Low Carbon Imperatives

Oil Industry's Initiatives

IndianOil R&D The Power of Possibilities

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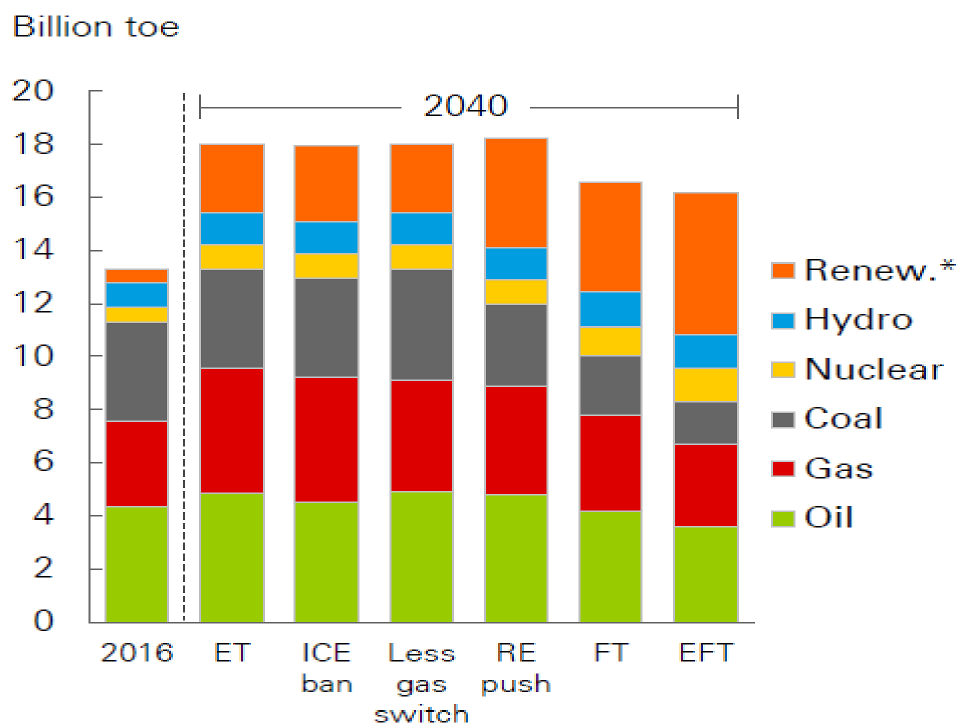
IndianOil Corporation Limited

Recent Advances in CO2 Capture Technology and Its Sectoral Application
ACBCCU-2018, 30th August, New Delhi

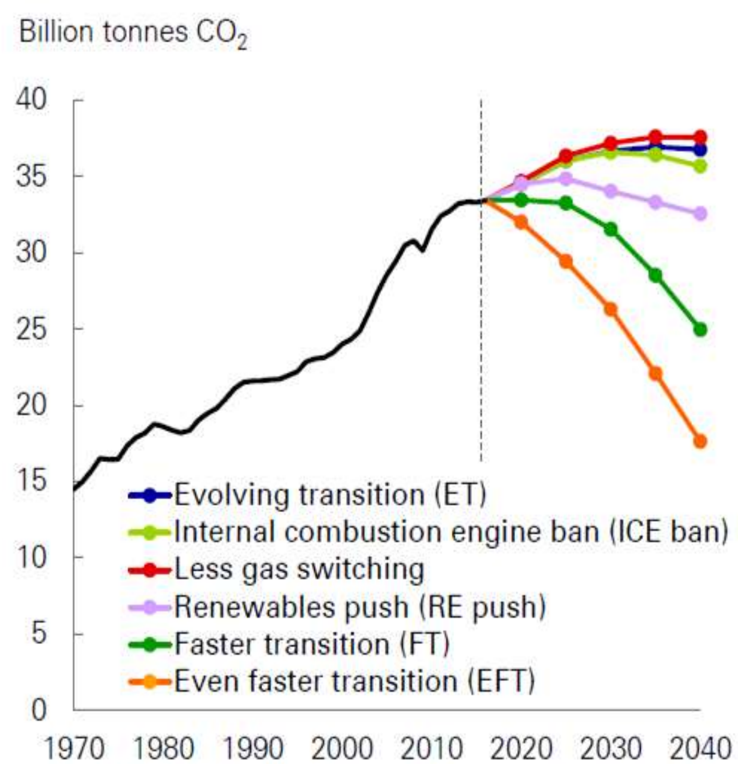
IndianOil R&D The Power of Possibilities

Global Energy Outlook

Primary Energy Demand (BTOE)



CO_2 Emissions

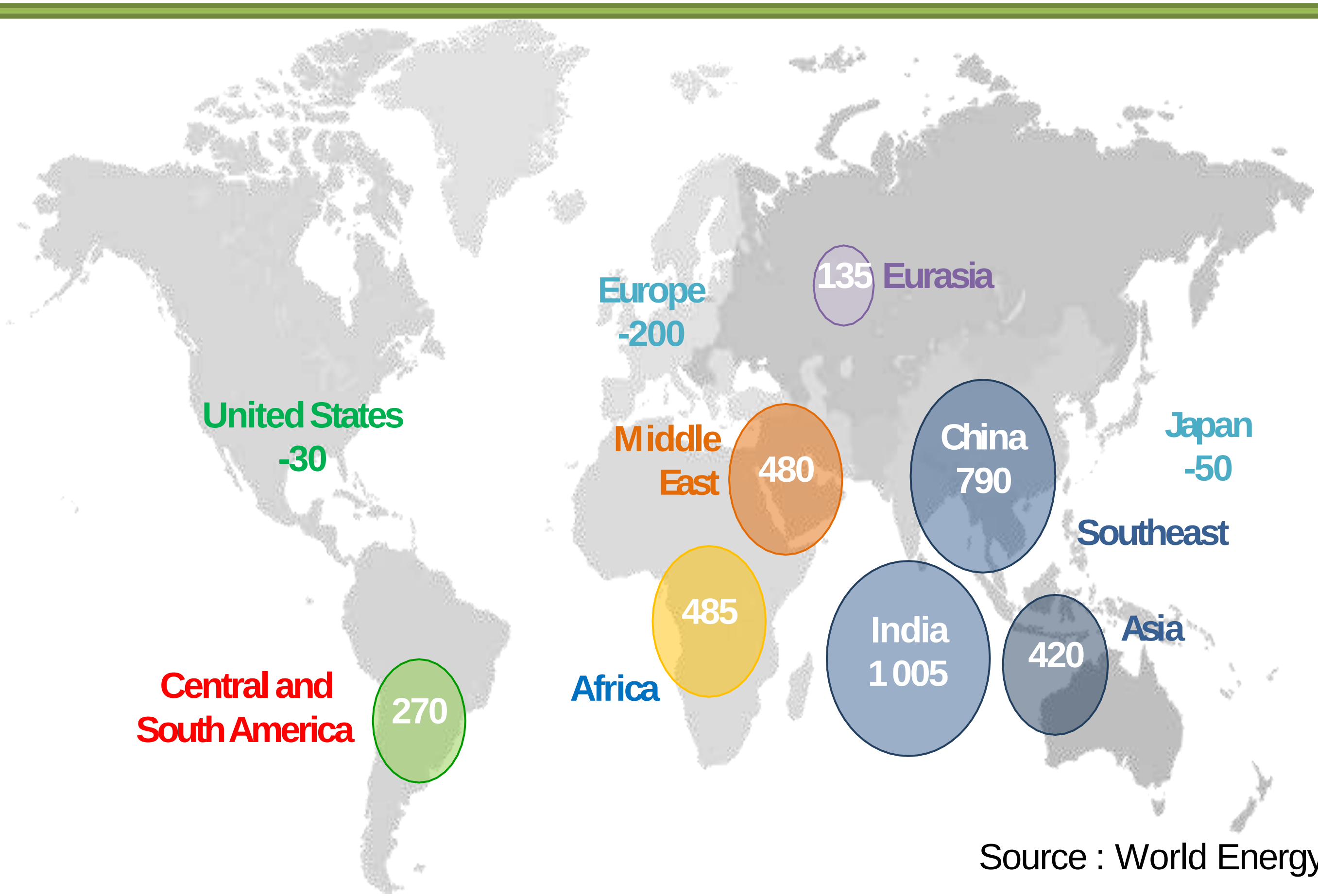


- **Transportation sector in developing countries driving the demand**
- **While overall diesel demand is expected to be more, developing countries will have relatively more gasoline demand**

Source: -BP Energy Outlook 2018

Global Energy Imperatives: India – Crouching Tiger

Change in energy demand, 2016-40 (Mtoe)

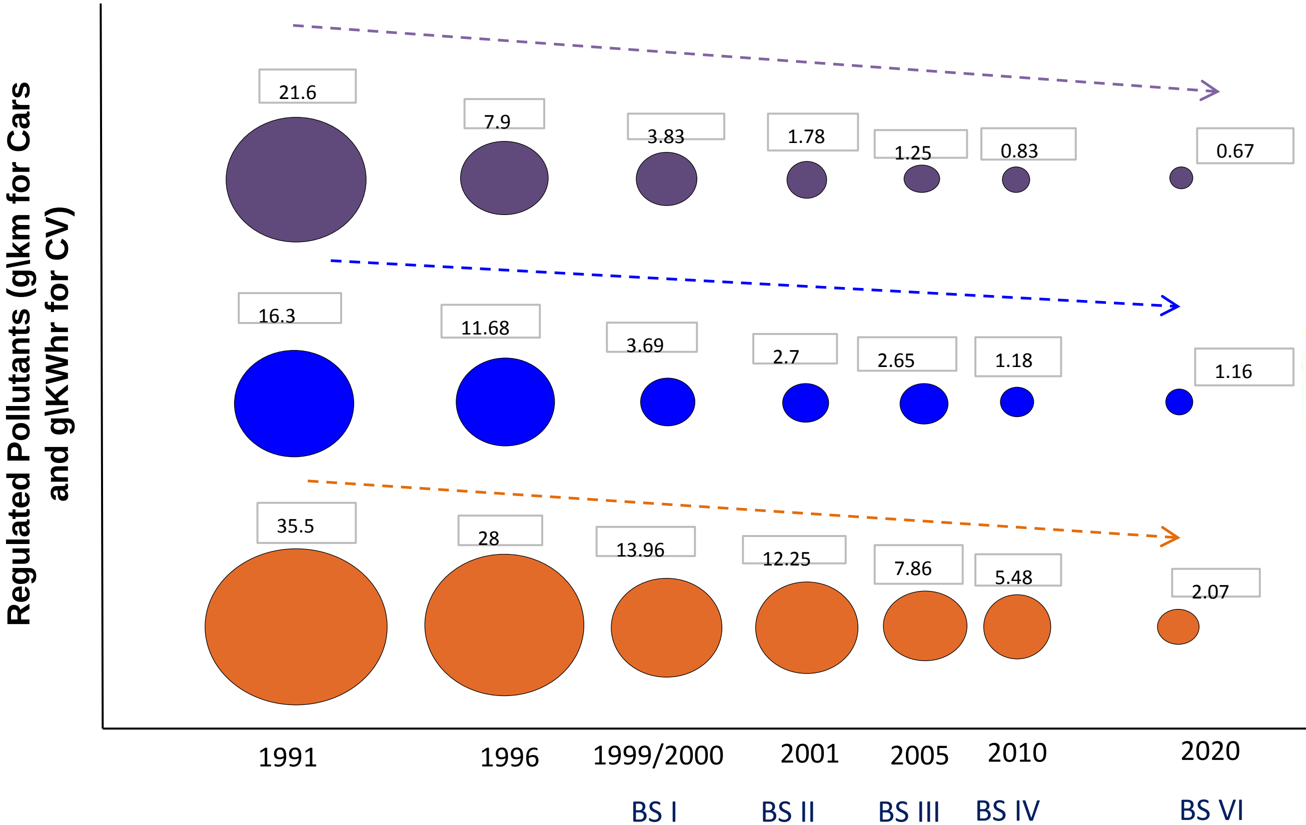


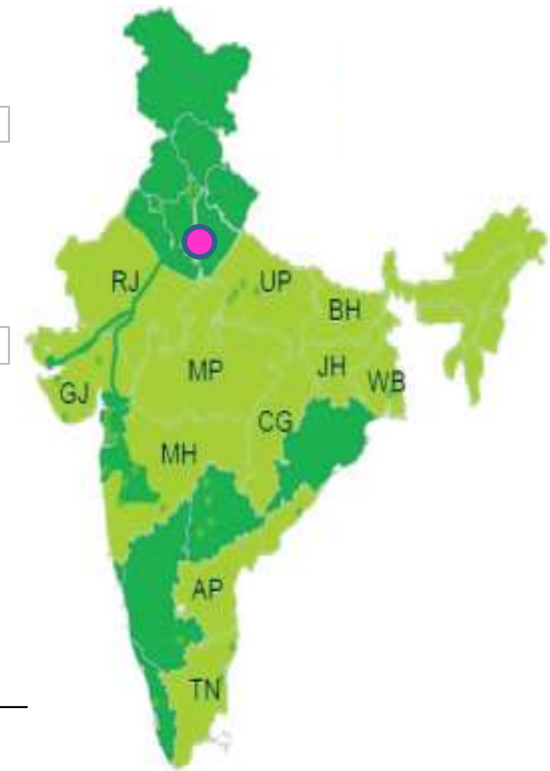
Source : World Energy Outlook, 2017

Old ways of understanding the world of energy are losing value as countries change roles

Asia-Pacific & Middle East is fast becoming a major energy consumer & US a major exporter

Changing Paradigm



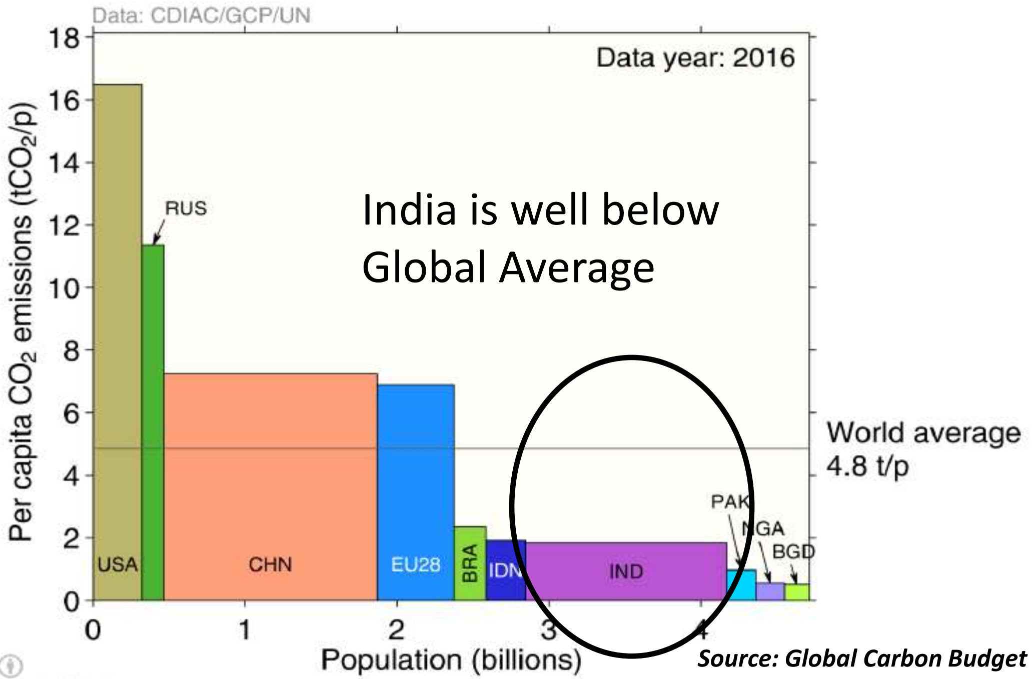


BS IV / VI Fuel availability in India

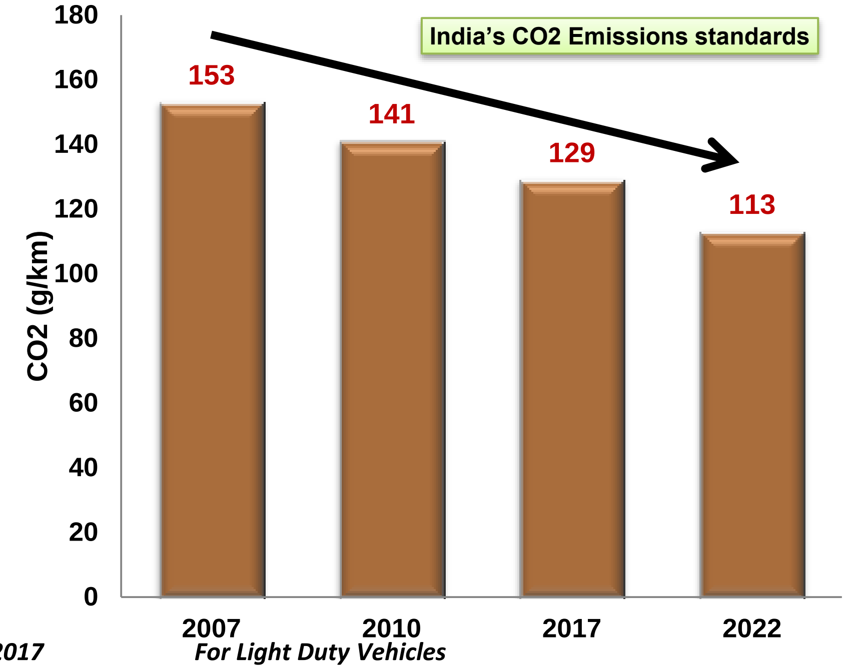
Cars/Light Duty -Diesel	Cars- Gasoline	Commercial Vehicle
95.7% reduction till BS 4 96.5% reduction till BS 6	92.8% reduction till BS 4 92.9% reduction till BS 6	92.8% reduction till BS 4 92.9% reduction till BS 6

- (green) → 1st April 2016
- (light green) → 1st April 2017
- (pink) → **1st April 2018**

CO2 Emissions and FE Norms



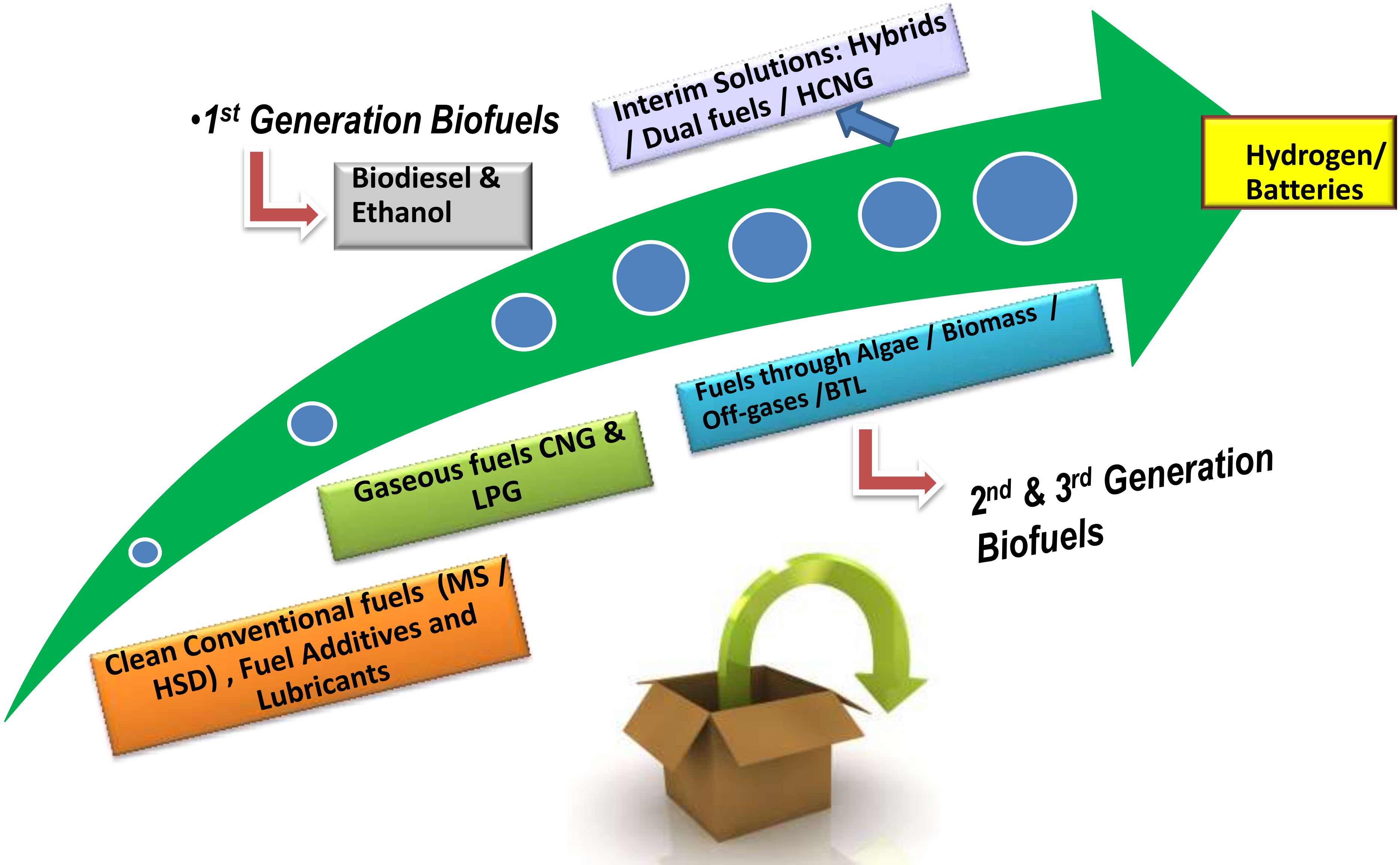
Source: Global Carbon Budget 2017



- ✓ Fuel Economy norms for **Heavy duty/commercial vehicles** issued recently by BEE
  - *Limits on constant speed fuel consumption for vehicles with GVW >12 tonnes*
  - *Compliance from 1st April 2018 covering diesel vehicles of M3 and N3 category*

- ✓ Notification of Min. of Power, The Gazette of India, Jan 30th, 2014 for **Light Duty Vehicles**
- ✓ *Average Consumption figures of 2009-2010 as base line*
  - ❑ *Covers MS,HSD,LPG & CNG*
  - ❑ *Applies to - Vehicles GVW< 3500 KG / 9 seater (max)*
- ✓ Average CO_2 targets 129 gm/Km in 2017 and 113 gm/km by 2022 - Compliance Started from April 1st 2017

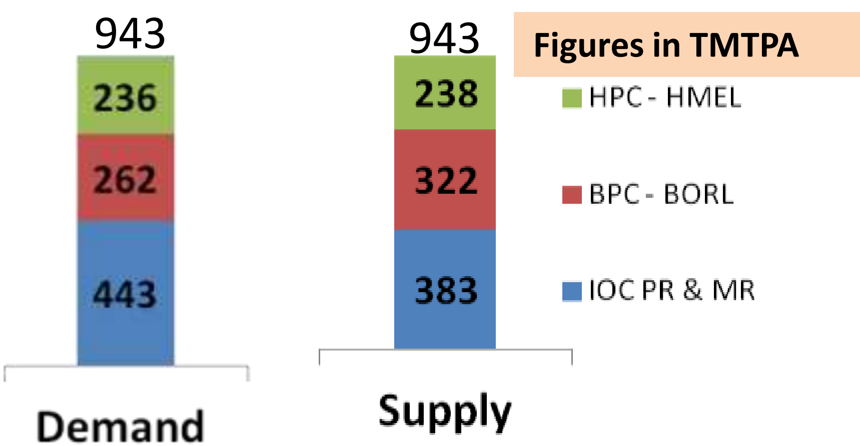
Low Carbon Options



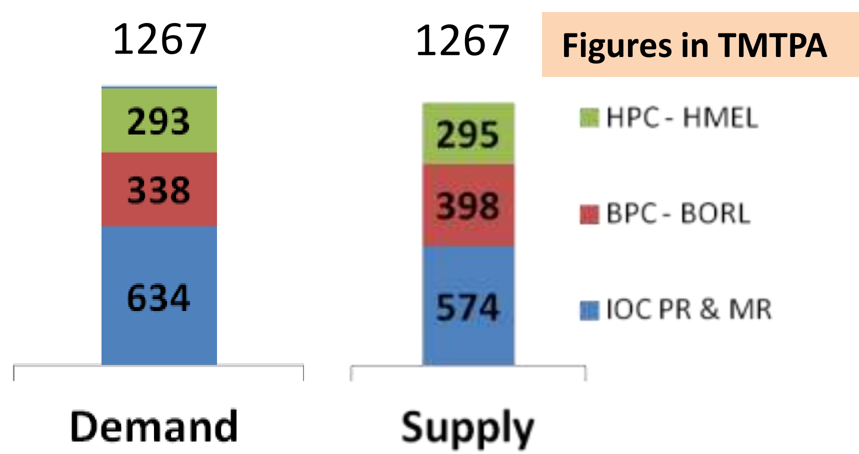
Disruptions on the anvil through Batteries / Fuel Cells / Solar / Wind Energy

Advancement of BS-VI Fuels in Delhi NCT

MS Projections in NCT for 2018-19



HSD Projections in NCT for 2018-19



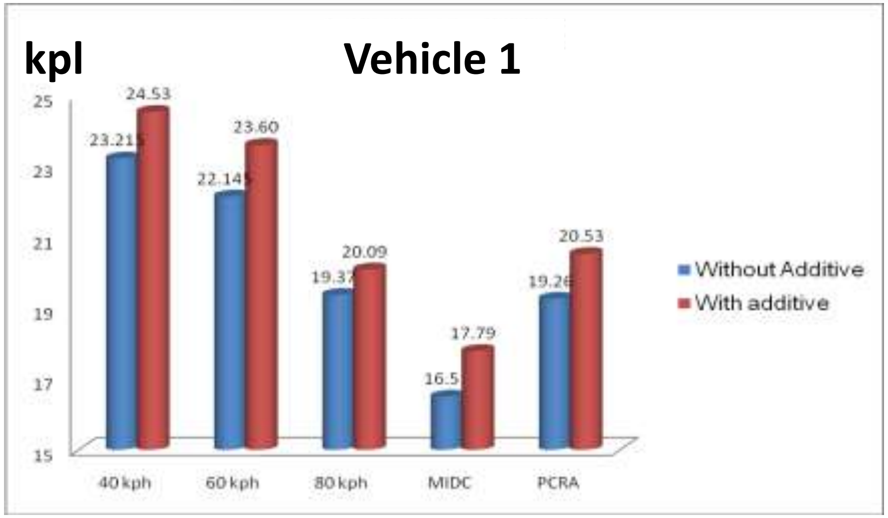
Fuel Additives

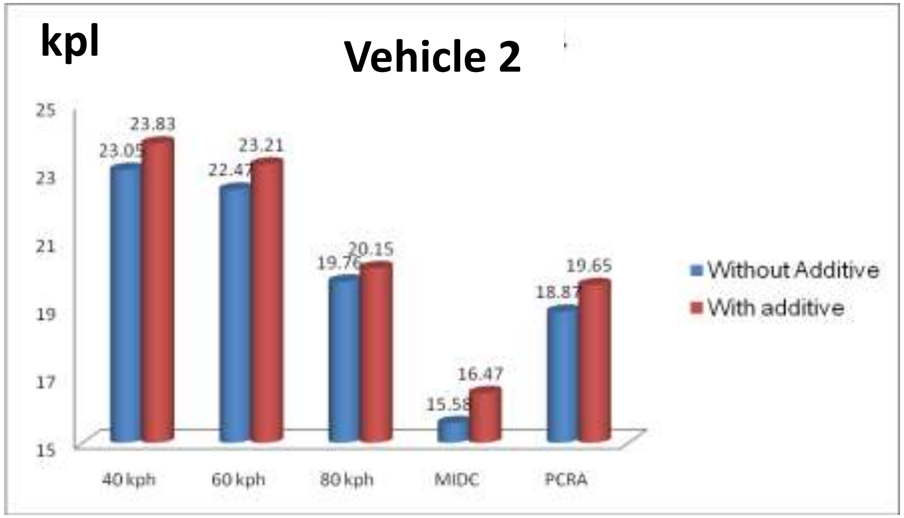
- **Additive is a fine chemical which modifies the characteristic of Refined Petroleum Fractions**
- **Additives Provide economical and easy means**
  - **of Improving Performance**
  - **Controlling quality during production, distribution, and while the product is in use**
  - **Impart Properties which are not present in the base fuel**
  - **Extend the life of the machine and expands the range of application**

Heavily Scored Inlet Valve with Untreated Fuel

Clean Inlet Valve with additive treated Fuel

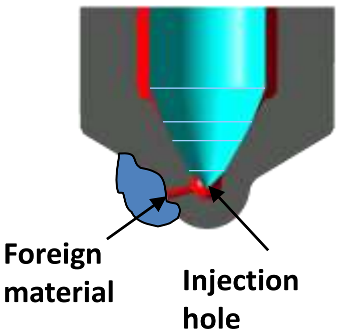
Effect of Gasoline MFA on fuel Economy / CO_2 emissions



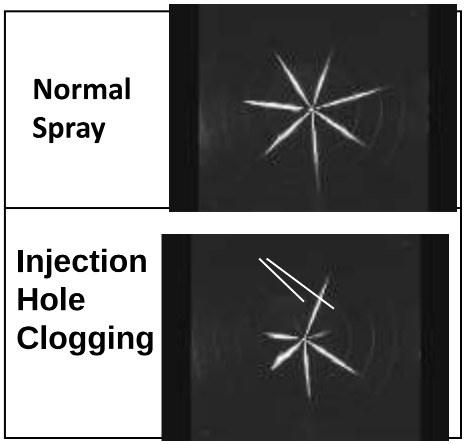


Diesel MFAs

Injector tip

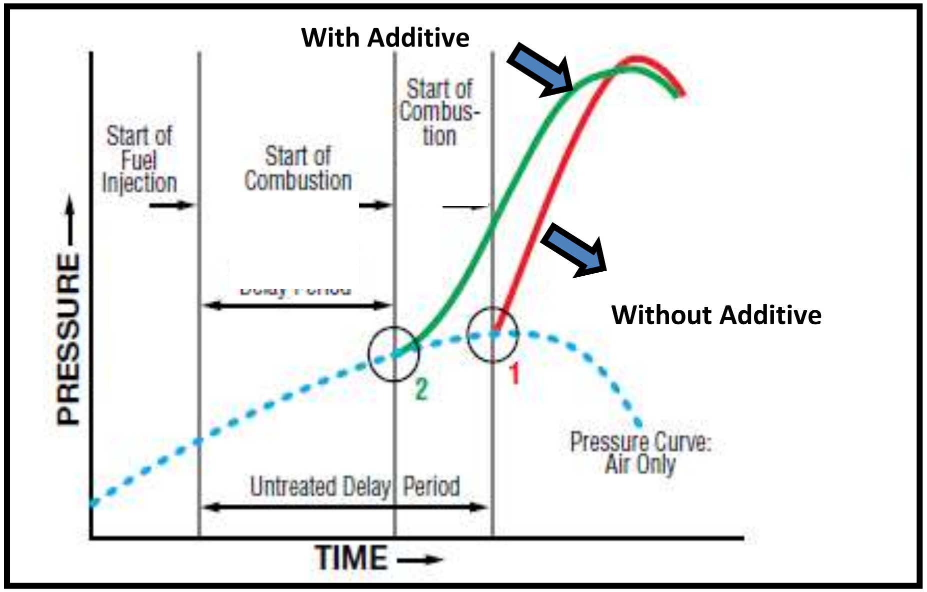


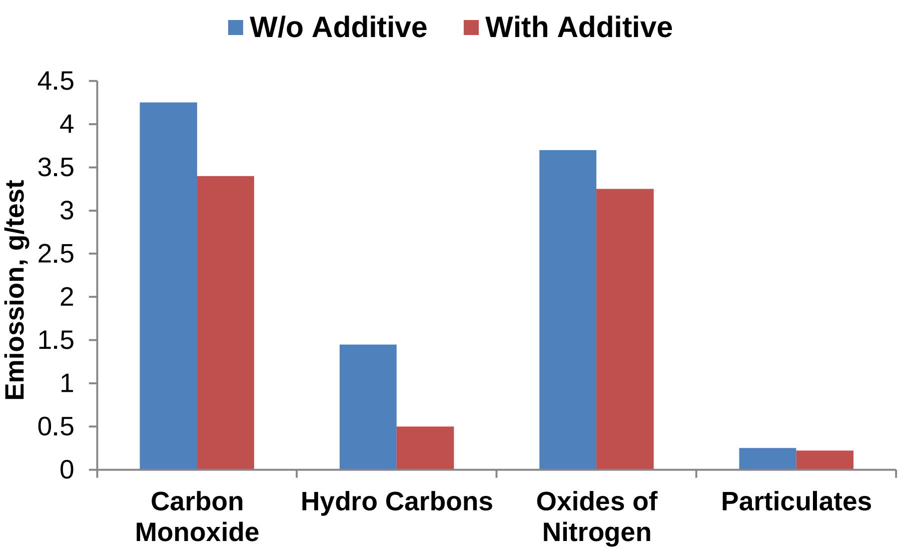
Bottom view



Heavily Scored Injector Pintle with Untreated Fuel

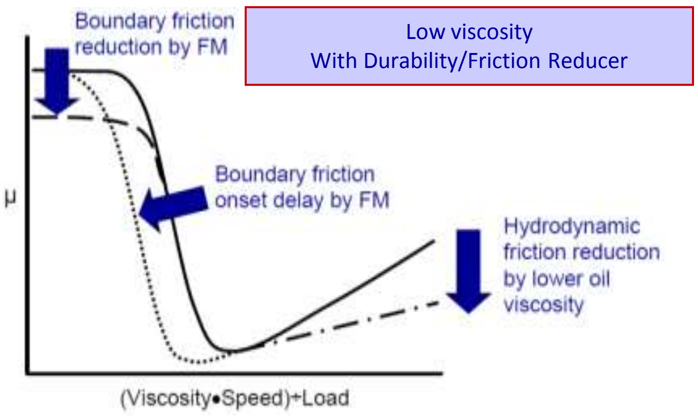
Clean Injector Pintle with additive treated Fuel

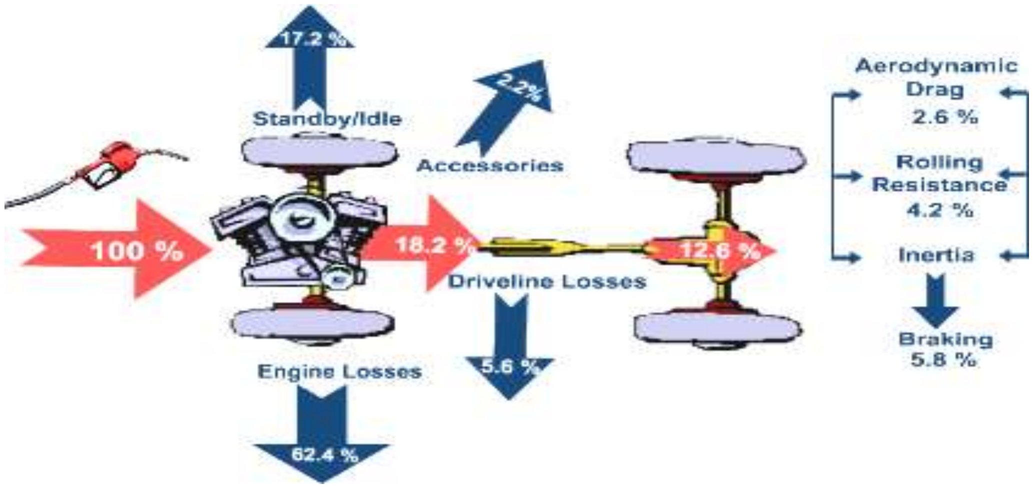




Source: Lubrizol

Fuel Efficient Passenger Car Diesel Engine Oil





Engine Oils	Fuel Economy (kpl)	% improvement w.r.t 15W40	% improvement w.r.t 5W40
SAE 15W40*	18.85		
A5 / B5 5W40 (Industry Ref.)	19.45	+3.19%	
Candidate A5 / B5 5W30 w/o FM	19.81	+5.08%	+1.83%
Candidate A5 / B5 5W30 with FM	19.95	+5.86%	+2.58%

Composite Fuel Economy Benefits in Commercial Vehicles

✓ **Lower Viscosity Grades**

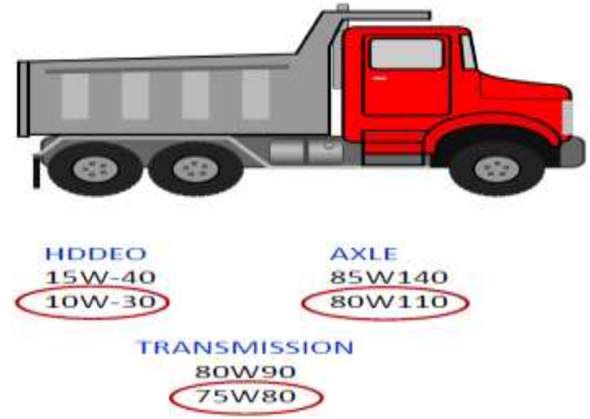
Engine Oil: API CI_4 + 10W-30

MTF: Dedicated 75W-80

Axle Oil: Dedicated 80W-110

✓ **Huge Benefits to Fleet Operators in Commercial vehicle sector**

Data Generated at IOC R&D
90 KW, BS III/ BSIV, Water cooled, Turbocharged DI Diesel Engine



Test	Type	% Imp. (Engine + Trans. + Axle Oil)*
DBDC Cycle	Cold	4.12
DBDC Cycle	Hot	4.65

Automotive Oils	Viscosity grade	ODI
Engine Oil	CI4 Plus 10W-30	1.5 Lac kms
Transmission oil	75W-80	2.4 Lac kms
Axle Oil	80W-110	2.0 Lac kms

Added Long Drain Potential

Expected Cost benefits to customer

Details	Existing grade	FE grade
No of vehicles	4000	4000
Average km/lt	3.5	3.62
ODI	1 lacs	2 lacs
Annual cost saving due to fuel only	--	1.3 crore

3.5-4.7 % improvement in FE in OEM fleet*

***Reference Oils : CI4 Plus 15W-40, Transmission oil 80W-90 & Axle Oil 85W-140**

INDMAX Technology

Ability to process wide range of feed stocks

Attractive yields of light olefins - Integration with Petrochemicals

Production of very high octane Gasoline component

Feedstock to Alkylation unit

Feedstock to ETBE, TAME, Dimer units

Flexibility to switch over to products suiting market demand

Easy to adopt in existing refinery

Integrates refining & petrochemical operations

Produces valuable feedstock for high octane gasoline components

0.15 MMTPA unit at Guwahati Refinery

4.17 MMTPA unit at Paradip Refinery

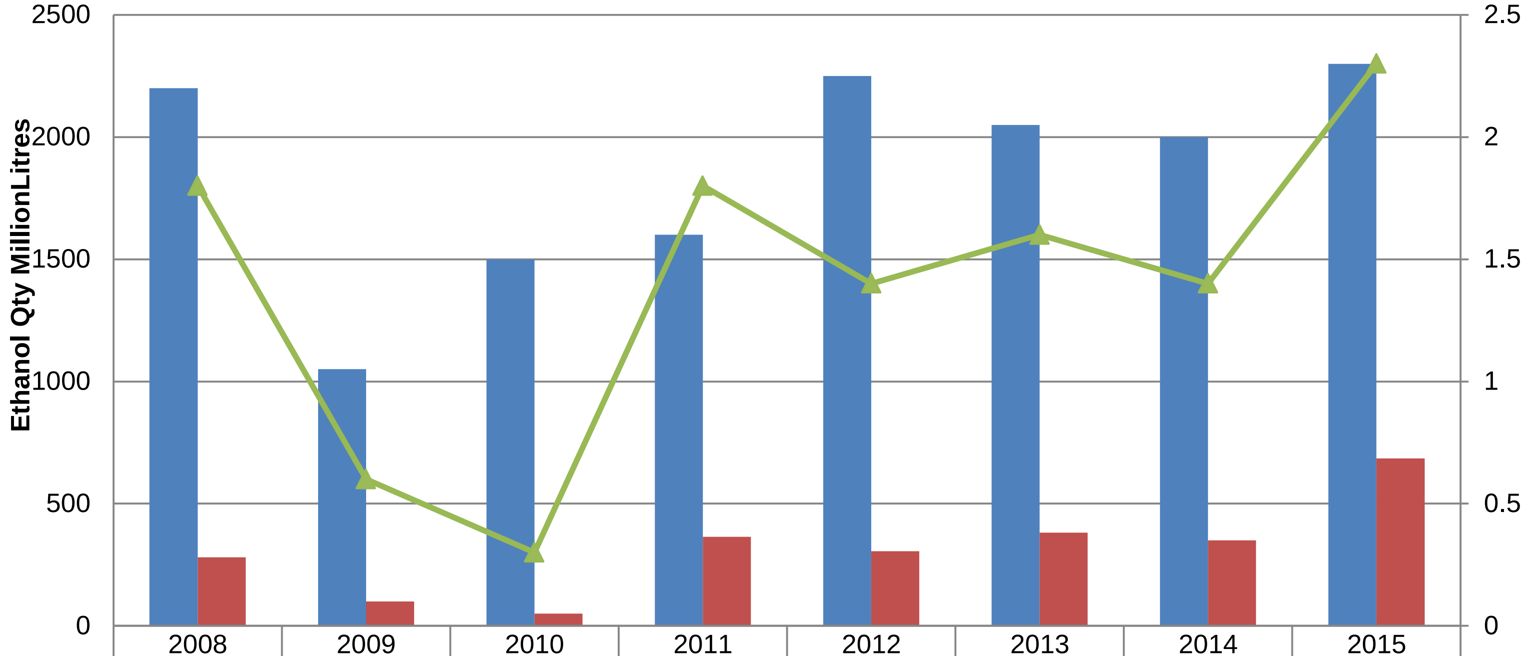
Environmentally Benign Process Technologies

Reducing Emissions thru Fuel Quality Upgradation

INDAdept^G	• Gasoline absorptive desulfurization • Ultra low sulfur product with low H_2 consumption
IndSelect^G	• Fixed bed mild hydrotreating • Removal of Sulfur & Di-olefins from Coker naphtha
IndeDiesel	• Hydrotreating of Diesel • Ultra low sulfur product
IndDSN/IndDSK	• Naphtha / Kerosene desulfurization process
Octamax	• Heterogeneous catalyst in place of toxic liquid catalyst • High RON gasoline blending component

Ethanol Supply and Demand Status

Total Ethanol Production, Fuel Ethanol Consumption and Blending



	2008	2009	2010	2011	2012	2013	2014	2015
production	2200	1050	1500	1600	2250	2050	2000	2300
Consumption as Fuel	280	100	50	365	305	382	350	685
Ethanol blend rate (%)	1.8	0.6	0.3	1.8	1.4	1.6	1.4	2.3

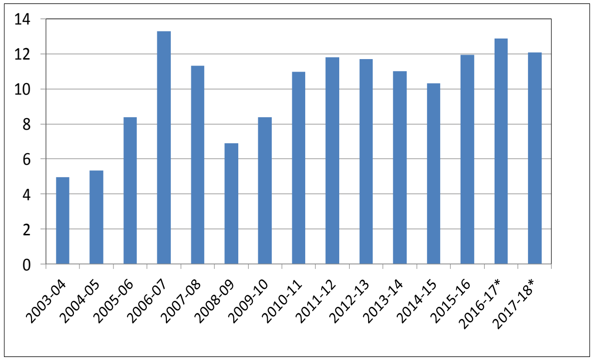
10% Bio-ethanol allowed in India but only 5% is the likely achievement in 2018-19

376 crore litres (~3.76 billion litres) ethanol required in FY 18-19 to meet 10% EBP target

1st Generation Ethanol

- •1 •Food Vs Fuel (same land for both)
- •2 • Limited availability of molasses
- •3 •Fails to achieve requirements of Biofuels

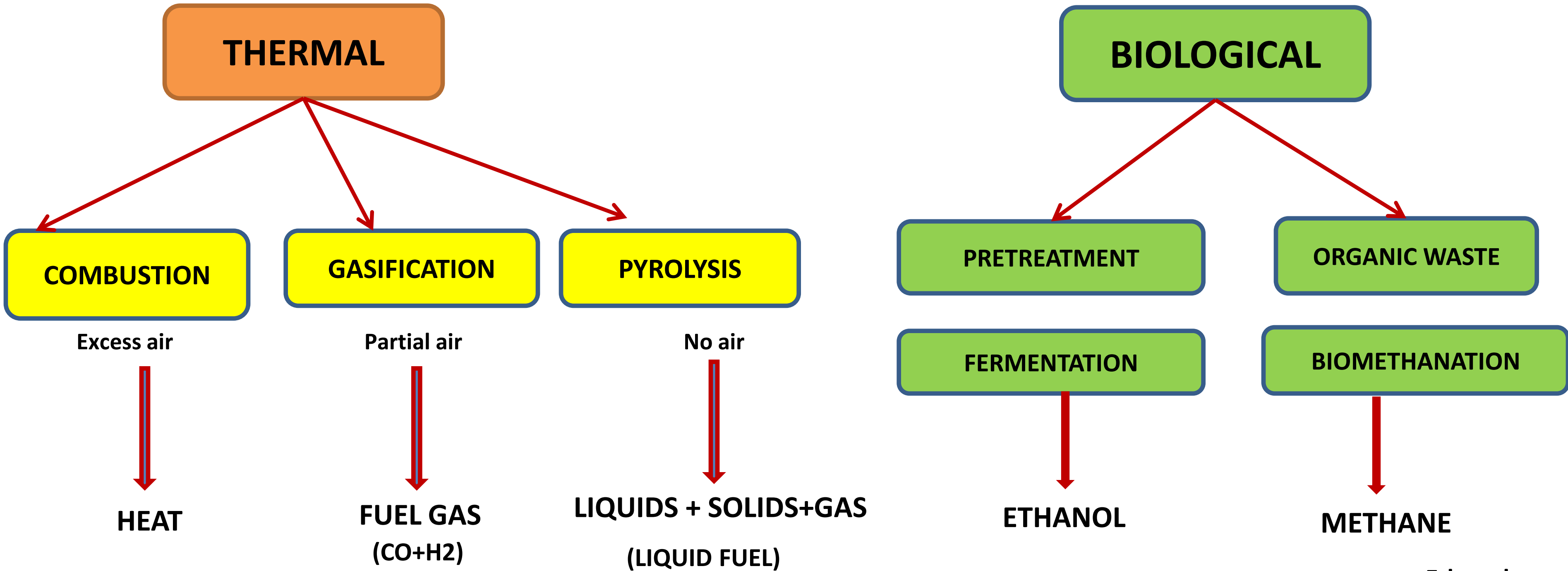
Production of Molasses (Million tonnes)



INDIAN ETHANOL PRODUCTION CAPABILITY

- Molasses production , linked to sugarcane production, varies from ~5 MMTA (2003-06) to ~12 MMTA (2017-18)
- Sustained supply of ethanol debatable
- About 40% of total ethanol production as fuel grade
- Even at peak production , it can meet only about 5 % blend level in gasoline
- 2nd Generation ethanol is sustainable

Biomass Conversion Pathways



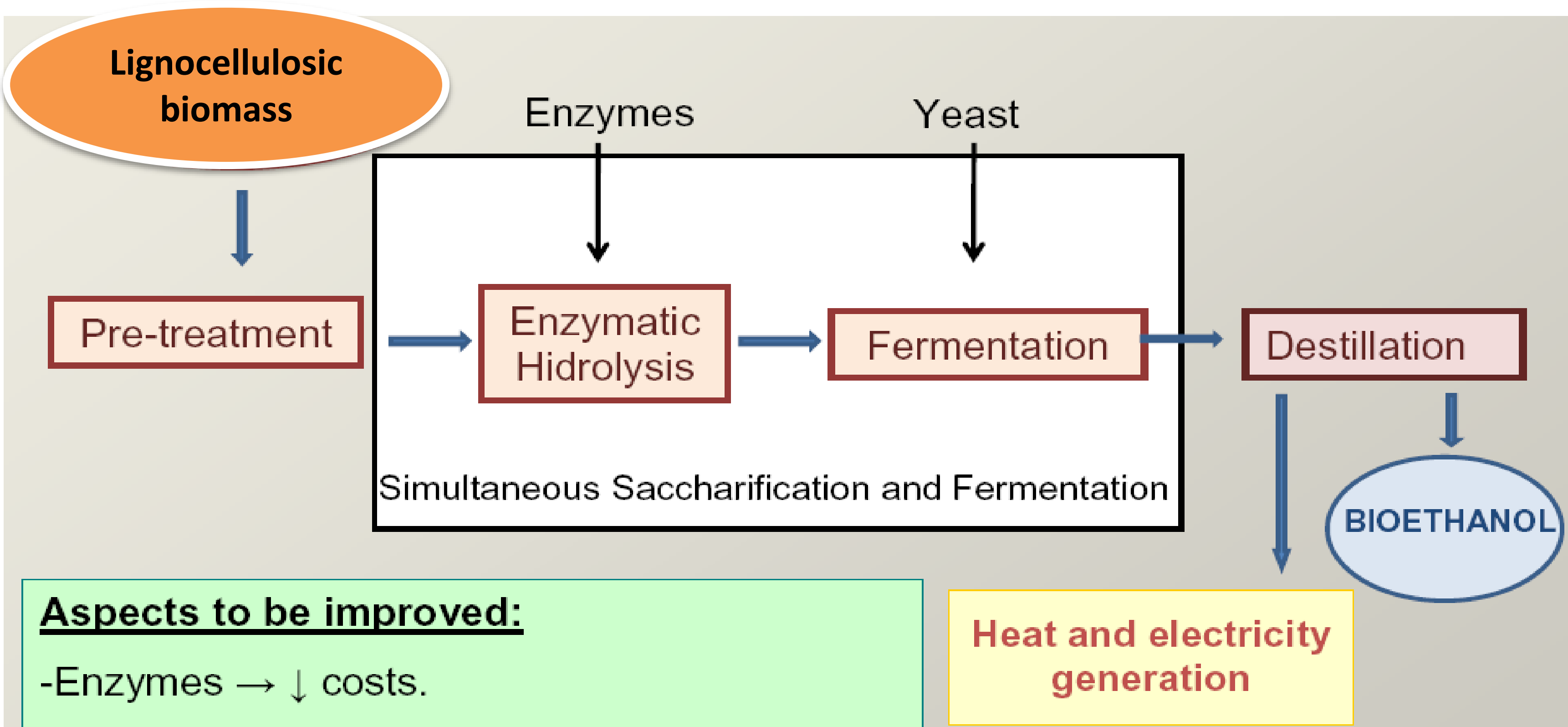
BIOMASS

CONVERSION PROCESS

PRODUCTS

- ENERGY — Ethanol, Hydrogen, Electricity, Heat
- CHEMICALS — Plastics, Solvents, Adhesive, Paints, dyes
- FOOD + FEED

Process Biomass to 2G Ethanol



Aspects to be improved:

-Enzymes → ↓ costs.

-Fermentation → Tolerant yeasts and pentoses fermentation.

- *Twelve 2-G ethanol plants being setup by OMCs at various locations*
- *Indigenization efforts required to establish financial sustainability*

Biomass Pyrolysis

- **Advantages :**

  Liquid Products from Solid feeds

  - **distributed units possible.**
  - **Attractive economics as huge availability of biomass**

- **Disadvantages:**
  - **Stabilization issues due to Oxygenates, Corrosive, Processing / treatment required**

Pilot Plant facility of 1-2 Kg/hr Set up at IOC R&D

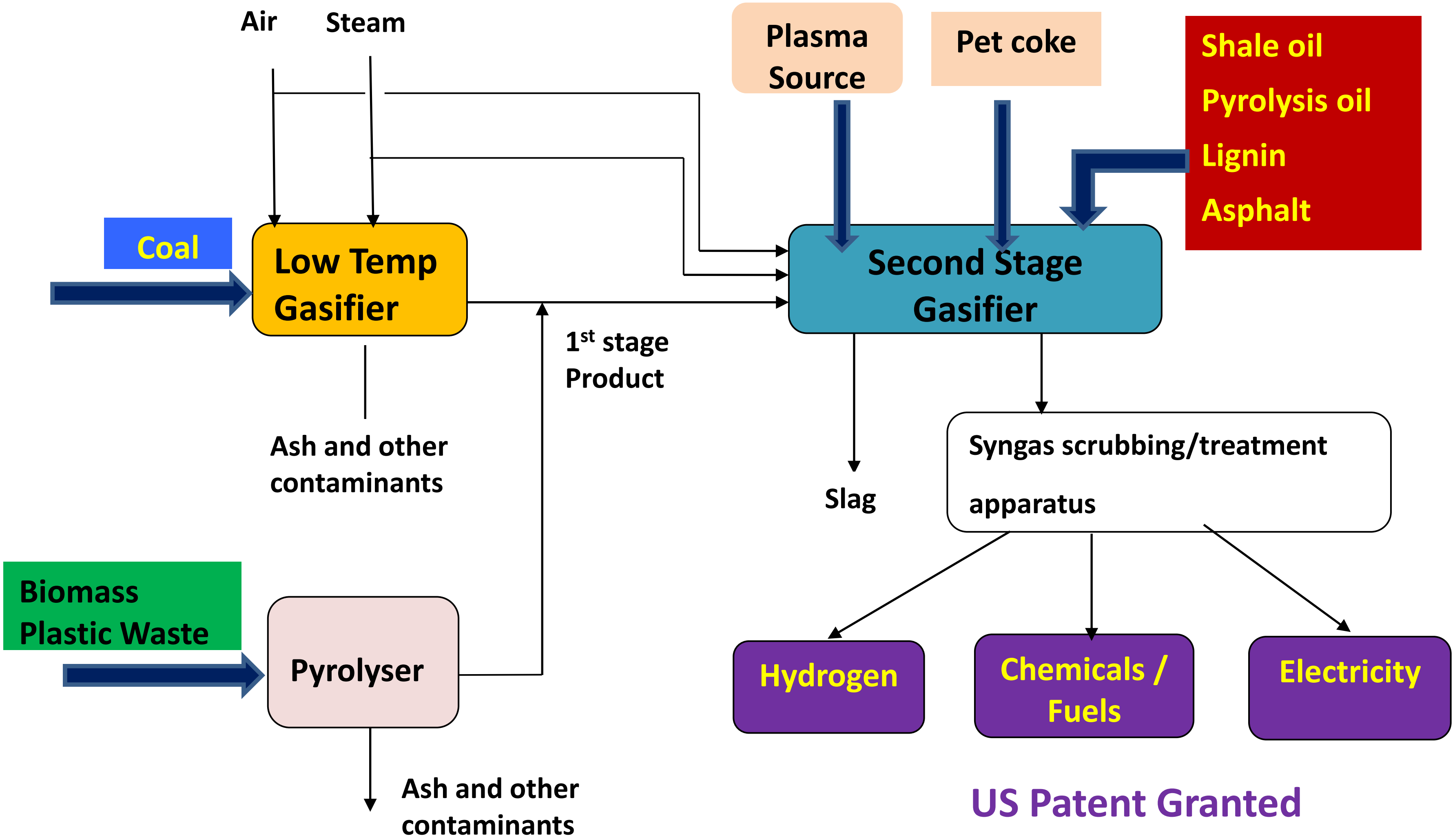
Gasification– an Attractive Alternative

- Environmental benefits
  - ✓ Much lower air emissions than for either direct combustion in conventional boilers or incineration
  - ✓ Amenable to sulfur removal as elemental sulfur through H_2S
  - ✓ Fixing of carbon in chemicals
  - ✓ High efficiency

- Flexibility of feedstock
  - ✓ Coal,
  - ✓ Residue
  - ✓ Petcoke
  - ✓ Disposal of refinery waste streams, including hazardous materials
  - ✓ Biomass derived feedstock

Gasification can provide clean, abundant and affordable energy

Integrated Gasification



Benefits

- Energy efficient process
- Ash and contaminants removed during first stage
- Clean up and treatment of Syngas minimized

Innovation in Waste Management

- 55 million tones of municipal solid waste (MSW) and 38 billion litres of sewage generated in urban areas in India.
- Waste in India is set to grow at 1-1.33% annually
- Potential of generating ~1700 MW electricity from urban waste and ~ 1300 MW from Industrial waste
- Only 6% has been realized

Source: EAI Consultancy

Bio-gas plant at Paradip Refinery Township

IndianOil initiative

Organic Waste Converters / Bio-Gas Generators

10 Organic Waste Converters & 8 Bio-Gas Generators installed .
Bio-gas from organic waste being used in canteens

IOC R&D Bio-methanation Process

- Developed biomethanation process for conversion of kitchen waste to biogas
- In-house developed high performance bacterial inoculum
- Results in very high methane content (80-85 % in biogas)

Indigenous Innoculum

50 kg/d Bio Gas plant at IOC R&D

5 tonnes per day bio-methanation plant being setup at Faridabad

Co-Processing of Vegetable Oils

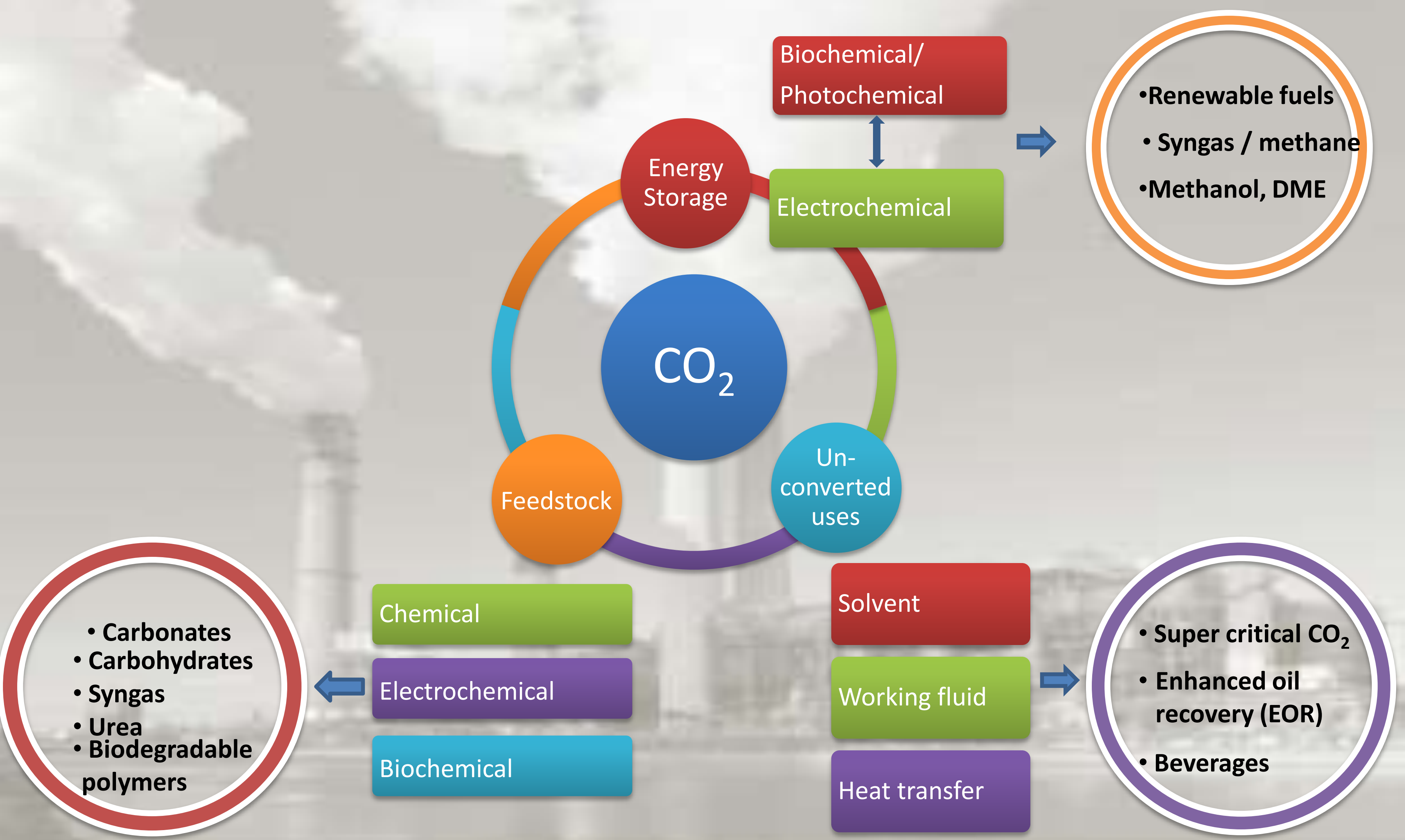
- **Co-processesing of Vegetable Oil with the Refinery feed – techno-economically better route for biodiesel production as compared to Conventional Trans-esterification process which gives Bio-Diesel**
- **Long duration experiments (1.5 years) conducted for Co Processing with 10% Jatropha oil at typical DHDT conditions/ catalyst**
- **Commercial trial done in one of the IndianOil's Refinery indicated 2-3 units improvement in Cetane number**

Degumming & demetallation of oil – Technology developed by IndianOil

- **Process developed & optimized to reduce metal content below 5 ppm**
- **Commercial trial done with Jatropha Oil feed with about 500 ppm metals. Product metals < 2 ppm**

US Patent Granted

Innovative CO2 Mitigation Techniques

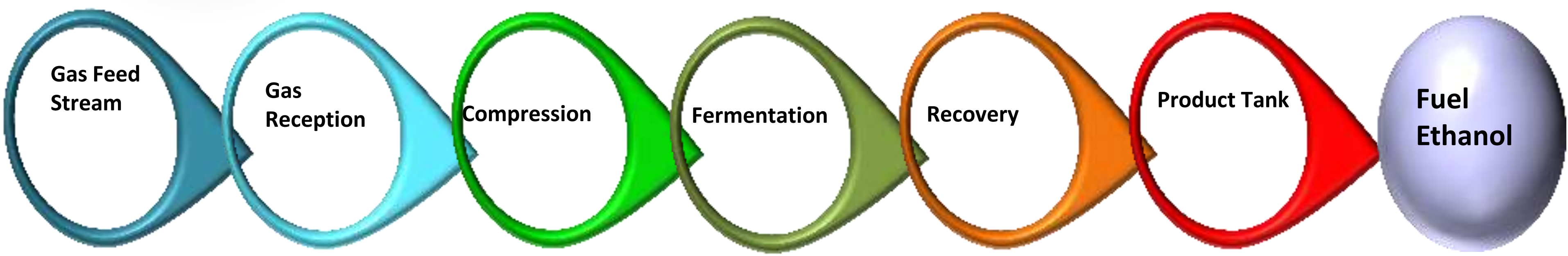


Ref. Off-Gases to Ethanol

- H_2+CO+CO_2

- PSA Tail Gas from Refinery / Hydrogen Generation Unit (HGU)

- IOC and Lanzatech under agreement to setup World's 1st Demo plant: 33,000 t/annum – 4 crore litres per annum

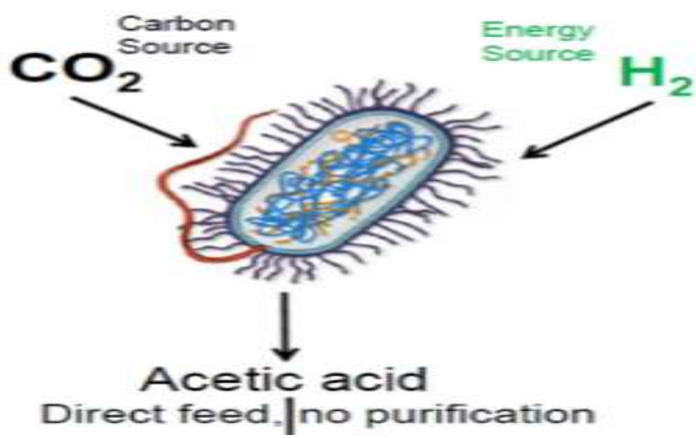


Significant CO_2 reductions to be achieved through this route

CO2 to Omega -3 Fatty Acids

LanzaTech Gas Fermentation Process

- Selectively produces Acetic acid (3-4%) from CO_2 / H2
- Proprietary anaerobe
- Extraction of acetic acid Uneconomical



•Cheap carbon source as acetate available

SYNERGISM -POTENTIALLY DISRUPTIVE PROCESS

- Extraction and Conversion of GHGs (CO_2)
- Sustainable
- High value co products

IOC R&D Process:

Thraustochytrids: (Micro -Algae)

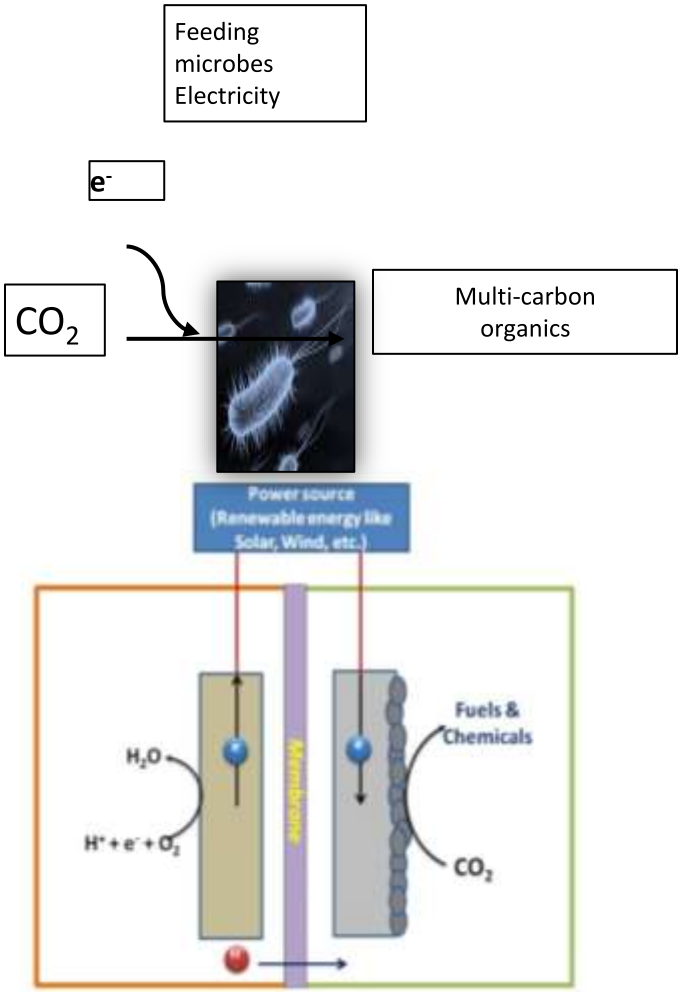
- Fast growing
- Heterotrophic
- High oil content (up to 80 % of CDW)
- 40-60 % of total oil suitable for biodiesel production
- Omega-3 fatty acids (40-60 % of total oil)
  - *Requires Carbon source - cost Element*

10 kg per day pilot plant inaugurated at IOC R&D on World Bio-fuel Day (10^{th} Aug'18)

Electro-biocatalyzed conversion of CO2 to Chemicals/ Fuels

Background

- CO_2 is transformed into hydrocarbons by electrochemical reaction at bio-cathode using electro- active microbes.
- Microbes receive electrons/energy from electrodes and use in metabolic activities to reduce CO_2 into chemicals and fuels



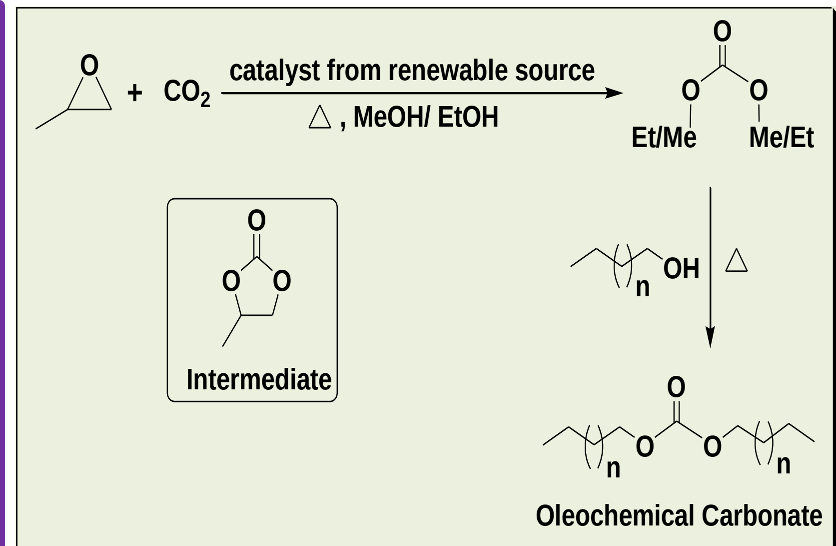
Advantages

- CO_2 capture and conversion akin to plant photosynthesis
- Process requires low energy input without external hydrogen source
- Alcohols like methanol, ethanol, butanol
- Organic acids like acetic, butyric and propionic acids

Synthesis of value added products using CO2 as Feedstock

Novel heterogeneous catalyst developed for utilization of CO_2 to value added chemicals

- Catalyst prepared from low cost renewable source – commercially viable
- Catalyst separation from reaction mixture easy.
- Single step reaction to produce dialkyl carbonates from alcohols and propylene oxide by utilizing CO_2
- Dialkyl carbonates synthesized can be tailored to long chain oleo-chemical carbonates
- High yield and purity of the final product.
- Reaction process kinetics investigated in detail



US patent granted 9,611,210B2 / Pat Appl No 201621023497

Products	RON	MON	R+M/2
Dimethyl carbonate	125-131	100-109	116
Diethyl carbonate	110-112	95-103	105
Di propyl carbonate	110-113	96-104	106

Dialkyl carbonates for use as fuel additive

Products	Density (g/cm^{-3})	Kinematic Viscosity (mm^2/s)	Cetane Number (CN)
Dioctyl carbonate	0.895	4.94	63.9
Didecyl carbonate	0.884	8.10	82.5
Dilauryl carbonate	0.883	8.57	84.3

- ➢Alkyl carbonate used successfully as structure modifier /coupler for high temperature greases

CO2 capture from Refinery flue gas to chemicals

A MoU project with M/s Carbon Clean Solutions (CCS), UK

Carbon Dioxide capture from DG Set flue gas and its utilization to value added products.

Strategy :
- Integration of technologies from M/s CCS & IndianOil R&D
- Collaborative research project with CCS,UK for demonstration of separation of CO_2 from DG set flue gas : CO_2 source
- Utilization of CO_2 to dialkyl carbonates- IndianOil R&D technology

IndianOil R&D The Power of Possibilities

CO2 to CO through Catalytic Route

•CO_2 is thermodynamically stable compound having low reactivity

•Transformation of CO_2 into other forms requires high energy

•Advanced Catalytic technologies may lower the activation energy required for CO_2 conversion

•Potential Technologies focused on converting CO_2 to synthetic fuels or precursors (i.e. CO) :

i) RWGS reaction,

ii) Dry reforming (DR) of CO_2 and CH_4 and

iii) Catalytic Hydrogenation of CO_2 to Methanol

• Many novel catalyst recipes / families being explored

IOC R&D is working with leading Indian research institute to convert CO_2 into CO in an energy efficient manner that will open vistas for other value added products

Nanotechnology Interventions

CO_2 Mitigation

Nanomaterials can help mitigating CO_2 by capture, sequestration and conversion into value added products.

- ❑Nano porous materials for CO_2 capture (Nanoporous PA and MOFs)
- ❑Nano catalysts for CO_2 sequestration and conversion (Nano Na_2VO_3)

Fuel Efficiency

Improving combustion efficiency and reducing friction can help enhancing the fuel economy, there by, decreasing carbon foot print.

- ❑Nano based fuel additive to reduce emission (Nanoparticles of CeO_2, FeO_3) / Nano-detergents for engine oil performance

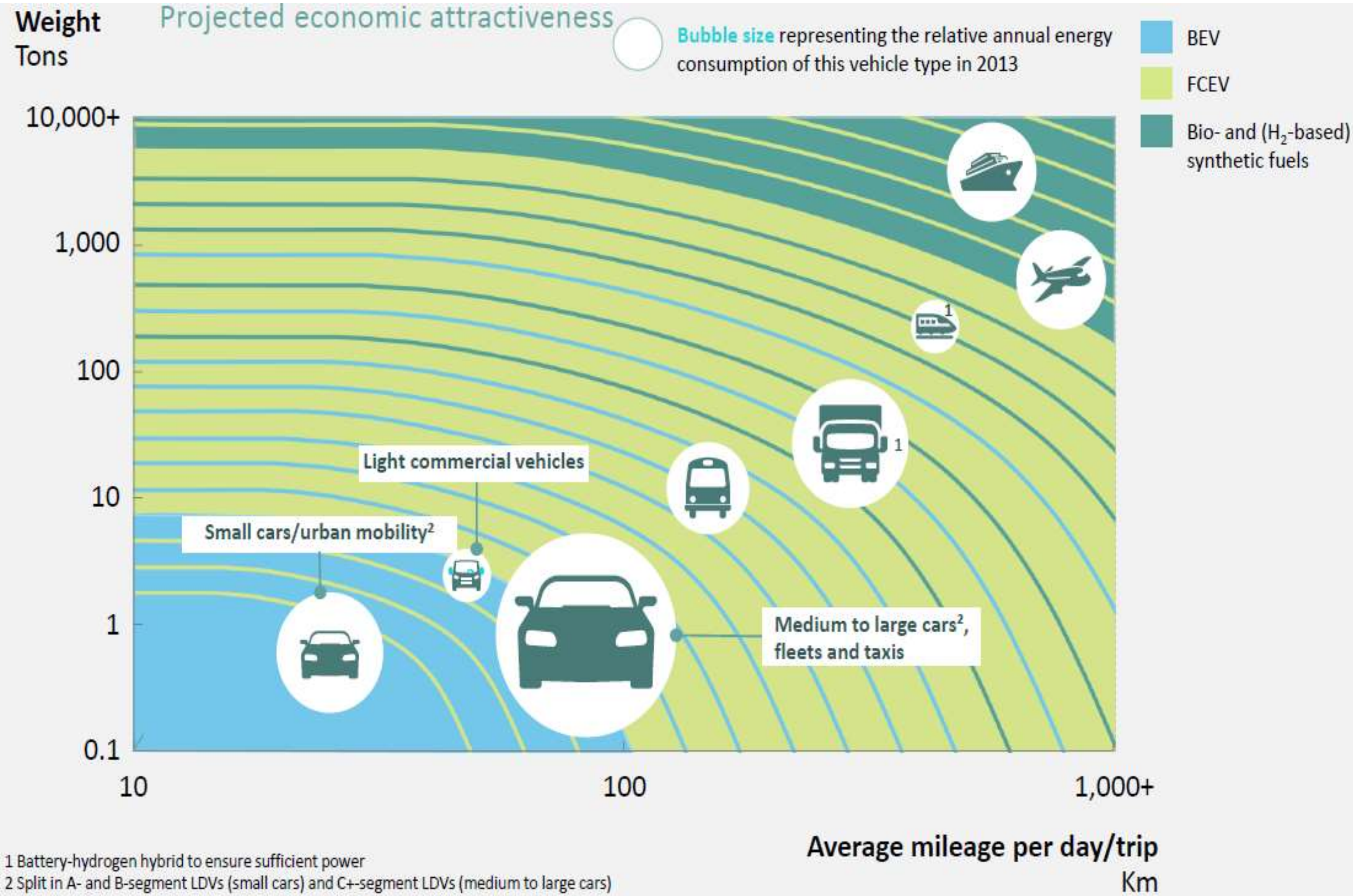
Indane Nanocut

- ❑ Applications: Metal cutting, brazing and other high temperature jobs.
- ❑ Improves: Higher cutting efficiency - *Low consumption of gaseous fuels*

Nano Dispersion For Boiler Fuel

- ❑A multimetal nano-dispersion for improving boiler efficiency and reducing carbon footprints

Emerging E-mobility options

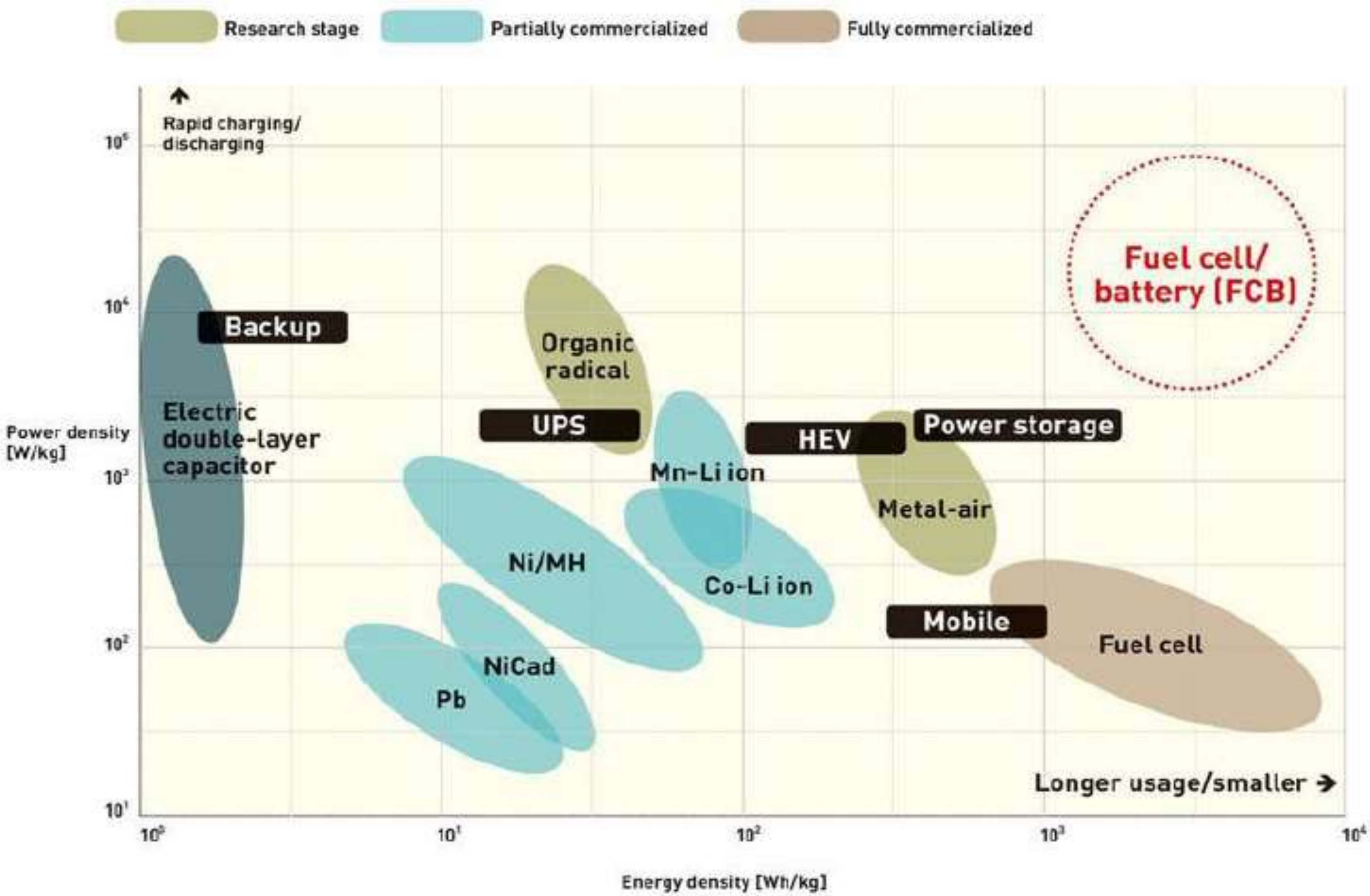


1 Battery-hydrogen hybrid to ensure sufficient power
2 Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

Source: Toyota, Hyundai, Daimler

IndianOil R&D The Power of Possibilities

Characteristics of Batteries



Ragone Plot comparing different energy storage devices

Source: Wikipedia

Lithium Ion viz-a-viz Metal Air Battery

Lithium Ion Battery

Advantages	Limitations

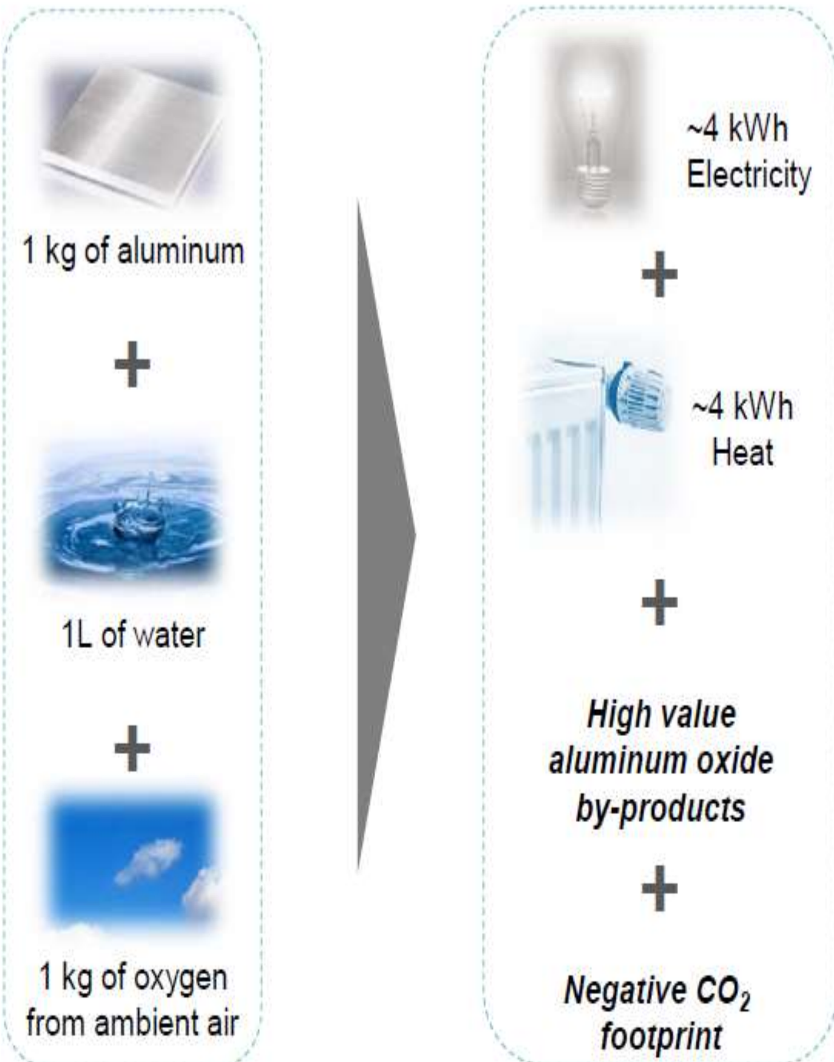
➢ Higher energy densities
➢ Lower Self Discharge
➢ Low maintenance
➢ No priming (electrolyte top up) required
	➢ Availability of Lithium in India?
	➢ Range anxiety
	➢ Lithium recyclability?
	➢ High Cost
	➢ Safety: Organic electrolyte
	    ➢ Safety Protection Required
	    ➢ Battery Transportation

Metal (Al) Air Battery

Advantages	Limitations
➢ Uses an anode made from pure metal ➢ Ambient air & Aqueous electrolyte are consumables ➢ Ultra lightweight ➢ Very high energy density ➢ Driving Range: ~1500 km ➢ Relatively low cost	➢ Anode Corrosion and by-product accumulation ➢ Replacement of aluminum anode plates required (Mechanical recharging) ➢ Recyclability of Aluminium Hydroxide ➢ R&D efforts required to mitigate range anxiety

Aluminum Air Battery with high energy density (8.1 kWh/kg) may emerge as a potential choice

Advantages



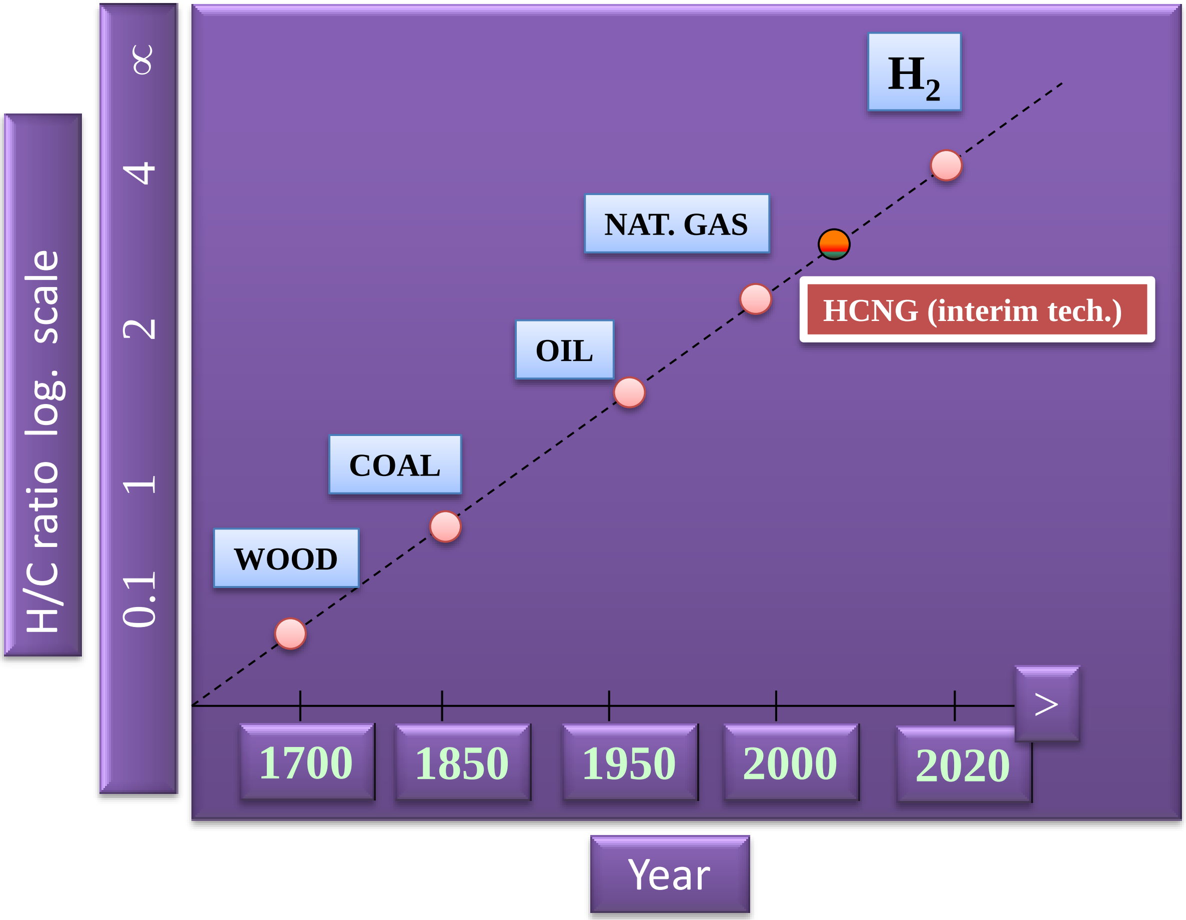
Source: Phinergy

- **High energy density–8 kWh / kg Al**
- **Zero CO2emissions–No polluting emissions**
- **Sustainability–abundant and sustainable materials**
- **Fully recyclable materials**
  - **Air-electrode and key parts are easily recyclable**
  - **Aluminium plates can be recycled into aluminium or used for other commercial applications**
- **Clean, abundant and safe raw material**
- **Cost competitive –Less than half of Li-ion price**

Imperative Journey Towards Hydrogen

Expected role of hydrogen

- Medium for energy sector decarbonisation
- Electrification of Mobility sector - Fuel cells
- Electrification of heat – Decentralized power generation
- Optimizing energy systems – energy carrier & storage medium



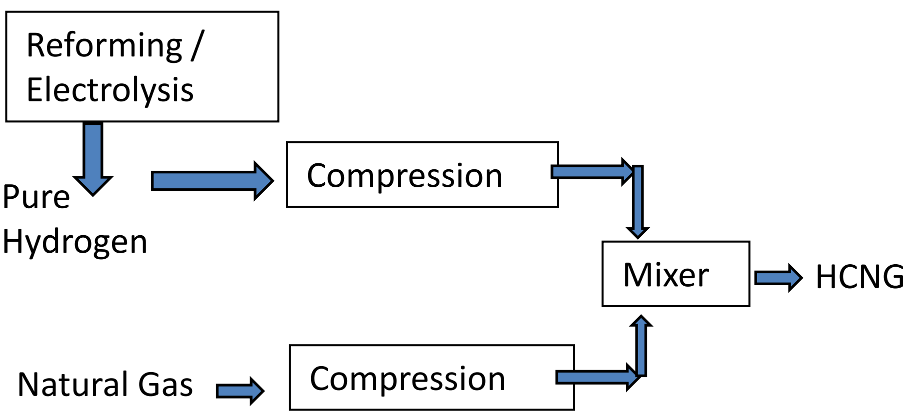
Hydrogen has potential to meet stringent environmental norms and mitigating climatic change without impacting the growth pace

HCNG Production Process

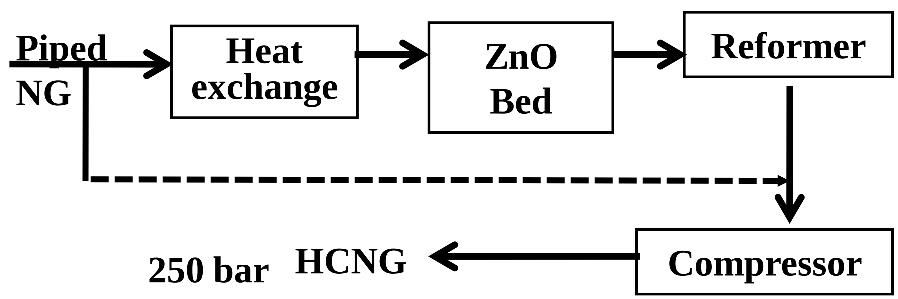
Salient Features

Cost can be reduced by innovative hydrogen / HCNG production technologies
Conventional process needs high pressure hydrogen blending
Multiple steps involved in the process adds to cost
Single step compact reforming of natural gas holds merit
Price differential w.r.t. CNG can be Rs.3-4/kg with significant emission reduction

Conventional Process



IOC's Compact Reforming Process

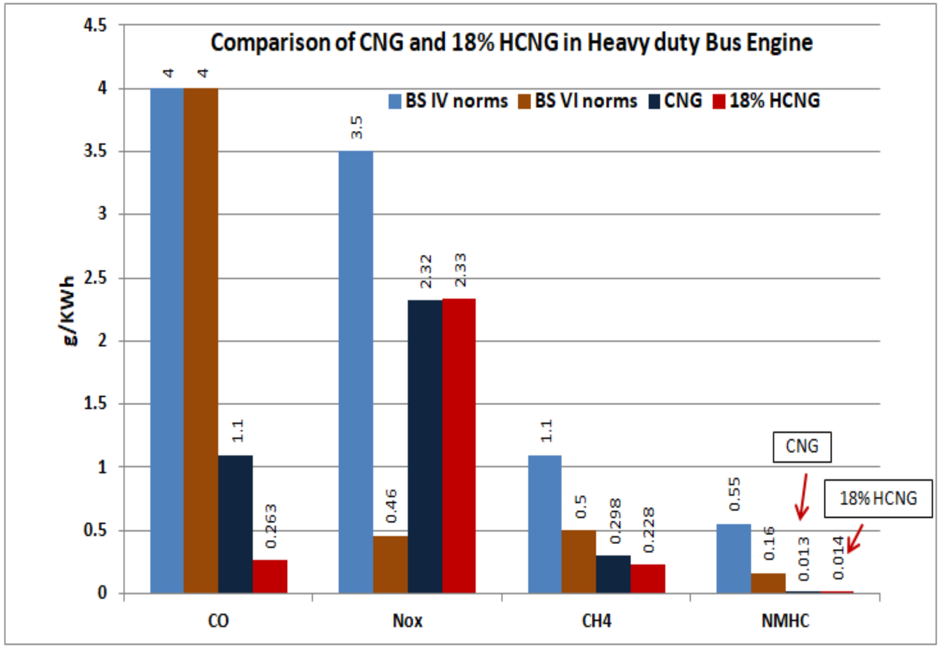


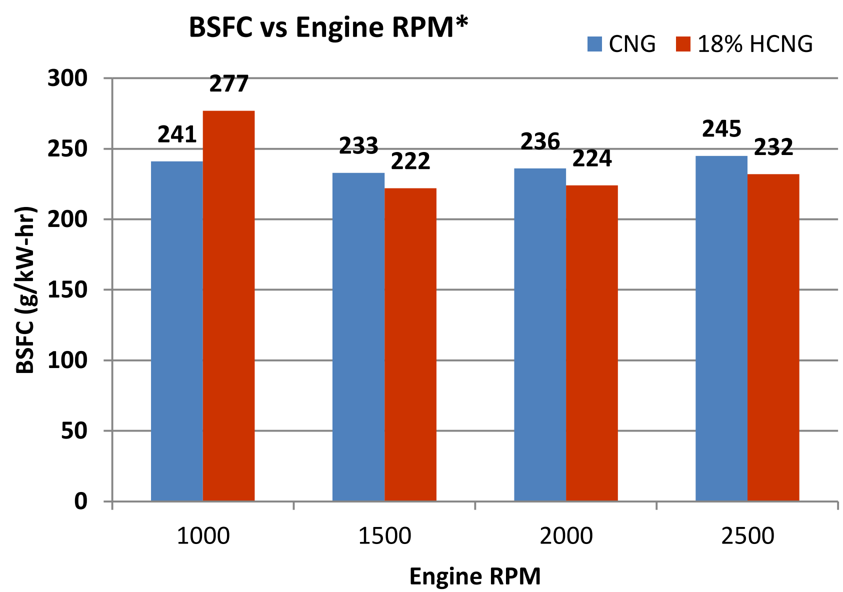
Indian Patent Granted (03/18)– 294969

Hydrogen blended CNG (HCNG)

- Collaborative project undertaken with consortium of Automotive OEMs
- HCNG blends evaluated on 7 light duty vehicles
- 18% HCNG shortlisted based on Power and Emission characteristics
- Long duration trials conducted on HCNG optimized vehicles
- HCNG reduces CO emissions by 26%, HC by 20% and Fuel Economy increases by 3%-4% as compared to CNG

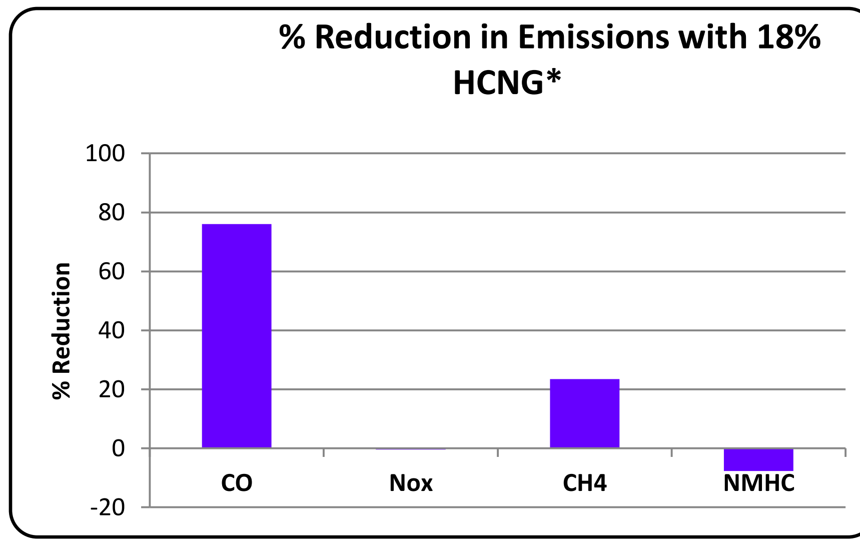
HCNG for Heavy Duty Applications





- 18% HCNG can meet CO & HC emission limits set for BS VI
- Nox emissions can be reduced by suitable calibration / exhaust after treatment interventions
- 4% - 5% benefits in fuel consumption achieved at full load.

Source: IOC R&D-ARAI Studies



**Based on tests conducted at ARAI,Pune on Heavy duty bus engine*

HCNG for Demo in Delhi: APEX Court

IOC to SC: Conducting study on using CNG-hydrogen mixed fuel

The court was told that hydrogen and CNG mixed fuel was a cleaner fuel compared to CNG and IOC has tried this technology

PRESS TRUST OF INDIA
New Delhi, August 13

INDIAN OIL CORPORATION (IOC) on Monday told the Supreme Court that it was conducting a study on using mixture of CNG and hydrogen fuel for buses and would take around six months to come out with a "workable result" on it.

The IOC told a Bench of Justices Madan B Lokur, S Abdul Nazeer and Deepak Gupta that following the study, the corporation would conduct trials which would take around six months thereafter. It said that around ₹14 crore was required for implementation of the pilot project.

Advocate Aparajita Singh, assisting the top court as an amicus curiae in the air pollution matter, told the bench that the corporation should expedite the process and ₹14 crore could be given to IOC from the money collected under environment compensation charge (ECC).

Singh said the Delhi-National Capital Region (NCR) had a robust CNG infrastructure in place which would help in this process.

The Bench, while accepting the submissions of the amicus, said that ₹15 crore from the ECC be sanctioned to IOC to conduct the study and carry out the pilot project.

The court listed the matter for further hearing in November. The amicus had earlier told the court that buses running on hydrogen and CNG mixed fuel would help tackle air pollution.

The court was told that hydrogen and CNG mixed fuel was a cleaner fuel compared to CNG and the IOC has tried this technology. The Bench had earlier suggested that the possibility of using hydrogen fuel cell-powered vehicles, which are of hybrid nature, and considered cost-effective compared to CNG or electric vehicles, should also be explored.

THE TIMES OF INDIA

Conducting study on using CNG-hydrogen mixed fuel: Indian Oil to SC

PTI | Aug 13, 2018, 06.03 PM IST

NEW DELHI: Indian Oil Corporation Ltd (IOCL) on Monday told the Supreme Court that it was conducting a study on using mixture of CNG and hydrogen fuel for buses and would take around six months to come out with a "workable result" on it.

The IOCL told a bench of Justices Madan B Lokur, S Abdul Nazeer and Deepak Gupta that following the study, the corporation would conduct trials which would take around six months thereafter.

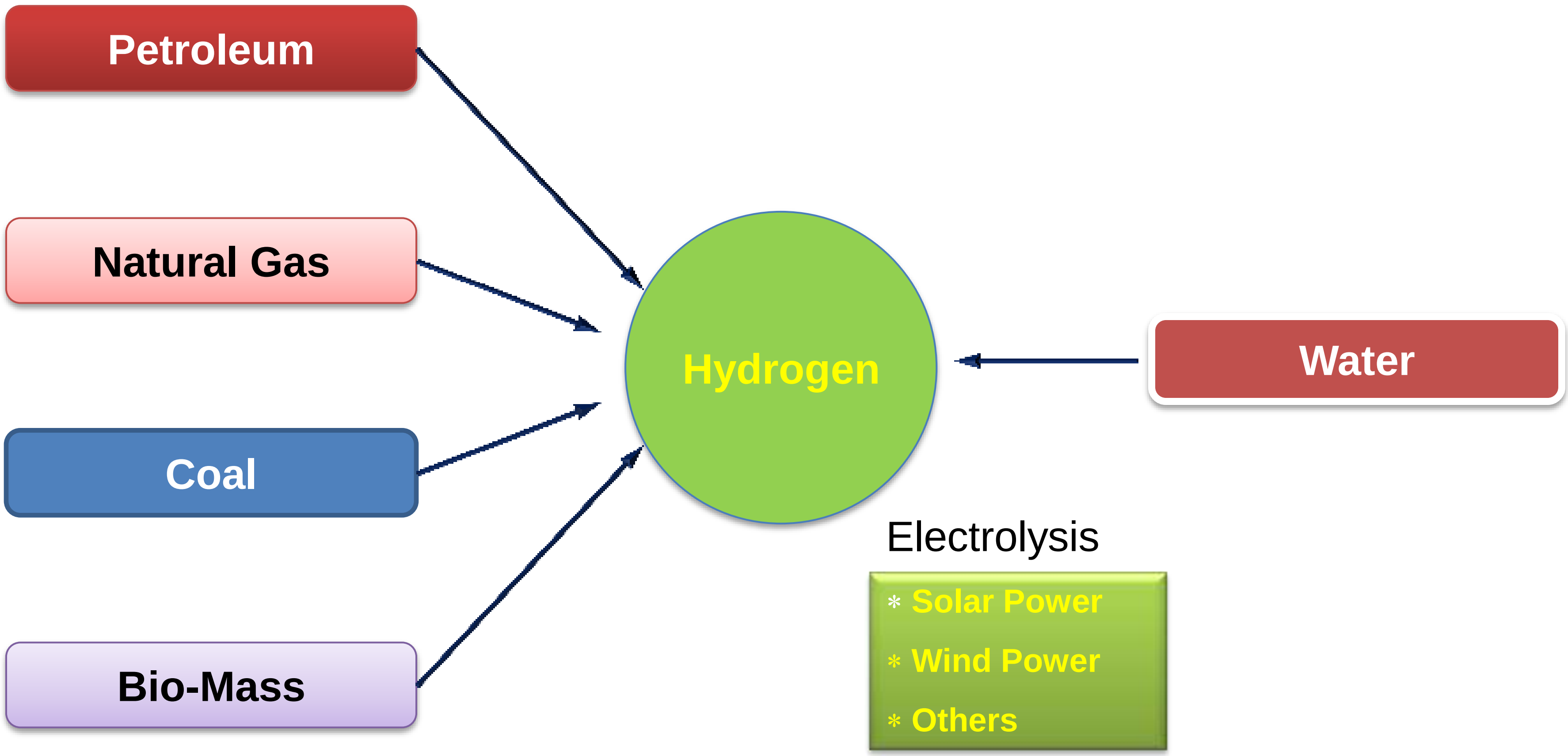
It said that around Rs 14 crore was required for implementation of the pilot project.

Advocate Aparajita Singh, assisting the top court as an amicus curiae in the air pollution matter, told the bench that the corporation should expedite the process and Rs 14 crore could be given to IOCL from the money collected under environment compensation charge (ECC).

The Bench, while accepting the submissions of the amicus, said that ₹15 crore from the ECC be sanctioned to IOC to conduct the study and carry out the pilot project.

Pilot trials to convert and run 50 buses on 18%HCNG produced through IOC's compact reformer technology

Hydrogen Production Pathways

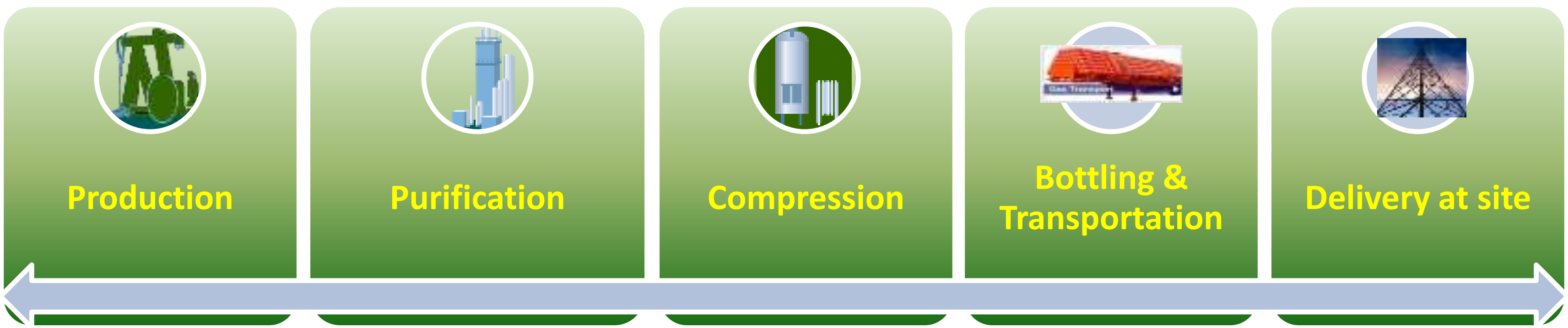


- Hydrogen can be produced from variety of sources
- SMR and Coal gasification - preferred technologies for hydrogen production upto 2050
- Refineries are the potential production centres for hydrogen supply for different applications

Hydrogen Production Cost

- **DoE Mandate:**
  - **Develop technologies to produce hydrogen from clean domestic resources at a delivered and dispensed cost of \$2-\$4 /gge H_2 by 2020**
- **Indian Scenario**
- **H_2 production cost (SMR big size)*** : **Rs 200-250 /kg (\$4-\$5/kg)**
- **Electrolysis*** : **Rs 350-450 /kg (\$7-\$9/kg)**
- **Chlor-Alkali Industry** : **Rs 200-250/kg (\$4-\$5/kg)**

*Only production cost



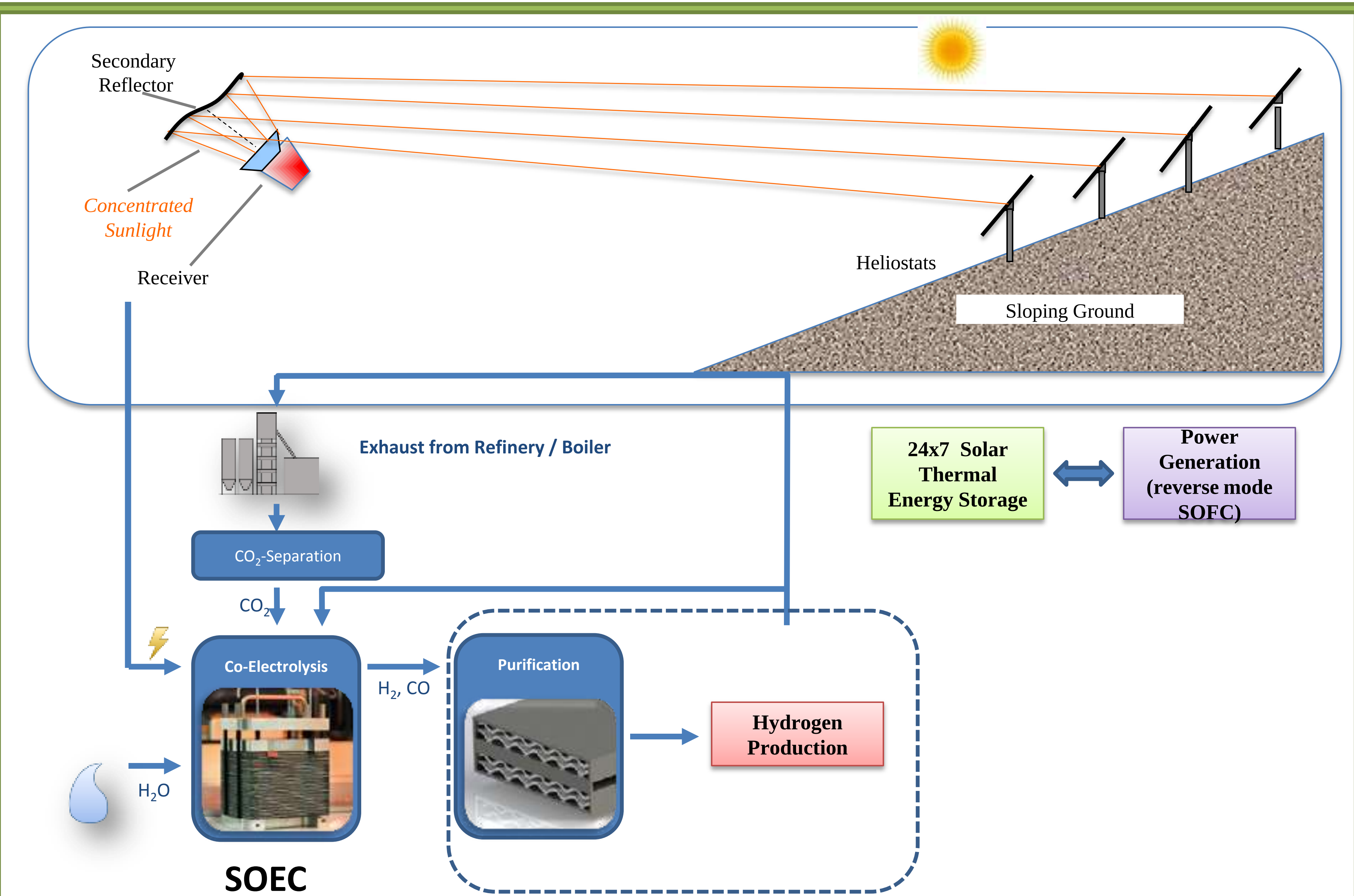
H_2 End-mile Cost in India (\$/kg)	
99.9%	\$ 11-12
99.99%	\$ 17-18
99.999%	\$ 21-22

1 gallon of gasoline in India: \$4.37

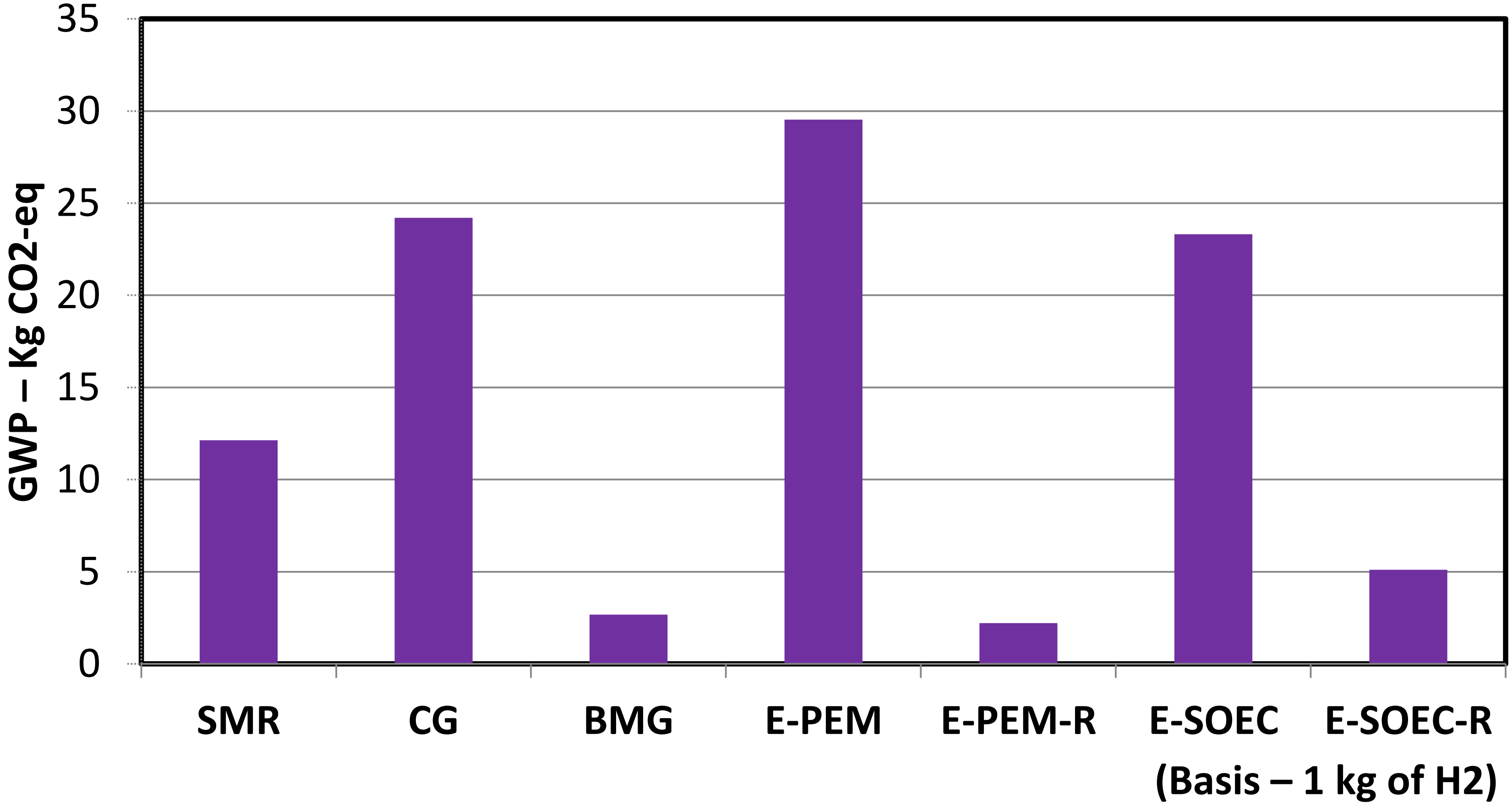
Note: 1 kg H_2 = 1 gge

IndianOil R&D *The Power of Possibilities*

Hydrogen Production through Solar Energy



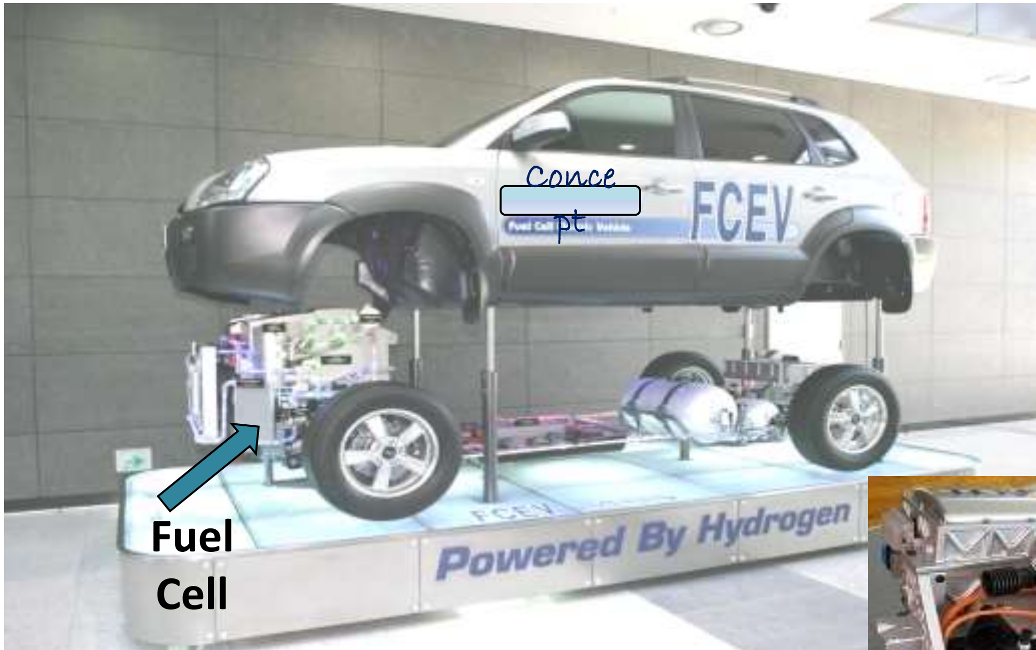
Life-cycle Emissions of Hydrogen Production Pathways

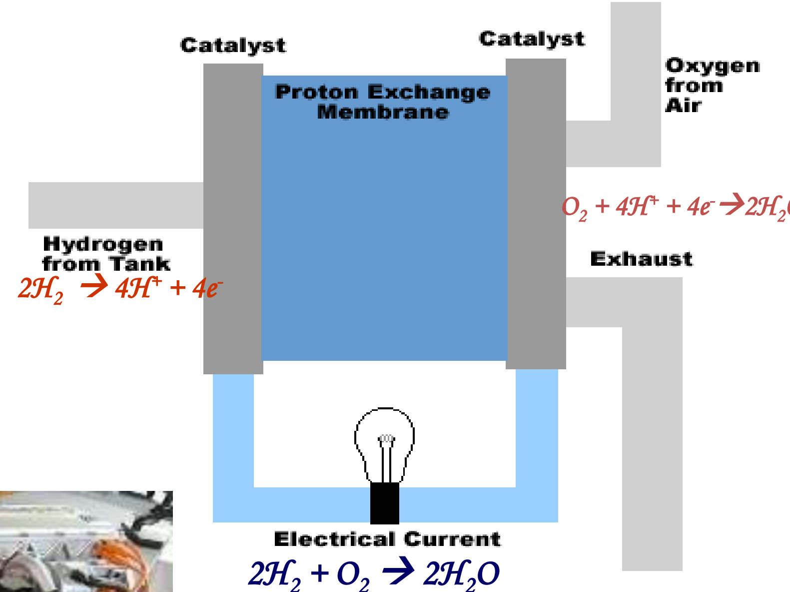


SMR – Steam methane reformer, CG – Coal gasification, BMG – Bio mass gasification, E-EPM – Electrolysis with Proton exchange membrane, E-PEM-R - Electrolysis with Proton exchange membrane using wind energy, E-SOEC – Electrolysis with solid oxide electrolysis cell , E- SOEC-R - Electrolysis with solid oxide electrolysis cell using wind energy

Source: MDPI *Environments* 2018, 5, 24; doi:10.3390/environments5020024

Fuel Cell Introduction





Expanded View - Fuel Cell System

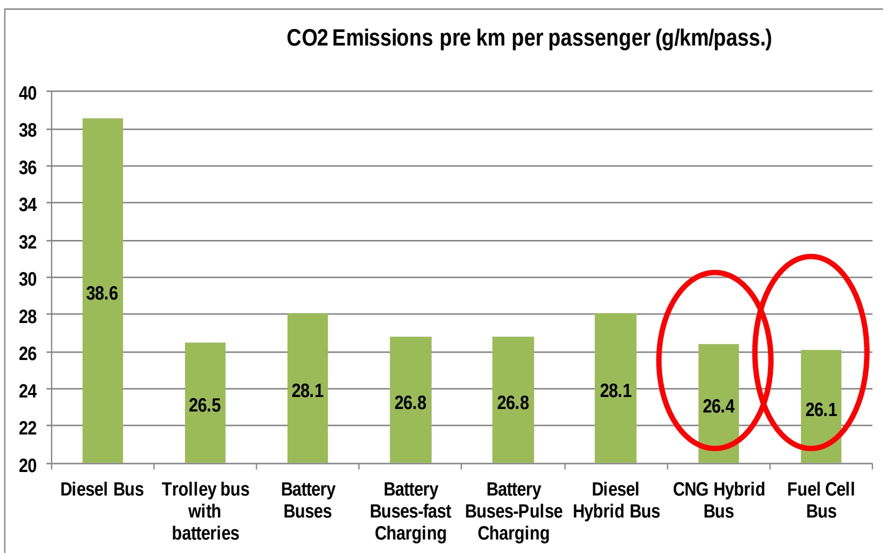
Diesel Car → 18 km/litre of diesel

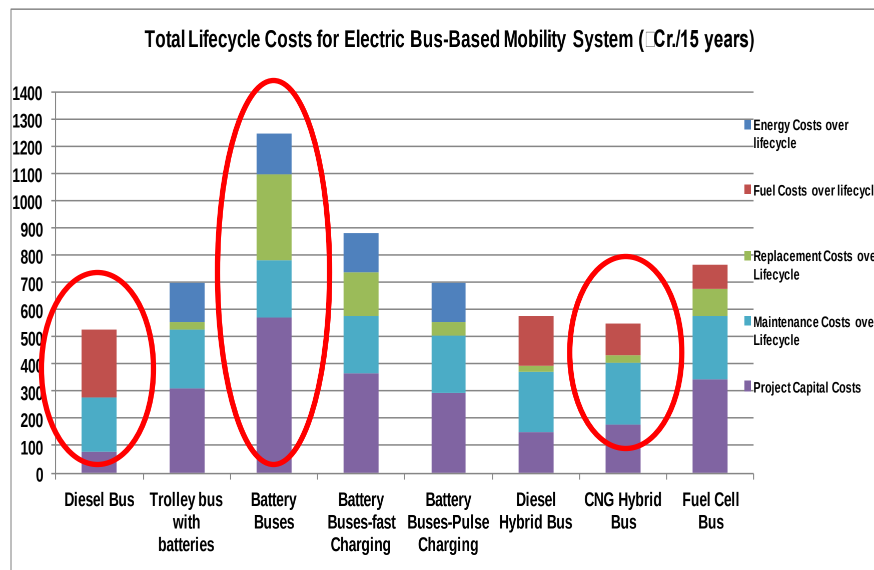
Fuel Cell Car → 100 km/kg of hydrogen

Fuel Cell Bus

Fuel Cell bus – 1st Fuel Cell Vehicle in India

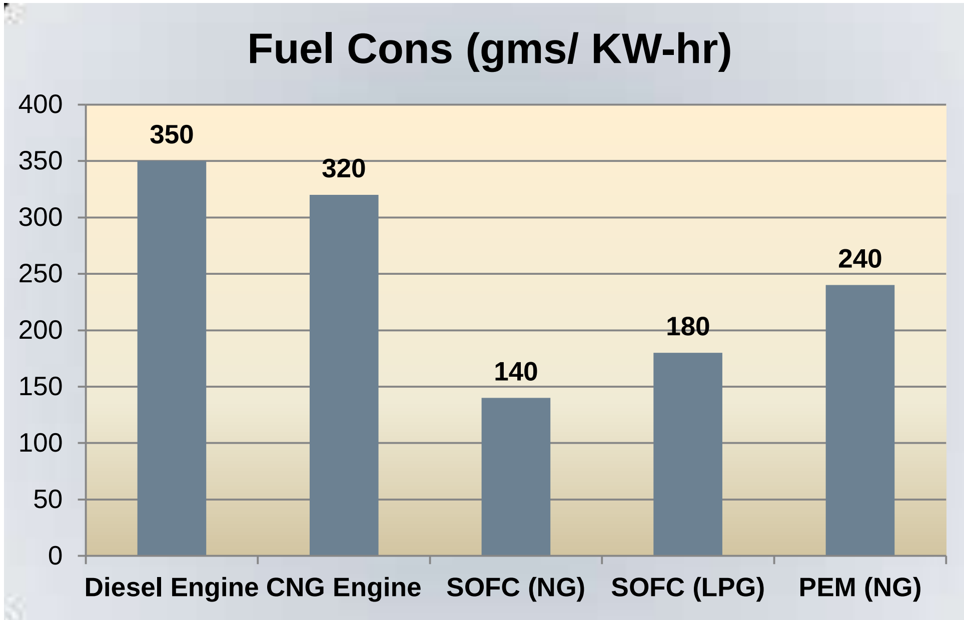
- Inaugurated on 10th March 2018
- 120 KW PEM Module
- On board High Pressure Type 3 composite cylinders 40 Kg H_2 @350 bar
- Fuel Cell bus range per fill ~300 Km
- Hydrogen refueling from IndianOil's dispensing stations
- Long duration Trials under progress

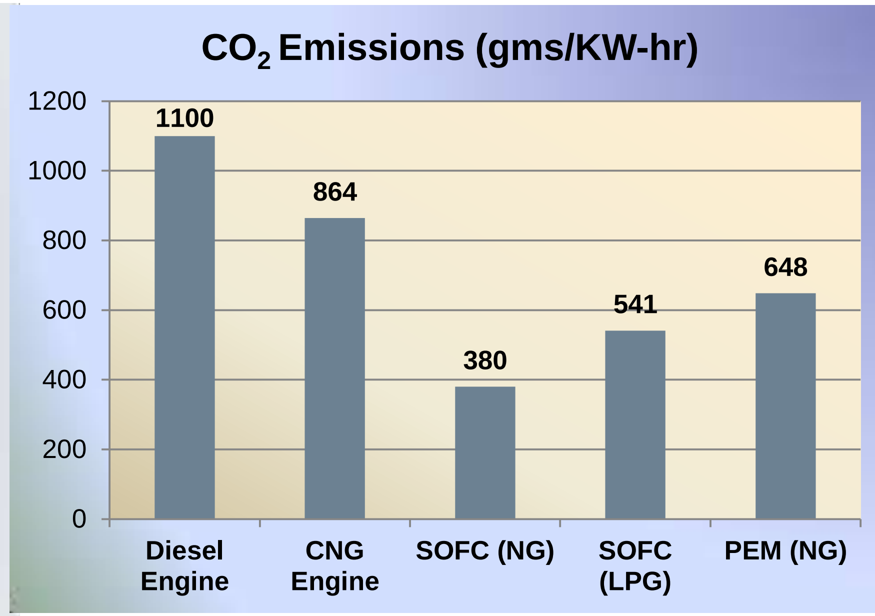




Source: Tata Motors

Potential CO2 Reduction





- 65% CO_2 reduction with SOFC (Natural gas)
- 50% CO_2 reduction with LPG SOFC
- 25% CO_2 reduction with PEM (H_2 from Natural gas reforming)

Source: IOC R&D studies based on Indian data

- With India setting 10% import reduction target, can this be the USP for fuel cell companies
- Economies of scale and available infrastructure favour low cost hydrogen generation with conventional fuels
- Lower solar energy generation cost, better economics for renewable hydrogen

SUMMARY

- Changing Energy Landscape
- Fuels & Lubricants – to play significant role in CO_2 reduction
- Bio-fuels – Coming of Age
- CO_2 utilization through chemical, bio-chemical & electro-chemical pathways – holds considerable promise
- Hydrogen –Cleanest energy option
- HCNG – A potential interim bridge technology
- Batteries need breakthroughs along their value chain to attain cost viability and meaningful CO_2 reduction
- Renewable hydrogen based fuel cells offer best promise of CO_2 reduction

“Changing the answer is evolution. Changing the question is revolution.”

Thank You