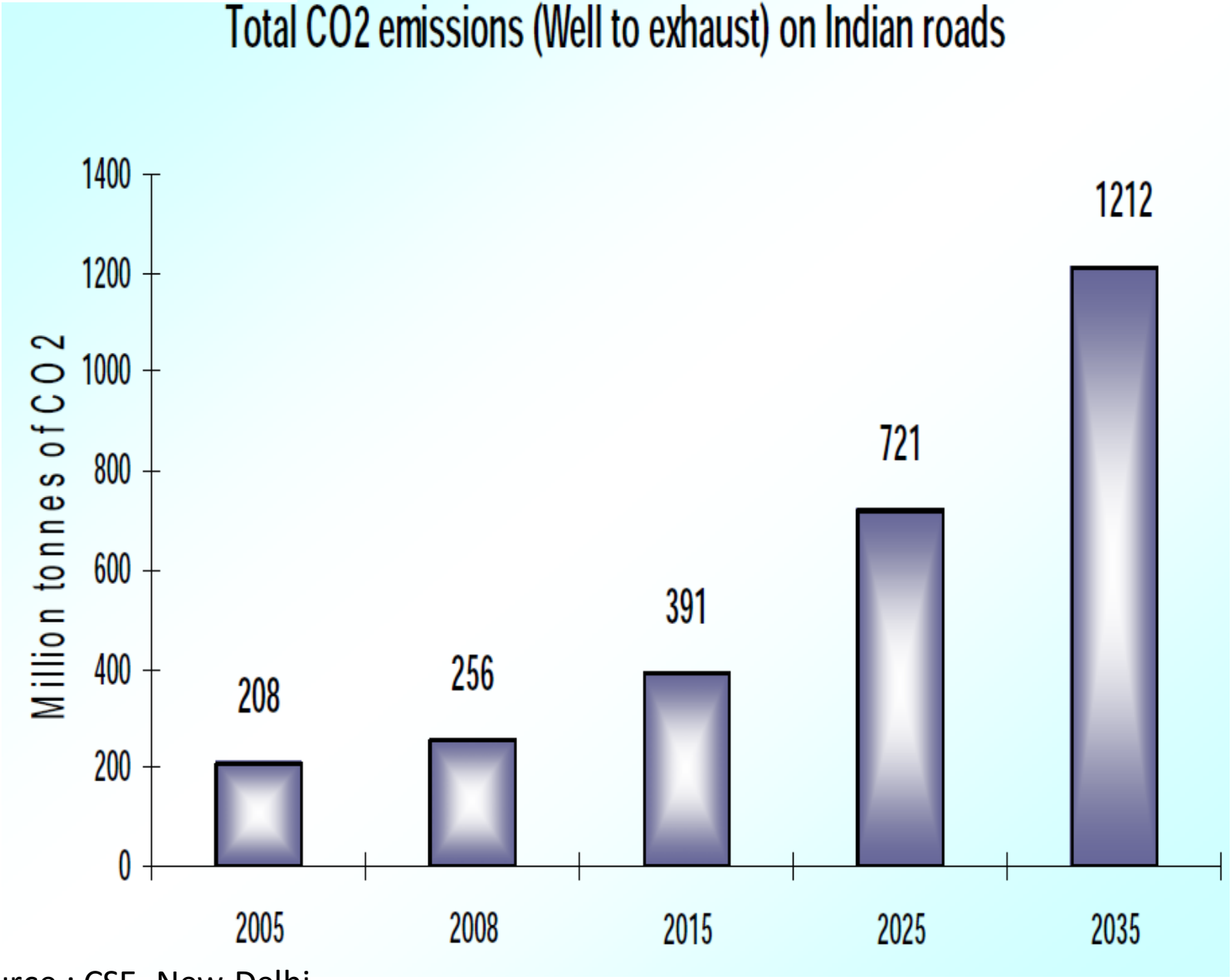
Transportation system built on Internal Combustion Engines are the most common systems for centuries

IC Engines operated on conventional petroleum fuels have become the most dominant polluter.

Simple way to control Pollution from transport sector is to use some renewable low-emission alternative fuels

Global Emissions of GHG's from Transport Sector

- Transport sector contributes around 14% towards the global emissions of green house gases
- Carbon dioxide represents the largest proportion of basket of greenhouse gas emissions
- The Road transport alone emits around 16% of the global CO^2 emissions

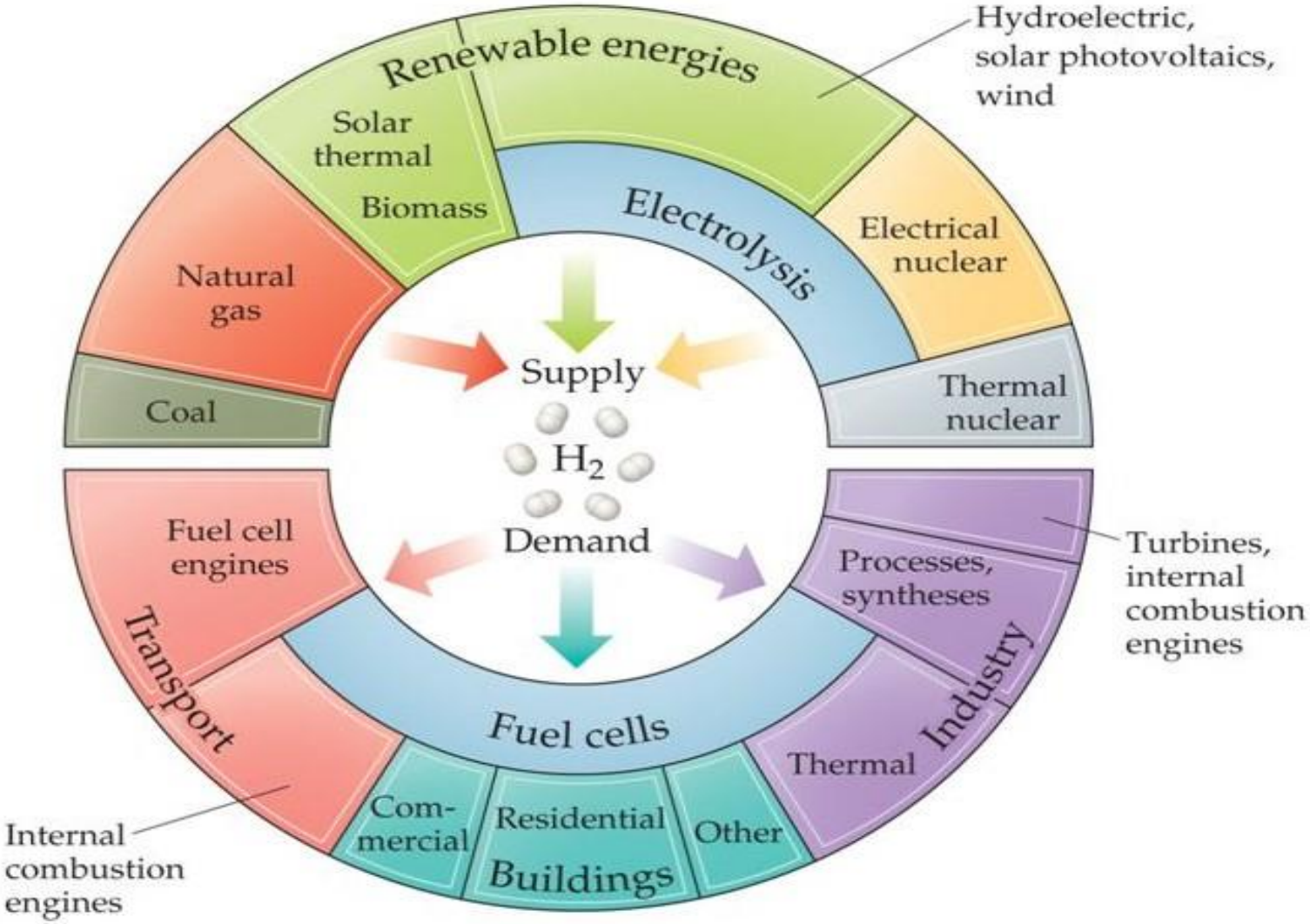


Source : CSE, New Delhi

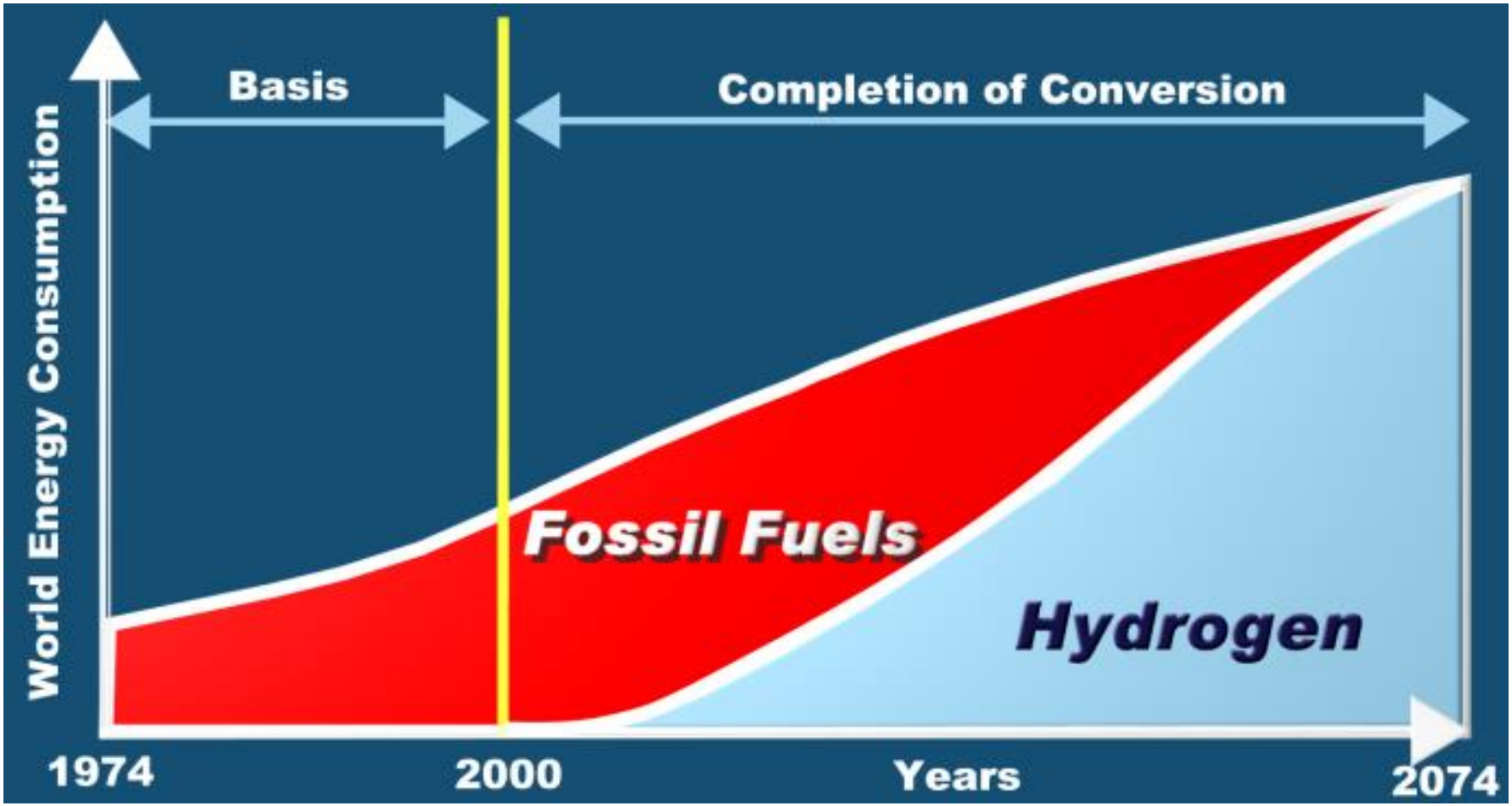
Alternatives : Approach to attain Sustainable Transport

- Hydrogen
- Compressed Natural Gas(CNG)
- Bio-Diesel
- Hydrogen Added Natural Gas
- Ethanol and Methanol
- Liquefied Petroleum Gas (LPG)
- Biogas
- Producer Gas
- BtL GtL and CTL
- Electric/Hybrid/battery operated systems

The Hydrogen Economy

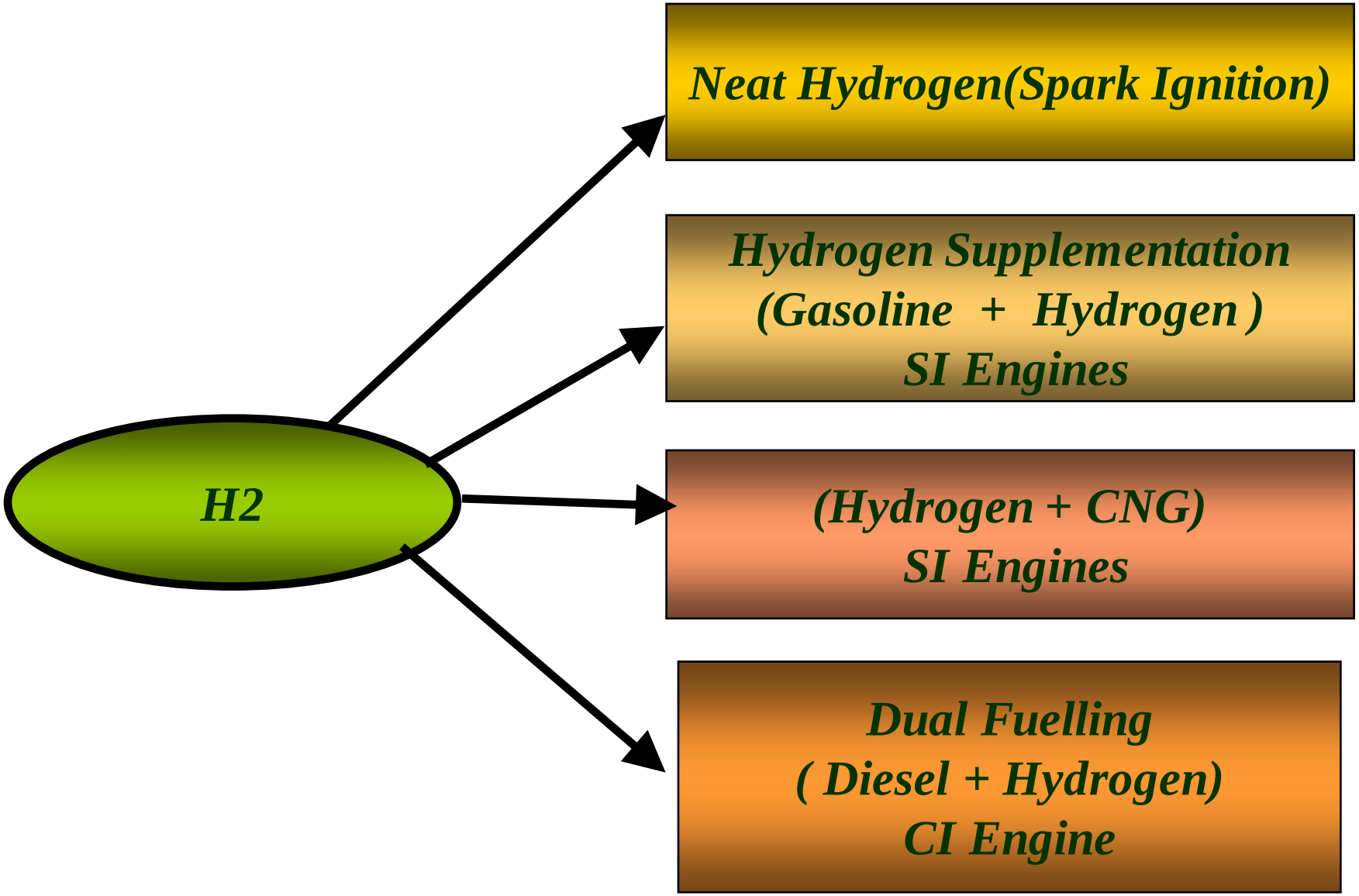


Building Hydrogen Energy



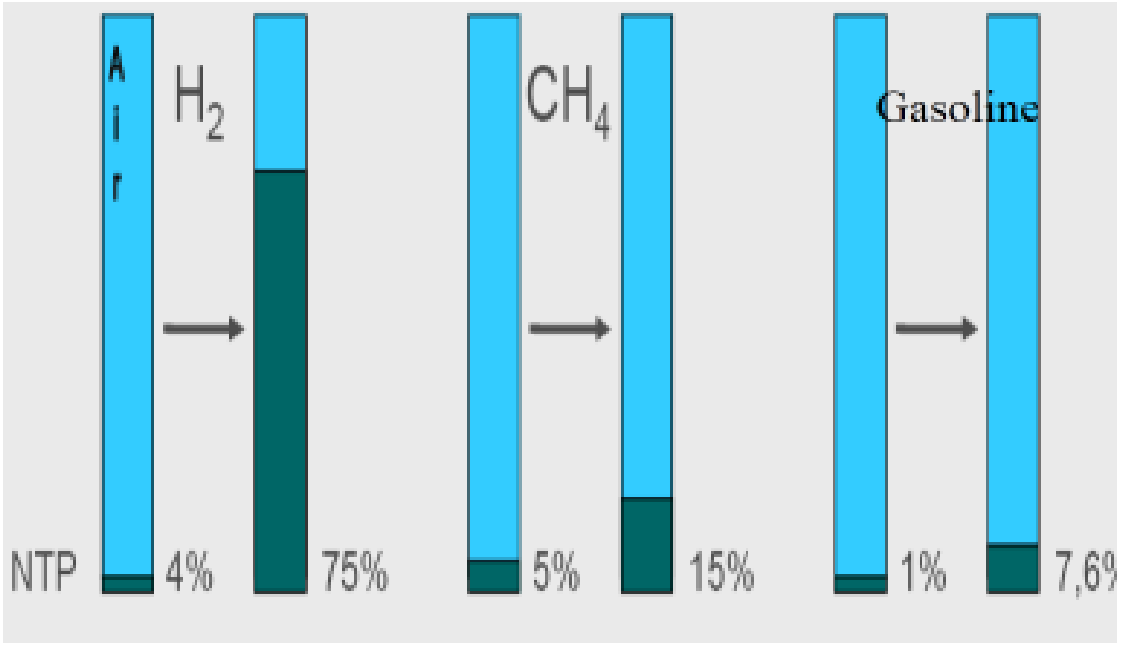
Source: T. Nejat Veziroglu , Hydrogen Energy Technologies, UNIDO

Use of Hydrogen in I C engines

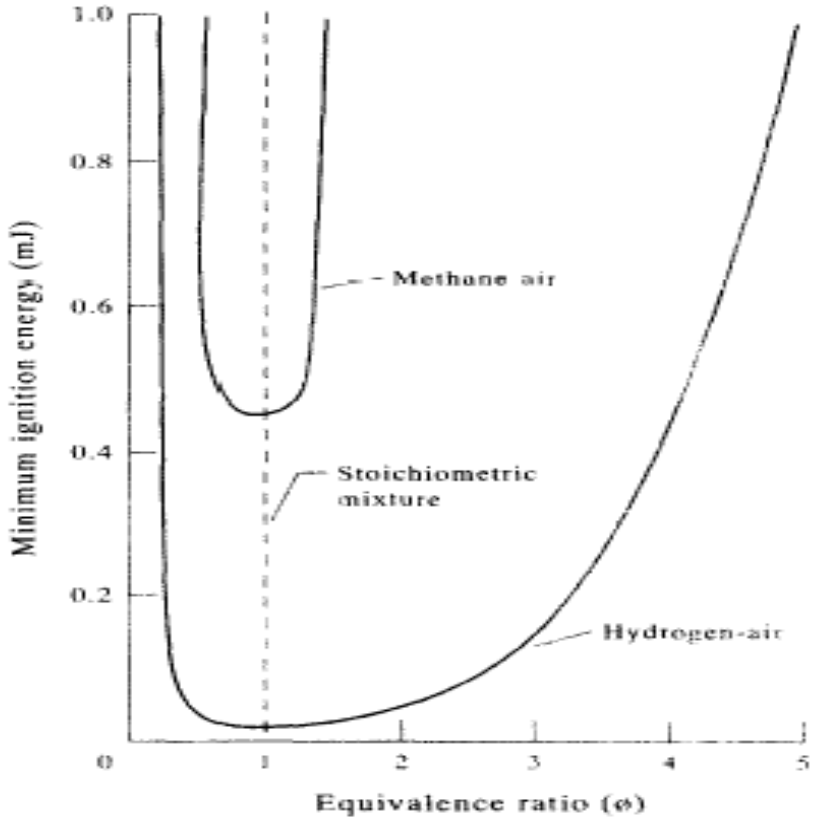


Flammability range

Comparison



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



Backfire: Achilles Heel for Hydrogen Engines

- *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*

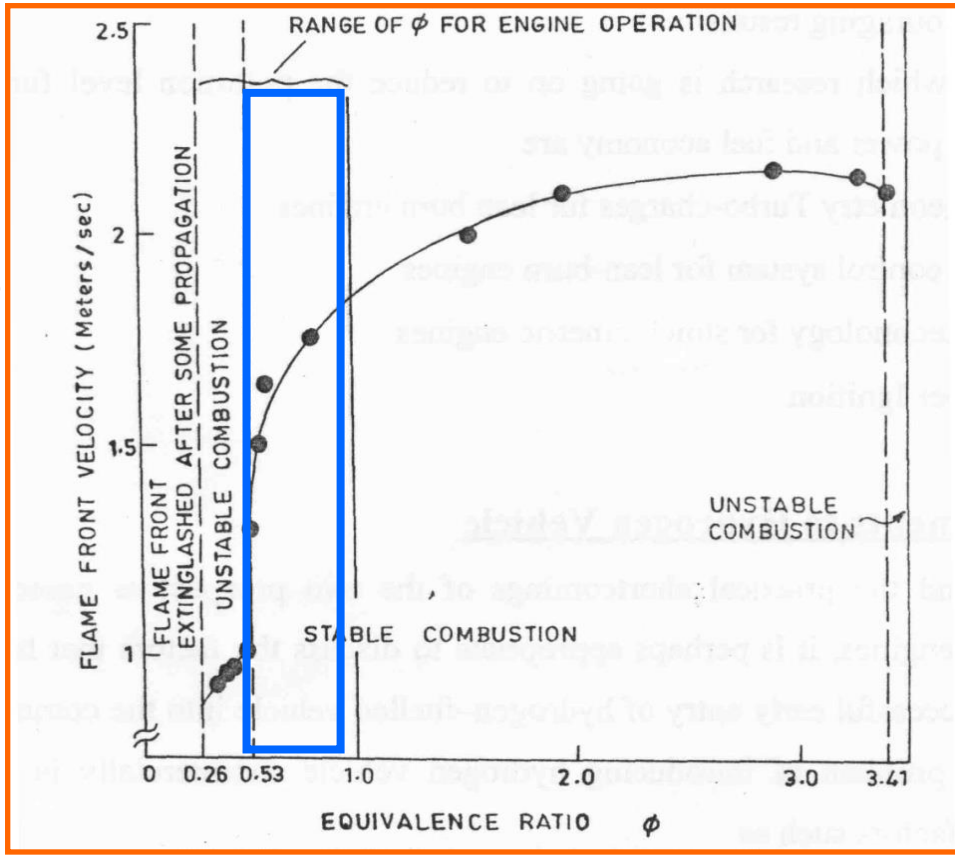
Optimum Fuel Induction into Hydroen Engine

Mixture formation	Classification	Hydrogen flow timing	Supply pressure
Continuous carburetion (CC)	Pre-IVC	Continuous flow	A little above atmospheric
Continuous manifold injection (CMI)	Pre-IVC	Continuous flow	Slightly greater than atmospheric
Timed manifold injection (TMI)	Pre-IVC	Hydrogen flow commences after opening of the intake valve but completed prior to Intake valve closure	1.4±5.5 kgf/cm^2
Low pressure direct cylinder injection (LPDI)	Post-IVC	Hydrogen flow commences after the intake valve closure and is completed before significant compression pressure rise	2.0±8.0 kgf/cm^2

*** Reference:** Das L M. Fuel induction technique for a hydrogen operated engine. Int J Hydrogen Energy 1990; 15(11):833-42.

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 $\phi < 0.4$



*J.Breton Office of Natl. Combustion Liquids, 11 487 Theses Faculte Des Sciences

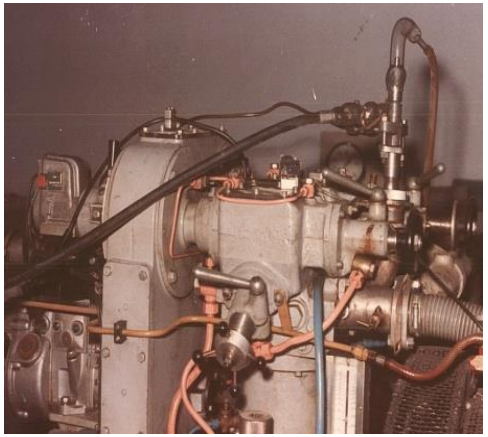
S.Wendlandt,Physik Chem.110 637 (1924)

#J.G.Finegold and Wm.D.Van Vorst "Engine performance with gasoline and hydrogen: A comparative sytudy"THEME confernce 1974

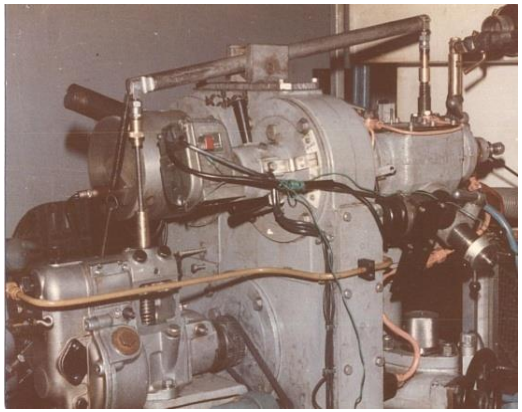
H.S.Yi,K.Min,E.S.Kim "the optimized mixture formation for hydrogen fuelled engines"Int.j.Hydrogen Energy 2000

Hydrogen engines system :Outcome of R&D pursuits in IITD

HYDRAULICALLY OPERATED INJECTION SYSTEM



CAM-ACTUATED INJECTION SYSTEM



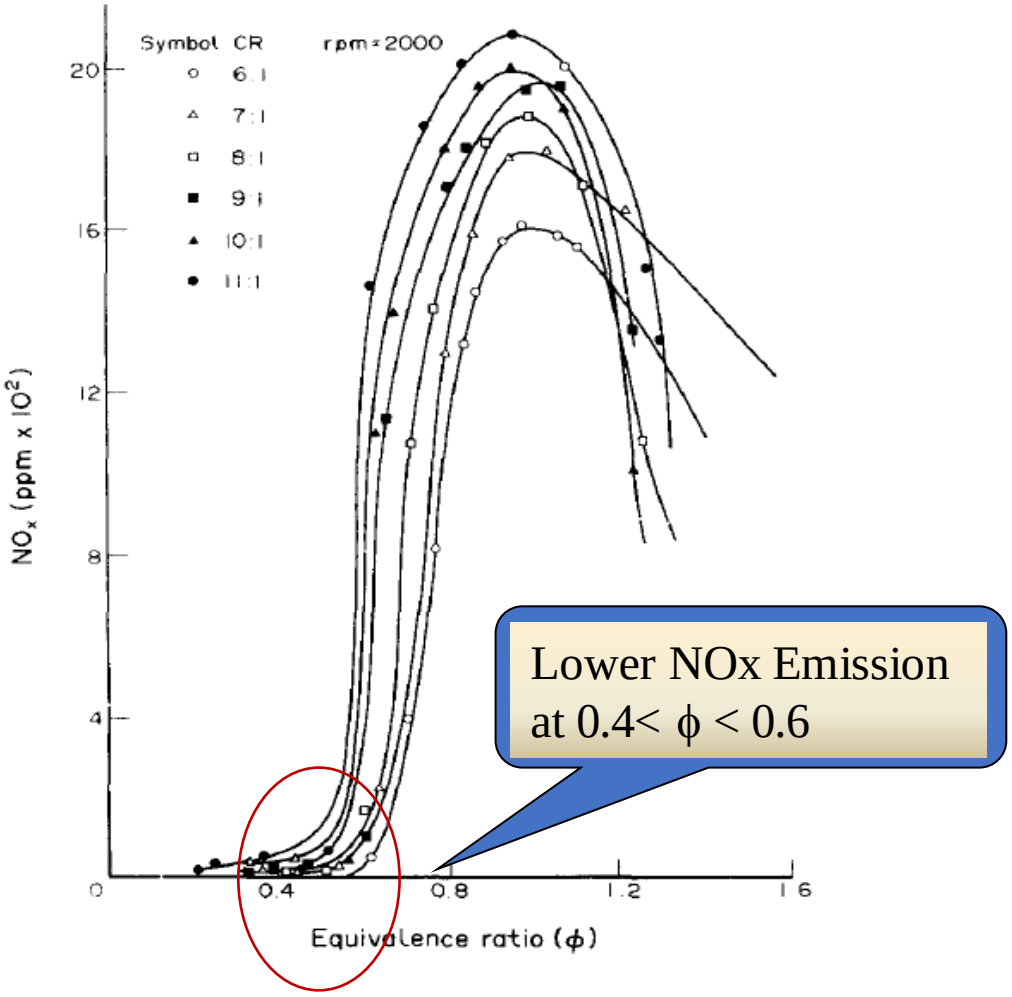
Neat Hydrogen-fuelled S.I. Engine Genset

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

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

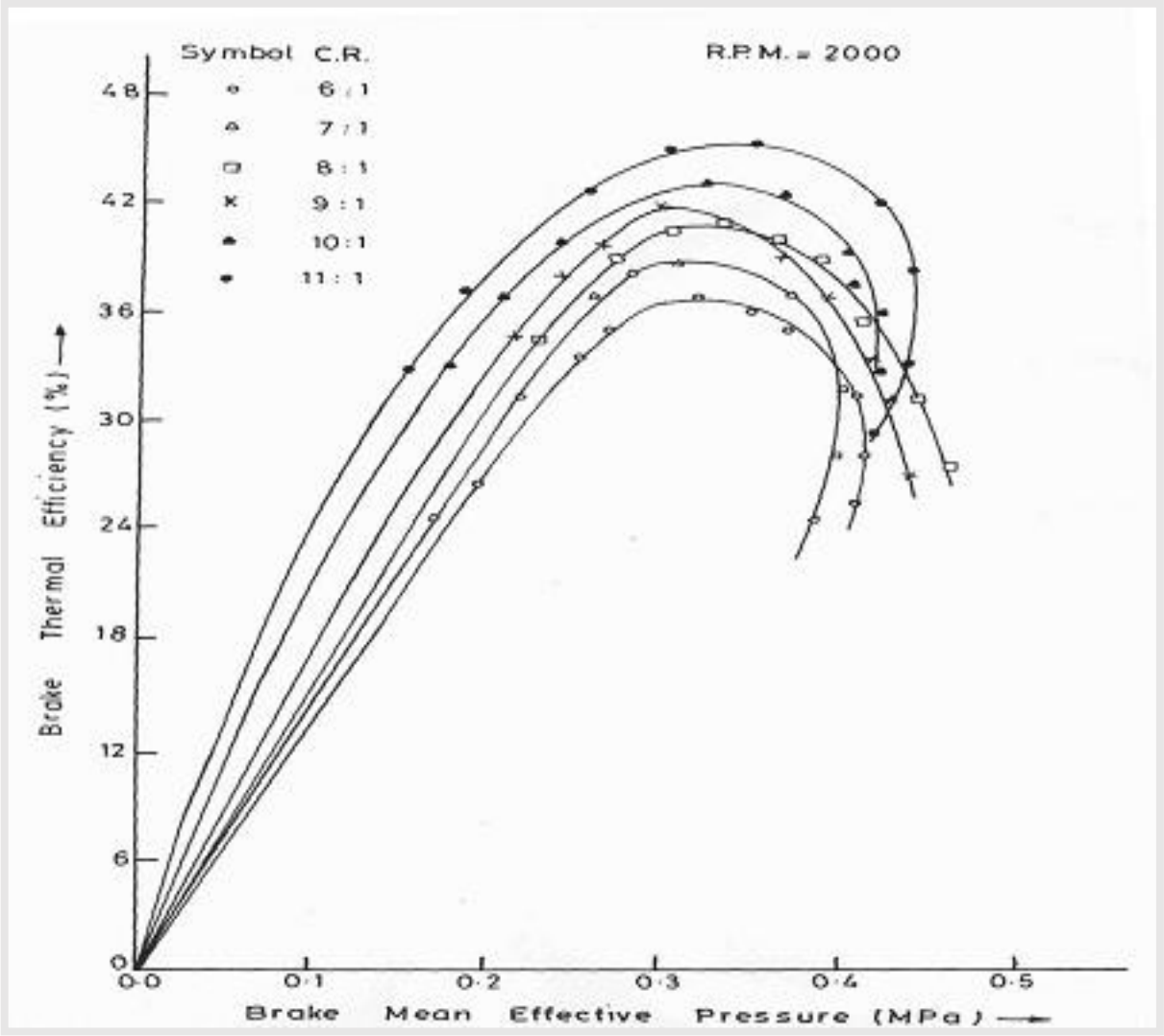
HYDROGEN FUELLED DIESEL ENGINE

Near Zero Emissions



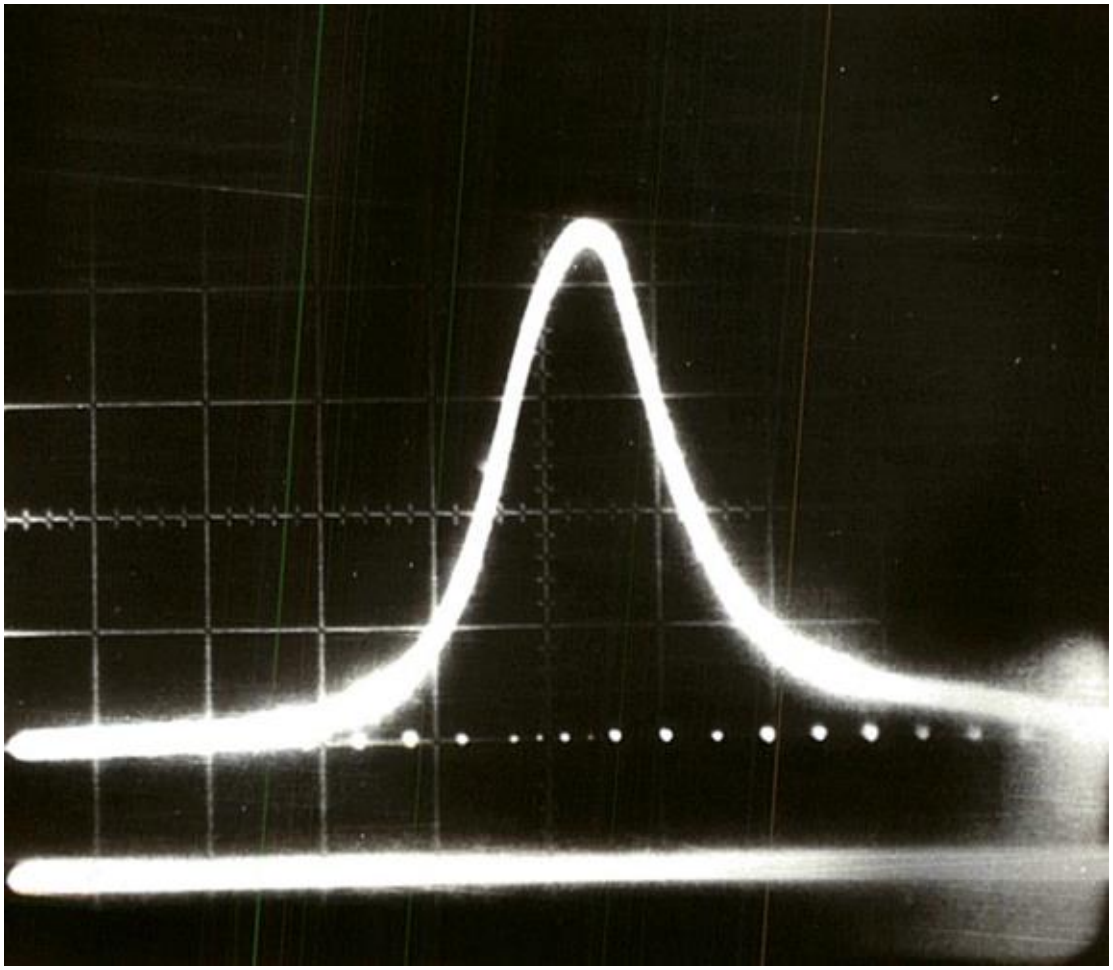
Reference: L.M.Das, Exhaust Emission Characterization of Hydrogen-Operated Engine System: Nature of Pollutants and Their Control Techniques, Int. J. Hydrogen Energy Vol. 16, No. 11, pp. 765-775, 1991.

Improved Thermal Efficiency



Maximum Thermal efficiency close to 44 % at lean engine operation

PRESSURE CRANK ANGLE DIAGRAM-H_2



Hydrogen as a Safe Automotive Fuel

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 :Compression Ignition (DIESEL) Engine

- **Auto ignition temperature of Hydrogen is 576^{o} 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 –converted to hydrogen-diesel operation and Multicylinder Diesel engine --- About 45% Energy substitution**

MULTICYLINDER HYDROGEN – DIESEL DUAL FUEL ENGINE

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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Transfer of Technology from Lab-to-Land (UNIDO-MNRE projects)

सत्यमेव जयते

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

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Mahindra

AIR PRODUCTS

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Genesis of the Project

To demonstrate H2 Technology: 15 H2 powered 3- Wheelers developed by IITD - support by UNIDO-ICHET.	Subsequent **support by MNRE** from Sept 2013 for the field trails	With **ITPO Cooperation** and presently vehicles are operational inside the pragati-maidan, New Delhi.

PROJECT PARTNERS AND THEIR ROLES

- Activities Coordination among the partners.
- Vehicle testing in lab.

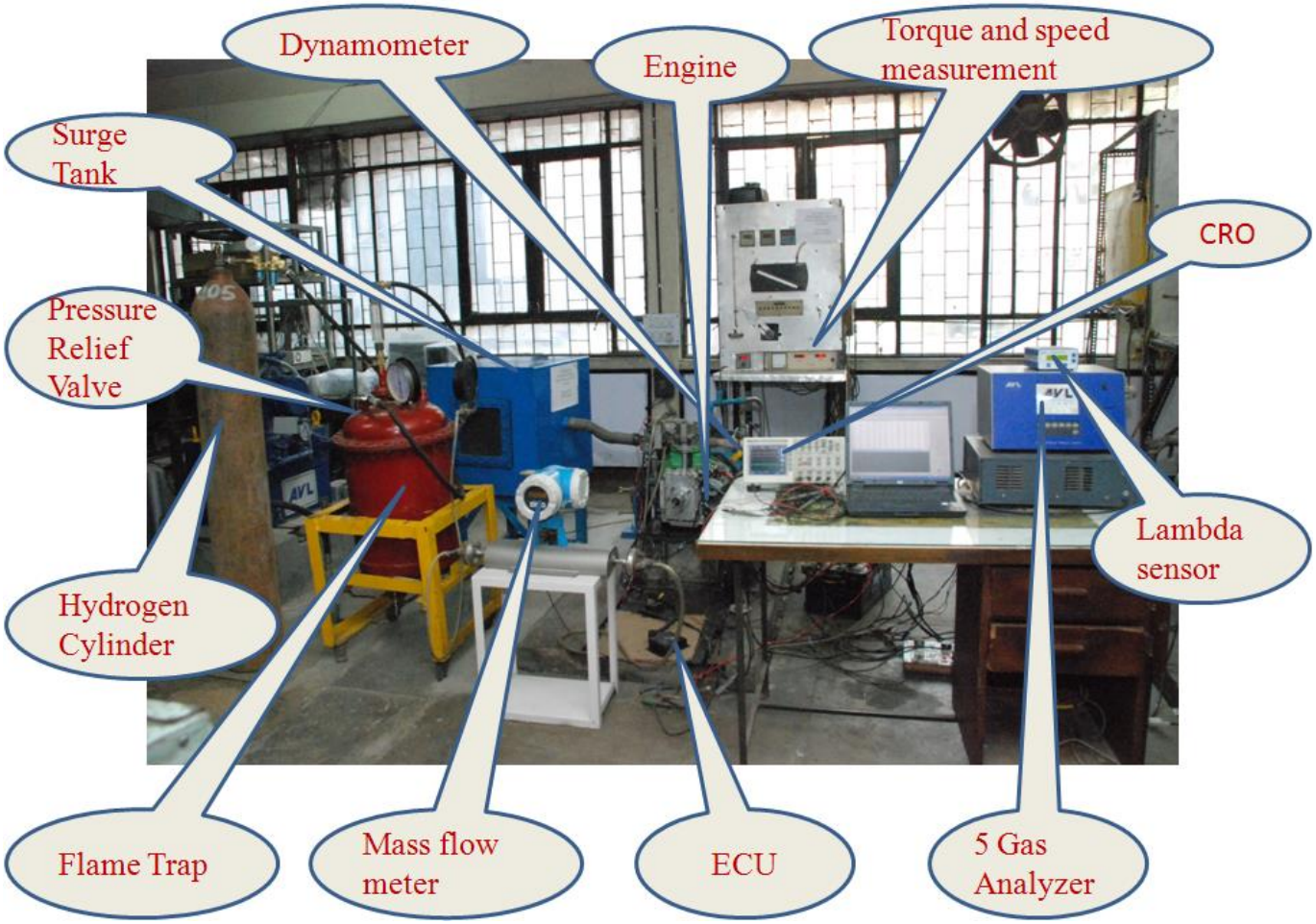
Mahindra

- Supply of Vehicles and maintenance.
- regulatory approvals for operation.
- Recruitment of drivers, security.

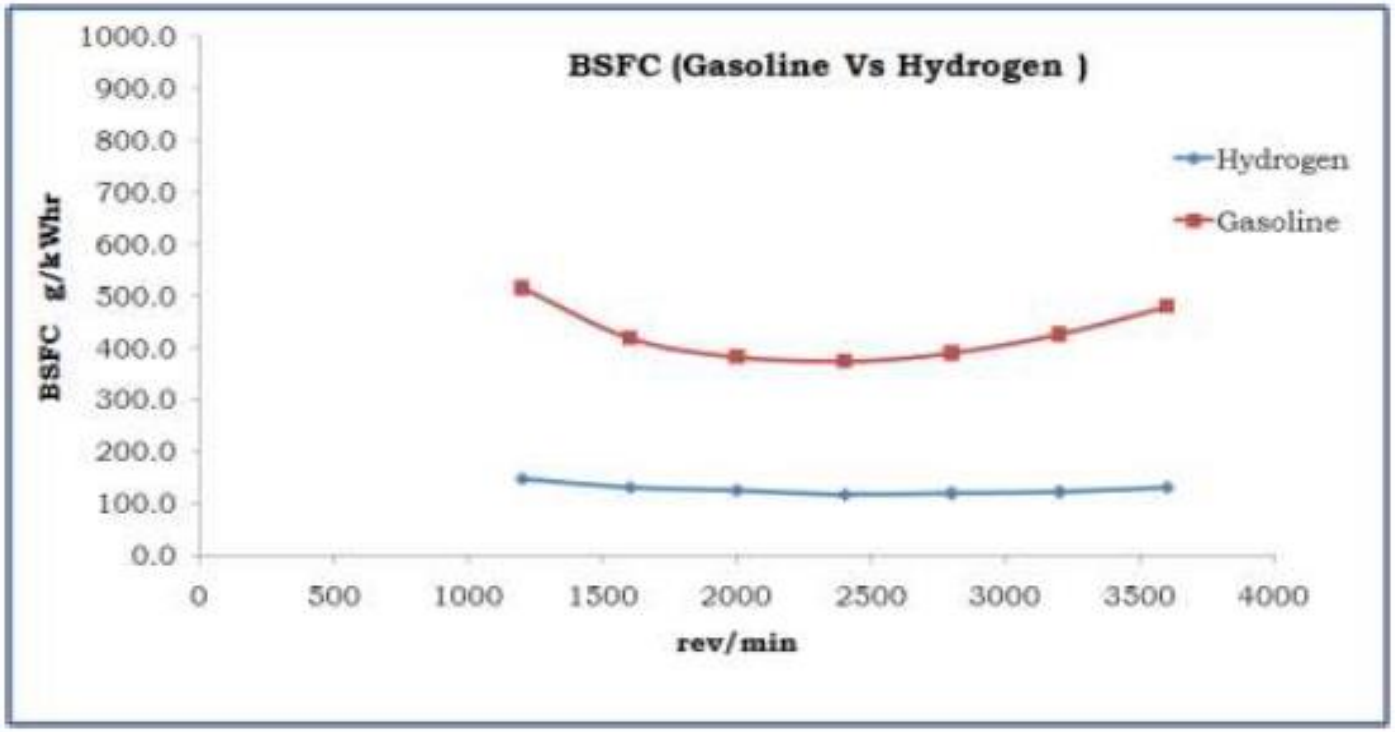
AIR PRODUCTS

- Supply of hydrogen to the dispensing unit.
- Maintenance of dispensing unit.

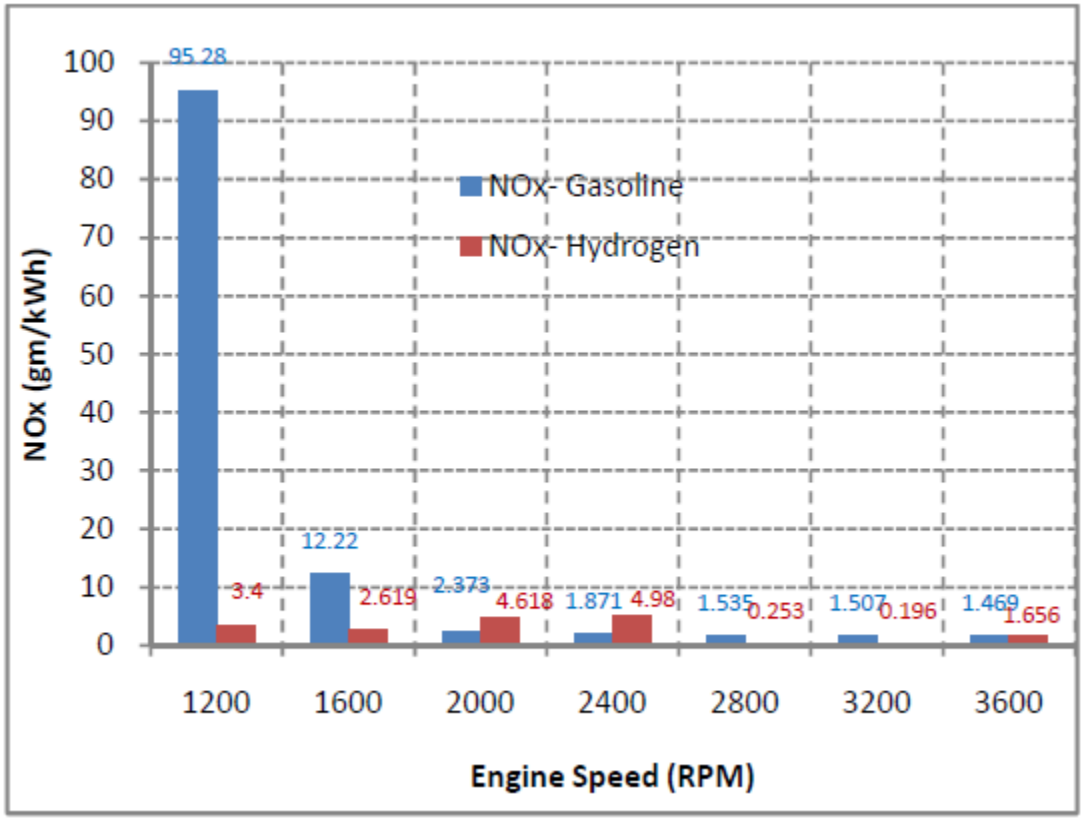
Lab Tests on the Three wheeler vehicular Engine



Performance Characteristics



Potential of “zero-emission” features



From left to right - Dr M. Hatipoglu, Mr. Nigel Gibson, Prof. L.M. Das, H.E. Burak Akcapar, Ms. Kiran Mehra-Kerpelman, Ms. Ayumi Fujino, Ms. Rita Menon, Dr. Pawan Goenka

Official inauguration was held on 9th January 2012 in Pragati Maidan, New Delhi

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Prof. L. M. Das, IITD at DELHY 3W Inauguration

Prof. L.M.Das, IIT-Delhi, at DELHY 3W Inauguration

Ms Rita Menon, Chairman-cum-MD of the IPTO at at DELHY 3W Inauguration


Dr. Pawan Goenka, President, M&M at DELHY 3W Inauguration

Dr. Pawan Goenka, President M&M, at DELHY 3W Inauguration

Ms Ayumi Fujino, UR, UNIDO India at DELHY 3W Inauguration

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

FUELLING STATION IN PRAGATI MAIDAN

Development of Hydrogen Bus(MNRE sponsored)

1) Coordination
2) Optimization of the Engine for better performance and Emissions ensuring proper combustion phenomena
3) Durability study
4) Dissemination

Mahindra

1) System spec & simulation, CFD
2) Engine Controller Development
3) Components Dept., Engine & vehicle integration , Safety systems incorporation
4) Develop two Hydrogen vehicles
5) Field trials

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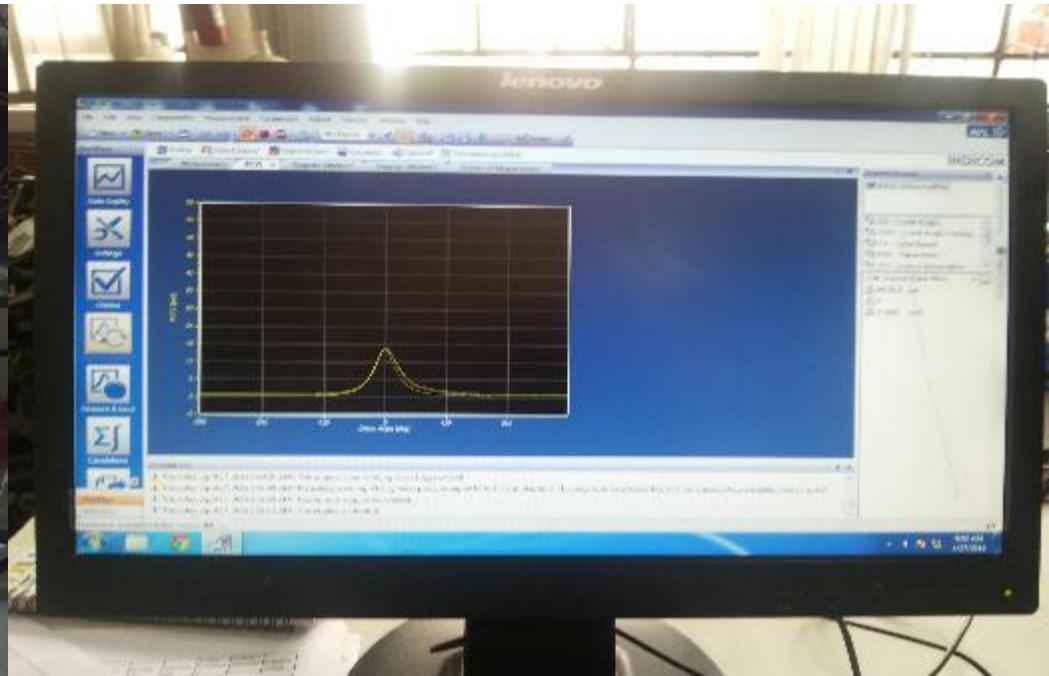
Mini Bus Engine Test Bed setup at IIT Delhi

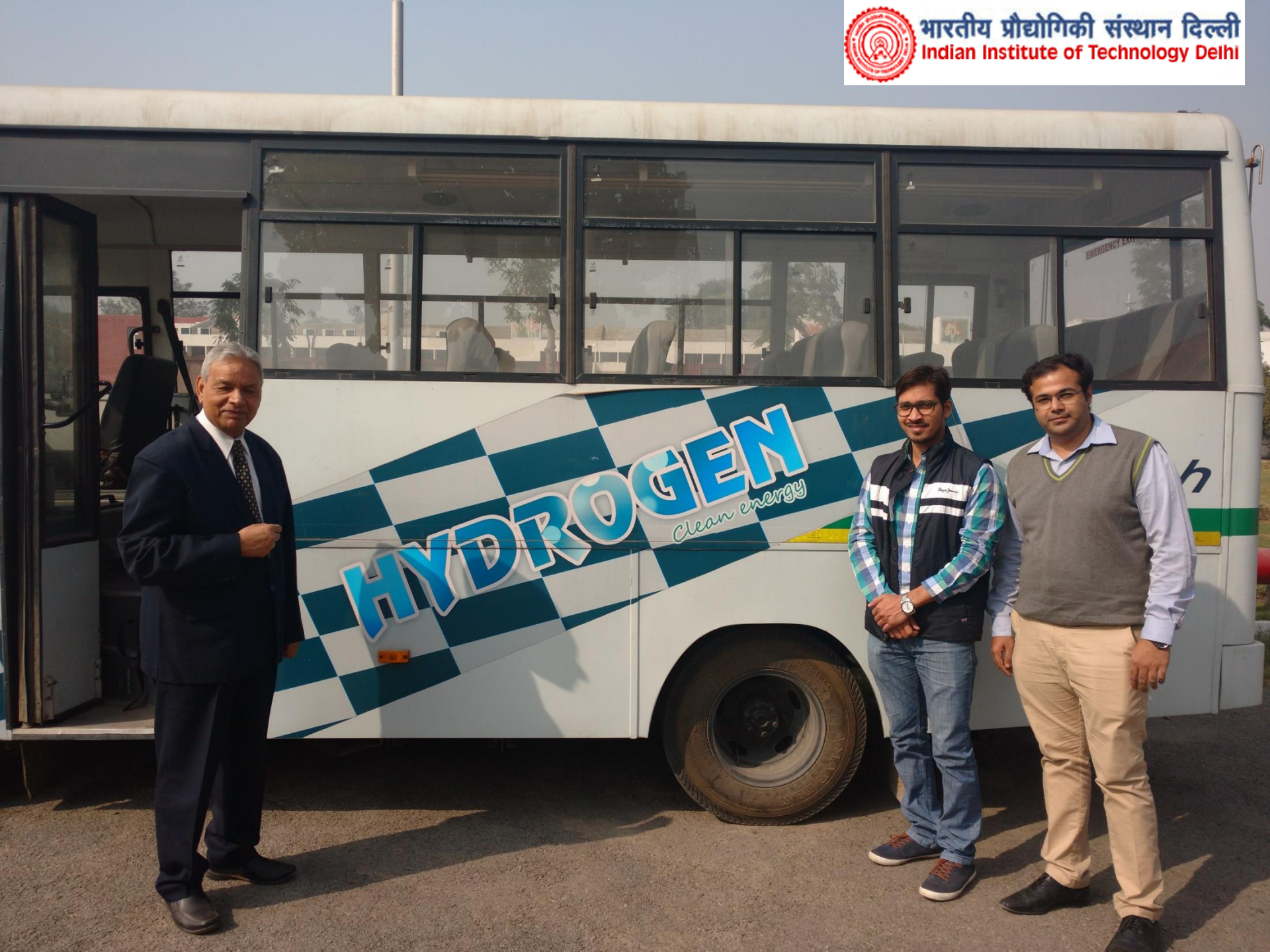


Video :Hydrogen operated three wheelers

Video: Hydrogen operated MiniBus

Hydrogen Fuelled MiniBus (MNRE Project)

- Hydrogen Powered Engines were Developed and Optimized at IIT Delhi.
- Power Developed : 90 hp @ 3600 rpm
- Two Hydrogen Mini Buses are powered by these engines
- Each vehicle will cover 1,00,000 km each.
- Vehicle Mileage: 25 km/kg H_2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HYDROGEN
Clean energy

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A glimpse of some of the Major R&D Activities and Prototypes Developed in the Field of Hydrogen Transport (IC Engines and Fuel Cell)

Tata Motors Hydrogen Fuel Cell Bus

Hydrogen Powered Car-ICE based

In Europe, a three-year (2004-2007) Integrated Project called **HyICE** resulted in the demonstration of engine concepts exceeding a specific power output of 100 kW/l and a peak efficiency of 42%. The project was funded in the 6th Framework Programme of the European Commission and coordinated by BMW.

FORD PRESENTS
A NEW SUV USING COMPRESSED H2

2.3 l four cylinder internal combustion engine, hybrid electric transmission SUV vehicle presented by **Ford U January 2003**

TOYOTA PRESENTS A NEW FUEL CELL CAR

Toyota Motor Corporation, Japan, presented its new fuel cell hybrid vehicle at the International Symposium on Fuel Cell Vehicles in Tokyo, Japan - March 2003

Bi-fuel (gasoline/hydrogen) VW Polo demonstrated by the University of Navarre

Forklift truck equipped with a H2ICE, part of the demonstration activities within the Hydrogen Region Flanders South- Netherlands project

Heavy Duty I C Engines

In Japan work was sponsored under the Next-generation Environmentally Friendly Vehicle Development and Commercialization Project (EFV21) of the Ministry of Land, Infrastructure, and Transport (MLIT).

The project aims to deliver a hydrogen ICE system combining high power output and low NO_x generation.

Separately, Tokyo City University, in cooperation with Hino, unveiled a hydrogen-powered truck offering roughly the same performance level as a diesel-engine hybrid model.

Hybrid light duty truck equipped with a 4 L 91 kW hydrogen engine, demonstrated by Tokyo City University

Microbus equipped with a 4.7 L 105 kW hydrogen engine, demonstrated by Tokyo City University

Hydrogen Fuel cell Based Application for Transport

- Polymer electrolyte membrane (PEM) fuel cells have been found to offer advantages for vehicles including low pollution, high efficiency, low noise, and fast startup.
- These advantages have promoted the application of PEM fuel-cell systems in various vehicles, including passenger cars, buses, golf carts, forklifts, scooters, and boats.

Honda FC car

Toyota FC car

Hydrogen Bicycle

- **Fuel cell bicycle** has been developed by Linde Group that has a range of 65 miles using just 34 grams of hydrogen.
- The battery usually found on electric bikes is replaced by a compact fuel cell which generates electric power from hydrogen and oxygen taken from the surrounding atmosphere.
- The H2 Bike uses a specially developed fuelling system that can refill the cylinder in less than six minutes.

MARINE APPLICATIONS OF HYDROGEN

- H2 /O2 fuel cells.(Particularly low temperature fuel cells) have characteristics which make them ideal for powering submarines :
  - *They do not produce any emissions or waste products except water, an can therefore maintain zero buoyancy*
  - *They operate quietly since there are no moving parts- thus reducing sonar signature.*
  - *They reject heat at low temperature – thus generating very low thermal signature*
- Fuel cell power plants are also used for surface ships and boats, both as main propulsion engines and as auxiliary generators.

'Shore-to-Store' Advances Zero-Emissions Transit Across Supply chain (June 2021)

PORT OF LOS ANGELES ROLLS OUT HYDROGEN FUEL CELL ELECTRIC FREIGHT DEMONSTRATION

Shore-to-store project in Los Angeles port

The Port of Los Angeles and its partners are launching a new era of pollution-free goods movement with the debut of five new hydrogen-powered fuel cell electric vehicles (FCEV) and the grand opening of two hydrogen fueling stations.

Under the $82.5 million Shore-to-Store (S2S) project, more than a dozen public and private sector partners have teamed up for a 12-month demonstration of the zero-emissions Class 8 trucks

Toyota -shell Hydrogen Truck in LA airport

Golden Gate :Water-go-round
passenger capacity of 84 :Hydrogen Tank capacity for two full days operation

- The **Golden Gate** is a strait on the west coast of North America that connects San Francisco Bay to the Pacific Ocean.

Hydrogen Powered Yacht

- The first PEM fuel-cell system for the propulsion of a yacht was developed by MTU Friedrichshafen GmbH in 2003.

- Four 1.2-kW PEM fuel-cell modules manufactured by Ballard Power Systems, it was installed in a 12-m-long yacht. The fuel-cell system, employing nine lead-gel batteries, generates a total power output of up to 20 kW

- The fuel-cell powered yacht has a maximum cruising range of 225 km at a speed of 8 knots (~14.8 km/h) with 6 kg of hydrogen stored in three high-pressure hydrogen tanks.

Hydrogen Powered Boats

- In 2007, the hydrogen material group at the University of Birmingham replaced the diesel engine installed in a canal boat with a PEM fuel-cell battery hybrid propulsion system.
- A 5-kW PEM fuel-cell system together with a lead-acid battery powers a DC electric motor to propel the boat in inland waterways using the hydrogen stored in a TieVeMneFe metal-hydride storage system.
- In 2012, Istanbul Technical University in Turkey launched a small fuel-cell boat powered by an 8- kW fuel-cell module that was supplied by Canadian-based Hydrogenics. The fuel-cell-powered boat can operate for 10 h on 5 kg of hydrogen with a maximum speed of 7 knots (~13 km/h).

Hydrogen Powered Boats

- Zemship (Zero Emission Ship) project, a fuel-cell ship FCS Alsterwasser was developed and deployed in the inland waterways of Hamburg in 2008.
- The ship was designed to transport up to 100 passengers at a speed of 14 km/h without producing any harmful pollutants. A PEM fuel-cell system is used as a power source to charge lead acid batteries or directly deliver electric power to a propulsion motor .

Hydrogen Powered Train

- European train builder Alstom presented its first zero-emission train in 2016.
- The zero-emissions Coradia iLint regional train replaces the diesel power plant with hydrogen PEM fuel cells, while offering the same level of performance.
- It has a maximum speed of 140 km/h (87 mph) with similar acceleration and braking performance, and a comparable passenger capacity

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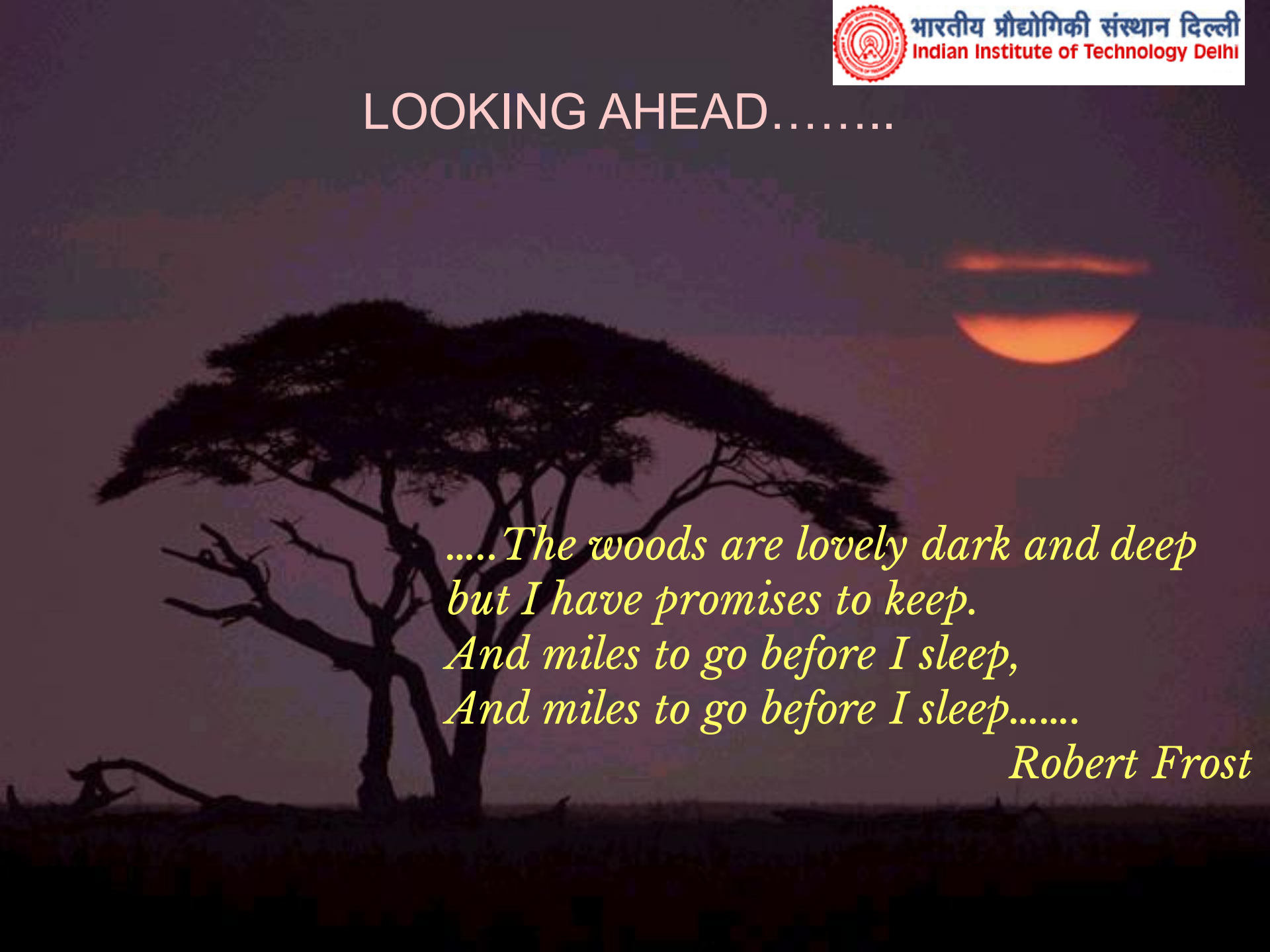
Indian Institute of Technology Delhi

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