Overview of Clean Diesel Requirements and Retrofit Technology Options

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Heavy Duty Fleets: Retrofitted, Refueled, and Funded for a Cleaner Ohio

November 30, 2005

Columbus, Ohio

Regulatory Strategy

New Standards for NEW diesels

Diesel engines in all mobile source applications--

- *Regulations adopted; now focused on implementation:*

Heavy-duty trucks & buses

Nonroad machines

Light-duty vehicles

- *Rulemakings underway for:*

Locomotives

Marine vessels

Ocean-going ships

- **Current Regulations**
  - Very large public health and environmental benefits will result:
    - By 2030, PM reduced by ~250,000 tons/year, NOx by ~4 million tons/year
    - Annual benefits expected to exceed $150 billion, with a cost of approx. $7 billion
  - 15 ppm sulfur cap gets immediate PM and SOx reductions from existing fleet of diesels
    - Highway (2006)
    - Nonroad (500 ppm in 2007, 15 ppm in 2010)
    - Locomotive and marine (500 ppm in 2007, 15 ppm in 2012)

A New Approach to Clean Air Programs for Mobile Sources

- In the past, EPA created separate programs for vehicle emission standards and cleaner fuels
- The new 2007 diesel program and the nonroad diesel program take a systems approach (vehicle & fuel) to optimize costs and benefits
- Also considers the inter-relationship with other programs (like gasoline desulfurization)

Key Elements of the Clean Air Diesel Rule

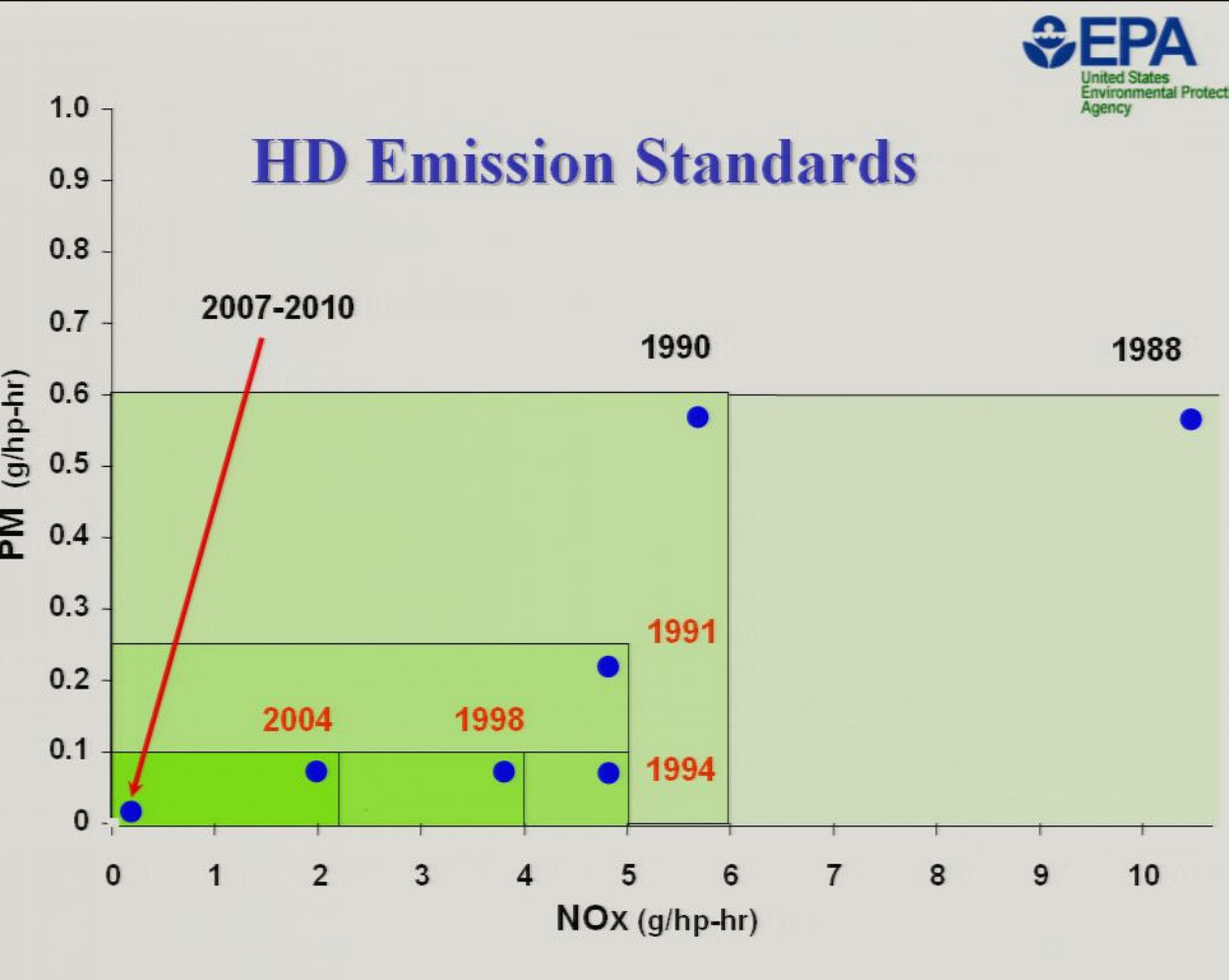
- Applies new NOx and PM standards to heavy-duty engines and vehicles
  - 90%+ emission reductions—gasoline-like levels
  - Based on high efficiency emission control devices (like passenger vehicle catalysts)
  - Phase-in of NOx standards 2007-2010
  - Incentives for early technology introduction

Key Fuel Elements of the Clean Air Diesel Rule

- Reduces diesel fuel sulfur levels nationwide
  - Enables use of advanced emission control technology
  - Highway diesel fuel sulfur cap of 15 ppm
    - 80% by 2006
    - 100% by 2010
  - Flexibility for small and Western refiners

Basic Program Requirements

	2006	2007	2008	2009	2010	2011	2012
PM		**100%** at **0.01** g/hp-hr					
NOx		**50%** at **0.20** g/hp-hr			**100%** at **0.20** g/hp-hr		
Fuel		**80%** at **15 ppm maximum sulfur** (under temporary compliance option)				**100%** at **15 ppm**	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HD Emission Standards
2007-2010
1990
1988
1991
2004
1998
1994
PM (g/hp-hr)
NOx (g/hp-hr)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
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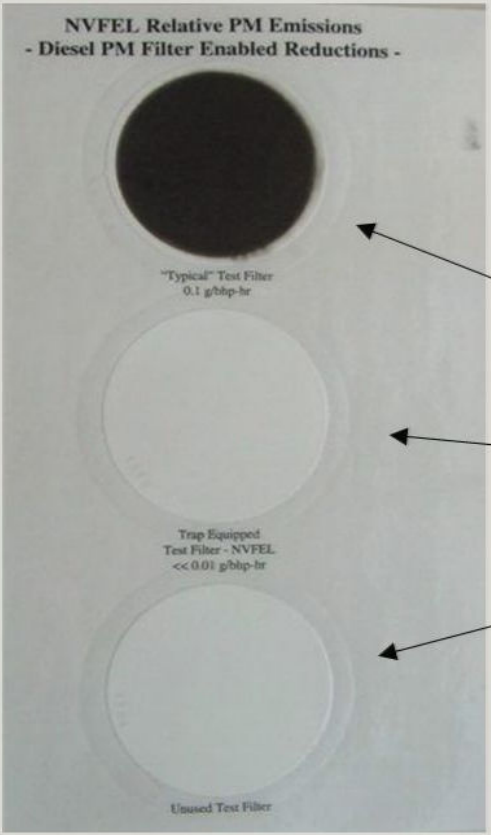
9
10



PM Emissions with Trap

- Typical test filter – current standards
- Test filter – 2007 standards
- Unused test filter

Clean Air Nonroad Diesel Rule

- May 11, 2004
- Exhaust emission standards apply to diesel engines used in most kinds of construction, agricultural, and industrial equipment
  - Excludes diesel engines used in locomotives or marine vessels

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Nonroad Program Requirements

Rated Power	First Year that Standards Apply	PM (g/hp-hr)	NOx (g/hp-hr)
hp < 25	2008	0.30	-
25 ≥ hp < 75	2013	0.02	3.5*
75 ≥ hp < 175	2012-2014	0.02	0.30
175 ≥ hp < 750	2011 - 2013	0.01	0.30
hp > 750	2011 - 2014	0.01	0.30

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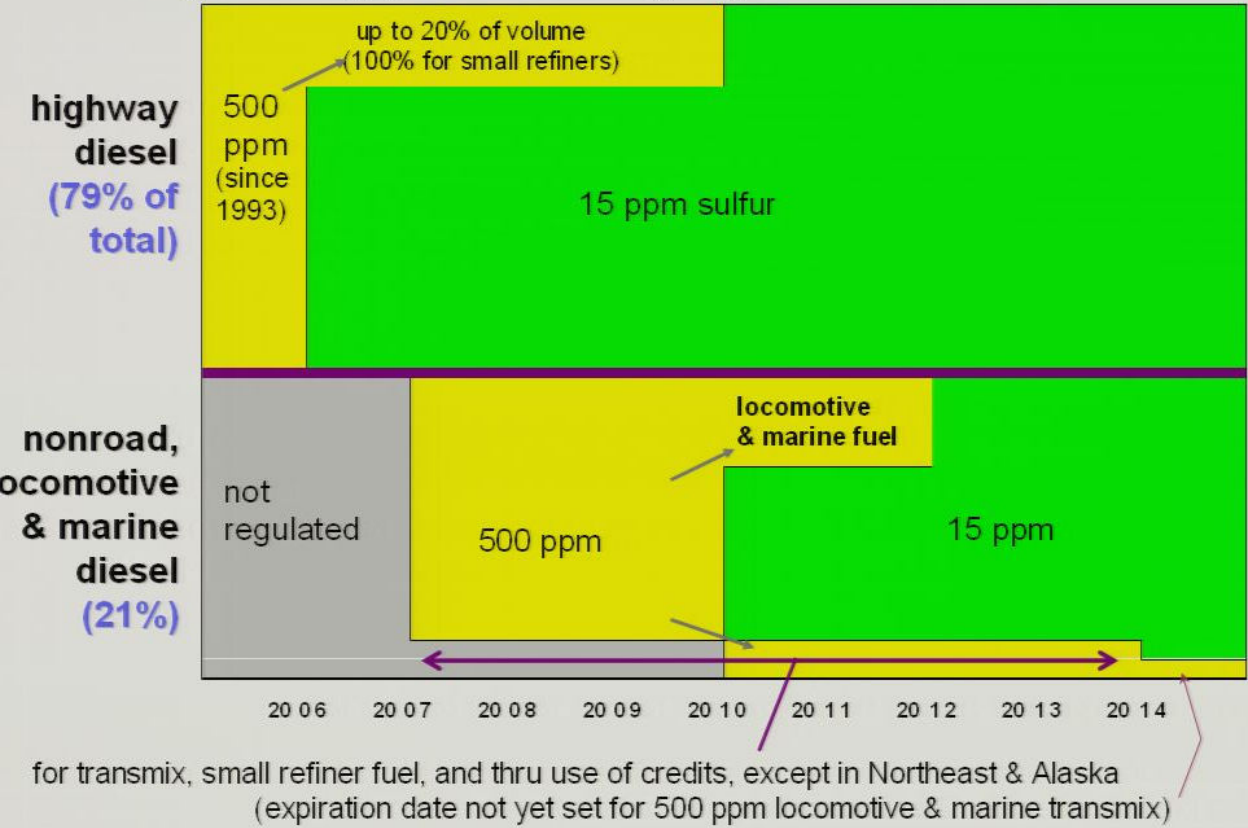
Nonroad Diesel Rule Fuel Provisions

- 500 ppm cap on sulfur in 2007
  - for all nonroad diesel fuel including locomotive and marine applications
- 15 ppm cap on sulfur in 2010
- 99% reduction from current levels (~3,400 ppm)

Sulfur in Diesel Fuel

Regulations apply June 1 at refinery, Aug 1 at terminal, Oct 15 at retailer



National Clean Diesel Campaign

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- **Regulations for new engines**
  - Heavy-Duty Highway, Nonroad, Light-duty Tier 2
  - Upcoming standards for Marine/Locomotives
- **Voluntary Programs to address existing diesel fleet**
  - Voluntary Diesel Retrofit Program – Midwest Clean Diesel Initiative
    - Projects involving: diesel exhaust catalysts, particulate filters, engine modifications, cleaner fuels, idle reduction
    - Project evaluation, Communications & Outreach
  - SmartWay Transport
    - Projects involving: idle reduction, tires, logistics, lubricants, aerodynamics, speed management, ECM reflash
    - Communications & Outreach

Goal: By 2014 reduce emissions from the over 11 million engines in the existing fleet

The 5 Rs + Operational Strategies

- Refuel- Use of advanced diesel fuels, i.e. ULSD can lower emissions

- Retrofit- Installation of exhaust aftertreatment devices such as Diesel Oxidation Catalyst (DOC), Diesel particulate filters (DPF), etc

- Repair/Rebuild- regular engine maintenance plays a critical role in maintaining emissions performance while engine rebuilding can upgrade emissions performance of older engines.

- Repower – replacing older engines with newer cleaner engines

- Replace- replacing the entire equipment to ensure that your new purchase utilizes the most cost effective emission reduction technology

- Operational Strategies- utilizing various strategies to reduce idling

Refuel

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- Low sulfur fuels: Ultra low sulfur diesel (ULSD): 15ppm
- EPA highway diesel (a.k.a., low sulfur diesel or LSD): 500ppm
- CARB highway diesel: 150ppm
- Emulsified Diesel - NOx (9-20%), PM (16-58%)
- Biodiesel
- Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG)
  - inherently cleaner
- Liquefied Petroleum Gas (LPG or propane)
  - Can reduce N0x and CO

Fuels -- ULSD

- Enabler for the application of advanced PM and NOx aftertreatment technologies
- Modest PM Reductions (5 to 7%)
- Easy to use "fill & go" technology; No engine modifications needed; Utilize existing fueling infrastructure;
- Path for mandated ULSD in 2006 (nonroad in 2008)
- No performance issues or fuel economy penalties;
- Incremental cost differential;
- Reduced lubricity overcome with additives
- Potential contamination issues with higher sulfur fuels at refinery and distribution points until federally mandated ULSD program takes effect.

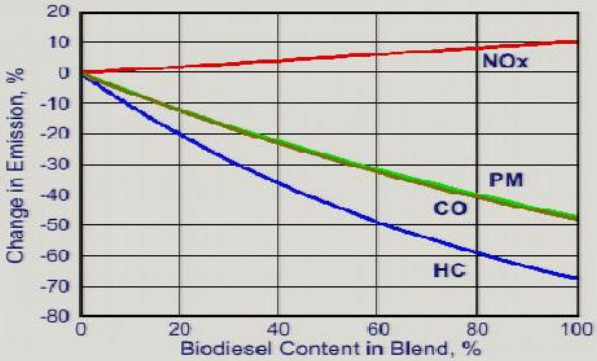
Fuels – Emulsified Diesel

- Improved atomization of fuel mixture during injection
- Increased ignition delay; increased pre-mixed combustion
- Higher combustion temperature & pressure => less PM (16-60%)
- Water cool combustion process => less NOx (9-20%)

Fuels -- Biodiesel

- No sulfur or ultra low sulfur content
- No aromatics contents (and no PAHs)
- About 11% oxygen content (petrodiesel contains no oxygen)
- Higher cetane value (typically 45-60)
- Lower heating value
- Better lubricity
- Higher viscosity
- Higher freezing temperature

COST = 10 – 50 cents/gal.



Retrofit

- Existing emission controls systems can greatly reduce diesel particulate matter (PM) emissions
  - Diesel oxidation catalysts and diesel particulate filters
- Existing and developing emission control systems can greatly reduce NOx and PM emissions
  - Lean NOx catalysts, EGR, SCR and combined systems
- Technologies to control crankcase emissions

Retrofit Technology Verification

- Objective: Evaluate the emission reduction effectiveness of retrofit technology
  - Verification provides stakeholders with confidence that these technologies will achieve quantifiable emission reductions

- Verification consists of the following:
  - Appropriate Testing Protocols
  - Statistical Sampling Methods
  - Durability Requirements

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Diesel Oxidation Catalyst (DOC)

What is it?

- Device that oxidize pollutants in the exhaust stream

What does it do?

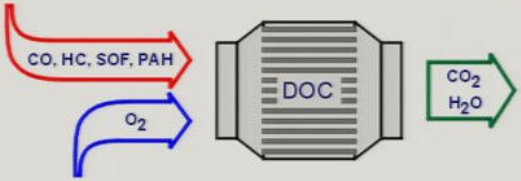
- Reduces PM (10-50%), HC 50%, CO 40%

Cost: $500 - $2,000

Issues:

- Most widely used technology
- No maintenance required
- Lower PM reductions than DPF
- Applicable to most engines and vehicles

Major manufacturers:
include Donaldson, Lubrizol



Hydrocarbons + O2 = CO2 + H2O
CO + ½ O2 = CO2

Diesel Particulate Filter (DPF)

What is it?

- Honeycomb or mesh devices placed within exhaust stream that physically trap and oxidize PM

What does it do?

- Reduces PM, HC, CO (+85%)

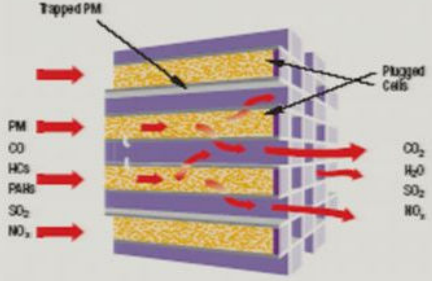
Cost: $5,000 - $10,000

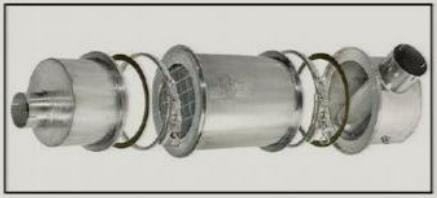
Issues:

- Must be used with ULSD
- Passive filters require higher operating temp. (>250 C)
- Periodic removal of unregenerated ash

Major manufacturers:

include Donaldson, Lubrizol,





Closed Crankcase Ventilation

What is it?

- System that directs crankcase "blow-by" emissions to intake system for re-combustion. PM collected in filter.

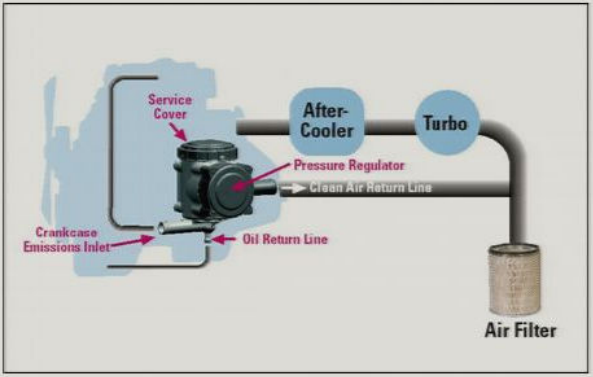
What does it do?

- Reduces PM (10%), HC, CO

Cost: $700

Issues:

- Likely used to meet 2007 requirements
- Can be paired w/ DOC for greater reductions



Selective Catalyst Reduction (SCR)

- What is it?
  - System injects urea (or some form of ammonia) into the exhaust stream and react over a catalyst to reduce NOx emissions.
- What does it do?
  - Reduces PM (~25%), NOx (60-90%)
- Cost: $10,500 - $50,000
- Issues:
  - Can be paired w/ DOC or DPF for greater reductions
  - Requires on-board urea injection system

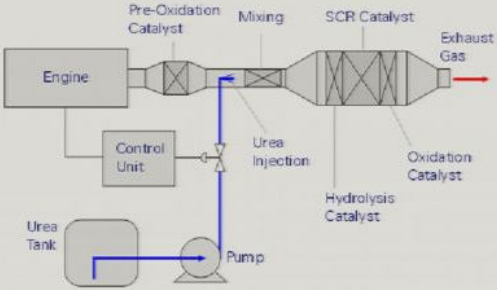


Figure 7. Open Loop Urea SCR System for Mobile Diesel Engines

Lean NOx Catalyst (LNC)

- What is it?
  - Systems injects diesel fuel into the exhaust stream and then catalyzes the reaction to reduce pollution.
- What does it do?
  - Reduces NOx (25-40%)
- Cost: $5,000 - $10,000 (when combined w/ DPF)
- Issues:
  - Can be paired w/ DPF for greater reductions
  - Fuel economy penalty of 3-5%

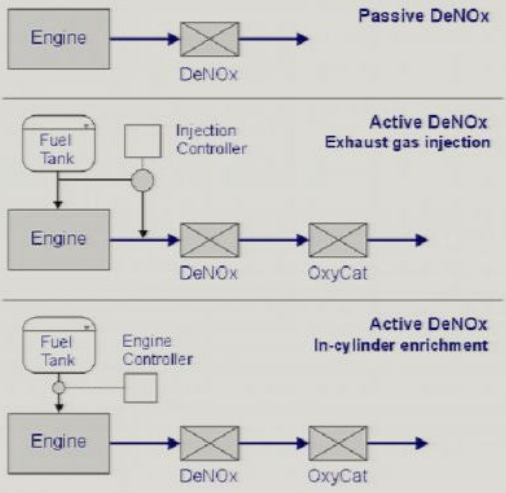
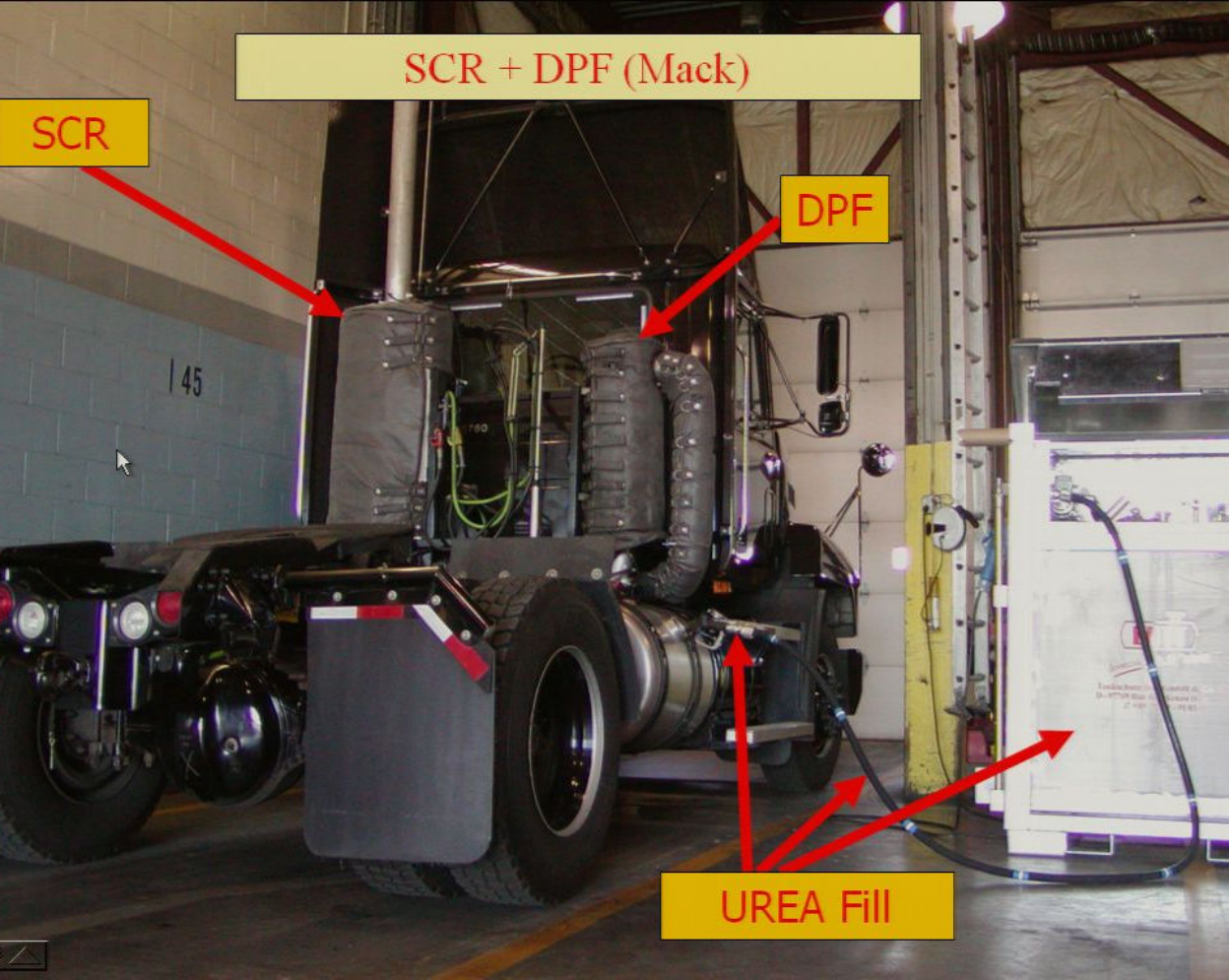


Figure 1. DeNOx Catalyst Configurations

$$\{HC\} + NO_x = N_2 + CO_2 + H_2O$$


SCR + DPF (Mack)
SCR
DPF
UREA Fill

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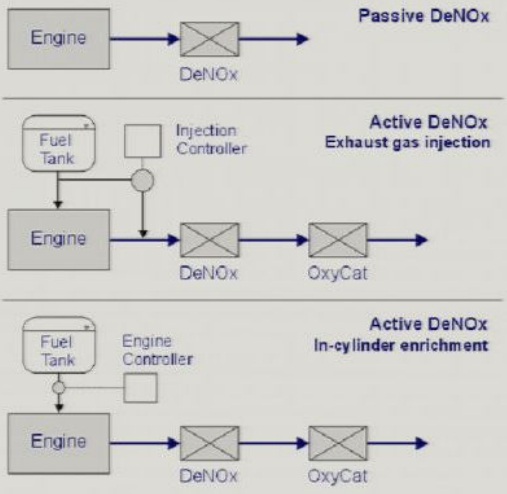


Figure 1. DeNOx Catalyst Configurations

$$\{HC\} + NO_x = N_2 + CO_2 + H_2O$$

Exhaust Gas Recirculation (EGR)

What is it?

- Device recirculates a portion of engine exhaust back into the engine to cool peak combustion temperatures and thus reduce NOx

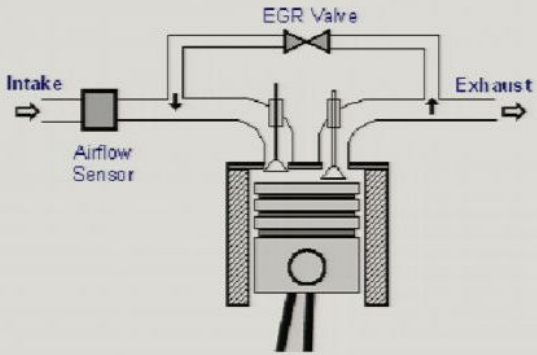
What does it do?

- Reduces NOx (40-50%) if paired with a DPF

Cost: $13,000 - $15,000

Issues:

- Can be paired w/ DPF for greater reductions
- Fuel economy penalty of 1-4%



Repair/Rebuild

- Engines that are properly maintained and tuned perform better and typically emit less particulate matter and other pollutants.
- Rebuilding an engine can also significantly lower emissions in some cases and can be a cost effective option for high value equipment.
- Unless engines are properly maintained, other measures to reduce emissions may be futile.
- Properly maintained or recently rebuilt engines lower emissions by burning fuel more efficiently and can reduce operation costs through improved fuel economy and extended engine life.

Repower

- Repower refers to replacing an older engine with a newer, cleaner engine or replacing a diesel engine with one that can use alternative fuels.

- Where appropriate, a repower can also include substituting a cleaner highway engine for a nonroad engine.

Replace

- Replacing entire vehicles or machines may be the best option for equipment that is nearing the end of its useful life or was manufactured before stringent emissions standards were put in place

- Port of NY/NJ – acquiring the cleanest available technologies
  - Calculated air emissions from 2002 thru 2004.
  - Although number of pieces of equipment up 19%,
  operating hours up 5%, and the total number of containers up 25%,
  - fuel savings 20%
  - overall emission estimates tons per year have decreased
  NOx - 31% reduction
  VOC - 32% reduction
  CO - 32% reduction
  PM - 32% reduction (10 ppm)
  SO2 - 35% reduction

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Key Considerations for Retrofit Programs

Consideration the following

- Retrofit Technology Checklist
  - Emissions Targeted
  - Engine Condition and Age
    - Perform maintenance
    - The condition of the engine is an important factor in making a decision whether to install retrofit control technology
    - How long vehicle/equipment is going to remain in service
    - Retrofit at the time of engine rebuild can be advantageous
    - Retire/Replace
  - Size
    - Properly sized control systems ensure low back pressure and maximum performance
  - Vehicle Integration
    - Space, accessibility and exhaust temperature are important vehicle integration issues
    - Devices are often installed in-line or as a muffler replacement

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Consideration the following …

- Retrofit Technology Check List (cont.)
  - Model Year
    - Generally, only 1994 and newer should get PM filters
    - Some newer engines came with DOCs from the factory
  - Fuel Type/Quality
    - For PM control, <15 ppm sulfur fuel allows for maximum emission control performance (even for DOCs) and best filter regeneration characteristics
  - Maintenance
    - Vehicles to be retrofitted should be properly and regularly maintained—key factor for success
    - Retrofit technologies should be maintained per their manufacturer's recommended procedures

Frequently Asked Questions Concerning Retrofit Programs

- Costs
  - Costs depend on many factors including:
    - Number of vehicles retrofitted (sales volume)
    - Retrofit technology used (oxidation catalyst, filter, etc.)
    - Engine size (displacement)
    - Engine out emissions
    - Fuel quality
    - Exhaust temperature and duty cycle (These factors will affect which retrofit technology will be appropriate.)
  - Costs are expected to decrease as the market expands

Frequently Asked Questions Concerning Retrofit Programs (cont.)

Technology	Cost per Device/System ($)
Diesel Oxidation Catalysts (DOC)	500 to 2,000
Diesel Particulate Filters (DPF)	7,000 to 10,000
Combined Lean NOx Catalyst/DPF Systems	15,000 to 20,000
EGR Systems	13,000 to 15,000
SCR Systems	12,000 to 20,000

Notes: DPF costs are higher for active systems and systems that include backpressure monitoring.

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Frequently Asked Questions Concerning Retrofit Programs (cont.)

- Drivability
  - Properly selected retrofit technologies do not impair driving performance
- Maintenance
  - Oxidation and lean NOx catalysts are virtually maintenance free - require only periodic inspection
  - Filters require very little maintenance (ash removal)
  - SCR maintenance, as per manufacturer's specifications
- Effects on Engine Life
  - Properly maintained engines and retrofit control systems do not shorten engine life

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Frequently Asked Questions Concerning Retrofit Programs (cont.)

- Fuel Penalties
  - Most oxidation and lean NOx catalysts have no effect on fuel consumption
  - Most filters have no effect on fuel consumption
  - Urea consumption in SCR systems results in an equivalent fuel penalty of 3-5%
  - Systems relying on fuel injection as reductant or heat typically result in 3-5% fuel penalty
  - EGR results in a 1-4% fuel penalty
- Warranties
  - Manufacturers provide various warranties as part of a purchase agreement

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Conclusions

- A wide variety of retrofit options are available for diesel engines to reduce HC, CO, PM and toxic emissions
- NOx retrofit controls are emerging
- A growing number of retrofit programs are being successfully implemented
- Technology development continues to expand the range of applications available for retrofit
- A successful retrofit program must be properly designed and implemented

Some Diesel Retrofit Web Sites

- U.S. EPA:
  - http://www.epa.gov/otaq/retrofit
- The Manufacturers of Emission Controls Association:
  - http://www.meca.org
  - Click on "Publications" to access MECA fact sheets and technical documents on diesel retrofit
- The Diesel Technology Forum:
  - http://www.dieseltechnologyforum.com/
- The California Air Resources Board's Diesel Risk Reduction Program:
  - http://www.arb.ca.gov/diesel/dieselrrp.htm

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