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ARAI
Progress through Research

TECHNOLOGY PERSPECTIVES TO MEET EURO 7 / BS VII FROM H2 IC ENGINES

Sustainable Mobility is the need of the hour

1

Energy Security

In FY22, **$120 Bn** oil imports which accounts for **>85%** import dependency

2

Global Commitment

Reduction of **45%** carbon intensity & **1 bn** tonne of CO_2 by 2030

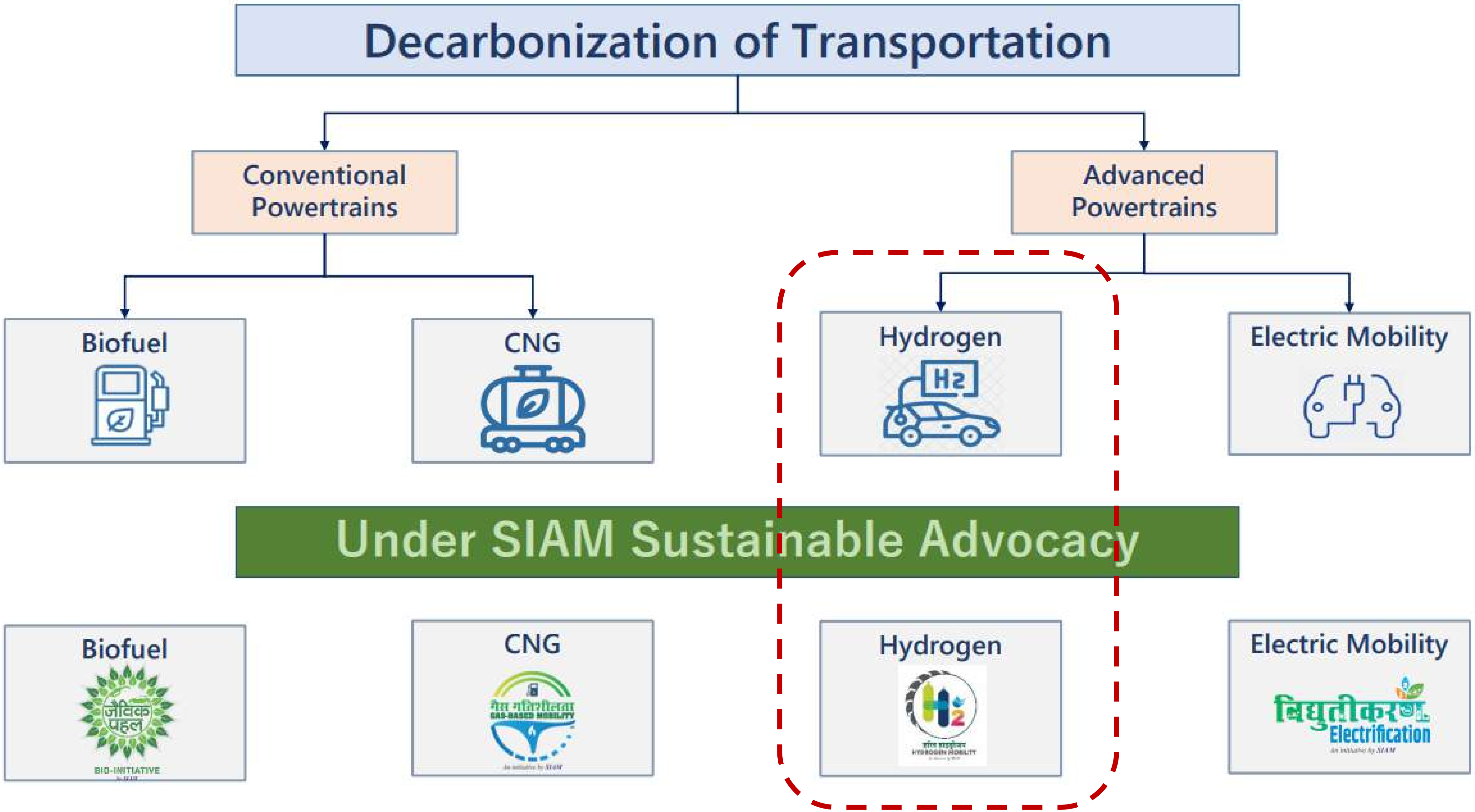
3

Pollution Mitigation

22/30 most polluted cities in the world are in India

Indian Automotive Industry is aligned with the Government of India's vision & priorities towards sustainability

Decarbonization in Transportation

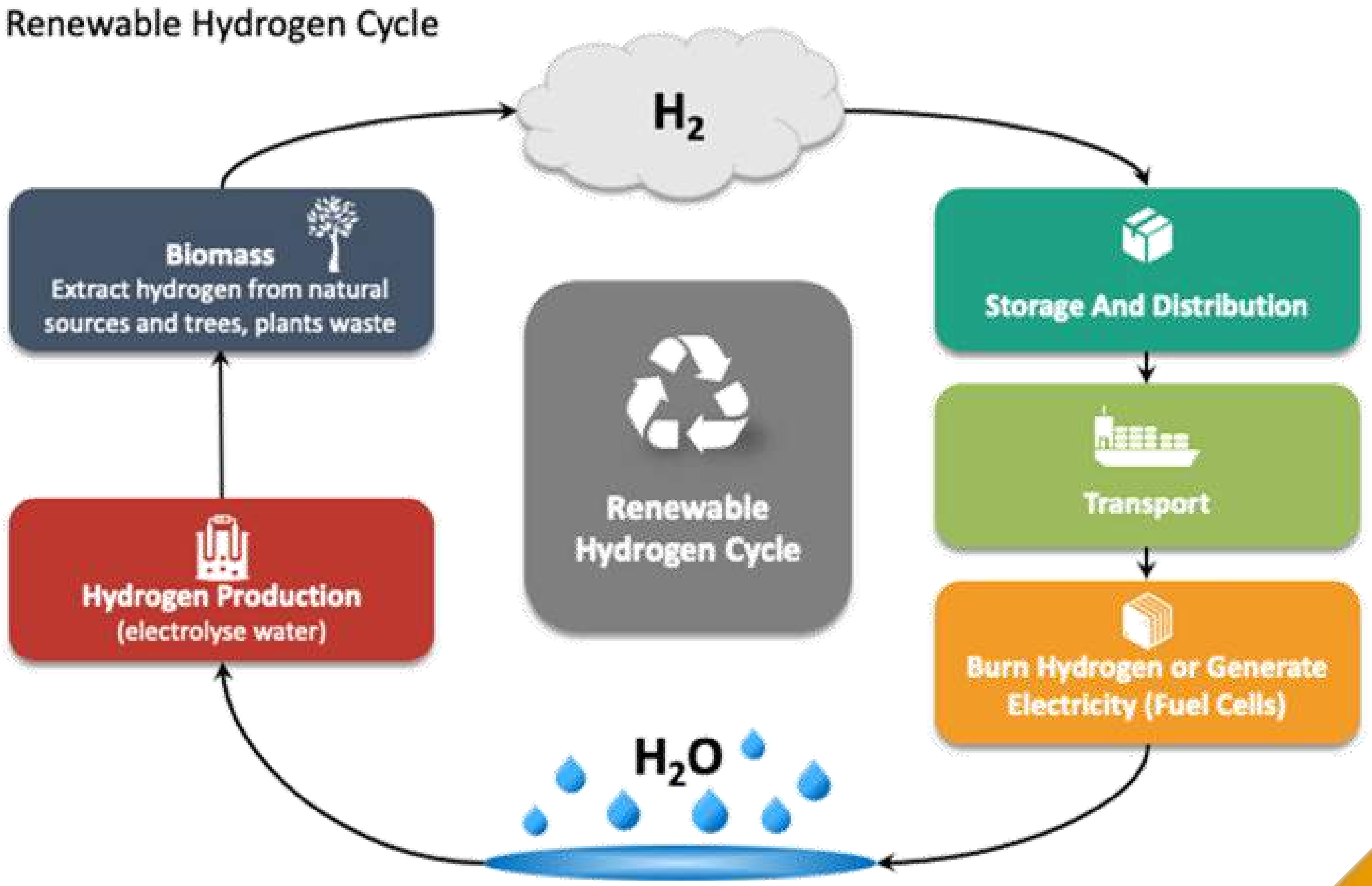


HYDROGEN FUEL

Energy Carrier

Zero Carbon

Highly Efficient



Types of Hydrogen

Color	GREY HYDROGEN	BLUE HYDROGEN	TURQUOISE HYDROGEN*	GREEN HYDROGEN
Process	SMR or gasification	SMR or gasification with carbon capture (85-95%)	Pyrolysis	Electrolysis
Source	Methane or coal	Methane or coal	Methane	Renewable electricity

***Note*: SMR = steam methane reforming.**

*** Turquoise hydrogen is an emerging decarbonization option**

Fuel Cell Vehicles vs. H2 Internal Combustion Engine Vehicles

Fuel Cell Vehicles

Fuel cell vehicles utilize a fuel cell stack to convert hydrogen gas into electricity, which powers the electric motor. They offer high efficiency and zero tailpipe emissions.

H2 Internal Combustion Engine Vehicles

H2ICE vehicles employ a modified internal combustion engine that burns hydrogen gas as fuel, generating power through combustion. These vehicles are relatively simpler in design and leverage existing infrastructure.

Hydrogen Program in India

GOVERNMENT OF INDIA
MINISTRY OF NEW AND RENEWABLE ENERGY

Nodal Ministry for the implementation of Hydrogen Energy and fuel in India

2004 — National Hydrogen Energy Board

Set up a Steering Group under Mr. Ratan Tata, Member of the Board and Chairman of Tata Sons, to prepare a National Hydrogen Energy Road Map with a target of one million vehicles based on hydrogen energy by 2020

2013 — MNRE

A high-level steering committee was constituted under the chairmanship of Dr K. Kasturirangan, ex-Chairman, ISRO, on Hydrogen and Fuel cells by MNRE which identified 07 mission mode projects for India

2021 — MNRE

Established another committee with 3 sub-groups for dealing with Hydrogen regulations and Standards.

2022 — National Green H_2 mission

NGHM was launched by Hon'ble PM Shri Narendra Modi on on 4 January 2022

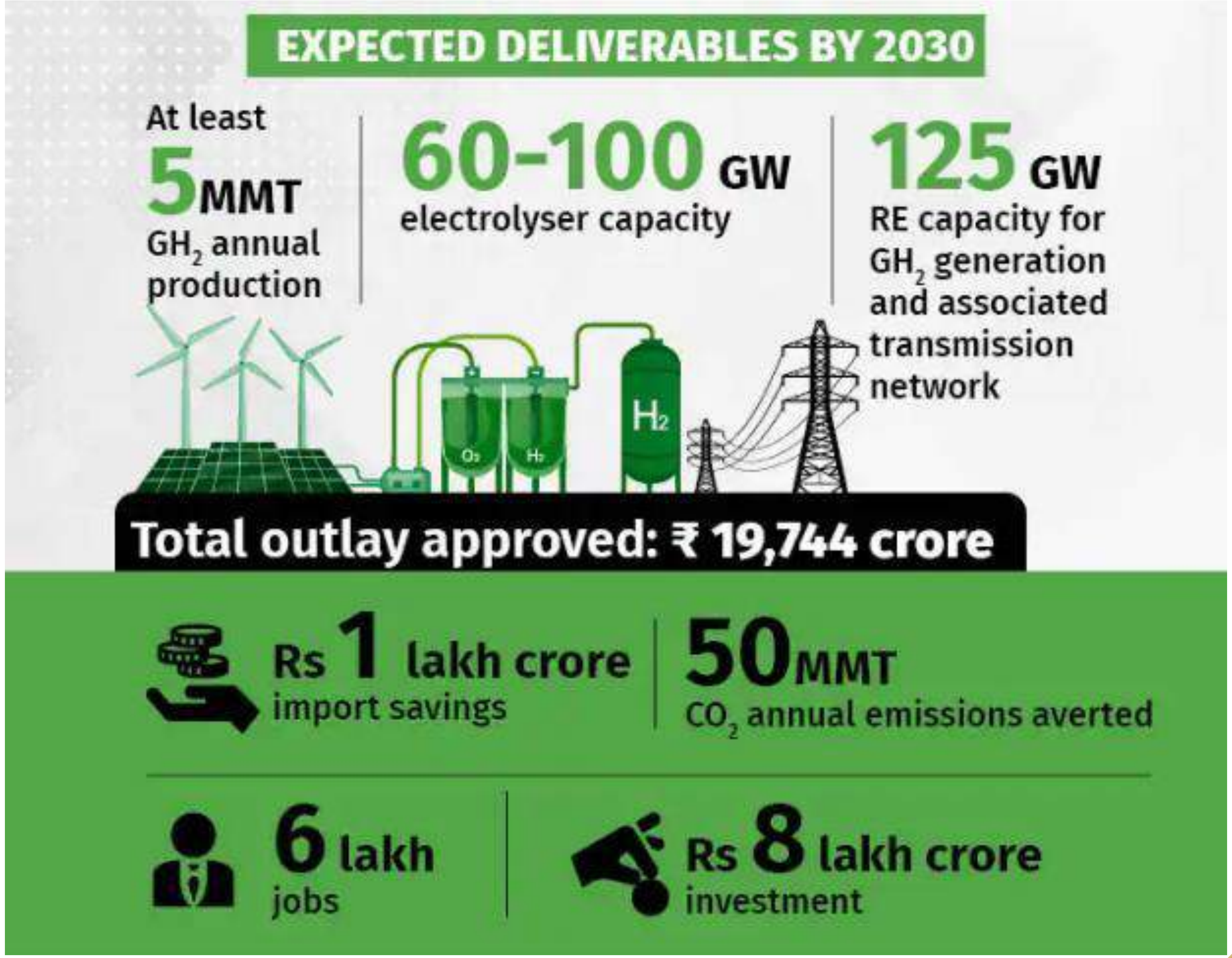
National Green Hydrogen Mission

Objective:

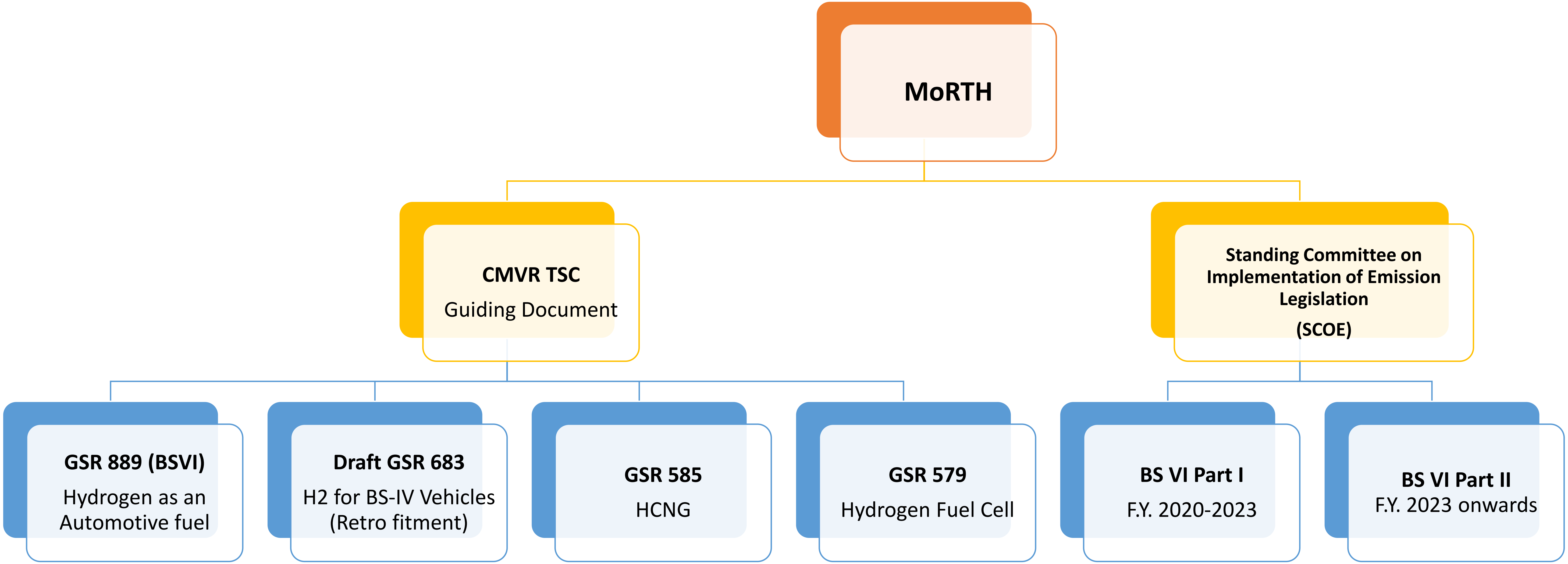
- Decarbonize energy/industrial/mobility sector
- Develop indigenous manufacturing capacities
- Create export opportunities for GH_2 & its derivative

Components of NGHM:

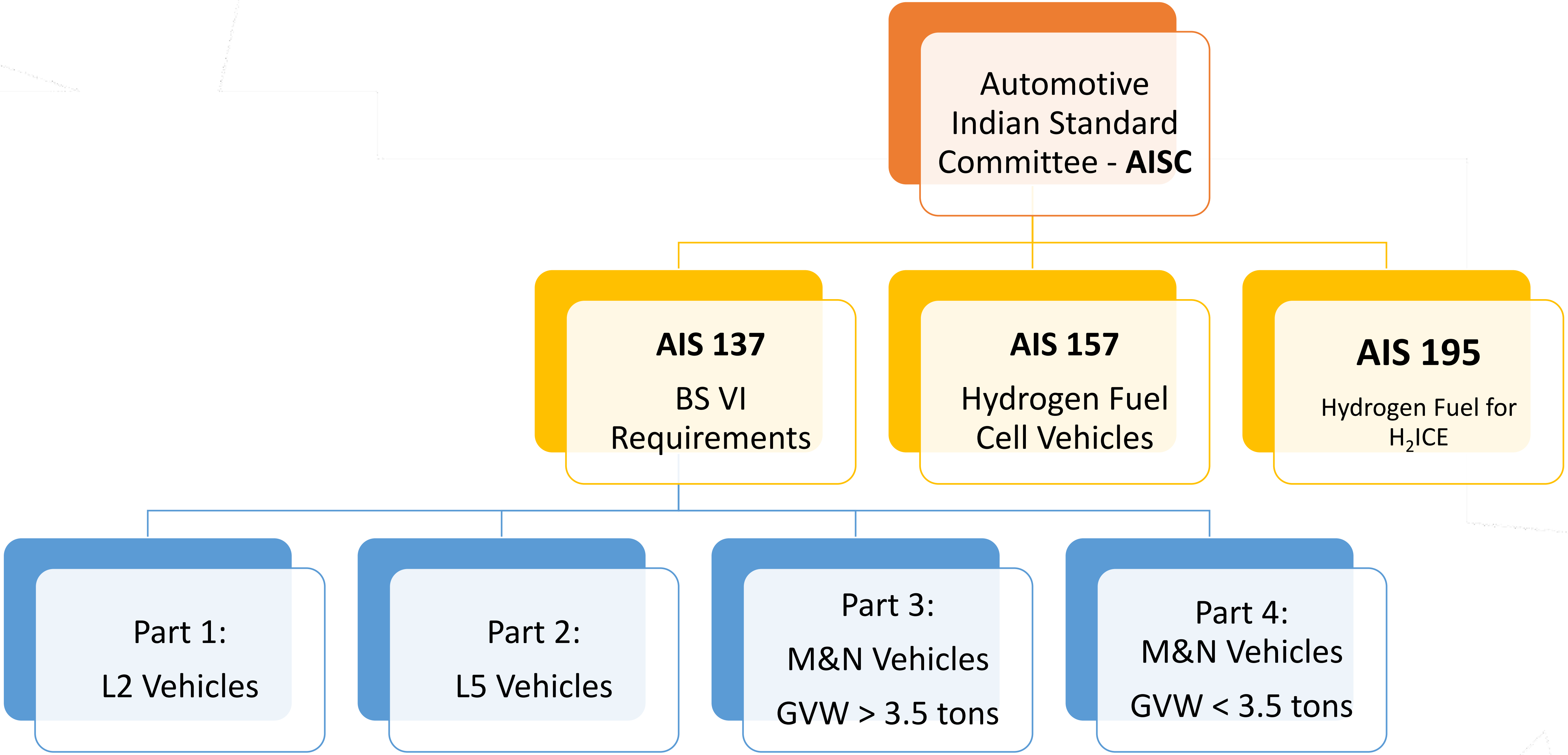
- Strategic Interventions for Green Hydrogen Transition Programme (SIGHT)
- Strategic Hydrogen Innovation Partnership (SHIP) (PPP for R&D)



Automotive Regulations for Hydrogen Fuel



Indian Regulations for Hydrogen Applications



What’s new in Euro-7 regulations?

- limits for emissions from brakes
- Rules for microplastic emissions from tyres
- longer durability
- more effective emission tests
- better market surveillance tests
- fuel and technology-neutral emission limits
- regulating additional pollutants
- On-road tests with broader range of driving conditions

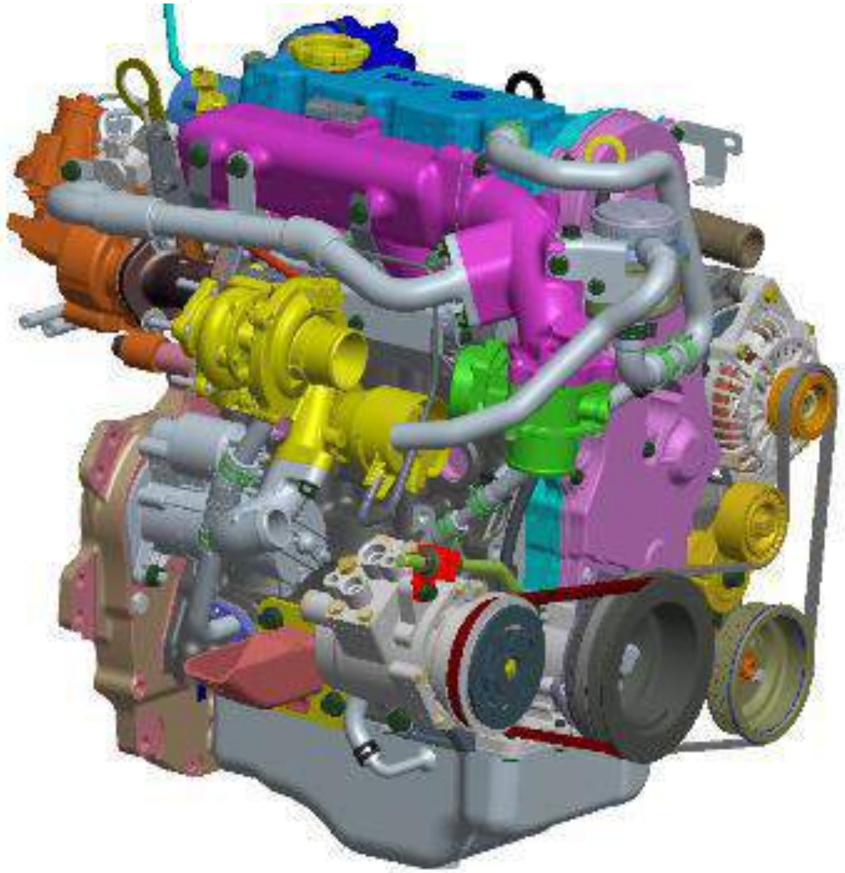
Changes from Euro 6 to Euro 7- Light duty

Parameter	Euro -6	Euro-7
Limits	Different for different technology/fuel/ category	Technology and fuel neutral limits for all category
Pollutants	Criteria pollutants	Lowest limits of Euro-6 for Criteria+ additionally NH3. THC and NMHC separate
Useful life	160000km/5 years	200000km/10 years
Boundary conditions	Standard	Much wider boundary conditions of temp/altitude, etc
Diagnostics	OBD	OBD+OBM+OBFCM
EVAP	Hot soak + diurnal	Hot soak+ diurnal +refuelling loss
Non-exhaust	Not applicable	Brake (PM and PN) and tyre emissions

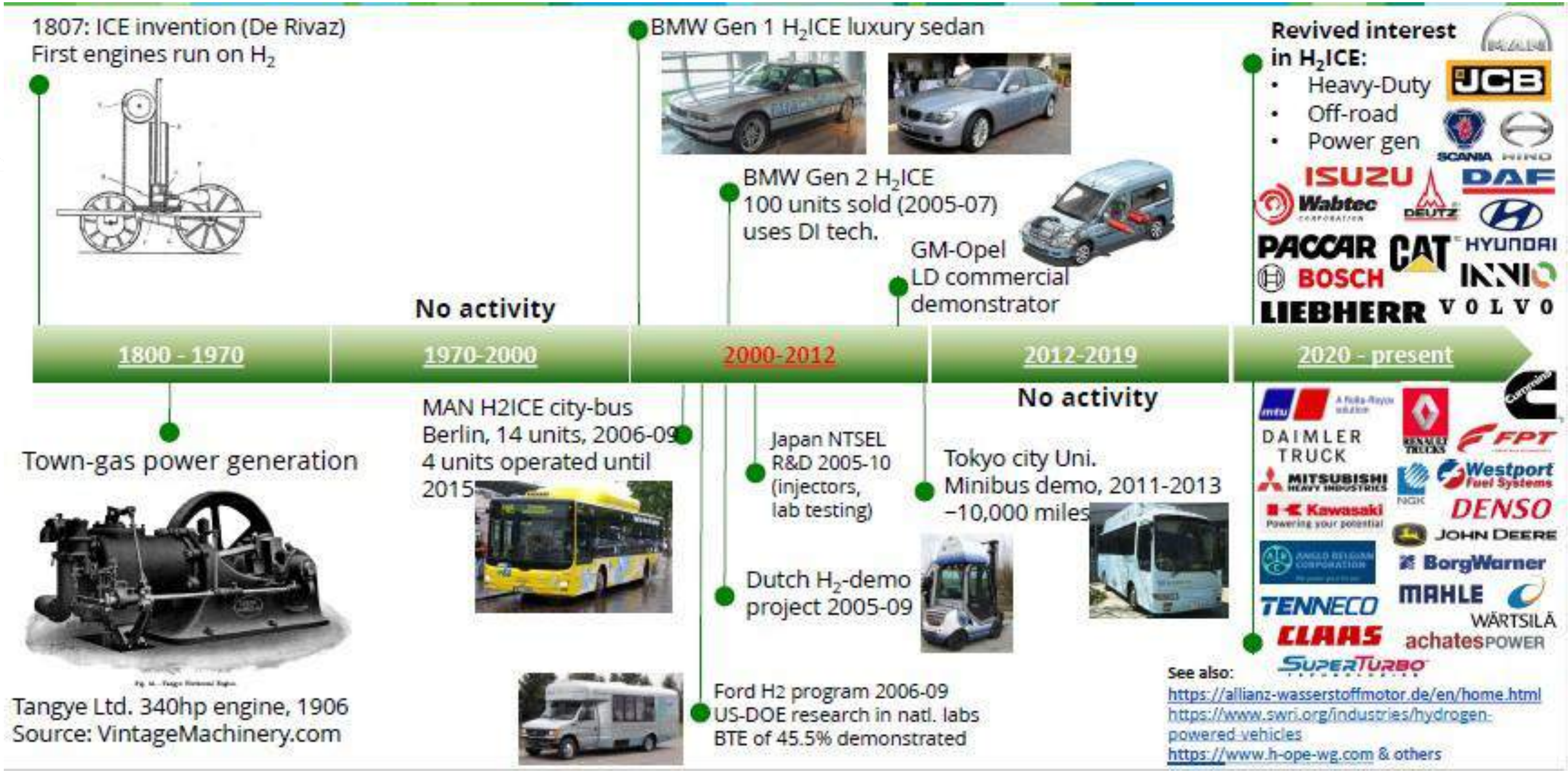
Changes from Euro 6 to Euro 7- Heavy duty

Parameter	Euro -6	Euro-7
Limits	Different for different technology/fuel/ category	Technology and fuel neutral limits for all category
Pollutants	Criteria pollutants	Lower numerical limits than Euro-6 for Criteria+ additionally NMOG, CH_4, N_2O, HCHO
Useful life	700000km/7 years	875000/15 years (N3/M3)
Boundary conditions	Standard	Much wider boundry conditions of temp/altitude, etc
Diagnostics/ FC	OBD	OBD+OBM+VECTO
Non-exhaust	Not applicable	Brake (PM and PN) and tyre emissions

Hydrogen Engine - Development



Historic Timelines for H2ICE



Favorable Factors for H2ICE

DRIVERS for H2ICE

LEGISLATION
- ICE bans
- Tank-to-wheel legislation
- Difficult-to-abate sectors

RAPID DECARBONIZATION
- No carbon in the fuel
- Green, pink H2 potential
- Low-carbon CCS H2 pathways

MATERIALS & INFRASTRUCTURE
- ICE: no limitations
- FCEV: Platinum
- Battery: Lithium/Cobalt
- Electrical grid limits
- Mining ramp-up

JOB SECURITY
- High added value jobs
- Domestic labor instead of imported materials

GEOPOLITICAL SECURITY
- No reliance on imported minerals
- Lower reliance on oil

TCO / UPFRONT COST
- Low upfront cost
- TCO
- Resale value

SUPPLY CHAIN
- Domestic supply chain
- No shortages foreseen

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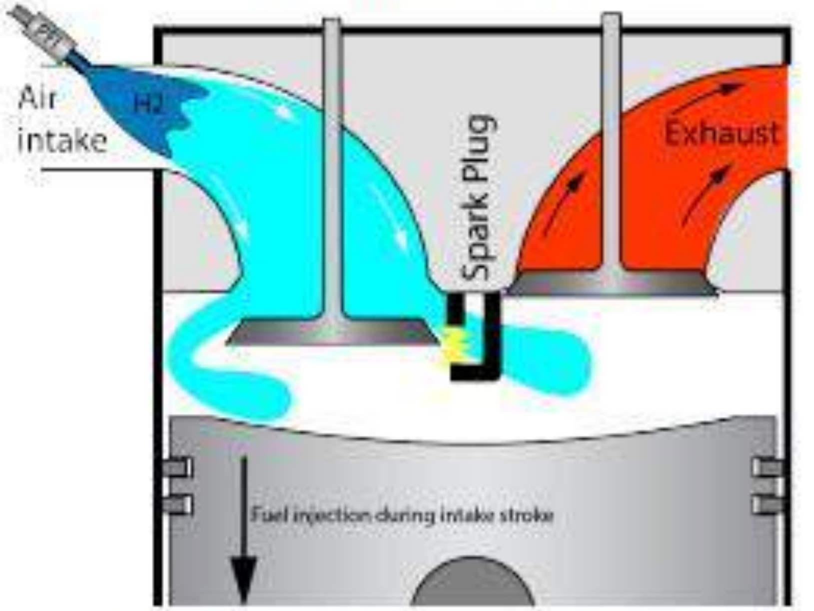
Fuel Injection Approaches for H2ICE for BS-VII

Port-injection spark-ignition
3-10 bar injection pressure

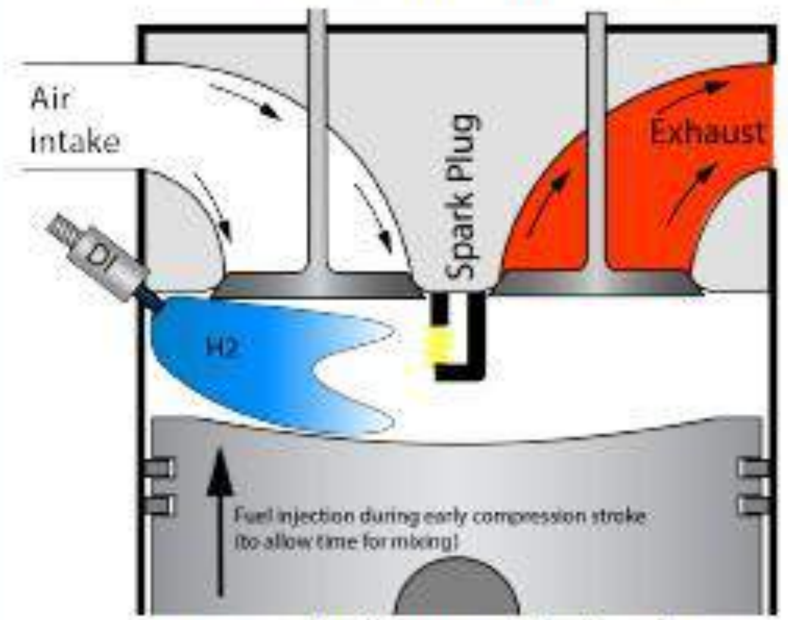


Key challenges: power density, abnormal combustion, efficiency

"Generation 1" H2ICE technology
~2025 market introduction, retrofits

- \+ Simplest system – minimal engine modification, low-cost fuel system
- \+ Typically low NOx emission
- \+ Simple to integrate with advanced ignition systems
- – Loss of power density
- – Efficiency
- – Risks of back-fire into intake manifold, highly-prone to pre-ignition
- – Poor transient response
- – Extreme turbocharging requirements

Direct-injection spark-ignition
10-50 bar injection pressure

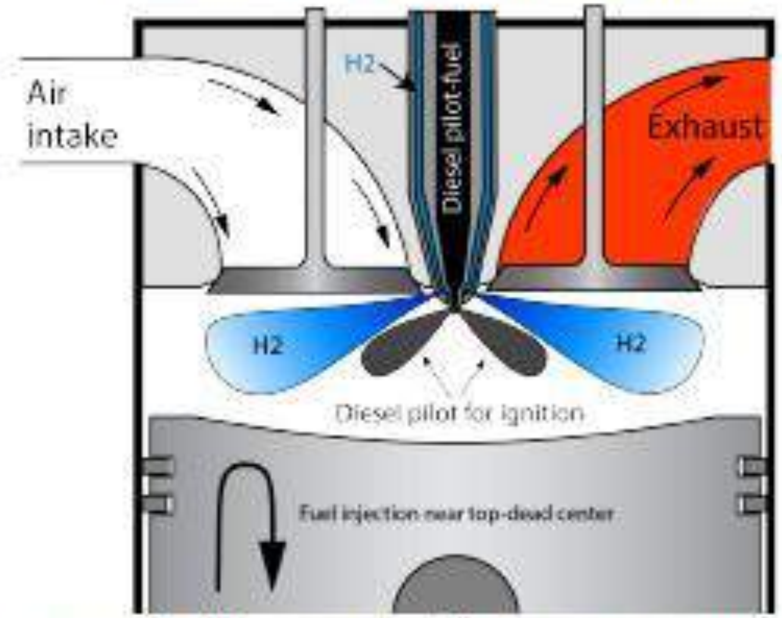


Key challenges: injection technology, abnormal combustion

"Generation 2" H2ICE technology
~2025-2030 market introduction

- \+ High power density, improved efficiency, transient response
- \+ Moderate engine modification required
- \+ No back-fire risk, reduced pre-ignition
- – Somewhat higher NOx emission
- – Residual pressure in "empty" tank
- – Injection system with high durability required
- – Development effort for optimization

High-pressure (100-600bar) direct-inj.
Pilot-fuel or pre-chamber ignition

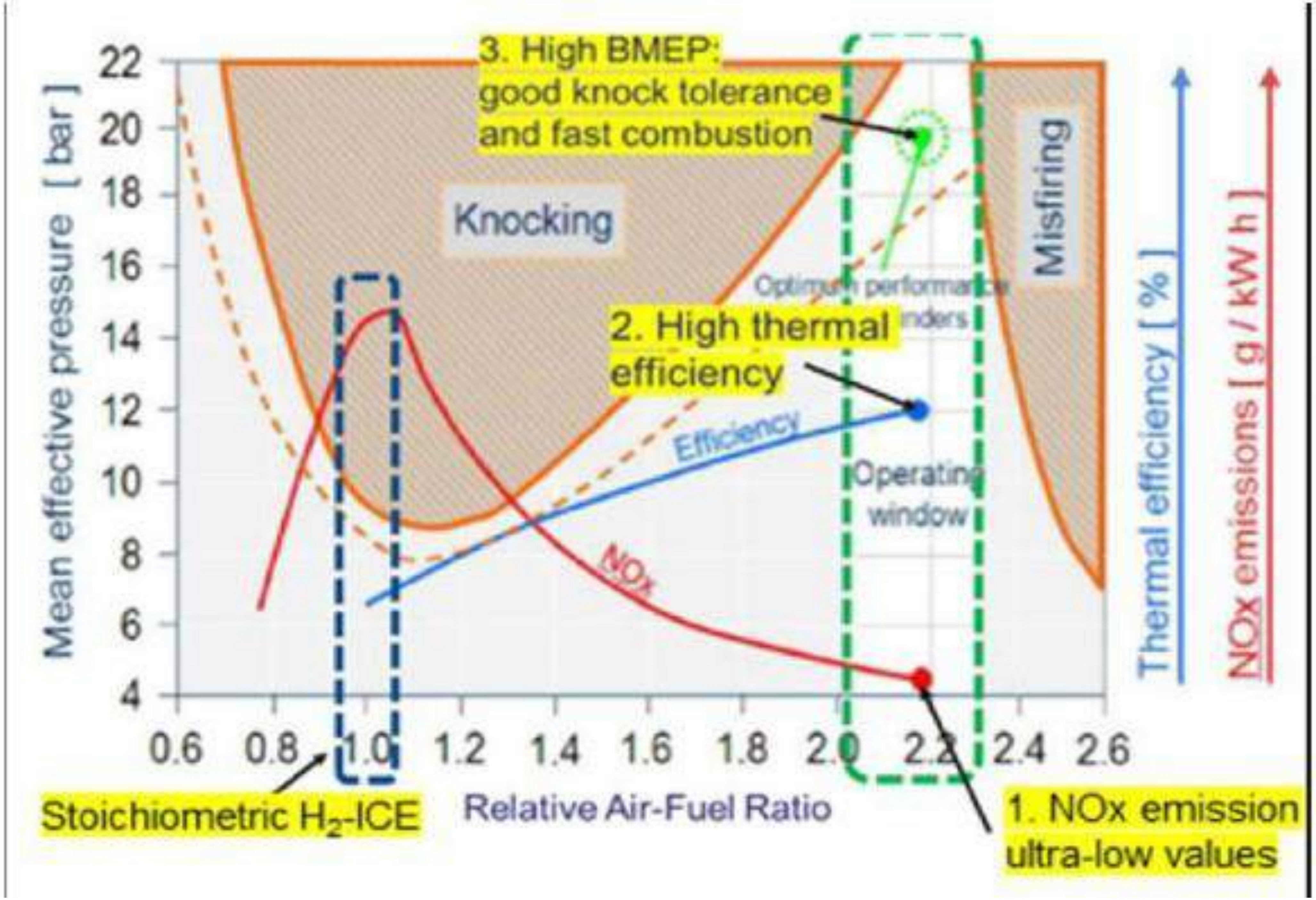


Key challenges: High-pressure pump, NOx, fuel compression energy

"Generation 2+" technology, best efficiency
Market readiness ~2025-2030

- \+ Best efficiency, power density, transient response
- \+ Reduced turbocharging req.,
- \+ Moderate engine modification required, reduced turbocharging
- \+ No back-fire risk, reduced pre-ignition
- – Somewhat higher NOx emission
- – Residual pressure in "empty" tank
- – Injection system with high durability required
- – Development effort for optimization

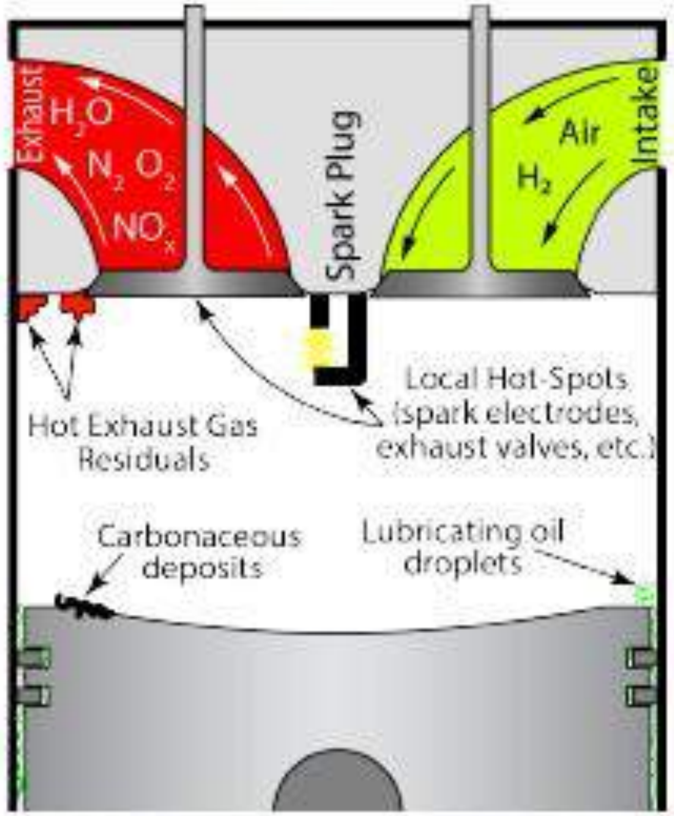
Lean Combustion for H2ICE



Hydrogen ICE Development Challenges for BS-VII

Current OEM perspective:
Urgent need to bring a H2ICE product on the market fast (PFI, modifying existing engines, efficiency is secondary)
Second generation H2ICE will be developed with focus on performance and emissions (DI, optimized configuration, etc.)

Understanding pre-ignition/knock mechanisms is key to successful mitigation
"Every engine is different"

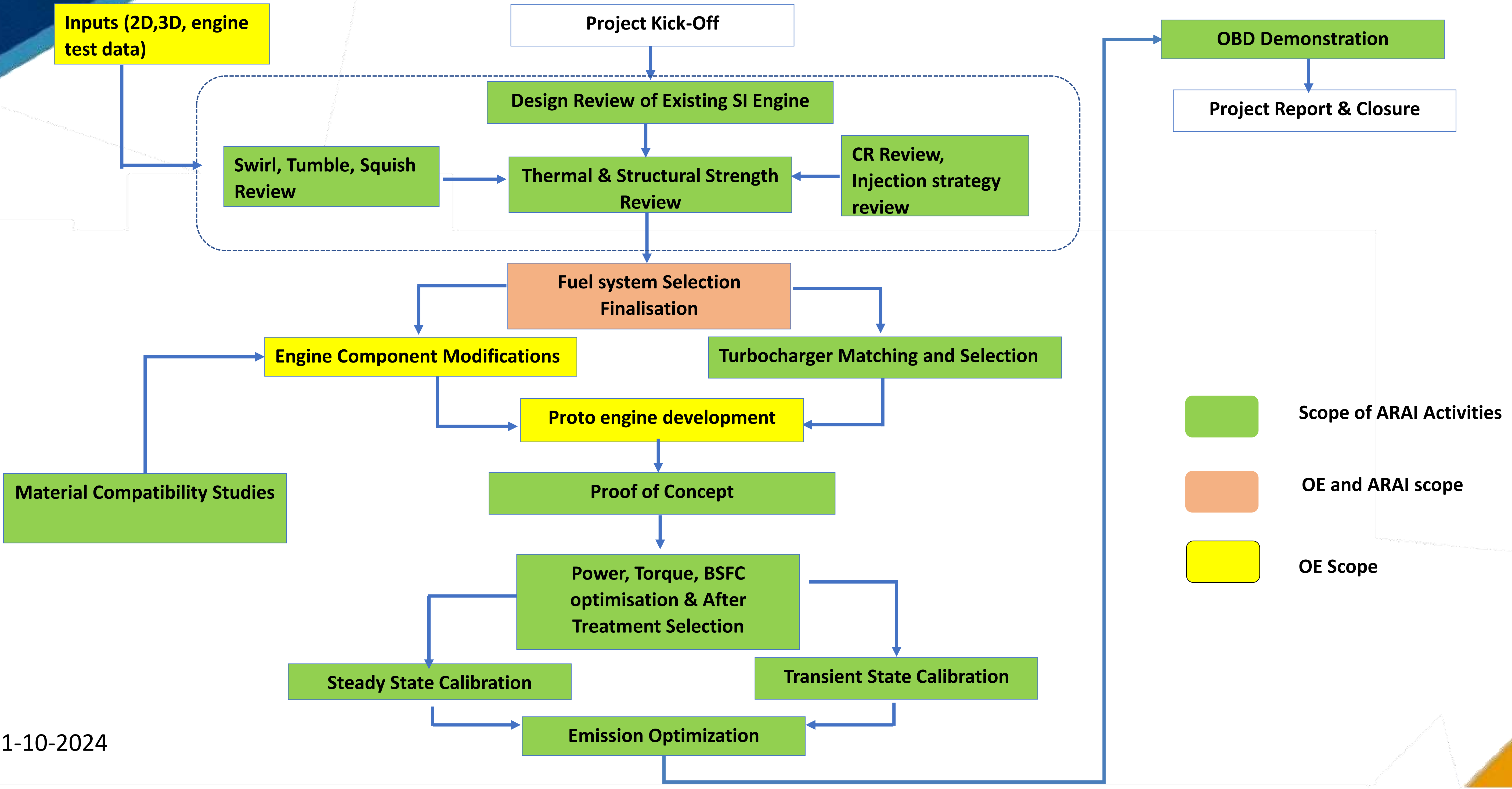


Challenges	Knowledge Gaps
Preignition & knock: mitigation and detection	Phenomenological understanding of key pre-ignition mechanisms
Injection and mixing: full optimization, NOx mitigation	In-cylinder mixing validation data Predictive CFD modelling Injector design guidelines
Flame/wall interactions Heat-loss, material thermal stress	H_2 near-wall quenching/reactions Accurate heat-loss models
Predictive simulations of H2ICE combustion process	Kinetics of H2/NG/renew. diesel fuel blends
Multi-fuel operation using single hardware configuration	Combustion strategies & controls
Reduced power density relative to diesel counterparts, efficiency	Strategies for increasing power density & efficiency
NOx emission in certain operating points	Alternative NO_x mitigation strategies (e.g. H_2O inj.)

Impact
Efficiency, range, emissions, cost, accelerated development

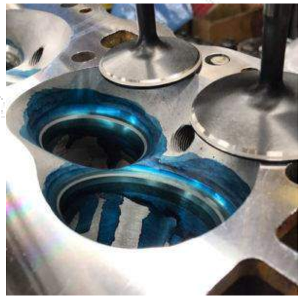
Improvements to existing products through component retrofit

Hydrogen ICE Development Approach for BS-VII



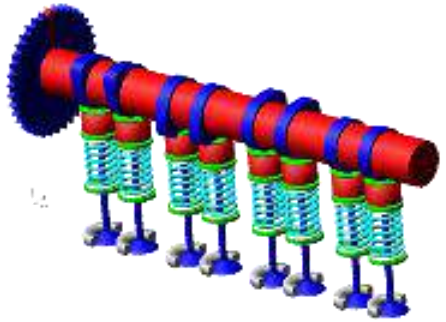
H_2 ICE Design Review

Catalytic Converter Review



Valve and Valve Seat Review

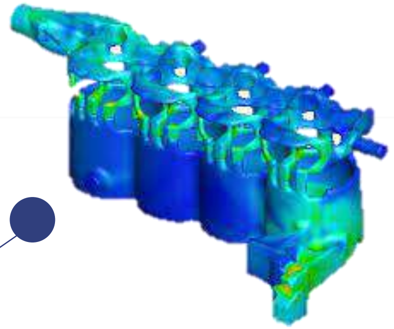
Piston Design Review



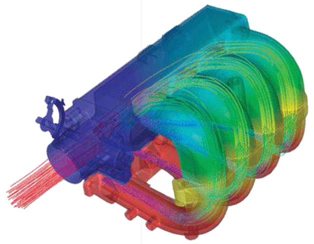
Valve Timing Analysis

Turbocharger Review

Cylinder Head Design Review

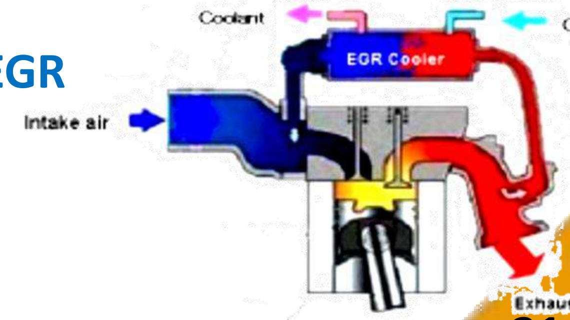


Cylinder Head Cooling and Water Pump Review



Intake Manifold Review

ECU Controlled Cooled EGR



H_2 ICE Design Changes to meet BS-VII norms

The following engine design considerations are required to be made for a hydrogen engine:

a) *Combustion chamber:* The bath tub or cylindrical shape helps produce low radial and tangential velocity components and does not amplify inlet swirl during compression. This can help to reduce pre-ignition and knock.

b) *Cooling system:* The cooling system must be designed to avoid hot spots , hence uniform flow and reach to be ensured at needed cooling location . (especially spark plug area cooling , provision or jet given in cylinder head)

c) *Bore-stroke ratio:* Since unburned hydrocarbons are not a concern in hydrogen engines, a large bore-to-stroke ratio can be used with this engine. ((Not to bother about crevice volume etc)

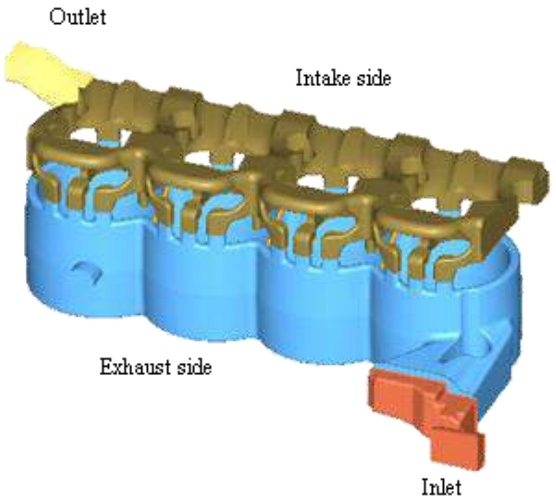
d) *Cylinder head design:* Additional measures to decrease the probability of pre-ignition are the use of two small exhaust valves as opposed to a single large one, and the development of an effective scavenging system. (keep chamber cool) (Theory only)

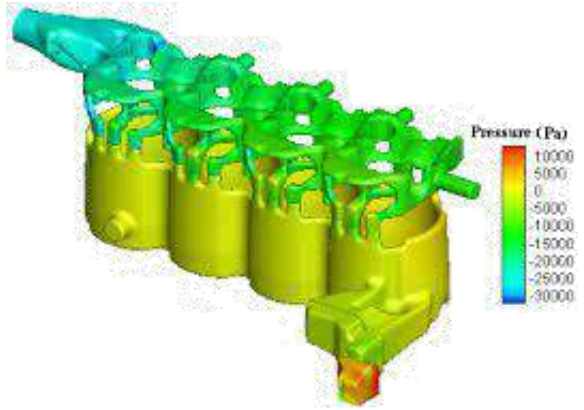
e) *Spark plug:* Ignition systems that use a waste spark system should not be used for hydrogen engines. (Flat earth electrode)

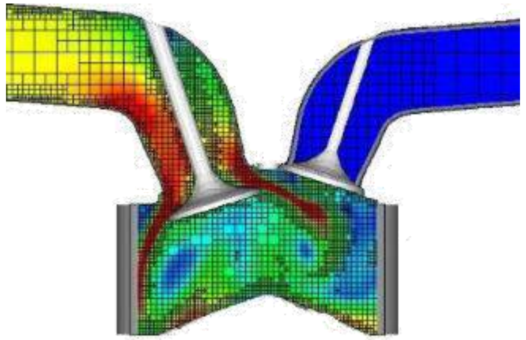
f) *Crankcase ventilation:* Crankcase ventilation is even more important for hydrogen engines than for gasoline engines. Hydrogen should be prevented from accumulating through ventilation. When hydrogen ignites within the crankcase, a sudden pressure rise occurs. To relieve this pressure, a pressure relief valve must be installed on the valve cover. (Rings design to be reviewed to reduce blow-by)

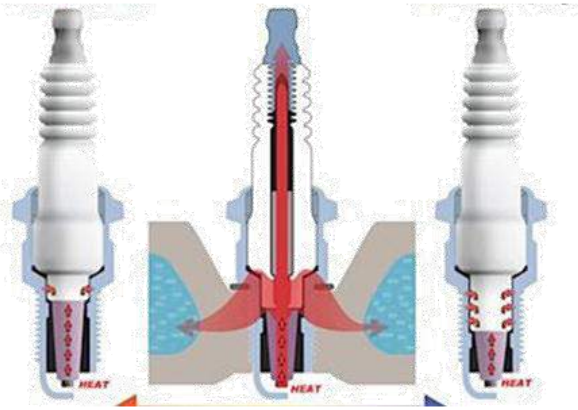
Cylinder Head Design Review

- Hydrogen engine requires minimum swirl, hence swirl reduction is required on existing cylinder head
- Review of adequacy of water jacket cooling for existing SI engine water pump for H2 ICE
- Spark Plug size and heat range to be selected and cooling requirements to be verified





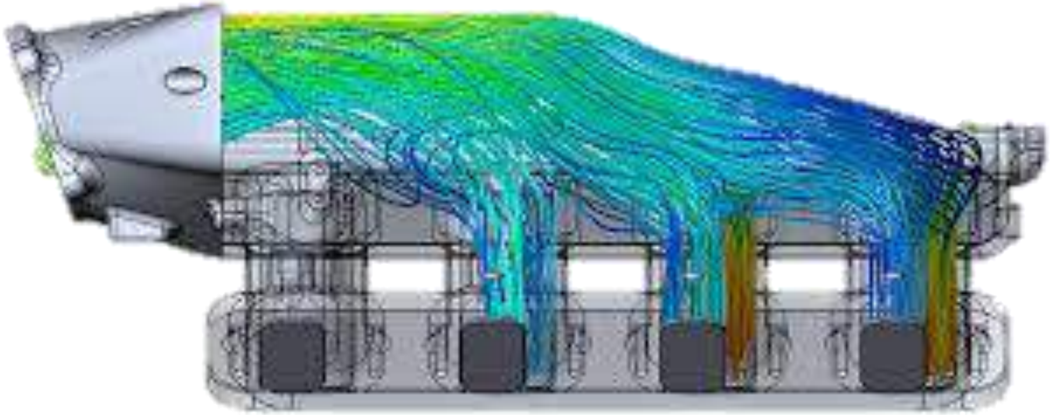


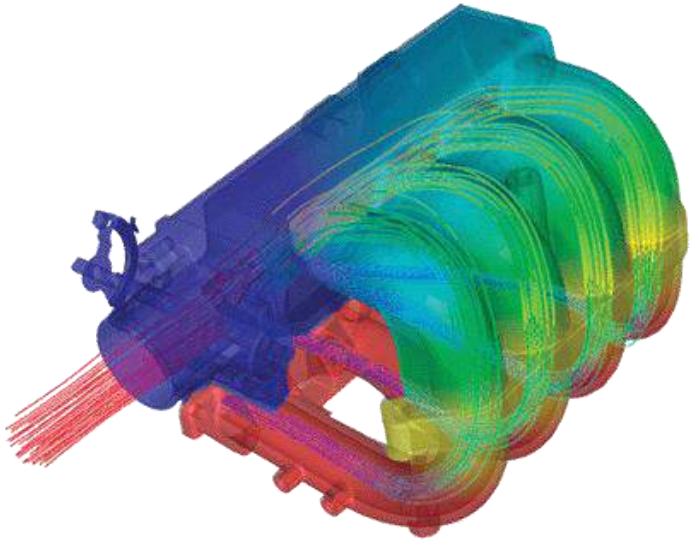


Intake Manifold Review

Review of existing manifold from charge distribution point of view

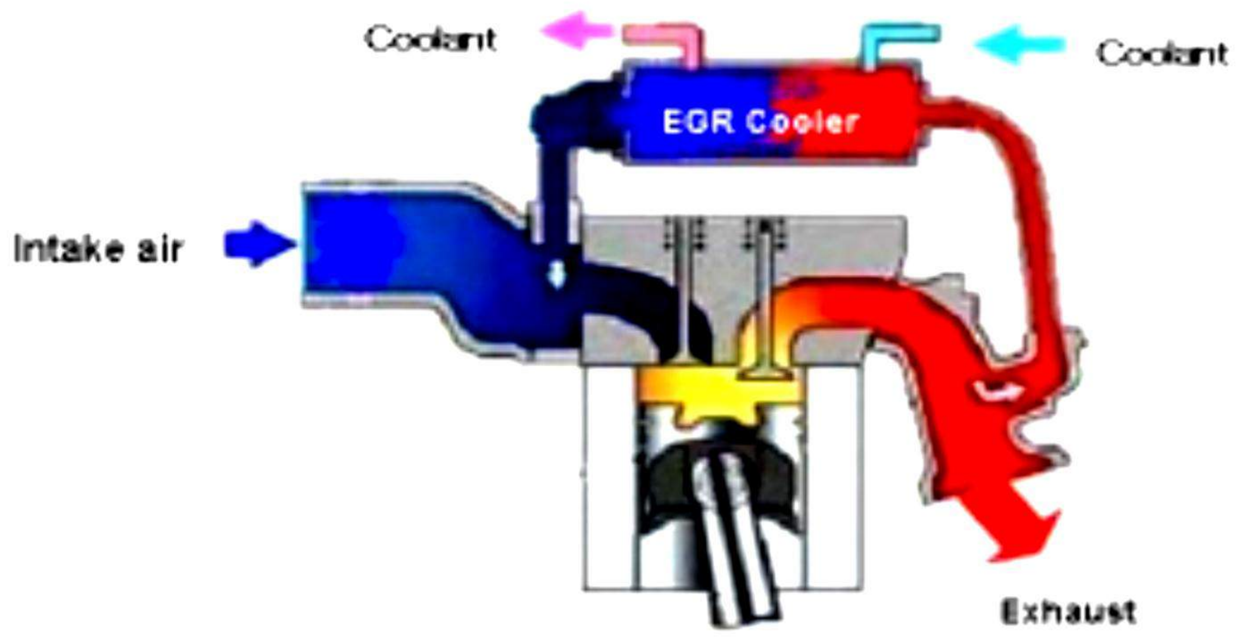
- Existing plenum volume & runner length are considered as base case on the basis of swirl test results.
- Then two separate conditions are taken for simulation purpose.
- Similarly with increased & decreased runner length simulation are carried for finalization of runner length

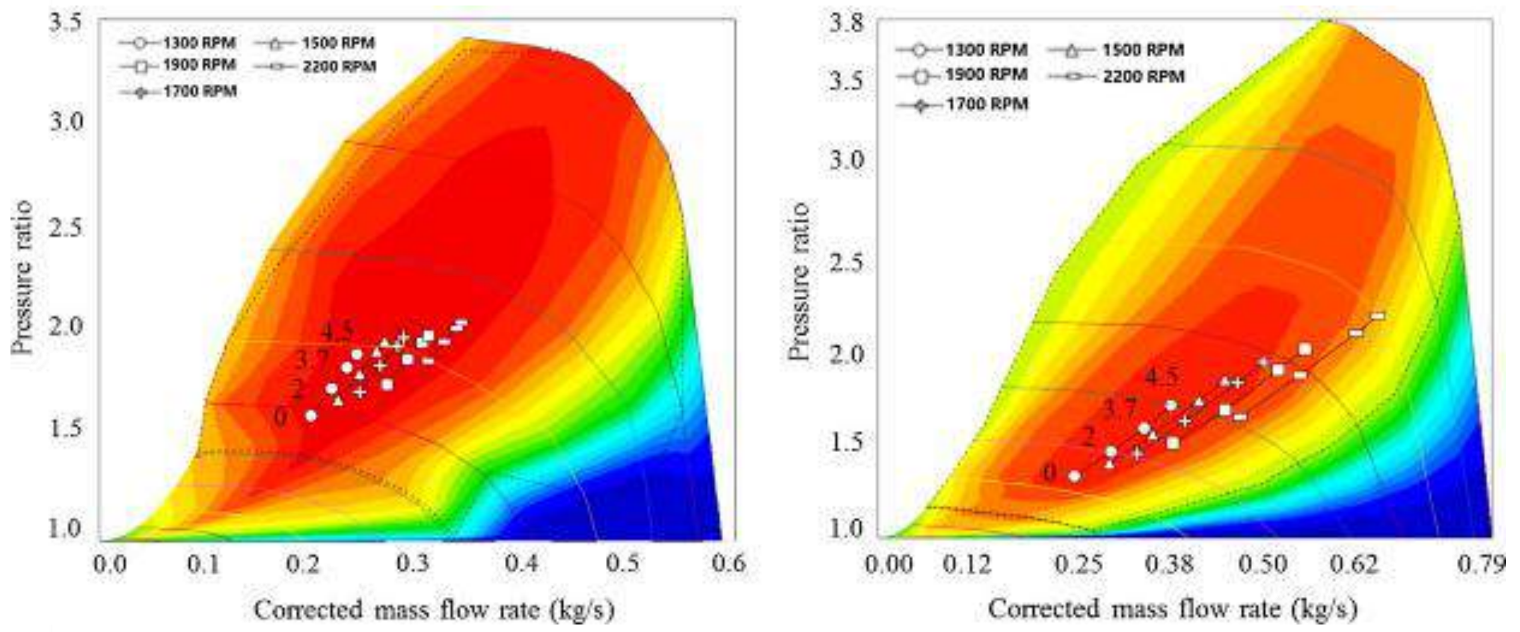




EGR and Turbocharger Review

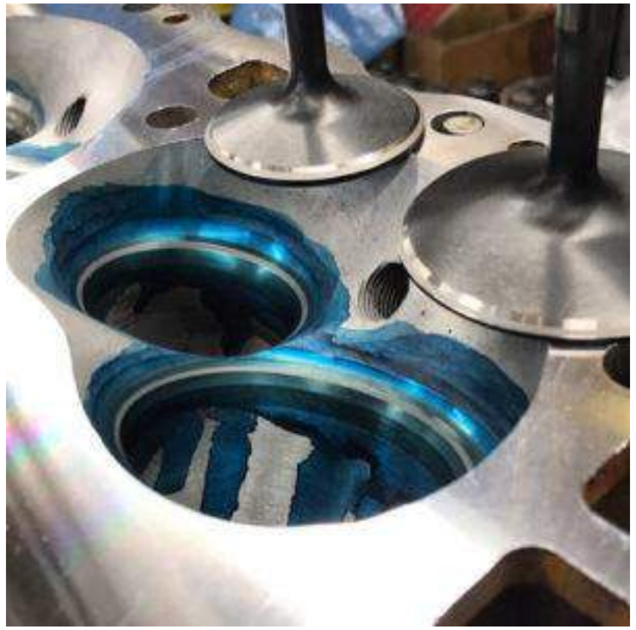
- Cooled EGR adaptation allows for higher compression ratios (greater compression via the piston of the air-gas mix inside the cylinder during combustion) and higher efficiency without getting knock.
- Turbocharger operation to be reviewed from material and efficiency perspective. Boost pressure & air /fuel flows requirements are calculated.

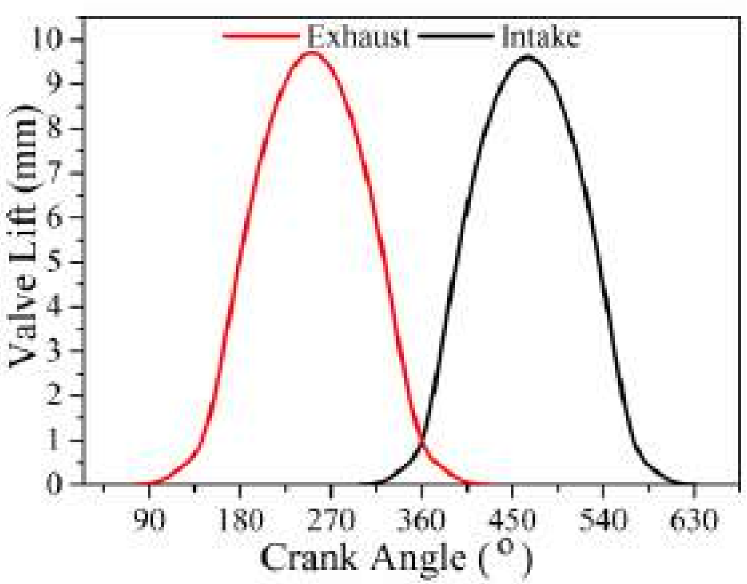


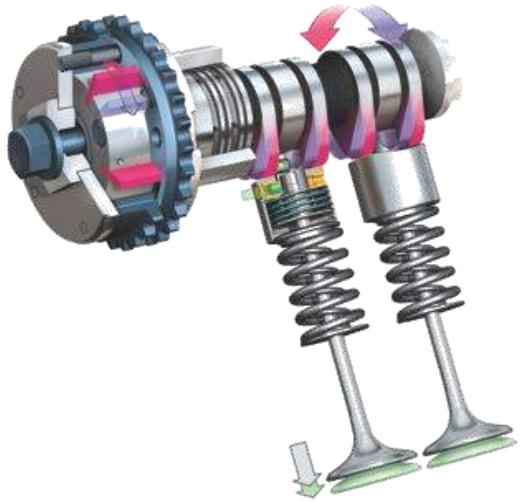


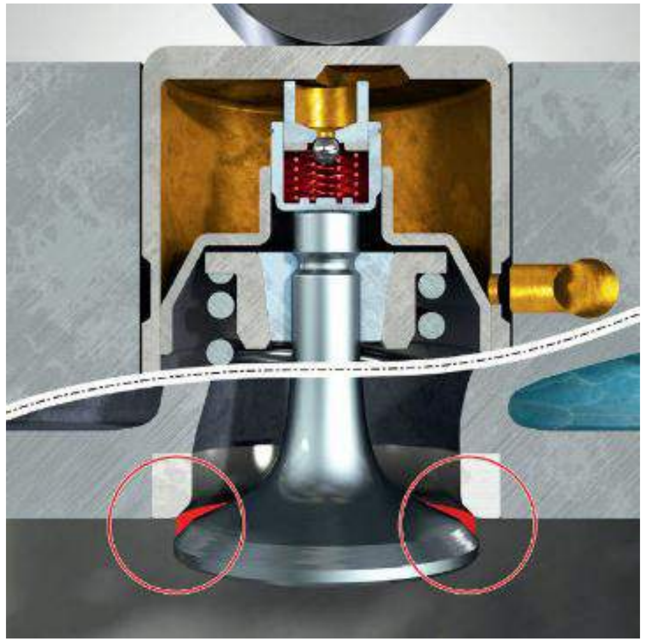
Valve, Valve Seat and Valve Timing Review

- Alloy material for exhaust valve should withstand high temperatures & material embrittlement
- Optimum valve timing (IVO, IVC, EVO, EVC) is recommended after evaluating different combinations

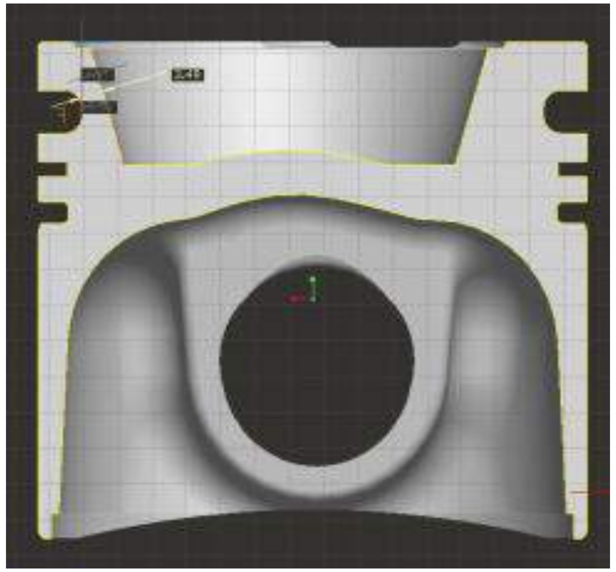








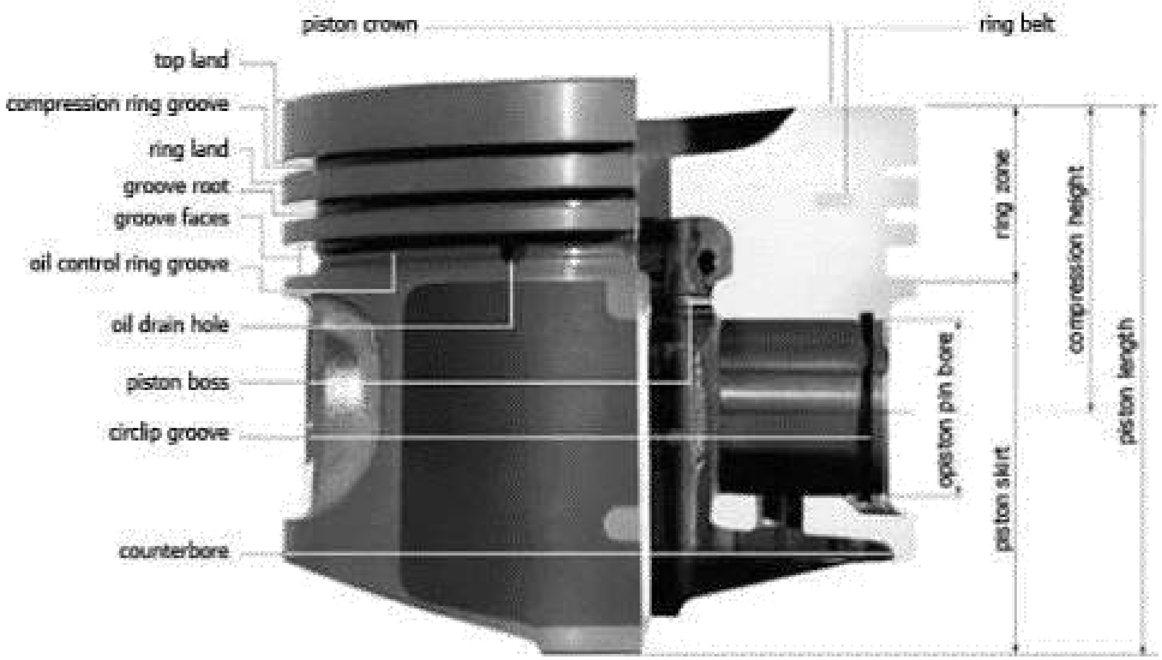
Piston Design Review



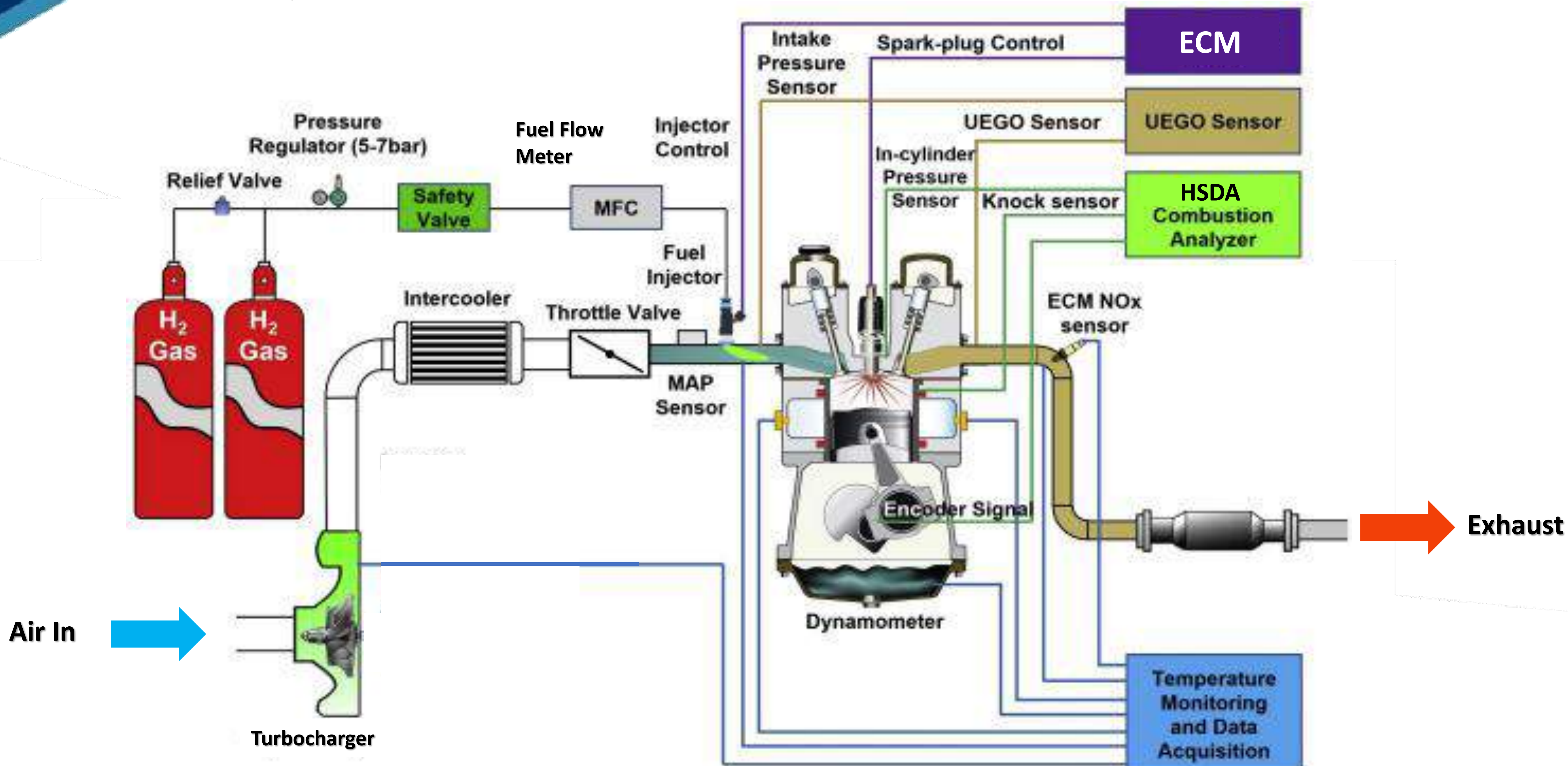
Piston and combustion chamber

- Following points are considered for combustion bowl optimization:
  - Compression ratio
  - High Squish for better turbulence
- Heat treatment for piston to withstand increased thermal load in consultation with Piston manufacturer

Gasoline



Layout for Hydrogen IC Engine Test Cell



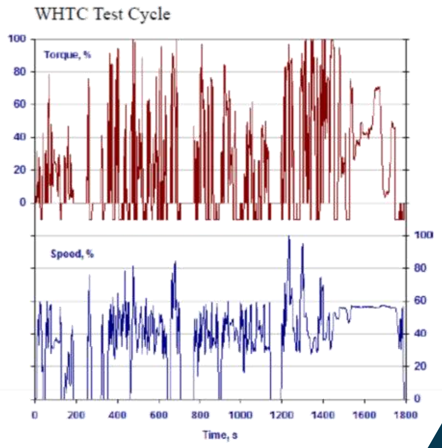
Hydrogen Engine Calibration Process

Pre-Run Calibration

- Sensor Characterisation
- Throttle mapping
- Volumetric Efficiency mapping
- Primary Ignition timing calibration
- Drag torque calibration

Steady State Calibration

- MBT Timing mapping
- Torque table mapping
- Exhaust temperature model mapping
- Catalyst temperature model mapping
- RELAMPC/RPM to engine mapping



Transient Calibration

- Turbo feedback mapping
- Torque Curve Calibration/Confirmation

- Transient fuel Control/confirmation
- Transient timing Control/confirmation

Emission Calibration

- O2 Closed loop Response time & time delay
- DFCO Calibration
- Commanded Lambda Calibration
- Rear O2 Calibration
- Engine start time & flare Calibration

OBD Calibration

- Sensor monitoring
- Oxygen sensor detororation
- Misfire
- Catalytic convertor low efficiency
- Knock Detection

Summary

- Hydrogen is a promising energy source for pollution reduction and meeting BS-VII regulations.
- Technology innovations are required to overcome challenges and meet BS-VII with sufficient margins
- Indian regulations are being continuously upgraded - Performance and safety aspects are given equal importance
- Development of R &D and certification facilities is the key for success of Hydrogen ICE and Fuel cell program in India.
- Emphasis to be given Training for awareness to concerned stake holders.
- The real challenge ahead is to ensure the best safety practices and continuous up gradation of technology in the coming years

THANK YOU!!