Diesel Retrofit Technologies: A Cost Effective Emissions Reduction Strategy

Joe Kubsh, MECA
Marty Lassen, Johnson Matthey

November 17, 2008
National Caucus of Environmental Legislators
Diesel Forum
Washington, DC

Manufacturers of Emission Controls Association (MECA)
www.meca.org
www.dieselretrofit.org

Diesel Engines

- Good Power
- High Efficiency
- Low Cost to Operate / Maintain
- Emissions
  - PM, HC, CO
  - NOx
- Lean-Burn Engines
  - Control PM, HC and CO Emissions with One Set of Technologies
  - Control NOx with a Different Set of Technologies

Diesel Retrofits: Today and Tomorrow

- Why Control Diesel Emissions?
  - Diesel PM toxicity and health effects
  - Ozone Non-Attainment (both HC and NOx)
  - It's the right thing to do
- Regulations Are Stimulating Technology Advances
  - EPA Voluntary Retrofit Program
  - CARB's Diesel Risk Reduction Program
  - Tighter emission standards on new engines worldwide
- Technology
  - Many proven & commercial diesel emission control technologies
  - ULSD availability enables the lowest emissions and ensures reliability
- Funding for Retrofit
  - Increasingly available at federal and state levels (DERA, CMAQ, SEPs, state incentive programs)

Technology Options And Benefits

Controlling PM, HC and CO

- DOCs, Partial Filters, DPF's
  - Oxidation Process for HC and CO
  - Capture and Oxidation of Soot
  - Filters Provide Reductions in Black Carbon – Climate Change Impacts
- Closed Crankcase Filters

Controlling NOx

- EGR
  - Recirculation of Exhaust to Lower Temperature in Cylinder
- LNC, SCR
  - Use of Reductant (Diesel Fuel or Urea)

Retrofit Technology Options And Benefits

- Diesel Oxidation Catalysts – LSD / ULSD
  - 25 to 50% PM, 60+% CO / HC Reduction
- "Partial" Flow Filters – LSD / ULSD
  - 50 to 75% PM, 60+% CO, HC Reduction
- Passive Filters - ULSD
  - >85% PM, 90%+ CO / HC Reduction
- Active Filters – LSD / ULSD
  - >85% PM, 0% CO, HC Reduction

PM

- Lean NOx Catalysts - ULSD w/ DPF
  - 25 to 30% NOx, > 85% PM, 60 - 90% CO / HC Reduction
- Exhaust Gas Recirculation – ULSD w/ DPF
  - 40 to 60% NOx, > 85% PM, 60 - 90% CO / HC Reduction
- Selective Catalytic Reduction – LSD w/ DOC, ULSD w/ DPF
  - 60 to 90% NOx, 25 - 85% PM, 60 - 90% CO / HC Reduction
- Lean NOx Traps – emerging as a retrofit technology; requires ULSD

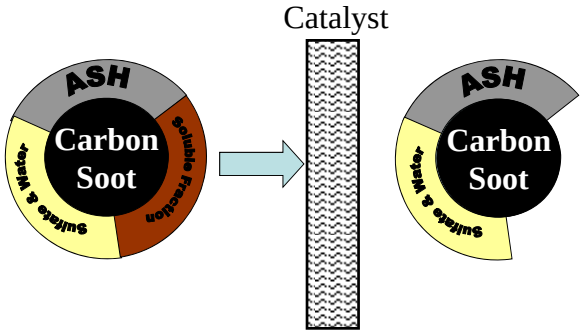
NOx

Technology Options And Benefits

Controlling PM, HC and CO

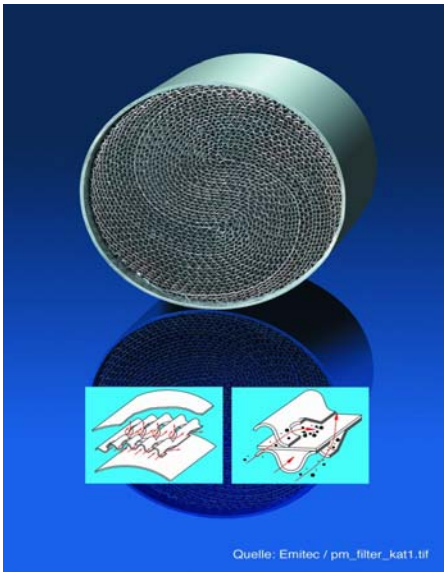
Diesel Oxidation Catalysts (DOCs)

- A flow through catalyst that reduces the HC portion of PM
- DOCs are the most flexible retrofit technology
  - Requires only 150 °C for reaction to start
  - Can be designed for operation on higher fuel sulfur levels
  - Reduces PM about 20 – 25% with no fuel penalty (Level 1)
  - Significantly reduces CO and toxic HC emissions



Note: Soluble fraction, sulfates and water are in vapor form.

"Flow-Thru" or "Partial" Filter



- A flow through catalyst with the potential for 50-75% PM reduction (Level 2)
- Can be catalyzed or used with a DOC
- Filtering achieved with sintered metal sheets or wire meshes
- Resistant to plugging

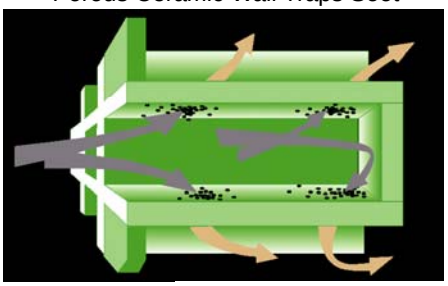
Technology Options And Benefits

High Efficiency Diesel Particulate Filters (DPF)

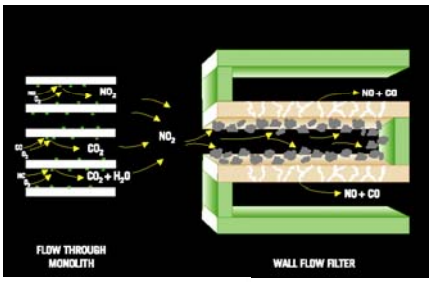
- Passive Regeneration
  - "Traps" and reduces PM by more than 85% (Level 3)
  - Reduces HC and CO by more than 90%
  - Uses the temperature in the exhaust – no external heat source
  - Requires exhaust temperature to be greater than 200 °C to 280 °C for 25 to 50% of the operating cycle
  - Uses NO_2 generated over the catalyst to burn soot
  - Requires periodic cleaning to remove lube oil ash
- Active Regeneration
  - "Traps" and reduces PM by more than 85% (Level 3)
  - Requires outside source of heat, i.e. electric hook-up or fuel for burner system (suitable for low exhaust temperature applications)
  - Requires periodic cleaning to remove lube oil ash
- Significant reductions in black carbon emissions provide climate change impacts

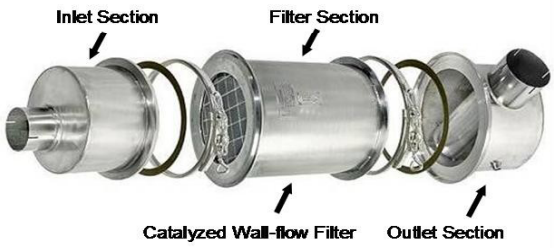
Particulate Filter – Wall-Flow Filters

Porous Ceramic Wall Traps Soot



Passive Regeneration Employs a Catalyst

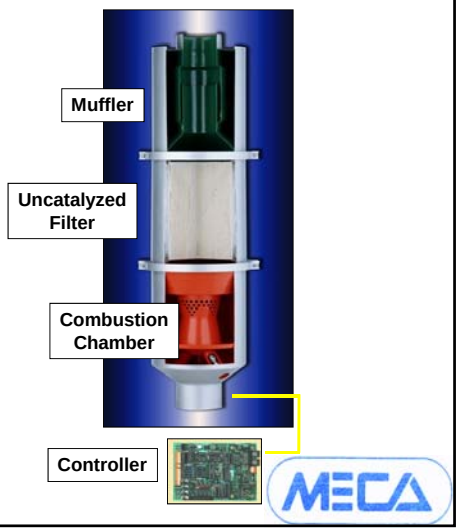




Examples of Active DPF Technology Options

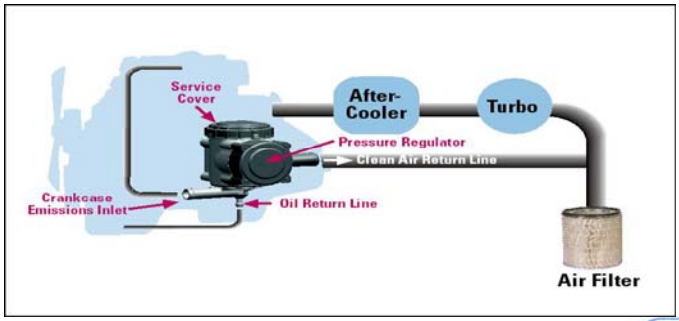
Catalyst-Based Filter with Electric Heater Assist

Uncatalyzed Filter with Fuel Burner



Closed Crankcase Filter Provides Additional PM Control

- Existing diesel engines (pre-2007) vent crankcases directly to the atmosphere
- Crankcase emissions include toxic hydrocarbons, heavy metals
- Closed crankcase filters eliminate crankcase emissions and can be combined with DOCs, partial filters, DPFs for additional PM control.



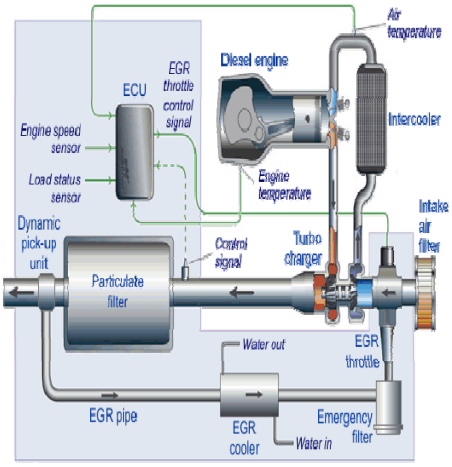
Technology Options And Benefits

Controlling NOx

Lean NOx Catalysts (HC-SCR)

- A flow through catalyst that reduces NOx with the injection of diesel fuel over the catalyst, aka, HC-SCR.
- LNC catalysts have operating temperature windows
- Retrofit systems usually provide about a 25 – 30% NOx reduction with 4 – 8% fuel penalty
- Can be combined with a wall-flow filter to reduce PM by > 85%

Low Pressure Exhaust Gas Recirculation (EGR)



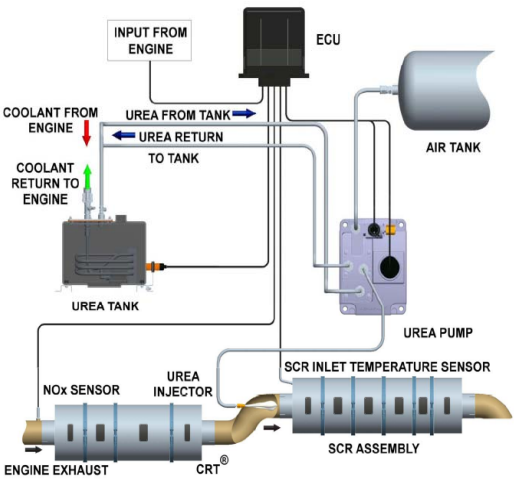
- Recirculates engine exhaust back into the combustion chamber to lower temperature in cylinder, reducing NOx
- Retrofit low pressure, cooled EGR – takes exhaust after it has been through a DPF, reintroducing clean exhaust into the combustion chamber for 40 – 60% NOx reduction with 85% PM reduction

Technology Options And Benefits

Selective Catalytic Reduction (SCR)

- A flow through catalyst that requires ammonia for reduction of NOx by 50 – 90%+
- Currently all systems inject urea which is converted to ammonia when injected into the exhaust stream
- SCR catalyst typically contains no precious metals
- SCR is a mature, commercial technology that has been used in stationary applications for over 30 years
- SCR technology is seeing growing applications on OE light-duty and heavy-duty diesel vehicles
- Can be combined with a DOC or DPF for PM reduction
- SCR technology is a retrofit solution and several systems are in verification with the EPA and CARB

Retrofit Selective Catalytic Reduction System



SCRT System

System Performance: California Fleet Trials

Ozark / Raley's Truck 1555 (2.5g NOx engine)

Vehicle	2005 Kenworth
Engine	2005 Cummins ISX 400 Hp 14 l
NOx Reduction	80.6%
Hours Run	191.3
Time Frame	11/16/2007 – 1/23/2008

SCRT System

Observations

- Maintenance
  - Periodic cleaning of the particulate filter, air dryer cleaning, and urea filter is required for proper operation
- Urea Required
  - Urea is available today from a number of CA businesses, including Cummins West/CES
  - Urea will be widely available for the release of the new 2010 compliant engines which will likely use SCR as one way to reduce NOx to the EPA's standard of 0.2g/bhp-hr
  - Urea usage is dependent on the drive cycle but is likely to be 2 – 4% of fuel usage
- Performance
  - No impact on engine performance
  - No measured fuel economy impact

Experience with Retrofits
Spans a Variety of On-Road Vehicle Applications

Experience with Retrofits
Spans a Variety of Non-Road Vehicle Applications

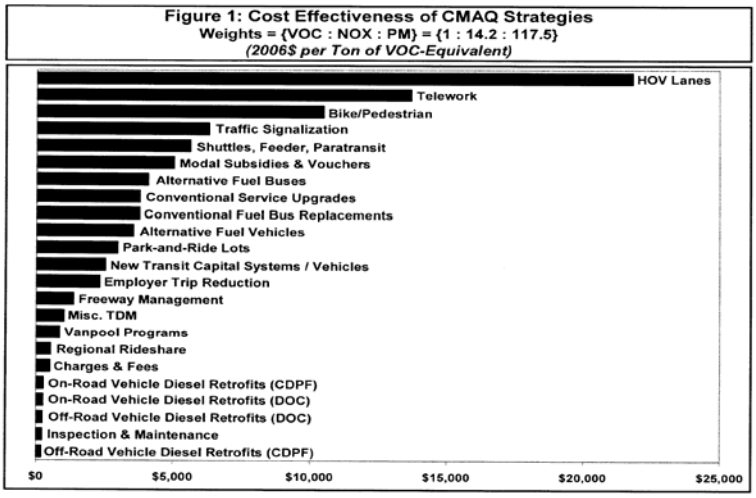
Range of verified off-road retrofit technologies expanding

Diesel Retrofits: Today and Tomorrow

Retrofit Challenges

- Engineering Intensive
  - Thousands of engine/vehicle combinations
  - Anticipated economies of scale not there
- Duty Cycles
  - Low temperatures limit application
  - Active temperature management is needed
- Verification
  - Required for SIP credits and funding
  - Complex and expensive
- Funding
  - Becoming more available but still not enough
  - Spending limits being set that don't reflect actual costs
  - Cost effective emission reductions
- NOx Reduction
  - Technologies only now becoming commercial
  - Requires control systems / injection systems
  - Adds more expense

Retrofits are a Cost Effective Emission Reduction Strategy



Source: ECTA 2007 CMAQ Cost Effectiveness Criteria Report

Diesel Retrofits: Today and Tomorrow

Solutions for Broadening Retrofit

- Public outreach and education
- Broad availability of ULSD
- Cooperative efforts
  - DOE / Engine OE / Technology Suppliers / Fuel Suppliers
  - Engine OE / Technology Supplier / Exhaust System Packager
  - Regulators / Technology Suppliers / Users / Funding Sources
- Optimization / Consolidation of Design
- Active Regeneration
- Simplify Verification
- Increased Funding Sources
  - Federal , State, Local budgets
  - Philanthropic sources
  - Incentives, financing
  - Creative “out-of-the-box” funding

Diesel Retrofits: Today and Tomorrow

Benefits of Clean Diesel Retrofit

- Allows continued use of diesel engine with all its positive attributes
- Reduces diesel exhaust emissions significantly
- Immediate, cost effective reductions in emissions inventory from today's long-lived diesel fleet
- EPA / CARB verification allows for SIP Credits
- Stimulates technology development
- Filter retrofits provide climate change impacts through reductions in black carbon emissions

Retrofit Technology Verification

• DOCs	- Verified EPA, CARB (on- & off-road)
• Crankcase Filters	- Verified EPA, CARB (on-road & off-road)
• Partial Filters	- Verified EPA, CARB (on-road)
• Passive Filters	- Verified EPA, CARB (on- & off-road)
• Active Filters	- Electric: verified EPA, CARB (on- & off-road) - Burner: Verified CARB (on- & off-road)
• Lean NOx Catalysts	- Verified CARB (on-road, off-road expected in 2009)
• EGR	- Verified CARB (on-road)
• SCR	- Verification expected in 2009 (on- & off-road)
• Lean NOx Traps	- Emerging as a retrofit option

CARB Verified Retrofit Technologies:
http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm

EPA Verified Retrofit Technologies:
http://www.epa.gov/otaq/retrofit/verif-list.htm

www.dieselretrofit.org

- Retrofit technology information
- Presentations covering the retrofit basics
- Retrofit technology case study reports
- Retrofit manufacturer contacts
- Filter maintenance information
- Retrofit FAQs