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Diesel Locomotive Emissions:
Emission Norms and Status of India

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RITES

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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

Type of Locomotives in USA

- Railroad operations are typically described in terms of two different types of operation, line haul and switching.

(1) Line haul Locomotives

- Refers to the movement of cargo over long distances (e.g., cross-country)
- Locomotives used for line haul operations are typically large, powerful engines of 3,000 to 4,000 hp or more.

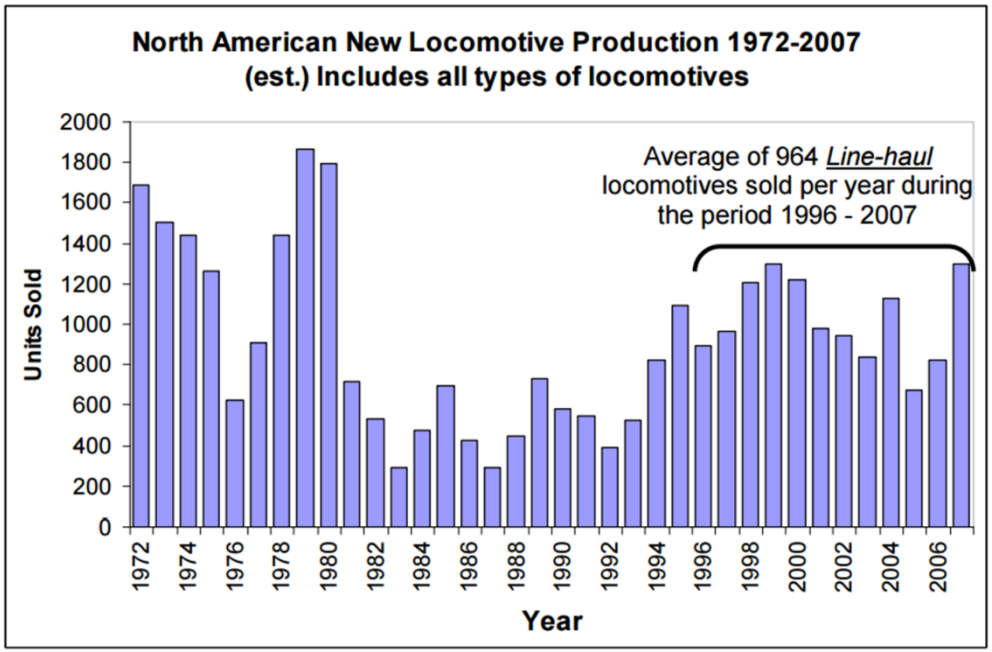
(2) Switching Locomotives

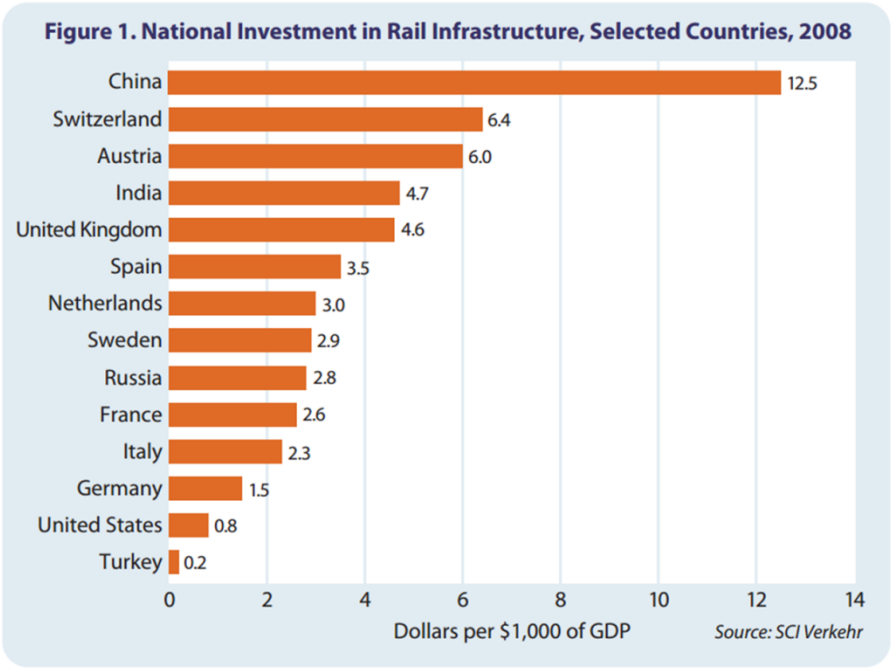
- Refers to the assembling and disassembling of trains at various locations
- Switch engines are smaller, typically having 1,200 to 3,000 hp.

Line haul Locomotives

Switching Locomotives

Status of Rail Transport Sector Globally





Emission Standards for Diesel Locomotives in USA

- US emission standards for railway locomotives apply to newly manufactured, as well as remanufactured railroad locomotives and locomotive engines.

Tier 0-2 standards:

- Tier 0-2 standards are met though engine design methods, without the use of exhaust gas after-treatment.
- ***Tier 0- F***irst set of standards applies (effective 2000) to locomotives and locomotive engines originally manufactured from 1973 to 2001.
- ***Tier 1-*** Locomotives and locomotive engines originally manufactured from 2002 to 2004. These locomotives and locomotive engines are required to meet the Tier 1 standards at the time of the manufacture and each subsequent re-manufacture.
- ***Tier 2-*** Locomotives and locomotive engines originally manufactured in 2005 onwards. Tier 2 locomotives and locomotive engines are required to meet the applicable standards at the time of original manufacture and each subsequent remanufacture.

Source: dieselnet.com

Emission Standards for Diesel Locomotives in USA

Tier 0-2 Locomotive Emission Standards, g/bhp·hr

Duty Cycle	HC*	CO	NOx	PM
Tier 0 (1973 - 2001)				
Line-haul	1.0	5.0	9.5	0.60
Switch	2.1	8.0	14.0	0.72
Tier 1 (2002 - 2004)				
Line-haul	0.55	2.2	7.4	0.45
Switch	1.2	2.5	11.0	0.54
Tier 2 (2005 and later)				
Line-haul	0.3	1.5	5.5	0.20
Switch	0.6	2.4	8.1	0.24
Non-Regulated Locomotives (1997 estimates)				
Line-haul	0.5	1.5	13.5	0.34
Switch	1.1	2.4	19.8	0.41
* HC standard is in the form of THC for diesel engines				

Locomotive Smoke Standards, % opacity (normalized)

	Steady-state	30-sec peak	3-sec peak
Tier 0	30	40	50
Tier 1	25	40	50
Tier 2 and later	20	40	50

Source: dieselnet.com

Emission Standards for Diesel Locomotives in USA

- The 2008 regulation strengthens the Tier 0-2 standards for existing locomotives, and introduces new Tier 3 and Tier 4 emission standards:
- Tier 0-2 standards- More stringent emission standards for existing locomotives, when they are remanufactured.
- ***Tier 3:*** Near-term engine-out emission standards for newly-built and remanufactured locomotives. Tier 3 standards are to be met using engine technology.
- ***Tier 4:*** Longer-term standards for newly-built and remanufactured locomotives. Tier 4 standards are expected to require the use of exhaust gas after-treatment technologies, such as particulate filters for PM control, and urea-SCR for NOx emission control.
- Exceptions for Tier 3-4 standards include (1) historic steam-powered locomotives, (2) electric locomotives, and (3) some existing locomotives owned by small businesses.
- Locomotives may discharge crankcase emissions to the ambient atmosphere, if the emissions are added to the exhaust emissions (either physically or mathematically) during all emission testing.

Source: dieselnet.com

Emission Standards for Diesel Locomotives in USA

Line-Haul Locomotive Emission Standards, g/bhp·hr

Tier	MY	Date	HC	CO	NOx	PM
Tier 0[a]	1973-1992[c]	2010[d]	1.00	5.0	8.0	0.22
Tier 1[a]	1993[c]-2004	2010[d]	0.55	2.2	7.4	0.22
Tier 2[a]	2005-2011	2010[d]	0.30	1.5	5.5	0.10[e]
Tier 3[b]	2012-2014	2012	0.30	1.5	5.5	0.10
Tier 4	2015 or later	2015	0.14[f]	1.5	1.3[f]	0.03

a - Tier 0-2 line-haul locomotives must also meet switch standards of the same tier.
b - Tier 3 line-haul locomotives must also meet Tier 2 switch standards.
c - 1993-2001 locomotive that were not equipped with an intake air coolant system are subject to Tier 0 rather than Tier 1 standards.
d - As early as 2008 if approved engine upgrade kits become available.
e - 0.20 g/bhp-hr until January 1, 2013 (with some exceptions).
f - Manufacturers may elect to meet a combined NOx+HC standard of 1.4 g/bhp-hr.

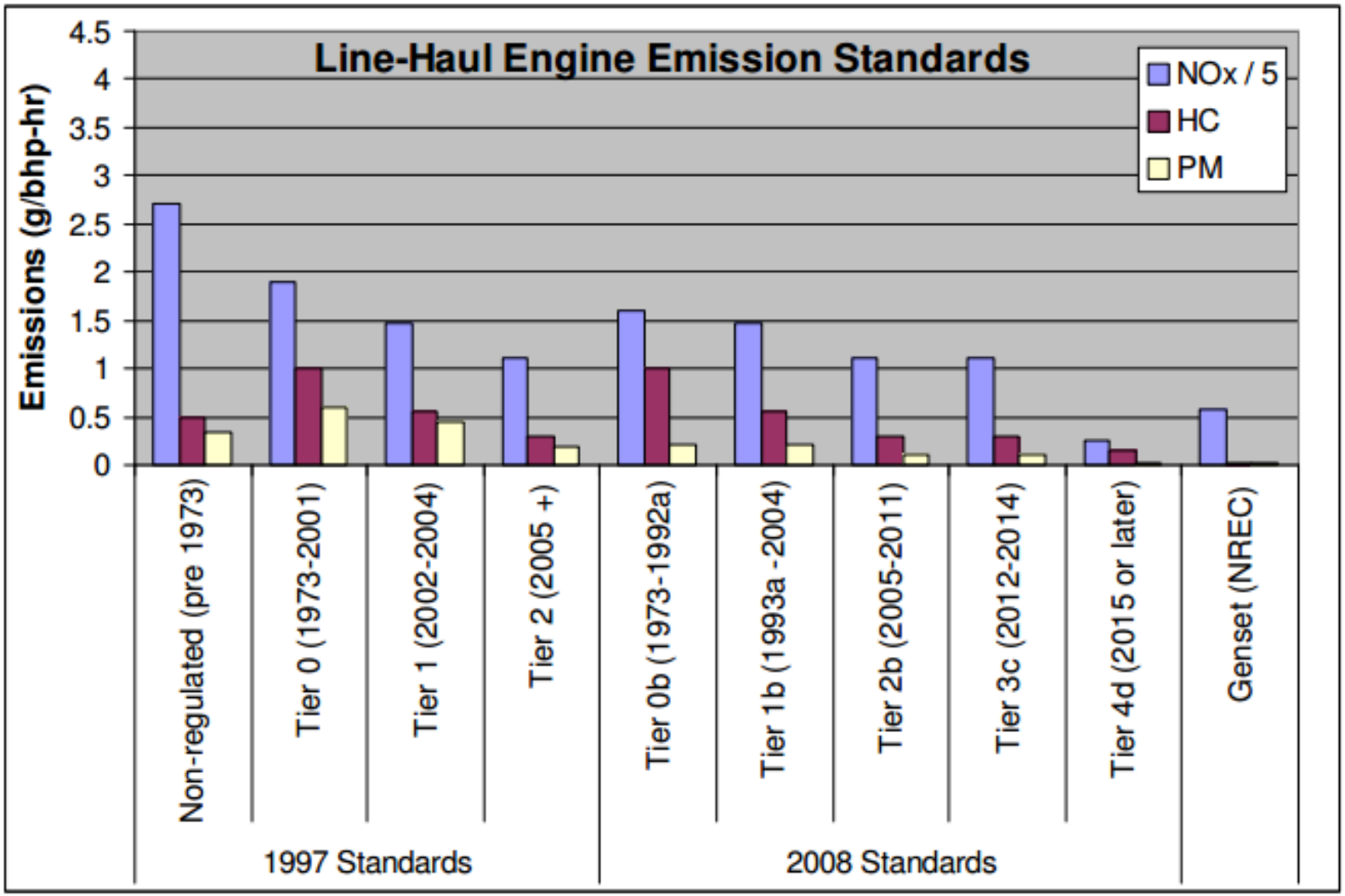
Switch Locomotive Emission Standards, g/bhp·hr

Tier	MY	Date	HC	CO	NOx	PM
Tier 0	1973-2001	2010[b]	2.10	8.0	11.8	0.26
Tier 1[a]	2002-2004	2010[b]	1.20	2.5	11.0	0.26
Tier 2[a]	2005-2010	2010[b]	0.60	2.4	8.1	0.13[c]
Tier 3	2011-2014	2011	0.60	2.4	5.0	0.10
Tier 4	2015 or later	2015	0.14[d]	2.4	1.3[d]	0.03

a - Tier 1-2 switch locomotives must also meet line-haul standards of the same tier.
b - As early as 2008 if approved engine upgrade kits become available.
c - 0.24 g/bhp-hr until January 1, 2013 (with some exceptions).
d - Manufacturers may elect to meet a combined NOx+HC standard of 1.3 g/bhp-hr.

Source: dieselnet.com

Comparison of US EPA Locomotive Emission Standards



Source: dieselnet.com

Emission Standards for Diesel Locomotives in California

There are three major categories of locomotives UP and BNSF operate in California.

- The first category is switch (or yard) locomotives with between 1,006 and 2,300 hp.
- The second category is medium horsepower (MHP) locomotives with between 2,301 and 3,800 hp.
- The third category is interstate line-haul locomotives with between 3,801 and 6,000 hp.

Summary of the Emissions from Switch Locomotives Operating in California in 2008

Type of Switcher Locomotives	Number of Locomotives	Emissions (tons per day)	
		PM	NOx
Existing Switch Locomotives			
Pre-Tier 0 Manufactured Before 1973	40	0.09	2.2
Pre-Tier 0 Manufactured 1973 or Later	63	0.14	3.4
Pre-Tier 0 Remanufactured to Tier 0	49	0.11	2.2
Subtotal	**152**	**0.34**	**7.8**
Ultra Low-Emitting Switch Locomotives			
Gen-Set Diesel	76	0.018	0.570
LNG-Powered	4	0.001	0.090
Battery Electric	12	0.003	0.037
Subtotal	**92**	**0.022**	**0.7**
Totals	**244**	**0.36 ***	**8.5 ***

Source: California Air Resources Board

Emission Standards for Diesel Locomotives in Europe

Stage III A and III B standards have been adopted for engines above 130 kW used for the propulsion of railroad locomotives (categories R, RL, RH) and railcars (RC).

Stage III A/B Emission Standards for Rail Traction Engines

Category	Net Power	Date	CO	HC	HC+NOx	NOx	PM
	kW		*g/kWh*				
Stage III A							
RC A	P > 130	2006	3.5	-	4.0	-	0.2
RL A	130 ≤ P ≤ 560	2007	3.5	-	4.0	-	0.2
RH A	P > 560	2009	3.5	0.5*	-	6.0*	0.2
Stage III B							
RC B	P > 130	2012	3.5	0.19	-	2.0	0.025
R B	P > 130	2012	3.5	-	4.0	-	0.025

* HC = 0.4 g/kWh and NOx = 7.4 g/kWh for engines of P > 2000 kW and D > 5 liters/cylinder

Proposed Stage V emission standards would apply to engines used for the propulsion of rail locomotives (RLL) and railcars (RLR) of any power rating and any type of ignition.

Proposed Stage V Emission Standards for Rail Traction Engines

Category	Net Power	Date	CO	HC[a]	NOx	PM	PN
	kW		*g/kWh*				*1/kWh*
RLL-v/c-1 (Locomotives)	P > 0	2021	3.50	4.00[b]		0.025	-
RLR-v/c-1 (Railcars)	P > 0	2021	3.50	0.19	2.00	0.015	1×10^{12}

Source: dieselnet.com

Global Trends in Emission Reduction from Diesel Locomotives

- GETS – US EPA Tier 0 -1 on the 7 FDL engine
  - US EPA Tier 2 on a new engine, higher bore and stroke and higher peak cylinder pressures, EFI, Turbo higher efficiency, after-cooler, separate after-cooling, higher CR
  - US EPA Tier 3 with intelligent and flexible fuel injection control
  - US EPA Tier 4 with cooled EGR
  - No after-treatment devices
- EMD – Combustion chamber geometry optimization, electronic fuel injection, separate after-cooling, turbocharger optimization, allowed fuel penalty
  - No after-treatment devices
- Cummins, CATERPILLAR – all above as also after-treatment devices used due to smaller size of engine

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

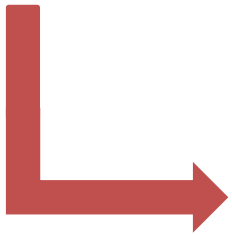
- Power Car engines
- Diesel generator sets on Railway Stations, Offices, Buildings, Colonies
- Diesel engines on Track cars
- Diesel Engines on Overhead monitoring cars
- Diesel engines on other measurement cars

Position of Indian Railways

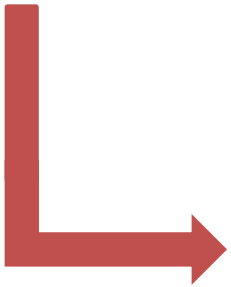
- Legal position – National Green Tribunal
- Emission inventory being carried out by RDSO
- MoR is in process of engaging an agency for developing the emission standards
- Projects taken up with IIT Kanpur and support by DST
- Some measures in progress
  - EFI, CReDI, Miller cycle turbo, Plate type after-cooler, 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

India - Terms of reference by NGT by Locomotive Emission Norms

- Committee to
  - Approach any specialized body anywhere in the country for necessary consultation and advice
    - Collect data
    - Complete study
    - Specify and prepare the guidelines
    - Within 6 months

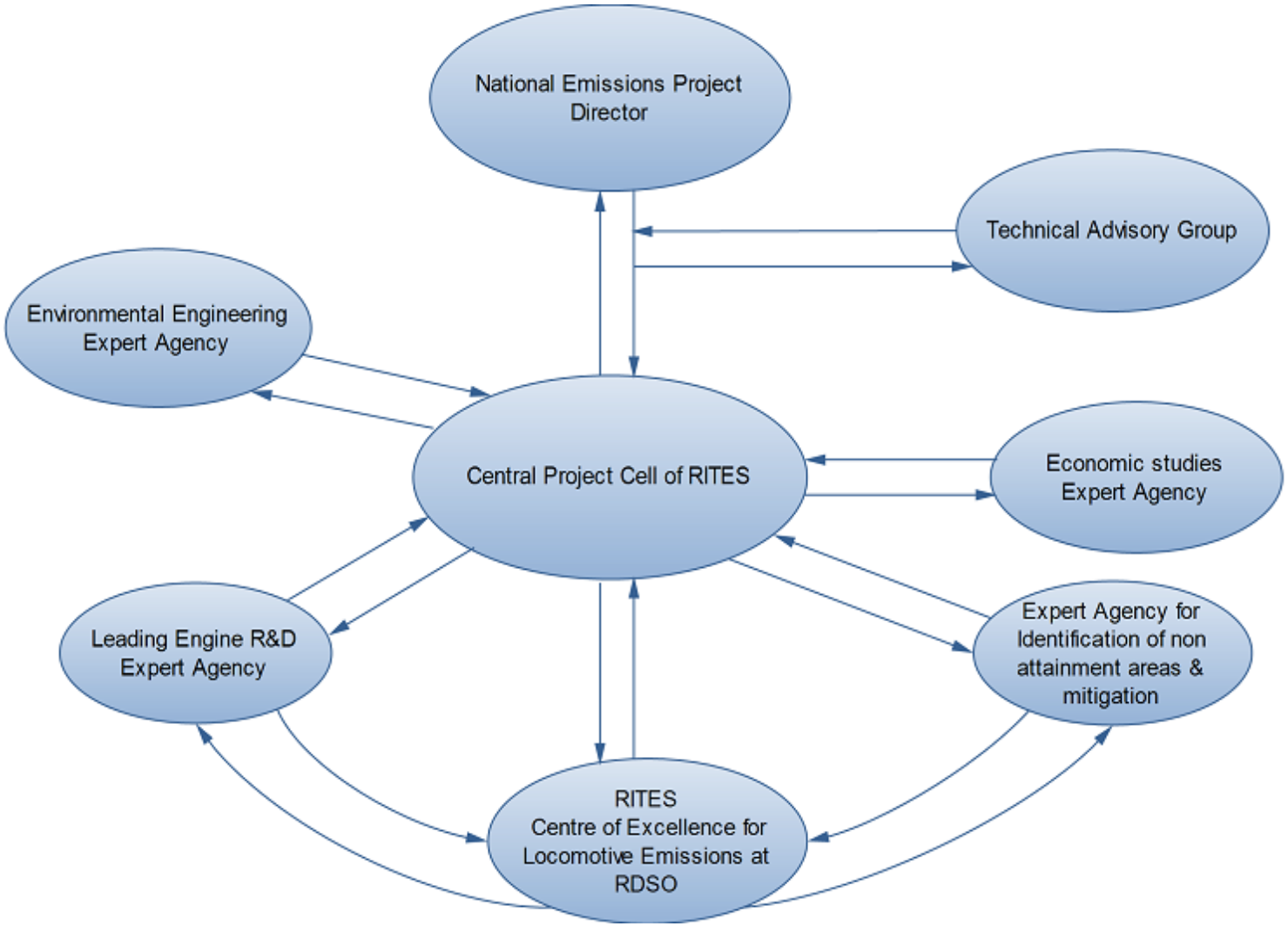


- CPCB to
  - Ensure implementation



- All concerned agencies to
  - Implement the emission guidelines
  - Ensure that no pollution results from the Railway locomotive engines

Road Map – Creation of Structure



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Diesel Locomotive Emissions: Challenges and Opportunities

4th September, 2015

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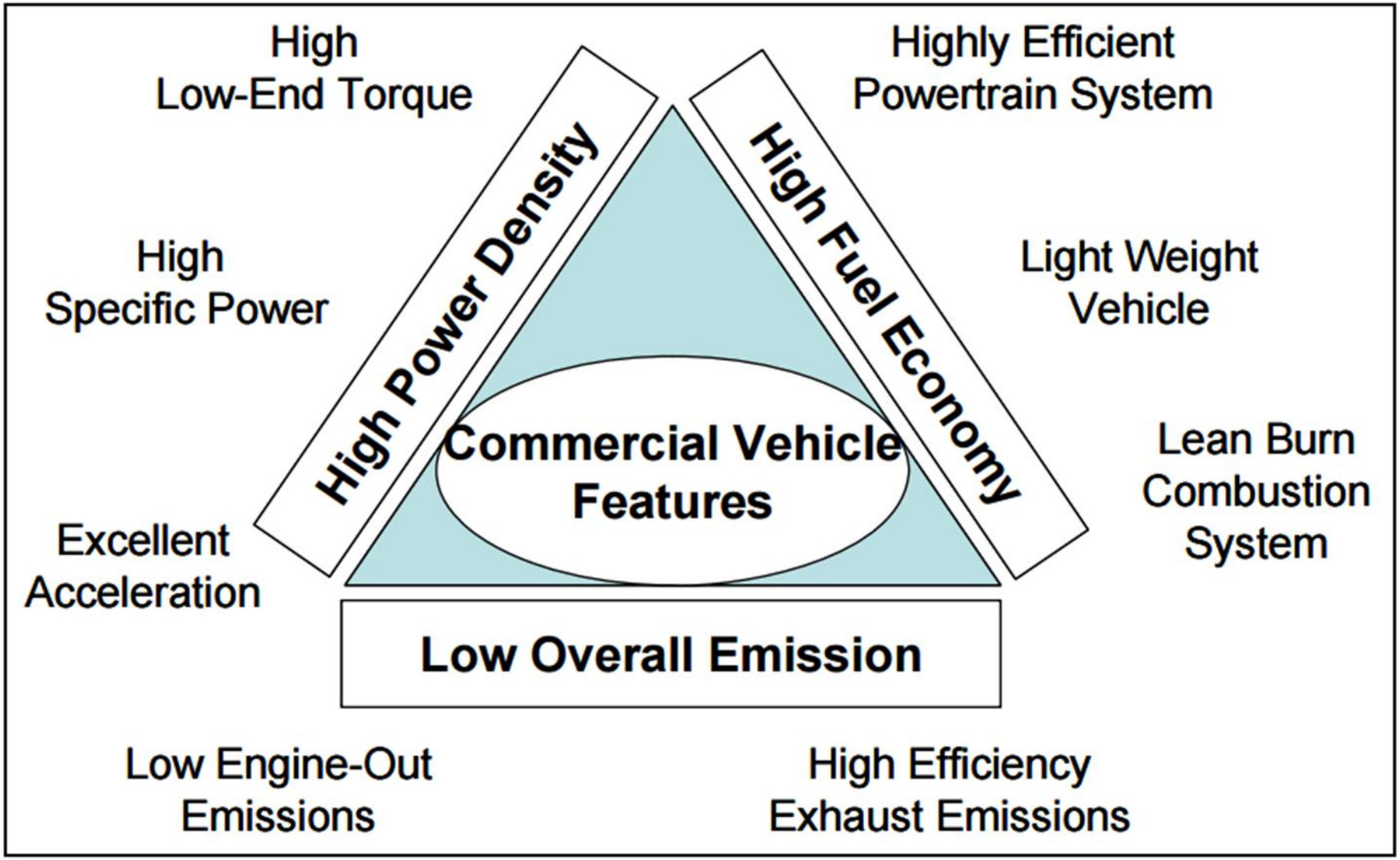
- Challenges Offered/ Opportunities to Grab….
- Main Constituents of Diesel Engine Exhaust Emissions
- Progression of Locomotive PM Regulations
- Pollutant Control Techniques
- International Case Studies
- Road Map for Indian Railways

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

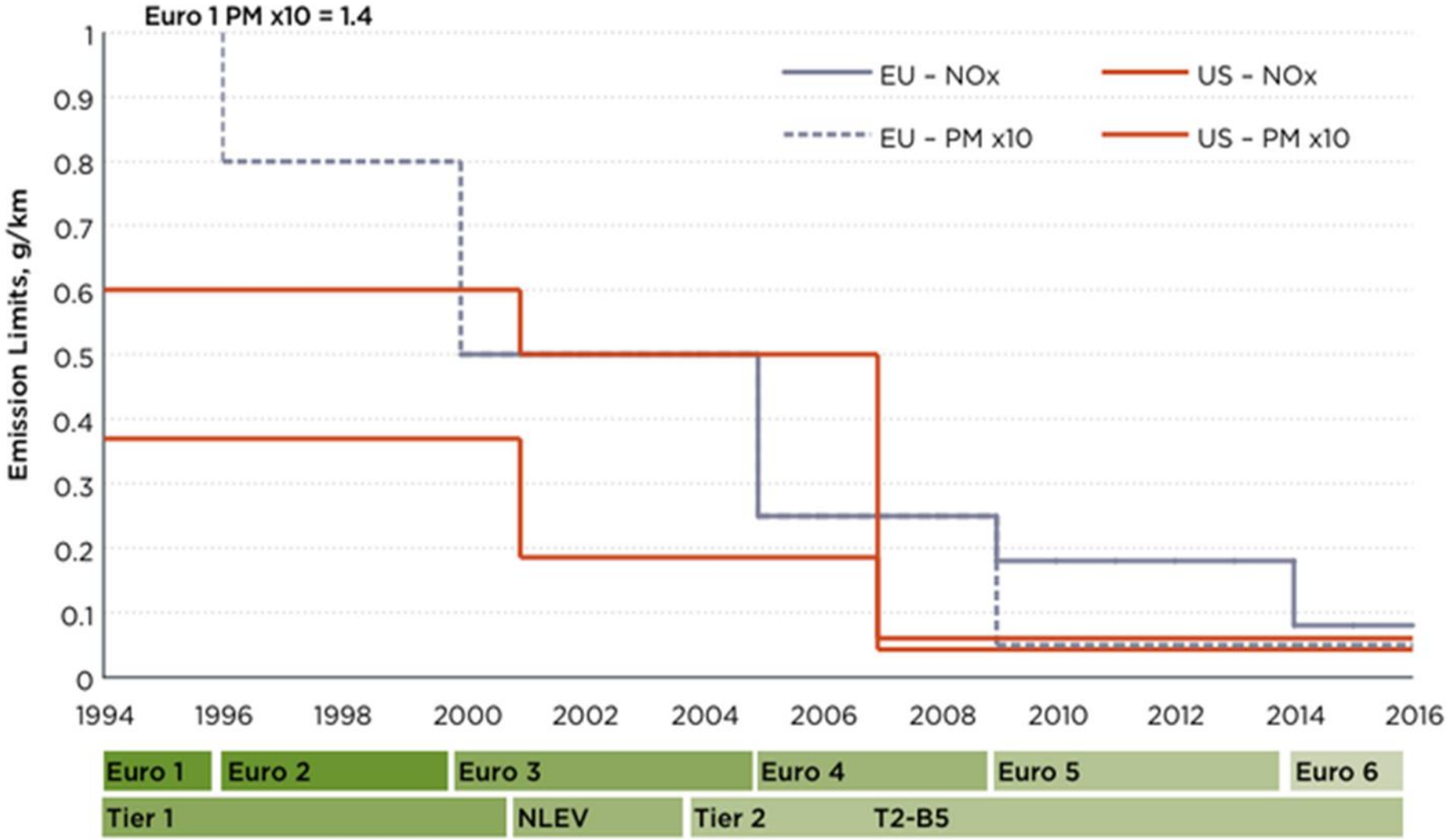
Indian Pollution Burden from Locomotive Engines

- 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

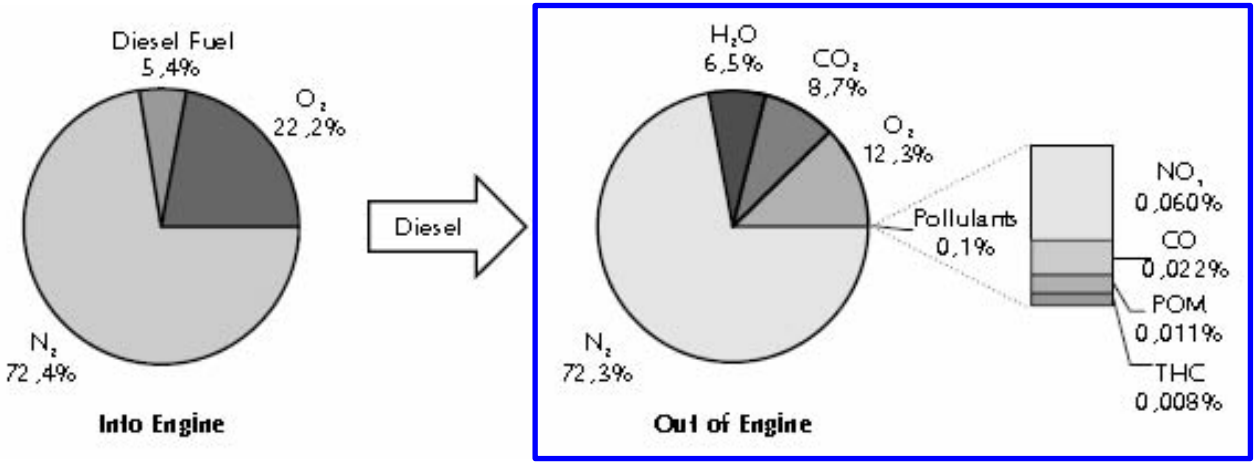
Diesel Emission Regulations



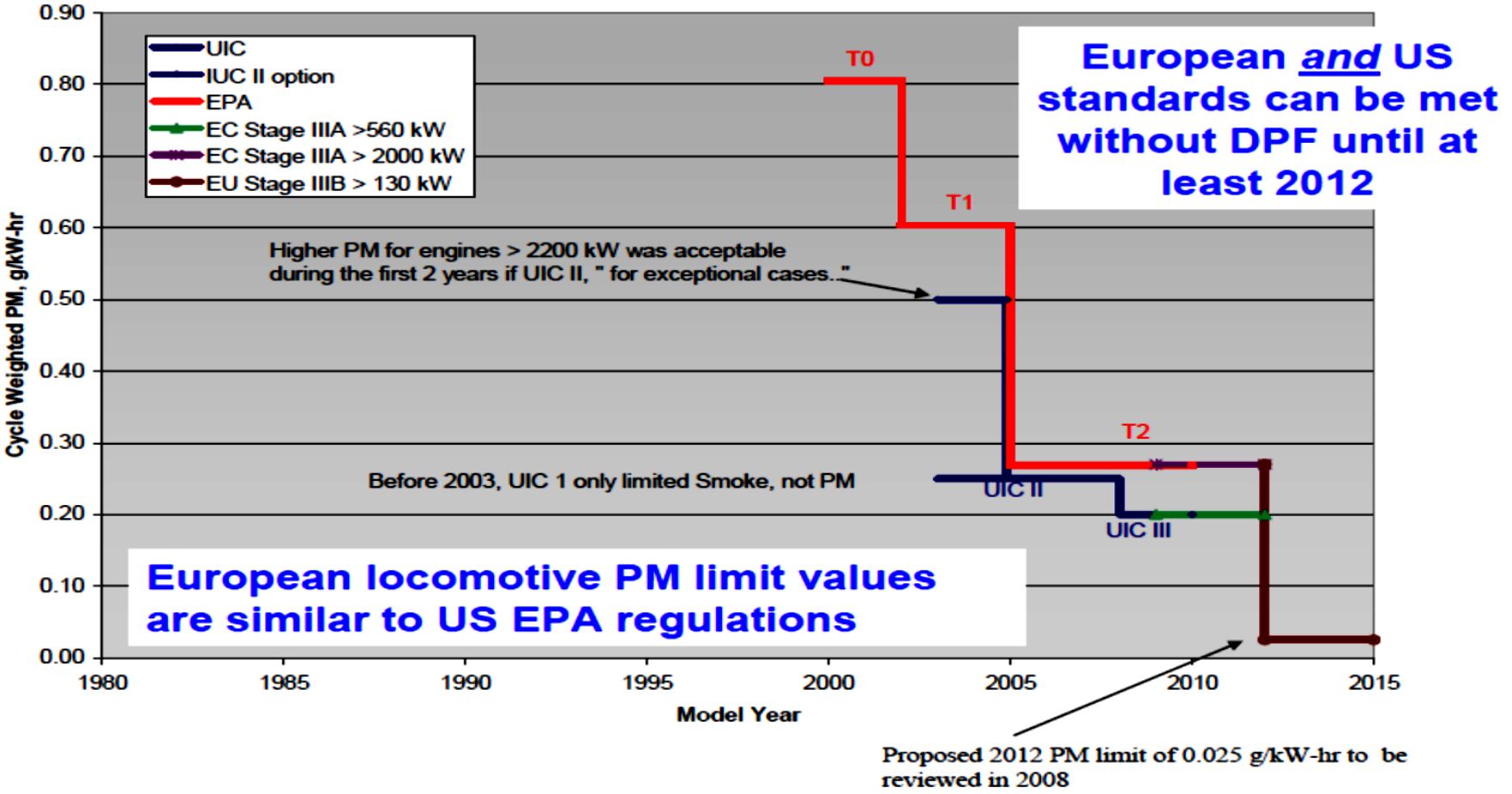
[http://transportpolicy.net/index.php?title=File:Ldv_emissions_graph_-_diesel.png]

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)

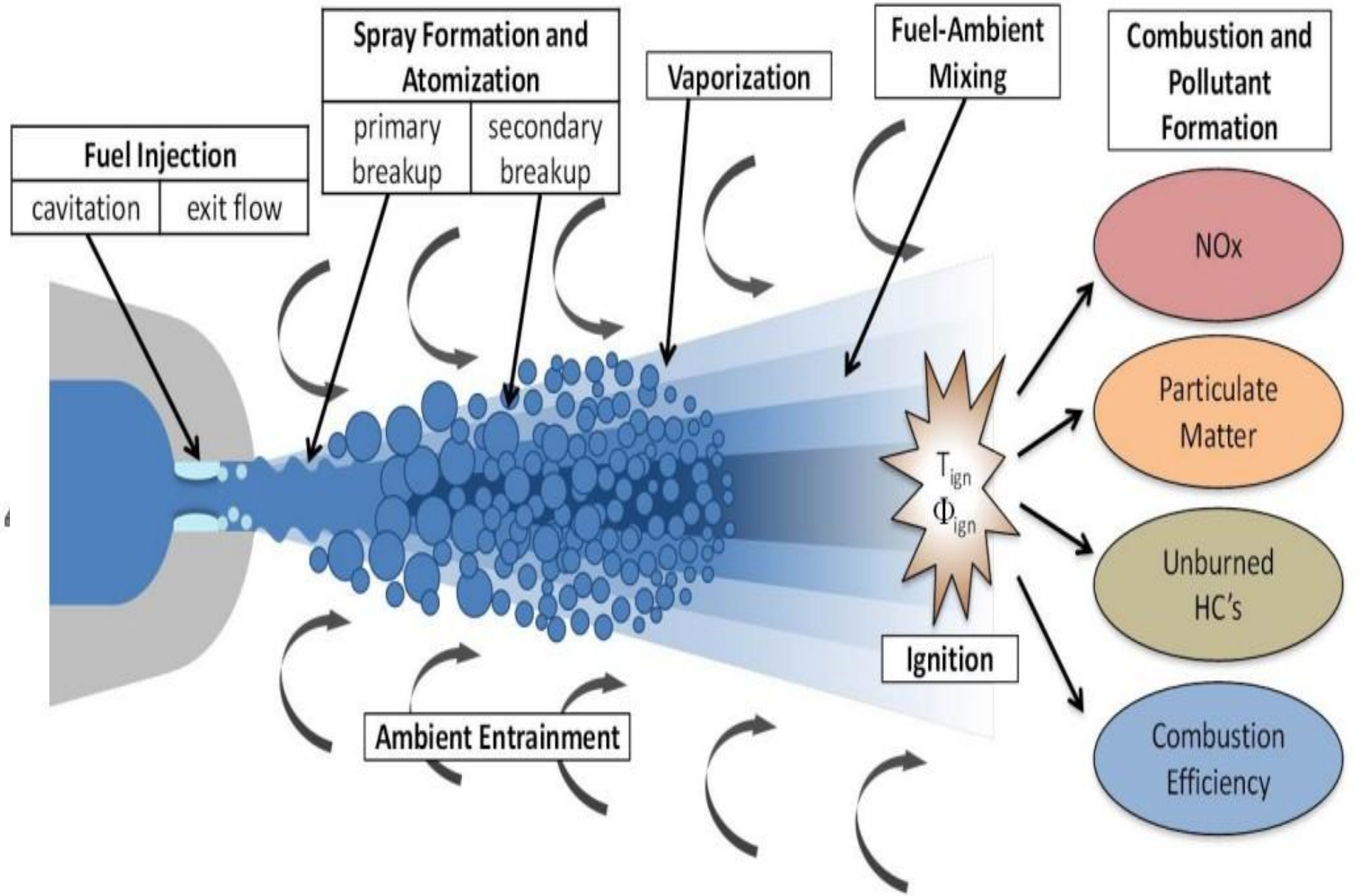
- Electronic fuel injection/ Common Rail
- High pressure injectors
- Higher rate of injection
- Higher compression ratio and optimized combustion chamber
- Miller cycle/ VGT turbocharger
- Higher effectiveness after-cooler (plate type)
- Separate after-cooling system
- Sizing and redesign of exhaust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

Emission Reduction (After-treatment)

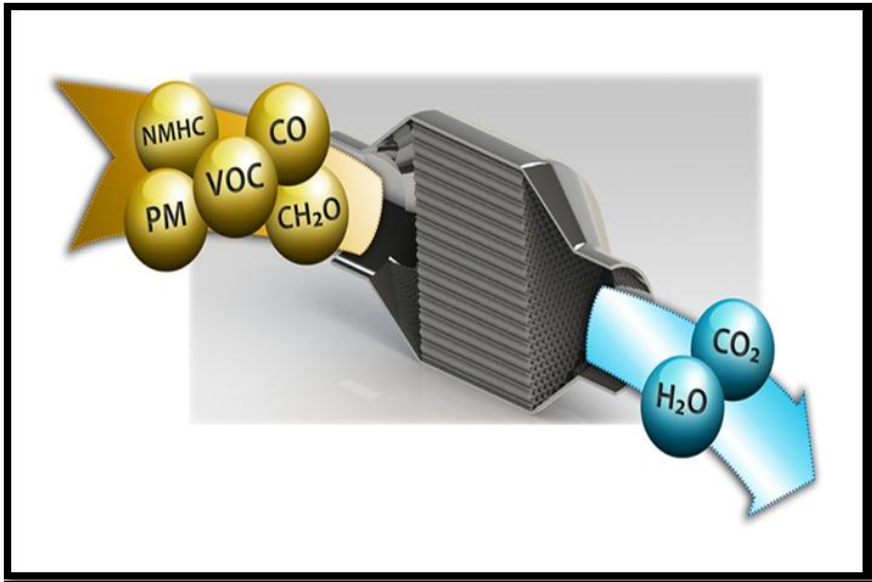
- Diesel Oxidation Catalyst
- Diesel Particulate Filter
- Selective Catalytic Reduction

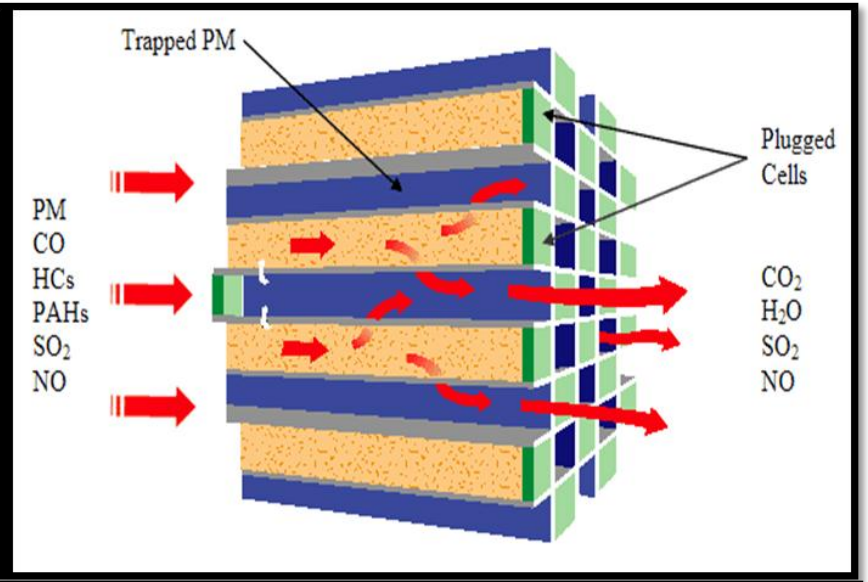
Issues and challenges in using after-treatment devices

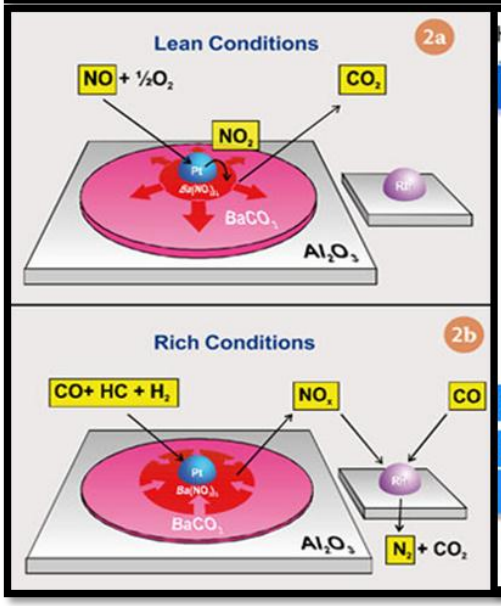
- Packaging problem due to high exhaust flow rates
- Axle load restrictions
- Maximum moving dimension restrictions
- Fuel efficiency deterioration not allowed

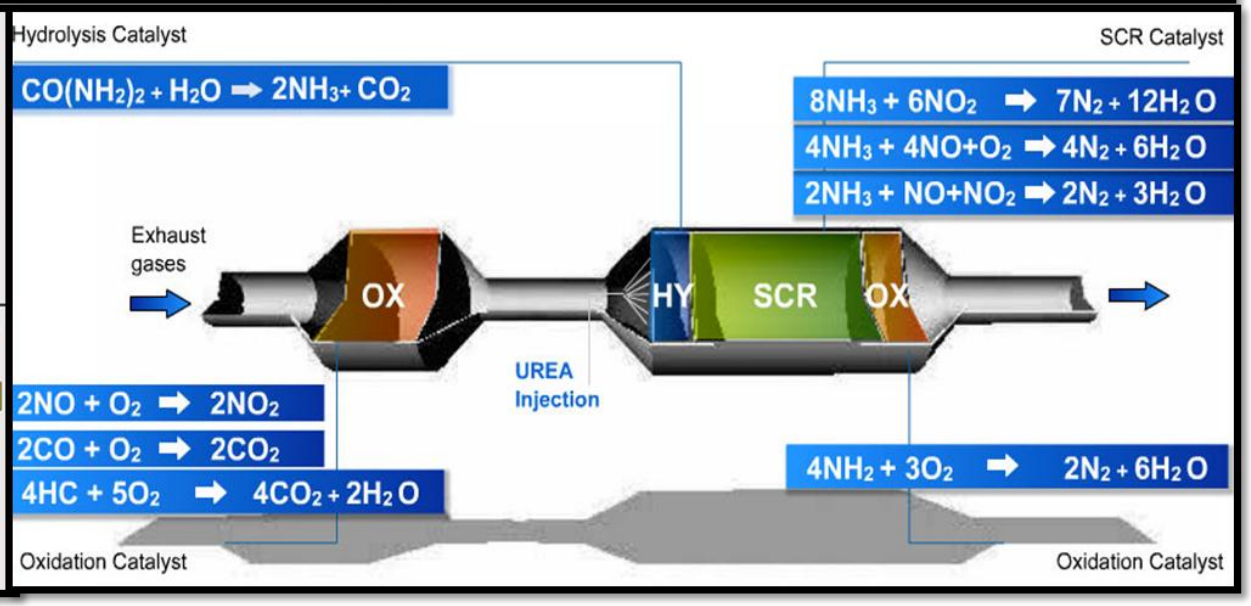

Fuel Injection
cavitation
exit flow
Spray Formation and Atomization
primary breakup
secondary breakup
Vaporization
Fuel-Ambient Mixing
Combustion and Pollutant Formation
NOx
Particulate Matter
Unburned HC's
Combustion Efficiency
T_{ign}
Φ_{ign}
Ignition
Ambient Entrainment

Locomotive Exhaust Emission Control Techniques

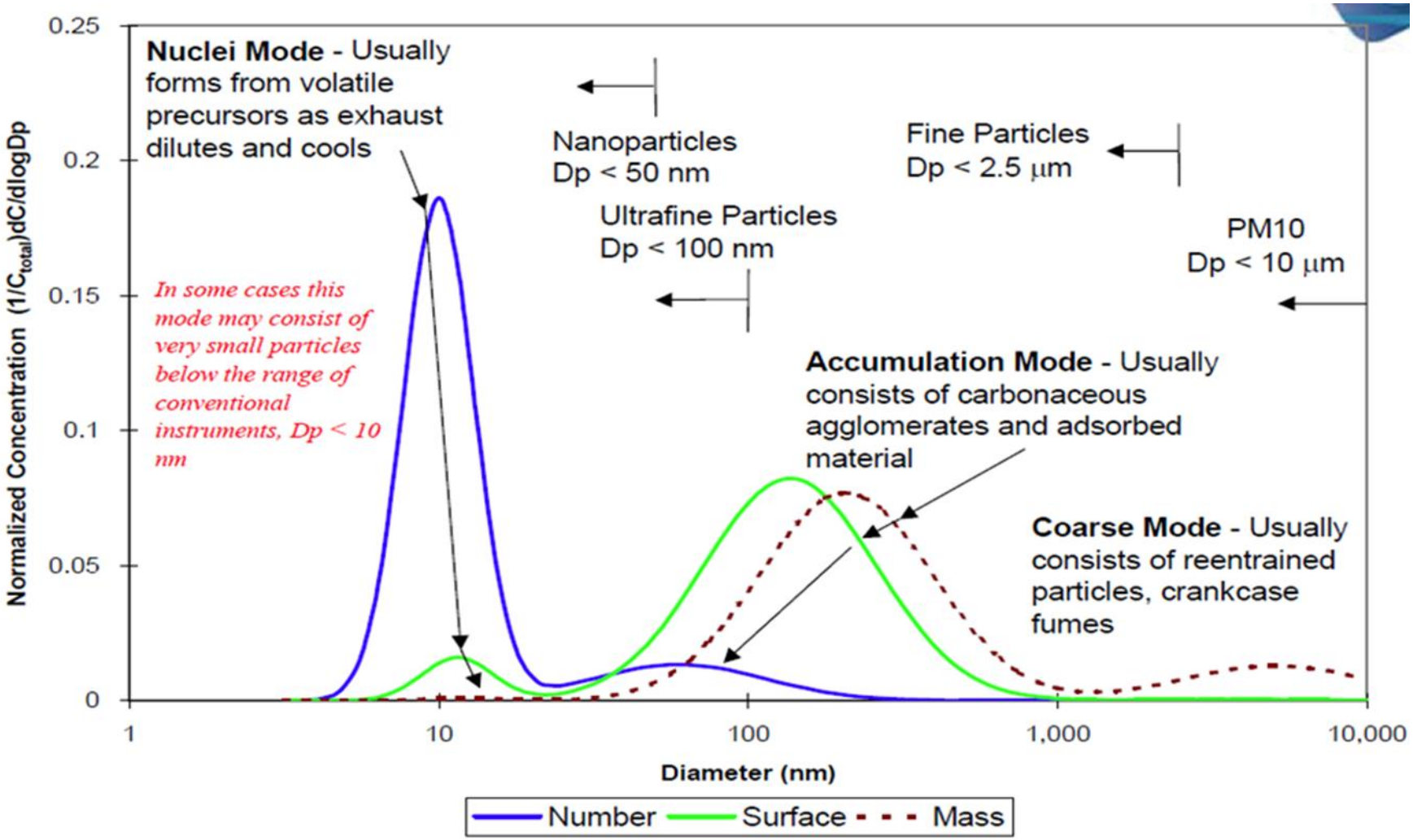








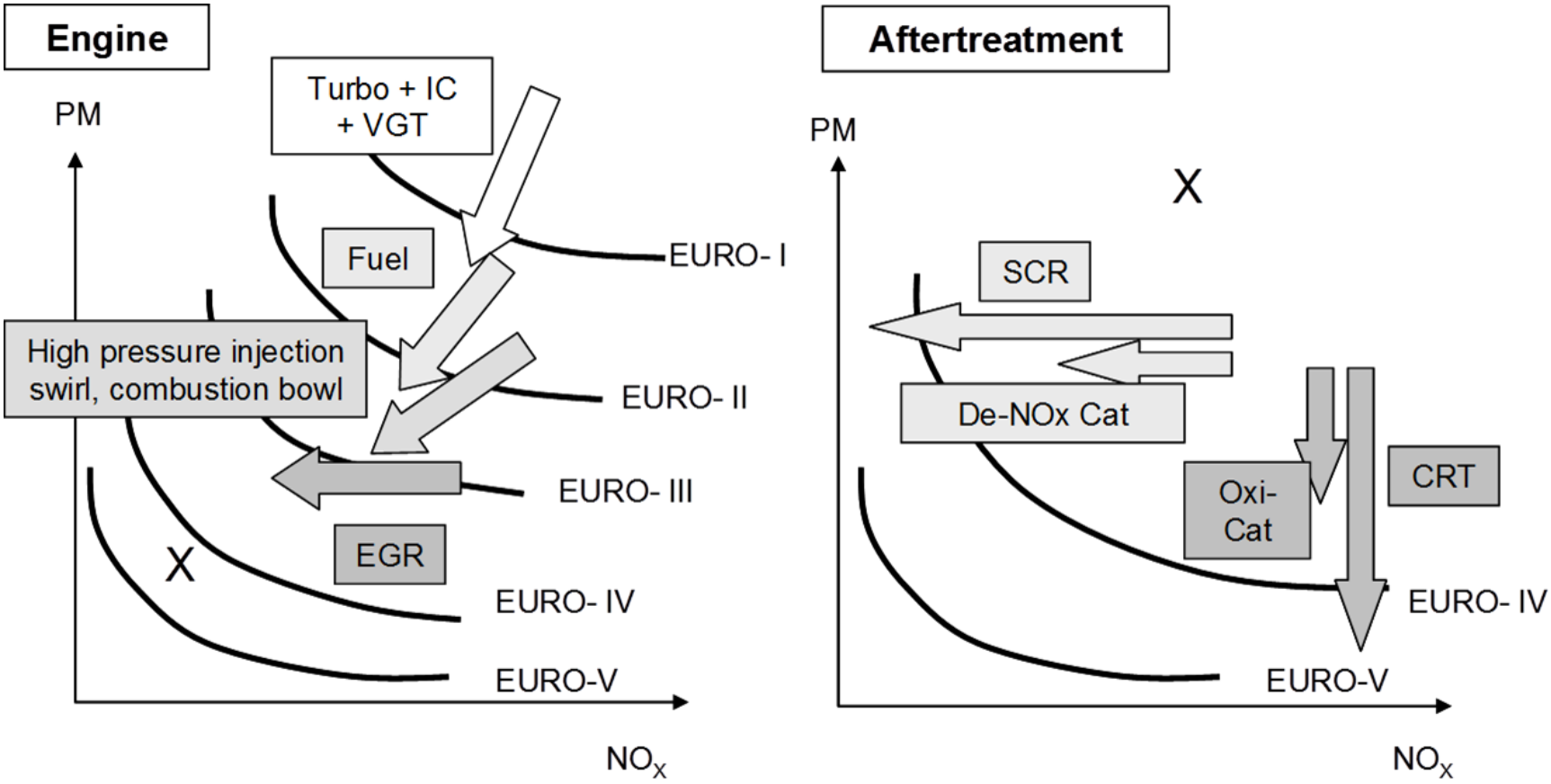
Size Distribution of DPM



Typical engine exhaust size distribution both mass and number weightings.

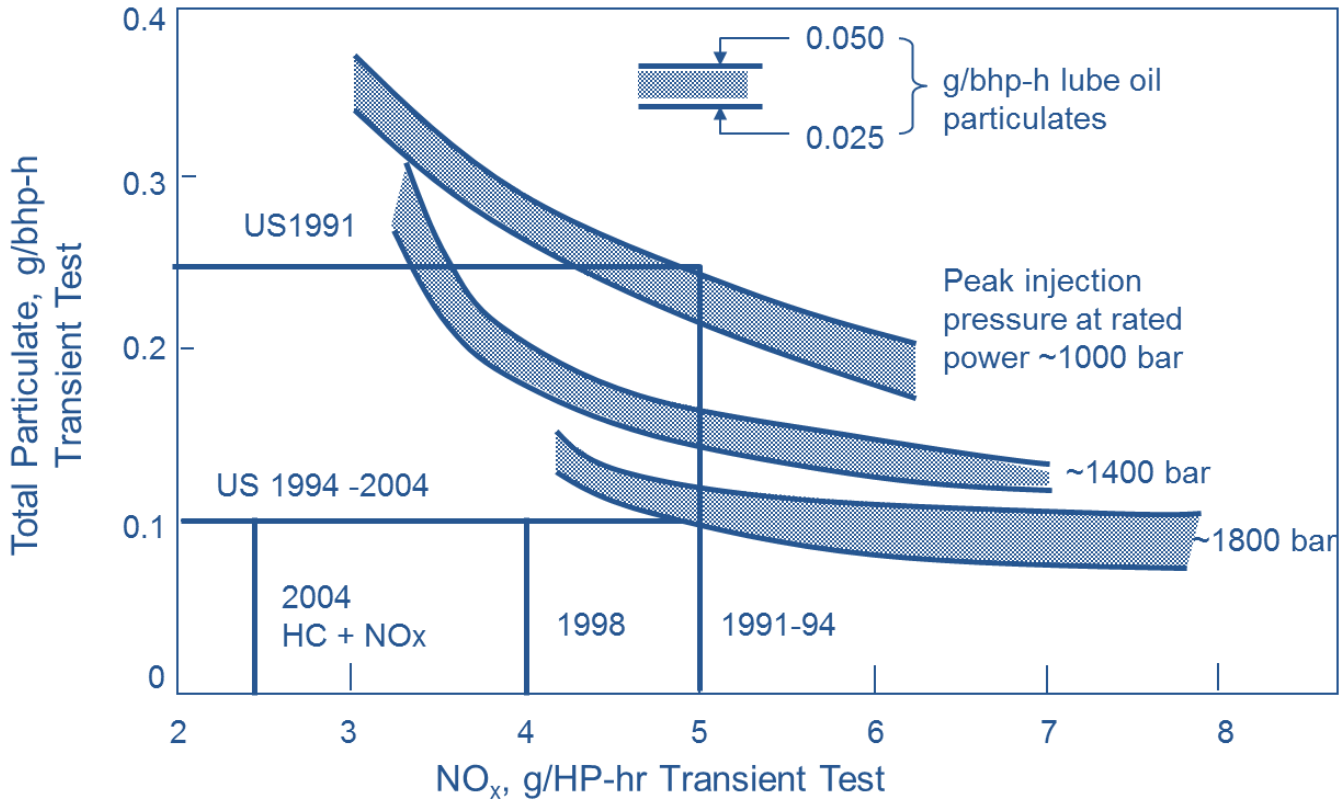
Source: Kittleson D B, 1998

Trends in Emission Control Technologies for CI Engines



Source: Pundir, 2007

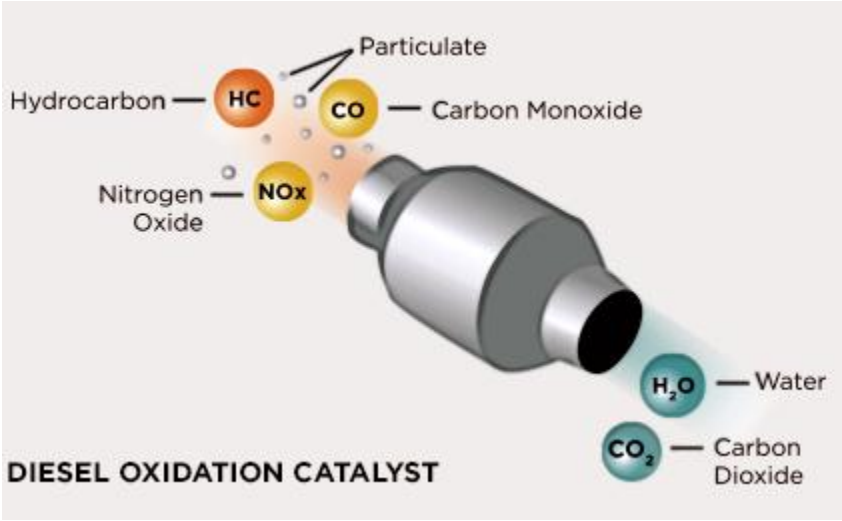
Effect of High Diesel Injection Pressure on NOx and PM



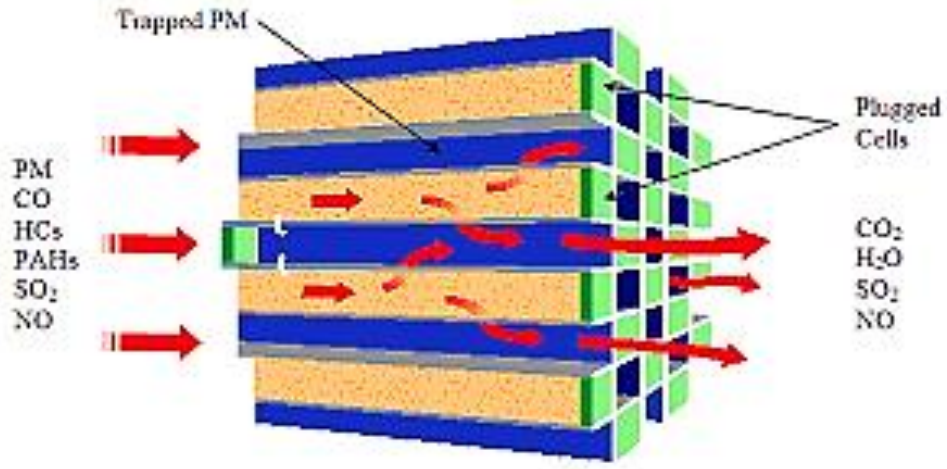
Source: USEPA Report

PM Reduction Suite

- Diesel Oxidation Catalyst

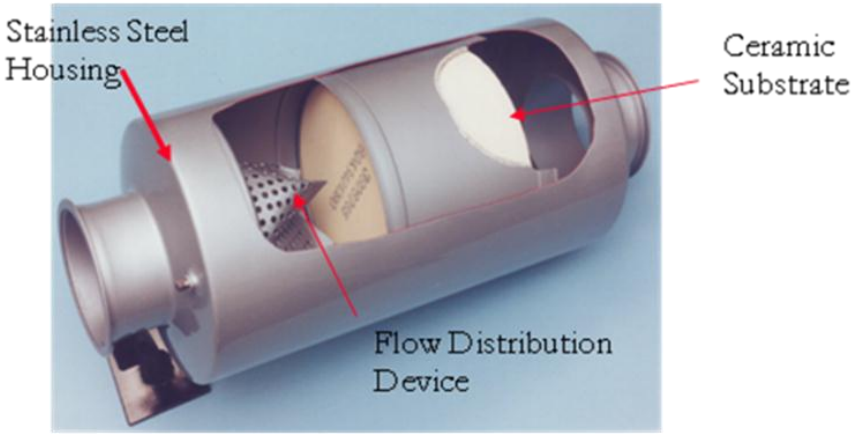


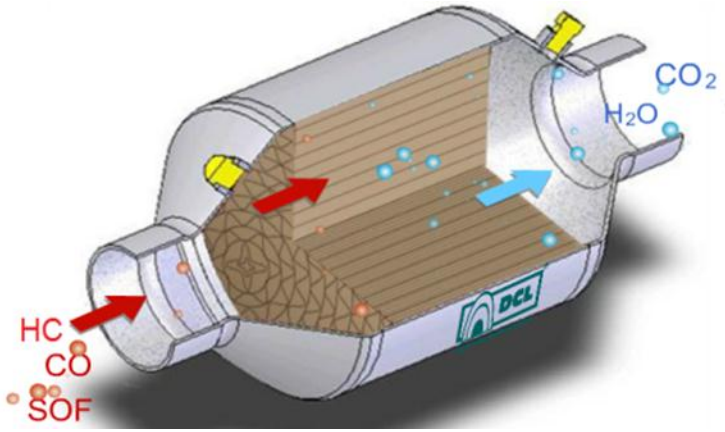
- Diesel Particulate Filter



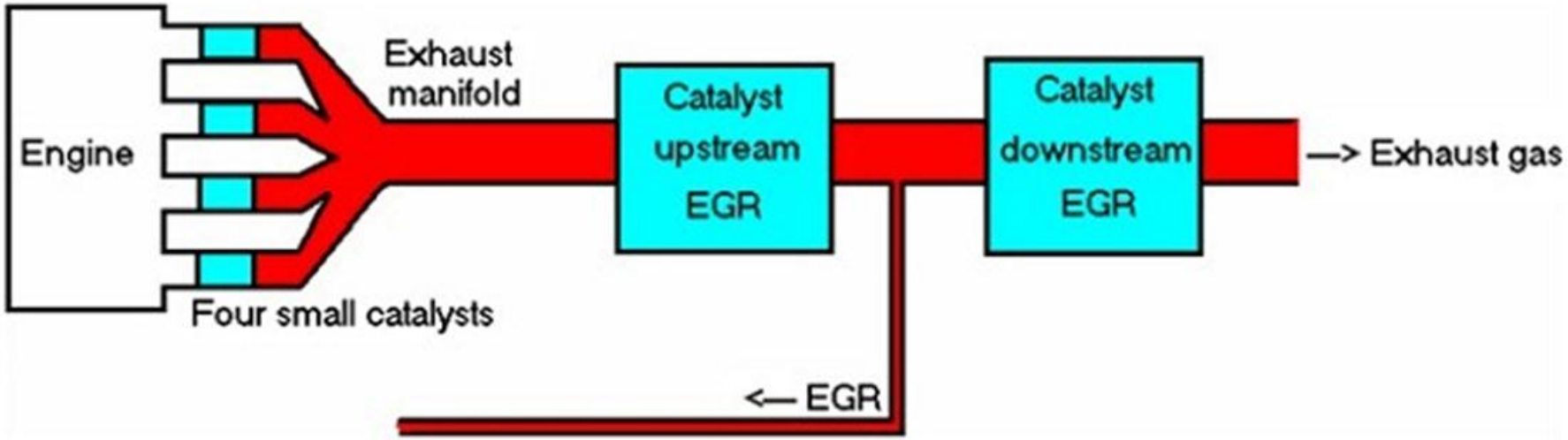
Particulate Control using DOC

- DOC will be a important component in diesel locomotives.
- DOC is mainly a flow through device with catalyst layer.
- Main objective of DOC is to remove the soluble organic fraction of particulates efficiently.
- Made of ceramic monoliths – provide strong adhesion for wash coat materials, lower cost.
- Need to investigate the DOC downstream particulate emission characteristics.
- Need to investigate the compatibility of DOC with alternative fuels like biodiesel.
- Recommended to use low sulphur diesel – limits formation of sulphates.

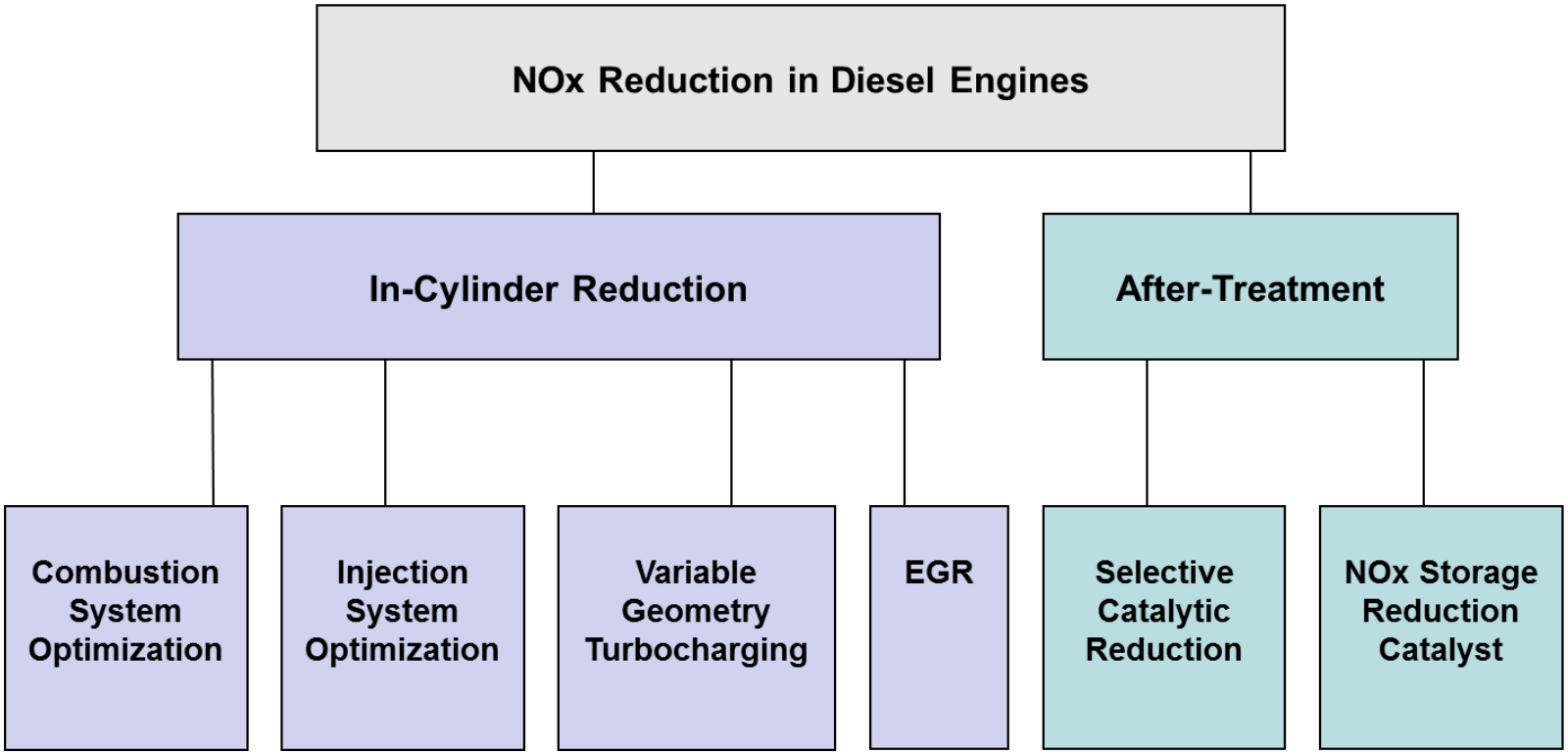




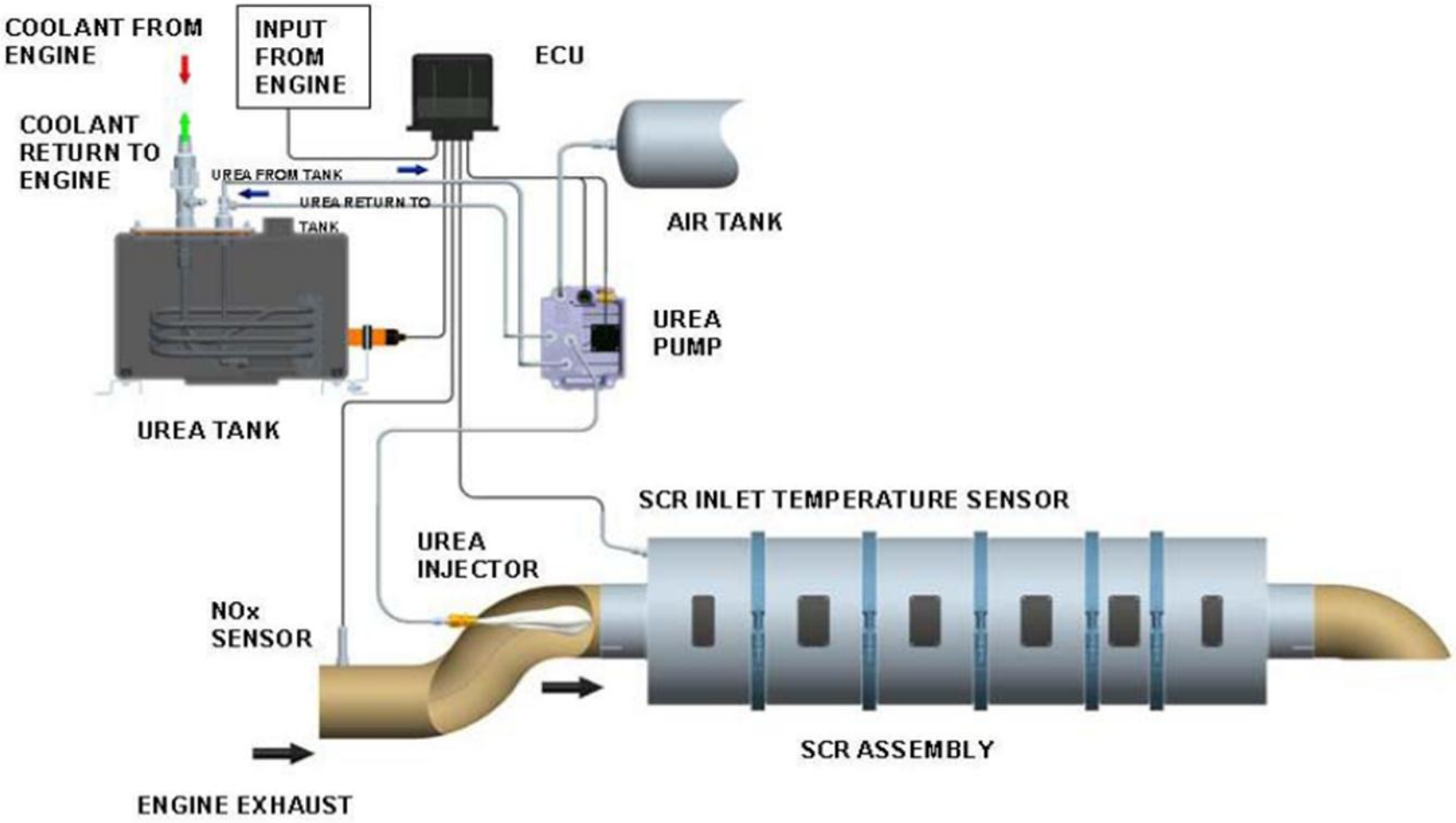
Typical DOC Configuration for Locomotive Engine



Schematic representation of the three different configurations used: four small catalysts in the exhaust manifold catalytic converter upstream of EGR port and downstream of EGR port [Zervas et al, 2010]


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

SCR Assembly for Locomotive Engines

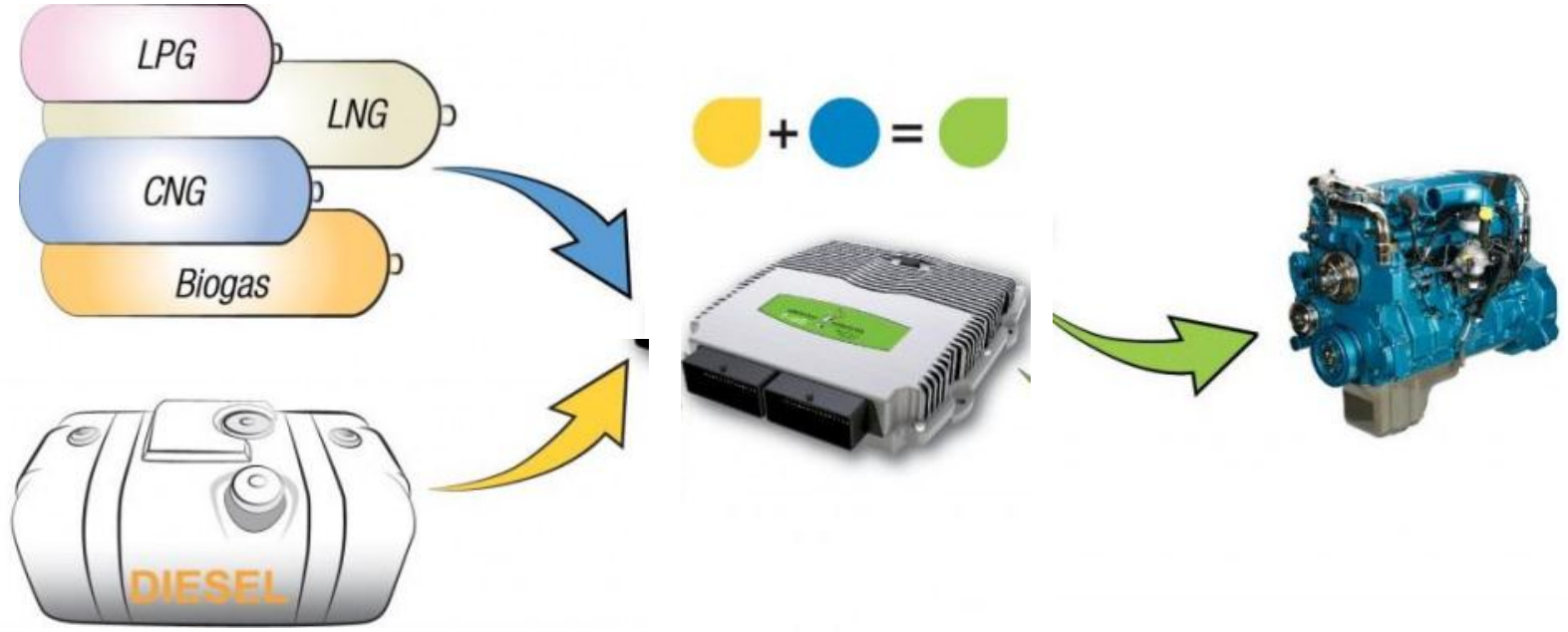


Source: dieselnet.com

Alternative Fuels/ New Technologies

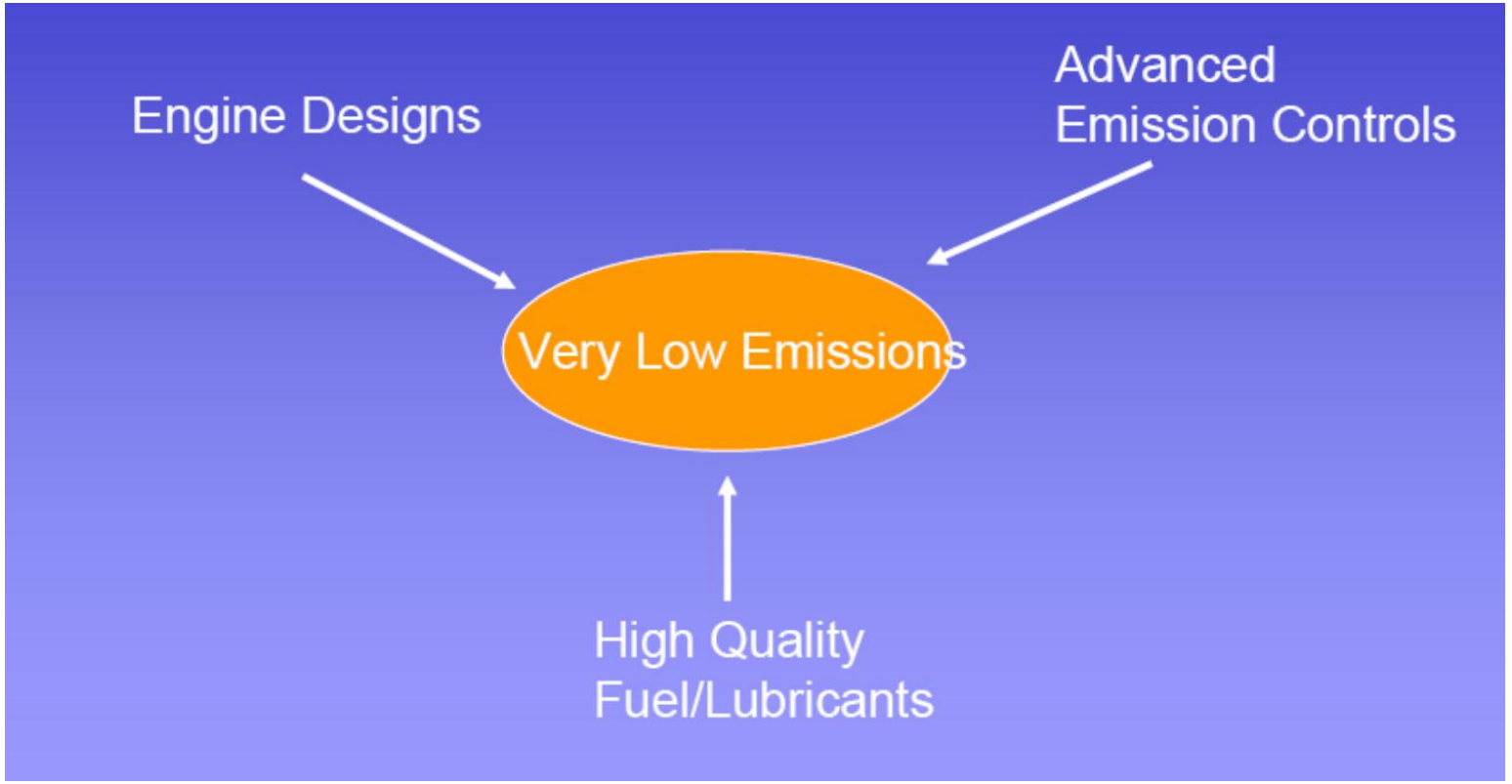
- Indian Railways have announced implementation of B5 biodiesel blends on complete fleet of diesel locomotives
- This is to be increased to higher blends depending on the availability of biodiesel
- Indian Railways have developed jointly a dual fuel CNG DEMU car which is on commercial service
- Developed 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



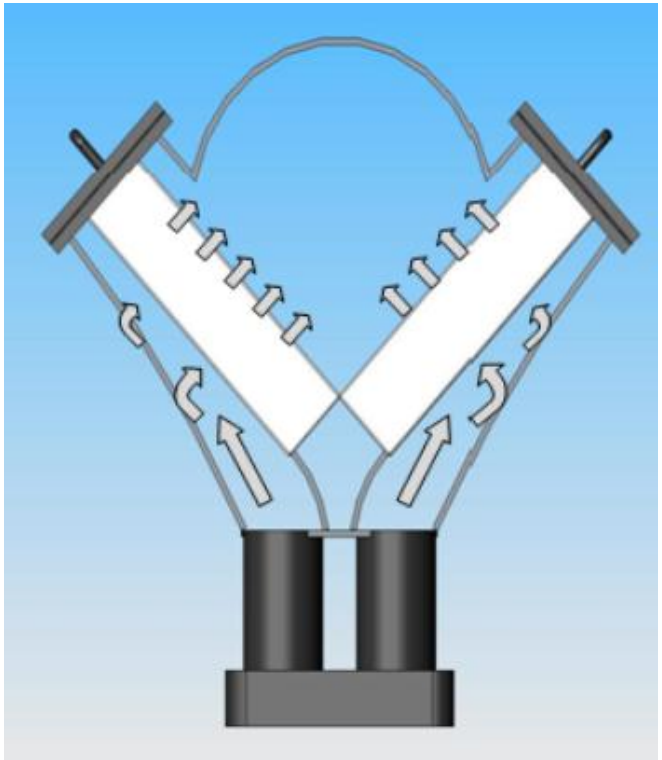
- In the oil and gas market, the fuel bill is one of the largest contributors to the total cost of operation.
- The rapid expansion and abundance of natural gas in some areas of the world is driving a dramatic cost advantage of natural gas over diesel fuel, making natural gas a very economical fuel source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

Integrated System Approach



International Case Studies

- Union Pacific and Progress Rail Services Locomotive Project – 3000 hp engine equipped with DOC + SCR: NOx reduction by 90%.
- Southwest Research Institute Locomotive Retrofit Project
  - Fitment of a DOC on a EMD 16-710-G3A engine
  - An in-manifold design
  - Reduction of PM upto 50%
- California Emissions Program (CEP)
  - Feasibility of installing DOC-DPF technology in locomotives
  - 1500 hp EMD switcher engine
  - DPF with active regeneration using diesel fuel burner
  - Trapping efficiency – 80%
  - White smoke during regeneration



Experimental DOC is an in-manifold design

Road Map for Indian Railways

- Collection of Emissions Data
- Preparation of Emission Standards for diesel locomotives of IR
- Development of in-cylinder technologies and validation in lab and field
- Manufacturing additional mobile emission test cars
- Implementation of emission reduction technologies during rebuilding of the locomotives
- Development of new locomotive designs

Thanks

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