Catalysts for Innovative Behavior: Exploring Further Efficiency Possibilities

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Behavior, Energy & Climate Change (BECC) Conference

Sacramento, CA
November 18, 2008

* In the spirit and tradition of Nobel Laureate and former Caltech physicist Richard Feynman, in his 1959 visionary talk, “There’s Plenty of Room at the Bottom.” See, http://www.its.caltech.edu/~feynman/plenty.html.
Eventually, Billy came to dread his father’s lectures over all other forms of punishment.

Hopefully a problem we can avoid here this afternoon...
Some Acknowledgments

• This presentation draws on the many ideas that have evolved from wide-ranging discussions with a variety of friends, colleagues, and collaborators over the years, including: Bob Ayres, Steve Bernow, Bruce Biewald, Marilyn Brown, George Burmeister, Penelope Canan, Tom Casten, Ken Colburn, Stephen DeCanio, Catherine Dibble, Jerry Dion, Karen Ehrhardt-Martinez, Neal Elliott, Andrew Fanara, Lorna Greening, Bill Halal, Don Hanson, Alan Heeger, John Hoffman, Tina Kaarsberg, Jon Koomey, Amber Leonard, Jeff Luke, Irving Mintzer, Dick Munson, Steve Nadel, Lynn Price, Bill Prindle, Wendy Reed, Art Rosenfeld, Matthias Ruth, Harvey Sachs, Alan Sanstad, Paul Stern, Ed Vine, Elizabeth Wilson, Ernst Worrell, and many, many others.

• The support of our funders has also proved invaluable. We deeply appreciate financial backing for our research in this critical area from the Energy Foundation, Sea Change Foundation, Civil Society Institute, and Kendall Foundation. With these two important caveats:

• I make no claim about my own innovative spirit, it’s just that I like to think about new possibilities; and yet,
• Any and all mistaken views are decidedly mine alone. . . .
Energy efficiency may be the farthest reaching, least-polluting, and fastest growing energy success story of the last 50 years. But it is a highly invisible success story.

We’ve accomplished a lot, but it’s just the tip of the potential improvement opportunity.

Needed are policies, innovations, and investments that create systematic improvements driven by the right economic motivation, and the innovative spirit.

And to begin promoting that path, let’s ask the question: Just how big is energy efficiency?
Since 2002, the estimated cumulative cost to the U.S. economy of not adopting smart energy policies suggested by ACEEE in 2001.

As of about 2:30 pm this afternoon. . . .
So, How Big Energy Efficiency?

• Today the U.S. economy uses about 102 quads of total energy for all end uses and in all sectors – about 7,200 gallons of gasoline equivalent per household.

• And what if I said there might be about 45 billion barrels of energy efficiency oil equivalent that might be tapped and deployed over the next two decades or so?
And now, let’s set up the problem...

But I’ll let you draw your own conclusions from what follows next...
There is no economic or physical law...

Imagine a U.S. economy that is 70% larger than today

Add productive technology
Add a little behavioral change
And with a little imagination...

The “official future”

Perhaps the biggest constraint is imagination and the political will...
“Images of the future are critical to choice-oriented behavior”

Kenneth Boulding
Our Ultimate Energy Efficiency Resource?

• Recalling the comment of early Twentieth Century UK essayist, Lionel Strachey, who remarked: “Americans guess because they are in too great a hurry to think.”

• Jerry Hirschberg, founder and former CEO of Nissan Design, who noted that: “Creativity is not an escape from disciplined thinking. It is an escape with disciplined thinking.”

• And Henry Ford once said, “Thinking is the hardest work there is which is the probable reason why so few engage in it.”
Estimating the Household Behavioral Energy Efficiency Resource

- Residential energy use and household use of personal vehicles amounts to about 38% of total U.S. energy consumption today.
- The question is, how much of an energy efficiency gain might be supported through smart or improved behavioral decisions?
- To answer this question we explored an estimated 100 separate conservation and energy efficiency measures (all cost-effective) that could be taken in a short period of time.
- Using a Monte Carlo probability simulation – allowing a random distribution of participation, effectiveness, and saving magnitudes – we found an energy savings potential on the order of about 9 quads compared to current use.

Source: Laitner, Ehrhardt-Martinez, and McKinney 2009 (Forthcoming)
## Potential Near-Term Household and Personal Transportation Energy Savings

<table>
<thead>
<tr>
<th>Category of Actions</th>
<th>Potential National Energy Savings (Quads)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation, Lifestyle, Awareness, Low-Cost Actions</td>
<td>4.9 (57% of total savings)</td>
</tr>
<tr>
<td>Investment Decisions</td>
<td>3.7 (43% of total savings)</td>
</tr>
<tr>
<td><strong>Total Energy Savings</strong></td>
<td>~8.6 ± 1.6 (22% of HH energy)</td>
</tr>
</tbody>
</table>

Source: Laitner, Ehrhardt-Martinez, and McKinney 2009 (Forthcoming)
How Much is 8.6 Quads of Efficiency?

- ~8.4% of total U.S. energy consumption in 2008;
- ~600 gallons of gasoline equivalent per household;
- ~240 medium coal-fired power plants; and
- Roughly equal to total annual energy consumption of either Brazil or South Korea, and just slightly less than total annual energy consumption in the UK (10 quads), France (11.4 quads) and Germany (14.5 quads)

Conclusion? If we take the time to understand the behavioral perspective and recognize its full “resource potential,” it is a very big deal – but only if we choose to develop it. . . .
The *Future* of Energy Efficiency
An Illuminating Thought Experiment?

Let’s start with the full electromagnetic spectrum, as shown below:

![Electromagnetic Spectrum Diagram](image)

*Not drawn to scale, but visible light is about one-thousandth of one percent of that full spectrum*

Our understanding of the physical world would be considerably more impoverished if we relied only on visible light to shape our insights into the topography, morphology, and composition of the elements and materials that make up the world in which we live.

*And yet, many of our energy future scenarios assume a knowledge based only on today’s technologies – the visible part of the technology spectrum – as if no other knowledge or insights were necessary to shape the future.* . . .
Three Quick Questions, Three Emerging Technologies and a Resource Estimate

- A presentation yesterday by Holmes Hummel suggests the many energy future scenarios “highlight an implausibly high pressure on energy supply innovations while the potential for energy efficiency improvements is systematically underestimated.” The evidence suggests that is a more than fair assessment.

- At the same time, a recent ACEEE study (May 2008) suggests that investments in energy-efficient technologies may already be three times as large as normal energy supply – with a clear opportunity to expand the potential big-time.

- Yet it appears our thinking may be unduly constrained by a 19th century view of technology – essentially a “Heat, Beat, and Treat” perspective rather than exploring “Chemistry in Action.”

- Hence, three questions, three emerging technologies, and an alternative resource estimate – all to build greater insights into the energy efficiency resource as it might positively impact both greenhouse gas emissions and the economy.

- Again, recalling the words of Kenneth Boulding: “Images of the future are critical to choice-oriented behavior.”
What is the Weight of the Internet?

- Each transistor on a chip requires about 40,000 electrons to charge up.*
- A typical email contains ~50 kilobytes, requiring ~8 billion electrons. One electron weighs $2 \times 10^{-30}$ pounds so a typical email weighs $\sim 2.6 \times 10^{-18}$ ounces.
- But email is only ~9% of total traffic with 75% due to filing sharing. Total daily internet activity – ranging from love letters and pornography to climate studies, home movies, and vacation plans – is ~40 petabytes.
- And, 40 petabytes $\sim 1.3 \times 10^{-8}$ pound, or on the order of 0.2 millionths of an ounce.
- By comparison, if all that information were on paper, it might be $\sim 6.7$ million tons per day.

*Note: Researchers today are working on a single electron transistor.
What is the Bekenstein Bound?

• Building on the foundations of information theory advanced by MIT graduate Claude Shannon in 1948, Princeton graduate student Jacob Bekenstein proved in 1973 there was a limit to the information that can be stored in any given region of space.
• Contrary to expectation, the limit to information does not depend on volume but on surface area.
• Rough calculations suggest that the Bekenstein Bound is $\sim 10^{70}$ bits/square meter.
• By comparison, CD’s now cram “only” $10^{13}$ bits/square meter.
• In other words, we’re not even close to the physical limit
What is the Current Record for Fuel Economy in a Research Vehicle?

- I suspect many will be more than surprised to learn that a French team (designers of the car, “the Microjoule”), participating in the 2004 Shell Eco-Marathon, had achieved the rather astounding result of: **10,705 mpg**.

- In late June 2005 students from the Federal Polytechnical School of Zurich set an even more impressive new world record for fuel efficiency: **12,665 mpg** — this time in a hydrogen fuel cell vehicle, also as part of the Shell Eco-marathon.

- I highlight these results, not to suggest that a standard consumer vehicle would ever achieve this level of efficiency — not in a way that is both cost-effective and comfortable; rather, it is to suggest *we know so little about real efficiency opportunities that we unnecessarily limit our options by excluding such possibilities in our future scenario analyses.*
Even a very small difference in assumptions can have a very big impact in the eventual outcome.

"Ha ha ha, Biff. Guess what? After we go to the drugstore and the post office, I'm going to the vet's to get tutored."
Let’s walk through just three of the dozens of ready examples of Emerging Technologies – ones that may impact future energy trends in perhaps some surprising ways. . . .
A Thought Experiment in Convergent Technologies

• If technology is explicitly represented in economic forecast and policy models at all, it tends to reflect only discrete structures and isolated energy systems; for example, separate photovoltaic (PV) systems which might be mounted on building rooftops.

• But, what if we instead think in terms of Building Integrated PV systems (BIPV) — using light emitting polymers and other materials that are integrated into a single structural composite? (These are among the possibilities being explored by the National Renewable Energy Lab and many others.)

• In such a case we can then imagine individual structural components that converge to do the work of five separate systems, providing:
  – Structural support, Thermal comfort, Lighting needs, Power generation; and Information flow and processing.

• *In this example, efficiency improvements can be 2-3 times as large as policy assessments otherwise suggest.*
The Cleaning and Powering of Clothing

• Advanced polymers may allow use of radio frequency cleaning and drying
• But why wash our clothes when bugs can eat them clean?
• And power supplies within our clothing?
• *While there is reason to be skeptical of what future changes may hold for clothing, it is very clear that within the decade or so, new combinations of fibers, materials and microprocessors will open a huge new world of services and demands that can also positively impact future energy demands.*
The Emergence of Instant Manufacturing

- Ink jet printers are providing the backbone for an entirely new generation of instant manufacturing technologies, producing everything from hearing aids, shoes, and cell phone covers to replacement bones and body tissue.
- The technique? Selective laser sintering of materials deposited by dozens or hundreds of micro-nozzles according to a pattern embodied within a 3-D print file.
- Such processes may be more energy-efficient and use a greater array of basic materials; they also benefit from negligible economies of scale — which means they can rely more on local resources, and be located closer to local production needs.
- The implications for both direct and transportation energy use may be significant and beneficial.
Other Emerging Technology Trends

- Movement away from commodity-based ownership to service-based leasing.
- Multiple outputs from convergent technologies so that we minimize waste and maximize product.
- Decentralized generation continuing to show net economic and environmental benefits.
- Information and communication technologies which reduce transaction costs, fostering more decentralized decision-making enterprises.
- Increased environmental awareness and concerns, enabled by new technologies that facilitate changes in preferences.
~25 years of really cool stuff
Lemelson-MIT Program and CNN present “Top 25” Innovations

- 1. Internet
- 2. Cell phone
- 3. Personal computers
- 4. Fiber optics
- 5. E-mail
- 6. Commercialized Global Positioning Satellites
- 7. Portable computers
- 8. Memory storage discs
- 9. Consumer level digital camera
- 10. Radio frequency ID tags
- 11. Micro-electromechanical machines (MEMS)
- 12. DNA fingerprinting
- 13. Air bags
- 14. ATM
- 15. Advanced batteries
- 16. Hybrid car
- 17. Organic light emitting diodes (OLEDs)
- 18. Display panels
- 19. High Definition TV
- 20. Space shuttle
- 21. Nanotechnology
- 22. Flash memory
- 23. Voice mail
- 24. Modern hearing aids
- 25. Short-range, high-frequency radio

Scenarios and forecasts that do not explicitly anticipate or incorporate or reflect these and many other technologies are likely giving us some very misleading insights into both our future problems and our emerging opportunities.
The Good News About Energy Efficiency
Investments and Climate Change Policies

• It is does not have to be about ratcheting down our economy;
• Rather, it can be all about:
  • using innovation and our technological leadership;
  • investing in more productive technologies (including both existing and new technologies); and
  • developing new ways to make things, and new ways to get where we want to go, where we want to work, and where we want to play.
• Most economic policy studies appear to assume the former – to the detriment of smart behavior, energy and climate policy.
Three Catalysts to Innovation

• Understand the scale – how big energy efficiency really?

• Ask the right questions about the emerging future and the emerging opportunities.

• Provide the collaborative, institutional support to innovate rather merely supervise or manage the intellectual and human capital we call “employees.”
Some Final Thoughts...

- Energy efficiency is an essential ingredient in efforts to maximize energy savings and expedite our transition to a low-carbon economy;
- Closing the efficiency gap requires new insights, policies, institutional support, and yes, expanded investments:
  - That develop economic, technological and behavioral mechanisms, and incentives to increase energy efficiency.
  - That catalyze innovation and develop multifaceted and integrated approaches to energy efficiency that include positive feedbacks.
High above the hushed crowd, Rex tried to remain focused. Still, he couldn't shake one nagging thought: He was an old dog and this was a new trick.
The difficulty lies not with the new ideas, but in escaping the old ones. . . .

John Maynard Keynes
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