



# Evaluating Diesel Reduction Strategies for Cost Benefits: Lessons from the Field

Presented at  
**Diesel Reduction Strategies and Financing Options**  
**CT Diesel Plan Special Act 05-07**  
**Connecticut's Department of Environmental  
Protection**

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- 1 Introduction
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## **Diesel engines provide high efficiency/fuel economy**

- Diesel engines predominate heavy-duty on-road, off-road, and marine applications
  - Good torque/hp performance over operating conditions
  - Extremely reliable and durable — “million mile engines” in over the road trucking applications
  - Excellent fuel economy in variety of applications from light-duty passenger cars and trucks to on-road heavy duty and off-road heavy duty vehicles
  - Excellent overall life-cycle costs in variety of applications

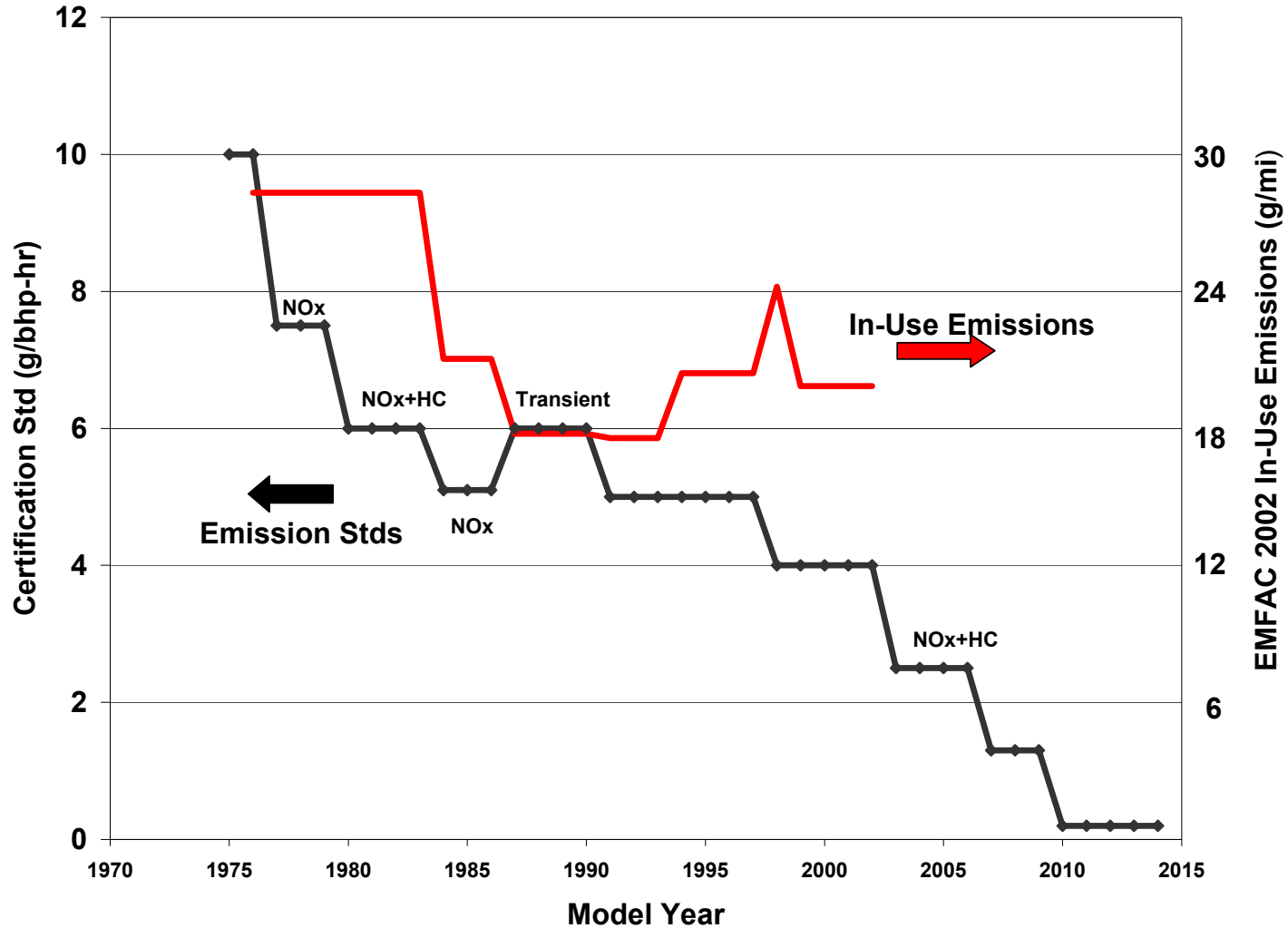


## Diesel Engine Emissions Contribute to a variety of air quality issues

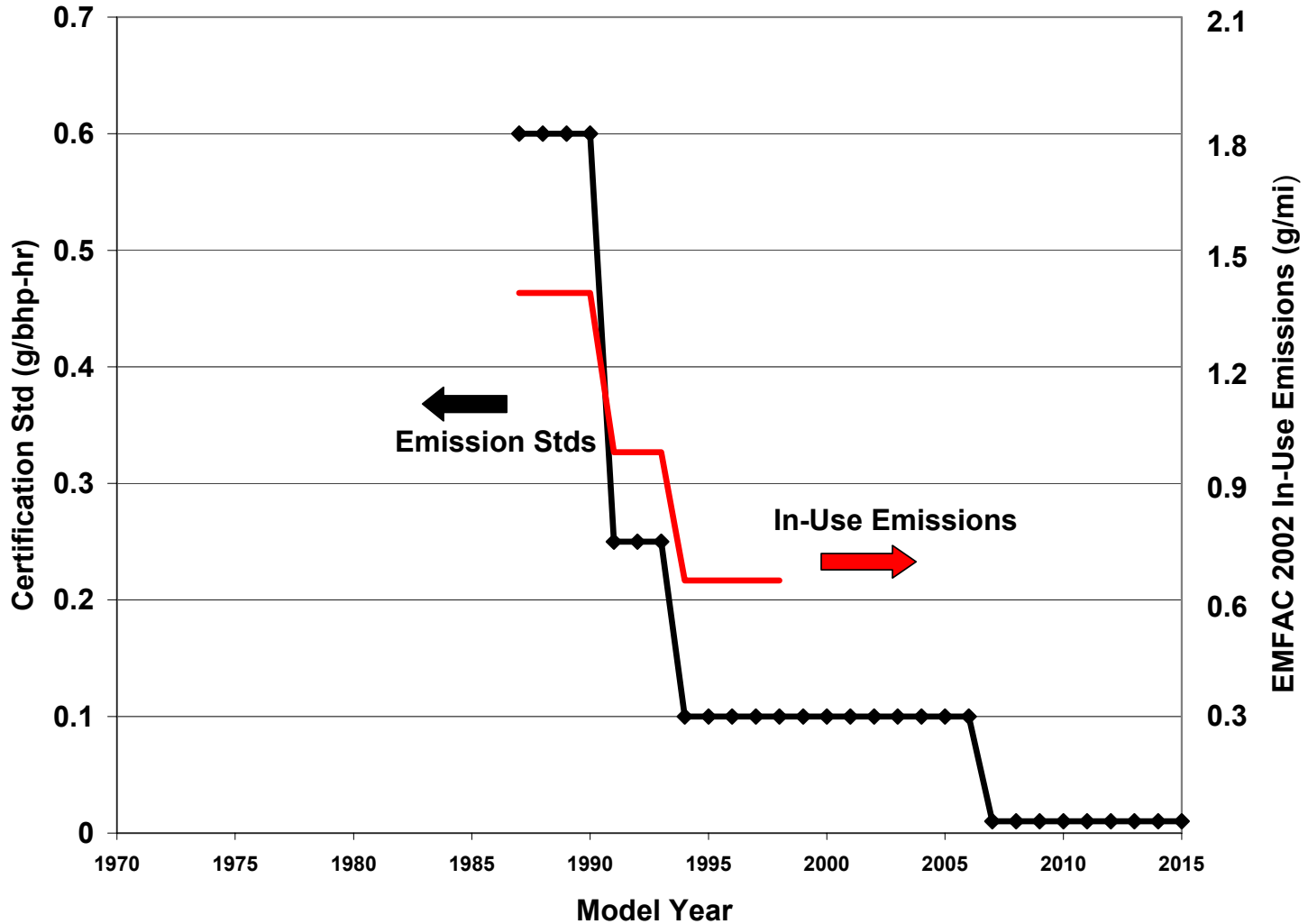
- NO<sub>x</sub> emissions
  - Combined with hydrocarbons and sunlight produces ozone
  - Reacts in atmosphere to form secondary particulate (<PM<sub>2.5</sub>)
- PM emissions
  - Primary or direct particulate emissions (<PM<sub>2.5</sub>)
  - Known or suspected carcinogen
- Other toxic emissions
  - Hydrocarbon emissions contain arsenic, nickel, benzene, formaldehyde, and polycyclic aromatic hydrocarbons (PAH's)



## NO<sub>x</sub> engine standards and in-use emissions



## PM standards and in-use emissions



## **Cleaning up emissions from existing vehicles critical to reducing health impact of diesel engine technologies**

- New Heavy Duty Standards for fuel and engines will substantially reduce impact of heavy-duty vehicles in the future
- Challenge is to cost effectively reduce impact of the existing diesel fleet across a variety of applications
  - On-road trucking, transit, etc.
  - Marine
  - Off-road applications
  - Locomotives
  - Agriculture
- Fleet turnover slow due to long life of existing vehicles, e.g. average age of on road trucks is over 20 years
- Need technologies and strategies that will be viable on older equipment

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- **Refuel:** Alternative and cleaner diesel fuels, e.g.:
  - CNG, LNG, L/CNG, Propane, Electric Drive
  - Diesel Emulsion
  - Synthetic Diesel
  - Ultra Low Sulfur Diesel
- **Repower:**
  - Remanufactured diesel engines
  - Tier 2 diesel engines to replace Tier 1 for off-road, marine, and locomotive
- **Replace:**
  - Fleet modernization with emission upgrades
- **Retrofit:** Aftertreatment devices, e.g.
  - Diesel Oxidation Catalysts (DOC)
  - Diesel Particulate Filter (DPF)
  - Exhaust Gas Recirculation (EGR) and DPF
  - Lean-NOx Catalyst (LNC)
  - Selective Catalytic Reduction (SCR)
- **Repair / Rebuild** to maintain lower emissions



*LPG-fueled yard hostler*



*Repowered diesel truck*



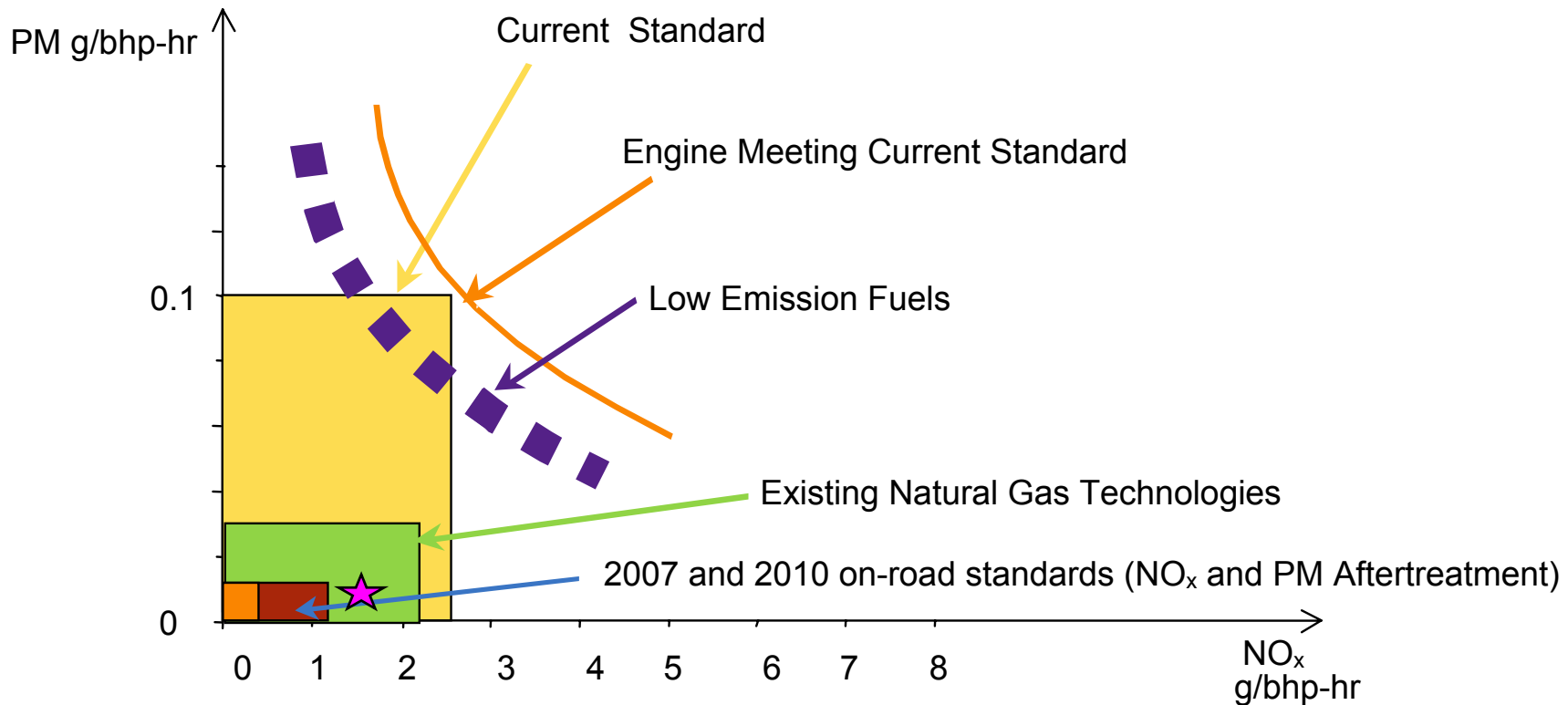
*Lift truck retrofitted with DPF*

Example construction equipment types



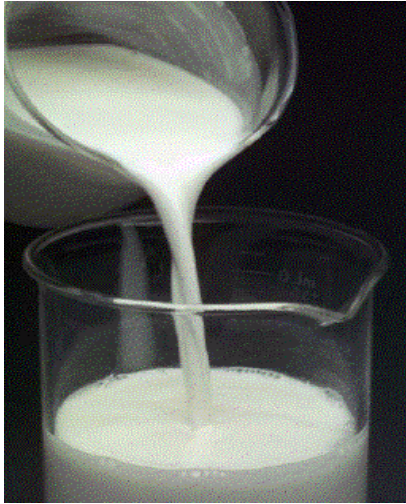
Source: eBay

**Potential emission reductions vary depending on the chosen approach and level of integration**



★ Example: 2005 John Deere 8.1 L Natural Gas Urban Bus Engine

## Alternative Diesel Fuels provide combined NOx and PM reductions



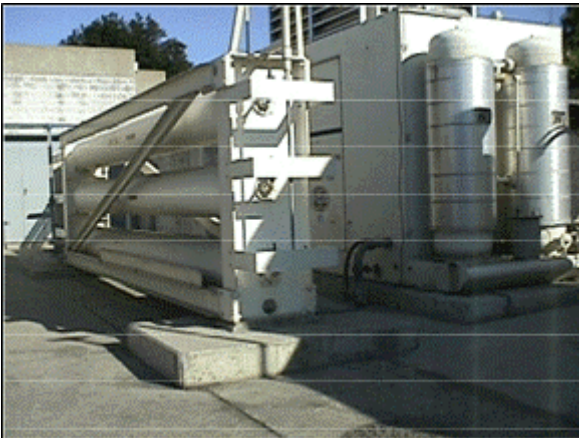
*Emulsified Fuel  
Manufacturing  
Facility in Dixon,  
Ca*

	Alternative Diesel Fuel
<b>Providers</b>	Lubrizol (PuriNOx); Aquazole; Clean Fuels Tech (Aquadyn); O <sub>2</sub> diesel (ethanol)
<b>Availability</b>	PuriNOx, O <sub>2</sub> -Diesel, commercially available; Aquazole looking for demonstration fleets
<b>Certification Status</b>	ARB and EPA verified
<b>Infrastructure Needs</b>	Fuel storage
<b>Hardware Needs</b>	Flame arrestor for O <sub>2</sub> diesel
<b>Cost</b>	\$0.10-\$0.18/gallon incremental cost;; ~\$100/vehicle for flame arrestor
<b>Benefit</b>	~15% reduction in NOx, ~60% reduction in PM *; For O <sub>2</sub> -diesel: ~5% reduction in NOx, ~40% reduction in PM *;

**Alternative fuels such as CNG Transit and School Buses have been viable options for reducing NOx and PM emissions**



*Blue Bird School Bus with John Deere Natural Gas Engine*



*RT's CNG Compressor Station*

	CNG Bus
<b>Engine Providers</b>	Cummins, John Deere
<b>Chassis Providers</b>	Blue Bird, New Flyer, Thomas, NOVA, Orion, Neoplan, El Dorado, NABI
<b>Availability</b>	Min 1 year between order and delivery
<b>Certification Status</b>	Various MY certified engines
<b>Infrastructure Needs</b>	Fueling facility Maintenance facility upgrades
<b>Cost</b>	\$25K to \$50K more/ bus \$0.5-\$2M-fast fill--\$500K timed fill \$400K to \$700K/facility upgrade, training
<b>Benefit</b>	40% - 50% reduction in NOx, ~90% reduction in PM *

\*Example: 2004 Deere 8.1 L CNG bus engine certified to 1.5 g/bhp-hr NOx + HC / 0.01 PM compared to 2004 diesel engine certified to 2.5 g/bhp-hr NOx + HC / 0.1 PM

**For many heavy-duty applications, repowers have been cost-effective options**

- Hundreds of heavy-duty on-road repowers have been performed
- Typical on-road repower: replace pre-1986 MY engine with post 1987 MY remanufactured engines
- ~25% have MY 1986 to 1992 engines (1.2 to 1.7 g/mile PM)
- These trucks can be repowered with newer engines (0.3 g/mile PM)



	Remanufactured Engine Repowers
<b>Providers</b>	All engine dealerships and service providers
<b>Availability</b>	Common industry practice, engines certified by ARB
<b>Infrastructure Needs</b>	None
<b>Cost</b>	\$30,000 average incremental costs
<b>Benefit</b>	25 to 40% NOx, 50 to 75% PM

- Lifetime cost effectiveness: NOx ~ \$6,800/ton, PM ~ \$160 to \$200 / lb.
- Recent thinking: repowers may be less viable for on-road vehicles

## Diesel Repowers also very viable in marine/off-road applications



- Typical project consists in replacing the two Detroit Diesel 12V71 engines with Detroit Diesel Series 60 engines
- Other marine projects include fishing boats and tugs

- One of the most cost effective Moyer Projects (typically below \$2,000/ton of NOx reduced)
- 19 tons of NOx reduced annually from three SF Bay Area repowers
- Many marine and construction repowers have been funded in South Coast under Moyer funding



**Fleet Modernization is another viable option to replace older, dirtier trucks**

- Replace pre-1987 with post-1998 trucks in specific vocations
- Unlike repowers, cab and chassis are also upgraded
- Engine’s ECM for 1994 to 1998 vehicles must be “reflashed” to low-NOx configuration



1994 Freightliner with Caterpillar engine

	Fleet Modernization
<b>Providers</b>	All HDV Dealers
<b>Feasibility</b>	Approved by ARB as pilot project (Gateway, Sacramento SECAT)
<b>Infrastructure Needs</b>	None
<b>Cost</b>	\$25,000 to \$32,000 is typical (depends on program)
<b>Benefit</b>	25 to 40% NOx reduction, 60 to 90% PM reduction

- Further benefits (both PM and NOx) can be achieved by retrofitting an aftertreatment device (e.g., a DOC, DPF, DPF + LNC, etc.)

## Retrofit Aftertreatment Devices: Selective Catalytic Reduction (SCR)



ADEC II system on a Gradall G3WD



Horizontal Exhaust with SCR in place of muffler

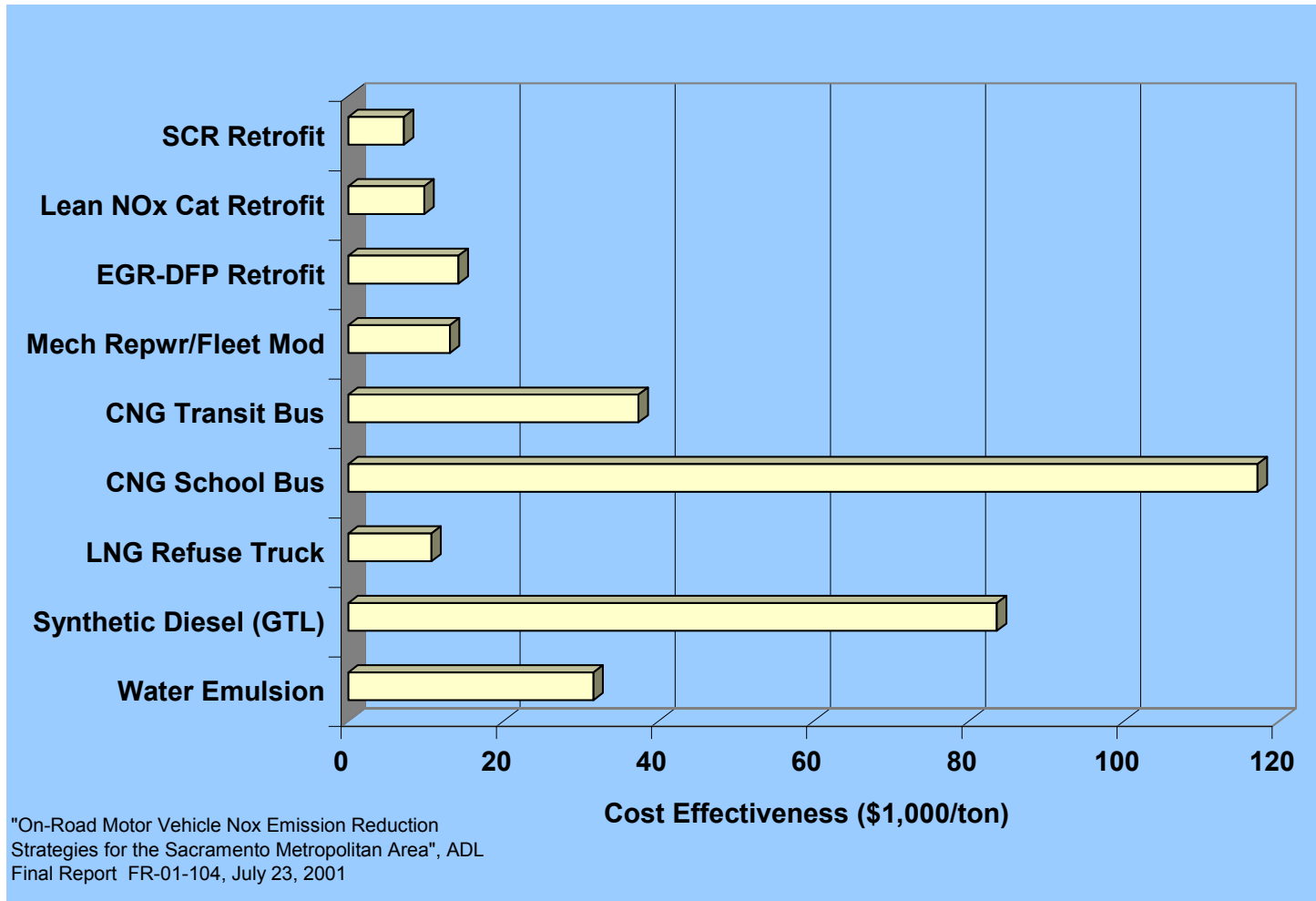
	SCR Catalysts*
<b>Providers</b>	Extengine Transport Systems (This is a SCR & DOC device)
<b>Availability</b>	2002-2007
<b>Certification Status</b>	California ARB verified for Cummins 5.9L engines only MY 1991-1995
<b>Infrastructure Needs</b>	Urea/ammonia storage and dispensing facility
<b>Hardware Needs</b>	Catalyst, Urea/NH <sub>3</sub> tank
<b>Cost</b>	\$12K-\$60K/SCR system Free/minimal charge for urea/NH <sub>3</sub> dispenser \$2-\$3/gal urea/NH <sub>3</sub>
<b>Benefit</b>	80% reduction in NO <sub>x</sub> ; 25% reduction in PM

## Summary of Emission Reductions Possible with Fuel and Aftertreatment Control Equipment

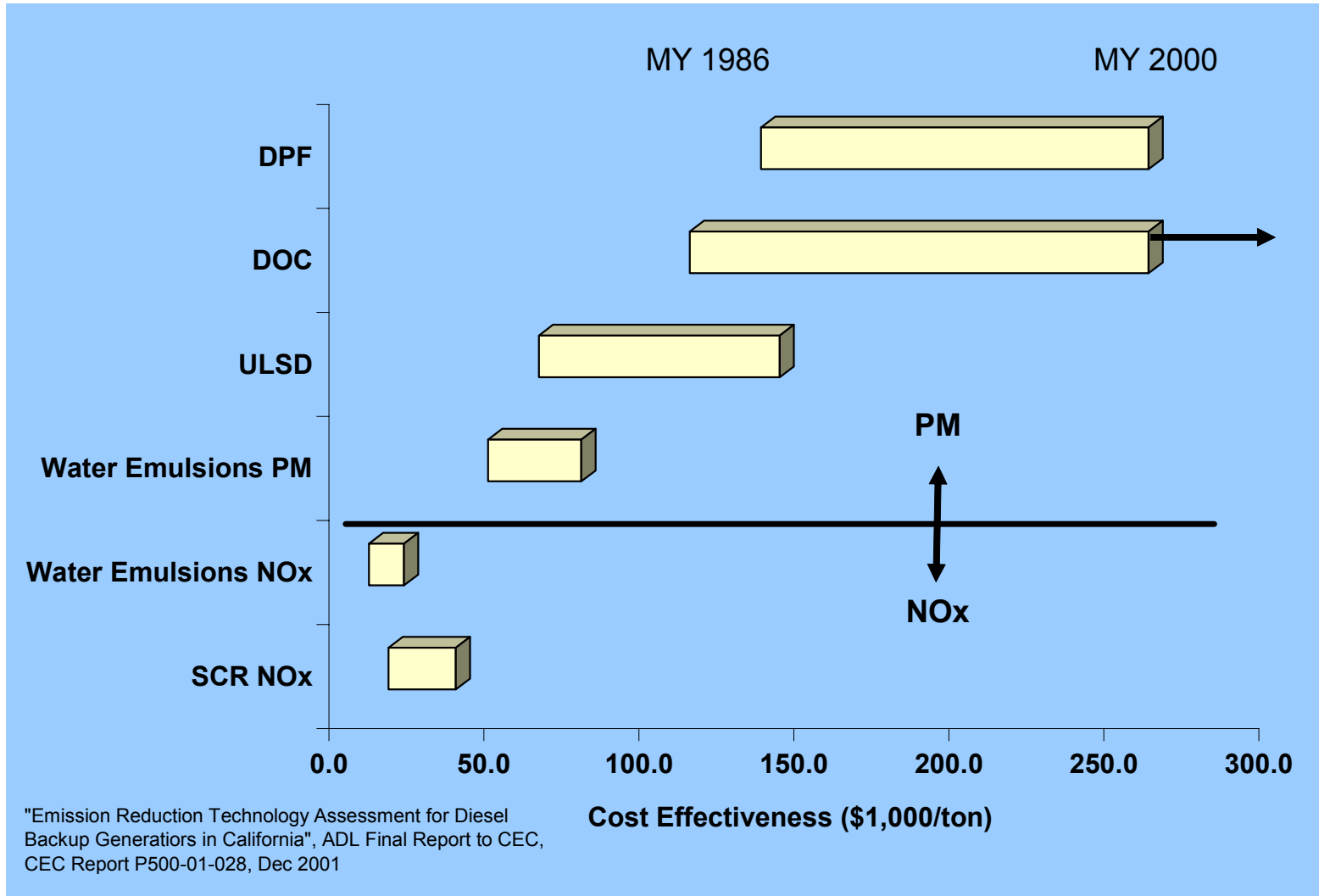
Technology	Example Products	% PM Reduction	% NOx Reduction	% CO Reduction	% HC Reduction	Fuel Penalty (%)
Diesel Oxidation Catalyst (DOC)	Donaldson 6000 , Johnson Matthey, Lubrizol	20-33	N.A.	13-40	40-66	0-2
Diesel Particulate Filter (DPF)	Engelhard DPX, Johnson Matthey CRT, Lubrizol Combifilter,	85	N.A.	60-75	60-85	1-4
Lean NOx + DPF	Cleaire Longview	85	25	60-75	60-85	4-7
Emulsified Fuel	Lubrizol PuriNOx	50	15	<34>	<30-120>	
Fuel Borne Catalyst	Clean Diesel Technology	10-30	10	50	50	<8>
Selective Catalytic Reduction (SCR) + DOC	Extengine Transport Systems	25	25	50	50	Equiv 4 of fuel

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## NOx Cost Effectiveness for On-Road Heavy Duty Vehicles



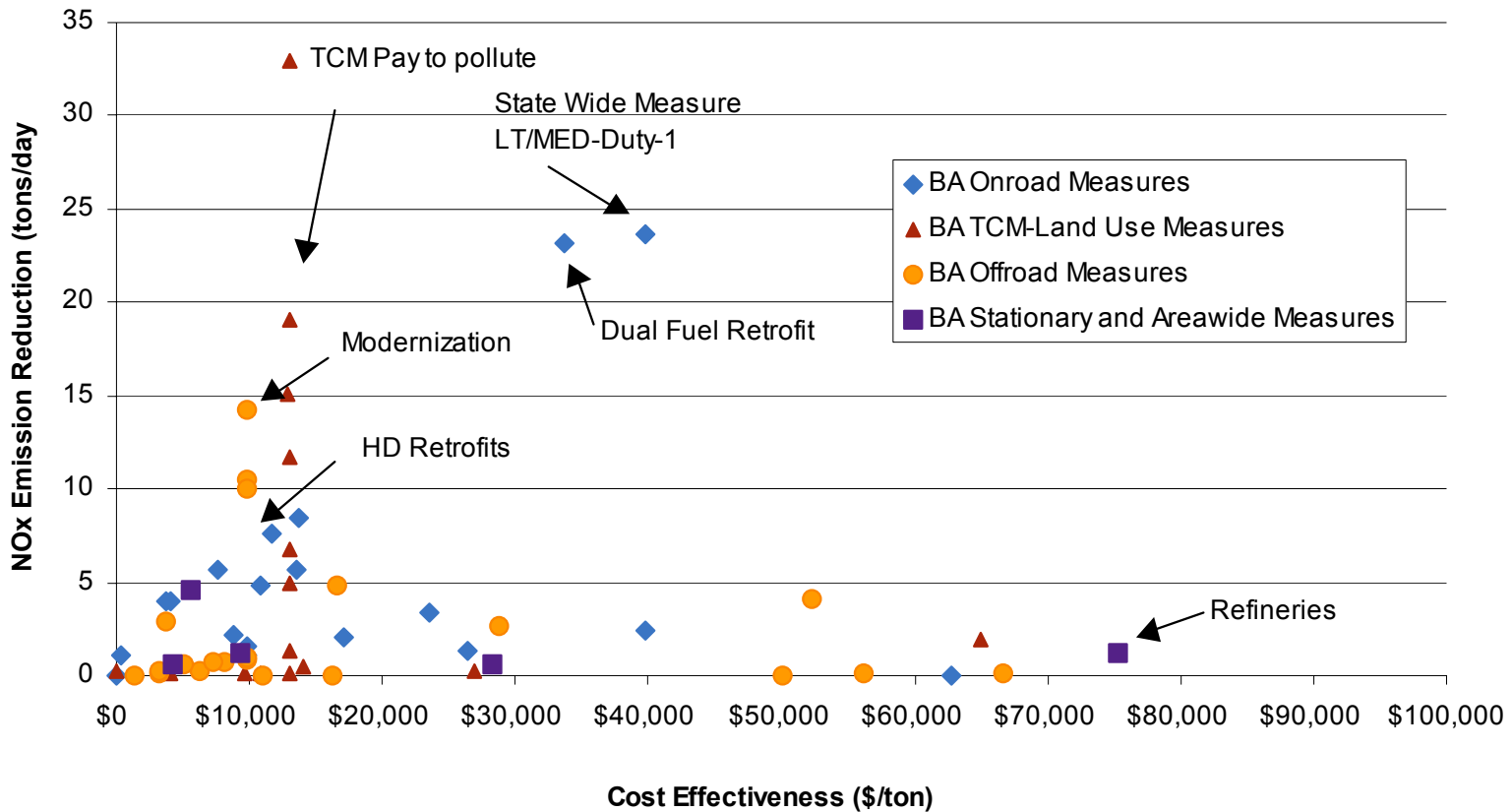
## Cost Effectiveness for 1-MW Diesel Generator Set



## **Cost Effectiveness Depends on Application, Duty Cycle, and Technology**

- Not all technologies work on all engines and applications
- Can not compare cost effectiveness for different applications or for similar applications but different duty cycles
  - Transit bus compared to school bus
  - Diesel genset to on road vehicle
- Cost effectiveness a useful tool to compare the relative ranking of technologies for reducing just NO<sub>x</sub>, PM, or other pollutants
- A more sophisticated cost effectiveness methodology needed to compare the relative ranking of technologies that provide multi benefits such as NO<sub>x</sub> and PM
  - Some consensus for valuing PM reductions X 10 compared to NO<sub>x</sub> reductions
  - CARB's proposed new Carl Moyer Program includes a methodology to estimate cost effectiveness on this basis
  - HC reduction benefits also included in formula

## Control measures providing NOx reductions under \$100,000/ton NOx reduced



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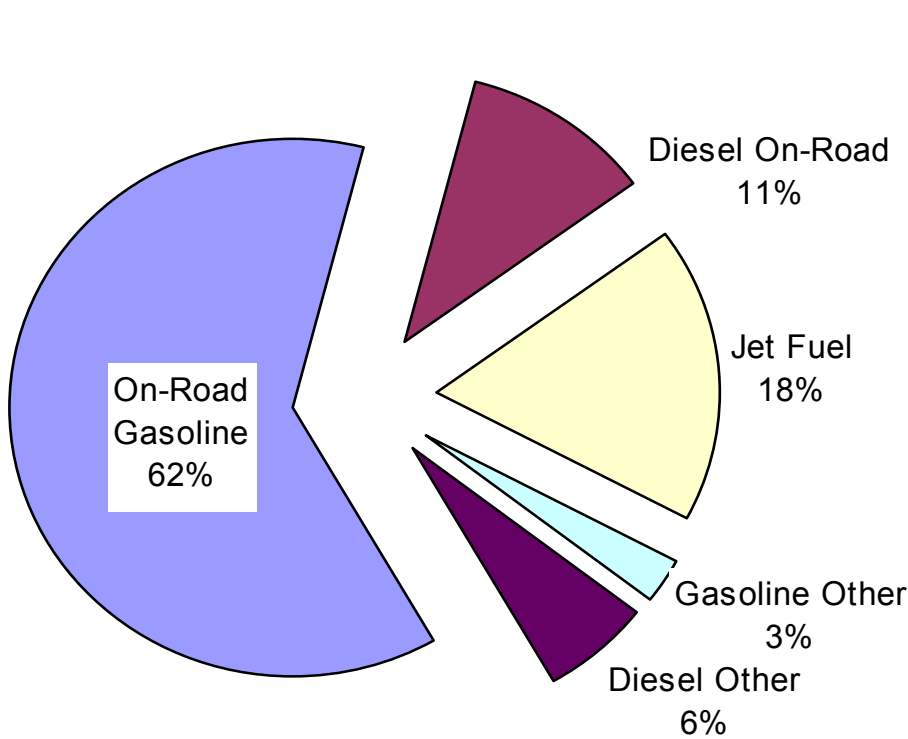
## **Policy Makers, Environmentalists, and Companies have a range of strategies to reduce diesel emissions**

- Encourage the purchase of new low emission vehicles
  - Accelerated fleet turnover including purchase of new alternative fuel vehicles
- Transportation control measures that promote or require operational changes, such as
  - Reduce/limited idling
  - Green or proactive contracting
  - Restricting hours of operation
- Reduce emissions from existing vehicles
  - Refuel, Repower, Replace, Retrofit, Repair/Rebuild

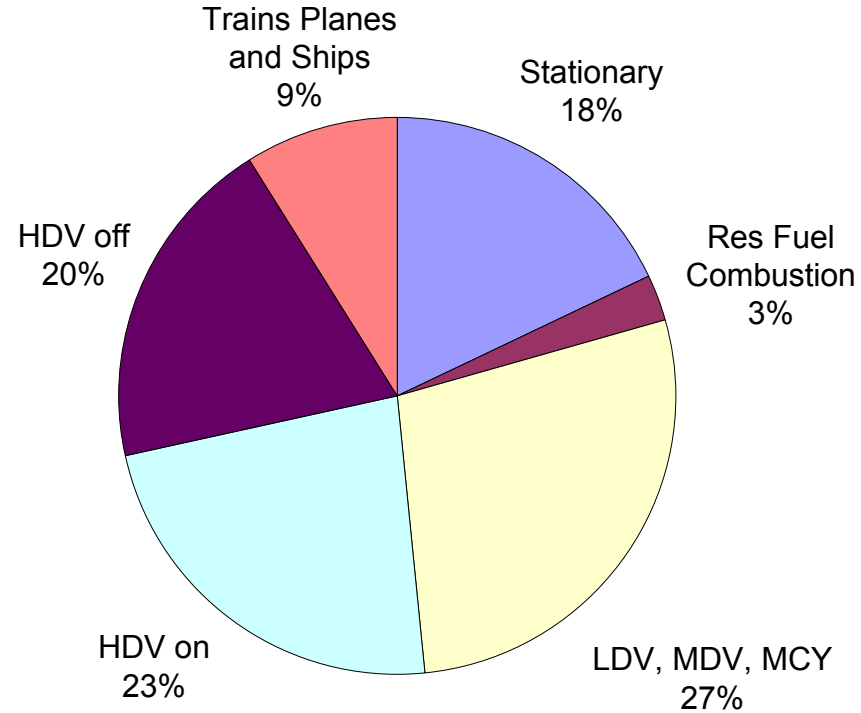
## Strategies will depend on what is being targeted

- Local, EJ areas
  - Primary focus is on reducing PM and other toxic emissions
- State or Regional Nonattainment areas
  - Primary focus has been on reducing ozone precursors NOx and HC
  - PM now also coming into focus
- Global areas
  - Focus on reducing petroleum use by improved efficiency/conservation or by fuel displacement
  - Less petroleum use results in lower production and distribution emissions as well as greenhouse gas emissions

**Strategies also depend on the inventory being targeted**



**Fuel Consumed**



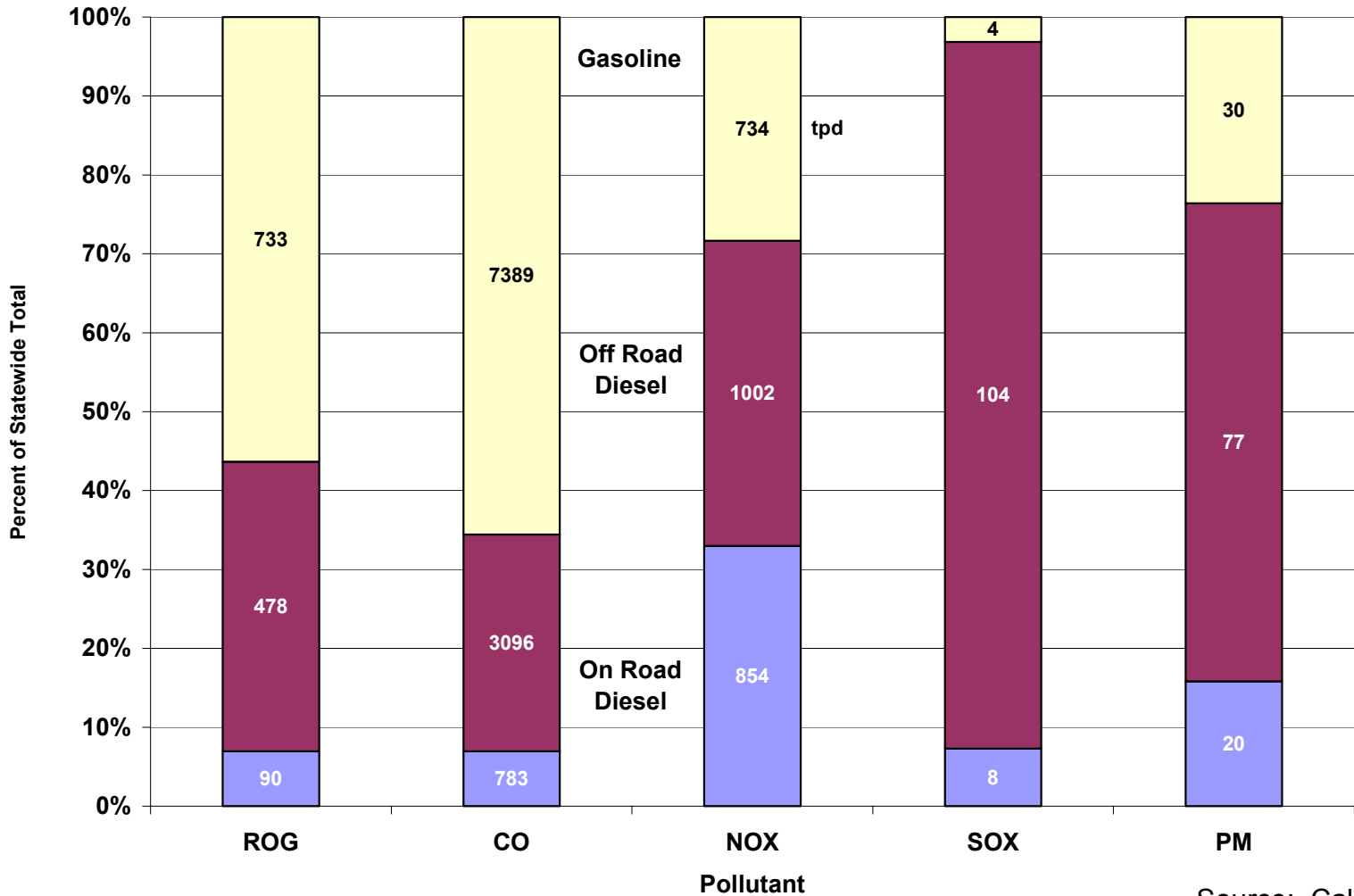
**NO<sub>x</sub> Emissions**

**NO<sub>x</sub> emissions dominated by diesel applications**

Source: California ARB



**PM and SOx mobile emissions also dominated by diesel technologies**



Source: California ARB



## **Diesel reduction strategies have targeted either NOx or PM**

- Moyer, SECAT, and Gateway have targeted cost effective NOx reductions
- Moyer aimed at a variety of on and off road applications, e.g.:
  - On-road Class 8 trucks, street sweepers, refuse trucks, etc.
  - Ag pumps
  - Marine such as tugs and fishing boats
  - Off-road vehicles such as yard hostlers and construction equipment
  - Locomotives
- SECAT has targeted on road vehicles
- Gateway has targeted on- and off-road vehicles
- ARB's diesel risk mitigation program targets PM reductions from various fleets including e.g.
  - Transit buses
  - School buses
  - Refuse haulers

## **Need to consider not only cost effectiveness but also other benefits and implementation issues**

- Most cost effective PM measure may not be the most viable control strategy
- Diesel emulsion fuel, E-Diesel and Synthetic Diesel are cost effective but may not be implemented due to lack of fueling infrastructure
- Diesel emulsion fuel also may not be viable in all engine types
- Some options may provide reduction in secondary PM through NOx benefits
- Best control measures depend on
  - Cost effectiveness
  - Size of reduction for application
  - Application population for which control measure will work
  - How receptive end users are to program implementation

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**Incentive Programs based on emission benefits have been the most successful to date at reducing impacts of existing diesel applications**

- Incentive programs have targeted NOx reductions from existing HD diesel applications
  - Funding based on value of NOx reductions, capped at upper level
  - Projects selected in region based on lowest cost effectiveness
  - Value of NOx benefit matches cost of control measure
  - End-users get additional benefits like newer truck or better fuel economy
- Tax incentive programs for low emission technologies have been less successful since level of incentive generally does not match cost of control measure
- Transportation control measures have had limited success but more emphasis may be placed on these measures as land use planning is integrated with air quality planning
- Fleet rule mandates are very effective but take political power to implement

## **Example Programs that have helped to reduce impact of heavy-duty diesel engine emissions**

- Federal Programs
  - Clean School Bus USA Program
  - Voluntary Retrofit & Replacement Program
  - US DOE's Clean Cities Program
- State Programs
  - California Moyer Program
  - Texas TCRP Program
  - Oregon's Clean Diesel Initiative
- Local Programs
  - Sacramento SECAT (local plus Federal CMAQ funding)
  - Gateway Cities Program
  - Placer County idling regulations

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**There are a wide variety of technologies, control strategies, and funding to reduce impacts of existing diesel engines**

- EPA and ARB have verified the emission benefits of in-use heavy duty control technologies
  - Most aftertreatment technologies provide PM benefits with some providing NOx benefits too. Most provide HC (toxic) and CO reductions.
  - Vehicle strategies provide NOx and PM benefits
- Cost Effectiveness of control measures depends on the type of application and on the specific duty cycle of the application
  - Low mileage applications have poor cost effectiveness compared to high mileage applications
- Control measures need to be evaluated on
  - Cost effectiveness on multiple pollutants
  - Size of reduction for application
  - Application population for which control measure will work
  - How receptive end users are to program implementation

**There are a wide variety of technologies, control strategies, and funding to reduce impacts of existing diesel engines**

- Control strategies can target local, state/regional, or global regions
  - Local areas have focused on PM reductions
  - State and regional areas have focused on NOx reductions
  - Some movement to consider combining both PM and NOx strategies
- Several Federal, state, and local agencies have successfully implemented programs to reduce diesel emissions, e.g.
  - Moyer, TCRP, SECAT, Gateway incentive programs
  - ARB diesel risk mitigation program
  - Oregon's tax credit and loan program
- The success of these programs strongly suggests that substantial further emission reductions are possible if more funding is available
  - The health benefits achieved exceed the cost of these programs

## *Thank You For Your Attention*



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