Opportunities for Reducing Transportation’s Petroleum Use and Greenhouse Gas Emissions

John B. Heywood
Professor of Mechanical Engineering
Director, Sloan Automotive Laboratory
M.I.T.

Transportation @ MIT Seminar
September 22, 2009
Big Transportation Issues

1. We (at least in the U.S.) like the transportation we’ve now got (not surprisingly since it has had a long time to evolve).

2. Can our transportation system, and those in other developed countries, continue along their current path?

3. And, in the developing world, “the greatest wave of mass mobility is yet to come… a potential economic, health, and economic disaster on a global scale.”
What are the Major Mobility Challenges?


A. Ensure the emissions of transport-related conventional (air) pollutants do not constitute a significant public health concern anywhere in the world.

B. Limit transport-related greenhouse gas emissions to sustainable levels.

C. Significantly reduce the total number of vehicle-related deaths and serious injuries from current levels in both the developed and the developing world.
What are the Major Mobility Challenges? - Continued

D. Reduce transport-related noise.

E. Mitigate congestion

F. Narrow the “mobility opportunity divides” that inhibit inhabitants of the poorest countries, and members of economically and socially disadvantaged groups within nearly all countries, from achieving better lives for themselves and their families

G. Preserve and enhance mobility opportunities for the general population of both developed and developing-world countries.
What Has Happened Since?

1. WBCSD MIT Report, *Mobility 2001*, clearly defined the “unsustainable” aspects of transportation.

2. WBCSD Sustainable Mobility Project Report, *Mobility 2030*, gave integrated summary of opportunities and challenges.

4. Due to the magnitude and complexity of these challenges we need to develop feasible integrated strategies for moving forward, but we seem to be “stuck.”
Global Transport-related Well-to-Wheels CO₂ Emissions by Mode, 2000 - 2050

Source: Sustainable Mobility Project calculations.
U.S. Transportation Energy Consumption by Mode (2003 Data from Transportation Energy Data Book)

(28% of total U.S. energy consumption [103.6EJ])

By Source

<table>
<thead>
<tr>
<th>Source</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum</td>
<td>96.5%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>2.6%</td>
</tr>
<tr>
<td>Biomass/Other</td>
<td>0.8%</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.1%</td>
</tr>
</tbody>
</table>
Focus on Transportation’s Fuel Consumption and GHG Emissions: Cars and Light Trucks

Examine these targets* for new vehicle sales mix:

In 2016: 25% reduction (e.g. U.S. CAFE)
In 2035: 50% reduction (e.g. match Europe)
In 2050: ~ 80% reduction (IPCC target for 550 ppm CO₂ in atmosphere)

*Relative to today’s values.
Issued a Series of Reports

ON THE ROAD IN 2020
A life-cycle analysis of new automobile technologies
Malcolm A. Weiss, John B. Heywood, Elisabeth M. Drake, Andreas Schaefer, and Felix F. AuYeung

Energy Laboratory Report # MIT EL 00-003
Energy Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139-4307
October 2000

On the Road in 2035
Reducing Transportation’s Petroleum Consumption and GHG Emissions
Amp Bandtredeker
Kristen Bedik
Lynette Cheah
Christopher Evans
Tiffany Groode
John Heywood
Emmanuel Kasseri
Matthias Kerrey
Malcolm Weiss

An Action Plan for Cars
The Policies Needed to Reduce U.S. Petroleum Consumption and GHG Emissions
John Heywood
Patricia Baptista
Irène Berry
Kandarp Bhatt
Lynette Cheah
Fernando de Sisternes
Valerie Karplus
David Keith
Michael Khusid
Donald Mackenzie
Jeff McAslan

MIT Energy Initiative Report No. 2009-01 RP
September 2009
GHG emissions of the avg new vehicle in US and EU

Notes:
• For US, unadjusted NHTSA fuel economy numbers used
• US CAFE target = 35 mpg by 2020; US factor of 2 target = Halve 2006 FC by 2035
• Conversion factor = 8,788 gCO2 per gallon gasoline (EPA 2005)
• For EU, historical data for EU-15 passenger cars shown (European Commission 2006)
• Lower EC target in 2012 (120 gCO2/km) includes use of biofuels
Factors that Reduce Vehicle Fuel Consumption

1. More efficient propulsion systems
   - Improved gasoline engines, turbo gasoline engines, diesel
   - Hybrids, plug-in hybrids
   - Battery electric vehicles, fuel cells (hydrogen)

2. Lighter (less heavy) vehicles
   - Substitute lighter materials
   - Vehicle redesign
   - Shift size mix downward (U.S.: Cars vs. Light Trucks)

3. Improved efficiency: fuel consumption/performance/weight trade-off
   - Emphasis on reducing fuel consumption (ERFC)

4. The aggregate new vehicle sales mix
Relative fuel consumption of future cars, by powertrain (at 100% ERFC)

- N.A. gasoline (reference)
- Turbocharged gasoline
- Diesel
- Hybrid-electric gasoline
- Plug-in hybrid
Fuel consumption vs. curb weight for MY2005 vehicles
A critical question is the extent to which the benefits of more efficient technologies go to reduce actual fuel consumption.

Quantify this with degree of emphasis on reducing fuel consumption (ERFC).

\[
ERFC = \frac{\text{Fuel consumption (FC) reduction realized}}{\text{FC reduction attainable with constant performance and size}}
\]
Trade-Off Between Acceleration and Fuel Consumption

![Graph showing the trade-off between acceleration and fuel consumption for different vehicle models and ERFC levels.](image-url)
Illustrative Example for U.S.: Many Technology Scenario

% of new car sales

Year


Conventional Gasoline

37.5%

25% Turbo Gasoline

7.5% Plug-In Hybrids

15% Gasoline Hybrids

15% Diesels

0%
Light-Duty Vehicle Fuel Use (in Billion Liters of gasoline equivalent per year)

No Change
Reference (50% ERFC)

Market Mix

2035 Advanced Technology Market Share (50% ERFC)

- Turbo Gasoline Engines: 25%
- Diesels: 15%
- Gasoline Hybrids: 15%
- Plug-In Hybrids: 7.5%

Note: Assumes 0.5% - 0.1% VKT/veh per year growth and 0.8% per year sales growth
Alternative Fuel Impacts:
Oil Sands and Ethanol Scenario

Fuel Mix in 2035 (percentages on energy basis)
- Non-Conventional Oil: 10%
- Corn Ethanol: 7%
- Cellulosic Ethanol: 7%

Net Change in GHG:
- Cellulosic Ethanol: -6.1%
- Corn Ethanol: -0.7%
- Reference: 0.0%
- Increase in GHG Emissions from Non-Conventional Oil: 1.2%

Change in Well-to-Wheel GHG Emissions (%)
-2.5% to 2.5%
-5.0% to 5.0%

Year
Examples of future vehicle scenarios

### New car curb weight (kg)

<table>
<thead>
<tr>
<th>Year</th>
<th>Baseline</th>
<th>Conservative</th>
<th>Optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>1,600</td>
<td>1,400</td>
<td>1,200</td>
</tr>
<tr>
<td>2000</td>
<td>1,200</td>
<td>1,000</td>
<td>800</td>
</tr>
<tr>
<td>2010</td>
<td>1,000</td>
<td>800</td>
<td>600</td>
</tr>
<tr>
<td>2020</td>
<td>800</td>
<td>600</td>
<td>400</td>
</tr>
<tr>
<td>2030</td>
<td>600</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>2040</td>
<td>400</td>
<td>200</td>
<td>0</td>
</tr>
</tbody>
</table>

### New vehicle fuel economy (MPG)

<table>
<thead>
<tr>
<th>Year</th>
<th>Baseline</th>
<th>Conservative</th>
<th>Optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>2000</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>2010</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>2020</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>2030</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>2040</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

### % Veh. weight reduction

<table>
<thead>
<tr>
<th>Year</th>
<th>Optimistic</th>
<th>Conservative</th>
<th>Total adv. powertrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>17%</td>
<td>25%</td>
<td>48%</td>
</tr>
<tr>
<td>2035</td>
<td>25%</td>
<td>30%</td>
<td>64%</td>
</tr>
</tbody>
</table>

### % Sales mix by powertrains

<table>
<thead>
<tr>
<th>Year</th>
<th>Conv. gas</th>
<th>Turbo gas</th>
<th>Diesel</th>
<th>Hybrid</th>
<th>Plugin hybrid</th>
<th>Total adv. powertrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>52%</td>
<td>26%</td>
<td>7%</td>
<td>15%</td>
<td>0%</td>
<td>48%</td>
</tr>
<tr>
<td>2035</td>
<td>36%</td>
<td>26%</td>
<td>9%</td>
<td>20%</td>
<td>9%</td>
<td>64%</td>
</tr>
</tbody>
</table>

### % MPG increase from today

<table>
<thead>
<tr>
<th>Year</th>
<th>Optimistic</th>
<th>Conservative</th>
<th>Total adv. powertrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>+38%</td>
<td>+100%</td>
<td></td>
</tr>
<tr>
<td>2035</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

19

9/22/09
To meet Federal fuel economy standards, average new vehicle weight must decline by 15-25% by 2020. The resultant fleet fuel savings is significant, but takes time to realize.
Impact on Fuel Consumption of Modifying Standard Drive Cycles: PSAT Simulation Results
Over a drive cycle, consumption increases with average acceleration.

Cycles with modified accelerations

Scaled acceleration (from 50-200%) maintaining velocity

Roughly exponential relationship between acceleration and fuel consumption

Results over an entire drive cycle
When average velocity increases, the fuel consumption curve has a U-shape.
“An Action Plan for Cars”

A coordinated set of policies which will pull improved fuel consumption into the U.S. light-duty vehicle fleet:

1. Continue CAFE requirements beyond 2020
2. Impose a Feebate system at time of vehicle purchase
3. Increase Federal fuel taxes 10¢/gallon per year over 10- years
4. Develop fuel economy labeling and eco-driving education initiatives
5. Alternative fuels (non-conventional petroleum, biofuels, electricity…)
   - Full life-cycle (well-to-wheels) carbon accounting
   - Develop national alternative fuels strategic plan
   - Develop appropriate policy incentives to move that plan forward

(In the near-term we need to avoid picking the winners prematurely)
Oil Supply Scenario

1. Need for “prototype production” phase, with volumes in tens of thousands, which lasts 5-10 years.

2. Initial costs of these vehicles are significantly higher (e.g. currently HEV ~ $5,000, PHEV (30 mile range) ~ $10,000, BEV ~ $15,000 depending on range).

3. Long-term projections suggest these price differentials may reduce by factor of 2.

4. Impact of BEV range limitation on vehicles’ attractiveness is major uncertainty.
5. Many pragmatic issues:
   • Availability of recharging locations
   • Recharging power requirements for “fast recharge”
   • Cumulative impact on electricity grid over time
   • Battery performance, weight, and cost issues
   • Near-term: we need to slow down and develop the technology

7. Electricity as viable longer-term energy option?
   • Systems analysis of an evolving transportation electricity supply option needed
   • GHG emissions of future electric grid, and of electricity used in transportation, a major question
What will it take to reduce GHG Emissions 75%

1. Will require significant reduction in impacts in 5 to 10 separate independent areas: e.g., vehicle technology, alternative fuels, vehicle usage, etc.

2. Note that:
   \[ 0.8 \times 0.8 \times 0.8 \times 0.8 \times 0.8 \times 0.8 = 0.26 \]

3. Six independent factors each achieving a 20% reduction yield a 75% reduction.
Achieving a 70 - 80% Reduction in Transportation’s GHG Emissions by 2050

Meeting these 2050 GHG emission targets will need:

- Major improvements in powertrain and vehicle efficiency
- Major vehicle size and weight reduction
- Stronger emphasis on fuel consumption reduction over performance and other attributes
- Substantial build-up of alternative green (low CO₂) sources of transportation energy
- Reductions in mobility impacts through mode shifts and conservation
- Extensive management of transportation infrastructure and its several modes
- Changes in urban land-use patterns
- And other “transforming” changes
Three Important Energy and GHG Emissions Paths Forward

1. **Improve:** increase the fuel efficiency of mainstream transportation vehicles and develop alternative liquid hydrocarbon fuel sources which can displace petroleum and reduce GHG emissions.

2. **Conserve:** reduce the demand for energy intensive personal and freight transportation services.

3. **Transform:** shift transportation’s energy requirements (and propulsion technologies) to alternatives with much lower GHG emissions.