Opportunities for Reducing Oil Demand for Transportation

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

NRC Workshop on Trends in Oil Supply and Demand
Washington, DC,
October 20, 21, 2005
Topics

1. Transportation energy demand in context
2. The technology for improving the fuel consumption of light-duty vehicles
3. Assessing future U.S. LDV fleet fuel consumption reduction opportunities
4. Some strategic conclusions
Projected total stock of light duty vehicles by region

Source: Mobility 2030, World Business Council for Sustainable Development Sustainability Project, 2004
Focus on energy, greenhouse gas and air pollutant emissions, and costs:

1. Well to tank
2. Tank to wheels
3. Cradle to grave

All three stages are significant in a total system accounting.
Two Important Paths Forward

1. Evolutionary Improvements
   - More efficient engines
     Gasoline ICE, diesel ICE, ICE hybrid
   - More efficient transmissions
   - Reductions in vehicle weight, drag, accessories

2. Radical Transitions
   - Fuels from tar sands, heavy oil, gas-to-liquids
   - Large-scale biofuels
   - Major vehicle weight and size reduction
   - Fuel cell propulsion systems and hydrogen
   - Electric vehicles and electricity
Technology Options in MIT Studies

1. Evolving mainstream technologies (baseline)
   • Vehicle: lighter conventional materials (e.g. high strength steel), lower drag
   • Gasoline engine: higher power/volume, improved efficiency, lighter weight
   • Transmission: more gears, automatic/manual, continuously variable

2. Advanced technologies
   • Vehicle: lightweight materials (e.g. aluminum, magnesium), lowest drag
   • Powertrain
     Hybrids (engine plus energy storage)
     Fuel cells (hydrogen fueled; liquid fueled with reformer)
   • Fuels: gasoline, diesel, natural gas, hydrogen
Gasoline Engine: Improvement Potential

- Friction reduction opportunities
- Synthetic lubricants for lower friction
- Smart cooling systems for reduced heat losses
- Variable valve timing and lift at full and part load
- Higher expansion ratio engines for increased efficiency
- Cylinder cut out at lighter loads
- Turbocharging and engine downsizing
- Variable compression ratio
- Gasoline Direct-Injection
- Effective lean NO_x catalysts; lean engine operation
- Further engine weight reduction
- Engine plus battery and electric motor in hybrid
- Etc.
Relative Consumption of Life-Cycle Energy and CO$_2$

- Total energy (LHV) from all sources consumed during vehicle lifetime
- Shown as percentage of baseline vehicle energy consumption
- Total energy includes vehicle operation and production of both vehicle and fuel

2001 REFERENCE: 137%
2020 BASELINE: 100%
GASOLINE ICE: 88%
GASOLINE ICE HYBRID: 64%
DIESEL ICE: 75%
DIESEL ICE HYBRID: 56%
HYDROGEN FC: 61/66%
HYDROGEN FC HYBRID: 52/56%
GASOLINE FC: 70/81%
GASOLINE FC HYBRID: 56/65%

Source: MIT 2003 Study
Technology Summary

1. Mainstream engines, transmissions, vehicles can be steadily improved over time to give a 35% fuel consumption reduction in new vehicles in about 20 years, at an extra cost per vehicle of $500-1000.

2. Hybrids can improve on this by 20-30 percent, at an additional cost of a few thousand dollars.

3. Prospects for the diesel in the U.S., attractive from a fuel consumption and CO₂ perspective, are uncertain due to the extremely stringent U.S. NOₓ and particulate standards, low U.S. fuel costs, and higher initial cost.
4. Fuel cell systems would result in more efficient vehicles than ICE-based technology. BUT the energy lost and CO$_2$ emissions released in producing hydrogen (from natural gas) are significant and result in no overall benefit.

5. If we need very low CO$_2$ emission transportation system in the longer term (~ 50 years), then fuel cells and hydrogen (from “non” CO$_2$ releasing sources) appear to be one of the potential options.

6. In the U.S., market demand for improving mainstream vehicle fuel consumption (at higher initial cost) has historically been low.
1. Technology must become market competitive in overall vehicle performance, convenience, and cost

2. Then technology must penetrate across new vehicle production to significant (more than 35%) level

3. Then need substantial in-use fleet penetration; more than 35% mileage driven
### Time Scales for Significant U.S. Fleet Impact

<table>
<thead>
<tr>
<th>Implementation Stage</th>
<th>Gasoline DI Spark-Ignition Boosted Downsized Engine</th>
<th>High Speed DI Diesel with Particulate Trap, NOx Catalyst</th>
<th>Gasoline SI Engine/Battery-Motor Hybrid</th>
<th>Fuel Cell Hybrid Vehicle On board Hydrogen Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Market competitive vehicle</strong></td>
<td>~ 5 years</td>
<td>~ 5 years</td>
<td>~ 5 years</td>
<td>~ 15 years</td>
</tr>
<tr>
<td><strong>Penetration across new vehicle production</strong></td>
<td>~ 10 years</td>
<td>~ 15 years</td>
<td>~ 20 years</td>
<td>~ 25 years</td>
</tr>
<tr>
<td><strong>Major fleet penetration</strong></td>
<td>~ 10 years</td>
<td>~ 10 - 15 years</td>
<td>~ 10 – 15 years</td>
<td>~ 20 years</td>
</tr>
<tr>
<td><strong>Total time required</strong></td>
<td>~ 20 years</td>
<td>~ 30 years</td>
<td>~ 35 years</td>
<td>~ 55 years</td>
</tr>
</tbody>
</table>
U.S. Light Duty Fleet Impacts

• Fleet Characteristics
  – Vehicle scrappage rates & miles driven per year will follow historical trends
  – New vehicle sales will grow 0.8% per year
  – Light truck sales will rise to ~ 60% from current level of ~ 50%
  – New technology fuel consumption benefits for cars and light trucks/SUVs are about the same
  – Average distance driven per vehicle will increase 0.5% per year
  – Median lifetime is 15 years
Improvement in Vehicle Fuel Consumption

![Graph showing relative fuel consumption over years for different vehicle types.]

- ICE SI Technological Potential
- SI Baseline
- Advanced SI
- Diesels
- Hybrids
Market Penetration Rates of New Technologies

- Advanced SI: 38.5%
- Gasoline Hybrids: 19.2%
- Diesels: 19.0%
- Fuel Cell Vehicles: 12.5%


Market Penetration (% of new car sales)
Light-Duty Vehicle Fleet Fuel Use

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

Year


Baseline Technology

No Change

Advanced SI

Diesels

Hybrids

Fuel Cell Vehicles

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

10/20&21/2005
Improvement in Vehicle Fuel Consumption (Full Technological Potential)
LDV Fleet Fuel Use: Full Technological Reduction Potential

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

Year


2035 Market Share:

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

No Change

ICE Baseline

Advanced SI

Diesels

Hybrids

Fuel Cell Vehicles
Moderating growth in demand has big payoffs

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

No Change
ICE Baseline
Baseline Technology Mix
0% VKT Growth
0.4% Sales Growth

Note: Baseline assumes 0.5% VKT growth and 0.8% sales growth

2035 Market Share:
Advanced SI : 30%
Diesels : 15%
Gasoline Hybrids : 15%
Hydrogen Fuel Cells : 5%
1. Reducing LDV fleet fuel consumption substantially below the “no change” continuing growth projection will be difficult and take decades!

2. Realizing as much as possible of the efficiency improvements (especially with mainstream gasoline ICE vehicles) in on-the-road fuel consumption is critical.

3. Delays in realizing such on-the-road fuel consumption improvements would be “bad news.”

4. Advanced gasoline and diesel ICEs, and hybrids have only modest fleet improvement potential before 2025.
5. Fuel-cell hybrid potential for reducing fleet petroleum use before about 2035 is small (about 2% of projected base technology mix consumption)

6. Fleet fuel use reductions for a given technology depend on how much of its efficiency improvement potential is realized in actual on-the-road fuel consumption reduction. For the next 30 years (or longer) high volume use of better technology and reduced vehicle weight/size is critical.
Hydrocarbon fuels from tar sands, heavy oil, gas-to-liquids

Advanced biofuels: liquid, gaseous

Different vehicle concepts (reduced weight, size)

Hydrogen from renewables or fossil fuel with carbon sequestration, in IC engines and/or fuel cells

Electricity from renewables (also nuclear), with advanced battery electric vehicles
# Share of Life-Cycle Energy & GHG

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Energy, % of Total</th>
<th></th>
<th>GHG, % of Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 Reference</td>
<td>75</td>
<td>16</td>
<td>9</td>
<td>74</td>
</tr>
<tr>
<td>2020 Baseline</td>
<td>74</td>
<td>15</td>
<td>11</td>
<td>71</td>
</tr>
<tr>
<td>Gasoline ICE</td>
<td>73</td>
<td>15</td>
<td>12</td>
<td>72</td>
</tr>
<tr>
<td>Gasoline ICE Hybrid</td>
<td>69</td>
<td>14</td>
<td>17</td>
<td>67</td>
</tr>
<tr>
<td>Diesel ICE</td>
<td>75</td>
<td>10</td>
<td>15</td>
<td>74</td>
</tr>
<tr>
<td>Diesel ICE Hybrid</td>
<td>70</td>
<td>10</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td>Hydrogen FC</td>
<td>45</td>
<td>34</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Hydrogen FC Hybrid</td>
<td>44</td>
<td>35</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline FC</td>
<td>67</td>
<td>14</td>
<td>19</td>
<td>66</td>
</tr>
<tr>
<td>Gasoline FC Hybrid</td>
<td>66</td>
<td>14</td>
<td>20</td>
<td>65</td>
</tr>
</tbody>
</table>
Three MIT Analyses of Future Automotive Technologies


Integrated Policy Approach

Combine Fiscal and Regulatory Measures to:

– Exploit *synergies*
– Spread *impact* and *responsibility*
– Generate positive *commitment* among all stakeholders
– Increase *effectiveness*
A Promising Combination of Policies

- **CAFE Standards**
  - 36 MPG for cars and 28 MPG for light trucks by 2020
  - 41 MPG for cars and 32 MPG for light trucks by 2030

- **Feebates**
  - Fees for gas guzzlers, rebates for gas sippers
  - Fee/rebate rate of $25,000/GPM (-$1500, +$400)

- **Gasoline Tax**
  - 10 cents/gallon/year increase
  - Revenue neutrality through tax credits

- **Increased renewable content of fuels**
  - 5-10 % cellulosic ethanol content by 2025
Potential 2030 U.S. Fleet Impacts

- 24% reduction in new vehicle fuel consumption
- 18% reduction improvement in the overall light-duty fleet fuel consumption
- 30-50% reduction in oil use and CO$_2$ emissions relative to no change scenario
- 14% decrease in Vehicle Kilometers Traveled as compared to no change scenario