New Transportation Technologies for Reducing Climate Change Impacts and Air Pollution

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Guadalajara, México
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Goal of the ICCT is to dramatically reduce conventional pollutant and greenhouse gas emissions from all transportation sources in order to improve air quality and human health, and mitigate climate change.

Promotes best practices and comprehensive solutions to:
- Improve vehicle emissions and efficiency
- Increase fuel quality and sustainability of alternative fuels
- Reduce pollution from the in-use fleet, and
- Curtail emissions from international goods movement.

The Council is made up of leading regulators and experts from around the world.
Outline

- The problem
  - Greenhouse gas and conventional pollution
  - Vehicle impacts growing

- Applicable California regulations
  - Climate Solutions Act (AB 32)
  - Pavley (AB)
  - ZEV
  - Heavy-duty
  - Low carbon fuels

- Technology strategies
  - Coming to a car near you
  - Where do diesels fit in?
  - Advanced technologies, critical in the long term
Transportation is 41% of GHG Emissions

California’s Anthropogenic GHG Emissions 2002 (CO₂-equivalent)

- Transportation: 41%
- Electric Power: 20%
- Industrial: 23%
- Agriculture & Forestry: 8%
- Others: 8%

Total statewide inventory: ~ 500 MMTCO₂E

Source: March 2006 CAT Report, adapted from CEC, 2005
Transportation CO₂ Inventory

Forecast 2020 emissions at 78.7 MMT above 1990

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-road gasoline</td>
<td>110.0</td>
<td>163.7</td>
</tr>
<tr>
<td>On-road diesel</td>
<td>18.9</td>
<td>37.3</td>
</tr>
<tr>
<td>Off-road gasoline/diesel</td>
<td>20.1</td>
<td>15.3</td>
</tr>
<tr>
<td>Jet fuel</td>
<td>38.3</td>
<td>60.3</td>
</tr>
<tr>
<td>Other</td>
<td>21.5</td>
<td>10.9</td>
</tr>
<tr>
<td>Total</td>
<td>208.8</td>
<td>287.5</td>
</tr>
</tbody>
</table>

Source: California Climate Action Team
Other types of pollution too…

- In addition to GHGs (CO$_2$, CH$_4$, N$_2$O, HFCs), vehicles are a source of:
  - Particulate matter (PM$_{10}$, PM$_{2.5}$, and ultrafine particles)
  - Ozone (smog) precursors (NO$_x$ and HC)
  - Other pollutants of concern to health and the environment (CO, SO$_2$, NO$_x$, toxics, carcinogens, etc.)

- Black particles and ozone are important both from a health and climate perspective
  - No evidence of a threshold for mortality impacts of PM—benefits continue to accrue even at the lowest levels
  - Together, soot (from fossil fuels) and ozone (non-methane) have about 1/4 the warming potential of CO$_2$
  - Reduction of black carbon may be one of the most effective near-term climate change mitigation measure
Importance of Non-CO$_2$ Pollutants

Effective Climate Forcings (W/m$^2$): 1750-2000

- CO$_2$: 1.5±0.2
- Other GHGs: 1.2±0.3
- CH$_4$: 0.4±0.2
- N$_2$O: 0.6±0.3
- O$_3$: Reflective Aerosols
- Black Carbon: Forced Cloud Changes
- Land Cover Change: -0.15±0.2
- Sun: 0.3±0.2

Units are watts per square meter alteration in global-average atmospheric radiation flow.

Source: Hansen et al., JGR, 110, D18104, 2005.
“It is probably implausible to keep additional global warming less than 1 degree celsius unless non-CO2 forcings are addressed aggressively,” (1)

“IT is the non-CO2 GHGs that have caused the most observed global warming,” (2)

Atmospheric Solar Heating by Black Carbon

More cars, traveling further

California VMT, 1972-2007

*Preliminary data for 2007
No metric given for data set, assuming ‘000 miles

Source: Caltrans, Traffic Data Branch, http://traffic-counts.dot.ca.gov/
Fuel Economy Not Improving

EPA Adjusted Fuel Economy by Make for All Vehicles, 1975-2007

Vehicle Weight Increasing

Inertial Weight by Maker for All Vehicles, 1975-20

Engine Size Displacement Increasing

Engine Size by Maker for All Vehicles, 1975-2007

California Takes on Climate Change

“I say the debate is over. We know the science. We see the threat. And we know the time for action is now.”

Governor Schwarzenegger
June 1, 2005 on UN World Environment Day

Statewide GHG Targets:
By 2010, Reduce to 2000 Emission Levels
By 2020, Reduce to 1990 Emission Levels
By 2050, Reduce to 80% Below 1990 Levels
California’s Global Warming Targets

- Global Warming Solutions Act (AB 32) sets an ambitious cap to return GHG emissions to 1990 levels by 2020 (estimated 29% reduction in emissions)

- Governor’s Climate Action Plan also has a longer-term target of 80% reduction by 2050

- California also has goal of displacing 20% of on-road transportation petroleum fuels with alternative fuels by 2020.
Key Transportation Strategies to Meet Targets

- **Cleaner Cars and Trucks**
  - Current CO2 emission standards for passenger vehicles (AB 1493/Pavely)
    - 30% reduction by 2016 (current under AB 1493)
    - 50% reduction, goal for 2020
  - Heavy Duty Truck programs (anti-idling and retrofits)
  - Zero Emission Vehicle (ZEV) requirements continue to play an important role

- **Reduction in Travel Demand (private cars)**
  - Some bond money can be spent to reduce car use:
    - 7% reduction by 2020
    - 20% reduction by 2050

- **Reducing Carbon in Fuels**
  - Low-Carbon Fuel Standard to reduce GHG emissions per unit of fuel
    - 10% reduction in carbon intensity by 2020
    - 75% reduction by 2050
Key Strategies for California: Cleaner Cars, Reduce Driving, & Low-Carbon Fuels

Passenger Vehicles CO₂ Emissions

- Baseline
- 1493 Vehicle Stds
- VMT Reduction
- Low-Carbon Fuel Std
California Vehicle GHG Standards

- Paveley Standards or AB 1493
- GHG standards for new passenger vehicles (adopted 2004)
  - 2009+ models
  - Phased-in over 6 years
    - 20% lower by 2012
    - 30% lower by 2016
- Feasible and economic
  - Off-the-shelf technologies applied widely
  - <5 year payback to owner in fuel savings (assumed $1.75/gallon)
Design Elements

- Vehicle category-based (or two-stepped weight-based) corporate average GHG emissions standard
- Greenhouse gases emitted by motor vehicles include:
  - CO₂, CH₄ and N₂O emissions resulting directly from operation of the vehicle,
  - CO₂ emissions resulting from operating the air conditioning system,
  - HFC (refrigerant) emissions from the air conditioning system due to either leakage, losses during recharging, or release from scrappage of the vehicle at end of life, and
  - Upstream emissions associated with the production of the fuel used by the vehicle.
- Allows non-tailpipe emission reduction technologies, such as improved air conditioning system.
Current Status

- Legal Status: Over EPA-staff objections, the federal government recently denied California’s waiver application.
  - California has challenged federal waiver denial in court.
  - A federal court has determined that the California program is not pre-empted by federal law.

- Eleven additional states have adopted this program and 6 more are considering it.
  - These state programs are also on hold pending the outcome of the waiver dispute.
Global Standards

The graph shows the CO₂ equivalent g/km converted to NEDC test cycle for various countries from 2002 to 2018. The countries represented include the United States, Australia, Canada, China, California, South Korea, and Japan. The graph indicates a trend of decreasing CO₂ emissions over time.
Average Improvement

- Japan: 19.0% average improvement 2004-2015 km/L JC 08
- EU: 18.2% average improvement 2007-2012 g CO2/km NEDC
- US LT: 7.5% average improvement 2005-2011 mpg CAFE
- US All: 26.3% average improvement 2011-2020 mpg CAFE
- CA: 30.0% average improvement 2009-2016 g CO2-eq/mi CAFE
- China: 12% average improvement 2002-2009 L/100-km NEDC
## Comparison for California
(California Air Resources Board, Feb 2008)

<table>
<thead>
<tr>
<th>Calendar Year</th>
<th>GHG Emissions Reduced*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>California GHG standard</td>
</tr>
<tr>
<td>2016</td>
<td>16.4</td>
</tr>
<tr>
<td>2020</td>
<td>31.7</td>
</tr>
</tbody>
</table>

*MMT CO₂ E/year
## Influence of Vehicle Weight and Engine Size

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Mass (kg)*</td>
<td>1245</td>
<td>1334</td>
<td>1769</td>
</tr>
<tr>
<td>Engine Size (liter)</td>
<td>1.5</td>
<td>1.7</td>
<td>3.4</td>
</tr>
<tr>
<td>CAFE mpg</td>
<td>39.3</td>
<td>40</td>
<td>24.7</td>
</tr>
<tr>
<td>NEDC CO₂/km</td>
<td>152</td>
<td>161</td>
<td>254</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Representative Cars</th>
<th>Honda Fit M5, Petrol, 1.5 L</th>
<th>Fiat Sedici M5, Petrol, 1.6 L</th>
<th>Fiat Doblo M5, Diesel, 1.9 L</th>
<th>Chrysler 300 Touring Ex A5, Petrol, 3.5 L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Mass (kg)</td>
<td>1215</td>
<td>1320</td>
<td>1320</td>
<td>1754</td>
</tr>
<tr>
<td>Engine Size (liter)</td>
<td>1.5</td>
<td>1.6</td>
<td>1.9</td>
<td>3.5</td>
</tr>
<tr>
<td>CAFE mpg</td>
<td>41.2</td>
<td>35</td>
<td>44.5</td>
<td>23.4</td>
</tr>
<tr>
<td>NEDC CO₂/km</td>
<td>145</td>
<td>173</td>
<td>153</td>
<td>269</td>
</tr>
</tbody>
</table>

*Vehicle mass is defined as the mass of vehicle in running order, which is an unladen vehicle with bodywork (plus a coupling device in the case of a towing vehicle) including coolant, oils, fuel tank filled to 90%, tools, a spare wheel, and a driver at 75 kg.
California ZEV Program

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Quantity on the road</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZEV</td>
<td></td>
</tr>
<tr>
<td>Fuel cell</td>
<td>160</td>
</tr>
<tr>
<td>Battery electric</td>
<td>4,400</td>
</tr>
<tr>
<td>Neighborhood electric</td>
<td>26,000</td>
</tr>
<tr>
<td>AT PZEV</td>
<td></td>
</tr>
<tr>
<td>Hybrid/CNG</td>
<td>109,000</td>
</tr>
<tr>
<td>PZEV</td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>672,000</td>
</tr>
</tbody>
</table>

- Lifetime emissions (VOC+NOx) for Partial Zero Emission Vehicles

<table>
<thead>
<tr>
<th>Model Year</th>
<th>VOC + NOx (kg)</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>1900</td>
<td>--</td>
</tr>
<tr>
<td>2005 ‘PZEV’</td>
<td>8</td>
<td>99.6%</td>
</tr>
</tbody>
</table>
ZEV - Status

- Goals
  - Drives of development of ZEVs
  - Supports bridging technologies like Hybrids
  - Maximizes air quality benefits with PZEVs

- Status
  - Implementation began 2005 model year
  - PZEVs marketed by all automakers subject to the regulation, 425,000 PZEVs sold to date
  - Hybrids very successful in the marketplace, 70,000 AT PZEV hybrids sold to date
  - 100 Fuel cell vehicles being placed in California in real world demonstration fleets
Zero Emission Bus Regulation

- Hydrogen-fuel cell, electric trolley, battery electric bus, or combination of the above technologies
- ZBus purchase requirements (also delayed)
  - Diesel path
    - Agencies with > 200 buses
    - Based on number of buses January 1, 2007
    - 15% 2008-2015
  - Alternative-Fuel path
    - Agencies with > 200 buses
    - Based on number of buses January 1, 2009
    - 15% 2010-2015
Shifting Transportation Demand

- Link funding for infrastructure planning & development to Smart Growth
- More accurate pricing for driving to cut carbon, pollution, and congestion
  - Pay-as-You-Go Insurance
  - Congestion Charges
  - Fuel taxes indexed to GHG & vehicle miles

Source: AC Transit
Lower Carbon Fuels

- California’s Low Carbon Fuel Standard:
  - 10% reduction in transportation fuel carbon intensity by 2020
  - Early action measures for adoption in 2008
  - Full fuel cycle, CO$_2$-eq/btu
  - Performance-based
  - Requirement on refiners, producers, blenders and importers of transportation fuels
Alternative Fuel Policy

- Major initiatives in late 1980s
- Rationale - Need to reduce emissions from mobile sources (concern for public health)
- Other drivers included reduced dependence on petroleum, fuel security and diversity
- Expectation that alternative fuels can lead to greater emissions reduction than gasoline or diesel
Non-Petroleum Fuels

- CA has been a pioneer in alternative fuels
  - Methanol (M85)
  - Electricity
  - Natural gas

- Looking to the future
  - Ethanol (E85)
  - Plug-in hybrid electric vehicles
  - Hydrogen fuel cell vehicles
Ethanol (E85)

- Flexible fuel vehicles
  - Can use E85 or gasoline
  - Over 300,000 flexible fuel vehicles operating in CA
  - 1 E85 fueling station

- E85 (85% Ethanol, 15% gasoline)
  - Better for air quality than low percentage blends
  - Lower GHG impact even with corn-based ethanol (not including land use impacts)
  - Cellulosic or other very low GHG ethanol is the goal
Energy Density of Fuels

Mega Joules per Meter $^3$

- Diesel: 39
- F-T Diesel: 37
- Gasoline: 34
- Propane: 25
- LNG: 24
- Ethanol: 22
- Methanol: 18
- Liquid H$_2$: 10
- CNG (@ 3626 psi): 10
- Compressed Hydrogen (@ 3626 psi): 3
- NiMH Battery: 1

Diesel Fuel

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION
## Technology Trends

### Powertrain Characteristics of US Passenger Cars
(percentage basis)

<table>
<thead>
<tr>
<th>Model Year</th>
<th>Sales Fraction</th>
<th>MPG (adj)</th>
<th>Engine</th>
<th>Energy Efficiency Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Displ.</td>
<td>HP</td>
<td>CVT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Port Fuel Injection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Variable Valve Timing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Diesel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hybrid</td>
</tr>
<tr>
<td>1975</td>
<td>.806</td>
<td>13.5</td>
<td>288</td>
<td>136</td>
</tr>
<tr>
<td>1985</td>
<td>.746</td>
<td>23.0</td>
<td>177</td>
<td>111</td>
</tr>
<tr>
<td>1995</td>
<td>.620</td>
<td>23.4</td>
<td>167</td>
<td>152</td>
</tr>
<tr>
<td>2000</td>
<td>.551</td>
<td>22.9</td>
<td>165</td>
<td>168</td>
</tr>
<tr>
<td>2005</td>
<td>.505</td>
<td>23.5</td>
<td>166</td>
<td>182</td>
</tr>
<tr>
<td>2007</td>
<td>.510</td>
<td>23.4</td>
<td>176</td>
<td>200</td>
</tr>
</tbody>
</table>

Available Technologies

Acura RSX

Variable valve timing and lift

Honda Accord

Toyota Matrix

* % CO₂ reduction
Available Technologies

Cylinder Deactivation

2005 Chrysler 300C Hemi

Audi TT 3.2 V6; A3

Automated Manual Transmission

* 6% CO₂ reduction, large car
Available Technologies

Gasoline Direct Injection w/dual cam phasers

Audi A4, VW Passat

BMW Valvetronic (continuously variable valve timing and lift)

5%

Volvo S60

Turbocharger

BMW 5 Series

8%

6%

* % CO₂ reduction
Emerging Technologies (2012-2016)

Integrated Starter/Generator

Homogeneous Combustion Compression Ignition

Chevrolet Silverado

Camless Valve Actuation

* 4% CO₂ reduction
Fuel Saving Measures: Demonstration Car

- Engine stop at idling (4%)
- Gearbox with long transmission (4%)
- Gearshift indicator (8%)
- Light weight seats (cuts 40 kg)
- Latent-heat storage
- Smooth under flow
- Cameras replace sideview mirrors (2%)
- Smooth covers & low rolling resistance tires (4%)

Source: Axel Friedrich, UBA
Range of advanced technologies

- Hybrids, diesels and electric vehicles were not considered in setting stringency of the CA GHG standards
  - Hybrids (20% to 50% benefit)
  - Diesels (~20% benefit)
  - Plug-in hybrids (possibly greater than 50% benefit)
  - Electric drive technologies will be critical in the longer term

- Advanced technologies for gasoline engines and non-propulsion improvements are also very promising
  - Direct injection and lean burn, combined with turbocharging and engine downsizing, for gasoline engines can achieve similar or greater benefits than diesels
  - Lightweighting gives an additional 20% GHG benefit with a 30% weight reduction
Passenger Car DPFs

Filtros (DPF) pueden controlar los emisiones de partículas de todos tamaños
Diesel Share of Car Markets in Europe 1980-1999

Source: ACEA, Eurostat/ECMT,AID/Industry Sources, 2000
Electric Vehicle Commercialization

Alternative HD Technologies

- **CNG**
  - Naturally cleaner fuel, technology in use since the 1980s.
  - Generally higher operating costs and maintenance requirements
  - CNG can have higher unregulated emissions than clean diesel including benzene, carbonyls, & PAHs (Deer 2003, Ayala 2003)

- **Compression Ignition Ethanol**
  - Low tailpipe emissions of NOx and PM, but ultrafine emissions unknown
  - Currently 500 buses in operation in Sweden, and fewer in Spain, Italy, Poland, China and Brazil
  - Similar configuration as diesel, with a minor changes in compression ratio, fuel injection, etc.
  - Sustainable fuel production critical (94% ethanol fuel)

- **Electric Trolley Bus**
  - Zero tailpipe emissions & much lower greenhouse gas emissions
  - Continue to operate in many cities around the world
  - Purchase price can be more than double, much higher infrastructure costs & operating costs vary

- **Fuel Cell**
  - Zero tailpipe emissions
  - Feasible but not yet commercial
  - Expensive: current incremental cost is US$ 2 million +
Improvements to Diesel Technology

- **Hybrids**
  - Reduction of direct CO\(_2\) emissions of \(\sim25\%\) (15-40%)
  - Incremental costs can be up to 50%

- **NOx aftertreatment (SCR) increases efficiency**
  - \(\sim85\%\) reduction in NOx emissions and reduction of CO\(_2\) emissions by \(\sim4\%\) (2-7%)
  - Low incremental costs, positive payback

- **DPF on new vehicles or retrofits**
  - 90-99% reduction in PM, reducing health and climate impacts of diesel
  - May have a small fuel economy penalty of \(\sim2\%\) (0-5%), somewhat reducing the overall CO\(_2\)-equivalent emissions reductions

- **Biodiesel**
  - Some reduction in PM but higher NOx emissions
  - Can be used in existing and new buses as a blend
  - Sustainability of fuel production is critical
Summary and Conclusions

- Air quality has improved substantially in California despite growth in population and vehicle miles traveled.
- Focus on public health impact of pollution has been key to sustained public and legislative support for strong environmental programs.
- Technology-forcing standards have worked.
- Incentive programs to remove older vehicles from the road have been successful in California.
Summary and Conclusions

- Regulatory programs should be based on sound science and set performance-based goals.
- A system approach for fuels and vehicles must be pursued.
- Technology-forcing standards provide the basis for the development of new and breakthrough technologies.
- Long term goals should be identified coupled with near, medium and long term actions.
- Zero emissions technologies should be the ultimate goal.
- Alternative fuels have been successful in providing competition to conventional fuels and producing cleaner burning gasoline and diesel.
- Fuel diversity is increasingly critical for energy security and diversity.