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Low-Hanging Fruit:
The Economics of Energy Efficiency

Michael S. Lubell
APS Director of Public Affairs
CCNY Professor of Physics
Study Group and Review Panel Members

**Study Group**
- George Crabtree, ANL
- Leon Glicksman, MIT
- David Goldstein, NRDC
- David Goldston (*Vice-Chair*), Harvard
- David Greene, ORNL
- Dan Kammen, UC Berkeley
- Mark Levine, LBNL
- Michael S. Lubell, CCNY
- Burton Richter (*Chair*), SLAC
- Maxine Savitz, The Advisory Group
- Fred Schlachter (*Research Staff*), APS
- John Scofield (*Research Staff*), Oberlin
- Daniel Sperling, UC Davis

**Review Panel**
- Robert A. Frosch
  Harvard Kennedy School
- T. J. Glauthier
  Electricity Innovation Institute
- Lee Schipper
  UC Berkeley
- James Sweeney (*Chair*)
  Stanford
End Use Energy Efficiency

- What is it?
- Why does it matter?
- How do we categorize it?
- How can we improve it?
  - What are the costs?
  - How long will it take?
  - How can science and technology help?
  - Why are policies important?
- What actions are needed?
End Use Energy Efficiency

◆ What is it?
End Use Energy Efficiency

◆
◆Why does it matter?
End Use Energy Efficiency

- How do we categorize it?
Figure 1
Energy usage in the U.S.
Distribution of U.S. energy usage in 2006, grouped by end-use sector (transportation, buildings and industry). Annual consumption for 2007 was 101.6 quads (10^{15} BTU).
End Use Energy Efficiency

- How can we improve it?
  - What are the costs?
Figure 2
U.S. mid-range abatement curve - 2030

Carbon dioxide abatement: estimated removal cost per ton of CO₂ in 2005 dollars and removal potential in gigatons/yr for various strategies.

COST: Real 2005 dollars per ton CO₂

Abatement costs <$50 per ton

Afforestation of copland
Coal power plants - CCS rebuilds with EOR
Commercial buildings - HVAC equipment efficiency
Residential buildings - HVAC equipment efficiency

Onshore wind - Low penetration
Onshore wind - High penetration
Biomass power - CO2ing
Industry - CCS new builds on carbon-intensive processes

Solar CSP
Coal power plants - CCS new builds
Car hybridization
Coal-to-gas shift - dispatch of existing plants

End Use Energy Efficiency

◆
◆
◆
◆
◆ How can we improve it?
  ◆ How long will it take?
  ◆ How can science and technology help?
  ◆ Why are policies important?
Figure 3
Electricity usage and economic growth for California and the United States

Gross Domestic Product (GDP) per capita
- U.S.
- California

Kilowatts hours (kWh) per capita
- U.S.
- California

Source: California Energy Commission
Overarching Conclusions

• Improving energy efficiency is a relatively easy and inexpensive way to significantly reduce the nation’s demand for imported oil and its greenhouse gas emissions without causing any loss of comfort or convenience.

• Numerous technologies exist today to increase the efficiency of our vehicles and buildings in ways that could save individual consumers money. But without federal policies to overcome market barriers, the U.S. is unlikely to capitalize on these technologies.

• Far greater increases in energy efficiency are available in the future, but realizing these potential gains will require a larger and better focused federal research and development program than exists today.
Transportation
Figure 5

U.S. miles per gallon

Sources: U.S. Environmental Protection Agency, National Highway Traffic Safety Administration
Figure 6

U.S. fuel economy vs. fuel efficiency

Fuel economy and fuel efficiency for cars and light trucks in the United States for the period 1975 to 2004. (The unit of efficiency in this figure only is ton-miles per gallon. This is the fuel efficiency mentioned in the text multiplied by the weight of the vehicle.)

Source: Lutsey and Sperling, 2005
Figure 7
Vehicle weight and acceleration, 1975-2007
Vehicle weight initially decreased to help meet the new standards, but has increased ever since.

Source: Environmental Protection Agency, 2007
Figure 11

On the road
Percent of sampled vehicle miles traveled (VMT) as a function of daily travel.

% of sampled vehicle VMT

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

Distribution of VMT by vehicles in the 2001 NHTS travel day file

Daily travel (miles per vehicle)

0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300

Sources: Santini and Vyas 2008; Vyas and Santini 2008

Figure 12

Electric-powered driving
Fraction of vehicle miles traveled (VMT) driven on electricity as a function of the plug-in hybrid electric vehicle (PHEV) electric range.

% of VMT on electricity

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

VMT satisfied by PHEV all electric range

PHEV electric range (miles)

0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300

Sources: Santini and Vyas 2008
### Table 1

#### Energy density per volume

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Volume Energy Density</th>
<th>Electrical Energy Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>34.6 MJ/l</td>
<td>9.7 kWh/l</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>38.6 MJ/l</td>
<td>10.7 kWh/l</td>
</tr>
<tr>
<td>Ethanol</td>
<td>24 MJ/l</td>
<td>6.4 kWh/l</td>
</tr>
<tr>
<td>Hydrogen at 1 atmosphere pressure</td>
<td>0.009 MJ/l</td>
<td>0.0025 kWh/l</td>
</tr>
<tr>
<td>Hydrogen at 10,000 psi</td>
<td>4.7 MJ/l</td>
<td>1.3 kWh/l</td>
</tr>
<tr>
<td>Liquid hydrogen</td>
<td>10.1 MJ/l</td>
<td>2.6 kWh/l</td>
</tr>
<tr>
<td>NiMH battery</td>
<td>0.3-1.0 MJ/l</td>
<td>0.1-0.3 kWh/l</td>
</tr>
<tr>
<td>Lithium-ion battery (present time)</td>
<td>0.7 MJ/l</td>
<td>0.2 kWh/l</td>
</tr>
</tbody>
</table>

#### Energy density per weight

(1 MJ = 0.278 kWh)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Energy Density</th>
<th>Electrical Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>47.5 MJ/kg</td>
<td>13.2 kWh/kg</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>45.8 MJ/kg</td>
<td>12.7 kWh/kg</td>
</tr>
<tr>
<td>Ethanol</td>
<td>30 MJ/kg</td>
<td>7.9 kWh/kg</td>
</tr>
<tr>
<td>Hydrogen at 10,000 psi</td>
<td>143 MJ/kg</td>
<td>39 kWh/kg</td>
</tr>
<tr>
<td>Liquid hydrogen</td>
<td>143 MJ/kg</td>
<td>39 kWh/kg</td>
</tr>
<tr>
<td>NiMH battery</td>
<td>0.34 MJ/kg</td>
<td>0.1 kWh/kg</td>
</tr>
<tr>
<td>Lithium-ion battery (present time)</td>
<td>.5 MJ/kg</td>
<td>0.14 kWh/kg</td>
</tr>
<tr>
<td>Lithium-ion battery (future)</td>
<td>1 MJ/kg</td>
<td>0.28? kWh/kg</td>
</tr>
</tbody>
</table>
Battery capabilities

Battery capabilities with PHEV comparisons of 40-mile electric range goals.

Source: Environmental Protection Agency (Adapted from a figure provided by Srinivasan, 2007)
Buildings
## Residential energy end usage

In 2006 the residential sector consumed 21.8 quads\(^4\) of primary energy. This chart shows the relative amounts going to various residential end uses.\(^5\)

<table>
<thead>
<tr>
<th>Space heating (^6)</th>
<th>Space cooling</th>
<th>Water heating</th>
<th>Lighting</th>
<th>Refrigeration</th>
<th>Wet cleaning</th>
<th>Cooking</th>
<th>Computers</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>32%</td>
<td>13%</td>
<td>13%</td>
<td>12%</td>
<td>8%</td>
<td>8%</td>
<td>5%</td>
<td>5%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Source: Energy Data Book (2007); EERE, U.S. Department of Energy

4. 1 Btu = British thermal unit, the amount of heat it takes to raise the temperature of 1 pound of water by 1 degree Fahrenheit. 1 quad = 1 quadrillion Btu = 10\(^{15}\) Btu. 1 Btu is also equal to 1054 joules, 1 joule being the metric unit of energy.

5. Numbers differ slightly from those in the DOE Building Energy Databook as the 4.7% adjustment has been eliminated and distributed proportionally to all other categories.

6. Energy for “space heating” is the energy used to heat a building. Energy used to heat domestic hot water is included in the category “water heating.”
### Commercial energy end usage

In 2006 the commercial sector consumed 17.9 quads of primary energy. This chart shows the relative amounts going to various end uses. The category “Other” includes non-building commercial use such as street lighting, lighting in garages, etc.

<table>
<thead>
<tr>
<th>End Use</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>27%</td>
</tr>
<tr>
<td>Space heating</td>
<td>15%</td>
</tr>
<tr>
<td>Space cooling</td>
<td>14%</td>
</tr>
<tr>
<td>Water heating</td>
<td>7%</td>
</tr>
<tr>
<td>Electronics</td>
<td>7%</td>
</tr>
<tr>
<td>Ventilation</td>
<td>6%</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>4%</td>
</tr>
<tr>
<td>Computers</td>
<td>3%</td>
</tr>
<tr>
<td>Cooking</td>
<td>2%</td>
</tr>
<tr>
<td>Other</td>
<td>15%</td>
</tr>
</tbody>
</table>

Source: Energy Data Book (2007); EERE, U.S. Department of Energy

7. Numbers differ slightly from those in the DOE Building Energy Databook as the 5.5% adjustment has been eliminated and distributed proportionally to all other categories. Non-building commercial use includes electricity for street lights, water treatment plants, airport lights, etc. All these numbers for energy uses should be viewed as rough approximations — more useful for comparing the relative sizes of various energy uses than as precise figures of any specific energy use.

8. Since lighting and space cooling are predominantly accomplished with electric energy, their relative importance compared to other end uses depends strongly on whether the focus is on primary (source) energy or site energy.
Figure 20

Total primary energy consumptions for buildings

Primary energy use (including that associated with electric use) for the residential and commercial sectors in Quad ($10^{15}$ Btu).

Numbers after 2006 are projections.

Source: EIA 2008 Annual Energy Outlook
Electric savings from California’s energy efficiency programs

Annual electric energy savings in California since 1975 associated with appliance standards, building energy standards and utility DSM programs.

Source: Art Rosenfeld, California Energy Commission
Figure 23
Impact of standards on efficiency of 3 household appliances

- Gas furnaces
- Central air conditioners
- Refrigerators

End Use Energy Efficiency

◆ What actions are needed?
R&D
Sample List of Opportunities

- Fuel Cells
- Batteries and Electrical Energy Storage
- Solid-State Lighting
- Catalysts
- Thermoelectric Devices
- Lightweight Materials
- Advanced Windows
- Advanced Ventilation
- Ultrathin Thermal Insulators
- Thermodynamic Cycles
- Behavioral Research
Recommendations
• Policies should be established to achieve 50 mpg by 2030
• Federal transportation R&D portfolio should have broader focus
• Grid improvements & time of use electricity metering needed for PHEVs
• Social science research required to better understand consumer behavior
• Set federal goal: buildings sector primary energy use in 2030 no more than in 2008
• Federal R&D program needed to achieve ZEB by 2030
• LEED certification should give energy efficiency highest priority
• Federal R&D funding for next generation building technologies should increase significantly
• Low-energy residential buildings R&D and demonstration program should be expanded
• DOE should comply with legislation to develop cost-effective, achievable appliance standards
• Federal government should use carrot & stick approach to get states to adopt DSM programs
• Energy standards for buildings such as those in California should be implemented nationwide
• DOE Office of Science should be funded at levels specified in America COMPETES Act
• DOE should fold long-term applied research into its programs more seriously than at present
• DOE should fully comply with 2005 EPACT mandate to coordinate basic and applied research
• ARPA-E, if funded, needs its purpose better defined: time horizon, private-sector coupling
• In transportation, closely connected long-term basic & applied research need more support
• In buildings, neglected long-term applied research in EERE needs much more attention