Day II – Clean Diesel : Roadmap for India

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Technology Changes improving diesel emissions

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ARAI
Progress through Research

ANIL AGARWAL DIALOGUE 2015

The Poor in Climate Change

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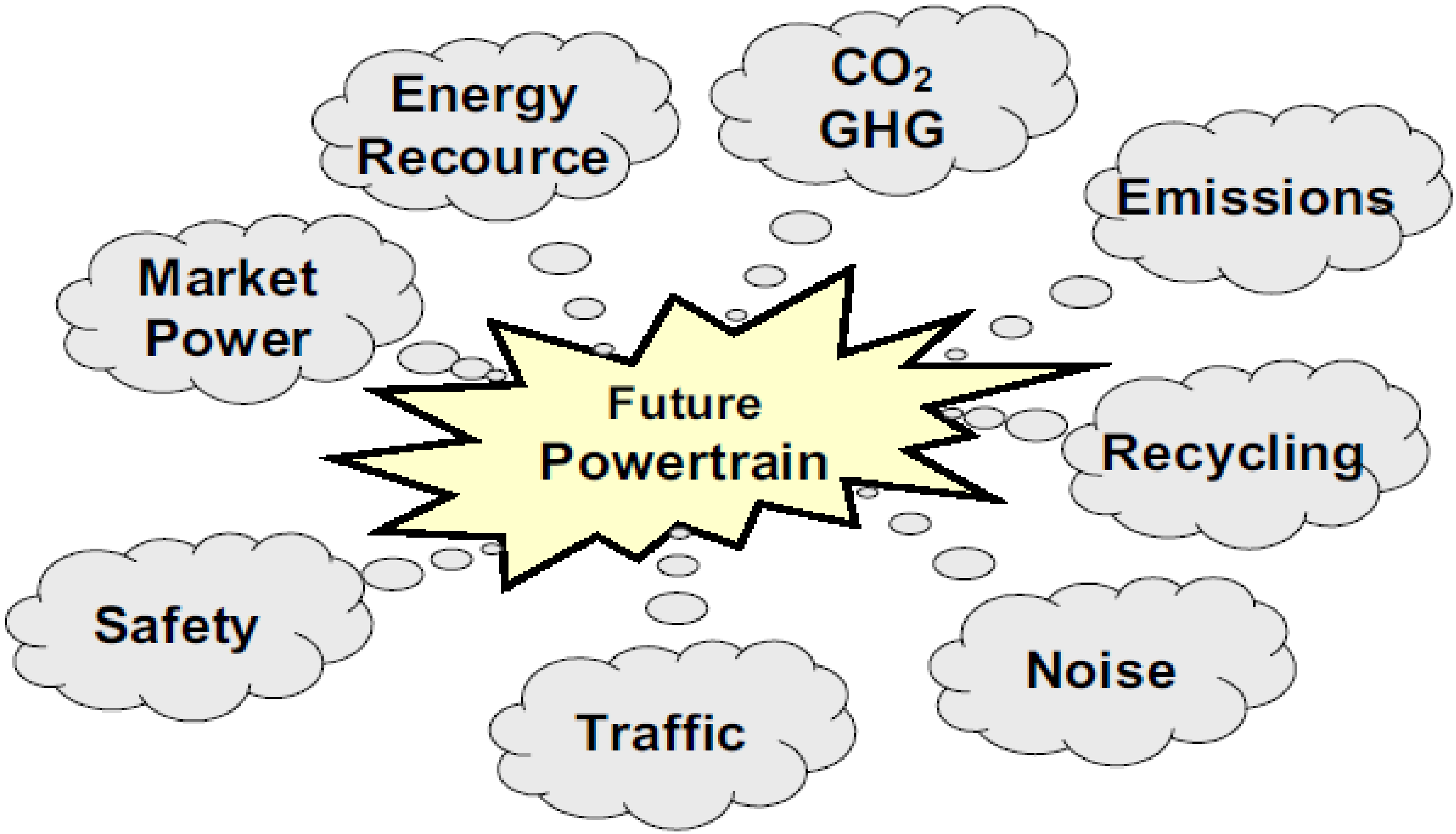
KEY OBJECTIVES OF FUTURE ROAD VEHICLES



Powertrain Performance attributes – customer's perspective

- Performance – Power, Torque
- Fuel economy and range
- Environment friendly – Exhaust Emissions
- Quietness - NVH
- Comfort – Ride quality
- Durability
- Reliability
- Product cost
- Operation & Maintenance cost
- Package volume – downsizing
- Recyclability – disposal issues

Customers

Market / Business Forces

Legislators

Customers

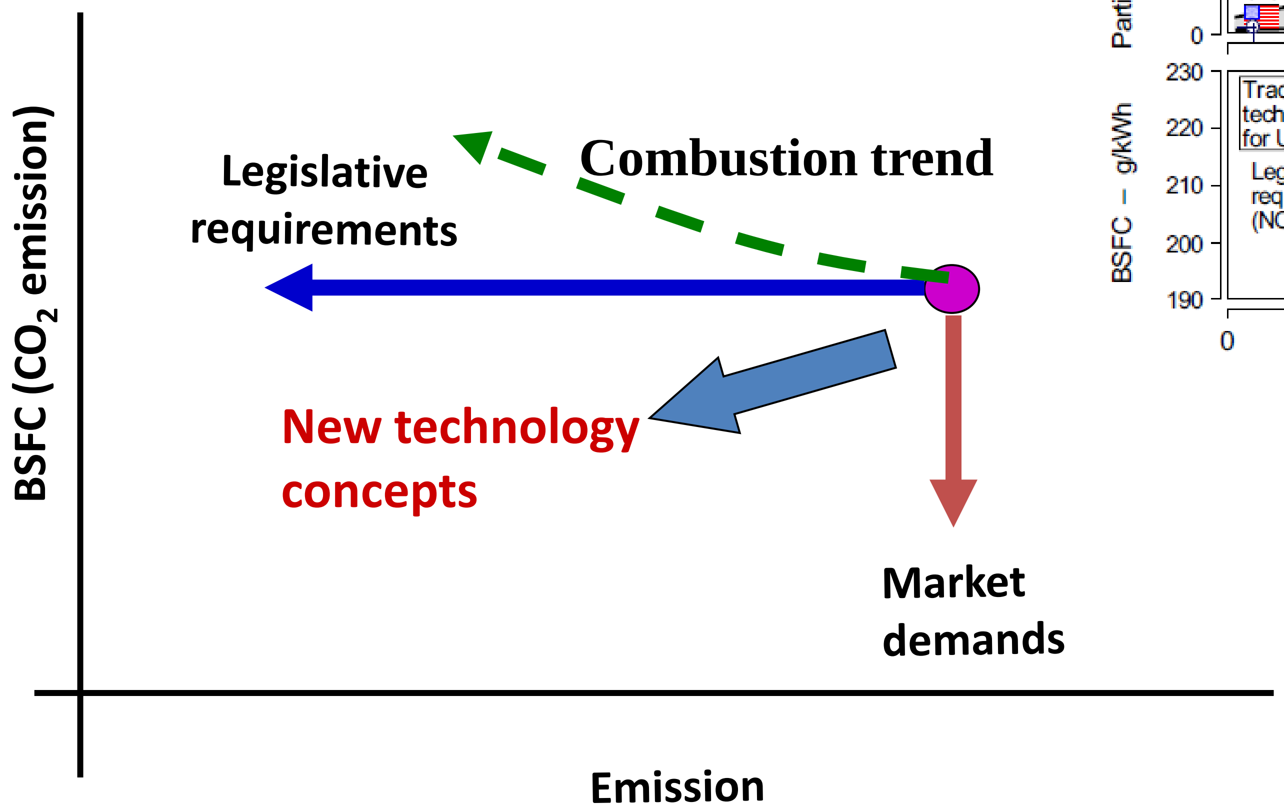
CLEAN AIR

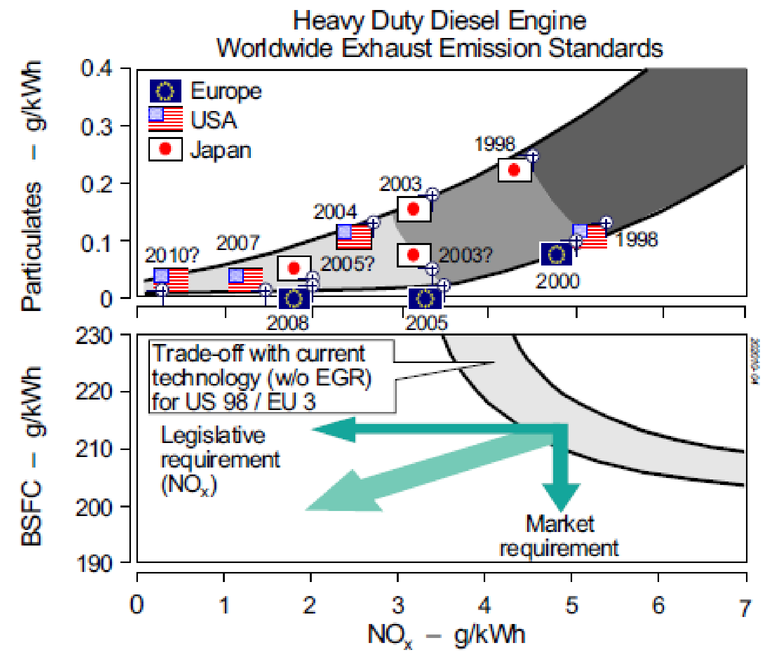
Market / Business Forces

Legislators

Lower Operating Cost

Conflicting Demands





Efficiency – Economy – less fuel consumption – less hydrocarbon burning – less CO_2 emission

Environment protection – less carbon and NOx emission

Exhaust EMISSION

NOISE EMISSION

Energy Conservation – fossil fuel consumption control – Alternate fuel sources

Efficiency – Economy – less fuel consumption – less hydrocarbon burning – less CO_2 emission

Environment protection – less carbon and NOx emission

Exhaust EMISSION

NOISE EMISSION

Energy Conservation – fossil fuel consumption control – Alternate fuel sources

Noise Emission – adverse effects

Often neglected, noise induces a severe impact on humans.

Annoyance

Physiological effects: ***breathing amplitude, blood pressure, heart-beat rate, pulse rate, blood cholesterol***

Loss of hearing: ***Long exposure to high sound level***

Human performance: ***loss of concentration when exposed long hours***

Nervous system: ***pain, ringing in the ears, feeling of tiredness***

Sleeplessness: ***disturbance in sleeping - restless and loose concentration***

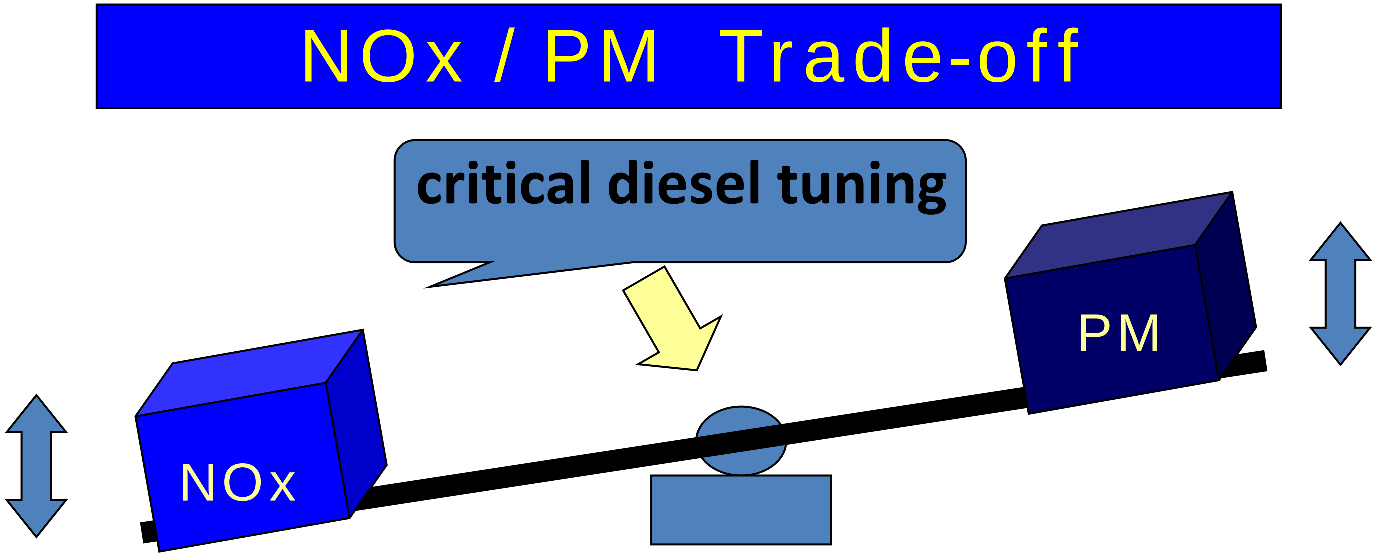
Damage to material : ***damage to buildings and materials when exposed to infrasonic / ultrasonic waves, may even collapse***

Diesel has unmatched unique combination

- power density
- Performance – high torque at lower speeds
- fuel efficiency
- cost-effectiveness
- scalability
- reliability
- fuel availability
- established nationwide fuel & maintenance infrastructure.

NOx / PM Trade-off

Attribute	Effect on NOx	Effect on PM
More air	↑	↓
Higher combustion temperature	↑	↓
Higher reaction time	↑	↓



Diesel Exhaust Emission

CO

HC

NOx

Particulate Matter (PM)

Black Carbon - SOOT

CO_2

Diesel Exhaust Emission

Health effects
Soiling
Acid rain
Ozone depletion
smog
Global Warming

CO

HC

NOx

Particulate Matter (PM)

Black Carbon - SOOT

CO_2

Diesel Exhaust Emission

Health effects

Soiling

Acid rain

Ozone depletion

smog

Global Warming

NOx

Particulate Matter (PM)

Black Carbon - SOOT

Local Effects of Diesel Emissions

Direct toxic and Nuisance effect	***CO*** *causes short term toxicity, blocking the uptake of oxygen by haemoglobin. This problem occurs mainly in confined areas such as garages.* ***NO_2*** *causes respiratory problems in lungs.* ***Particulate matter*** *mechanically overloads the lungs; soot in combination with SO_2 forms an acute toxic.* ***Aldehydes*** *irritate the bronchi and other mucous membranes, and are acute toxics, especially the aldehydes with the lower molecular weights.*
Summer smog (ozone)	***Ozone*** *causes respiratory problems and irritations of the mucous membranes, damages biomolecules and probably diminishes resistance to virus infections. Ozone and other photochemical oxidants are formed by volatile organic compounds (VOC) and NOx under sunlight.*
Long Term Toxicity	***Benzene,*** *a haematotoxic, is also a suspected carcinogen. Toluene and xylene are less toxic.* *Each of the* ***Polycyclic Aromatic Hydrocarbons (PAHs)*** *in exhaust gases has some mutagenic and carcinogenic acitivity. Soot is mutagenic and carcinogenic and increases allergenic reactions.* ***SO_2*** *causes cell destruction.* ***Lead*** *affects the psychic development of children*
Material damage	***Soot*** *fouls buildings.* ***SO_2****, in combination with nitrogen compounds and photochemical oxidants, generates material damage.*
Winter smog	***Particulate matter*** *and* ***SO_2*** *together cause winter smog*

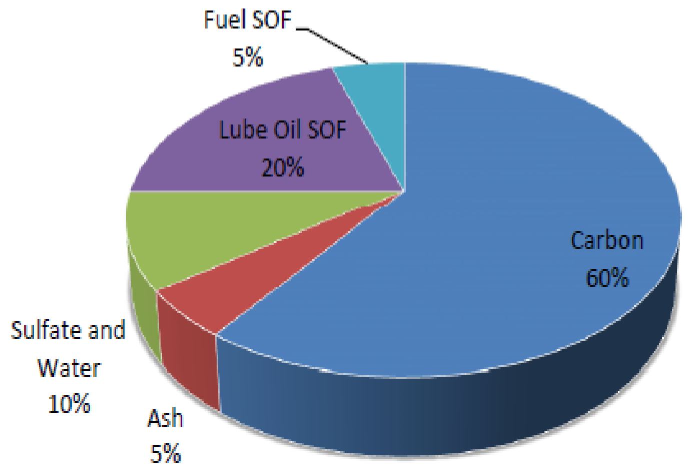
Diesel Black Carbon – Global Warming Facts

- Black carbon is one of the largest contributing pollutants to global warming.
- As a warming pollutant, black carbon is about 2000 times more potent than the equivalent amount of CO_2 over a 20-year period.
- Black carbon particles warm by absorbing sunlight and radiating heat into the air (like a blacktop road). Black carbon can darken snow and ice, and directly accelerate melting.
- Over half of black carbon comes from diesels
- Black carbon is a short-lived pollutant with an atmospheric lifetime of around a week.

Particulate Matter composition

Particulate matter is generally divided into three groups, based on chemical and physical properties:

- the solids fraction composed of elemental carbon and ash;
- the soluble organic fraction, which is made up of organic material derived from engine lubricating oil and fuel; and
- sulfate particulates that originate from the sulfur present in the fuel and lube oil.



- **Diesel Engine Fuel Economy improvement technology options**

- **Diesel Engine NOx, PM, SOOT emission reduction technology options**

- **General Diesel Technology Evolutions from future perspective**

Fuel Economy improvement (engine Controls)

Engine Efficiency

Combustion, Boosting, High Pressure Direct Injection, downsizing

Reduced Inertia

Downsizing, moving parts - Lighter weight, Less weight,

Reduced weight

Structural parts, Stiffness vs weight, reduced cost

Fuel Economy improvement (engine Controls)

Factors in favour of Engine downsizing

- **Reduced pumping losses**

  - less volume is swept on each engine revolution, higher average load on driving cycle, higher average intake pressure

- **Reduced gas-to-wall heat transfer**

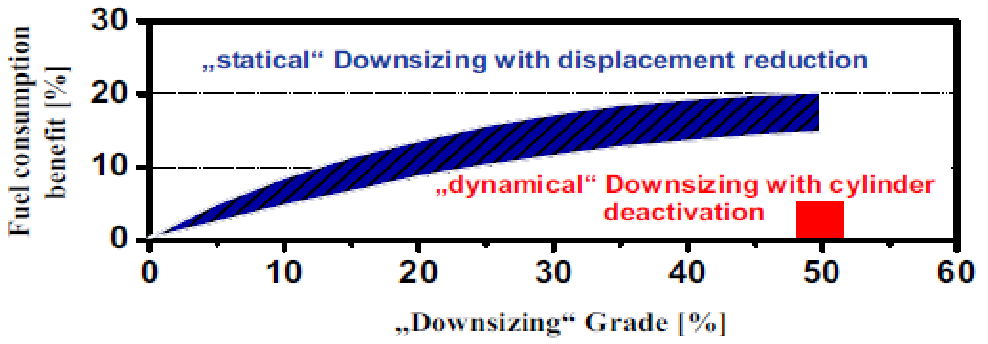
  - reduced internal surface area and faster combustion resulting in reduced gases-wall heat exchange duration

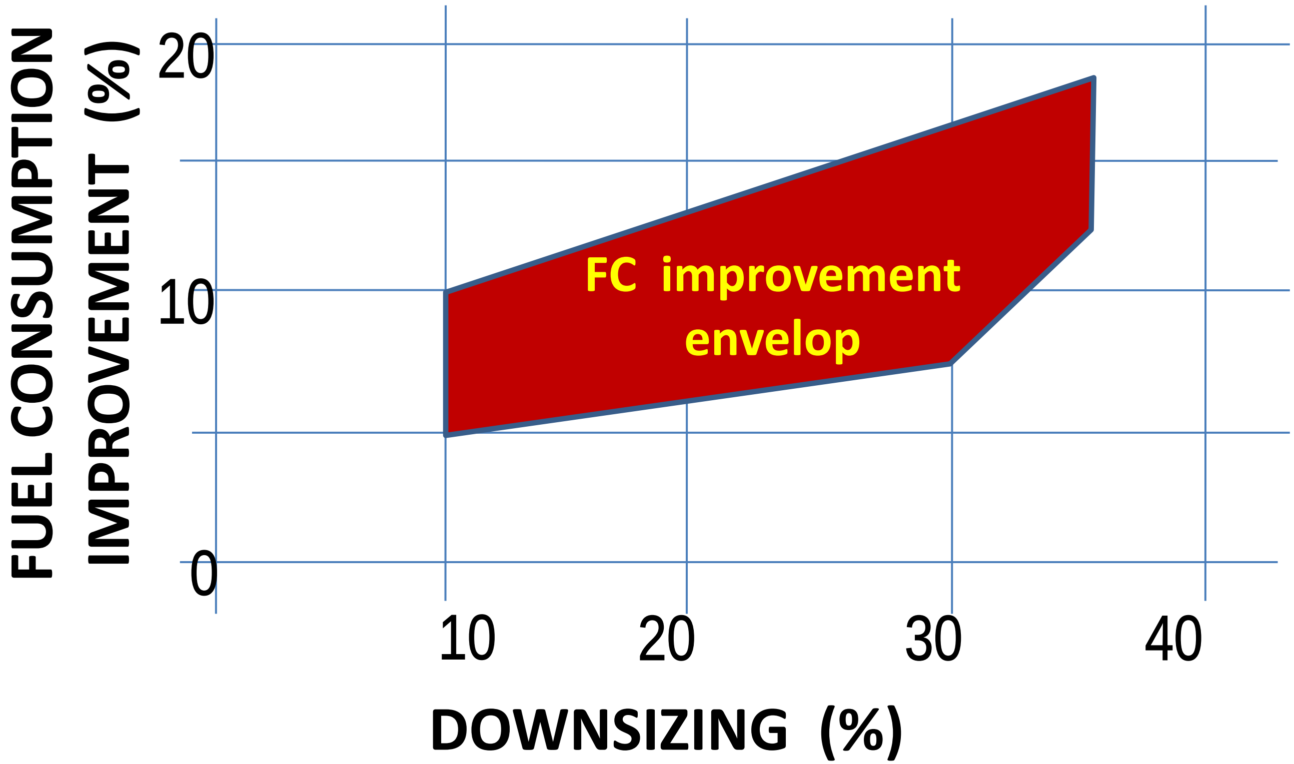
- **Reduced friction losses**

- **Smaller size and number of moving parts.**

Engine Downsizing vs Fuel economy

Downsizing range : 10 – 35 %
FC improvement upto 18 %





Fuel Economy improvement (engine Controls)

- **Reduced Frictional and other losses**

  Least optimum sizing, tribological considerations, material compatibility , thermal and cooling management, valve train management

- **Reduced parasitic losses**

  Thermal losses, pumping losses,
  Auxiliary power consumption reduction

- **Dual Fuel & Hybridisation**

Diesel Vehicles - Fuel Saving Technologies

Engine Efficiency

- High peak cylinder pressure
- Increased turbocharger efficiency
- Improved heat management
- Reduced engine friction

Aerodynamics

- Rounded exteriors
- Air dams
- Gap seals
- Trailer streamlining

Low-Resistance Tires

- Design improvements
- Super singles

Drive Train

- Improved lubricants
- Optimized gearing
- Non-driven axle (tag axle)

Efficient Accessories

Weight Reduction

Idling Energy

- Auxiliary power units
- Truck stop electrification

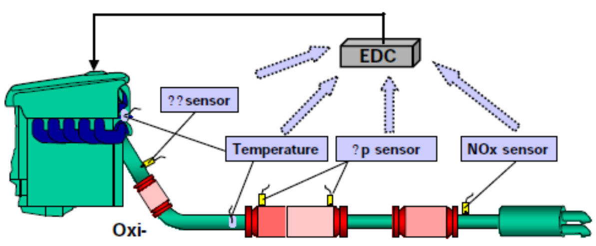
Diesel emission reduction

Development Strategies

Emission reduction

In-cylinder combustion improvement

After Treatment



Diesel emission reduction (in-cylinder measures)

HC Control measures

- Optimised combustion chamber shape & volume
- Increased compression ratio
- Reduced quench area
- Reduced dead volumes
- Optimum spray hitting plane
- Low sac / zero sac nozzles – VCO nozzles
- Optimum injection timing
- Rapid needle closing – no dribble
- No secondary or after injection
- High injection pressure – atomisation
- Ring pack optimisation
- Oil consumption control

Diesel emission reduction (in-cylinder measures)

CO control measures

- Combustion chamber optimisation
- High air-fuel ratio – high excess air
  - Turbocharging
  - Multi-valve configuration
- Swirl optimisation
- Controlled wall wetting
- Optimum injection duration
  - reduce late burning
- Higher compression ratio
- Higher cylinder temperatures

Diesel NOx Reducing Technologies

Engine Improvements	Exhaust-Control Technologies
• Fuel-injection systems: ◆ *High pressures* ◆ *Injection rate shaping* ◆ *Pilot & post injections* ◆ *Timing retard* • Exhaust gas recirculation: ◆ *Cooled* ◆ *Faster response* ◆ *Increased levels* • Combustion chamber: ◆ *4-valve cylinders* ◆ *Increased swirl* ◆ *Bowl geometry* • Charge air cooling	• Lean NOx catalysts • Selective catalytic reduction • NOx adsorbers • Plasma-assisted catalysis **Fuel Reformulations** • Diesel fuel changes: ◆ *Lower sulfur content* [a] ◆ *Increased cetane* ◆ *Decreased aromatics* • Diesel fuel additives: ◆ *Water emulsifications* ◆ *Surfactants/cosurfactants*

Technologies designed to control oxides of nitrogen (NOx) include:

- Exhaust gas recirculation (EGR)
- Selective catalytic reduction (SCR)
- Lean NOx catalysts (LNCs)
- Lean NOx traps (LNTs)

Diesel emission reduction (in-cylinder measures)

Wall wetting control measures – SOOT control

- Smaller nozzle hole sizes with larger number of holes
- More centrally positioned injector
- Larger bowl dia
- More intense swirl
- Higher mean injection pressures

Diesel PM Reducing Technologies

Engine Improvements

- Fuel-injection systems:
  - *High pressures*
  - *Increased rate*
- Turbocharging during acceleration
- Homogenous charge compression ignition

Fuel Reformulations

- Diesel fuel changes:
  - *Lower sulfur content*
- Diesel fuel additives:[a]
  - *Cerium, sodium, copper, iron, other metals*

Exhaust-Control Technologies

- Diesel oxidation catalysts
- Particle traps
  - *Passive regeneration*
    - *Fuel additives*
    - *Catalyst loaded*
  - *Active regeneration*
    - *Electric burner*
    - *Microwave regeneration*
    - *Exhaust gas throttling*

a. Metal-based fuel additives are one strategy for particulate trap regeneration

Technologies designed to control particulate matter (PM) include:

- Diesel oxidation catalysts (DOCs)
- Diesel particulate filters (DPFs)
- Closed crankcase ventilation (CCV)

Diesel technology Evolution

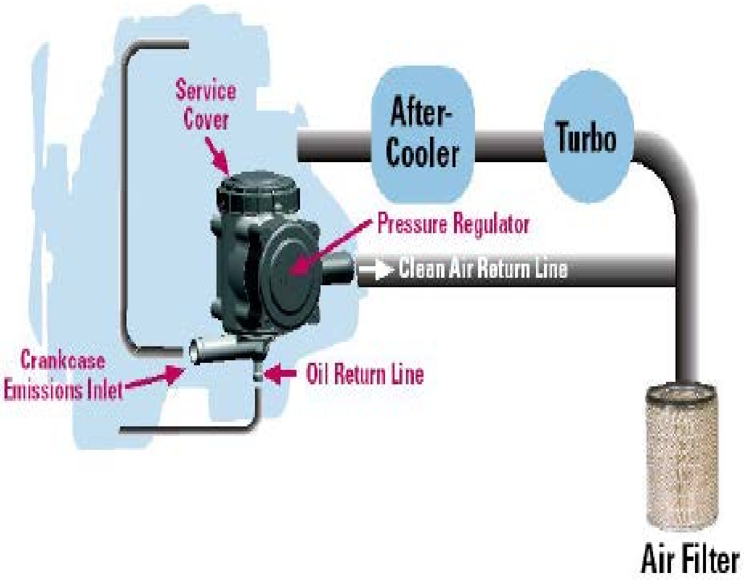
High Pressure Common Rail Direct Injection (HPCRDI) Diesel

In-Cylinder PM Control

Advanced engine calibration techniques and the implementation of electronic controls in new diesel engines have improved air-fuel mixtures and produced significant in-cylinder emissions reductions in both PM and NOx. Emissions of PM can be reduced by changes in engine design that adjust the mixture of fuel and air in the engine cylinder. The fuel injection system design should also be carefully matched to the air management system. The main goal is to control the local concentration of fuel and air inside the combustion chamber and to avoid the conditions that lead to PM formation

Crank Case Ventilation (CCV) – PM control measure

- In most of the current turbocharged, after-cooled diesel engines, the crankcase is vented into the atmosphere through a directed draft tube. A substantial amount of uncontrolled particulate is released to the atmosphere .
- Typical systems consist of a filter housing, a pressure regulator, a pressure relief valve and an oil check valve. Oil is seperated from the crank case gases and returned to oil sump. Oil-free gases are redirected into the intake system mixing with charge air.
- These systems greatly reduce crankcase emissions.
- Closed crankcase filter systems can be combined with DOCs or DPFs to reduce PM emissions associated with both the ventilation of the crankcase and the tailpipe.



Diesel technology Evolution – energy security drive

Dual Fuel Diesel – CNG/LNG operation

- In dual-fuel systems diesel is used as pilot fuel in predefined speed-load zone, which ignites the air-CNG/LNG mixture.
- Low speed and close to full loads are operated in diesel-alone mode.
- Vehicles can also be operated on diesel only in case of non-availability of CNG/LNG. This makes them fit for operation in regions with limited CNG infrastructure.
- the engine is able to operate on either 100% diesel fuel, or alternately, on a mixture of diesel fuel and natural gas (or other combustible gases). At no time is the engine able to operate on natural gas exclusively.
- ARAI has developed such dual-fuel engines and demonstrated on road. Approx 33% fuel cost reduction is achieved with upto 72% max displacement of diesel. Average diesel displacement is 53%.

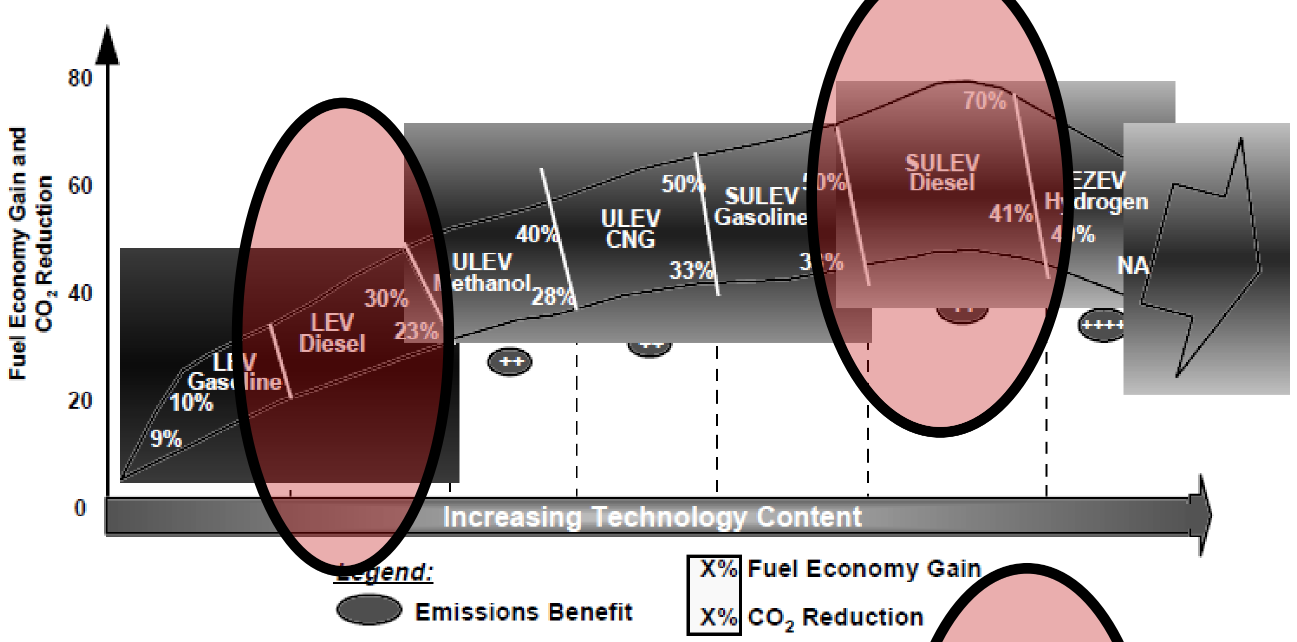
Diesel technology Evolution – energy security drive

Diesel – Electric Hybridisation

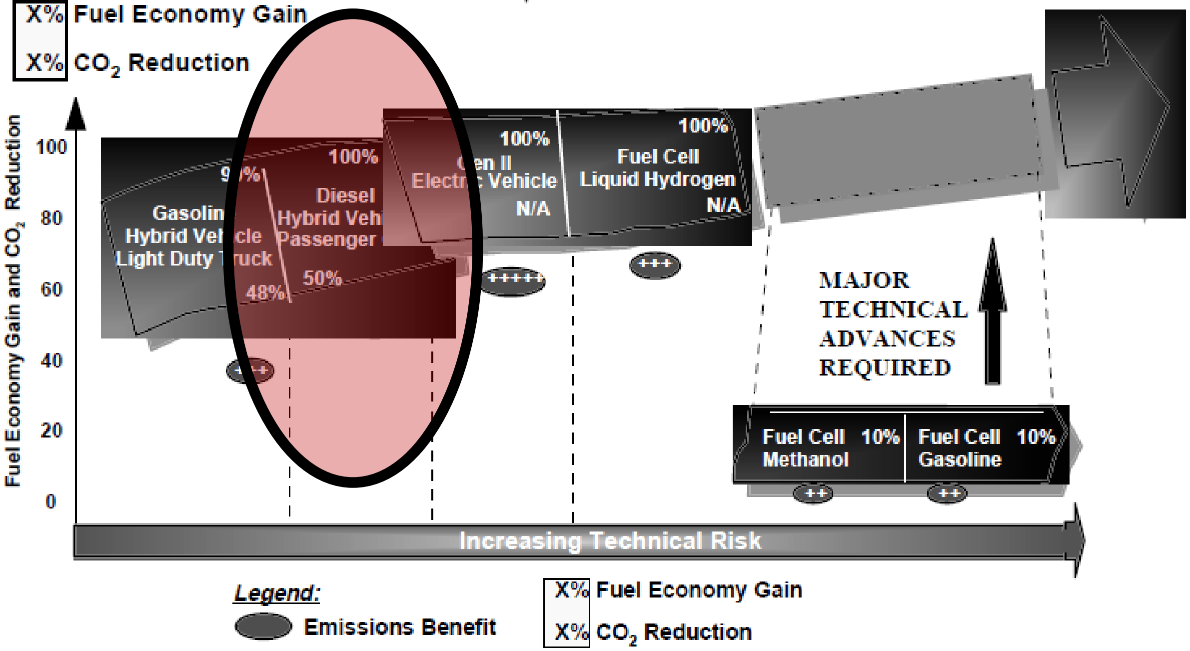
- Diesel-electric Hybrid vehicles combine the benefits of diesel engines and electric motors and can be configured to obtain different objectives, such as improved fuel economy, conservation of fossil fuel usage, increased power, reduced emissions of soot/PM, reduced engine size , etc.
- Beyond the reduction in fuel use, lower emissions and longer service intervals are other potential factors strengthening the case for diesel-electric hybrid technology
- Combine the high cost of diesel with potential maintenance savings and possibility of some kind of tax incentives, the business case for hybrid-electric vehicles can become more and more favorable
- Electric-only mode (with the engine-off) will significantly contribute to the improvement in fuel economy and reduction in use of fossil fuel.
- Overall 15 – 25% fuel economy improvement has been reported.

Diesel technology Evolution

– energy security drive



Diesel – Electric Hybridisation



Near Term Generation Power train Trends

Diesel technology Evolution

Cylinder deactivation

By deactivating half of the cylinders, the remaining active cylinders operate at twice the load that the engine would normally operate at if all cylinders were active.

This reduces the pumping losses and improves fuel consumption.

Engines with cylinder deactivation can be found in several vehicles under various trade names such as Multiple Displacement System (MDS) and Active Fuel Management (AFM).

To date, cylinder deactivation has been applied to a few V6, V8, and V12 engines.

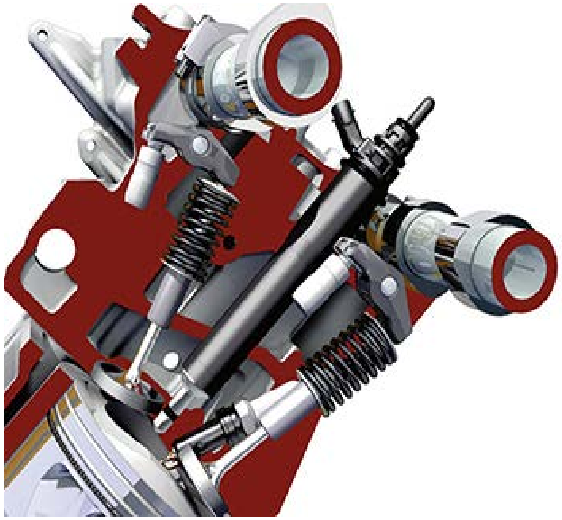
Diesel technology Evolution

Optimised/advanced cooling and electric water pump

- **These technologies account for coolant and oil thermal inertias to help reduce fuel consumption.**
- **During engine operation, the centre housing is integrated into the cooling loop of the engine.**
- **After the engine's shutdown, the residual heat is carried away by means of a small cooling circuit, which is driven by a thermostatically controlled electric water pump.**

Diesel technology Evolution

Variable Valve Timing and Lift

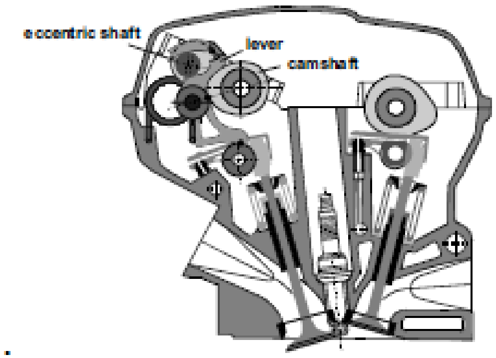


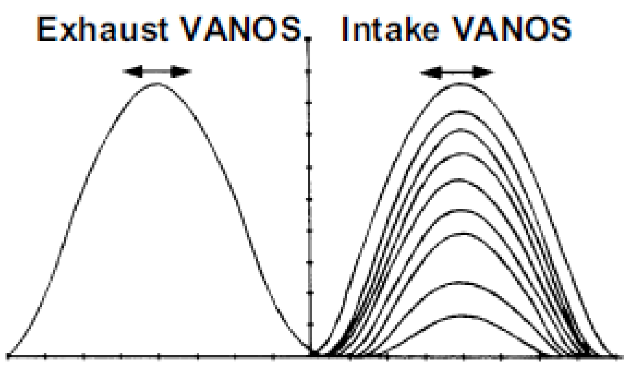
- Valves open and close to allow air and fuel to enter cylinders and for the products of combustion to exit.
- Different valve timings produce different results (more power, better fuel economy). Traditionally, there is a single valve timing by design.
- But many modern engines can vary valve timing, allowing for example the default low RPM range of the engine to have more economical timing, and the higher RPM range to go for max power.
- This allows a smaller displacement engine to produce more peak power, so it allows for downsizing and fuel savings.

Diesel technology Evolution

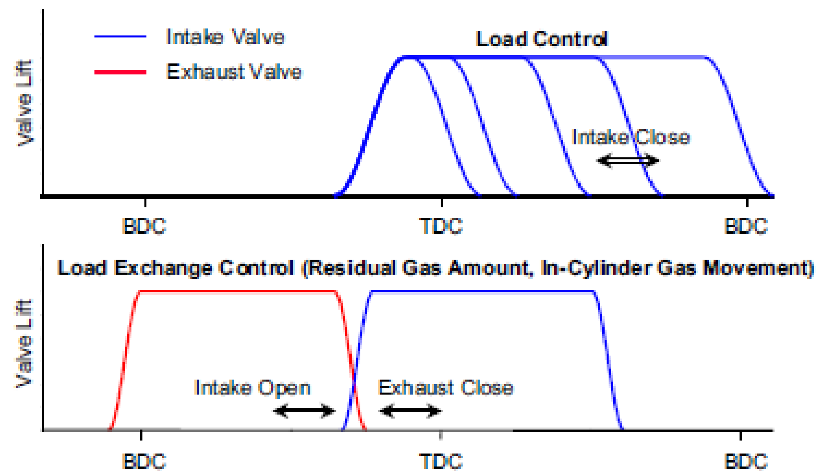
Variable Valve Timing and Lift

Mechanical





Electromagnetic



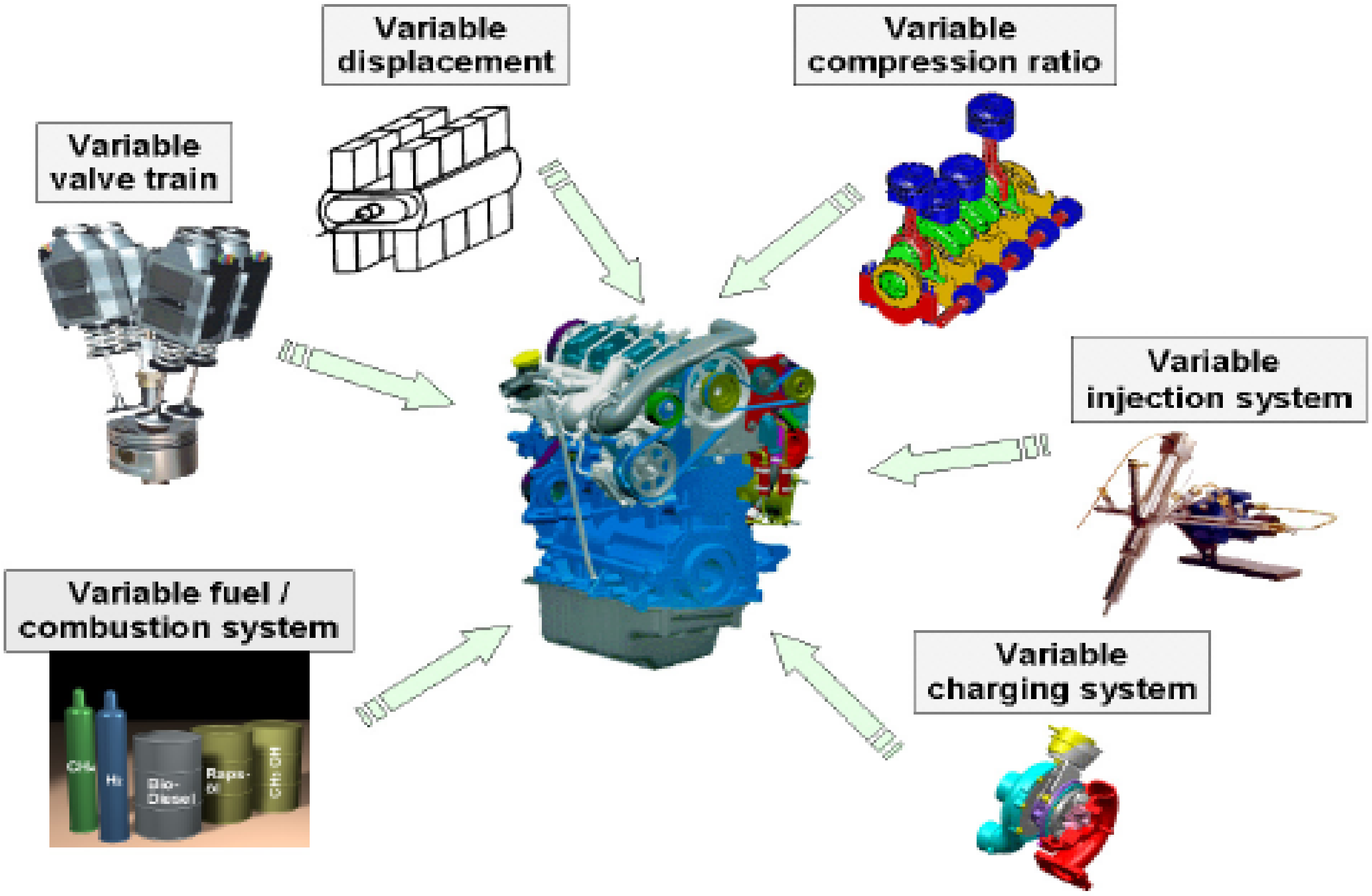
Diesel technology Evolution

Constant further development and optimisation is required for following diesel engine technologies :

- High pressure fuel injection system
- Fully flexible Electronic Control Unit (ECU)
- Gas Exchange – intake system, variable valve lift and timings, no and size of valves, turbocharging / supercharging, EGR
- Friction reduction measures
- Weight & Inertia reduction measures
- Oxidation Catalyst improvisation
- NOx after-treatment measures
- Particulate after-treatment measures
- Ultra-low / no-sulfur diesel fuel

Diesel technology Evolution

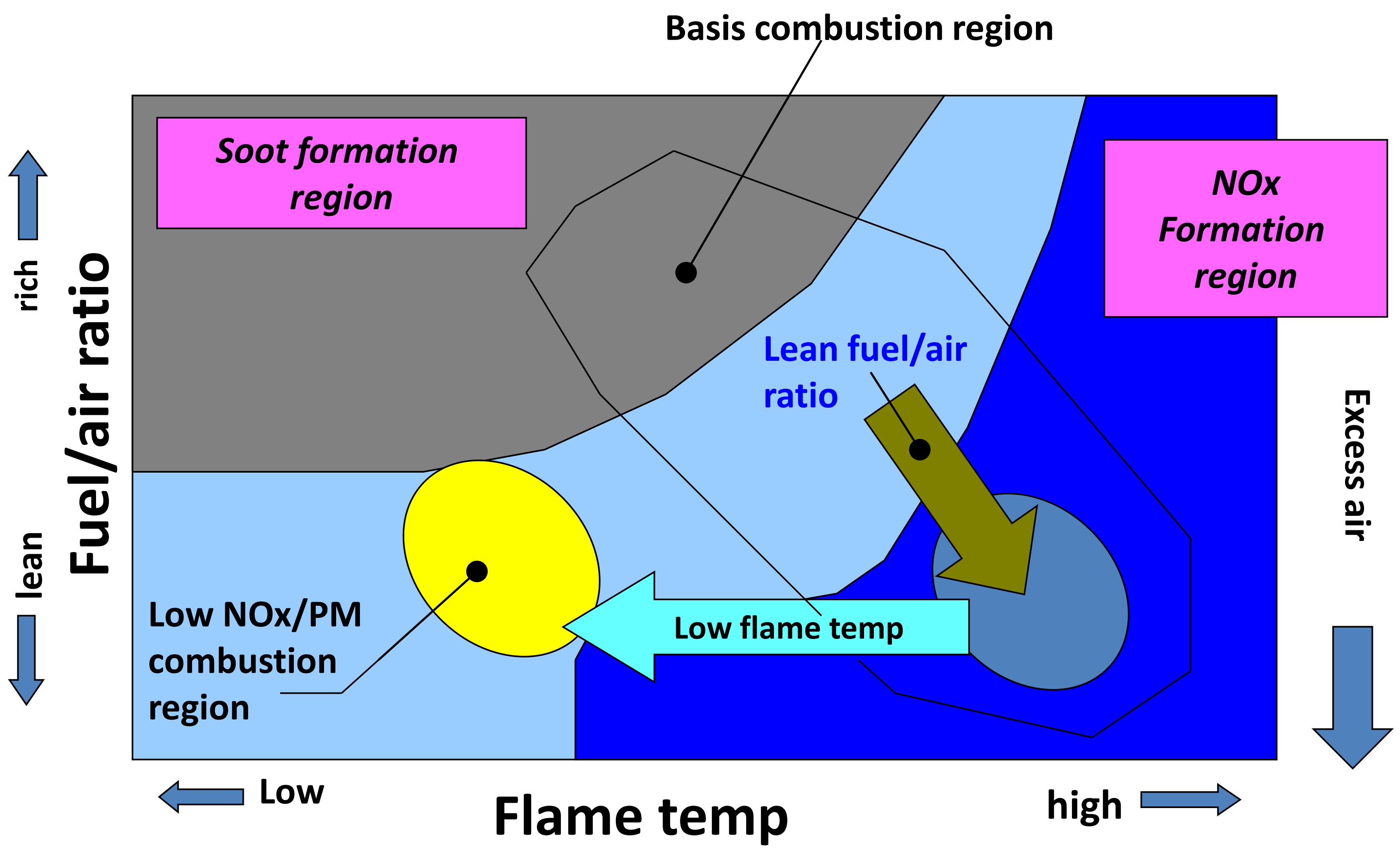
Variable Control Diesel Engine

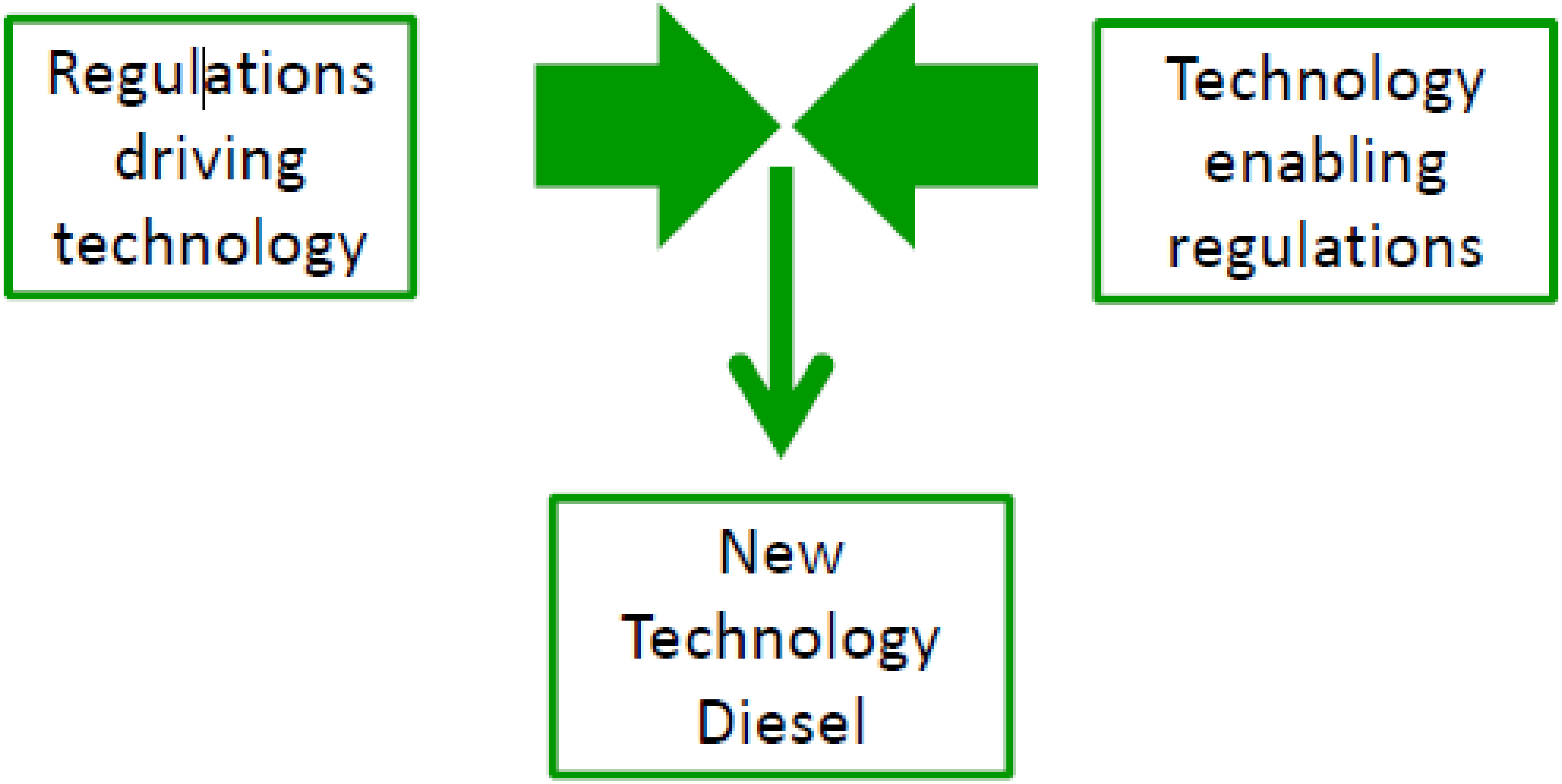


Key diesel technologies needing optimisation and further research work :

- Higher power density > 80 kW/liter (increased downsizing, high speed concepts – higher BMEP levels and peak combustion gas pressures), Thermal efficiency improvement
- Low-temperature combustion – early IVC, Miller Cycle, HCCI
- Advance high pressure fuel injection systems > 3000 bar with injection rate shaping capability
- More utilisation of VVT, variable swirl
- Advance turbocharging – two stage turbocharging, turbo-compounding, turbo-supercharger combination, electrically operated supercharger
- EGR – Nox after treatment combination
- Light-off temperatures improvement for catalytic reactions
- Low cost, compact after treatment devices, Catalyst cooling
- Cam-less valve actuation
- Friction reduction, auxiliary losses reduction, waste heat recovery

Concept of low NOx / PM formation




Regulations driving technology
Technology enabling regulations
New Technology Diesel

SUMMARY (1)

- Diesel emissions from mobile sources have raised health and welfare concerns, but a number of technologies exist that can greatly reduce emissions from diesel-powered vehicles.
- Diesel oxidation catalysts, diesel particulate filters, SCR, exhaust gas recirculation and crankcase emission controls will bring definite success to substantially control PM and NOx emission in general and Black Carbon in particular.
- Availability of ultra low sulfur diesel for on-road vehicles will enable the effective application of advanced emission after-treatment control systems for diesel engines and vehicles as regards durability and robust performance.
- There is a greater potential to further enhance Fuel economy / Efficiency from diesel engines by advance design concepts and employing revolutionary systems such as full variable diesel engines.

SUMMARY (2)

- Dual-fuel diesel-CNG/LNG can provide additional life to diesel power trains combining individual merits and still ensuring non-redundancy in case of unavailability of CNG/LNG.
- Diesel – Electric hybrid has potential to become preferred choice for commercial sector and off-road segment.
- With advance, maturing and reliable technologies in place, substantial reduction is feasible in diesel emissions of NOx and Black Carbon. NEAR-ZERO Emission diesel performance could be a reality.
- DIESEL WILL NOT BE A DIRTY FUEL, if proper maintenance, controlled fuel quality and proper driving habits complement advance engine system; to ensure sustained performance over the design life period.

Thank you.....

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