Transforming Transportation
Toward a Very Efficient, Low-Carbon Energy Future

...as seen by a policy wonk, regulator, and academic

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University of California, Davis
and
Board Member, California Air Resources Board

DOE Annual Merit Review
Arlington, VA

14 May 2012
Good news and bad news

Soaring Global Demand for Vehicles (and Oil)

Sperling and Gordon (2009), based on DOE, JAMA, other
WE MUST REDUCE OUR DEPENDENCY ON MID EAST OIL.
“Oil” Ain’t What it Used to Be (according to ExxonMobil)

Carbonization of Transportation Fuels

Supply “Curve” of World Hydrocarbon Resources

IEA, 2005
SPECIAL REPORT GLOBAL WARMING

BE WORRIED. BE VERY WORRIED.

Climate change isn’t some vague future problem—it’s already damaging the planet at an alarming pace. Here’s how it affects you, your kids and their kids as well

EARTH AT THE TIPPING POINT

HOW IT THREATENS YOUR HEALTH

HOW CHINA & INDIA CAN HELP

SAVE THE WORLD—OR DESTROY IT

THE CLIMATE CRUSADERS
“Greenhouse gas emissions and global warming are among humanity’s most pressing concerns. Societal expectations on climate change are real, and our industry is expected to take a leadership role.” (Jan 2012)
What does this mean for transportation?
IEA 2050 Global Scenario to Meet 450 ppm (2°C)

75% of energy for LDVs & urban trucks is biofuels, H2, electricity

IEA, 2012, provided by Lew Fulton
California (CARB) Scenario for LDVs to Achieve 60-80% Reduction in GHGs by 2050

CARB scenario (2) for light duty vehicles, to justify aggressive ZEV requirements
Transforming Transportation

- Transforming vehicles
- Transforming fuels
- Transforming mobility
Why gov’t initiative is needed (R&D and policy)

A Long List of Market “Failures”

- Environmental and energy externalities
- Principal agent problem (rental cars, truck trailers, company cars)
- Network externality. Complementary products requiring large non-recoverable investments and investments that cannot be made by individual consumers—such as when different vehicles or different infrastructures are required (H2, bike paths for biking, smart paratransit, etc)
- Technology lock-in
- Market power (cartels, oligopolies, etc)
- High entry barriers in auto industry
- R&D under-investment due to:
  - industry diffusion (ag industry)
  - R&D spillovers. When R&D findings cannot be fully captured (leading to under-investment in R&D)
  - Learning-by-doing spillovers where mfg savings not fully captured
- Consumer cognition (eg, buying cars), resulting in under-investment in efficiency (related to information and loss-aversion)
- Volatile oil prices create uncertainty which leads to under-investment in alternatives
1st Leg

The Motor Vehicle Revolution

Cars of future will be far more efficient and will be powered mostly by electric-drive

1) Vehicle efficiency improvements are far easier and less expensive than previously thought....
   Lightweight materials, transmissions, engines, hybridization

2) New evidence suggests that batteries and fuel cells will be far less expensive than previously thought

3) Trucks and planes are bigger challenges—modest increases in energy efficiency and dominant user of biofuels
Horsepower Race is Over!

1st Leg

Vehicles

Toyota RAV4, 2008

Ferrari 308 GTS, 1984

7.3 seconds from 0-60 mph

Tom Selleck as Magnum, PI
Vehicle Efficiency Improving Everywhere (doubling in US from 2010 to 2025)

[Diagram showing CO₂ emissions trends for different regions: US-LDV, California-LDV, Canada-LDV, EU, Japan, China, South Korea, and Australia. Each line represents historical performance, enacted targets, proposed targets, and unannounced proposals.]

[Notes: 1. China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower. 2. US and Canada light-duty vehicles include light commercial vehicles.]
Many Energy Efficient Technologies Are Being Commercialized—thanks to many in this room

<table>
<thead>
<tr>
<th>Vehicle system</th>
<th>Technology</th>
<th>Approximate GHG-per-mile reduction *</th>
<th>Percent U.S. adoption (MY2008) #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Variable valve timing</td>
<td>2-8%</td>
<td>53%</td>
</tr>
<tr>
<td></td>
<td>Cylinder deactivation</td>
<td>3-6%</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Turbocharging</td>
<td>2-5%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Gasoline direct injection (stoich. and lean)</td>
<td>10-15%</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Compression ignition diesel</td>
<td>15-40%</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>Digital valve actuation</td>
<td>5-10%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Homogeneous charge compression ignition</td>
<td>15-20%</td>
<td>0%</td>
</tr>
<tr>
<td>Transmission</td>
<td>5 speed</td>
<td>2-4%</td>
<td>32%</td>
</tr>
<tr>
<td></td>
<td>6+ speed</td>
<td>3-5%</td>
<td>21%</td>
</tr>
<tr>
<td></td>
<td>Continuously variable</td>
<td>4-6%</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Automated manual, dual clutch</td>
<td>4-8%</td>
<td>1%</td>
</tr>
<tr>
<td>Overall vehicle</td>
<td>Lightweight</td>
<td>10-20%</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Aerodynamics</td>
<td>5-8%</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Tire rolling resistance</td>
<td>2-8%</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Efficiency auxiliaries (steering, alternator, A/C)</td>
<td>2-10%</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Stop-start mild hybrid</td>
<td>5-7%</td>
<td>0.2%</td>
</tr>
<tr>
<td></td>
<td>Hybrid electric system</td>
<td>20-50%</td>
<td>2.2%</td>
</tr>
</tbody>
</table>

* Many technologies can be combined, but percents are not strictly additive; Estimations are based on NAS 2002 CAFE; US EPA/NHTSA, 2009; NESCCAF, 2004.  # From US EPA, 2009
Aggressive 2025 Stds Can Be Met with “Conventional” Vehicle Technology

(US/CARB Analysis of Technology Needed for Compliance)

<table>
<thead>
<tr>
<th>% change/yr GHG/CAFE</th>
<th>% Hybrids</th>
<th>% PEVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>4%</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>5%</td>
<td>43</td>
<td>1</td>
</tr>
</tbody>
</table>
Continuum of Electrification

ICE  Mild Hybrid  Full Hybrid  Short AER PHEV  Long AER PHEV  Full BEV  FCV

Potential for Disruption
PEVs and FCVs Poised for Commercial Success—Finally?!

Old Generation EVs/FCVs

New Generation PEVs/FCVs (w/strong industry support)

1st FCV

Volt

Leaf

FCV

E-scooter

GM EV1

Neighborhood EV
The Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil.

Sheikh Zaki Yamani, Saudi Arabian oil minister for 2+ decades

- Today: Transport is 94% dependent on oil
- Future: Diversity of Fuels
Many Promising Replacements
Some better than others...

-100 -50 0 50 100
Carbon Emissions Relative to Conventional Gasoline
Fuel *du jour* Phenomenon
Disruptive and wasteful

- 30 years ago – Synfuels (oil shale, coal)
- 25 years ago – Methanol and CNG
- 20 years ago – Electricity (Battery EVs)
- 10 years ago – Hydrogen (Fuel cells)
- 5 years ago – Ethanol
- Today – Electricity (again)
- *What’s next?*

GOVERNMENT POOR AT PICKING WINNERS …
NEED DURABLE POLICY (such as low carbon fuel standard)

The Hype Cycle
Gartner (2012)
All energy alternatives are difficult and face major barriers

- Biofuels
- Hydrogen and FCVs
- EVs
- CNG

And thus need flexible, performance-based, technology-forcing policy.
3rd Leg

Transforming Mobility (and Land Use)

In U.S. and abroad, we’ve created a transportation monoculture, with shrinking choices and increasing sprawl.

Many ways to provide equal accessibility at less cost—with less energy and GHG emissions
Americans Drive Much More than Others

Source: Millard-Ball and Schipper (2010).
Not all vehicle trips are “high value”!
Key Strategy: Innovation to Expand Traveler Choice

- Dynamic Ridesharing
- Smart Paratransit
- Carsharing
- Conventional Transit
- NEVs

NEW MOBILITY OPTIONS
Vehicle Transformation Is Fastest and Easiest
(in near and medium term in OECD countries)

- Vehicle technology: efficiency, electric-drive
- Decarbonize fuels: biofuels, electricity, hydrogen
- Mobility and land use

Most

Least

Feasibility

Quantity Reduced (oil, GHGs)
What does this all mean?

• Future is highly uncertain—for consumers, industry, and policymakers
  - BEVs or FCVs?
  - electricity and H2 (from NG) with CCS?
  - What type of PHEV will dominate? PHEV10, PHEV40, with NG or biofuels?
  - How much and what type of charging infrastructure?

→ Portfolio Approach—All of the Above!

→ Ramp up R&D (gov’t and industry)

→ Policy leadership with technology, fuels, VMT
  (doing fairly well with vehicles, but not fuels or VMT)
"We stand at a crossroads. One path leads to despair, the other to destruction. Let's hope we choose wisely."

Woody Allen

Headed into a painful century… but humans are incredibly creative. Eventually we will rise to the challenge—with leadership from all of you!

Thank You