How Big Energy Efficiency?

*Exploring Further Possibilities**

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Balancing Energy and the Environment

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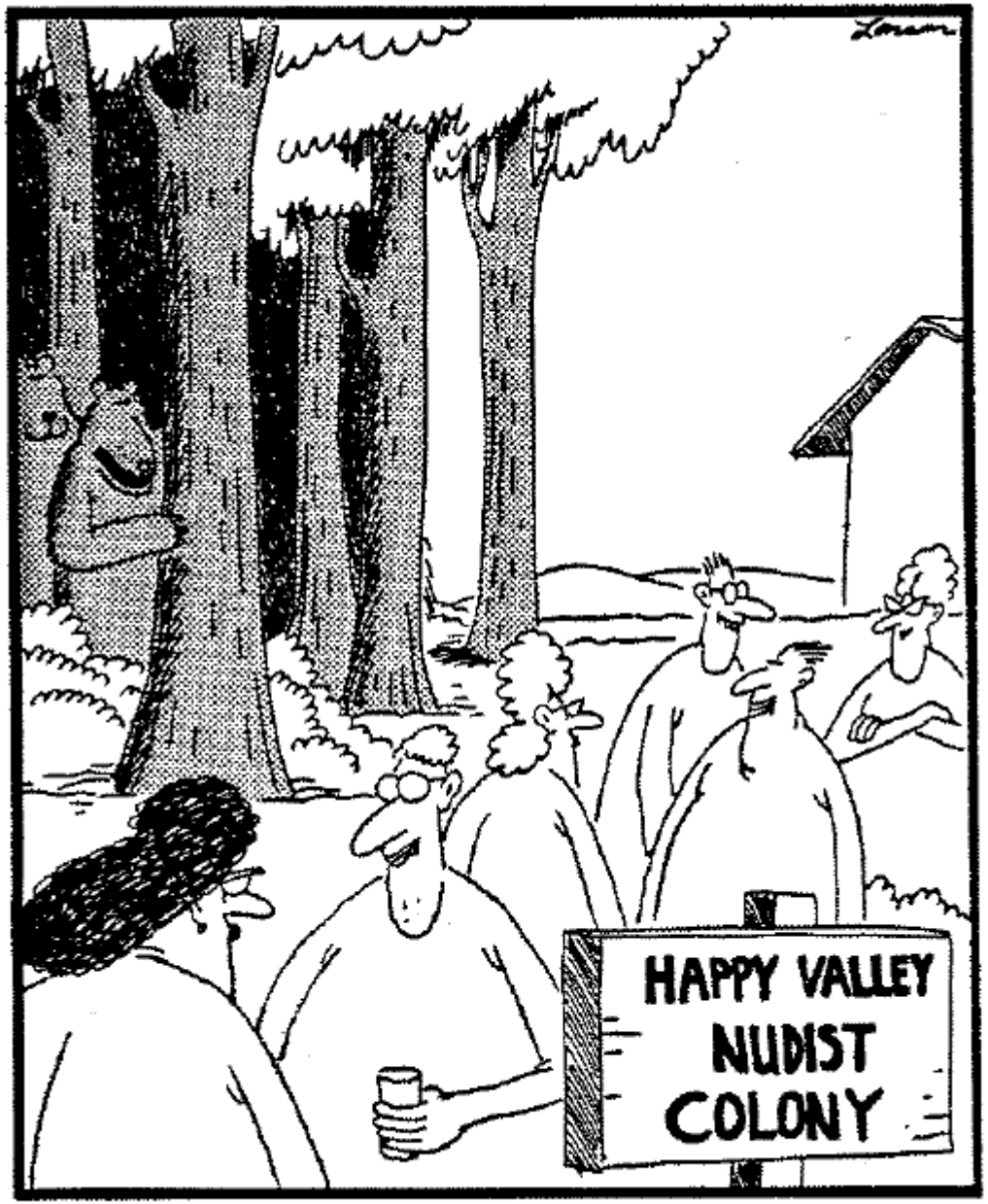
*** In the spirit and tradition of Nobel Laureate and former Caltech physicist Richard Feynman, in his 1959 visionary talk, "There's Plenty of Room at the Bottom." See, http://www.its.caltech.edu/~feynman/plenty.html.**

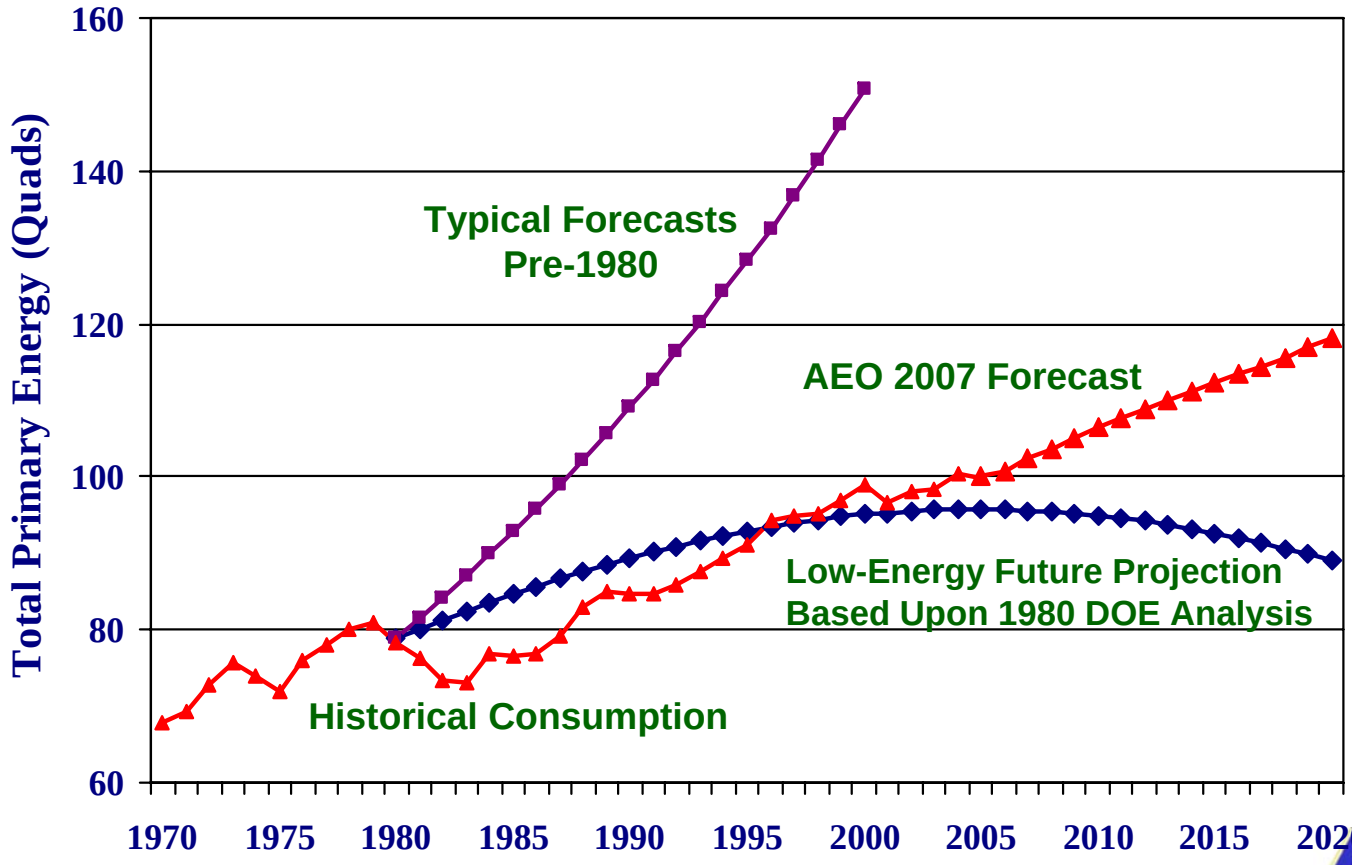
Some Acknowledgments

- 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. I would like to acknowledge the many invaluable insights and thoughts from a very broad community, including: Bob Ayres, Steve Bernow, Fatih Birol, Bruce Biewald, Marilyn Brown, George Burmeister, Penelope Canan, Tom Casten, Ken Colburn, Ruth Schwartz Cowan, Laura Cozzi, 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, Irving Mintzer, Dick Munson, Lynn Price, Wendy Reed, Art Rosenfeld, Matthias Ruth, Alan Sanstad, Elizabeth Wilson, and Ernst Worrell.
- I would also like to extend my deep appreciation to ACEEE's own Steve Nadel and Bill Prindle who encouraged me to rejoin the research community after an absence of more than a decade; and to those of you here today who have come together to explore critical ideas that will make this forum a very real and important contribution to the dialogue.
- Any and all mistaken views are mine alone, however. . . .



"Well, there goes *my* appetite."

Comparison of U.S. Energy Projections:
A Difference in Technology Assumptions?

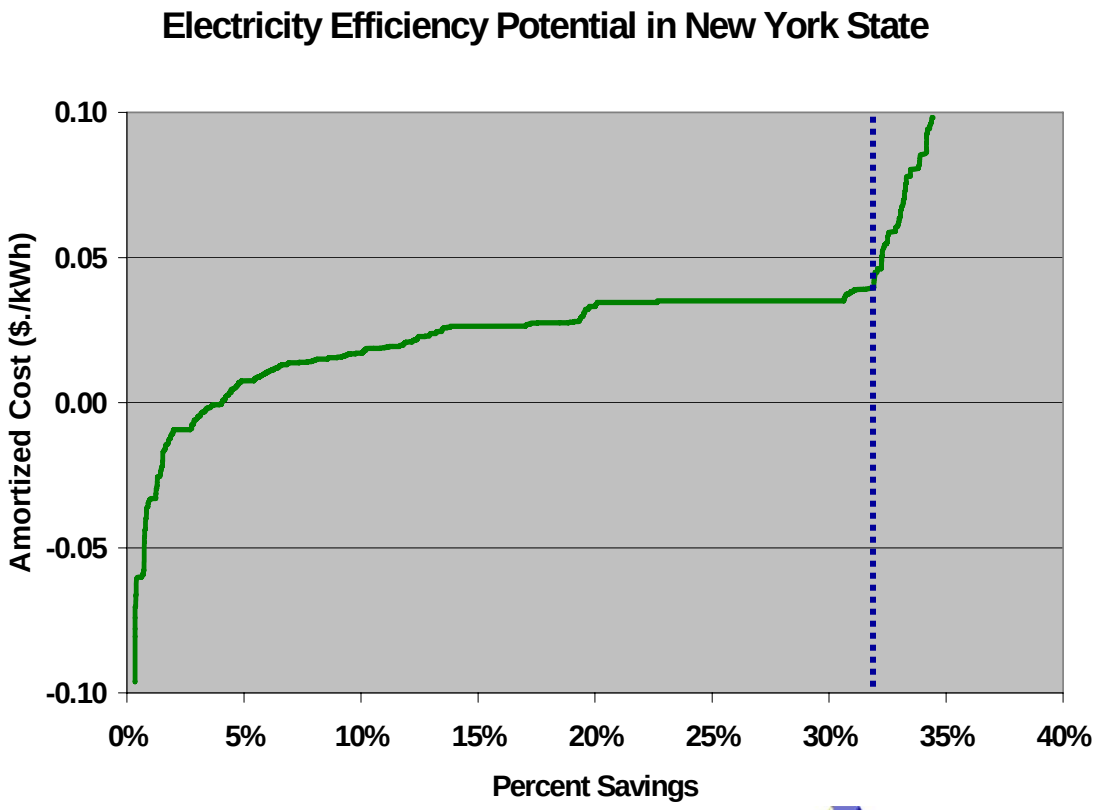


Source: AEO 2007, ACEEE estimates 2007, and 1980 DOE Policy Analysis

So What is the Cost-effective Efficiency Potential?

A large number of studies:

- NYSERDA study suggests a potential 30% electricity savings at $0.05/kWh or less (shown at the right)
- Energy Star suggests a cost-effective potential savings of 30%
- An Oak Ridge National Lab assessment suggests cost-effective building efficiency improvements could lead to perhaps a reduction of 200 MtC by 2025
- Among many others. . . .



Visit the ACEEE website for more ideas and information:
http://www.aceee.org

Three Quick Questions, Three Emerging Technologies and a Resource Estimate

- A new dissertation 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 new ACEEE study (November 2007) will suggest that investments in energy-efficient technologies may already be twice 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.
- ***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 2×10^{-30} pounds so a typical email weighs ~2.6×10^{-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 ~ 1.3×10^{-8} pound, or about ***0.2 millionths of an ounce.***
- By comparison, if all that information were on paper, it might be ~6.7 million tons per day.

Note: Researchers today are working on a single electron transistor.

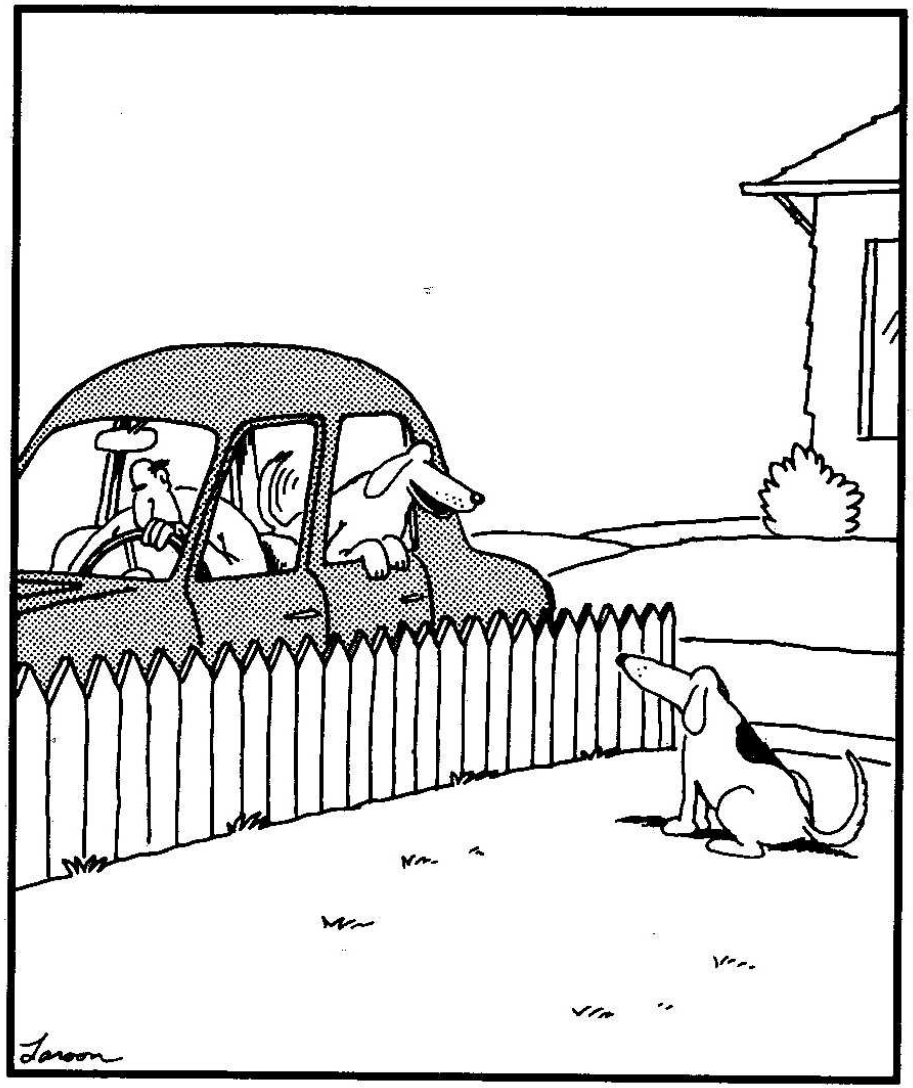
What is the Bekenstein Bound?

- 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 ~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 *(or for that matter, not even close to the production frontier).*

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 NREL 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 two or three times as large as energy models might otherwise suggest.***

The Cleaning and Powering of Clothing

- **Advanced polymers may allow use of radio frequency cleaning and drying**
  - Revolutionary fabrics will enable clothing which can change its thickness, and therefore thermal properties, according to the outside temperature, but that can also resist dirt and sweat as well as enable an easier process of cleansing and drying so that a 30-40 minute cycle for a load of wash may take only 1-3 minutes, or even less.
- **But why wash our clothes when bugs can eat them clean?**
  - Eventually, the garments in your wardrobe may be able to support a variety of bacteria engineered to eat odor-causing chemicals and human sweat. Other bacteria might secrete waterproof and protective coatings to extend the life of clothing and produce antiseptic materials for bandages.
- **And power supplies within our clothing?**
  - Low power chips, battery management and power management systems, low power reflective light displays, and even shoes that can generate electricity have been invented. We may soon see common use of fuel cells and possibly solar power, maybe even built into clothing. Powering our cell phones and PDA's by way of the clothing we wear may reduce the need to plug in power supplies at home.
- ***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.***

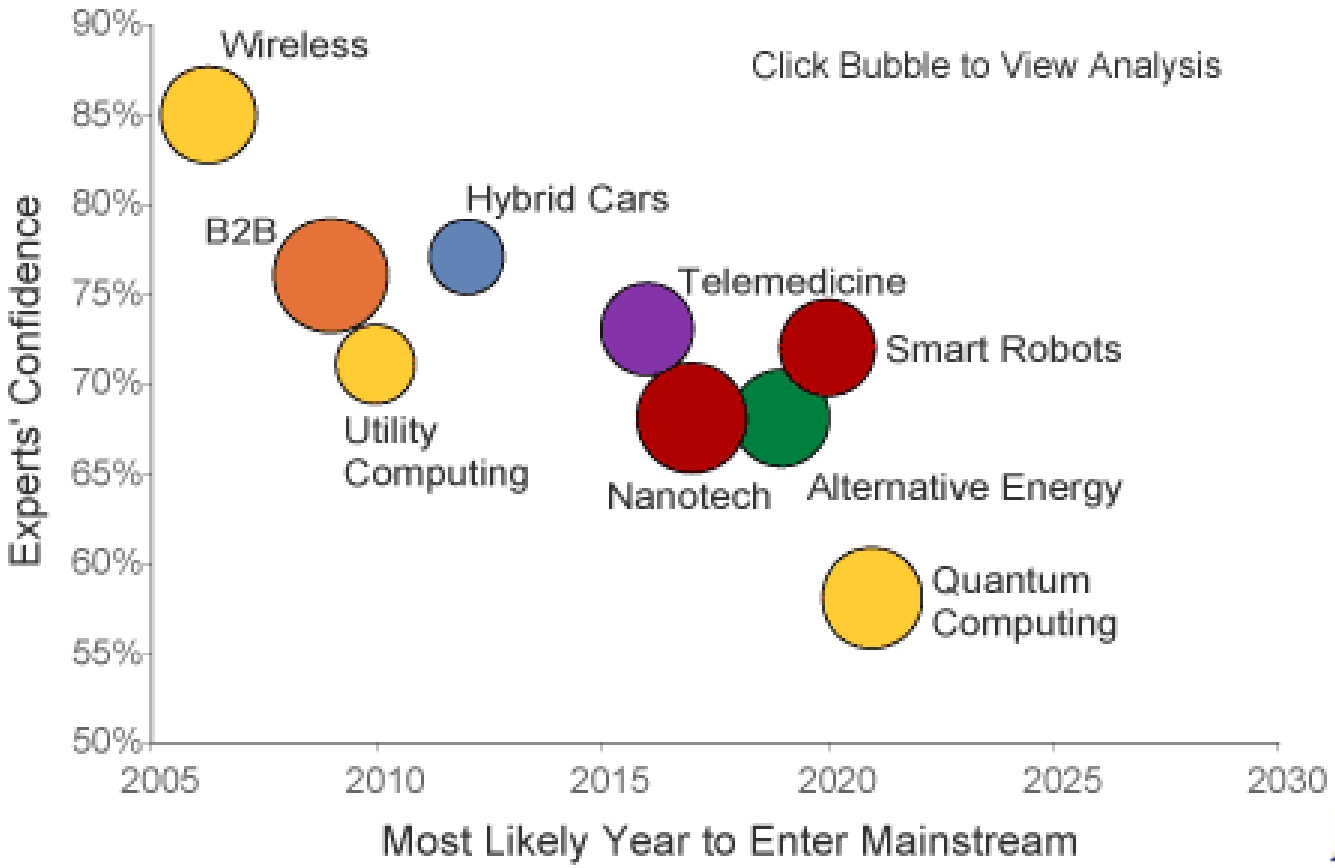
The Emergence of Instant Manufacturing

- While clearly not the typical Star Trek “replicator,” 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. And could even produce large scale buildings.
- 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.
- Reduced transaction costs fostering smaller and more decentralized business decision-making enterprises through improved information and communication technologies.
- Increased environmental awareness and concerns, enabled by new technologies which facilitate changes in consumer and business preferences.

Tracking the Technology Revolution – Suggesting a Reference Case that May be Significantly Different than Usually Forecasted



See: http://www.techcast.org

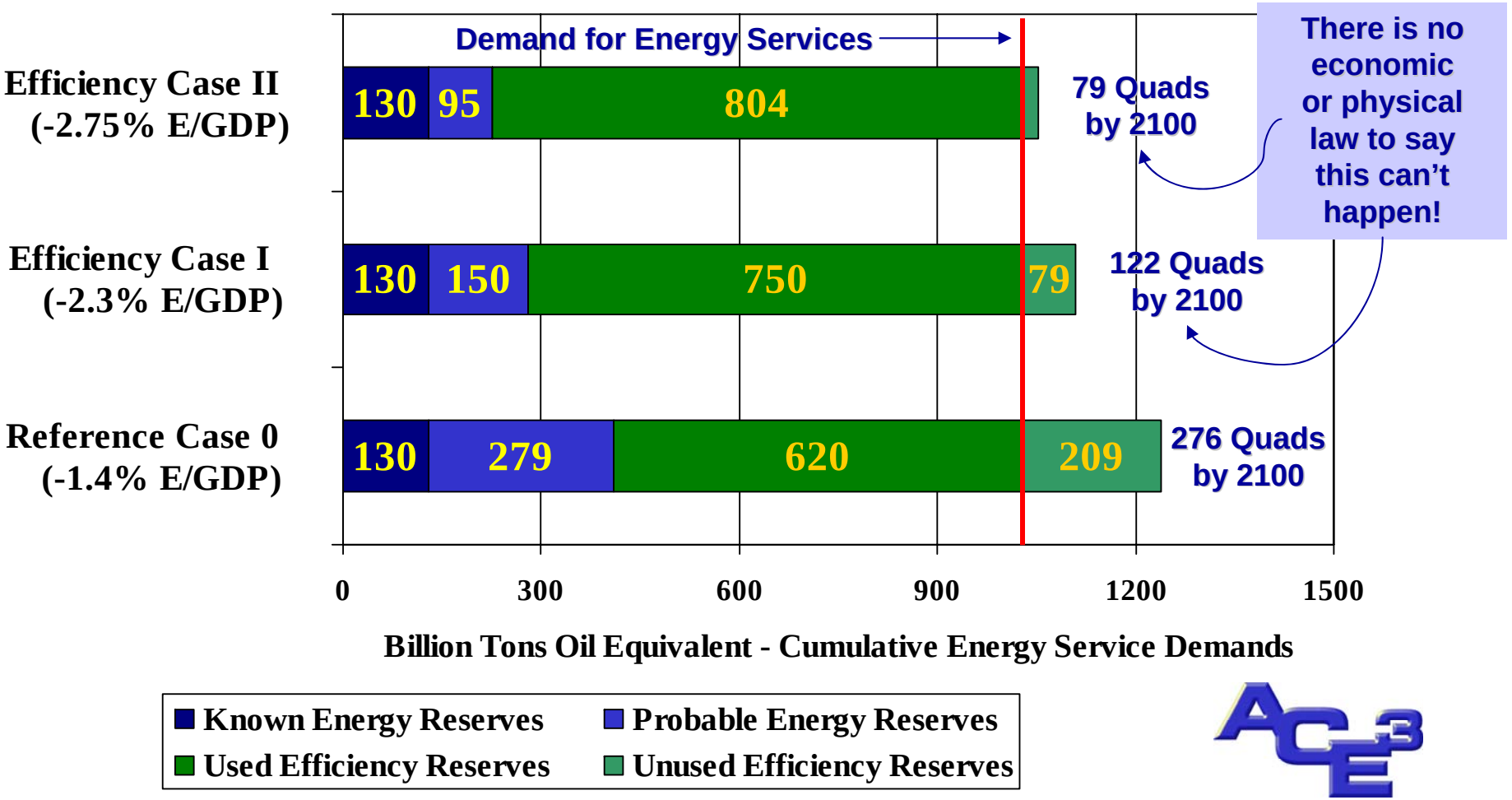
25 years of really cool stuff

Lemelson-MIT Program and CNN present “Top 25” innovations
January 14, 2005; updated January 26, 2006

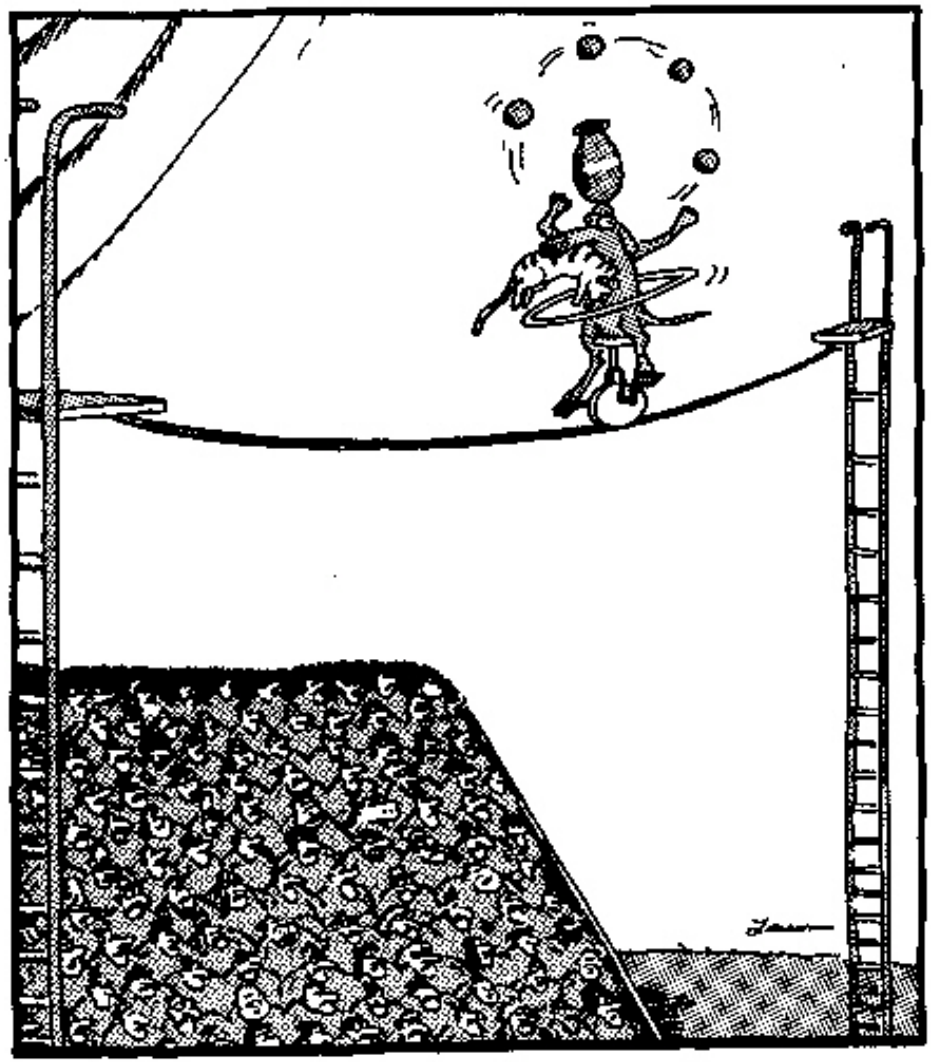
- 1. Internet
  2. Cell phone
  3. Personal computers
  4. Fiber optics
  5. E-mail
  6. Commercialized Global Positioning Satellites
  7. Portable computers
  8. Memory storage discs
  9. Consumer level digital camera
  10. Radio frequency ID tags
  11. Micro-electromechanical machines (MEMS)
  12. 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.

Exploring U.S. Cumulative Energy and Energy Efficiency Reserves 2008-2100*



* Methodology and assumptions available from author in January on request



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 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 increasing energy productivity:
  - 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.
- ***But this assumes innovation and insights which now are mostly missing from our policy deliberations and discussions.***

The difficulty lies not with the new ideas, but in escaping the old ones

John Maynard Keynes

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