Extreme Energy Efficiency: *Possible? Profitable? Necessary!*

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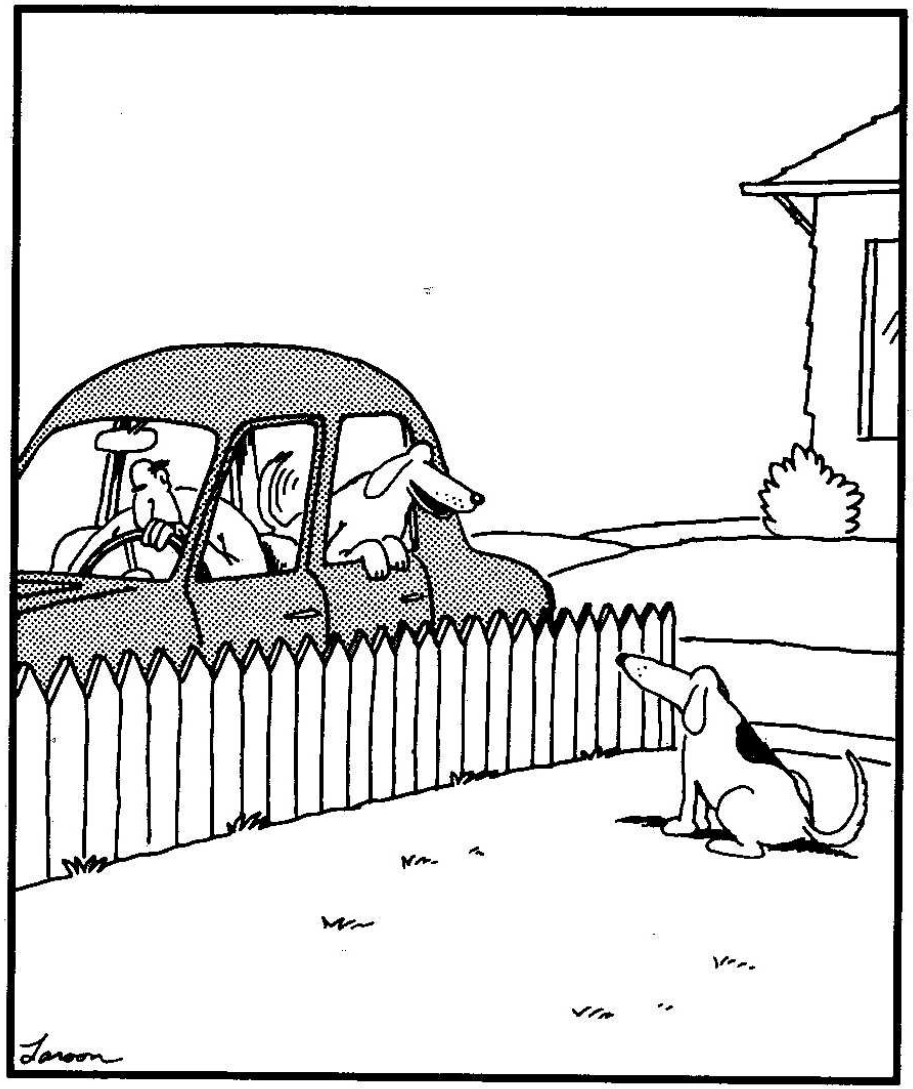
A Thesis and Some Opening Caveats

- For purposes of this clearly heuristic inquiry, “extreme energy efficiency” means an average two percent annual rate of decline (or greater) in worldwide energy intensity per unit of output or GDP over the next century.
- In the spirit of Popper’s notion of a testable hypothesis, the evidence suggests that there are no physical or economic limitations on policies which might promote this rate of energy efficiency improvement.
- This is not to say, however, that there are no environmental or economic barriers which might otherwise impede some accelerated rate of improvement in energy efficiency.
- Nor is this to say that this rate of accelerated energy efficiency is an autonomous trend; in other words, it will require a clear and persistent set of policy signals to approach any such practical opportunities.
- Finally, this is not to say that what is possible should necessarily be what is done.

Especially in thinking about the future, I suspect we can all agree that a 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."

The Short Road Ahead

- Revisit some economic fundamentals
- Rethink historical and future forecasts
- Update the emerging technology perspective
- Review economic benefits and costs
- Offer some closing thoughts and perspectives

A Few Economic Fundamentals

Energy Services and Economic Activity

- Standard neoclassical economic growth theory suggests that the production of goods and services is a function of some mix of capital and labor with a significant contribution from technological progress (Solow 1957†).
- But the evidence also suggests that production in the real world cannot be understood without taking into account the role of (inefficient) materials and energy consumption (Georgescu-Roegen 1976†).
- From start to finish — from the mining, processing and fabrication, to consumption and, finally, waste disposal — our use of natural resources, at best, may be only 15 to 20 percent efficient (updated from Claasen and Girifalco 1986†).

† See the bibliographic appendix for a complete citation of references used in this presentation.

Energy Services and Economic Activity

- Ayers and Warr (2005†) further demonstrate that improvements in energy services may be the critical factor in the growth of an economy, perhaps one of the primary drivers that underpin "technological progress."
- From a longer term perspective, if sustainable economic activity is to continue — but without proportional increases in emissions and waste, it is essential to reduce energy use per unit of work or dollar of economic activity.
- ***In other words, increased energy efficiency may be the key to long term sustainability; and, one might add, the key to long term international development and security.***
- The good news is that efficiency improvements do not have to be about ratcheting down the economy. Instead, they can be all about providing new services, making new products, and providing new ways to both work and play (Hanson et al. 2004†).

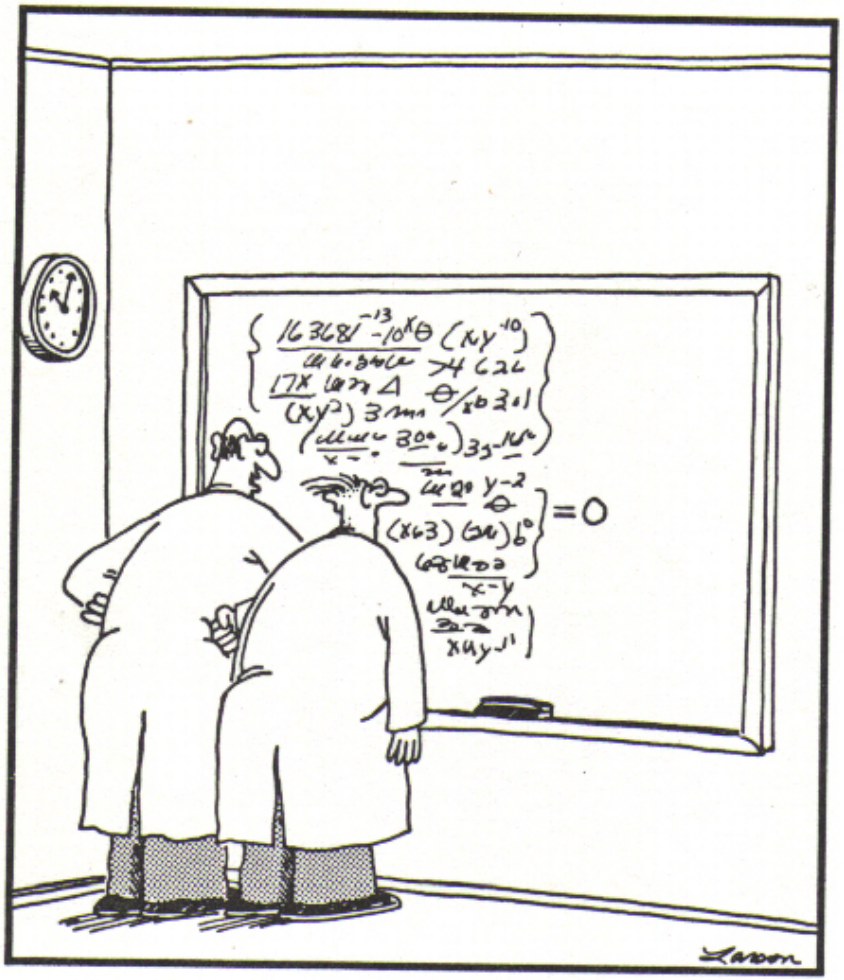
† See the bibliographic appendix for a complete citation of references used in this presentation.

Some Additional Thoughts

- Our forecasts and best thinking about likely outcomes and future options have been eroded by outdated paradigms (e.g., *Pareto optimality*[††]) and misunderstood contexts (e.g., *reproducible capital*[††] and *thermodynamic limits*[††]).
- As an example of the latter, the conceptual convenience of the *central station paradigm*[††] and alleged *Carnot efficiencies*[††] have tended to limit our thinking about technologies and energy efficiency improvements.
- Expanding our understanding of technology beyond Carnot limits to the full thermodynamic opportunities of chemistry in action (Feynman 1959[†] and Gillett 2002[†]), constraints to efficiency and productivity improvements are largely non-existent in the foreseeable future (Laitner 2004[†]).

† See the bibliographic appendix for a complete citation of references used in this presentation.

†† See the glossary appendix for a brief description of key terms used throughout this presentation.

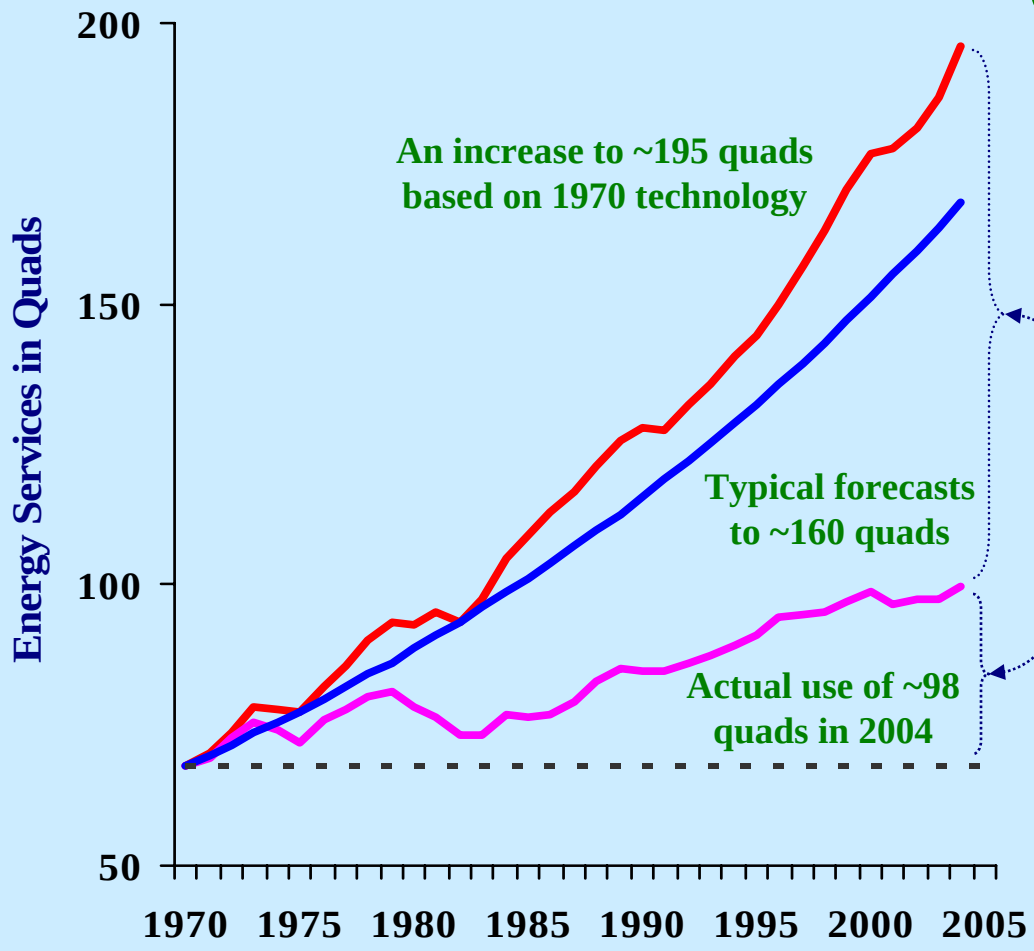


"No doubt about it, Ellington—we've mathematically expressed the purpose of the universe. God, how I love the thrill of scientific discovery!"

Although less than infinity, the evidence clearly suggests that opportunities for technological change and cost-effective energy efficiency investments are significantly greater than zero. Just what that outcome will be, however, very much depends on the choices we make.

Forecast Review and Why It Matters

Without New Efficiency Technology,** Energy Use Would Be Almost 3 Times 1970 Levels



Contrast 3 Energy Patterns

- ✓ Using 1970 Technology
- ✓ Standard 1970s Forecast
- ✓ Actual energy use since 1970

Since 1970, energy efficiency has met 75% of new energy service demands in the U.S, while new energy supplies have perhaps contributed only 25% of new energy service demands.

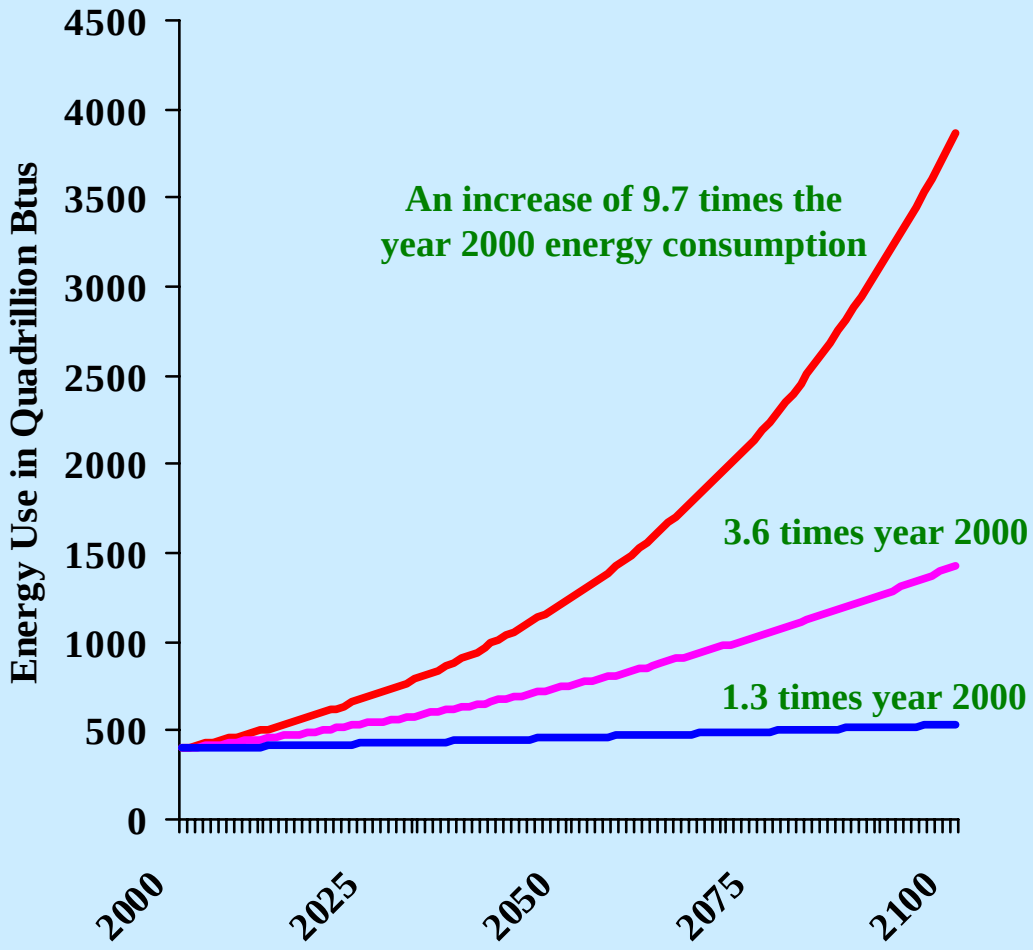
**** Where "energy efficiency" is broadly defined as the difference between the 1970 and 2004 energy intensities.**

Without New Efficiency Technology, Energy Consumption Will Increase Significantly

Contrast 3 Scenarios

- ✓ Using Year 2000 Technology
- ✓ Assuming a standard 1% Annual Rate of Improvement in Energy Efficiency
- ✓ Assuming a 2% Annual Rate of Improvement in Energy Efficiency

Where each scenario assumes a 2.3 percent level of worldwide economic growth (in GDP) over a 100-year period, but employs a different mix of technologies and efficiency improvements (Laitner 2004†).



The Prospect of Emerging Technologies

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 separate 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? 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: (a) efficiency improvements can be perhaps two or three times as large as energy models might otherwise suggest, and (b) conventional concepts like energy intensity†† and E/GDP†† may no longer have the same relevance as today's familiar set of metrics.***

The Emergence of Instant Manufacturing

- While clearly not your typical Star Trek “replicator,” ink jet printers may provide the backbone for an entirely new generation of instant manufacturing technologies (Amato 2003), producing everything from hearing aids, shoes, and cell phone covers to replacement bones and body tissue. And even 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 positively beneficial.

The Possibility of CO_2 Fuel Cells??

- Under the existing paradigm, carbon dioxide is viewed only as a problem; but from perhaps a different perspective it becomes a useful energy resource. How?
- The continuous oxidation of scrap iron in the presence of a constant CO_2-rich gas stream and water can be a means to sequester CO_2 as well as generate hydrogen gas and electricity.
- ***Imagine the possibilities of using Fe/CO_2 fuel cells for both CO_2 mitigation and energy production — at a net profit of \$30/tCO_2 (Rau 2004).***

Other Emerging Technology Trends

- Movement away from commodity-based ownership to service-based leasing.
- Increased linkages between waste minimization and product maximization (Bailey and Worrell 2004†).
- Multiple outputs from convergent technologies.
- Decentralized generation continuing to show net economic and environmental benefits (Casten and Downes 2005†).
- Reduced transaction costs fostering smaller and more decentralized business decision-making enterprises.
- Increased environmental awareness and concerns, enabled by new technologies which facilitate changes in consumer and business preferences.

A Quick Commentary on the Possibility of Net Economic Benefits

The Economic Costs <u>and</u> <u>Benefits</u> of Energy Technology Investments

- **At Least Four Categories of Costs**
  - Direct Investment Costs
  - Operating and Maintenance Costs
  - R&D and Program Costs
  - Transaction and Search Costs
- **But Also at Least Four Categories of Benefits**
  - Direct Savings from Lower Compliance Costs
  - Process Efficiency and other Productivity Gains
  - Environmental Benefits not Captured within normal Market Transactions
  - Spillovers and/or learning created/induced by either the technology investment, or the R&D efforts
- ***A complete technology benefit-cost assessment suggests that continued energy efficiency investments can show a long-term net positive benefit*** *(Laitner 2005*[†]*)*.

Some Closing Perspectives

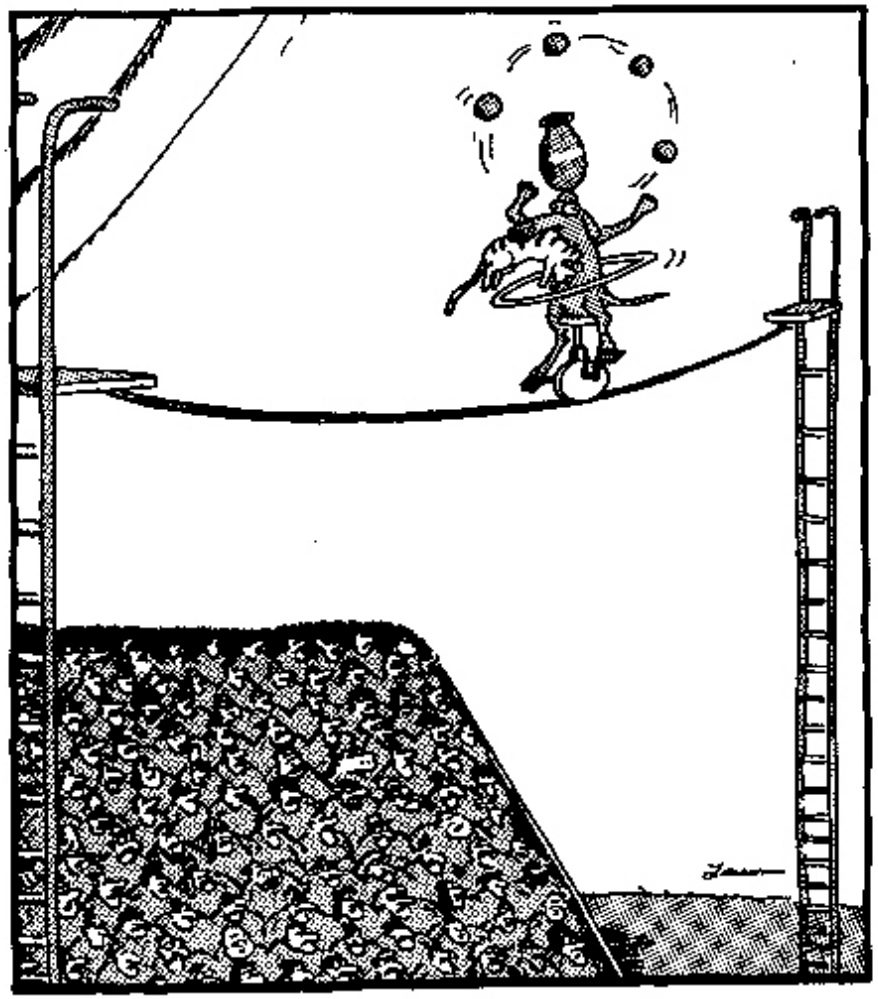
Reviewing the Long-Term Perspective

- Energy analysts of all perspectives suggest the likelihood of a significant increase in the cost or a shortfall in the availability of conventional fossil fuel resources by 2030 — and perhaps sooner.

- Economist Kenneth Boulding once commented : ***"Images of the future are critical to choice-oriented behavior."***

- For example, whether we include in our analysis the nuclear, hydrogen, renewable, or non-conventional fossil fuel resource options, can we afford to rule out energy efficiency?

- ***And yet, economic models and conventional policy analyses tend to assume that energy efficiency can make only a limited — and "not always cost-effective" — contribution to our nation's energy future. This is no longer satisfactory.***



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.

Or perhaps paraphrasing John Maynard Keynes: "The difficulty lies not with the new ideas, but in escaping the old ones."

And Perhaps This Final Perspective . . . .

Nolan Ryan is a hall of fame pitcher who closed his career in 1993 with the President's former team, the Texas Rangers. But he would have won considerably fewer than his 324 games had he taken the field without his catcher, his infield, or even outfield. ***In a similar way, the full mix of efficiency and environmental technologies should be among the serious modeling and policy options as we map our future scenarios and evaluate the economic impacts of our alternative technology paths.***

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The ideas contained in this presentation to the Emerging Technologies Summit are believed to rely on credible and accurate sources of information. Any errors in the analysis are solely the responsibility of the author. The results described herein should not be construed as reflecting the official views of either the Environmental Protection Agency or the U.S. Government. A more complete analysis that underpins this presentation can be found in Laitner, John A. “Skip,” 2004. “How Far Energy Efficiency?” *Proceedings of the 2004 ACEEE Summer Study on Energy Efficiency in Buildings*, Asilomar, CA.†

Supplemental Slides

Acknowledgments

Even a compact presentation such as this one benefits from on-going collaboration with a large number of colleagues within a variety of disciplines and circumstances. For their time and thoughtful conversations about where the rubber meets both the road and the sky, all of which have contributed to the development of my thinking in this particular area, I would like to thank:

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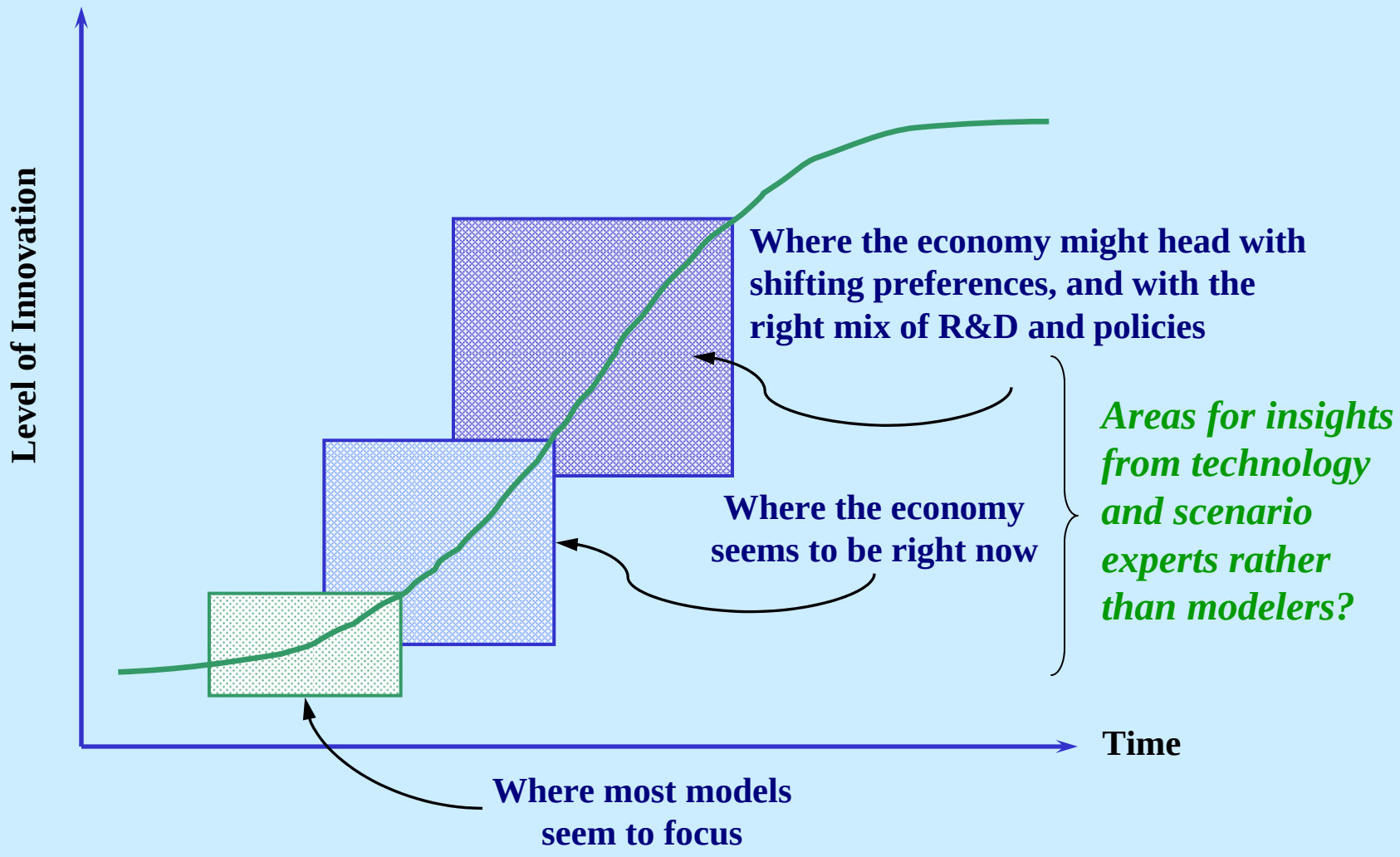
Notwithstanding their invaluable contributions, and those from many other colleagues, any mistakes, errors, or misinterpretations within this presentation remain my own responsibility. As previously noted, the views expressed do not necessarily reflect those of the U.S. Environmental Protection Agency or the U.S. Government.

Standard Forecasts and the Technology Gains from Efficiency and Structural Improvements



Further Caveats and Thoughts

- While the focus of this presentation is to highlight opportunities and *images of the future*, this again is not to say there are no economic barriers or environmental problems to be resolved as we seek an appropriate level and mix of energy efficiency technologies and policies. And such opportunities will absolutely require a coordinated and persistent policy signal.
- Greater levels of population and economic growth (than those implied by the discussion here) will clearly impact requisite efficiencies, as well as generate an even greater level of environmental impact that must be prevented and/or remediated.
- "Individuals have a natural tendency to choose from an *impoverished option bag* (emphasis in the original). Cognitive research in problem solving shows that individuals usually generate only about 30 percent of the total number of potential options on simple problems, and that, on average, individuals miss about 70 percent to 80 percent of the potential high-quality alternatives" (Luke 1998[†]).

Other Useful Perspectives

- By 2004, improved energy efficiency (compared to 1970 technologies and market structure) was already providing 75 percent of all U.S. energy services, which is:
  - 1.3 times total energy production
  - 8.9 times total domestic oil production
  - 3.7 times total oil imports
- New approaches to 'whole-system multiple-benefit design' can boost resource productivity by up to tenfold, often at a lower initial cost than traditional engineering approaches. The traditional design process focuses on optimizing components for single benefits rather than whole systems for multiple benefits—thereby "pessimizing" the system. Whole-system, multiple-benefit design can result in dramatic energy savings in a wide range of engineering applications and disciplines, including the design of air-handling, cleanroom, lighting, drivepower, chiller, insulating, heat-exchanging, and other technical systems, and of buildings in a wide range of sizes, programs, and climates.

Note: this slide is adapted from comments and insights provided by Bob Olson, drawing on information and resources from the Rocky Mountain Institute. See: http://www.rmi.org.

Glossary

- ***Carnot efficiency:*** Named after a French engineer Sadi Carnot, the maximum efficiency of a heat engine is 1 – Low Temperature / High Temperature (as measured in °Kelvin). Given combustion temperatures in power plants, for example, the maximum practical efficiencies are now are about 45 percent However, heat recovery systems can increase this to as much as 70-90 percent.
- ***Central station paradigm:*** The idea that economies of scale provide less expensive energy supply resources compared to distributed or on-site resources where the supply is more closely match to actual need (e.g., providing a mix of steam and electricity, for example, with combined heat and power technologies). Improvements in both design, materials, and electronics are dramatically altering technology cost and performance so that economies of scale are moving closer to zero.
- ***Energy efficiency:*** Broadly speaking, a measure of how much energy is needed to provide one dollar of the nation's Gross Domestic Product; sometime referred to as reducing the nation's energy intensity, or E/GDP. This may be the result of improved technology performance or shifts in the economy away from energy intensive production processes to higher value-added manufacturing sectors and services
- ***Pareto optimality:*** After an Italian economist Vilfredo Pareto, an assumption in many economic models that economic welfare is presumed to be maximized in reference case projections. In other words no one can be made better off without someone else being made worse off following a reorganization of production. Hence, environmental policies, by implication, will cost the economy.
- ***Reproducible capital:*** The nation's artifacts, equipment and structures which are assumed to be easily replaced or reproduced using new materials or substitutes with little concern for waste or environmental impact.
- ***Thermodynamic efficiency:*** Thermodynamic efficiency is the ratio of the amount of work done by a system compared to the amount of heat generated by doing that work. Although the tendency is to think of thermodynamics solely in terms of Carnot efficiency (see above), thermodynamic efficiency is also influential at the atomic level of chemical reactions. Thermodynamic efficiencies (when measured as the change in Gibbs free energy divided by the change in enthalpy at standard temperature and pressure) of greater than 90 percent are possible. As an example, the efficiency of car engines are subject to Carnot limits while the chemical reactions within fuel cells are constrained only by the larger thermodynamic limits.

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