UPCOMING ENGINE EMISSION DESIGNS AND ENGINE OIL TRENDS

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Topics

- **Emissions Strategies 2010 – up**
  - **On-Highway**
    - **OEM Strategies and Types of Devices**
    - **Engine Oil Effects**
  - **Off-Highway**
    - **Tier 3 and 4 Engines and OEM Strategies**
    - **Engine Oil Effects**
  - **Effects of Biodiesel on Engine Oils**

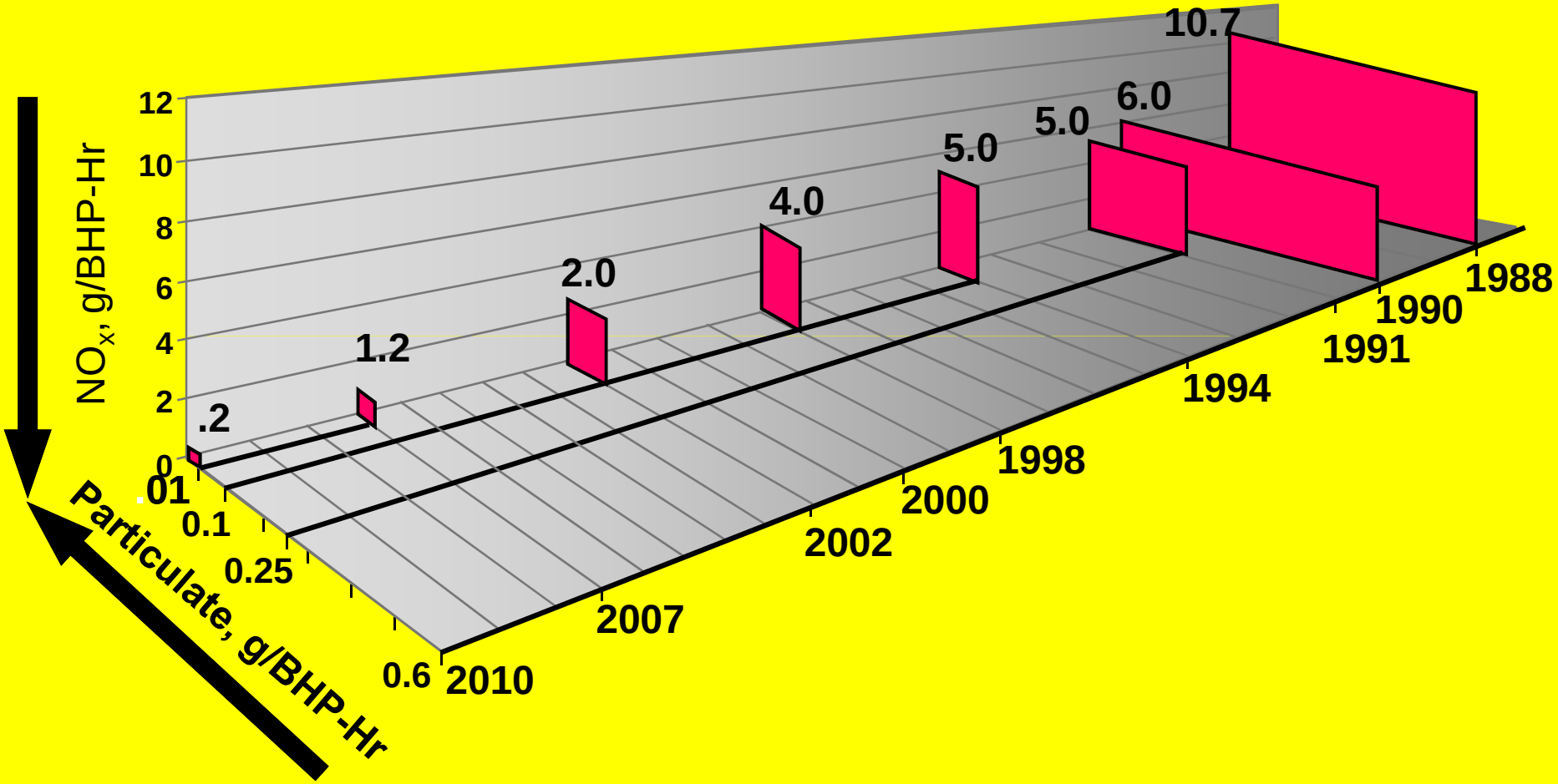
Regulations

- **The Clean Air Act of 1990 mandated a reduction emissions for both gasoline and diesel engines.**

- **Since 1997 the EPA has adopted stringent emission standards for on-highway diesel engines in order to reduce Nitrous Oxide (NO_X) and Particulate Emissions(PM).**

- **In 2008 off-highway diesel engines began to be more severely regulated for NO_X and PM Emissions.**

Emission Standards for NO_X and Particulates - On Highway Diesel



DIESEL FUEL SULFUR TIME TABLE

Year	2006	2007	2008	2009	2010	2011	2012
On-Road	500 – 15 ppm (Oct 15)	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm
Off Road	5000 Max	5000 – 500 Max (June)	500 Max	500 Max	500 – 15 Max (June)	15 Max	15 Max Marine Locomotive (June)

On-Highway

Emission Strategies & Devices

2010 Technology Strategies – On Highway

- Exhaust Gas Recirculation (EGR) (increased amounts)
- Closed Crankcase Ventilation (CCV)
- Exhaust after-treatment
  - Diesel Oxidation Catalysts (DOC) (up-stream of DPF)
  - Diesel Particulate Filters (DPF)
  - NO_X Absorbers (Navistar)
  - Selective Catalytic Reduction (SCR)
- On-Board Diagnostics.

EGR

- **Used since 2002 to control NO_X.**
- **Cycles up to 35% of cooled engine exhaust back into the engine air intake.**
- **A Variable Geometry Turbocharger balances the fresh air/EGR ratio.**
- **Dilutes the oxygen content of the intake air in the combustion chamber resulting lower peak combustion temperatures.**

Closed Crankcase Ventilation (CCV)

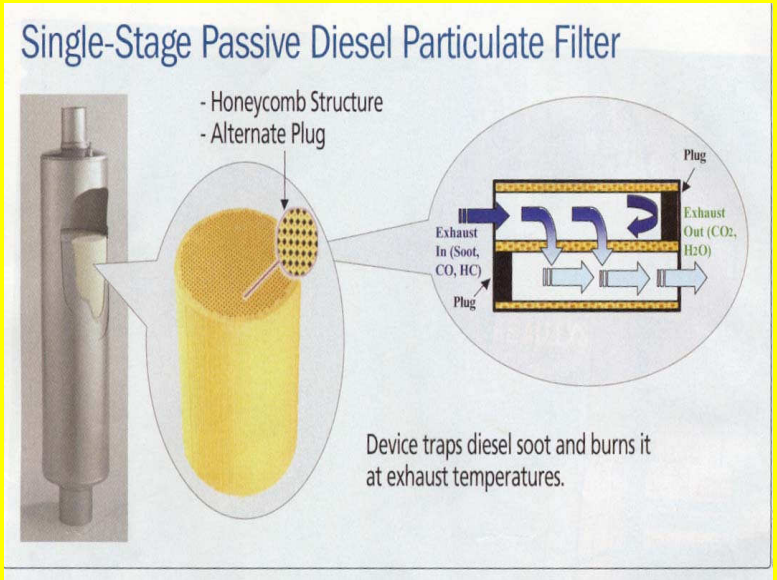
- **CCV was first used to meet the 2007 emissions requirements .**
- **Removes harmful vapors generated in the crankcase.**
- **Vapors are discharged into the engine's intake system,(usually via the intake manifold), where they are burned as part of the combustion process.**
- **Recovers the evaporated oil and carries it through the exhaust stream.**

Exhaust After-treatment

- **All OEMs will use either a combination of DOC and DPF or NO_X Absorbers and DPF to meet 2010 emissions requirements.**

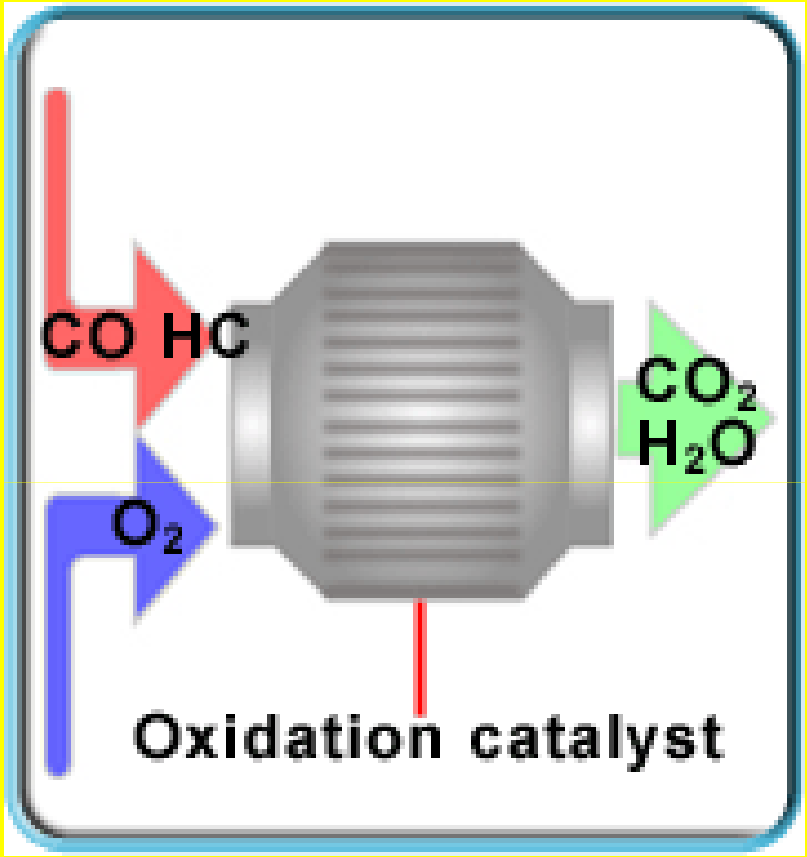
- **With the exception of Navistar the OEMs will use Selectively Catalytic Reduction (SCR).**
  - **Will use Massive Exhaust Gas Recirculation and emission credits.**
    - **Up to 50% of cooled exhaust gas recirculated.**
    - **Advanced fuel injection system that operate at 35,000 psi.**

What Is A Diesel Particulate Filter?



- **DPFs are aftertreatment devices used to remove particulate matter from diesel exhaust.**
- **DPFs physically capture particulates in the diesel exhaust and prevent their discharge from the exhaust pipe. Collected particulates, such as soot are removed from the filter by burning them off at elevated temperatures.**

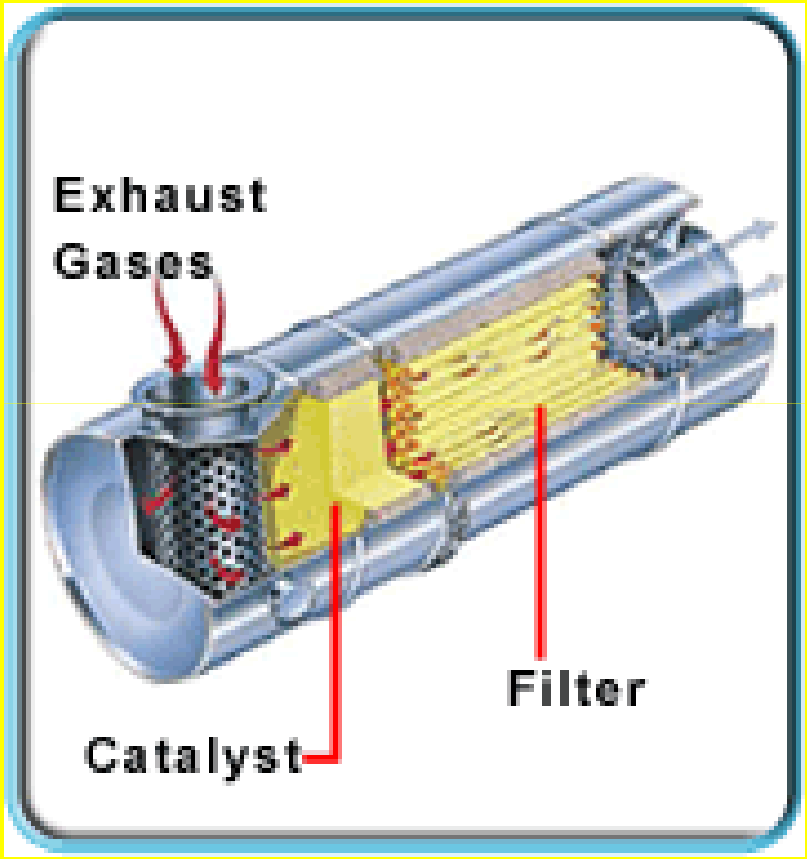
Diesel Oxidation Catalysts (DOC)



DOCs catalytically convert organic particulates, hydrocarbons, and CO in diesel exhaust to CO2 and water

- DOCs are used to remove organic particulates (which come from unburned fuel and the engine oil), hydrocarbons and carbon monoxide from diesel exhaust.
- DOCs use catalysts such as platinum or palladium to promote oxidation of organic particulates, hydrocarbons and carbon monoxide, thereby converting them to carbon dioxide and water.

Continuously Regenerating Traps (CRT)



- CRTs combines a DOC upstream of a particulate filter.
- DOC coverts NO_X to nitrogen dioxide (NO_2) before the exhaust enters the DPF.
- NO_2 lowers the temperature required to oxidize/burn off the particulates.
- Allows the CRT to continuously clear itself of trapped particles.

NO_X Absorbers

- **Technologies include Lean NO_X Traps (LNT), Lean NO_X Catalysts (LNC) and DeNO_X Catalysts.**

- **Used to remove or convert NO_X into a harmless gas.**

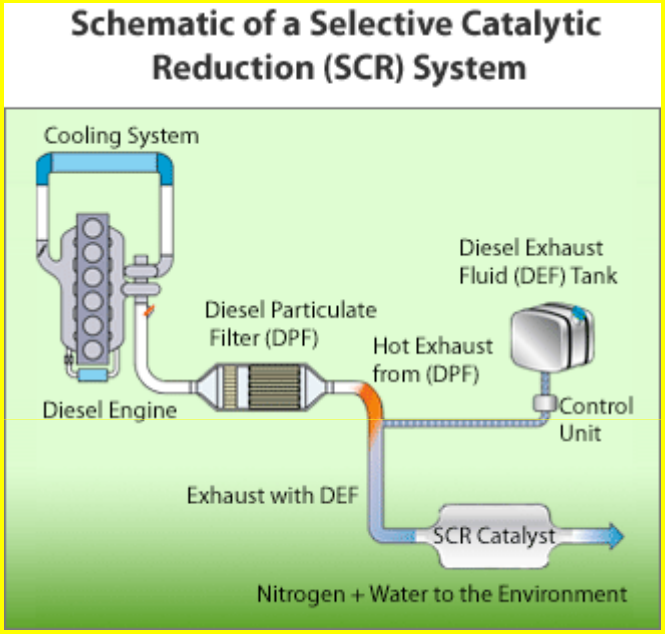
Lean NO_X Catalysts (LNC)

- LNC is also known as $DeNO_X$ catalysts.
- Uses noble metal catalysts of platinum, palladium or a mixture in the presence of hydrocarbons to reduce nitrogen oxides into harmless nitrogen gas.
- Can be passive or active.
- Passive LNC uses hydrocarbons from the exhaust stream.
- Active LNC requires enrichment of the exhaust stream by the addition of fuel being injected into the exhaust stream.

Lean NO_X Traps (LNT)

- LNT are also known as NO_X absorbers or NO_X Storage Reduction Catalysts (NSRC).
- Removes nitrogen oxides from emissions in two stages.
- During the first stage precious metal catalysts convert nitrous oxides to nitrogen dioxide and store the nitrogen dioxide in an alkaline earth oxide as a nitrate salt.
- The stored nitrogen oxides are released by creating a temporary rich exhaust condition and then catalytically reduced to nitrogen gas using unburned fuel as the reducing agent.

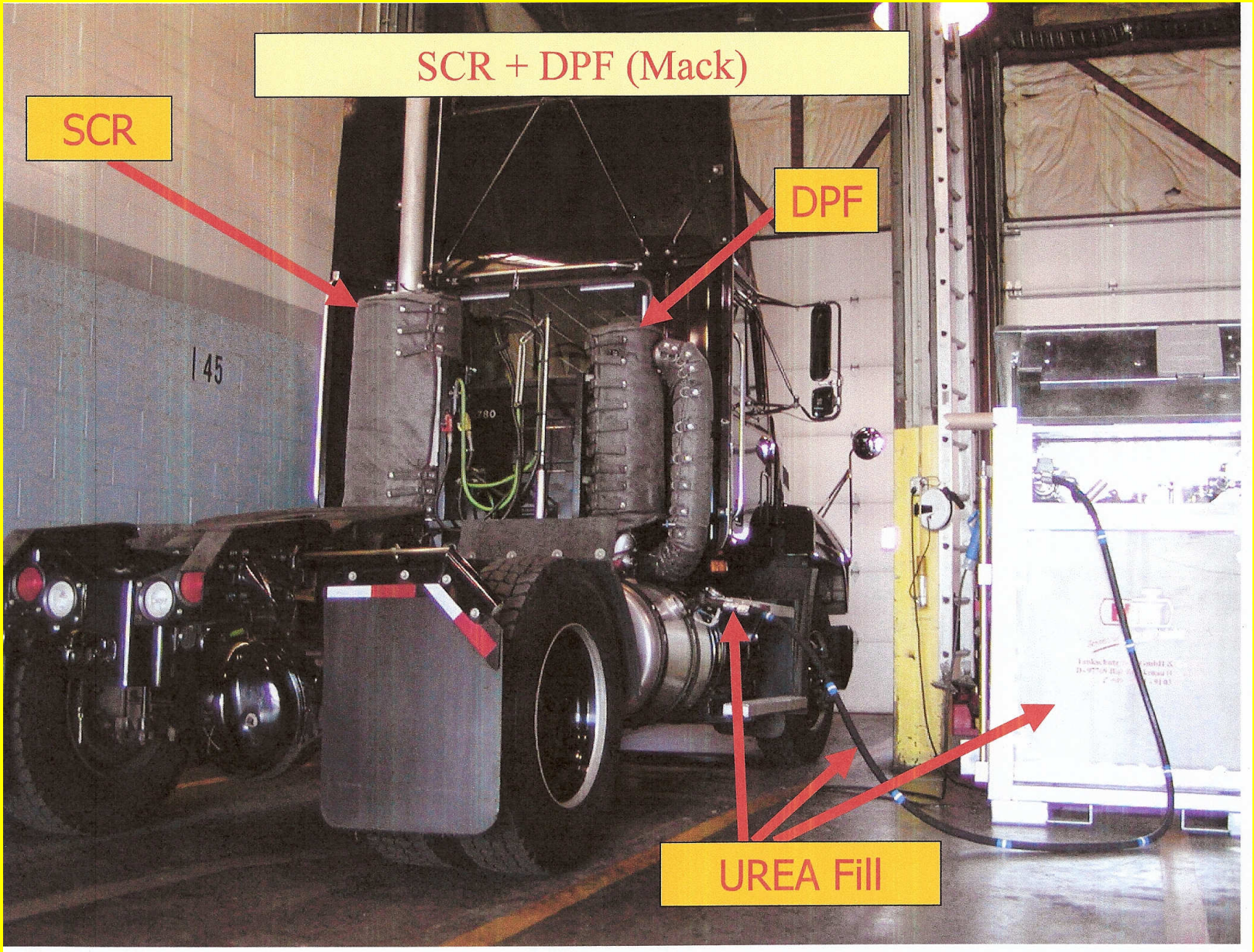
Selectively Catalytic Reduction (SCR)



- **Removes NO_X by injecting a finely atomized Diesel Exhaust Fluid (DEF) from a storage tank into the exhaust stream before it enters a catalyst system.**
- **The DEF is composed of a 32.5% urea and water solution.**
- **In the presence of the SCR catalyst the exhaust and the DEF react to convert NO_X into nitrogen and water vapor.**
- **Any remaining ammonia that may be present is removed by an oxidation catalyst.**

Selectively Catalytic Reduction (SCR)

- Technology is used extensively in Europe.
  - DEF marketed as AdBlue.
- DEF tank must be refilled periodically
  - Consumed at rate of 2-4 gallons for every 100gals of diesel fuel the vehicle consumes.
    - Truck that does 120,000 miles/yr uses 20,000 gallons of fuel/yr at 6 mpg would use 400 gallons of DEF (2% rate)
  - DEF tank size is scaled to ~2.5 times the size of the fuel tank capacity.
    - Assuming 3% dosing tank capacity equals 3 gals X 2.5 = 7.5 gals.
    - Tank sizes will generally range from 5 to 30 gallons for medium duty vehicles.


SCR + DPF (Mack)
SCR
DPF
UREA Fill

Selectively Catalytic Reduction (SCR)

- **SCR will offer 3 to 5% fuel economy benefits over existing technologies.**
  - **More efficient engine operation.**
  - **Allows for reduced EGR flow rates and better fuel use.**
    - **Slight improvement in performance with higher power density.**

Urea Issues

- **Corrosive to aluminum. Must be stored in stainless steel or polyethylene tanks.**
- **Freezes at about 11°F.**
- **Above 86°F begins to separate and evaporate.**
- **DEF injectors have to be self purging to prevent the build-up of crystallized urea.**
- **Storage tanks will add vehicle weight.**

Urea Issues

- **Possible extra maintenance.**
  - **Filter changes (changes at 150,000 miles)**
- **Cost for Urea.**
- **Vehicles equipped with sensors.**
  - **If bad urea solution or no urea engine will de-rate and vehicle will lose power.**
  - **Vehicle speed limited at 15 mph.**
  - **Shut down and no re-start without re-fill.**

Engine oil effects

- MEGR can introduce more soot and increase engine operating temperatures.
- Use of SCR and EGR will decrease levels of soot.
- Retrofits containing DPF mandated by CARB and other governmental agencies will require the use of low SAPs engine oils.
  - All vehicles that operate in CA must be upgraded by 2014.
- API CJ-4 will meet the demands of 2010 engines.
  - More robust additive technology.
    - Provides increased soot and corrosion protection.
  - Low SAPs.

Off-Highway

Emission Strategies & Devices

Off-Highway emissions

- **Off-highway engines from 50 to 750 HP (37 to 560 kW) have been regulated for NO_X and Particulate Matter emissions.**
  - **Emissions reductions have been slowly phased in since 1996 according to horsepower ratings by Tiers.**
    - **Tier 1 spanned 1996 through 1999**
    - **Tier 2 spanned 2001 through 2004**
    - **Tire 3 spanned 2006 through 2008**
    - **Interim Tier spans 2008 through 2012**
    - **Final Tier 4 spans 2012 through 2015**
  - **By 2015 NO_X emissions will be reduced by more than 90% and Particulate Matter by more than 95%.**

Emission Standards – Off Highway

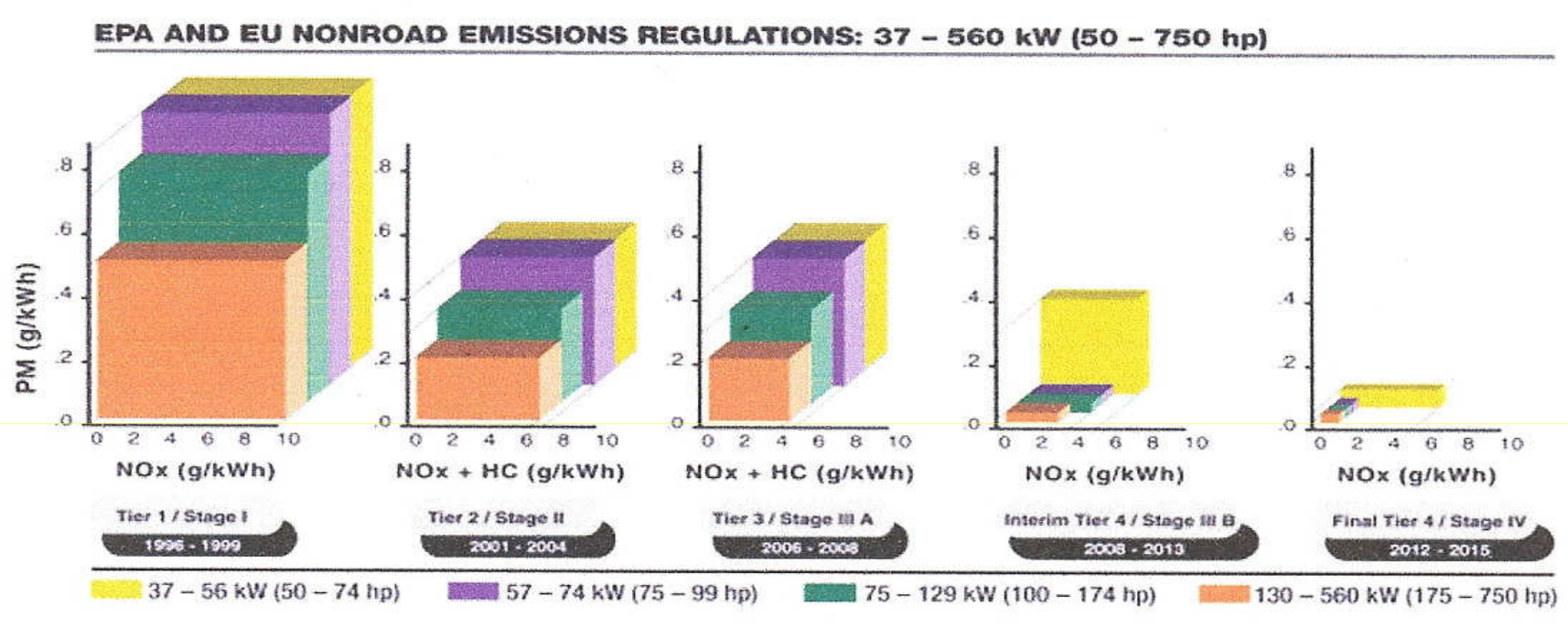


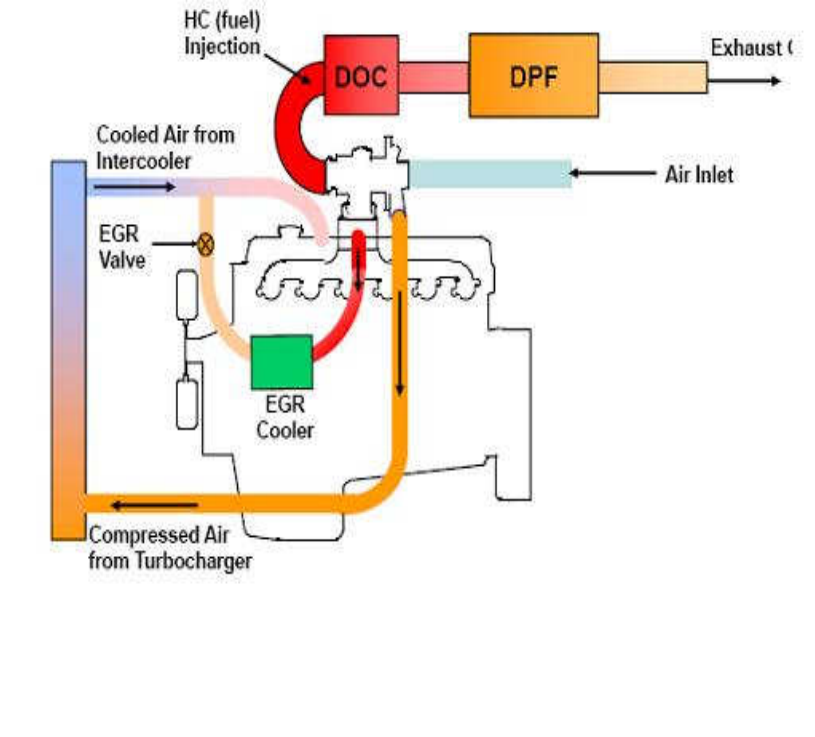
Table 2.2 Final Off-Road Emissions Standards

Rated Power	First Year that Standards Apply	PM†	NOx†
hp < 25	2008	0.30	—
25 ≤ hp < 75	2013	0.02	3.5*
75 ≤ hp < 175	2012-2013	0.01	0.30
175 ≤ hp < 750	2011-2013	0.01	0.30
hp ≥ 750	2011-2014 2015	0.075 0.02/0.03	2.6 / 0.50 0.50

Off-Highway emissions

- Current off-road emission regulations cover Tier 3 and Tier 4 Interim engines.
- Tier 3 took effect in 2006, while Tier 4 Interim takes effect in January, 2011 for engines above 173HP (129kw)
- To meet Tier 3 the following emission technologies are being used:
  - ACERT (Cat) or Cooled EGR
  - Variable Geometry Turbocharging
  - Common Rail Advanced Fuel Injection
    - Electronically controlled unit injectors
    - High injection pressures – up to 35,000 psi

Off-Highway emissions – Interim Tier 4



- To meet Tier 4 Interim emissions the following technologies will be used by the OEMs:
  - Current Tier 3 strategies but EGR rates will increase.
  - Closed Crankcase Ventilation
  - DOC and DPF with either active or passive regeneration.
    - DPF needs to be cleaned periodically

Off-Highway emissions – Tier 4 Final

- **Tier 4 Final emission begin to become implemented in 2012 and fully take effect in January of 2015.**

- **To meet Tier 4 final emissions off-highway OEMs will utilize either MEGR, NO_X absorbers or SCR.**

Off-Highway engine oil effects

- **Currently most off-highway OEMs recommend the use of CI-4 or CI-4+ engine oils.**
- **Introduction of Tier 4 Interim engines into fleets will require the use of CJ-4 quality engine oils.**
- **In California any person, business or government agency that owns or operates off-road diesel equipment of 25 or more HP must use best available technology such as DPF to reduce emissions.**
  - **Construction, mining, industrial, airport ground support.**
  - **If DPF are used instead of repowers or engine replacements the use of CJ-4 quality engine oils will be required.**

Effects of Biodiesel on Engine Oils

OEM position on biodiesel

- Most OEMs and fuel injector equipment manufacturers approve the use of up to B5.
- Some OEMs such as Cummins and John Deere allow up to B20.
  - John Deere factory fills with B2.
- Requires that the B100 used to blend biodiesel blends meet:
  - ASTM D-6751-08
  - EN 14214 (EU specification)
  - Produced by a BQ-9000 Accredited Producer
    - Certification by National Biodiesel Board
- Finished fuel blends between B6 and B20 should also meet ASTM D-7467-08 Specification for Diesel Fuel, Biodiesel Blend B6 to B20.

Biodiesel & engine oil - problems

- **Increased potential for fuel dilution.**
- **Effects due to biodiesel oxidation stability.**
- **Materials compatibility with DPF's.**
- **Wear and Corrosion.**

Fuel Dilution

- Rate of fuel dilution is expected to be higher.
  - More pronounced in engines that use common rail injection and HUEI type fuel injection systems.
  - Biodiesel has higher viscosity, density and surface tension.
- Sticks to the cylinder walls and forms large droplets.
  - Gets scraped down into the oil sump.
- Accumulates in the oil sump due to its lower volatility and narrower boiling range.
  - Progressively builds up over time.
- Older diesel engines especially prone.
  - Clearances between piston rings and cylinders not as small.

Fuel Dilution

- **Excess fuel dilution causes:**
  - **Reduction in engine oil viscosity.**
  - **Increased wear.**
  - **Tie up of additive systems due to complex chemical reactions, especially if the biodiesel is oxidized.**
  - **Increased water contamination of the engine oil.**
    - **1% fuel dilution can introduce 10ppm of water.**
- **Oil drains may have to be cut in half.**

Effects due to biodiesel oxidation stability

- Unburnt biodiesel entering the oil sump may become oxidized thus promoting lubricant degradation.
- Oxidation by products present in biodiesel can cause:
  - Fuel filter plugging
  - Fuel pump failure.
  - Injector deposits.
  - Fuel system corrosion.
  - Engine bearing corrosion.
  - Piston deposits and stuck rings.
    - Increase quantity of soot and blow-by gases.

Materials compatibility with DPF

- **Biodiesel may assist DPF regeneration due to its ability to produce less soot or amore combustible type of soot.**

- **However, if the biodiesel contains high levels of calcium, magnesium, sodium and potassium compounds these can contribute to the build up of metallic ash in the DPFs.**
  - **Blocked filters leading to increased backpressure.**
  - **Increased fuel consumption and loss of power**
  - **Reduced DPF efficiency.**
  - **Increased emissions.**
  - **Increased service maintenance intervals for cleaning of DPF filters.**

Wear and Corrosion

- **Biodiesel oxidation byproducts and any free fatty acids that are present are known to be aggressive towards lead and copper used in bearings.**
  - **Evidence of such corrosion is mixed.**
- **Increased water contamination can promote increased wear and corrosion.**
- **High levels of fuel dilution can lead to increased wear due to a reduction in viscosity.**
  - **Usually happens at fuel dilutions levels of 5% or greater.**

Biodiesel OEM recommendations

Case Construction – B5 to B20 approved. Must meet ASTM D-6751

Case-IH – B5 approved for use in 90% of models. Must meet ASTM D-6751

Caterpillar – Up to B20. Must meet ASTM D-6751. Refer to SEBU 6250-15, SEBU 6385-07 and SEBU 6251-10 for further recommendations.

Cummins – Up to B20 approved for use 2002 and later models. Must meet ASTM D-6751.

Detroit Diesel – Authorizes the use of B5 only. Must meet ASTM D-6751 and sourced from a BQ-9000 accredited producer.

Fiat Power-Train – B20 approved for all fuel systems except common rail.

International/Navistar – Unconditionally warrants blends up to B5 meeting ASTM D6751 and ASTM D-975. Use of B6 to B20 blends is at the discretion of the operator and will not void warranty.

Isuzu – Neither approves or prohibits using biodiesel. Recommends only using up to B5. Must meet ASTM D-6751. Will not warranty any failure from the use of biodiesel fuel.

Biodiesel OEM recommendations

JCB – From January 2008 all JCB Dieselmax engines have been approved for the use of B20. Must meet ASTM D-6751.

John Deere – Places B2 factory fill in all of its diesel equipment. B5 preferred. Up to B20 in petroleum diesel can be used in John Deere engines through Tier 3/Stage 3a models including all non-emission certified engines. Must meet ASTM D-6751.

Kubota – All Kubota engines can run up to a B5 blend. Must meet ASTM D-6751 and be bought from a BQ-9000 supplier.

MTU Detroit Diesel – B5 approved for all engines. Must meet ASTM D-6751.

Mack – B5 made from Soy methyl ester only. The biodiesel supplied must be supplied by a BQ-9000 supplier.

Mercedes Benz – Approves use of B5 in all common rail injection diesel CDI engines including Bluetec engines. Must meet ASTM D-6751.

Perkins – Use of B20 approved for its 400D and 1100 series engines. Must meet ASTM D-6751.

Biodiesel OEM recommendations

Volkswagen – B5 is approved for use in all TDI diesel vehicles. Biodiesel blend must meet ASTM D-6751 and ASTM D-975.

Volvo – Up to B5 is approved for use. Must meet ASTM D-6751.