Technological Opportunities and Challenges to Achieving Sustainable Mobility

Stephen R. Connors
Analysis Group for Regional Energy Alternatives
Laboratory for Energy and the Environment
Massachusetts Institute of Technology
One Amherst St., Cambridge, MA 02139-4307, USA

Engines, Fuels, Feedstocks

• Engines and Power Trains
  › Internal Combustion
    (Spark Ignition, Compression Ignition)
  › Direct Energy Conversion
    (Electricity Production = Fuel Cells, PVs)
  › Degrees of “Hybridization”
    (Electric Assist, Electric “Drive Trains”)

• Feedstocks & Fuels/Energy Carriers
  › Fossil (Gasoline, Diesel, Nat.Gas, Propane)
  › Bio & Waste (Ethanol, Biodiesel, Food, etc.)
  › Common Carriers [Made from above plus others]
    (Electricity, Hydrogen, Methanol, etc.)
Coordinated Energy Carriers

- Hydrogen – Another Energy Carrier

What About Hydrogen?

- Pop Quiz...
  - Name for Me the Member Nations of OHEC

- Where Are You Getting Your Hydrogen Atoms?
  - Hydrocarbons (Nat.Gas, Oil, Coal?)
  - Carbohydrates (Biomass)
  - Di-hydrogen Oxide (Water)

- How Are You Freeing Them Up?
  - Electrolysis of Water with Electricity
  - Steam Reforming of Methane
  - Gasification of Biomass, Coal, etc.
  - Hydrogen Purification Issues
Hybrids, Diesels, etc.

• Where do the “efficiency savings” really come from?

Newer & Better Hybrids

• What’s New?
  (http://www.fueleconomy.gov/feg/hybrid_news.shtml)
Before A Transition to Hydrogen Transportation

• An AGS Energy Flagship Research Project
  » Lead Participants: MIT and PSI
• Focus:
  » Well-to-Wheels & LCA Performance of Various Light Duty Vehicles & Alt. Fuels
  » Commercial Viability and “Penetration” into Manufacturers Production Volume.
  » Sales and Penetration into (growing) “On Road” Vehicle Fleets
  » **Only Then** Can Impacts/Value of New Vehicle Technologies

Don’t Hold Your Breath...

• How Soon – Hybrids and Hydrogen Vehicles?

*Time Scales for New Vehicle Technologies to Affect US Transportation Energy Use*

<table>
<thead>
<tr>
<th>Implementation Phase</th>
<th>Vehicle Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gasoline Direct-Injection Spark-Ignition</td>
</tr>
<tr>
<td>Market competitive vehicle</td>
<td>~ 5 years</td>
</tr>
<tr>
<td>Panetration across new vehicle production</td>
<td>~ 10 years</td>
</tr>
<tr>
<td>Major fleet penetration</td>
<td>~ 10 years</td>
</tr>
<tr>
<td>Total time required</td>
<td>~ 20 years</td>
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Before “Distinctive Themes”

• Update and Expand Vehicle Analysis
  › Add battery EV, plug-in hybrids (adds electricity as “fuel”)
  › Improve the prediction of production increases for new techs.
  › Evaluate “marketability” of new vehicle technologies
  › Analyze stages of technology development and implementation
  › Combine analyses to evaluate a broader range of technology and production volume scenarios, including vehicle sizes/concepts

• Emphasize Fuel and Fleet Impacts, not Just Individual Vehicle Performance.
  › Bring well-to-tank and cradle-to-grave aspects to provide insights into USA and European fleet impacts of new LDVs.
  › Include assessment of potential contribution from non-conventional liquid fuels—tar sands, gas-to-liquid fuels, biomass-based fuels.
  › Evaluate alternative portfolios of government policies, and new technology costs and savings, are likely to affect the more plausible scenarios and their fleet impacts.

Baseline Fleet Penetration

From Bandivadekar and Heywood October 2005

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Baseline Fuel Consumption

Light-Duty Vehicle Fuel Use (in Billion Liters of gasoline equivalent)

- No Change: 827
- ICE Baseline: 688
- Advanced SI: 626
- Diesels: 594
- Hybrids: 554
- Fuel Cell Vehicles: 391

2035 Market Share:
- Advanced SI: 30%
- Diesels: 15%
- Gasoline Hybrids: 15%
- Hydrogen Fuel Cells: 5%

Note: 1 liter ~ 0.264 gallons
100 billion liters per year ~ 1.72 million barrels per day

Aggressive Hybrid and Diesel Scenario

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

- No Change: 827
- ICE Baseline: 688
- Advanced SI: 626
- Diesels: 594
- Hybrids: 554
- Fuel Cell Vehicles: 391

2035 Market Share:
- Advanced SI: 25%
- Diesels: 25%
- Gasoline Hybrids: 25%
- Hydrogen Fuel Cells: 5%
**Full Technological Reduction Potential**

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

- **No Change**: 827
- **Baseline Technology Mix**: 497
- **Advanced SI Diesels**: 543
- **Hybrids**: 554
- **Fuel Cell Vehicles**: 391

2035 Market Share:
- Advanced SI: 30%
- Diesels: 15%
- Gasoline Hybrids: 15%
- Hydrogen Fuel Cells: 5%

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**The Consequences of Delay (Baseline Scenario)**

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

- **No Change**: 827
- **Ten Year Delay**: 758
- **Five Year Delay**: 712
- **Peak Fuel Consumption in Year**
  - Base Technology Mix: 668 (2025)
  - Five Year Delay: 712 (2029)
  - Ten Year Delay: 758 (2035)
  - No Change: 827 (2035)

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Preliminary Lessons

- Reducing LDV fleet fuel consumption substantially below the “no change” continuing growth projection will be difficult and take decades!
- Realizing as much as possible of the efficiency improvements (especially with mainstream gasoline ICE vehicles) in on-the-road fuel consumption is critical.
- Delays in realizing such on-the-road fuel consumption improvements would be “bad”.
- Advanced gasoline and diesel ICEs, and hybrids have only modest fleet improvement potential before 2025.
- Fuel-cell hybrid fuel consumption impacts small, especially prior to 2035.
- Results depend on initial fleet composition, rate of change, and near-term vehicle improvements

Stuck in Traffic

- 2005 Urban Mobility Report (May05)
  › Texas Transportation Institute (mobility.tamu.edu)

1982–0.7 Billion Hrs 2003–3.7 Billion Hrs
Newton Rules!!!

- **Transportation is Different!**
  - Energy = Work
  - Work = Force x a Distance
  - Force = Mass x Acceleration

- **Can’t Get Around It**
  - Mass = Vehicle Size/Weight
  - Distance = Trip Length(s)
  - Acceleration = Driving Style, Congestion

Sir Isaac Newton (1642-1727)

Vehicle efficiency is just part of the story.

Distance & Driving “Style”

- How do they affect vehicle emissions?

- How far & on what type of roads?
  - Highways? Arteries? Side Streets?
  - How many Stop signs? Stop lights?

- How’s Traffic?
  - Free Flow (Steady State)?
  - Speed-up/Slow-Down?
    (At what average speed?)
  - Stop-and-Go?
    (Highway, Artery or Side Street?)
Magical Mobility Equation...

• Which Is the Most Important?
• Can Any Be Ignored?

The Demand for Transport

The Three “Ats” And in Between

• At Home
• At Work
• At Play

The Most Environmentally Responsible?

Having Fun Working at Home!
A Life-Cycle Perspective

But, Flows of People and Materials are Different

Those Material Flows are Significantly Different

AGS Knowledge & Insight

- Sustainable Mobility Research Must Focus On More Than Just Alternative Vehicles/Fuels
  - Personal Transportation Modes/Fleets (Road, Rail, Air)
  - Freight Modes/Fleets (Road, Rail, Ship, Air)
  - Transportation Networks, Modes, Capacity & Traffic

- Sustainable Solutions: Three Levels of “Feasibility”
  - Technical Feasibility (effective)
  - Economic Feasibility (affordable)
  - Political Feasibility (implementable)

- Insights Useful to Stakeholders, Decision Makers, Individual Consumers, etc.