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Railway Locomotive: Status, Challenges and Opportunities in India

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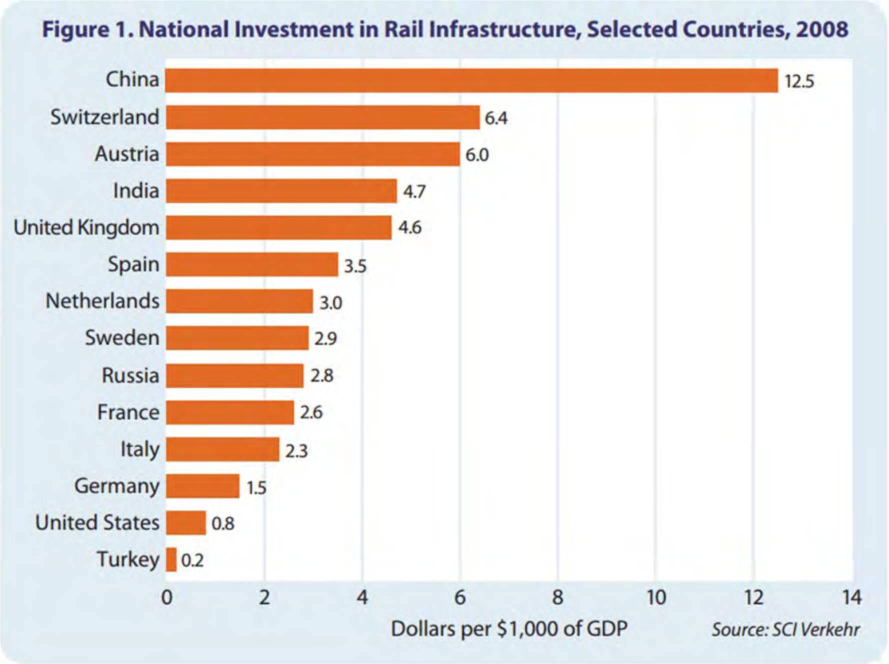
Introduction of Indian Railway/ Locomotive Sector

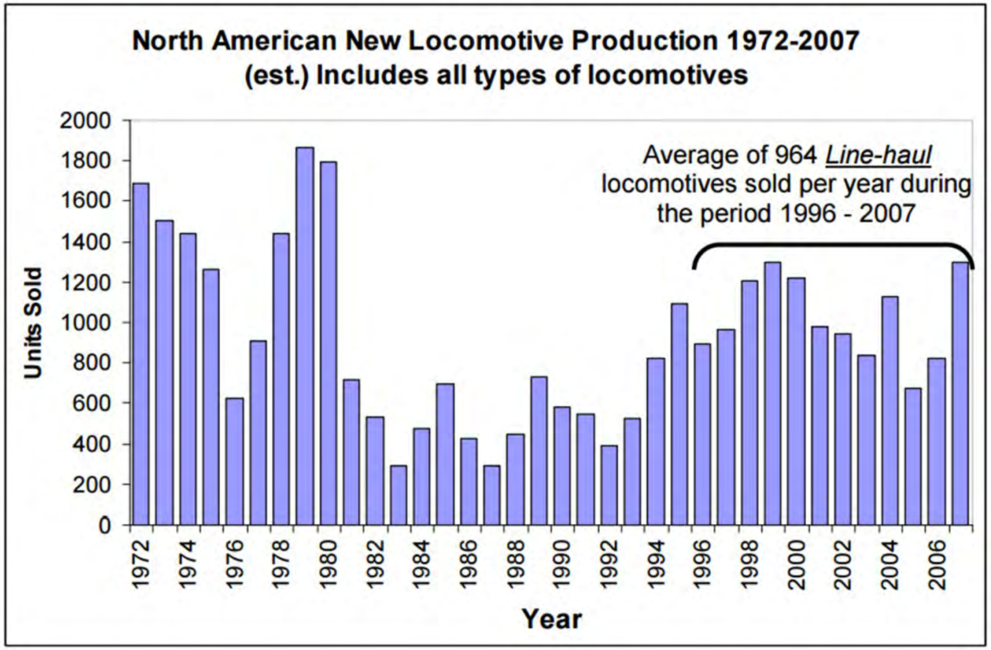
- World's second largest railway network under a single management.
- Total staff strength is about 1.4 million
- Total route length of rail network exceeds 64,000 kilometers.
- ~20 million passengers/day and ~2.5 million tons of freight/day are transported.
- Large fleet of diesel locomotives ~5000 nos. Growing @ 250 locomotives per year.
- Diesel fuel consumption of 2.6 billion liters/ year.
- Diesel locomotives have the **least life cycle energy consumption**; green house gases emissions; harmful pollutants emissions.

Sector	As percentage of GDP (at factor cost and constant prices)									
	1999-2000	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
Transport of which:	6.0	6.0	6.0	6.2	6.3	6.7	6.7	6.7	6.7	6.6
Railways	1.3	1.3	1.2	1.2	1.2	1.0	1.0	1.0	1.0	1.0
Road Transport	3.8	3.9	3.9	4.1	4.3	4.8	4.8	4.8	4.7	4.8
Water Transport	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Air Transport	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Services *	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4

Source: Central Statistical Organisation Report

Status of Rail Transport Sector Globally





Diesel Locomotives/ Engines in India

ALCO (ALCo) –DLW Diesel-Electric

- 6, 12, 16 cylinder versions
- 16 cylinder version largest population (about 5000)
- 4-stroke, 9" x 10.5" bore / stroke
- 10.9 liter displacement / cylinder
- 200 -225 hp per cylinder
- Water cooled
- Turbocharged and after-cooled
- Mechanical fuel injection
- Do not meet any International Emission Standard

EMD (Electro-Motive Diesel)

- 16 cylinder version only, although design exist for 12 cylinder version also
- About 1500 population, growing @ 200 per year
- 2 stroke, 11"x12" bore/ stroke
- 11.5 liter displacement/ cylinder
- 280 hp/ cylinder
- Water cooled
- Turbocharged and after-cooled
- Mechanical fuel injection
- Do not meet any International Emission Standard

Diesel Multiple Units

- Equipped with Cummins KTA 50L engines
- About 1000 population
- 4-stroke, 6.25" x 6.25" bore/ stroke
- 3 liter/ cylinder
- 85 hp/ cylinder
- Water cooled
- Turbocharged and after-cooled
- Mechanical fuel injection
- Meets US EPA Tier 0 standard

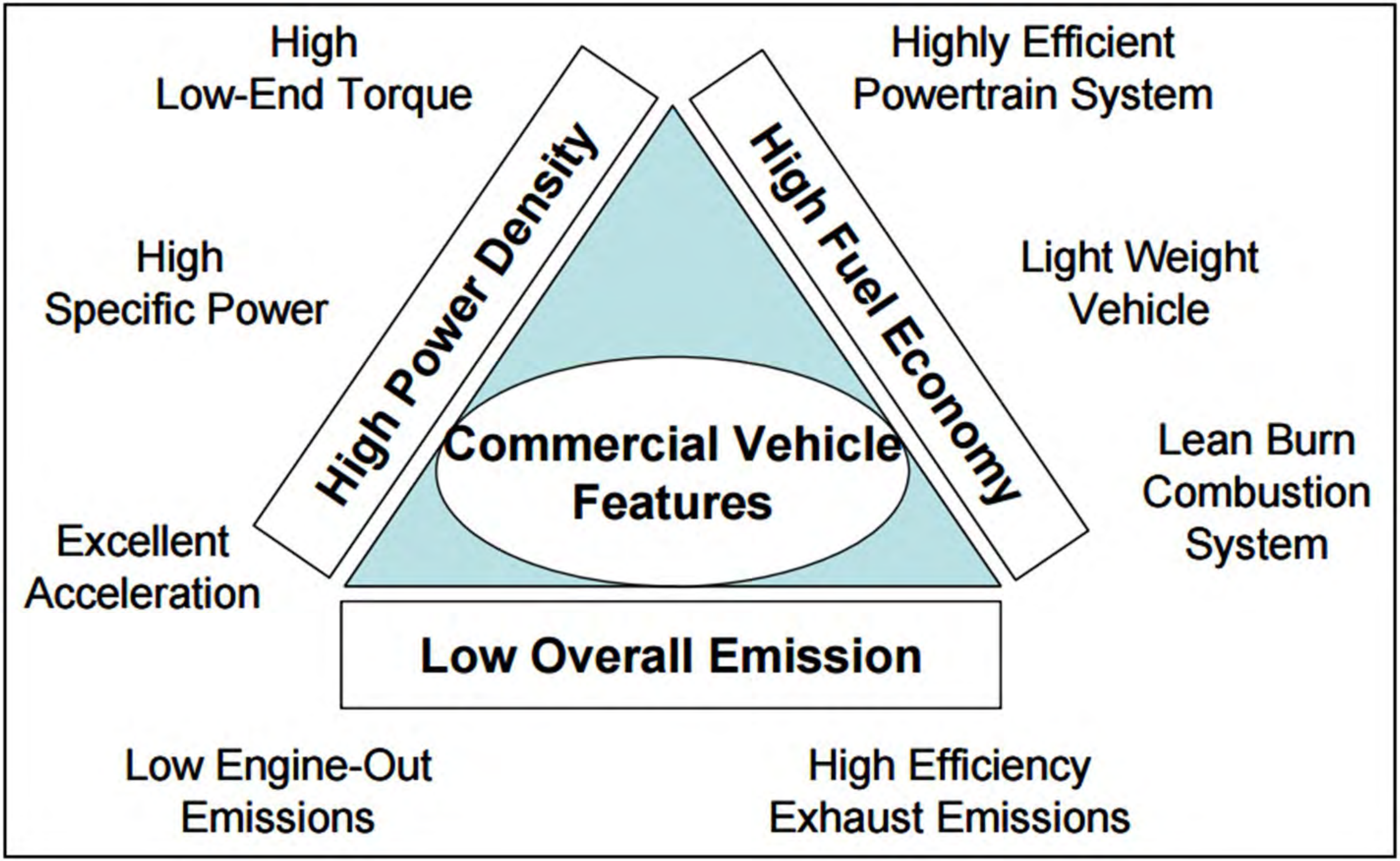
Modern Engines

- Power Car engines
- Diesel generator sets on Railway Stations, Offices, Buildings, Colonies
- Diesel engines on Track cars
- Diesel Engines on Overhead monitoring cars
- Diesel engines on other measurement cars

Position of Indian Railways

- Legal position – National Green Tribunal
- Emission inventory being carried out by RDSO
- MoR is in process of engaging an agency for developing the emission standards
- Projects taken up with IIT Kanpur and support by DST
- Some measures in progress
    - EFI, CReDI, Miller cycle turbo, Plate type after-cooler, separate after-cooling, higher PCP engine block etc.
    - Developed World's first Mobile Emission Test Car
    - Lab emission measurements systems put in place
    - Set up FTIR to measure unregulated and harmful emissions like aldehydes, ketones, etc.
    - Set up Engine Exhaust Particle sizer (EEPS) to measure distribution of particle size of exhaust

Expectations from a Locomotive Engine



Challenges Offered/ Opportunities to Grab….

- New locomotives must meet a wide range of railroad company, customer, and community requirements, including:
  - Safety
  - Exhaust emissions performance
  - Extensive range
  - High horsepower
  - High tractive effort
  - Fuel economy
  - Reliability
- Continuous improvements in locomotive design have played a critical role in keeping the railroad industry competitive and viable by improving the cost structure of the industry. These improvements include:
  - Increased locomotive reliability,
  - Greater horsepower,
  - Greater power to weight ratio,
  - Improved traction motors,
  - Better fuel economy.

Social Cost of Diesel Engine Emissions

Country	NO_x per ton		PM per ton	
	low	high	low	high
USA	$ 1,590	$ 23,340	$ 13,740	$ 187,480
EU	€ 4,400	€ 12,000	€ 25,453	€ 73,422
Australia	A$ 543	A$ 1,629	A$ 120,977	A$ 362,932

Source: International Union of Railways (UIC), International Energy Agency Handbook 2009

Indian Pollution Burden from Locomotive Engines

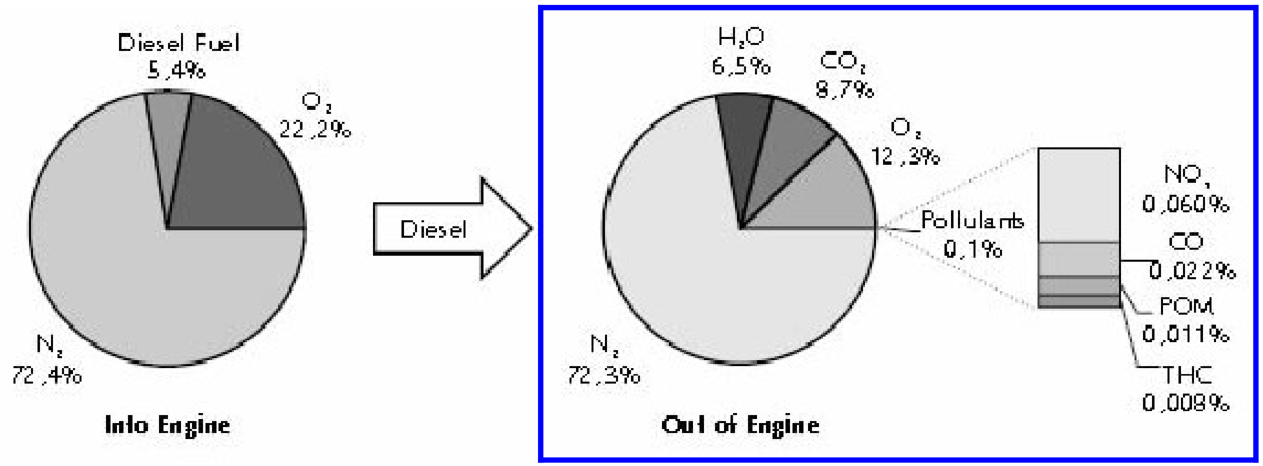
- 600 Kilotons of NOx,
- 25 Kilotons of particulate matter (PM) and
- 50 Kilotons of unburned hydrocarbons (HC) annually into the atmosphere

Cities	Low cost estimate (Rs. Per ton)				High cost estimate (Rs. Per ton)			
	CO	HC	NO_x	PM	CO	HC	NO_x	PM
Delhi	50	600	7,310	63,730	460	6,730	108,260	869,570
Kolkata	10	170	2,110	18,200	130	1,920	30,920	248,360
Chennai	10	170	2,040	17,670	130	1,860	30,020	241,130
Mumbai	30	400	4,870	42,050	310	4,440	71,430	573,780

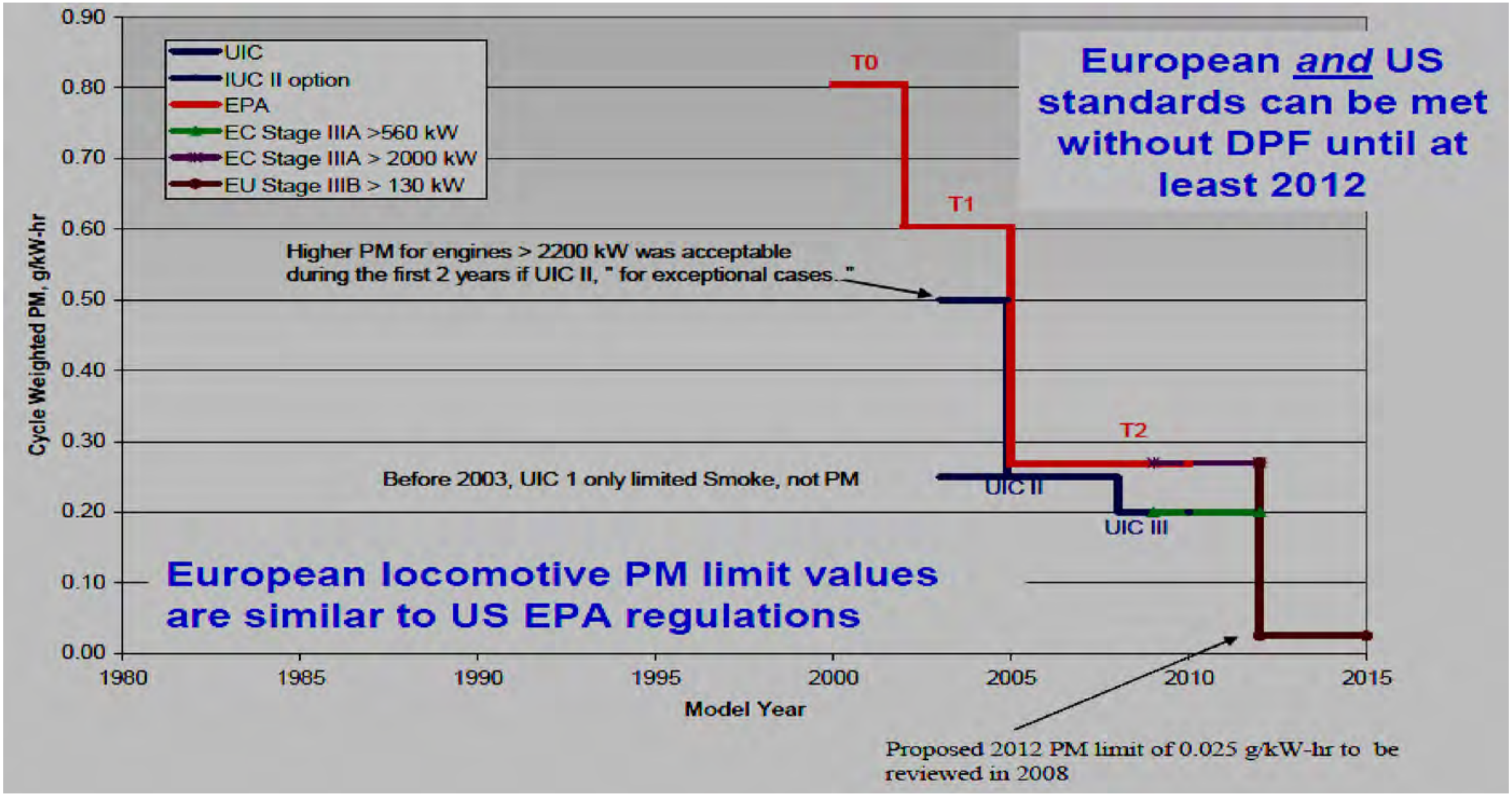
Source: International Union of Railways (UIC), International Energy Agency Handbook 2009

Main Constituents of Diesel Engine Exhaust Emissions

- Carbon (soot)
- Water (H_2O)
- Carbon monoxide (CO)
- Carbon dioxide (CO_2)
- Nitrogen (N_2)
- Oxides of nitrogen (NOx)
- Oxides of sulphur, Alcohols
- Aldehydes
- Ketones
- Various hydrocarbons (HC)
- Polycyclic aromatic hydrocarbons (PAHs)
- Particulate Matter (PM)



Progression of Locomotive PM Regulations



- Diesel particulate is carcinogenic and a photochemical smog component.
- Both size and chemical composition of PM is responsible for its health and environmental impacts.

Emission Reduction (In-cylinder Techniques)

- Electronic fuel injection/ Common Rail
- High pressure injectors
- Higher rate of injection
- Higher compression ratio and optimized combustion chamber
- Miller cycle/ VGT turbocharger
- Higher effectiveness after-cooler (plate type)
- Separate after-cooling system
- Sizing and redesign of exhaust manifolds
- Intake and exhaust ports redesign
- Electrically assisted turbocharging
- Variable valve timing
- Cooled Engine Exhaust Gas Recirculation

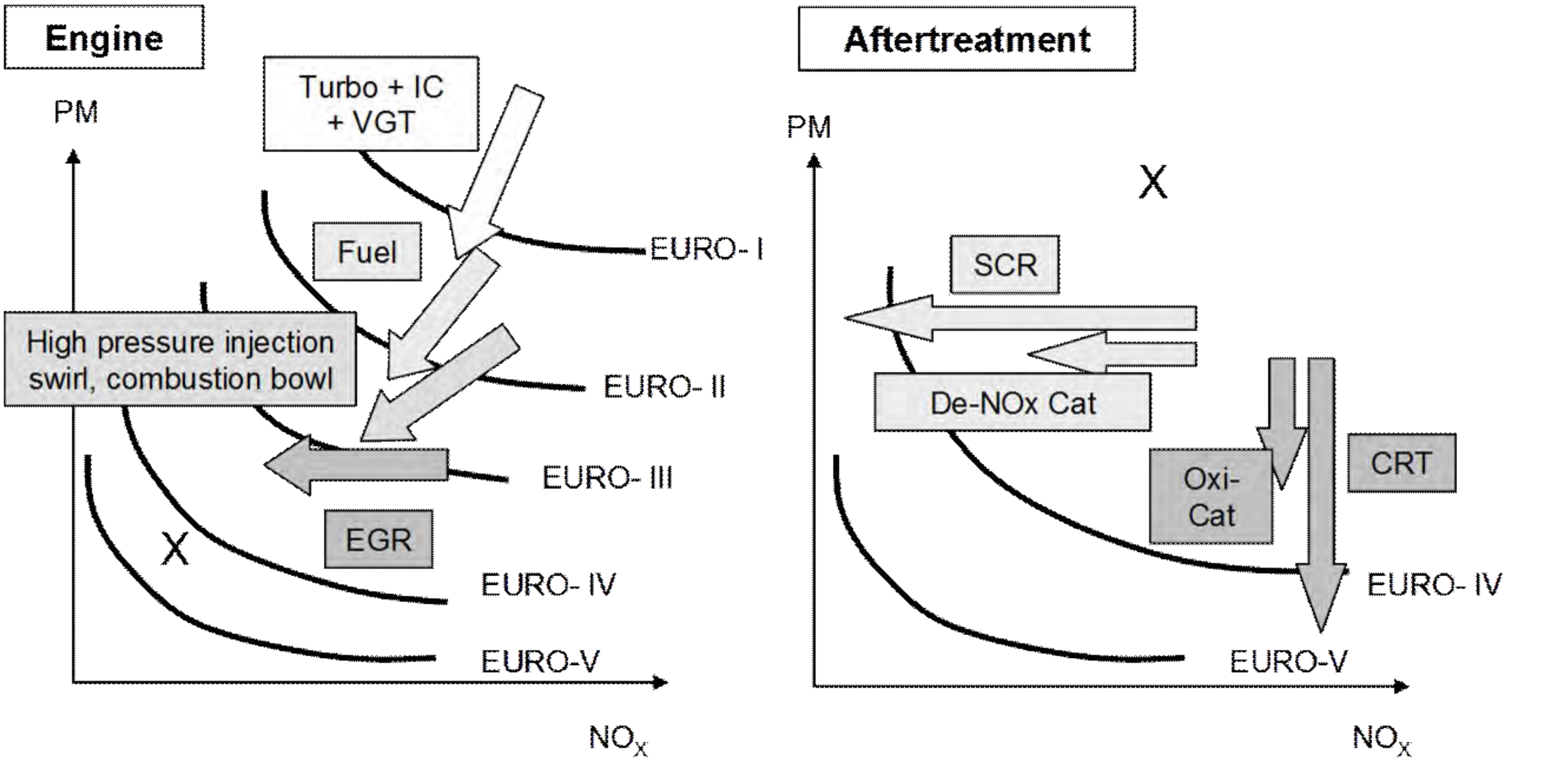
Emission Reduction (After-treatment)

- Diesel Oxidation Catalyst
- Diesel Particulate Filter
- Selective Catalytic Reduction

Issues and challenges in using after-treatment devices

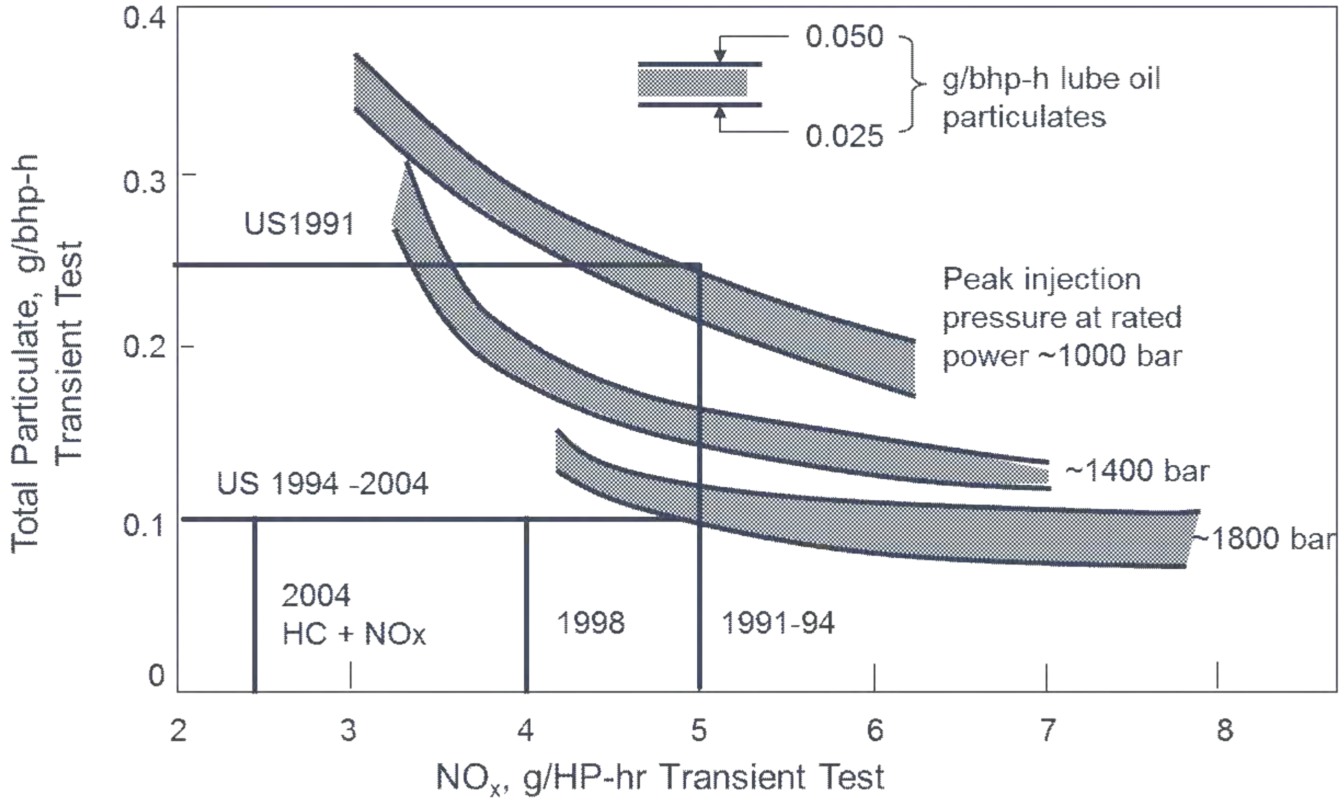
- Packaging problem due to high exhaust flow rates
- Axle load restrictions
- Maximum moving dimension restrictions
- Fuel efficiency deterioration not allowed

Trends in Emission Control Technologies for CI Engines



Source: Pundir, 2007

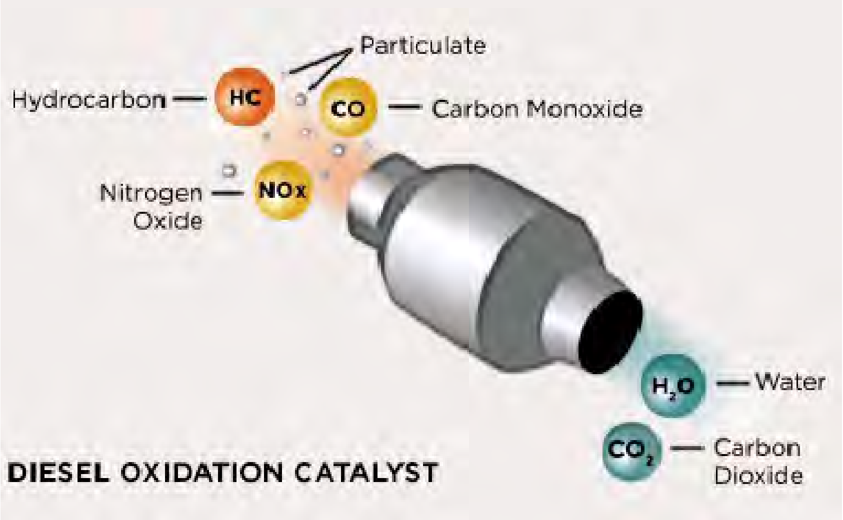
Effect of High Diesel Injection Pressure on NOx and PM



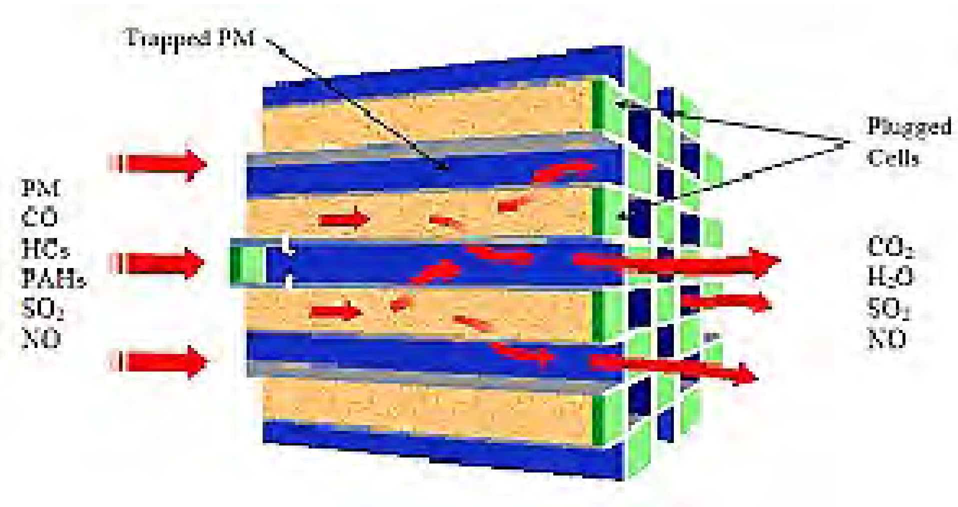
Source: USEPA Report

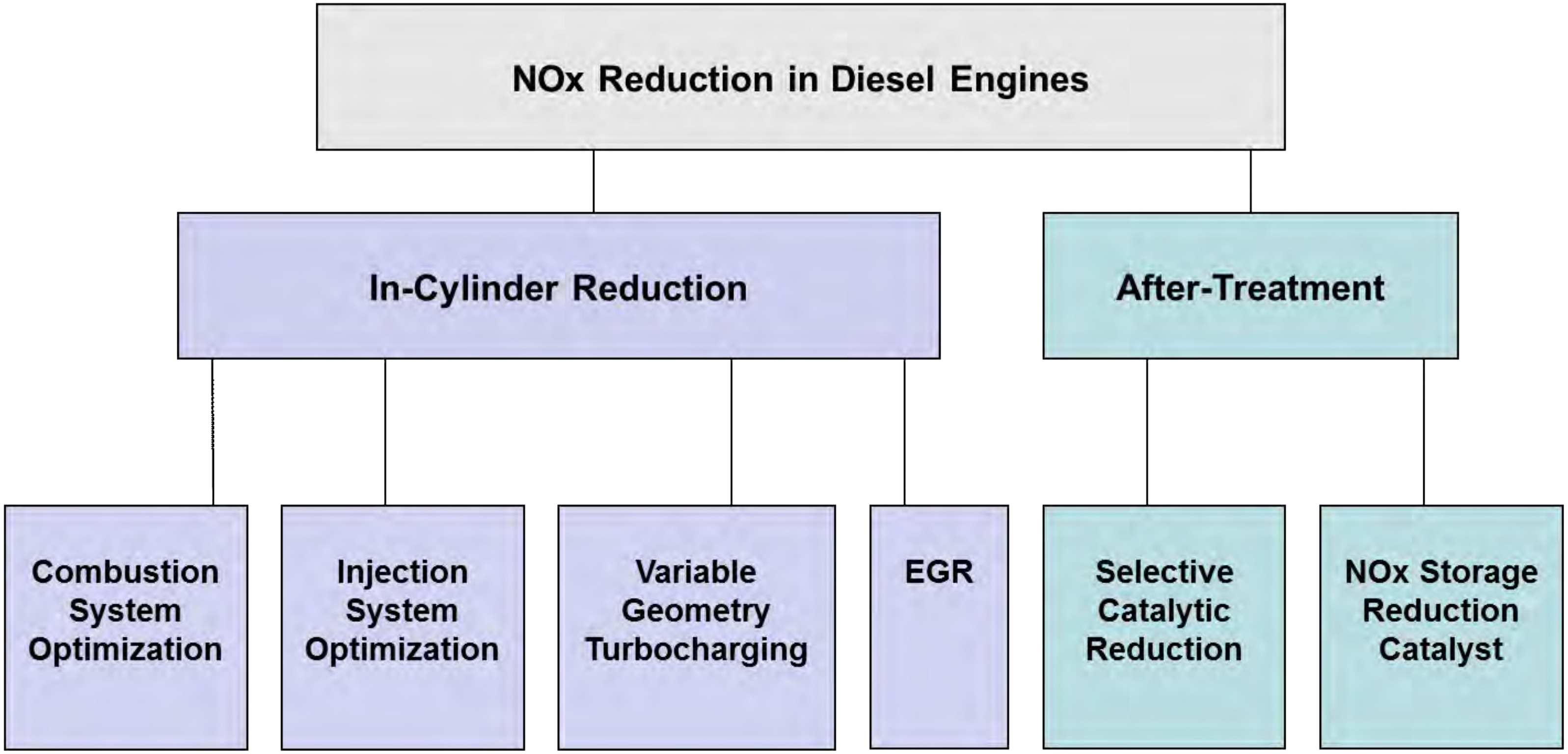
PM Reduction Suite

- **Diesel Oxidation Catalyst**



- **Diesel Particulate Filter**

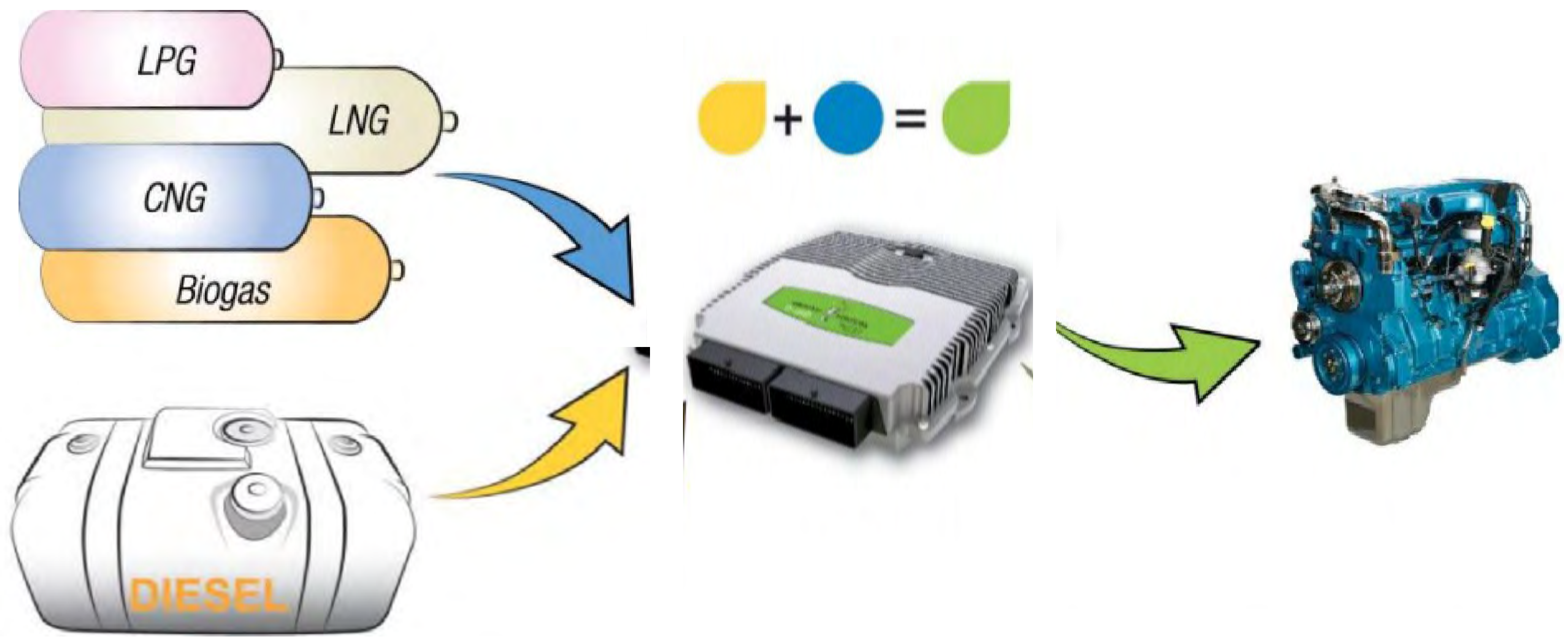



NOx Reduction in Diesel Engines
In-Cylinder Reduction
After-Treatment
Combustion System Optimization
Injection System Optimization
Variable Geometry Turbocharging
EGR
Selective Catalytic Reduction
NOx Storage Reduction Catalyst

Alternative Fuels/ New Technologies

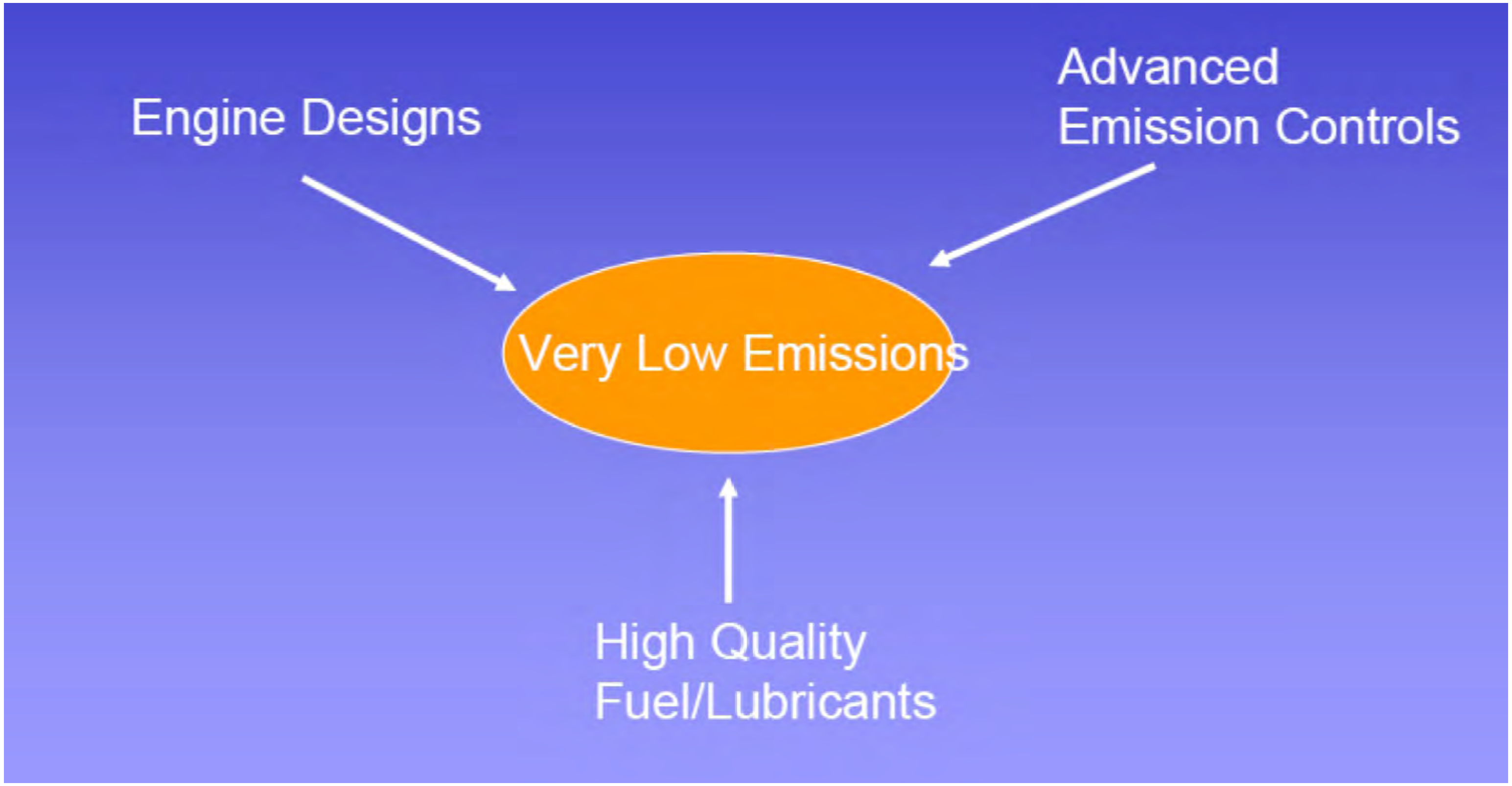
- Indian Railways have announced implementation of B5 biodiesel blends on complete fleet of diesel locomotives
- This is to be increased to higher blends depending on the availability of biodiesel
- Indian Railways have developed jointly a dual fuel CNG DEMU car which is on commercial service
- Developed a "GenSet" locomotive with very low emissions – some operational problems
- Working on developing a LNG fuelled locomotive
- Development of Gas Turbine based locomotive also taken up

Dual Fuel



- In the oil and gas market, the fuel bill is one of the largest contributors to the total cost of operation.
- The rapid expansion and abundance of natural gas in some areas of the world is driving a dramatic cost advantage of natural gas over diesel fuel, making natural gas a very economical fuel source for oil and gas operations.

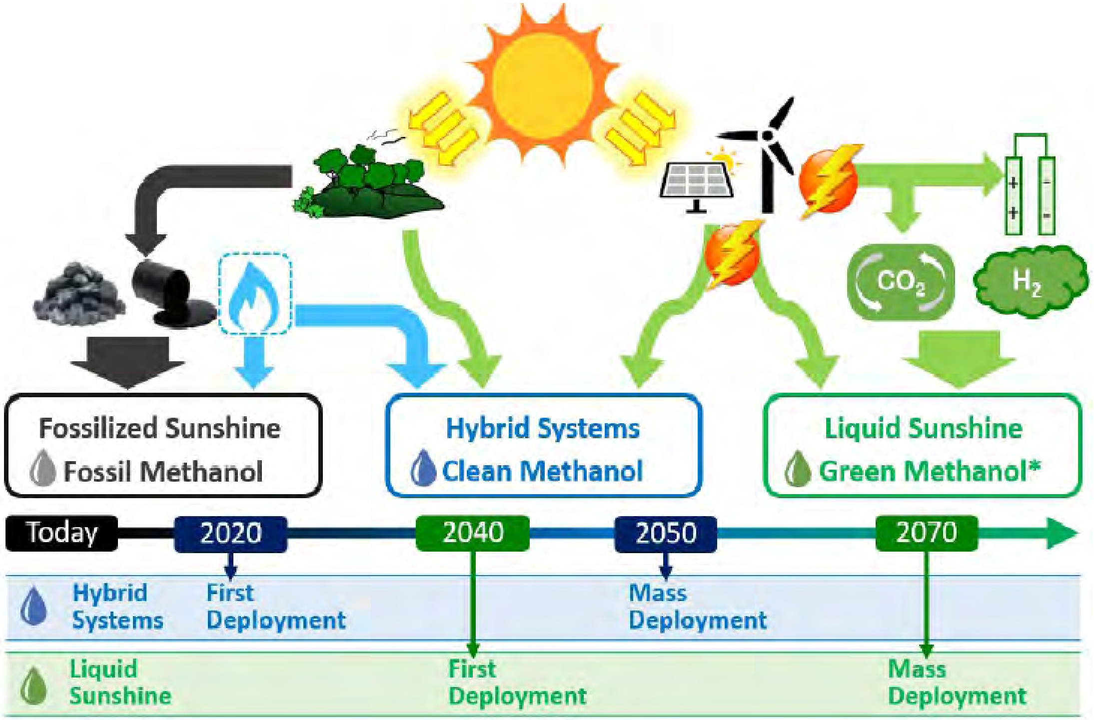
Integrated System Approach



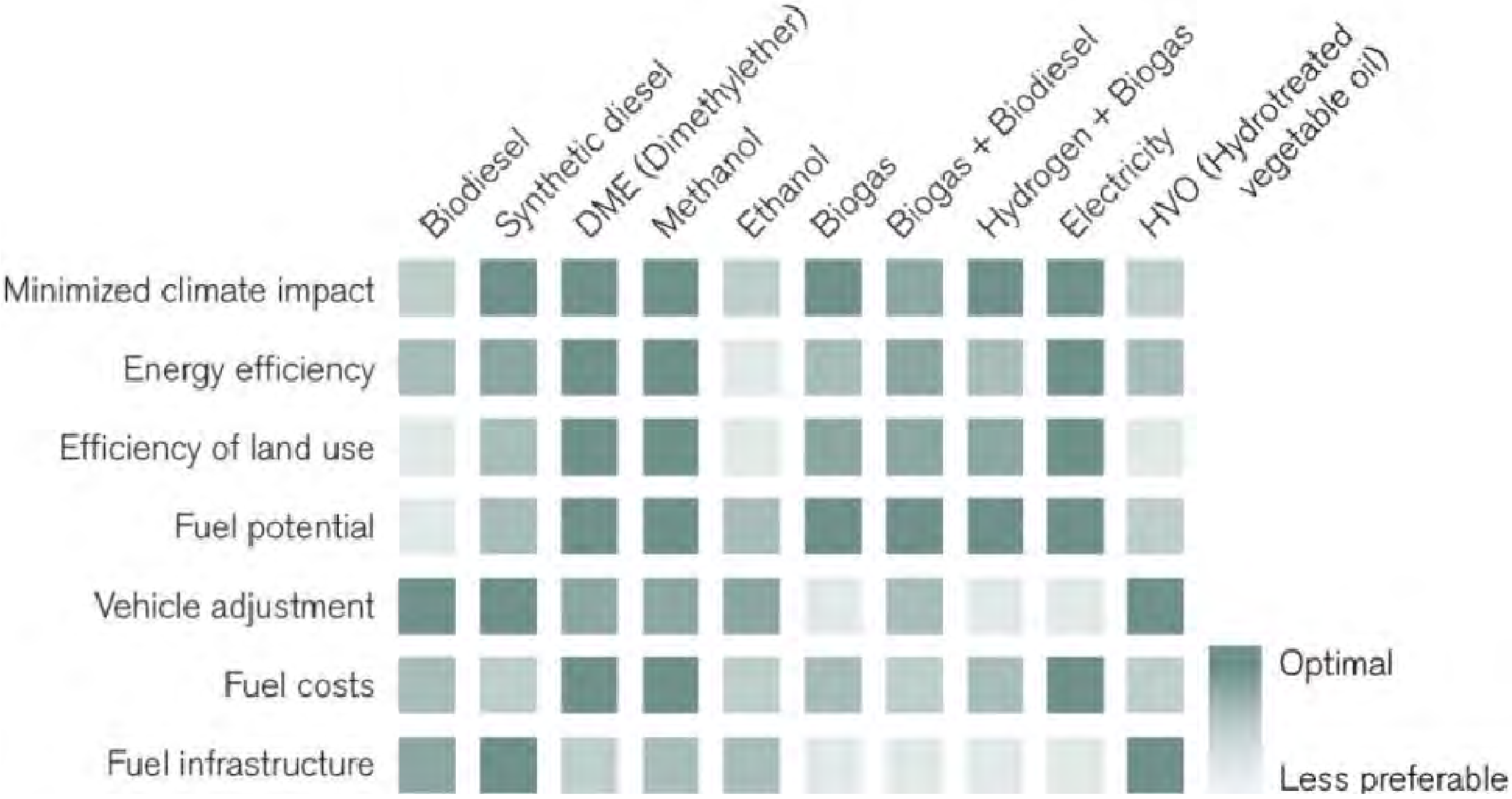
Properties of Alcohols and Conventional Fuels

Fuel Property	Methanol	Ethanol	Gasoline	Diesel
Octane No (Research)	106	107	92-98	–
Density, kg/L	0.792	0.785	072-0.78	0.81-0.89
Latent Heat of Vaporization, kJ/kg	1178	923	349	233
Higher Heating Value, MJ/kg	22.7	29.7	47.3	43.8
Lower Heating Value, MJ/kg	20.0	26.9	44.0	41.0
Lower Flammability Limits, Vol %	7.3	4.3	1.4	1.0
Autoignition Temperature, °C	464	423	246 - 280	210
Stoichiometric Air-Fuel Ratio	6.47	9.00	14.6	14.4

Methanol – Liquid Sunshine fuel



Evaluation of Fuel Pathways

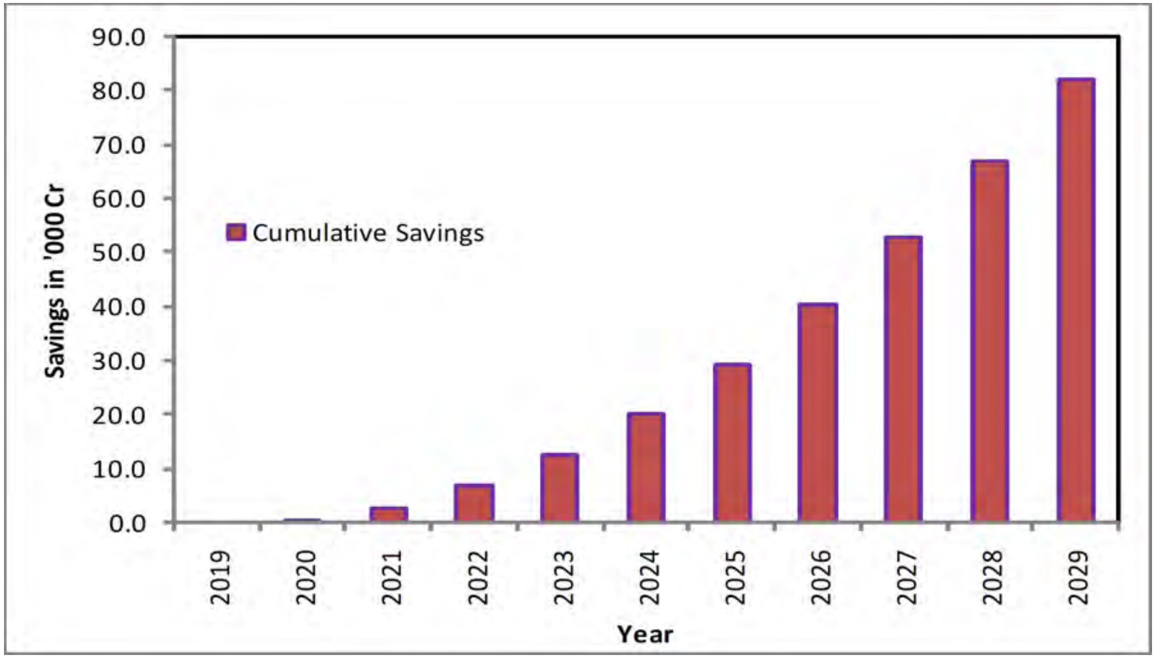


Reference https://www.wlpga.org/wp-content/uploads/2016/05/4.-Rohan-Cook_Alternative-fuels-for-commercial-vehicles.pdf

Cost comparison of Methanol vs. Diesel

Diesel	**10900**	kcal/Kg	45.8	MJ/Kg
Methanol	**5476.19**	kcal/Kg	23	MJ/Kg
Cost of diesel	70	Rs/Kg	1.53	Rs./MJ
Cost of Methanol	25	Rs/Kg	1.09	Rs./MJ

Savings due to Methanol Switch on IR



Savings due to Efficiency Improvements

Sn.	Energy efficiency increase measure	Yearly savings (Rs. Cr)
1.	Common rail fuel injection system	960
2.	Variable Geometry Turbocharger	160
3.	High effectiveness aftercooler	160
4.	Cast engine block	120
5.	Separate after cooling for the locomotive	180
6.	Auxiliary Power Unit	320
7.	Guided Optimised Locomotive Driving (GOLD)	640

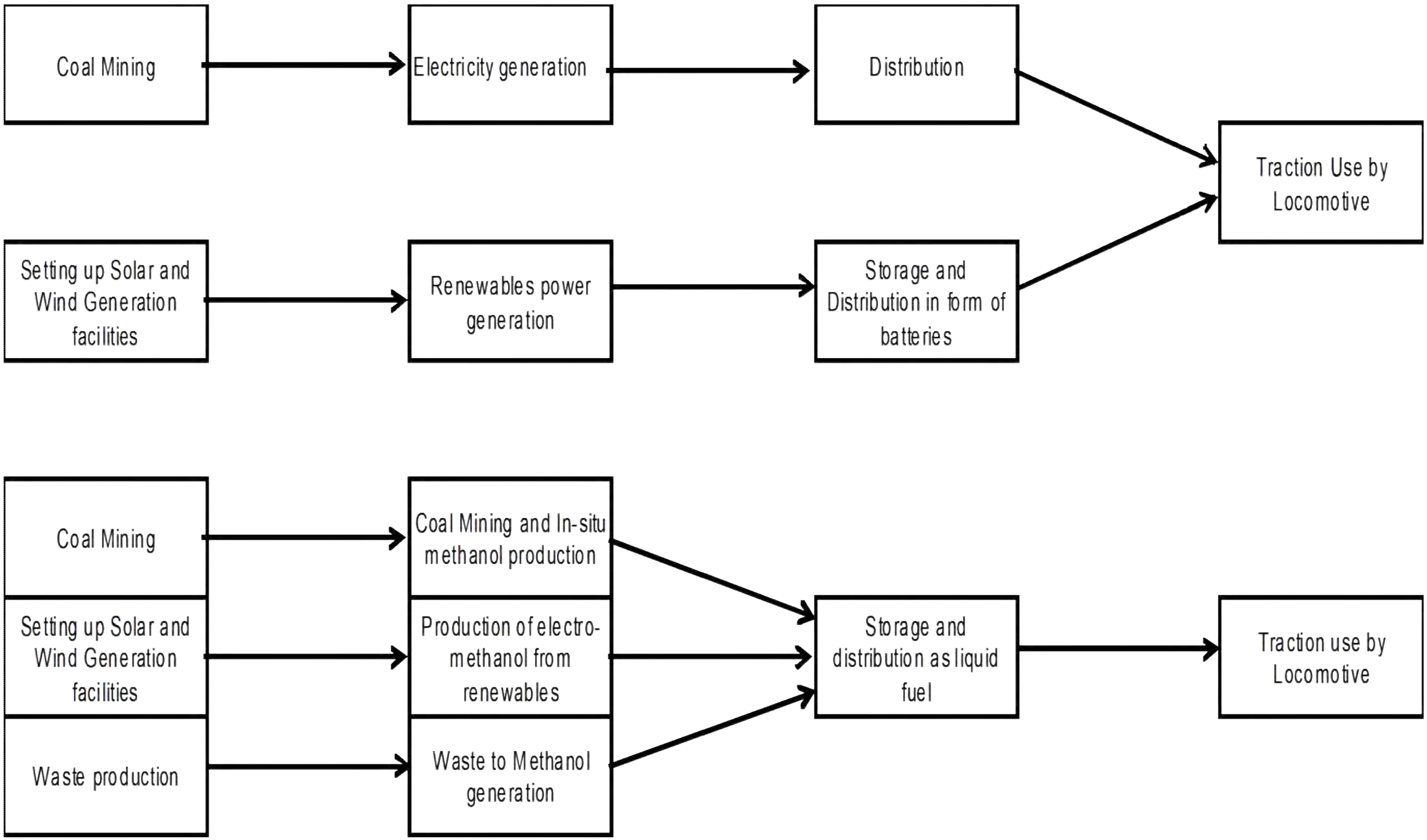
Future – Methanol Fuel-Cell Powered Train-sets

- **Made by ALSTOM for German Railways**
- **Future of Rail Traction**

Way forward for Indian Railways…

1. For reliability, It is necessary to have multiple modes of traction.
2. Indian Railways should invest in Methanol Economy and traction. Methanol is the best electro-fuel to store renewable energy.
3. Li-Ion batteries have two orders of magnitude lower energy density and power density than liquid fuels like methanol. They are at least one to two orders of magnitude more expensive also.
4. Projected savings of Rs. 81,000 Cr over a decade by switch of IR to methanol.
5. Financial and economic analysis show ROR of more than 10% indicating feasibility of conversion.
6. Government of India has taken up Methanol Economy as a Mission area.
7. Methanol fuel-cell based train-sets are the future of traction.
8. Life cycle assessment must be done before adopting any fuel/ technology. Methanol LCA shows best economy and lowest environmental impact.
9. India and Indian Railways must embrace Liquid Sunshine with open arms…..

Reliability Considerations: Single Mode vs Dual Mode Traction



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