The Logic of Energy Efficiency

Alan Meier
Lawrence Berkeley National Laboratory
&
UC Davis Energy Efficiency Center
The Question

You want to remove 1 gram of mass from a car and obtain the greatest possible increase in vehicle efficiency.

From what part of the vehicle do you remove the 1 g?
A Demand-Side Perspective
Treating Energy Demand as a Black Box (and note the assumptions!)

Estimated U.S. Energy Use in 2009: ~94.6 Quads

Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527
Electricity

**Generation**

Oil, Gas, Hydro, Nuclear, Coal

**Use**

Everything else

Motors!
Electricity

**Generation**

- hydro

- Everything else

**Use**

- refrigerators

- Everything else
Electricity supply and demand

- Wind: 1%
- Residential standby power: 2%
- Everything else: 99%
- All other electricity use: 98%
Refrigerator Energy Use Over Time

United States Refrigerator Use v. Time

Average Energy Use per Unit Sold (kWh/yr) vs. Refrigerator Size (cubic ft) vs. Energy Use per Unit (KWH/Year)

- Refrigerator volume (cubic feet)
- Refrigerator energy use per unit sold (kWh/yr)
- Energy use per unit (KWH/Year)
Retrofit & Replacement (~1990)

Figure 1. Impact of Refrigerator Maintenance Measures and Replacement

Figure 1. Impact of Refrigerator Maintenance Measures and Replacement
Refrigerator Energy Use Over Time

United States Refrigerator Use v. Time

Average Energy Use per Unit Sold (kWh/yr)

Refrigerator Size (cubic ft)

Energy Use per Unit (KWH/Year)

Refrigerator volume (cubic feet)

End Use Breakdown in a Single Building

A typical grocery store has 150 – 200 electric motors

Can you make a chart like this for a ship?

Fig. 1 Electricity End-Use in a Typical Large Arizona Grocery Store

- Refrigeration: 52%
- Interior Lighting: 21%
- Heating, Ventilation, and Air Conditioning: 15%
- Other: 2%
  - Office Equipment (Non-PC): 2%
  - Personal Computers: 2%
  - Motors: 2%
A device transforms energy into a useful output, service, or product.
Devices convert energy into some sort of output that provides a service.
Energy Use of Escalators: Active & Standby

Proportions of active and standby mode to overall energy consumption of two escalators.
- Power consumption does not differ significantly by mode
- No meaningful sleep or auto power down modes detected in any of the boxes surveyed.
A Service Plot for Water Heating

- Reduce demand
- Reduce standby
- Raise efficiency
- Reduce demand

Input Energy

Output (liters of hot water)
Rack Design Strongly Affects Fuel Consumption

Source: Whispbar 2011
Vehicle Alternators

• A car alternator generates about 800 kWh/year
  – 1/10 of average residential electricity use
  – Cost of electricity is $1/kWh, about 5 x higher than grid electricity and about the same as PV electricity

• Virtually no literature on measured efficiency and output

• Alternator capacities are growing every year because of increasing electrical loads
Categories of Energy-Saving Actions

• Direct energy savings
  – Reducing demand for output
  – Raising efficiency
  – Reducing fixed consumption

• Indirect energy savings
  – Linked activities
  – Upstream/downstream activities
  – Savings through re-design

• Changing the rules of the game
True Cost of Fuel Delivered to the Battlefield

Cost of delivered fuel is much higher than the DESC standard price.

Notes:
FEBA = Forward Edge of Battle Area
DESC Standard Price is price paid by Service to DESC - fixed annually, worldwide price
Cost of delivering fuel to Army battlefield varies from 10’s to 100’s $/gallon, depending on scenario
Real Numbers: DESC standard price, AF in-flight refueling, Army FEBA and FEBA + 100Km
Usability is Important

An interface that is difficult to use is an obstacle to correct operation

VCRs in the 1980s & 90s

An interface that is difficult to use is an obstacle to energy-efficient operation

– Digital programmable thermostats, plug-in hybrids, utility bills, etc.
Thermostats Are Confusing to Operate
Programmable Thermostats

Recently Energy Star concluded that homes with programmable thermostats were using more energy than homes with manual thermostats.

In 2008 Energy Star terminated the specification for programmable thermostats until it could “fix” the usability problem.

Goal: Quantifying usability gives manufacturers and regulators a means of measuring improvement.

Premise: Improving the usability of thermostats will facilitate energy-saving behavior.
How to Measure Usability in Thermostats?

And now the video ...
How to Measure a Thermostat’s Usability?

1. Define tasks
2. Quantify peoples’ ability to accomplish tasks
3. Compute “score” based on metrics
4. Compare to reference model
Define Tasks

**Task 1:** Turn the thermostat from “off” to “heat.”

**Task 2:** Set the correct time.

**Task 3:** Identify the temperature the device is set to reach.

**Task 4:** Identify what temperature the thermostat is set to reach for Thursday at 9:00 PM.

**Task 5:** Put the thermostat in “hold” or “vacation” to keep the same temperature while gone.

**Task 6:** Program a schedule and temperature preferences for Monday through Friday.
Details of Usability Tests

- 5 thermostat interfaces
- 31 participants
- 2 interfaces per person
- 6 tasks for each test
- 62 tests total
- > 350 videos!
Distribution of Times for Subjects to Complete Task 1

Task 1: Turn the thermostat from “off” to “heat.”

<table>
<thead>
<tr>
<th>Time Range</th>
<th>Percentage of Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>60%</td>
</tr>
<tr>
<td>31-60</td>
<td>10%</td>
</tr>
<tr>
<td>61-90</td>
<td>10%</td>
</tr>
<tr>
<td>91-120</td>
<td>10%</td>
</tr>
<tr>
<td>120+</td>
<td>10%</td>
</tr>
</tbody>
</table>
Average Time to Complete a Task by Model
(a simple metric)

**Task 1: Turn the thermostat from “off” to “heat.”**
Converting Task Time & Success into a Metric “Combined Completion Coefficient”

\[ M_i = 2c\left(1 - \frac{e^x}{1 + e^x}\right) \]

Where,

\[ c = \begin{cases} 
0, & \text{if subject failed to complete task} \\
1, & \text{if subject completed task} 
\end{cases} \]

\[ x = \frac{t}{k} \]

\[ t = \text{time for subject to complete task (in seconds)} \]
\[ k = \text{an empirically-derived constant weighting value of failures to complete} \]

Note that \( M_i \) will always be between 0 and 1.
“Combined Completion Coefficient” based on 3 tasks – A Usability “Score”
Conclusions

Many different approaches to saving energy
1. What are the services provided?
2. Where does the energy actually go?
3. What kinds of conservation measures can be applied?
4. What are the economics?

Think about removing 1 g ....
end

akmeier@lbl.gov
Today’s Top 10 Battlefield Fuel Users

SWA scenario using current Equipment Usage Profile data

Of the top 10 Army battlefield fuel users, only #5 and #10 are combat platforms

1. **TRUCK TRACTOR: LINE HAUL C/S 50000 GVWR 6X4 M915**
2. **HELICOPTER UTILITY: UH-60L**
3. **TRUCK TRACTOR: MTV W/E**
4. **TRUCK TRACTOR: HEAVY EQUIPMENT TRANSPORTER (HET)**
5. **TANK COMBAT FULL TRACKED: 120MM GUN M1A2**
6. **HELICOPTER CARGO TRANSPORT: CH-47D**
7. **DECONTAMINATING APPARATUS: PWR DRVN LT WT**
9. **WATER HEATER: MOUNTED RATION**
10. **HELICOPTER: ATTACK AH-64D**

List produced by CASCOM for TAA-2007 using FASTALS for SWA. For more details, see backup slides.

Blue: Supply transport vehicles; Green: field kitchen systems; Red: weapons platforms
Pentagon Fuel Study Findings

The study resulted in five findings:

- Although significant warfighting, logistics and cost benefits occur when weapons systems are made more fuel-efficient, these benefits are not valued or emphasized in the DoD requirements and acquisition processes.

- The DoD currently prices fuel based on the wholesale refinery price and does not include the cost of delivery to its customers. This prevents an end-to-end view of fuel utilization in decision-making, does not reflect the DoD's true fuel costs, masks energy efficiency benefits, and distorts platform design choices.

- The DoD resource allocation and accounting processes (PPBS, DoD Comptroller) do not reward fuel efficiency or penalize inefficiency.

- Operational and logistics wargaming of fuel requirements is not cross-linked to the Service requirements development or acquisition program processes.

- High payoff, fuel-efficient technologies are available now to improve warfighting effectiveness in current weapon systems through retrofit and in new systems acquisition.
What Does Poor Usability Look Like?

What “state” is the device in?

What do the labels tell us?

“folk labeling”