US Department of Transportation and US Department of Energy
Workshop on
Compressed Natural Gas and Hydrogen Fuels:
Lessons Learned for the Safe Deployment of Vehicles

Overview of Indian Hydrogen Programme &

Key Safety Issues on Hydrogen Fuel

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Overview of Indian Hydrogen Programme & Key Safety Issues on Hydrogen Fuel

- National Hydrogen Energy Road Map
  - **Initiatives**
  - **Target 2020 : GIFT**
  - **Programme in India**
  - **CNG – H_2 Programme**
  - **Partnership**
  - **Technology Development**
  - **Concerns & Challenges**
- Key Safety Issues
  - CNG Lessons
  - Material compatibility
  - Dispensing Stations
  - Vehicular applications
    - IC Engines
    - Fuel Cells
    - Crash Test
  - Post incident procedures
- Ideas for cooperation

Proposed Time Frame for Alternative Fuel Strategy

Time Frame	Alt Fuel Tech
Short term	*Ethanol, CNG, LPG*
Medium term	*Bio-Diesel, Hybrid, Electric*
Long term	*Hydrogen ICE / Fuel Cell*

National Hydrogen Energy Road Map in India (NHERM)

- Based on Public-Private Partnership
- Roadmap is an Industry driven Planning Process
- Support by Government and other stakeholders viz. Research Organizations, Academia, NGOs
- Development of sustainable and cost effective hydrogen energy technologies & infrastructure
- Issues relating to Production, Storage, Delivery / Transport, Applications, Safety and Awareness, capacity building being addressed

National Hydrogen Energy Road Map (Contd…)

- Provides long term solution to meet growing energy needs of India while ensuring energy security
- Identifies paths for gradual introduction of hydrogen energy in the country
- Accelerate commercialization efforts
- Facilitate creation of hydrogen energy infrastructure
- Total systems approach for developing hydrogen energy technologies

Indian NHERM: Two Major Initiatives

- 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

- Green Initiative for Power Generation (GIP)
  - Set up 1,000 MW Hydrogen Based Power Generation Capacity
    - 50 MW small IC engine stand alone generators
    - 50 MW stand alone fuel cell power packs
    - 400 MW Gas Turbine Based Power Plants
    - 500 MW Central Fuel Cell Power Plants

- Targets up to 2020

Programs in India

- Prototypes
  - IC Engine based devices
  - Hydrogen fuelled motorcycles, three wheeler & Small Cars
- Ongoing Projects
  - Hydrogen fueling station by Indian Oil Corporation
  - SIAM Demonstration Project on Hydrogen-CNG vehicles in partnership with five auto majors
  - Near Future - Dedicated Hydrogen IC Engine Projects

Designation of Hydrogen and Hydrogen blends as automotive fuel

The CNG-H_2 Programme

- Three Light Commercial Vehicles
- One car,
- One utility vehicle
- Two three wheelers

Use up to 20% blend in existing CNG engines
Optimize engines for power & NO_x
Retrofit in existing fleet

Goal : Introduce Hydrogen in the fleet, Environment impact, & Energy Security

Technology Development

Suggested Mission Mode Projects

- Clean Coal Gasification Technologies for Hydrogen Production
- Hydrogen Production through Biological Routes / Nuclear/Thermo-chemical routes
- **Hydrogen Storage in Hydrides / Carbon Nanostructures**
- **Development of IC Engine for Hydrogen fuel**
- **Development of PEM and SOFC Fuel Cell Technologies**

Concerns & Challenges

- Higher cost of hydrogen
- Need to improve production rates from different methods.
- Development of compact & inexpensive storage capacity
- Development of high pressure cylinders (~700 bars)
- Capacity of hydrogen storage system to give a range of 150-500 km per charge
- Development of hydrogen fuelled IC engines with higher life and costs comparable to IC engines.
- Efficiency improvement for different types of Fuel Cell systems
- **Regulations and codes**
- **Vehicles leading regulation.**

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  - **Vehicular applications**
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CNG : Lessons - 1

- Education and Training
  - Manufacturers / Kit suppliers
  - Testing Authorities
  - Transport officials
  - Inspection & Maintenance officials
  - Fueling Station
  - Mechanics
  - Fleet operators
  - Converters
  - Users
  - Drivers
  - Police & Fire Department
  - Policy makers ……..

CNG : Lessons - 2

- Dispensing Stations
- Filling procedure
- Nozzle and Receptacle
- Conversion kits & type approval
- Safety audits
- Inspection and maintenance
  - High Temperatures / Exhaust Temperatures
  - Wiring Harness
  - Sparking
  - Valves and components
  - Catalytic converters
- Accident investigation
- No CNG Two wheeler yet !

Hydrogen Safety, Codes and Standards

New Codes and Standards Need to be Developed or by adopting world-wide standards in the areas of:

- natural gas fuel processors/electrolysers and renewable energy based on-site generation
- compressed cylinders/metal hydride canisters
- liquid hydrogen/gaseous hydrogen tanks or pipelines
- Hydrogen energy devices/systems including fuel cells/internal combustion engines & turbines
- Setting up of Hydrogen Dispensing Stations within the premises of normal fuel station. ……

Safety for Infrastructure

Critical Work Areas

Maintenance:

Leak Detection Systems, Emergency Response Plan For Hydrogen Leaks, Fire Detection Systems

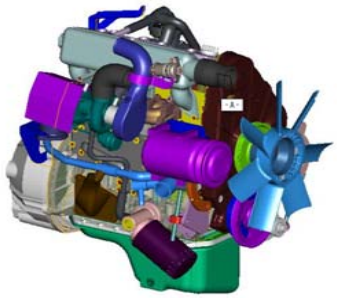
Fueling Facility:

Electrical Design, Mechanical Design, Clearances, Safety Provisions, Materials, Security, Maintenance, Liquid Hydrogen Fueling Facilities

Emergency Response Plan For Hydrogen Fires

- Electrical Classification For Hazardous
- Locations
- Positive Ventilation
- Emergency Stop Equipment
- Designated Parking and Storage

Public Perception : Education

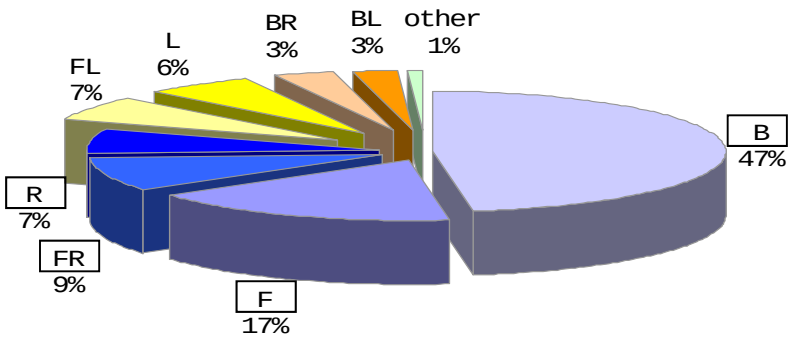


Safety Issues for Hydrogen IC Engines

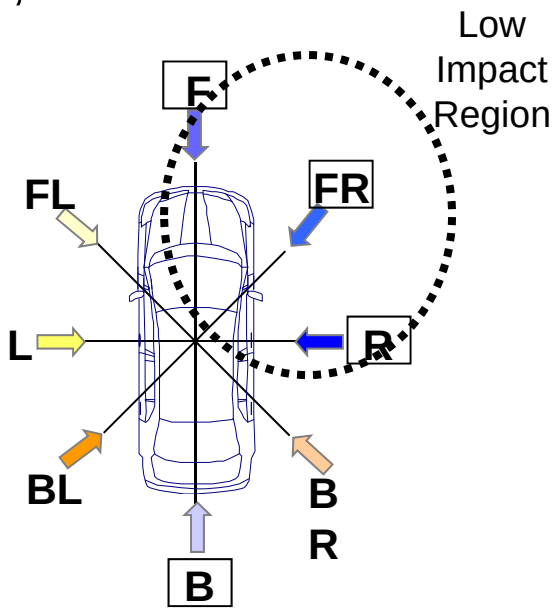
Item	Critical Technologies
Storage	High pressure(up to 700 bar) tank technology (Metal or metal composite) Hydrogen storage efficiency(wt%) in metal-hydrides Controlled heat exchanging in metal-hydride storage Substitution of critical rare earth materials
SI IC Engines	Engine refinement with e.g. high compression ratio, reliable engine cranking EMS optimization Development of suitable engine and fuel line components
Vehicle	High pressure fuelling system(Compressed hydrogen) Safety(fuel handling and crash worthiness) Ventilation in crank case area Valve material Leak detection

Crash Test Conditions

- Crash test conditions (speeds, impact points, impact directions)
- Statistically most likely to be encountered in crashes being studied
- To avoid the risk of hydrogen leakage essential to include both
  - Performance requirement standards - Crash test procedures
  - Installation requirements standards - main shut off valve, container check valve, pressure relief device, etc.
- Eg.: Japanese Study



Two / Three Wheeler ?



Post Incident Procedures 5 –R's

- Response
- Rescue
  - Vehicle Access
  - Securing the vehicle (Safety)
- Removal
- Repair
- Reintroduction in the fleet. Recertification?

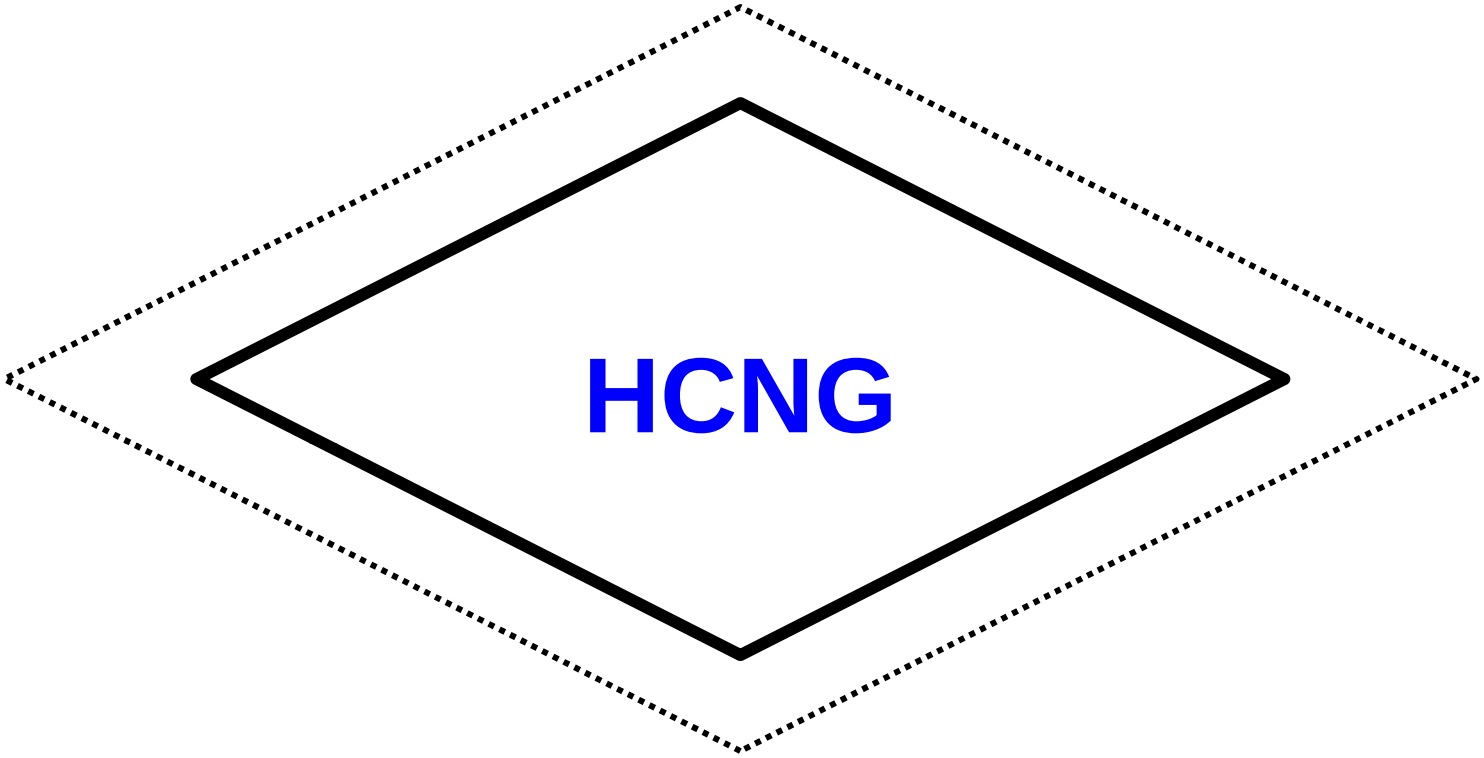
Codes, Manuals, Education, Training

Material Compatibility

- Accelerated exposure tests
- Material specifications
- Mandatory marking of key components
- Regular inspection and certification
- Two mixtures proposed to be tested
  - 20%
  - 30%

Challenge to regulate after market

Label for HCNG fueled vehicles



Label shall be coloured '**white'** and sized 80 mm x 80 mm square. Label shall have on them the text "**HCNG**" in a central position not less than 20 mm high, coloured '**Blue**'. The label shall have a '**Black** ' border 1 mm wide and 5 mm inside the outer edge and running parallel to it. The 80 mm dimension is measured from the outer edge.

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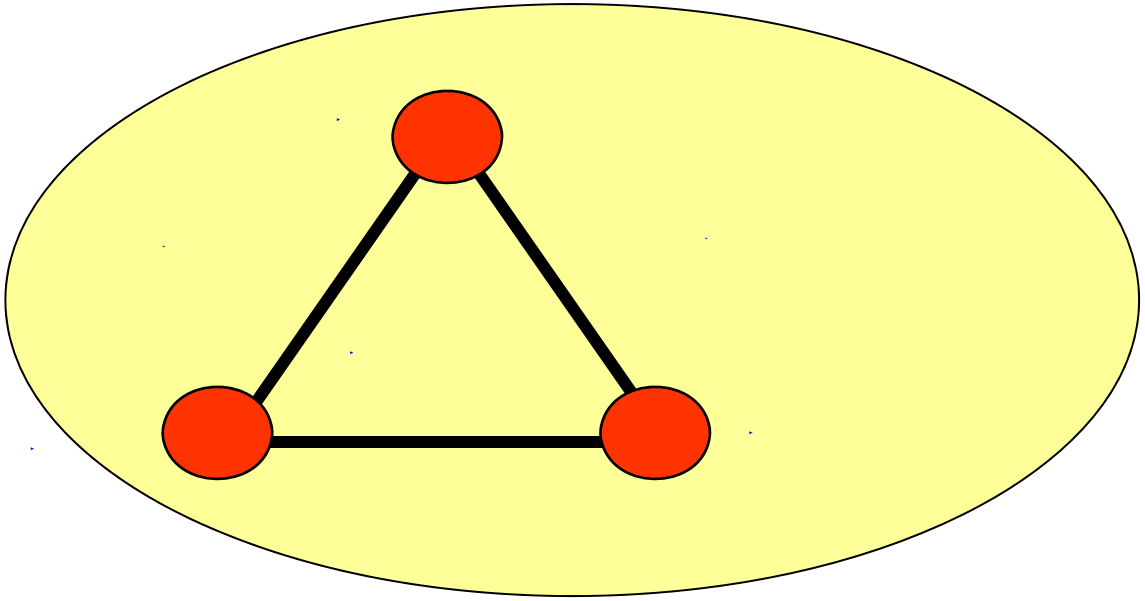
Partnerships are the Enablers

- Vehicle & other equipment manufacturers
- End consumers
- Hydrogen producers
- Hydrogen infrastructure: logistics and retail sites
- Scientific & research organisations
- Government
  - Commitment
  - Targets
  - Incentives
- **International cooperation**



International Cooperation: Ideas -1

- Collate and Communicate :
  - Issues and Concerns
  - Best Practices
  - Standard formulation efforts & results
  - Progress in Code development
  - Training & Education: Material & methodology
  - Public out reach programmes
  - Fueling & fleet operations

International Cooperation: Ideas -2

- Cooperate and Collaborate
  - Standard making , ISO, WP 29, Harmonization
  - Code and best practices
  - Development of Testing methodology & centers
  - Accident investigation & analysis
  - In use vehicle monitoring
  - R & D
    - High temperature behaviour
    - Two & Three wheelers
  - Pilot programmes
  - Training & Development

International Cooperation: Ideas -3

- Continue Dialogue
  - Evolution of Standards, codes & practices
  - End of life regulation
  - Enforcement
  - Education & Training
  - 5th EFV Confernce US is host

Thank you for your attention
For further details please write to:
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Key Safety Issues

- Production Challenges
- Setting up of Testing Facilities
- Need to develop and notify appropriate Codes & Standards for H-CNG & H_2
  - Onsite Hydrogen Production
  - Transportation from source of Production to Dispensing Outlets
  - Fueling Stations : Multi fuel
  - Vehicles
  - Retrofit, aftermarket material compatibility
  - Inspection & Certification
  - In Service Compliance
- Education & Training of personnel

Hydrogen Transportation & Delivery

OVERVIEW

Most common method: pressurized tanks (150-400 bar) by road or rail

Compact forms of hydrogen storage are easier to transport

Transporting liquid hydrogen is more efficient in the case of large quantities

OPTIONS

- Road
- Rail
- Air
- Sea
- Pipelines

Hydrogen Storage

- Compressed Hydrogen
- Solid State Storage
  - Intermetallic hydrides/complex hydrides
  - Carbon nanotubes & nanofibres
  - Metal Organic Complexes & more
- Storage in Chemicals
  - Ammonia
  - Methanol
- Bulk storage

Fuel Cells

- Phosphoric Acid Fuel Cell (PAFC)
- Proton Exchange Membrane (PEMFC)
- Solid Oxide Fuel Cell (SOFC)
- Direct Methanol (DMFC)
- Molten Carbonate Fuel Cell (MCFC)
- Alkaline Fuel Cell (AFC)

Challenges for Fuel Cell Applications

- Proper conversion of chemical energy (hydrogen) to electrical energy
- Integration of Fuel tank, fuel processor, fuel cell stack, power converter into a vehicle
- Need for pure hydrogen
- Development of FCs for auxiliary power unit to support heating, A/C, lighting etc in existing system could enable applications in bigger vehicles in short term

Hydrogen Industry in India

- Indian industry is producing hydrogen commercially for use in:
  - Oil refineries, fertilizer plants, and chemical industry
  - Chlor-alkali industry produces hydrogen as a by-product
- Over 3 MMT per annum of hydrogen is currently produced in petroleum refineries and fertilizer plants
- Hydrogen Storage in pressurized cylinders is the most common method of commercial supply

Pressure Relief Device in Common

- In the case of multiple containers linked together,
- To avoid risks, the installation requirement “main shut off valve, PRD and container non-return valve shall be mounted directly on each container”
- Other Performance Test
  - Hydraulic test with extreme temperature
    - to validate the safety at end of life
  - Target vehicle lifetime range
    - 360,000mile ~ 15 years