Comparison of US and EU programs to control light-duty vehicle emissions

Kate Blumberg, Francisco Posada

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Outline

- Overview on new vehicle standards
  - Weight classifications
  - Test cycles
- New vehicle emissions standards
  - Limit values
  - Durability
  - Evaporative emissions
  - OBD
- New vehicle greenhouse gas standards
- Compliance and enforcement of new vehicle standards
- Standards and programs for vehicles in circulation
  - Vehicle inspection
  - Remote sensing
  - Low emission zones
### Overview

<table>
<thead>
<tr>
<th></th>
<th>US &amp; California</th>
<th>European Union</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel quality</strong></td>
<td>• Gasoline: 30 ppm sulfur average / 80 max (2006); 10 ppm average / 80 max (2017)</td>
<td>• Gasoline &amp; diesel: 50 ppm sulfur max (2005)</td>
</tr>
<tr>
<td><strong>Test cycle</strong></td>
<td>Federal Test Procedures + Supplemental Cycles:</td>
<td>New European Drive Cycle:</td>
</tr>
<tr>
<td></td>
<td>• FTP-75 (city cycle, includes cold start)</td>
<td>• NEDC (city and extra urban, includes cold start)</td>
</tr>
<tr>
<td></td>
<td>• US06 (high speed)</td>
<td>World-Harmonized Light-Duty Vehicle Test Procedure:</td>
</tr>
<tr>
<td></td>
<td>• SC03 (air conditioning)</td>
<td>• WLTP (cold start, low, medium, high and aggressive driving in a single cycle)</td>
</tr>
<tr>
<td></td>
<td>• HWFET (highway cycle, fuel economy only)</td>
<td>• Expected implementation in 2017</td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td>Emissions:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Tier 2 standards cover all vehicles up to 3,855 kg GVWR and passenger vehicles</td>
<td>Emissions:</td>
</tr>
<tr>
<td></td>
<td>up to 4,535 kg; LEV II and III and Tier 3 extend coverage to all complete</td>
<td>• Limit values set for passenger cars &amp; light commercial vehicles by vehicle</td>
</tr>
<tr>
<td></td>
<td>vehicles up to 6,350 kg GVWR</td>
<td>class/weight up to 2610 kg (RM)</td>
</tr>
<tr>
<td></td>
<td>GHG:</td>
<td>CO₂:</td>
</tr>
<tr>
<td></td>
<td>• Light-duty standards cover all LDVs (up to 3855 kg) and MDPVs (up to 4535kg)</td>
<td>• Passenger car standards apply to vehicles designed for the carriage of</td>
</tr>
<tr>
<td></td>
<td>• Heavy-duty standards (all other on-road vehicles, including all trucks above</td>
<td>passengers (up to 3.5 tonnes GVWR)</td>
</tr>
<tr>
<td></td>
<td>3855 kg)</td>
<td>Light commercial vehicle standards include all light trucks with RM up to 2610</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kg in the N1 category (up to 3.5 tonnes GVWR)</td>
</tr>
<tr>
<td><strong>Timeframe</strong></td>
<td>Emissions:</td>
<td>Emissions:</td>
</tr>
<tr>
<td></td>
<td>• US Tier 2 (phase in 2004-2009), Tier 3 (phase in 2017-2025)</td>
<td>• Euro 4 (2005 for new vehicle type approval, 2006 all)</td>
</tr>
<tr>
<td></td>
<td>• California LEV II (phase in 2004-2010), LEV III (phase in 2015-2028)</td>
<td>• Euro 5a (2009 new, 2011 all); 5b (2011 new, 2013 all)</td>
</tr>
<tr>
<td></td>
<td>GHG:</td>
<td>• Euro 6 (2014 new, 2015 all); Euro 6c adds RDE (~2017)</td>
</tr>
<tr>
<td></td>
<td>• Light-duty standards include 2012-2016 standards and 2017-2025 standards</td>
<td>CO₂:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Current standards apply for the 2015 model year. 2020 standards are fully</td>
</tr>
<tr>
<td></td>
<td></td>
<td>phased in for the 2021 model year and apply for all years beyond, until</td>
</tr>
<tr>
<td></td>
<td></td>
<td>replaced.</td>
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</tbody>
</table>
### US & California

#### Pollutants
- Emissions:
  - NO$_x$ + NMOG and CO (bin certification, fleet averaging)
  - HCHO (limit value)
  - PM mass (limit values, phased in)

#### GHG:
- CO$_2$ (fleet average)
- CH$_4$, N$_2$O (limit values)
- F-gases (credits available)

#### Design
- Emissions:
  - All passenger vehicles and vehicles under 3,856 kg GVWR certify to a single set of bins, with a fleet average requirements
  - Different bins for medium-duty cargo vehicles (3,856 – 6,350 kg GVWR)
  - Standards phase in over time, as fleets are required to meet lower average emissions and/or higher-emission bins are eliminated

#### Durability
- 193,000 km or 10 years (Tier 2/LEV II)
- 240,000 km or 15 years (Tier 3/LEV III)

### European Union

#### Emissions:
- NO$_x$, HC, NO$_x$+HC (diesels), PM and PN (limit values per vehicle category)

#### CO$_2$:
- CO$_2$ (fleet average)

#### Design
- Emissions:
  - Different maximum limit values set for diesel and gasoline
  - Values stay stable until for multiple years, until new standards are introduced

#### CO$_2$:
- Single year, mass-based standard, applying to an increasing percentage of the fleet in preceding years.
- Super credits (for vehicles with 50 g/km or less CO2 emissions) and eco-innovation credits (up to 7 g/km).

#### Durability
- 160,000 km or 5 years, whichever comes first
Light and medium-duty weight classifications

Weight classification mismatch between European and North American standards
## Weight classifications

<table>
<thead>
<tr>
<th>Standard</th>
<th>Classification</th>
<th>RM (EU) o LVW (US)</th>
<th>GVWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU, Euro 6</td>
<td>Euro 6</td>
<td>Up to 2610 kg, up to 2840 kg at manufacturer request</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PV</td>
<td>All</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LT N1</td>
<td>Class II 0-1305 kg</td>
<td>0-3500 kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Class II 1306-1760 kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Class II More than 1760 kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LT N2</td>
<td></td>
<td>3500-12,000 kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US, Tier 3</td>
<td>Tier 3</td>
<td></td>
<td>Up to 6350 kg</td>
</tr>
<tr>
<td>PV</td>
<td>PV</td>
<td></td>
<td>3856 kg</td>
</tr>
<tr>
<td></td>
<td>MDPV</td>
<td></td>
<td>3856-4536 kg</td>
</tr>
<tr>
<td>LDT</td>
<td>LDT1</td>
<td>0-1701 kg</td>
<td>Less than 3856 kg</td>
</tr>
<tr>
<td></td>
<td>LDT2</td>
<td>More than 1701 kg</td>
<td></td>
</tr>
<tr>
<td>MDV</td>
<td>Class 2b</td>
<td></td>
<td>3856-4536 kg</td>
</tr>
<tr>
<td></td>
<td>Class 3</td>
<td></td>
<td>4536-6350 kg</td>
</tr>
<tr>
<td>Mexico, NOM 042</td>
<td></td>
<td></td>
<td>Up to 3856 kg</td>
</tr>
</tbody>
</table>
Test cycles

**NEDC** (1970s / 1990s)

- 130 km/h vs. 120 km/h
- More dynamic driving
- Longer test cycle

**WLTP** (2014, replace NEDC in 2017)

- 130 km/h vs. 120 km/h
- More dynamic driving
- Longer test cycle
- Improved test procedure

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**FTP**, plus supplemental family

- SC03 (Air conditioning)
- US06 (Aggressive Driving)
- HWFET (Highway, Fuel Economy only)

### Emissions standards

#### Tier 3 Bins (FTP)

<table>
<thead>
<tr>
<th>Tier 3 Bins (FTP)</th>
<th>NMOG+ NOX (mg/km)</th>
<th>PM(^a) (mg/km)</th>
<th>CO (mg/km)</th>
<th>HCHO (mg/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin 5</td>
<td>56+44=100</td>
<td>6</td>
<td>2610</td>
<td>11</td>
</tr>
<tr>
<td>Bin 160</td>
<td>100</td>
<td>2</td>
<td>2610</td>
<td>2</td>
</tr>
<tr>
<td>Bin 125</td>
<td>78</td>
<td>2</td>
<td>1305</td>
<td>7</td>
</tr>
<tr>
<td>Bin 70</td>
<td>44</td>
<td>2</td>
<td>1057</td>
<td>2</td>
</tr>
<tr>
<td>Bin 50</td>
<td>31</td>
<td>2</td>
<td>1057</td>
<td>2</td>
</tr>
<tr>
<td>Bin 30</td>
<td>19</td>
<td>2</td>
<td>622</td>
<td>2</td>
</tr>
<tr>
<td>Bin 20</td>
<td>12</td>
<td>2</td>
<td>622</td>
<td>2</td>
</tr>
<tr>
<td>Bin 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Tier 2 Bins (FTP)

<table>
<thead>
<tr>
<th>Tier 2 Bins (FTP)</th>
<th>NMOG (mg/km)</th>
<th>NOx (mg/km)</th>
<th>PM(^a) (mg/km)</th>
<th>CO (mg/km)</th>
<th>HCHO (mg/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin 8</td>
<td>78</td>
<td>124</td>
<td>12</td>
<td>2610</td>
<td>11</td>
</tr>
<tr>
<td>Bin 7</td>
<td>56</td>
<td>93</td>
<td>12</td>
<td>2610</td>
<td>11</td>
</tr>
<tr>
<td>Bin 6</td>
<td>56</td>
<td>62</td>
<td>6</td>
<td>2610</td>
<td>11</td>
</tr>
<tr>
<td>Bin 5</td>
<td>56</td>
<td>44</td>
<td>6</td>
<td>2610</td>
<td>11</td>
</tr>
<tr>
<td>Bin 4</td>
<td>44</td>
<td>25</td>
<td>6</td>
<td>1305</td>
<td>7</td>
</tr>
<tr>
<td>Bin 3</td>
<td>34</td>
<td>19</td>
<td>6</td>
<td>1305</td>
<td>7</td>
</tr>
<tr>
<td>Bin 2</td>
<td>6</td>
<td>12</td>
<td>6</td>
<td>1305</td>
<td>2</td>
</tr>
<tr>
<td>Bin 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Euro 6 standards by vehicle class

<table>
<thead>
<tr>
<th>Euro 6 standards by vehicle class</th>
<th>NMOG+ NOX (mg/km)</th>
<th>PM(^a) (mg/km)</th>
<th>CO (mg/km)</th>
<th>PN (#/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT, N2 &amp; N1, III</td>
<td>215</td>
<td>5</td>
<td>740</td>
<td>6.0 x 10(^11)</td>
</tr>
<tr>
<td>LT N1, II</td>
<td>195</td>
<td>5</td>
<td>630</td>
<td>6.0 x 10(^11)</td>
</tr>
<tr>
<td>LT N1, I &amp; PV</td>
<td>170</td>
<td>5</td>
<td>500</td>
<td>6.0 x 10(^11)</td>
</tr>
<tr>
<td>Gasoline (NMOG &amp; NOx are set as separate limits)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT, N2 &amp; N1, III</td>
<td>242</td>
<td>5</td>
<td>2270</td>
<td>6.0 x 10(^11)</td>
</tr>
<tr>
<td>LT N1, II</td>
<td>205</td>
<td>5</td>
<td>1810</td>
<td>6.0 x 10(^11)</td>
</tr>
<tr>
<td>LT N1, I &amp; PV</td>
<td>160</td>
<td>5</td>
<td>1000</td>
<td>6.0 x 10(^11)</td>
</tr>
</tbody>
</table>

- Bin 5 (fleet average) becomes the highest (interim) bin in Tier 3
- Euro 6 standards are similar in stringency to Tier 2
- Realworld NOx emissions from Euro 6-certified diesels are ~600 mg/km.
US EPA Tier 3 and CA LEV III Program

- Unlike Euro standards, US Tier 3 & CA LEV III standards:
  - Are fuel-neutral (same for gasoline and diesel).
  - Apply to all passenger vehicles and light trucks, phasing down to a single fleet average for all.
  - Cover medium-duty commercial trucks (separate bins provided), previously regulated with heavy-duty engine standards.

- Fleet average, bin standards:
  - NMOG+NOx are fleet average standards: each vehicle certified to a per-vehicle “bin” standard and values are sales weighted to calculate fleet-average emissions.
  - Bin structure allows manufacturers flexibility, provides motivation for marketing of significantly cleaner vehicles.

- PM is a per-vehicle limit:
  - Phased-in as a % of new vehicle sales.
  - Final Tier 3 limit is 3 mg/mi (1.9 mg/km) in 2022, LEV III includes additional phase-in period to 1 mg/mi (0.6 mg/km).

<table>
<thead>
<tr>
<th>Tier 3 NMOG+NOx (mg/mi)</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025+</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDV &amp; LDT1</td>
<td>86</td>
<td>79</td>
<td>72</td>
<td>65</td>
<td>58</td>
<td>51</td>
<td>44</td>
<td>37</td>
<td>30</td>
</tr>
<tr>
<td>LDT2, 3,4 &amp; MDPV</td>
<td>101</td>
<td>92</td>
<td>83</td>
<td>74</td>
<td>65</td>
<td>56</td>
<td>47</td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tier 3 PM (mg/mi)</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase-in (%)</td>
<td>20%</td>
<td>20%</td>
<td>40%</td>
<td>70%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>FTP certification (mg/mi)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>FTP In-use (mg/mi)</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>
US and European standards are not equivalent

- Very little change from Euro 3 to 6 in exhaust emissions. Evaporative emissions go down for Euro 6 gasoline vehicles.
- Diesel emissions might decline as WLTC and Real Driving Emissions (RDE) are incorporated into Euro 6.
- Different test cycle complicate comparison: NEDC is a little stronger for gasoline vehicles (cold start is more important) but weaker for diesels (higher loads are more important). WLTP is more similar to FTP.
- US Tier 2 and 3 standards are fleet average standards, whereas Euro 6 is based on maximum limits. Current NOM 042 standards also set maximum value limits, which do not provide incentive to introduce cleaner models.
Test cycle makes a difference in stringency

- Lack of aggressive driving and high load conditions make NEDC particularly weak for diesel vehicles.
- In contrast, the high apportionment of cold start makes it a more stringent cycle for gasoline vehicles.

Values for ARB LEV and EPA Tier programs are fleet average values; Euro program values are max-per-vehicle values.

Only LEV III and Tier 3 have set NMOG+NOx standards; all other “standards” presented here are the summation of independent NOx Standards and NMHC or NMOG.
Useful Life of Emissions Control Systems

- **Useful Life (years)**
- **Useful Life (km)**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Useful Life (years)</th>
<th>Useful Life (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro 4, 5, 6</td>
<td>2</td>
<td>150,000</td>
</tr>
<tr>
<td>Tier 2/ LEV II</td>
<td>14</td>
<td>300,000</td>
</tr>
<tr>
<td>Tier 3/ LEV III</td>
<td>16</td>
<td>300,000</td>
</tr>
</tbody>
</table>
Real NO\textsubscript{x} emissions of Euro 6 diesel cars are on average 7 times higher than allowed limit

On-road emission results, by vehicle

Average NO\textsubscript{x} [g/km]

Average CO\textsubscript{2} (as % of type-approval [g/km])

Above type-approval
Below or equal to type-approval
Above Euro 5 limit
Above Euro 6, below Euro 5 limit
Below Euro 6 limit

Euro 5 limit
Euro 6 limit

15 test vehicles in total (6 manufacturers), with different NO\textsubscript{x} control technologies:
- 10 selective catalytic reduction (SCR)
- 4 exhaust gas recirculation (EGR)
- 1 lean NO\textsubscript{x} trap (LNT)

Average Euro 6 NO\textsubscript{x} conformity factors (ratio of on-road emissions to legal limits):
- all cars: 7.1
- best performer (Vehicle C, SCR): 1.0
- bad performer (Vehicle H, LNT): 24.3
- worst performer (Vehicle L, SCR): 25.4

http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars
Passenger vehicle GHG standards

- Mexico 2016: 145
- Brazil 2017: 138
- Japan 2020: 122
- China 2020: 117
- India 2021: 113
- S. Korea 2020: 97
- EU 2021: 95
- US 2025: 97
- Canada 2025: 97

- Historical performance
- Enacted targets
- Proposed targets or targets under study
GHG standards

- Standard stringency
  - Similar stringency for both passenger cars and light trucks, standards are similarly split

- US standards
  - Annual fleet average standards with banking of credits and debits, ensure ongoing fleet improvement while allowing flexibility in compliance
  - Footprint-based standards allow for GHG reductions/efficiency improvement due to weight reductions
  - Rigorous testing requirements, more comprehensive test cycles, and real compliance enforcement

- European standards
  - Standards are 4 years ahead of US standards
  - Fewer light trucks result in better overall fleet average
  - Higher share of diesels further increase fuel economy
In-Use Emissions
Compliance and Enforcement

- **Pre-production testing**: Certificate of Conformity
  - Conformity tests about 10% of vehicles
  - Selective Enforcement Audit + Confirmatory Road Load Testing

- **In-use verification**: Test on random sample
  - Confirmatory Road Load Testing
  - In-use surveillance random / selected sample

Vehicle design and build 0 km

0 km → 50,000 km → 100,000 km

BMW to fix fuel economy labels on Mini Coopers after U.S. EPA test

U.S. Fines Hyundai, Kia for Fuel Claims
Penalty of $300 Million Is Largest Ever, Could Set Pricey Precedent for Other Auto Makers

[Link to article](http://www.theicct.org/blogs/staff/bought-tiger-got-hello-kitty-how-fix-vehicle-fuel-economy-fraud-china)
$\text{NO}_x$ emissions of Euro 6 diesel cars higher than the Euro 3 limit value

Diesel cars: Nitrogen oxides ($\text{NO}_x$) emissions (in g/km)

- **Euro 3**
  - 2000
  - On-road measured value (Carslaw, 2011) / (ICCT, 2014)

- **Euro 4**
  - 2005
  - Euro emission limit

- **Euro 5**
  - 2009
  - 0.18

- **Euro 6**
  - 2014
  - 0.08

http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars
Real-world fuel consumption of new cars in EU is about 30+% higher than claimed by manufacturers

http://www.theicct.org/laboratory-road-2014-update
The growing gap appears to be largely attributable to models being strongly optimized to the test cycle.
A growing gap means that only part of the expected fuel consumption/CO$_2$ reduction may be real
There are many ways to optimize vehicles for the laboratory testing:

- Disconnecting the alternator prevents the battery from charging, and reduces energy use.
- Carmakers can optimize the engine controls to reduce emissions.
- Careful lubrication and use of special lubricants help the car run more efficiently.
- Using higher gears can allow the engine to operate more efficiently than normal.
- Taping over indentations or protrusions on the body reduces aerodynamic drag.
- Altering wheel alignment reduces rolling resistance.
- Fitting special tyres with a lower rolling resistance.
- Overinflating the tyres reduces rolling resistance.
- Pushing the brake pads fully into the callipers reduces rolling resistance.
- The rolling road is programmed with the minimum weight or inertia class.
- Laboratory instrumentation.
- Optimising the test drive & Ambient conditions.
- Taking advantage of test tolerances and Adjusting the results Header.
- CO₂ results declared by the manufacturer can be up to 4% below the actual test results.
Vehicle inspection

- **European Union**
  - Requires periodic inspection of all vehicles and trailers at regular intervals
  - Allows for unannounced roadside inspections of commercial vehicles in any EU country, regardless of place of registration
  - Sets standards for implementation
  - Member states are responsible for implementation

- **United States**
  - Clean Air Act requires I/M for certain regions, based on air quality, population and location
  - Sets standards for implementation and QA/QC
  - States are responsible for I/M implementation
  - State programs may include tailpipe emissions tests (idle, acceleration, etc) and/or OBD tests for MY1996+, along with visual checks, evaporative emissions tests (primarily gas cap)
  - Mostly focus on gasoline vehicles, set cutpoints, frequency, and MY requirements by state
Widely used in US and Europe

- US OBDII and EU EOBD Systems are very different, with different software and hardware requirements
- EOBD systems: Euro 5 communication compliant with ISO 15031-5
  Euro 6 communication compliant with ISO 15765-4
- OBDII systems are complaint with ISO 15765-4

Ensuring proper implementation

- Provisions (like those to be discussed by ARB) are critical to guard against cheating are critical to ensure effectiveness of programs
- Also need requirements in place for reporting of defects, doing field fixes and implementing running changes

OBD appears to be a relatively robust tool for controlling emissions from vehicles in use, if proper safeguards and procedures are in place
Remote sensing

- Programs are widespread in Europe and U.S.
- Useful tool for monitoring mean on-road fleet emissions
  - Ensure that new vehicle standards are operating as intended
  - Ensuring the effectiveness of I/M programs, including guarding against corruption in test centers
  - Can be used to better calibrate emissions modeling
- Challenging to use results for enforcement or to replace I/M
  - Requires a mandate to repair/further inspect identified high emitters
  - Clean screen can reduce the burden of I/M programs
Remote sensing: OBD effective
Remote sensing: high diesel NOx emissions

Fig. 4. Mean hot NOx emission factors of gasoline (left) and diesel (right) passenger cars and light commercial vehicles as a function of model year. Whiskers represent the 95% confidence interval over the mean. Added are the type approval limit values for Euro 1 to Euro 5 passenger cars over the homologation test cycle in force in the respective year. For conversion from limit values in g per km see SI (using measured fuel consumption rates from Hausberger (2010)). For color plot consult online version.
Low Emission Zones

- **Definition:** designated geographic areas within which certain categories of vehicles – usually the highest-emitting vehicles in a fleet – are restricted from operating.
  - Outright ban of certain class of vehicles or emission standard
  - Ban during certain times of the day
- LEZs are very popular in Europe and China, not in the U.S.
- Labeling is a strong complementary policy to LEZ
  - Generally based on original certification level, with retrofit option if available

<table>
<thead>
<tr>
<th>Emission groups</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stickers</strong></td>
<td>no sticker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Requirements for diesel engines</strong></td>
<td>Euro 1 or worse</td>
<td>Euro 2 or Euro 1 + particulate filter</td>
<td>Euro 3 or Euro 2 + particulate filter</td>
<td>Euro 4 or Euro 3 + particulate filter</td>
</tr>
<tr>
<td><strong>Requirements for petrol engines</strong></td>
<td>Without a reg. cat according to Ann. XXIII StVZO</td>
<td></td>
<td></td>
<td>Without a reg. cat according to Ann. XXIII StVZO or. Euro 1 or better</td>
</tr>
</tbody>
</table>

- Clearly specified timelines for implementation with increasing stringency
- Effective enforcement with appropriate penalties to deter non-compliance
  - “Appropriate” varies by region. In Italy, equal to a parking ticket (70 Euros). In Denmark, equal to the cost of a DPF (10,000 Euros).
Low Emission Zones – selected results

<table>
<thead>
<tr>
<th>City / Region</th>
<th>Year of LEZ Introduction / Measurement</th>
<th>Indicator</th>
</tr>
</thead>
</table>
| Berlin        | 2008 / 2009                            | -24% diesel PM  
               |                                        | -8% overall PM$_{10}$ |
| Munich        | 2006-7 / 2008 / 2009-10                | -60% transport contribution  
               |                                        | from 1.1 to 0.5 µg/m³ elemental carbon$^{18}$ |
| Netherlands – 9 cities | 2007 / 2008                        | up to 2µg/m³ PM reduction |
| London        | 2008 / 2008-2012                       | -5.8% PM$_{10}$  
               |                                        | -13% average annual PM$_{10}$ concentration$^{19}$ |
| Cologne       | 2008                                  | 4µg/m³ PM$_{10}$ reduction  
               |                                        | 1.2µg/m³ NO$_2$ reduction |
| Stockholm     | 1996 / 2000                            | -60% PM$_{10}$  
               |                                        | -20% NO$_x$ |
| Milan – emission-based congestion charge | 2011 / 2012                        | -19% PM$_{10}$$^{20}$  
               |                                        | -14% NO$_x$  
               |                                        | -15% CO$_2$ |
Conclusions

- Compliance and enforcement is the most critical aspect of all regulations and the key to success of US and CA policies.

- US/CA programs are both more complex and more rigorous while providing more flexibilities to manufacturers:
  - Bin system encourages manufacturers to design and market increasingly clean vehicles.
  - Footprint-based GHG standards reward weight reduction.
  - Enforcement is a real threat, standards are very detailed to eliminate loopholes.
  - OBD enforcement mechanisms both reduce ability to cheat and increase information to regulators (defect reporting requirements).

- European LEZs have been effective in reducing air pollution in key areas and accelerating fleet turnover.
Autoline interview with Oliver Schmidt, Powertrain Development, VW