Strengthening fuel quality and vehicle emissions standards

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Clean Fuels and Vehicles Forum
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ICCT’s Mission and Activities

| The mission of ICCT is to dramatically improve the environmental performance and efficiency of cars, trucks, buses, and transportation systems in order to protect and improve public health, the environment, and quality of life. |
| Non-profit research organization |
| Air Pollution and Climate Impacts |
| Focus on regulatory policies and fiscal incentives |
| Activity across modes including aviation and marine |
| Global outreach, with special focus on largest markets |
To improve the environmental performance and energy efficiency of all modes of motorized transportation—passenger cars, heavy-duty trucks and buses, ocean-going ships, and commercial aviation—and the fuels they burn to address air pollution and climate change.
Pollutants of concern from motor vehicles

- Carbon monoxide (CO)
- Ozone (VOC + NOx)
- Haze
- NOx, SOx, VOC, ammonia
- Toxics - Diesel particles - Benzene - Heavy metals
- Particles (PM$_{10}$/PM$_{2.5}$)
- Greenhouse Gases - CO$_2$, Methane, Black Carbon, N$_2$O, HFC

Source: Michael Walsh
Diesel is a key problem...

Diesel engine exhaust carcinogenic

12 June 2012 — After a week-long meeting of international experts, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization, today classified diesel engine exhaust as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer.

Read the press release from IARC on diesel engine exhaust.
…especially diesel trucks

Diesel trucks are just 5% of China’s vehicle fleet

But they emit 61% of all vehicular particulate matter

Source: MEP
Characteristics of diesel soot (a.k.a particulate matter (PM))

- Diesel PM is
  - Tiny
  - Dangerous
  - Mostly BC

Deposition of particles in the human lung

<table>
<thead>
<tr>
<th>Lung structures</th>
<th>Particle size</th>
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<tbody>
<tr>
<td>Nose-pharynx</td>
<td>5-10 μm</td>
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<tr>
<td>Trachea</td>
<td>3-5 μm</td>
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<tr>
<td>Bronchi</td>
<td>2-3 μm</td>
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<tr>
<td>Bronchioli</td>
<td>1-2 μm</td>
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<tr>
<td>Alveoli</td>
<td>0.1-1 μm</td>
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</table>
Big ideas

1. Close the loop: what matters is ambient air quality improvement
2. Act comprehensively: new vehicle standards, clean fuels, in-use vehicle emission control programs
3. Advanced standards and technologies are extremely effective at reducing vehicle emissions to near-zero levels
4. Developing countries have incredible opportunity to learn from international experience (both good and bad!)
5. National action is preferred, but cities/regions can also lead
US approach to air quality management

Source: Handbook of Air Quality Management [https://www.aqbook.org/read/?page=62](https://www.aqbook.org/read/?page=62)
Air quality attainment is main driver of US motor vehicle emission control programs (1)

- Federal EPA sets ambient air quality standards *based on health impacts alone, not considering compliance costs*
  - Ambient air quality standards are periodically updated based on latest health studies
  - PM example: [http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_history.html](http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_history.html)

### History of the National Ambient Air Quality Standards for Particulate Matter During the Period 1971-2012

<table>
<thead>
<tr>
<th>Final Rule</th>
<th>Primary/Secondary</th>
<th>Indicator</th>
<th>Averaging Time</th>
<th>Level [μg/m³]</th>
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<td>1971</td>
<td>Primary</td>
<td>TSP</td>
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<td>50</td>
<td>Annual arithmetic mean, averaged over 3 years</td>
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<td>1997</td>
<td>Primary and Secondary</td>
<td>PM[10]</td>
<td>24-hour</td>
<td>150</td>
<td>Initially promulgated 99th percentile, averaged over 3 years; when 1997 standards for PM[10] were vacated, the form of 1987 standards remained in place (not to be exceeded more than once per year on average over a 3-year period)</td>
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Federal EPA determines which counties are not in compliance
Air quality attainment is main driver of US motor vehicle emission control programs (2)

- States develop emissions inventories and air quality models to determine source apportionment
- States propose State Implementation Plans (SIPs), which EPA must approve, to improve air quality
- Driven by needs identified in SIPs, Federal EPA sets regulations for many source categories including motor vehicles and fuels
  - National-level regulations prevent conflicting/burdensome regulatory landscapes in 50 States.
  - Exception: California, which is permitted to establish its own vehicle emission limits upon receiving a waiver from the federal government. Other States may adopt California’s standards but may not develop their own.
- Helping States meet air quality goals is #1 driver of increasing stringency of vehicle emission standards in the US
Example – justification of upcoming Tier 3 standards

- From Regulatory Announcement: “Emission reductions from the Tier 3 program would lead to immediate air quality improvements that are critically important for states to attain and maintain the existing health-based National Ambient Air Quality Standard (NAAQS). In the absence of additional controls such as the Tier 3 standards, many areas would continue to have air pollution levels that exceed the NAAQS in the future.”

- Also in opening paragraph of actual proposed rule (see right)

In the US, emissions declined by 68% despite growth in economy, population and amount of driving over the past four decades.

Fundamentals of controlling air pollutant emissions from motor vehicles

New vehicle standards
Technology neutral (but technology-forcing...) emissions standards for new vehicles.
Must consider emissions from all mobile sources: on-road, off-road, marine, locomotives, aviation, construction...
Limit values only as good as:
- Compliance and enforcement
- Real-world performance

Fuel quality standards
High fuel quality (especially low sulfur levels) enables advanced emission control technologies to be deployed in the fleet.
Fuel quality compliance programs critical to prevent damage to engines and prevent misfueling

In-use vehicle emission control
Clean up legacy vehicles on the roads
Comprehensive program includes:
- Catching gross-emitters (I/M, remote sensing, maintenance, etc.)
- Cleaner fuels
- Scrappage/replacement programs
- Retrofit programs
- Complementary strategies (low emission zones, driver training, etc.)

"Systems Approach"

Note shown but also important: transportation demand management, modal shift, traffic optimization, and more
Progressively stringent tailpipe emission standards are extremely effective at reducing emissions to near-zero levels.
Particulate standards for heavy-duty engines lowered by an incredible 99% in US and EU.

Diesel particulate filters achieve dramatic emission reductions

Overview: The exhibits above are actual PM collection samples from an engine testing laboratory used to collect and measure diesel particulate matter (PM) emissions. Test conditions are:

- Test Cycle: UDDS (Urban Dynamometer Driving Schedule)
- Test Distance: 5.5 miles over 17 minutes
- Fuel Consumed During Test: 1.1 gallons
- Test Vehicle: Heavy-duty truck with a 370 hp Cummins engine (1999 model year)
- PM material on collection samples is 1/1,800th of actual
Heavy-duty NOx standards also making dramatic progress

Technology options: Heavy-Duty Diesel

- **European Standards– Diesel**

  - **Euro II**
    - Turbochargers
    - In-line or rotative fuel pump
    - Fuel injection delay for NOx control
    - Emissions:
      - NOx: 7.0 g/kW-h
      - PM x 10: 2.0

  - **Euro III**
    - Turbochargers
    - In-line or rotative fuel pump
    - Fuel injection delay for NOx control
    - Emissions:
      - NOx: 6.0 g/kW-h
      - PM x 10: 1.5

  - **Euro III +** (Euro III with enhancements)
    - Electronic Unit Injectors
    - Common-rail
    - Variable injection (PM and NOx control)
    - DOC
    - Emissions:
      - NOx: 5.0 g/kW-h
      - PM x 10: 1.0

  - **Euro IV**
    - Electronic Unit Injectors or Common-rail
    - Variable injection
    - Electronic Unit Injectors or Common-rail
    - DOC
    - Emissions:
      - NOx: 4.0 g/kW-h
      - PM x 10: 0.5

  - **Euro IV +** (Euro IV with enhancements)
    - Electronic Unit Injectors or Common-rail
    - Variable injection
    - DOC
    - Emissions:
      - NOx: 3.0 g/kW-h
      - PM x 10: 0.2

  - **Euro V**
    - Variable Geometry Turbo (VGT)
    - High pressure and high flexibility injection system
    - Dual turbo
    - EGR
    - SCR
    - DOC (or FTF)
    - Emissions:
      - NOx: 2.0 g/kW-h
      - PM x 10: 0.1

  - **Euro VI**
    - Variable Geometry Turbo (VGT)
    - High pressure and high flexibility injection system
    - Dual turbo
    - EGR
    - SCR
    - DOC (or FTF)
    - Emissions:
      - NOx: 1.0 g/kW-h
      - PM x 10: 0.05
Technology options: Heavy-Duty Diesel

- **US Standards– Diesel**

    *Electronic control
    *Electronic Unit Injectors 1500-1700 bar
    *Variable injection
    *Combustion improvements

    *Electronic unit injectors or Common-rail 1700-1900 bar
    *Variable fuel injection
    *Piston redesign
    *EGR (cooled)
    *DOC

    *Variable geometry turbo (VGT)
    *Electronic unit injectors or Common-rail 1800-2000 bar
    *Variable injection
    *EGR calibration and optimization
    *DOC+DPF

    *VGT or double stage turbo
    *High pressure, high flexibility fuel injection system
    *P> 2000 bar
    *Advanced combustion R&D
    *Sub-systems integration
    *EGR cooled and/or double stage
    *DPF improvements
    *SCR

![Graph showing emission limits from US 1998 to US 2010](chart.jpg)
Progress in light-duty gasoline vehicle emission limits

Light-Duty Technologies by Regulatory Level

**Gasoline Technologies**

- **Euro 2**
  - TBI to MPI requires one fuel injector per cylinder
  - Improved sensor response and control algorithms (ECU)
  - TWC Underfloor
  - O2 sensor (AF control)

- **Euro 3**
  - Euro 3 OBD requires secondary O2 sensor (heated)
  - Improved ECU capabilities (handle OBD)
  - EGR
  - Cold start required for TA. TWC is divided in closed coupled (CC) and Underfloor (UF)

- **Euro 4**
  - Improvements over Euro 3 technology: fueling strategy for cold start control
  - TWC improvements, catalyst and washcoats

- **Euro 5**
  - Improvements over Euro 4 technology: combustion improvements and faster O2 sensors
  - TWC improvements, OSC and coating techniques

- **Euro 6**
  - No technology changes for pollutant control
  - Improvements focused on CO₂ and fuel economy

- **Emission limits g/km**

**Categories**
- NOx
- HC
- CO/10
- NOx+HC
Light-Duty Technologies by Regulatory Level

### Diesel Technologies

- Rotary fuel inj. pump
- IDI combustion
- Low pressure Inject (700-800 bar)
- EGR low-pressure mechanic operation

Euro 3 technology +
- A/F management and combustion improvements
- Electronic control of fuel injection
- P\textsubscript{inj} 1300 bar
- Cooled EGR
- DOC for PM reduction (volatile fraction)

Euro 4 technology +
- Improv. in comb., air induction, variable fuel injection
- P\textsubscript{inj} 1900 bar
- Tumble and swirl
- Variable geometry turbo. (VGT)
- Variable fuel injection timing for DPF regeneration
- Variable valve timing (VVT)
- DOC + DPF
- LNT may be required in some engines (Vd>2.0 L)

Euro 5 technology +
- Variable fuel inj. timing and metering, including rate shaping
- P\textsubscript{inj} >2100 bar
- Variable geometry turbochargers for air induction tailoring
- Variable fuel injection timing for DPF regeneration
- DOC + DPF, if Vd<1.4 liters
- DOC+DPF +LNT, if 1.4 < Vd< 2.0 L
- DOC+DPF+SCR, if Vd>2.0 L

**Graphs:**
- Emission limits g/km
- NOx, PMx10

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*Note: The graph shows emission limits for various Euro standards, with Euro 2, Euro 3, Euro 4, Euro 5, and Euro 6 technologies listed.*
Global progress in tailpipe emission standards

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* India and China have more advanced standards in selected cities; shown here are national-level standards.
Global progress in fuel sulfur levels

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<td>South Africa</td>
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<td>500 (50 in some markets)</td>
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* India, China, and Brazil (diesel only) have more advanced standards in selected cities; shown here are national-level standards.
US approach to motor vehicle emission control and key features

- Technology neutral
  - Set performance standards and allow market to dictate most appropriate technologies

- Lots of flexibility built into regulations
  - Averaging, banking, and trading
  - Exceptions and extensions for small manufacturers
  - Standards are phased-in over a few years

- Extremely strong compliance programs
  - Strong legal authority of EPA to issue fines and recalls
  - Most testing burden borne by manufacturers, who are audited by EPA
Latest development in US: Tier 3

- Tier 3 standards include new limit values for light-duty vehicles as well as reduced sulfur levels for gasoline.
- Phased-in 2017-2025
- Harmonized with California’s LEV III program
- EPA-estimated costs:
  - $130 per vehicle
  - 1 cent/gallon
- Health benefits estimated to be 3-8x costs
- *EPA’s experience is that motor vehicle emission control programs regularly deliver benefits dramatically exceeding total cost!*
More info…

- http://www.theicct.org
  - Policy briefs and analysis
  - Best practice documents
  - Cost/benefit analysis
  - Issue-specific research reports

- http://www.transportpolicy.net
  - Country-specific policy summaries
  - Global comparison maps and tables

- My contact info:

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