

Current Trends in Diesel Emission Regulations

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● Environmental/Health Impact of Diesels

- **Benefits**

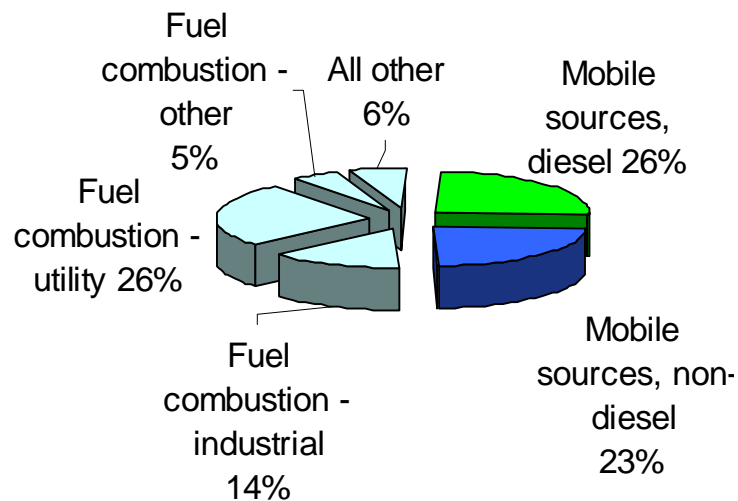
- good fuel economy / high efficiency
- low “greenhouse gas” emissions, both CO₂ and N₂O
- low hydrocarbon (HC) emissions
- low carbon monoxide (CO) emissions
- low cold start and evaporative emissions
- safe handling of fuel (relative to gasoline, NG, LPG)

- **Drawbacks**

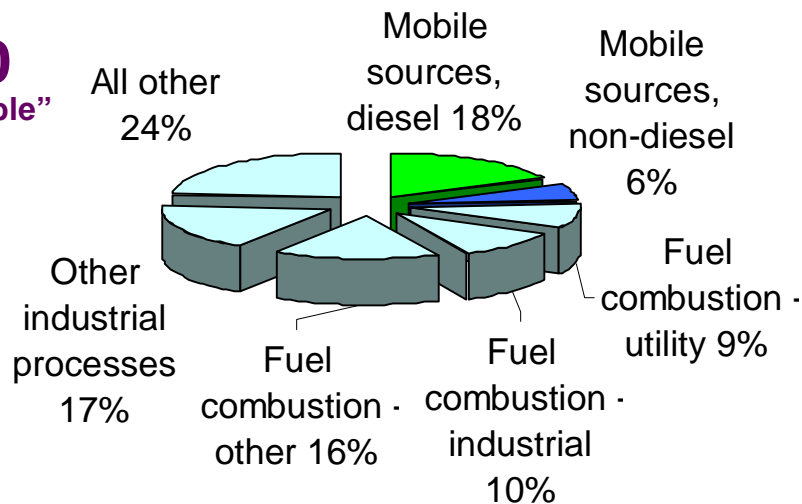
- high particulate matter (PM) mass emissions (relative to SI)
- high nitrogen oxides (NO_x) emissions (relative to 3-way catalyst equipped SI)

● Diesel Emission Inventory: NOx & PM-10

NOx



PM-10 "controllable" sources



- Diesel engines are significant contributors to the U.S. nationwide NOx and PM-10 emission inventory

- 26% of total NOx
- 18% of total PM-10

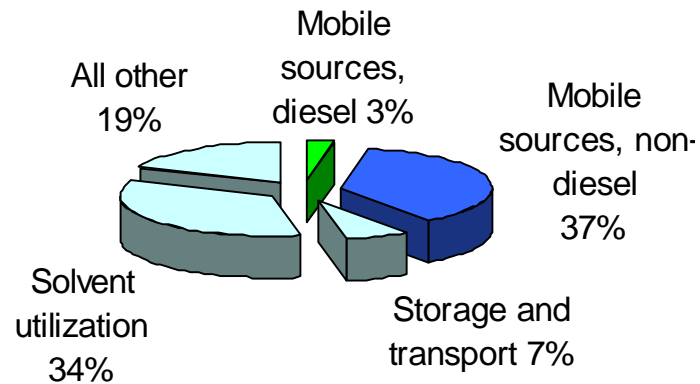
USA, 1997. Data after EPA Emission Trends 1970-1997

Railway and marine vessel emissions are included in "diesel."

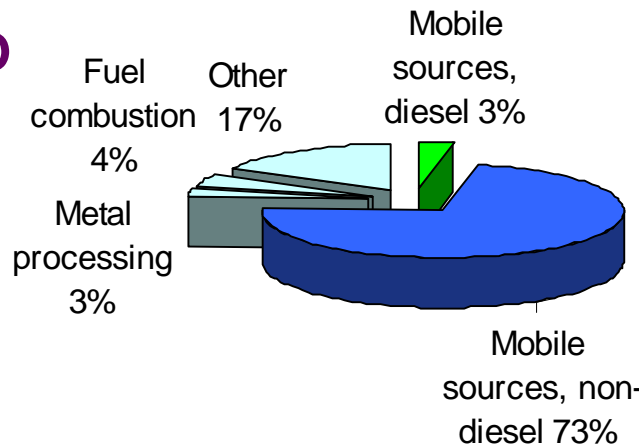
All PM-10 data for mobile sources includes exhaust, tire, and brake wear emissions

● Diesel Emission Inventory: HC & CO

VOC



CO



- Diesels have no significant contribution to the U.S. nationwide VOC and CO emission inventory

- 3% of total VOC
- 3% of total CO

USA, 1997. Data after EPA Emission Trends 1970-1997

Railway and marine vessel emissions are included in "diesel."

● **Types of Diesel Emission Regulations**

- 1. Tailpipe emission standards for new engines / vehicles**
- 2. Retrofit programs for existing vehicle fleets**
- 3. Occupational health regulations**

● **Tailpipe Emission Standards**

- **Established and enforced by environmental protection authorities (e.g., the U.S. EPA)**
- **Set emission limits for engines / vehicles**
- **Specify emission test cycles to measure emissions**
- **Enforced through engine certification programs**
- **Duty to comply on engine / vehicle manufacturer**

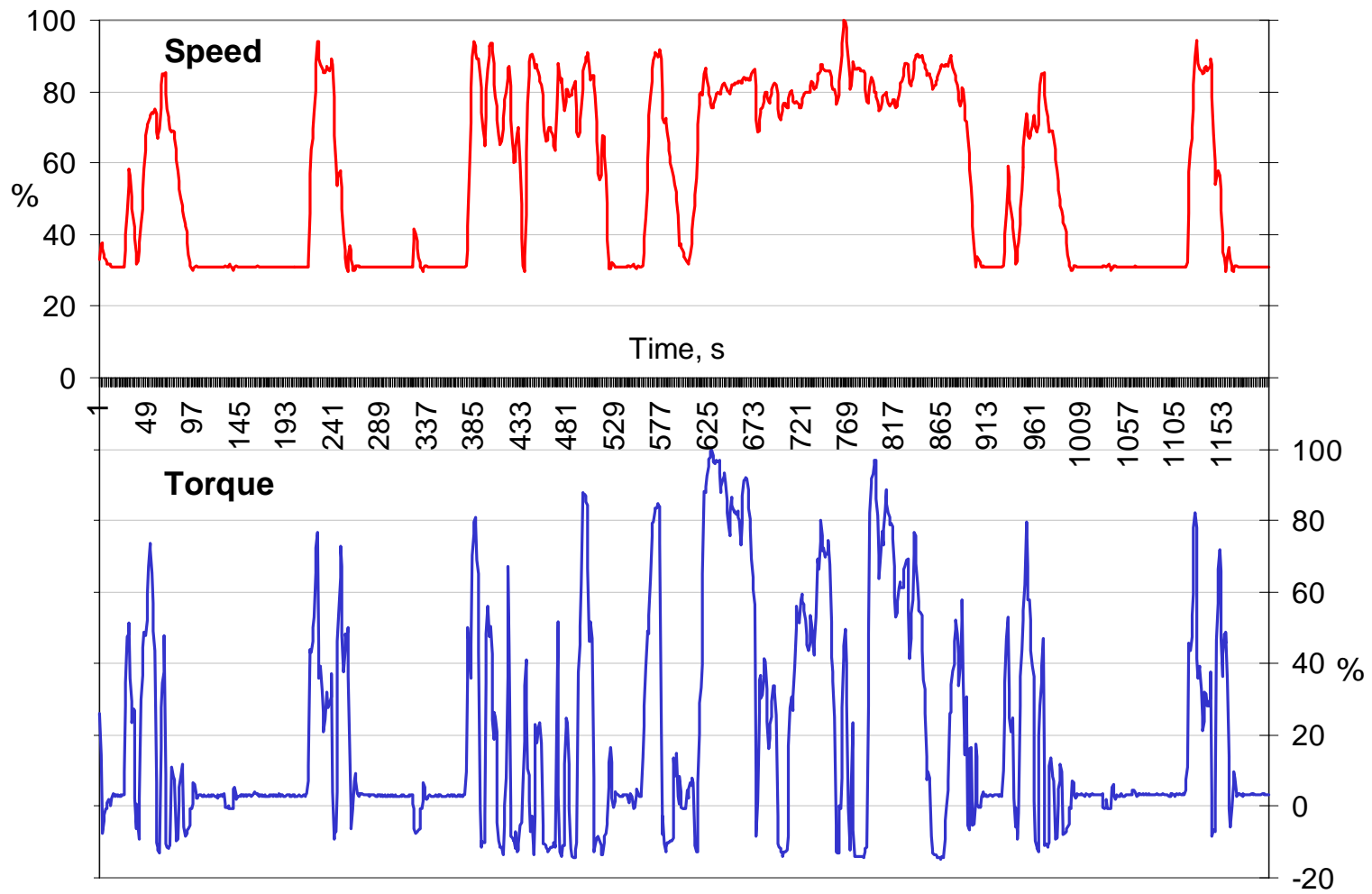
● **Tailpipe Emission Standards (2)**

- **Historically, the first type of emission standards.**
- **All diesel engine categories regulated in the U.S.**
 - highway, HD and LD
 - off-road, including small utility engines (1998)
 - railway locomotives (1997)
 - marine engines (proposed regulation)
- **Highway and off-road diesel engines regulated in the EU and Japan**
- **Countries worldwide adopt EU or U.S. standards**

● Emission Test Cycles

- **Sequence of engine speed and load conditions**
 - Steady-state cycles
 - Transient cycles
- **Engine and vehicle cycles**
 - Engine cycles conducted on an engine dynamometer, emissions in **g/bhp-hr** or **g/kWh**
 - Vehicle cycles conducted on a chassis dynamometer, emissions in **g/mile** or **g/km**

● U.S. FTP Transient Cycle



● ISO 8178

Weighting Factors of Selected B-Type ISO 8178 Test Cycles

Mode number	1	2	3	4	5	6	7	8	9	10	11
Torque, %	100	75	50	25	10	100	75	50	25	10	0
Speed	Rated speed					Intermediate speed					Low idle
Off-road vehicles											
Type C1	0.15	0.15	0.15	-	0.10	0.10	0.10	0.10	-	-	0.15
Type C2	-	-	-	0.06	-	0.02	0.05	0.32	0.30	0.10	0.15
Constant speed											
Type D1	0.30	0.50	0.20	-	-	-	-	-	-	-	-
Type D2	0.05	0.25	0.30	0.30	0.10	-	-	-	-	-	-
Locomotives											
Type F	0.25	-	-	-	-	-	-	0.15	-	-	0.60
Utility, lawn and garden											
Type G1	-	-	-	-	-	0.09	0.20	0.29	0.30	0.07	0.05
Type G2	0.09	0.20	0.29	0.30	0.07	-	-	-	-	-	0.05
Type G3	0.90	-	-	-	-	-	-	-	-	-	0.10
Marine application											
Type E1	0.08	0.11	-	-	-	-	0.19	0.32	-	-	0.30
Type E2	0.20	0.50	0.15	0.15	-	-	-	-	-	-	-

● Regulated Emissions

- Carbon monoxide (CO)
- Hydrocarbons (HC)
- Oxides of nitrogen (NO_x)
 - NO_x = nitric oxide (NO) + nitrogen dioxide (NO₂)
 - nitrous oxide (N₂O) is not part of NO_x
- Diesel Particulate Matter, DPM or PM (mass)
 - DPM = solids + SOF + sulfate
 - sampled from diluted exhaust at 52°C (125°F)
- *Smoke opacity - as an auxiliary measure*
- *Formaldehyde (HCHO) - only in some regulations*

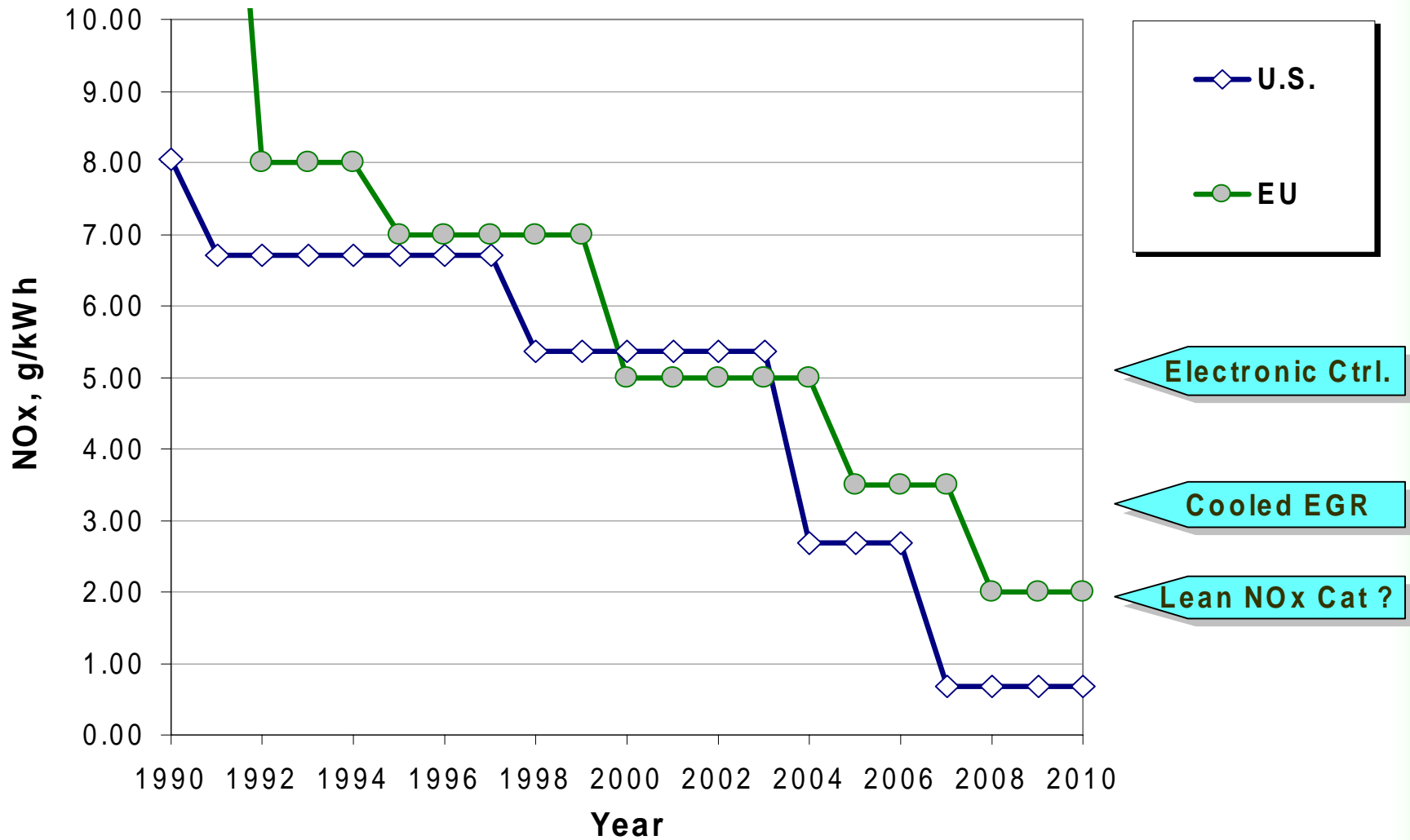
● Emission Standards – Milestones (HD Engines)

- **U.S.**
 - 1994: 0.1 g/bhp-hr PM (0.13 g/kWh)
 - 2004: 2.5 g/bhp-hr NO_x+HC (3.35 g/kWh)
- **EU**
 - 2005: 0.02/0.03 g/kWh PM
 - 2008: 2.0 g/kWh NO_x
- **Next challenge (U.S. EPA)**
 - **0.5 g/bhp-hr NO_x** (0.67 g/kWh)
 - **0.01 g/bhp-hr PM** (0.013 g/kWh)

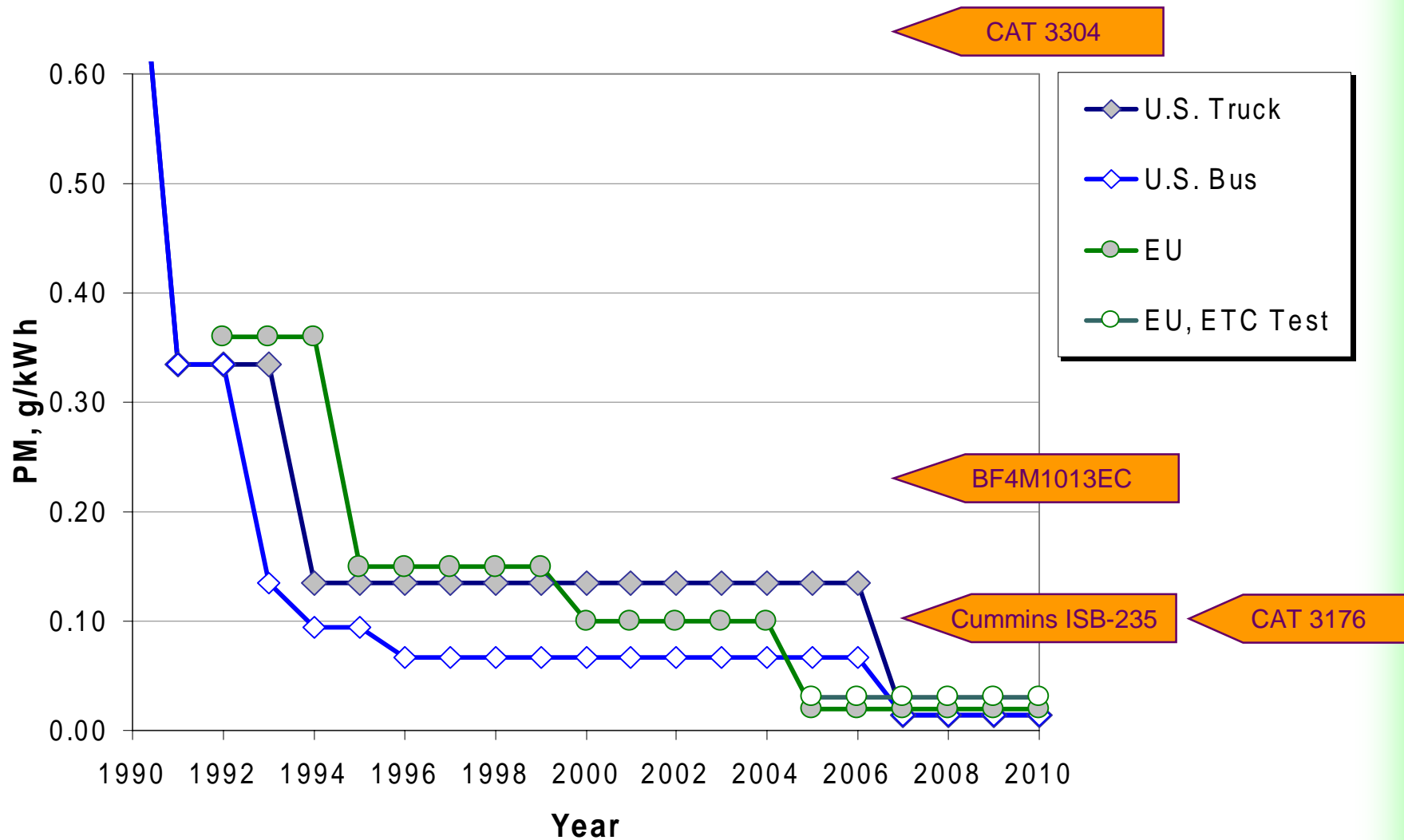


Emission standards summary available at www.DieselNet.com

● HD Diesel Truck & Bus Emission Standards -- NOx



● HD Diesel Truck & Bus Emission Standards -- PM



● **Technologies to Meet Emission Standards**

- **Advanced engine design, electronic engine control**
 - U.S. 1994 PM standard
- **Electronic injection systems** (HEUI, common rail)
- **Clean fuels introduced worldwide** (sulfur, cetane #)
- **Diesel oxidation catalysts**
 - EU cars, some HD engines in the U.S.
- **EGR, cooled EGR**
 - U.S. 2004 NOx standard
- **Diesel particulate filters**
 - first commercial DPF system by Peugeot in 2000
 - Euro IV (truck & bus), U.S./CA light-duty Tier 2 / LEV 2
- **Lean NOx catalysts/traps** (still under development)

● **Retrofit programs for existing vehicle fleets**

- **Introduced in large urban areas worldwide to control emissions from existing diesel engines**
- **Retrofitting of urban buses, trucks, off-road engines with emission control systems**
 - engine upgrade kits
 - diesel particulate filters
 - diesel oxidation catalysts
- **Mix of compulsory, market-, and tax-incentive programs**
- **Formal certification / approval of emission control equipment**

● **Examples of Retrofit Programs**

- **Urban Bus Rebuild/Retrofit - UBRR (U.S. EPA, 1995)**
- **Environmental Zones (Sweden, 1996)**
- **HD Diesel Retrofit/Rebuild Program (NESCAUM, 1999)**
- **Retrofit Initiatives in Cities Worldwide**

● **Occupational Health Regulations**

- **Established and enforced by occupational safety and health authorities (e.g., OSHA, MSHA)**
- **Regulations based on recommendations by medical science (e.g., ACGIH)**
- **PELs for pollutants in ambient air**
- **May establish additional engine regulations**
 - minimum ventilation rates (mining)
 - regulate an emission control technology (e.g. DPF)
- **Enforced through workplace inspections / air quality surveys**
- **Duty to comply on engine user (e.g., mine operator)**

● Exposure Limits for Gases

ppm vol., 8-hour time weighted averages (TWA)

Substance	CAS#	OSHA PEL	OSHA 88*	MSHA TLV	ACGIH TLV
CO	630-08-0	50	35	50	25
CO ₂	124-38-9	5000	5000	5000	5000
NO	10102-43-9	25	25	25	25
NO ₂	10102-44-0	(C) 5	1 ^d	5	3
HCHO	50-00-0	0.75			(C) 0.3 A2
SO ₂	7446-09-5	5	2	5 ^a / 2 ^b	2

* - not legal limits (PELs adopted in 1988 were later remanded by court)

a - for metal/nonmetal mines

b - for coal mines

d - 15-minute short term exposure limit (STEL)

(C) - Ceiling value

A2 - Suspected human carcinogen

Typical mining ventilation rates

- 150 cfm per hp in older, mechanical engines
- 50 cfm per hp in newer, EC engines

● **Exposure Limits for Diesel Particulates**

- **No limit for diesel particulate matter (DPM) in most countries yet. In the past DPM was considered health-neutral.**
- **Germany - TRK (technically achievable) exposure limit set in 1993/1996**
- **U.S.- proposed ACGIH limit, proposed mining limits (MSHA)**
- **No agreement on the definition of DPM / sampling method**
 - Size selective sampling
 - Respirable Combustible Dust
 - Total carbon (elemental carbon + organic carbon)
 - Elemental carbon
- **Increasing use of diesel particulate filters in occupational settings (BACT, legislation of control technologies, ...)**

● Exposure Limits for Diesel Particulates (2)

Limit	Value, mg/m ³	DPM Definition
<i>Current Limits</i>		
Germany, general occupational settings	0.1*	Elemental carbon
Germany, tunneling & non-coal mining	0.3*	Elemental carbon
Ontario, underground non-coal mining	1.5	RCD
<i>Proposed Limits</i>		
MSHA, proposed TLV, non-coal mining	0.4 ... 0.16**	Total carbon
ACGIH, proposed TLV - 1995	0.15	Unclear
ACGIH, proposed TLV - 1998	0.05	Unclear
* - technically achievable TRK limits, as opposed to the health-based MAK limits		
** - phase-in over a 5 year period		

Typical occupational DPM exposure levels

Occupational Group	Exposure Level, mg/m ³
Underground miners	0.10 – 1.70
Urban fire stations	0.10 – 0.48
Forklift operators, dock workers, railroad workers	0.02 – 0.10
Truck Drivers	0.04 – 0.06

● **Emission Regulations - Future Trends**

- **Increasingly stringent “aftertreatment-forcing” standards for NOx and PM**
- **Health concern with diesel particulates**
 - CARB identified diesel particulates as “toxic air contaminant”
 - EPA announces Integrated Urban Air Toxics Strategy:
 - Polycyclic Organic Matter (POM) listed as a HAP
 - Health assessment for diesel particulates
- **Regulation of currently unregulated diesel emissions - nanoparticles**
 - new engine regulations (tailpipe emissions)
 - occupational health regulations