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A Half Century of Long-Range Energy Forecasts: Errors Made, Lessons Learned, and Implications for Forecasting

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This paper assesses the major U.S. long-range energy forecasting studies conducted over the past half century, identifies the errors made and lessons learned in energy forecasting, and discusses the implications for current and future attempts to accurately forecast energy consumption, production, and prices. Over the past several decades, long-range energy forecasting has been extremely difficult and the accuracy of the major forecasts has, in retrospect, often been found wanting. Although, in hindsight, a large portion of the forecasts and associated policy recommendations turned out to be inaccurate and mistaken, here we conduct a careful review of 50 years of energy forecasting to determine how some of the major pitfalls can be avoided in future efforts. We identify: (1) lessons that can be learned from these past forecasting exercises that may improve our track record in the future; (2) basic trends and truisms that may be discerned that may allow us to more accurately forecast energy technologies and variables; (3) insights for doing the job better in the future; (4) the most egregious forecasting errors made in the past that can help us avoid making similar errors in the future; (5) assumptions that may aid us in better predicting the long-run energy future; and (6) how this review can assist policymakers in formulating energy policies and technology and R&D priorities for the future.

KEY WORDS: Energy forecasting; economic forecasting; future energy requirements.

"Prior to determining where we are going, we must first ascertain from whence we came."

–A. Lincoln

I. INTRODUCTION

Over the past several decades, long-range energy forecasting has been extremely difficult and the accuracy of the major forecasts has, in retrospect, often been found wanting. Even the most basic data have frequently been misforecast by orders of magnitude. Nevertheless, ascertaining the likely energy trends and parameters for the United States and the world over the next several decades remains an important exercise with critical economic, environmental, and political implications.

Although, in hindsight, a large portion of the forecasts, projections, predictions, and associated policy recommendations turned out to be inaccurate and mistaken, the issue at hand is whether a careful review of 50 years of energy forecasting can be helpful in avoiding some of the past pitfalls in future related efforts. What lessons can be learned from this review of past energy forecasting studies? What basic trends and truisms can we discern that may allow us to more accurately forecast energy technologies and variables? Can a review and assessment of previous long-range energy forecasts provide insights for doing the job better in the future? Can identification of the most egregious forecasting errors made in the past

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help us avoid making the same errors in the future? Do there exist basic trends and assumptions that may aid us in better predicting the long-run energy future? What lessons can we learn from these past forecasting exercises that may improve our track record in the future? How can this review assist policymakers in formulating energy policies and technology and R&D priorities for the future?

These are the types of questions we sought to address by reviewing the major long-range energy forecasting studies conducted over the past half century, as part of a larger study of approaches to evaluating long-run R&D.[1]

II. THE STUDIES REVIEWED

We identified over 100 studies by a variety of organizations conducted between 1952 and 2001 that attempted to forecast long-term energy developments for the United States and the world, and we systematically analyzed 49 of them. These are summarized in Table 1, which lists the studies chronologically.

First, the major studies were identified and assessed in accordance with their relevance for this project. Next, the most important were reviewed and analyzed to identify information and insights. For each study, the following specific questions were addressed:

- What were the specific objectives of the analysis?
- What types of analyses and forecasts were conducted?
- What were the major assumptions, guidelines, and constraints employed?
- What technology and market scenarios were considered?
- To what degree did the studies specify barriers to be overcome and suggest long-range targets for technology development?
- What were the major conclusions and findings derived?
- What unforeseen technological, environmental, and institutional developments occurred since the research was conducted?
- What are the major strengths and weaknesses of the study?
- What lessons relevant to future forecasting efforts can be derived from the study?

[1] See Hirsch and Management Information Services, Inc., January 2002.

III. LESSONS TO BE LEARNED FROM PAST FORECASTS

In hindsight, a large portion of the forecasts, projections, predictions, and associated policy recommendations turned out to be inaccurate, which is not surprising. The issue at hand is how a careful review of the past 50 years of energy forecasting can improve similar efforts in the future.

Our review of previous energy forecasts vividly illustrates how very difficult such forecasts are to make. On the one hand, a number of elements of past forecasts were correct and are likely to persist into the future. On the other hand, predictions that consistently turned out to be inaccurate in the past often provide guidance as to pitfalls to avoid in the future.

First, our analysis identified lessons learned that may aid current and future energy forecasting efforts. With respect to past energy forecasting errors, we think those summarized below are of particular note.

Many past forecasts consistently underestimated the size of world energy resources, particularly oil and natural gas. For example, world oil production has been predicted to peak within the next 10–15 years for at least the past 50 years. At present, the "experts" predict that world oil production might peak somewhere between 2020 and 2040. This may very well occur—at least for "cheap" conventional oil production. However, as (or if) the real price of oil increases substantially, new supplies of unconventional oil will likely be produced.[2] Nevertheless, the oil resource is finite and depleting, and at some point world oil production will peak.

Many of the major forecasts made over the past 50 years have tended to underestimate the role of prices and the adaptability of markets. The free market works, often with a vengeance, but this seems to be a lesson *not* learned.

Energy technology forecasters frequently failed to fully appreciate that they are dealing with moving targets, for existing technologies will continue to be improved over time. Thus, while impressive advances in some new technologies are being made, substantial improvements in the competition, such as conventional electric power generation or the internal combustion engine, are also occurring. Thus, in some cases, energy technology forecasters are like "the generals who are very good at fighting the last war."

[2] However, it is worth noting that the current 2002 real (inflation adjusted) price of oil is likely no higher than it was in the late 1800s and that the current real price of gasoline is about what it was in 1949.

Table 1. Selected major energy technology forecasting studies, 1952–2001

Study	Author	Date Published	Forecast Period	Years Covered	Major Findings
Energy Needs, Choices, and Possibilities: Scenarios to 2050	Shell International	2001	50 years	2000–2050	Entering a particularly innovative period of energy development; oil production peaks after 2025, gas peaks between 2025 and 2050, nuclear power is not competitive, renewables constrained by storage requirements; new vehicle technologies emerge; shift toward distributed and decentralized power options.
International Energy Outlook 2001	DOE/EIA	2001	21 years	1999–2020	World energy consumption will increase 59% by 2020, with most of the increase occurring in the developing world; by 2020, world oil price will increase to $22 (1999 $); by 2020, developing nations will consume as much oil as developed nations; by 2020, natural gas will supply 44% more energy than coal; nuclear power will increase until 2010, then decline; world CO_2 emissions will increase 60% by 2020.
GRI Baseline Projection: 2000 Edition	Gas Technology Institute	2001	15 years	2000–2015	Electric generation industry will be transformed by deregulation and decentralization; gas supplies from the Gulf of Mexico and Canada will become increasingly important; gas producers will adopt just-in-time manufacturing to minimize risk and monetize resources.
Scenarios for a Clean Energy Future	Five DOE Laboratories	2001	50 years	2000–2050	Identifies policies and R&D requirements that could significantly accelerate development of clean energy technologies; energy R&D policy must address global warming, air pollution, oil supply vulnerability, and energy infrastructure inefficiencies; achieving clean energy goals will require dramatic change in government policies and national will.
Annual Energy Outlook 2001	DOE/EIA	2000	20 years	2000–2020	World oil production will increase from 76 million bbls/day in 1999 to 117 bbls/day in 2020, and OPEC production will double; real U.S. electricity prices will decline continuously through 2020; U.S. energy consumption will increase from 96 quads in 1999 to 127 quads in 2020; U.S. energy intensity will decline through 2020.
World Energy Outlook 2000	International Energy Agency	2000	20 years	2000–2020	More decisive action is required to reduce global CO_2 emissions; energy use and GHG will grow much faster in the world's poorer nations than in the wealthier ones; world will become more dependent on Middle East oil; energy-related CO_2 emissions will increase 60% by 2020.

Table 1. Continued.

Study	Author	Date Published	Forecast Period	Years Covered	Major Findings
Projecting Energy Trends into the New Century	Stanford Energy Modeling Forum and EIA	2000	25 years	1995–2020	EIA forecasts have consistently underestimated energy consumption; forecasts usually err by projecting current energy policies into the future; most models are still probably overestimating future oil prices; most forecasts predict greater electrification, more natural gas, and less coal and nuclear.
Future World Oil Prices and the Potential for New Transportation Fuels	DOE and DOE Laboratories	2000	20 years	2000–2020	Availability of alternative fuels will limit OPEC's ability to raise prices; Fischer-Tropsch diesel will be the first alternative fuel to become economically viable; ethanol is not a viable alternative for either replacing oil imports or for reducing GHG; most alternative fuels will not be produced in the United States.
Vision 21: Fossil Fuel Options for the Future	National Research Council	2000	20 years	2000–2020	DOE should focus on advanced technologies that provide options for using fossil fuels in a carbon-constrained world; substantial improvements are required to eliminate nearly all environmental emissions and wastes; focus of the program should be on coal gasification.
Electricity Technology Roadmap: Powering Progress	EPRI	1999	50 years	2000–2050	Electricity-based innovation is central to productivity growth; electricity will increasingly shoulder society's burden for energy-related environmental control; a new mega-infrastructure is emerging from the convergence of electricity and communications.
Energy Markets and Policies over the Next 25 Years	Stanford Energy Modeling Forum	1999	25 years	2000–2025	Renewables and natural gas are forecast to gradually replace coal and oil; government policies will restrain growth of fossil fuels, even if they are cheaper; surprises are likely to result from aggressive environmental policies for specific pollutants; new smaller, modular nuclear technologies will emerge.
Meeting America's Kyoto Protocol Target: Policies and Impacts	American Council for an Energy Efficient Economy	1999	20 years	2000–2020	The United States can meet its emissions target under Kyoto; new policies are needed to stimulate energy efficiencies and to accelerate the adoption of renewable energy sources and the shift from carbon-intensive fossil fuels; new policies are justified even if global warming is not a concern.
Natural Gas: Meeting the Challenges of the Nation's Growing Natural Gas Demand	National Petroleum Council	1999	16 years	1999–2015	Actual U.S. natural gas consumption has exceeded forecasts, and is projected to continue to do so; electricity generation will account for 50% of increased gas requirements through 2010; new environmental regulations could increase gas demand; U.S. gas demand will be met by domestic production, increasing imports from Canada, and increased LNG.

Global Energy Address	Peter Bijur–Texaco	1998	17 years	1998–2015	Future changes to the energy industry will be revolutionary, not incremental; new energy companies will emerge as high-tech, high service, high solution firms; distinction between oil, gas, and electricity will blur as new entities offer“units of power”, emergence of new technologies and relationships will drastically alter energy markets and businesses.
Federal Energy Research and Development for the Challenges of the 21st Century	PCAST	1997	33 years	1997–2030	World energy demand will double by 2030 and increase four-fold by 2100; fossil fuels will supply 67% of world energy demand in 2030 and 50% in 2100; R&D challenges include controlling energy costs, reducing U.S. oil imports, and building international markets for U.S. energy technologies.
Energy Technologies for the 21st Century	International Energy Agency	1997	33 years	1997–2030	IEA members must collaborate on development of new energy and environmental technologies; the need to contain GHG will drive technology development; major barriers to new technologies are nontechnical; demonstration and testing of new technologies should be a joint government/ private industry initiative and should be accelerated.
Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond	DOE Interlaboratory Working Group on Energy Efficient and Low Carbon Technologies	1997	25 years	1995–2020	A vigorous national commitment to appropriate energy technologies can reduce U.S. energy consumption and carbon emissions in 2010 to levels of the early 1990s; energy savings from the technologies can equal or exceed the costs; the next generation of energy technologies can enable the continuation of an aggressive pace of carbon reductions beyond 2020.
Energy Innovations: A Prosperous Path to a Clean Environment	ASE, ACEEE, NRDC, TI, and USC[a]	1997	35 years	1995–2030	A balanced national strategy is required to put the United States on the path to an economically and environmentally sustainable energy future; moving to the new energy system would reduce energy consumption, improve the environment, and save money; changes in public policies are required to achieve this path.
World Energy Outlook, 1995	International Energy Agency	1995	15 years	1995–2010	Global energy system will remain overwhelmingly dependent on fossil fuels; most increases in energy requirements will come from developing nations; the importance of natural gas will increase significantly; increasing energy demands will generate formidable investment requirements; increased energy consumption will degrade the environment, and CO_2 emissions will increase by 40% by 2010.

Table 1. Continued.

Study	Author	Date Published	Forecast Period	Years Covered	Major Findings
Coal: Energy for the Future	National Research Council	1995	45 years	1995–2040	DOE planning horizon should be extended to 2040; increased R&D required for clean fuels, emissions reductions, and efficiency; second and third generation gasification systems should be given highest priority; DOE's coal liquefaction program should be extended; systems analysis should be given increased priority in DOE's R&D program.
Global Energy and Electricity Futures	Chauncy Starr, Electric Power Research Institute	1993	70 years	1990–2060	Increased energy consumption and at least a doubling of carbon emissions are inevitable; climate change is inevitable, but manageable; potential for renewable energy is limited; nuclear power must be relied on to provide required energy.
Energy for Tomorrow's World	World Energy Council	1993	30 years	1990–2020	Declining benefits from energy efficiency measures; fossil fuels will continue to dominate through 2020 and well beyond; nuclear power will increase in importance; greenhouse gas emissions may double by 2020; $30 trillion (U.S.) investments in energy required by 2020; key issue remains economic growth and access to adequate energy supplies.
Energy for 300 Years	Institute for Risk Research, University of Waterloo	1992	300 years	2000–2300	World population will stabilize at 10 billion within the next century; adequate, sustainable energy future is possible if population stabilizes; risks from producing the required energy are small relative to the benefits; energy sources of the future are coal and nuclear breeder technology.
America's Energy Choices: Investing in a Strong Economy and a Clean Environment	ACEEE, ASE, NRDC, UCS[b]	1991	40 years	1990–2030	Energy consumption and carbon emissions can be reduced; energy efficiency and renewable energy use can be greatly expanded to provide required energy services; government intervention is required to ensure this result.
Fuels to Drive Our Future	National Research Council	1990	20 years	1990–2010	U.S. oil production is declining and oil companies are investing abroad; increased R&D can significantly expand U.S. reserves; production of alternate liquid fuels will occur outside of the United States; biomass-derived fuels will cost more than fossil-derived fuels.
The Potential of Renewable Energy: An Interlaboratory White Paper	Five U.S. Department of Energy Laboratories[c]	1990	40 years	1990–2030	Contribution of renewable energy will increase, only the rate is uncertain; greatly expanded federal R&D and policy incentives for renewables are required; nonmarket externalities must be incorporated into energy planning; United States is falling behind foreign competitors in renewable technologies; federal leadership is key.

Energy Security to 2000	NIRA, CSIS, RIIA[d]	1987	15 years	1985–2000	Periodic crises in energy and oil supplies will continue; the share of Middle East oil will increase; low oil prices will reduce investments in new energy technologies and conservation, and government intervention is required to prevent this; strong government actions required; R&D should focus on renewables, coal liquefaction and gasification, and transportation fuels.
Global Energy: Assessing the Future	Institute for Energy Analysis, Oak Ridge National Laboratory	1985	65 years	1985–2050	Rate of growth in energy demand slows substantially; world oil prices fall through 2000, then rise and level off by 2025; electricity becomes increasingly important in final energy use; conservation in end-use fuels is thwarted by need for higher-quality fuels; dramatic shifts in fuel shares occur; United States becomes an oil exporter by 2050; coal becomes the dominant primary energy source.
Energy After the Eighties	International Energy Agency	1984	26 years	1984–2010	There are economically efficient and technically feasible alternatives to continued heavy dependence on imported oil; without vigorous action, energy dependency will worsen by 2000; investments in energy technologies must increase at a rate faster than GDP growth.
Energy Projections to the Year 2000	DOE	1981	20 years	1980–2000	U.S. net oil imports will plateau until 1985 and then decline continuously thereafter; domestic U.S. energy production will increase continuously through 2000; oil prices will continue to increase at a rate faster than other energy prices.
Energy in Transition, 1985–2010: Final Report on Nuclear and Alternative Energy Systems	National Research Council	1980	30 years	1980–2010	Reducing energy consumption is the key; energy conservation is required; federal energy R&D should emphasize energy conservation, energy efficiency, and renewable energy.
Energy Future: Report of the Energy Project at the Harvard Business School	Robert Stobaugh and Daniel Yergin, editors	1979	23 years	1977–2000	Extremely pessimistic as to prospects for increased energy supply; oil imports must be limited to their 1977 levels; a 40% reduction in energy consumption from 1979 levels is possible; substantial federal R&D expenditures and policy incentives for energy conservation and renewables are required; major problems are market imperfections and institutional barriers.
Energy In America's Future	Sam Schurr–Resources for the Future	1979	22 years	1978–2000	The key problems with U.S. energy policy are political and institutional, not technological or economic; rate of growth of energy consumption can be slowed significantly; national energy needs can be supplied at prices twice the real 1978 levels; energy shortages are not a constraint to economic growth; environmental problems associated with energy can be managed.

Table 1. Continued.

Study	Author	Date Published	Forecast Period	Years Covered	Major Findings
Alternative Energy Demand Futures to 2010	National Research Council–Committee on Nuclear and Alternative Energy Systems (CONAES)	1979	35 years	1975–2010	It is technically feasible to use the same amount of energy (or less) in 2010 as in 1975 and still accommodate population and economic growth; regulation and incentives are required to achieve this; the most important constraints are economic, not technological; the costs of energy efficiency are modest compared to the costs of developing new energy supplies.
U.S. Energy Supply Prospects to 2010	National Research Council, National Academies of Science	1979	32 years	1978–2010	World oil production will peak and then level off sometime between 1990 and 2000; U.S. oil imports will begin declining in the early 1980s; U.S. conventional oil and gas production will decline beginning in the 1980s and will be replaced by synfuels; nuclear power is vital beyond 1990; breeder reactor development should be accelerated.
Energy: The Next Twenty Years	Ford Foundation and Resources for the Future	1979	20 years	1980–2000	There is no serious energy gap or crisis and the world is not running out of energy; world will remain dependent on Middle East oil indefinitely; energy prices should reflect energy costs; conservation is cleanest, quickest, and cheapest short term and long term option; R&D offers no panacea.
Domestic Policy Review of Solar Energy	U.S. Department of Energy	1979	25 years	1975–2000	"Maximum practical effort" could increase renewable energy share to 20% of U.S. total in 2000; U.S. energy consumption must be curtailed; increased energy R&D required; substantial energy policy changes and government intervention are required.
Alternative Energy Futures: An Assessment of U.S. Options to 2025	The E235 Alternative Energy Futures Study Team–Stanford University	1979	45 years	1980–2025	Large reductions in future U.S. energy consumption are possible; substantial changes in societal values and energy consumption patterns are required by 2025 to achieve this; Americans must become more cooperative, interdependent, and energy and environmentally conscious; societal restraints, government intervention, and major federal energy R&D programs are required.
The Least-Cost Energy Strategy: Minimizing Consumer Costs Through Competition	Roger Sant/Carnegie Mellon	1979	22 years	1978–2000	A least-cost energy strategy and increased energy productivity could reduce U.S. energy consumption significantly with no changes in lifestyles; federal energy R&D should be focused on developing energy efficient technologies, but no financial incentives should be given to energy conservation or renewables.

Toward a National Plan for the Accelerated Commercialization of Solar Energy: The Implications of a National Commitment	MITRE Corporation	1979	22 years	1978–2000	Achieving the national goal of having solar energy provide 20% of U.S. energy requirements by 2000 is possible, but will be extremely difficult; achievement will require extraordinary federal R&D investments and incentives policies; solar energy utilization will vary greatly by region and market; accelerated solar initiatives will increase environmental pollution.
Pathway to Energy Efficiency: The 2050 Study	Friends of the Earth	1979	70 years	1980–2050	The United States can achieve a 64% reduction in energy use per capita; reduction in energy use is the only way to avoid confrontation with developing nations; major changes in social institutions, community patterns, demographics, and in the mix of goods, services, and employment are required.
Solar Energy: A Comparative Analysis to the Year 2020	MITRE Corporation	1978	43 years	1977–2020	Solar energy can displace significant quantities of fossil and nuclear fuels; by 2020, solar energy could supply 18% of U.S. energy requirements, but major contributions do not occur until after 2000; economic and social incentives are required; solar energy applications are highly market and region dependent.
The National Energy Plan	Executive Office of the President	1977	10 years	1975–1985	United States poised at third historic energy transition; energy consumption and rate of growth of energy demand must be reduced; energy conservation and renewable energy must be emphasized; coal is the key bridge fuel.
Providing for Energy: Report of the Twentieth Century Fund Task Force on United States Energy Policy	Twentieth Century Fund	1977	25 years	1975–2000	Increased energy production is the key; rapid development of U.S. domestic energy resources is required; federal energy R&D must be greatly expanded; price incentives are required to develop U.S. energy resources.
Solar Energy in America's Future	Stanford Research Institute	1977	45 years	1975–2020	United States consumes 180 quads in 2020; western coal production, shale oil, and synfuels increase dramatically, oil and natural gas production decline, and by 2020, 600 1000-MW nuclear power plants are in place in United States; solar energy increases to 44 quads by 2020; key factor is public attitude toward nuclear energy; without nuclear power, United States is energy constrained.
Energy Supply to the Year 2000	Workshop on Alternative Energy Strategies	1976	25 years	1975–2000	World oil production will peak in 1990, level off, and then decline after 2000; natural gas will be limited by transportation and distribution problems, not supply; coal production will expand three-fold by 2000; nuclear will supply 20% of world's energy by 2000; synfuels production will increase rapidly; limited prospects for hydro, geothermal, and renewables.

Table 1. Continued.

Study	Author	Date Published	Forecast Period	Years Covered	Major Findings
A Time to Choose: America's Energy Future	Energy Policy Project of the Ford Foundation	1974	26 years	1974–2000	United States can and should reduce its rate of growth of energy consumption to near zero; there is no set relationship between rate of growth of GDP and rate of growth of energy requirements; United States should embark on a massive public and private campaign of energy conservation; federal policy, incentives, and R&D should be redirected from energy supply to energy conservation.
Energy R&D and National Progress	Ali Cambel–Interdepartmental Energy Study Group	1965	35 years	1965–2000	U.S. energy resources are adequate through 2000; depletion of U.S. oil reserves requires development of alternative fossil fuels; there is a strong necessity for federal energy R&D and energy strategy; optimistic: smooth transition to nuclear and synthetic fuels is anticipated.
Resources for Freedom	Paley Commission	1952	25 years	1950–1975	Finite energy resources constrain growth, but technological improvements will keep pace; there is a fixed relationship between energy and GDP; government intervention is required to ensure adequate energy technologies and supplies.

Note: Management Information Services, Inc., 2003.

[a] Alliance to Save Energy, the American Council for an Energy-Efficient Economy, the Natural Resources Defense Council, the Tellus Institute, and the Union of Concerned Scientists.

[b] American Council for an Energy Efficient Economy, Alliance to Save Energy, Natural Resource Defense Council, Union of Concerned Scientists.

[c] Idaho National Engineering Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, Sandia National Laboratories, and the Solar Energy Research Institute.

[d] National Institute for Research Advancement, Tokyo; Center for Strategic and International Studies, Washington; Royal Institute of International Affairs, London.

Many past forecasts have assumed/predicted a new environmental/conservation/energy ethic on the horizon for the United States. This has not occurred, although the nation has continued to improve its efficiency in the use of energy (energy per unit of GDP, for example). Part of the problem may be that, although in public opinion polls (and often in the voting booth) Americans are overwhelmingly in favor of the environment, energy efficiency, and renewable energy, they overwhelmingly do not vote that way with their dollars and lifestyles. Thus we should heavily discount any energy forecast that even hints that people or society will act any differently in the future than in the present or the past. Many studies have assumed long-term changes in the U.S. population's energy preferences, environmental ethics, lifestyle, commuting habits, and even dietary preferences. A more likely assumption is that people will behave over the next 20, 30, or 40 years in about the same way they have over the past 20, 30, or 40 years.

One of the most important parameters to forecast is total U.S. primary energy consumption. However, most forecasts have overestimated primary energy consumption by substantial amounts.

Many forecasting studies identify the barriers to new energy technology development as being institutional, political, and policy related, rather than economics, which has in fact been the primary barrier. They then state that these barriers must be removed so that the favored technologies can flourish. This can be interpreted as saying "if businesses and consumers will not adopt these technologies voluntarily for economic reasons, we must pass laws to force them to do so."

Photovoltaics, fuel cells, wind power, and a variety of other technologies have been predicted to become economically viable within 5 years for a very long time. These and other technologies appear to hold great promise for the future and, indeed, they may someday become viable. Nevertheless, the experience of the past four decades suggests that it is not without considerable risk to suggest that these technologies may be '5 years away from being commercially viable'.

Even the most sophisticated energy forecasts are strongly influenced by events and trends of the time of the forecasts. Most obviously, all of the major forecasts made during the 1970s and early 1980s predicted that the real price of oil would increase dramatically in the near future which, of course, did not happen.

Government energy forecasts seem to be at least indirectly influenced by politics and political constraints. At a minimum, even the high-quality EIA work is constrained by mandated policy and regulatory assumptions. Some forecasts are more directly influenced by political considerations. Was a series of optimistic forecasting studies by the DOE laboratories during the 1990s relating to energy efficiency and renewable energy favored by the Clinton Administration influenced by politics? In the early 1980s, the first comprehensive forecasts made by the Reagan Administration predicted that U.S. oil imports would decline after 1985 as a result of the policies of the new Administration and the reversal of the "failed" policies of the past. Was politics a factor? In fact, energy efficiency and renewable energy programs are still struggling, and U.S. oil imports have been increasing relentlessly for the past 30 years.

Objective, rigorous studies can derive some contradictory findings. For example, the 1977 Stanford Research Institute study *Solar Energy in America's Future* concluded that nuclear power was the key to the U.S. energy future,[3] but that has not proven to be the case, at least thus far.

Engineering and technical feasibility forecasts often err by confusing what is technically feasible or feasible in an engineering sense with what is likely in the future. Thus we have 30 years of optimistic forecasts for various technologies and concepts that have yet to achieve significant market penetration.

The current accepted wisdom is basically "in gas we trust." However, not too long ago, in the United States we tried to prohibit use of natural gas in many industrial and utility applications, and some jurisdictions even banned its use to heat people's swimming pools, because forecasts at the time had the United States running out of natural gas.

The United States cannot decide what it wants to do with coal and nuclear power—this has not changed in 40 years.

The future contribution of solar energy and renewables has been consistently misforecast for the past 50 years; for example, the 1952 Paley Commission report predicted 10 million solar homes in the United States by 1975; the 1977 U.S. National Energy Plan predicted 2.5 million solar homes by 1985, the DOE laboratories studies during the 1990s predicted solar commercialization within 10 years, etc. Although many advocates have great expectations for renewable energy, all of the major objective studies reviewed here indicate that the contribution of renewables will remain very small for at least the next 20 to 30 years.

Many studies have blamed the failure to include "negative externalities" in energy costs as the reason

[3] Stanford Research Institute, 1977.

for certain technologies not being cost competitive. Although theoretically appealing, rigorous studies of this issue indicate that the actual price adders for externalities are quite low and may not be that important. For example, the National Research Council of the National Academy of Sciences has estimated that the externality price adder for gasoline in the United States is only about $0.30.[4] Thus, beware of this pitfall in forecasting.

Over the past three decades, many researchers in academia, the DOE, the DOE laboratories, advocacy organizations, and research institutes have invested their entire professional careers in specific energy technologies and energy systems. Their analysis and forecasts reflect this—if even inadvertently. This potential bias must be kept in mind in assessing related forecasts.

Over the past 40 years, some of the most egregious forecasting errors have often been made by the smartest people, working for the most prestigious organizations, with the most money; for example, the 1974 Ford Foundation study, the 1977 Stanford study, the 1979 Harvard study, etc.[5] Thus it is important to keep in mind that the accuracy and validity of an energy forecast is not necessarily correlated with status of the persons making it or the money invested in the project.

The only new energy source the world has developed over the past century is nuclear power, and, after 60 years experience with the technology, we still do not know what we want to do with it. This should be a cause for serious reflection.

A major topic in some recent forecasts concerns the future market potential for distributed generation, decentralized small energy systems, etc. Actually, many of them are not new, for example, wood fireplaces, coal stoves, rural windmills, etc. Technological progress has moved in the opposite direction for 200 years. Are we really going to reverse ourselves over the next several decades? Do businesses and consumers really want to have to manage their own micro energy plants 24 × 7? The same people who do not change the oil in their car or program their VCR? Once again, forecasts based on assumed changes in people's behavior must be viewed with a high degree of skepticism.

In many countries, especially in Europe, retail energy prices are relatively unresponsive to changes in actual energy costs and prices, because most of the retail price consists of taxes. From a free market standpoint, this is unfortunate, because it obscures market signals and contributes to the instability of world energy markets.

The major energy forecasting studies conducted from the early 1970s through the early 1980s disagreed on many things, but they generally agreed on four major points, namely that by 2000: (1) world real energy prices would rise substantially; (2) world oil production would peak and then decline; (3) energy conservation would become the new ethic; and (4) renewable energy technologies would become cost competitive and flood the market. However, *none of these actually came to pass*. This should make us cautious and humble in preparing energy forecasts.

The most important event of the past quarter century, and one that *no one* predicted, was the implosion and disintegration of the Soviet Union. This has had a profound effect on world energy supply and demand. The above point may provide some caution even today. The most important factor that "everyone" currently agrees on is the critical role of China over the next several decades in determining total world energy requirements, demands for new energy technologies, coal production and utilization, nuclear power, environmental pollutants, and global warming. However, how viable is the current hybrid Chinese communist/ socialist/ free market system? It is at least conceivable that China could collapse into political and economic chaos, or at least vastly underperform current expectations. This could have profound, unforeseen effects on world energy markets.

Fusion has been 20–30 years away from commercialization for over 30 years. Today, virtually no one expects fusion to make any significant impact before 2050; although, once again, this does not necessarily mean that it will not happen.

Beware of studies (of which there are many) that conclude that "technology X" will save the world if only we will spend $___ billion in R&D on it over the next 20 years. Many have so spoken, and relatively little has been realized.

IV. OBSERVATIONS AND IMPLICATIONS FROM PREVIOUS ENERGY STUDIES

As discussed above, a large fraction of previous forecasts, projections, and predictions turned out to be inaccurate in very significant ways. Predictions that were consistently incorrect in the past can provide guidance as to pitfalls to avoid in the future.

[4] National Research Council, 2002. Also, see the discussion in Krupnick and Burtraw.

[5] Ford Foundation, 1974; Stanford Research Institute; Stobaugh and Yergin.

Conversely, a number of elements of past forecasts were correct, and many may well persist into the future and influence energy and technology forecasts; these include the following:

- The U.S. population will continue to increase.
- U.S. economic growth will likely continue at a long-term average rate of about 2%–3% annually. U.S. energy consumption will continue to increase, but at a slower rate of between 1% and 2% annually. Thus, absent any major policy or societal shifts, the U.S. economy will continue to become less energy intensive over time, but the energy consumption per capita will nevertheless continue to increase.
- The gradual electrification of the U.S. economy will continue, and the economy will become more electricity intensive over time.
- Natural gas will continue to increase in importance, although it is unclear how long this trend will last. In any case, its price will remain volatile.
- In the United States, the price of electricity will likely continue to gradually decline in real terms. Over time, this will make it increasingly difficult for many new energy technologies to compete on a nonsubsidized basis.
- U.S. net oil imports will continue to gradually increase, reaching 65%–70% in the 2015–2020 timeframe. There appears to be no politically or economically feasible way to alter this trend.
- The United States and the world will gradually become even more dependent for oil on the OPEC members in the Middle East.
- World oil prices will remain volatile but may increase little in real terms over the next 20 years.
- The U.S. population will remain adverse to any substantial increases in energy taxes.
- Environmental protection will remain a high priority in the U.S., and global warming will remain a major concern.
- Energy technologies, technology requirements, and technology development will be more influenced by environmental concerns than by most other factors.
- “Magic bullet” breakthroughs in potentially important technologies will remain elusive but periodically much hyped.
- The shape and form of the energy industries will likely change, but precisely how remains uncertain.
- World population will continue to increase, primarily in the developing nations. This will increasingly influence future energy and environmental trends, related problems, and the policies and technologies developed to address them.
- The developing nations, especially China and India, will account for an increasing share of world energy consumption, environmental emissions, and GHG, and by 2010 will likely surpass the developed nations in these areas. Therefore future energy and environmental technology development will be increasingly dictated by developing nations’ circumstances.
- Increased world carbon emissions are likely inevitable under any realistic scenario.
- Maintaining adequate economic growth, especially for the developing nations, will remain much more important than artificially limiting the growth of energy consumption.
- Nonhydro renewables will continue to increase in importance and account for a larger share of U.S. energy supply; however, because they start from such a small base, barring technological breakthroughs or new regulations, their overall contribution will remain negligible.
- There will likely continue to be periodic “energy crises” that will generate intense concern and interest in the short run, but will be largely forgotten in the longer term. Thus policy changes are less likely, once prices decline and normalcy returns.
- Surprises—both pleasant and unpleasant—will periodically continue to occur. Examples from the past include the collapse of the Soviet Union, the collapse of oil prices in the late 1980s, the Internet, personal computing, wireless technologies, the development of deep water production capabilities, and the terrorist attacks of September 11, 2001, to name but a few.

V. ENERGY FORECASTS RETROSPECTIVE AND PROSPECTIVE: SOME CAUTIONARY EXAMPLES

One of the major findings that emerged from our study is that accurate long-range forecasting of even the most basic energy data is difficult, and the track record of the studies reviewed here is not good. The difficulties encountered over the past several decades can be illustrated with several examples.

First, one of the most important parameters to forecast is U.S. primary energy consumption. However, few

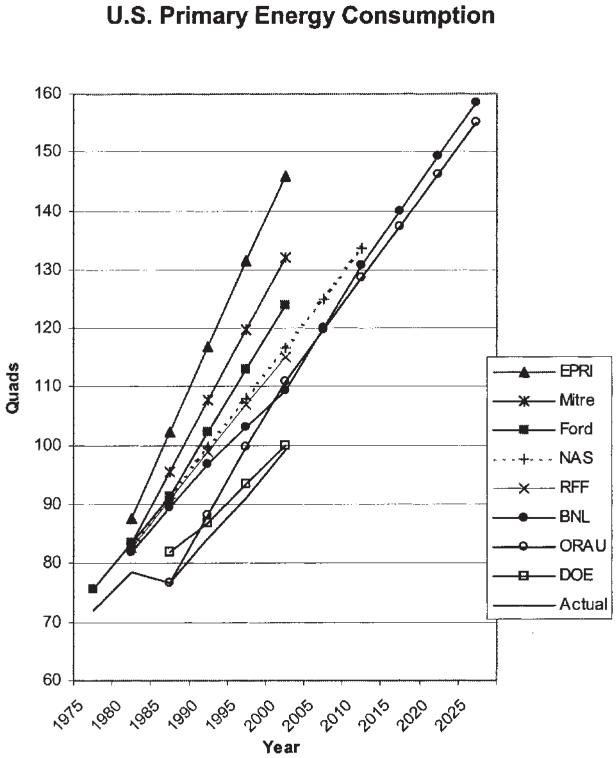

Fig. 1.

of the major forecasting studies reviewed here did an adequate job of forecasting this parameter, as illustrated in Fig. 1. This figure compares actual 2000 U.S. primary energy consumption with forecasts made between 1974 and 1985 by the Ford Foundation (1974), the Electric Power Research Institute (1978), Resources for the Future (1979), the MITRE Corporation (1979), Brookhaven National Laboratory (1979), the National Research Council of the National Academy of Sciences (1980), Oak Ridge Associated Universities, Oak Ridge National Laboratory (1985), and the Department of Energy's Energy Information Administration (1982).[6]

Figure 1 illustrates that, with the exception of EIA, all of the forecasts were highly inaccurate and substantially overestimated U.S. energy consumption. For example:

- EPRI's *conservative* forecast, made in 1978, overestimated 2000 U.S. primary energy consumption by nearly 50%.
- MITRE's forecast, made in 1979, overestimated 2000 U.S. primary energy consumption by more than 30%.
- The Ford Foundation's "Technical Fix" forecast, made in 1974, overestimated 2000 U.S. primary energy consumption by 25%.
- RFF's *midrange* forecast, made in 1979, overestimated 2000 U.S. primary energy consumption by 15%.
- Even the most recent of the forecasts, that by Oak Ridge made in 1985, overestimated 2000 U.S. primary energy consumption by 11%.

Further, this figure indicates that the gap between actual and forecast energy consumption generally increased over time and, if we revisited this exercise in 5 or 10 years, the inaccuracies would be even more pronounced. Once again, the only exception to this is the DOE forecast, the midrange estimate made in 1981, which converged over time to the actual value and precisely forecast 2000 U.S. primary energy consumption of 100 quads. Although there are obviously many reasons for the differences in the forecasts, it is worth noting that, for all of the political and institutional constraints under which DOE/EIA labors, it probably deserves some credit for getting this forecast right.

Second, another very important variable of interest is the price of oil; over the past three decades immense effort has been expended in attempting to forecast future world oil prices. Nevertheless, as illustrated in Figs. 2, 3, and 4, the studies that we reviewed did a

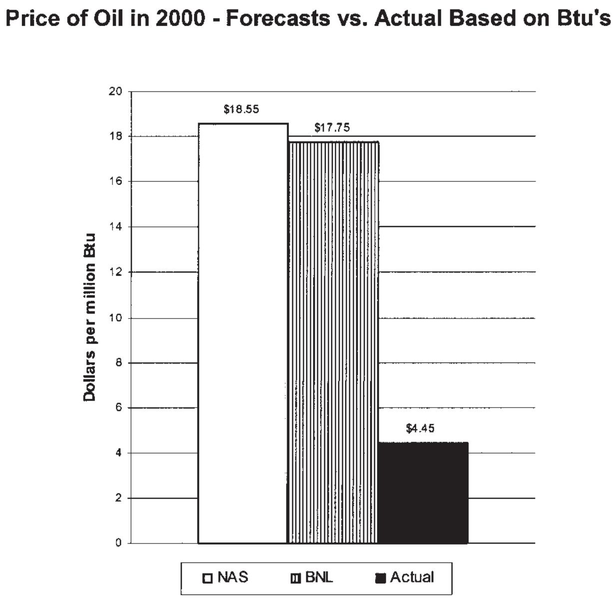

Fig. 2.

[6] Ford Foundation, 1974; Electric Power Research Institute, 1978; Hans Landsberg; MITRE Corporation, 1979; National Research Council, 1980; Jae Edmonds and John Reilly; U.S. Department of Energy, Energy Information Administration, 1982.

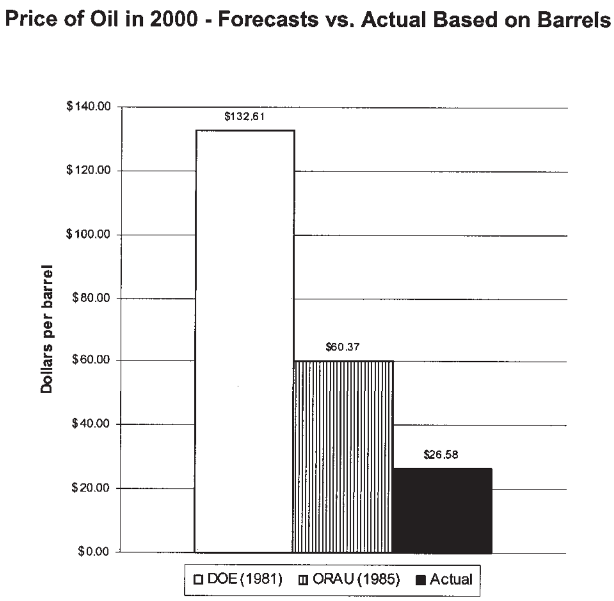

Fig. 3.

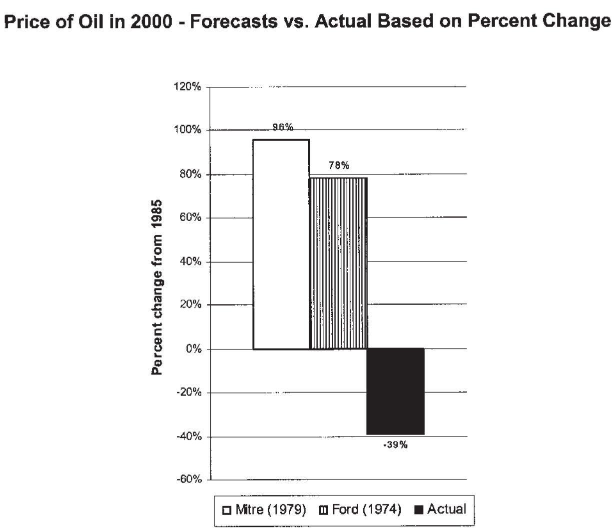

Fig. 4.

generally abysmal job of forecasting the actual 2000 world oil price:

- As shown in Fig. 2, in terms of dollars per MMBTU, both NRC/NAS and Brookhaven were high by more than a factor of four.
- As shown in Fig. 3, in terms of dollars per barrel, DOE was high by a factor of more than five. More discouraging, even the Oak Ridge forecast made in 1985—when oil prices had already collapsed—was high by a factor of more than two.
- As shown in Fig. 4, in terms of percentage change from the 1985 price, MITRE predicted a doubling and Ford anticipated a 75% increase; however in actuality, the real price of oil declined by nearly 40%. Thus the studies erred not only in the magnitude of the change but also in the direction of the change.

The price of oil is one of the most important commodity prices in the world and perhaps the one subjected to the closest scrutiny. Nevertheless, for decades, oil prices have stubbornly refused to behave as predicted. Inaccurate forecasts have created much skepticism about forecasting, as well as emphasizing the difficulties of energy industry planning.[7]

Finally, as noted earlier, forecasts of energy technology innovation and commercialization have often been highly inaccurate and overly optimistic. For example, consider Fig. 5, which compares the actual 2000 U.S. energy supply provided by solar energy (including wind) with the forecasts made by the MITRE Corporation (1979), the National Research Council of the National Academy of Sciences (1980), the Harvard Business School Energy Project (1979), the Department of Energy's Energy Information Administration (1981), and Brookhaven National Laboratory (1979).[8]

The actual solar/wind contribution to U.S. energy requirements in 2000 was 0.1 quad, whereas:

- The MITRE Corporation, in 1979, forecast that solar/wind would provide 8 quads.
- The Harvard Business School Energy Project, in 1979, forecast that solar/wind would provide 5 quads.
- The National Research Council, in 1980, forecast that solar/wind would provide 4.1 quads.
- The Department of Energy's Energy Information Administration, in 1981, forecast that solar/wind would provide 1.8 quads.
- Brookhaven National Laboratory, in 1979, forecast that solar/wind would provide 1.4 quads.

Thus the most accurate forecast was high by a factor of 14, the forecast made with the shortest time

[7] See the discussion in Cambridge Energy Research Associates and Arthur Anderson and Company.

[8] MITRE Corporation, 1979; National Research Council, 1980; Robert Stobaugh and Daniel Yergin; U.S. Department of Energy, Energy Information Administration, 1982; and Brookhaven National Laboratory, 1979.

Solar and Wind Supply in 2000 - Forecasts vs. Actual

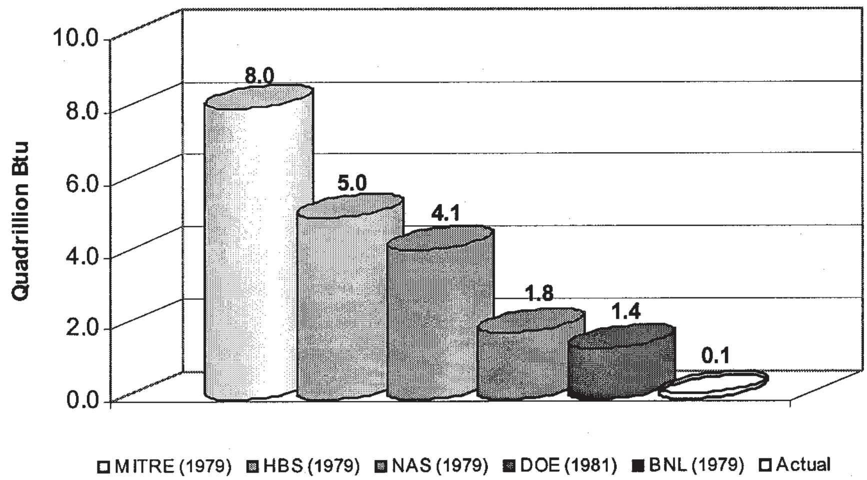

Fig. 5.

horizon was high by a factor of 18, and the average forecast of the five studies was high by a factor of more than 40. This gross inaccuracy is especially troubling because during the 1970s and early 1980s enormous time, effort, and resources were devoted to solar and wind energy technology specification, assessment, commercialization, and forecasting—probably more than for any other technology.

The point of the above examples is not to chastise the organizations or analysts that produced inaccurate forecasts. In truth, all of the studies involved good faith efforts, state-of-the art modeling techniques, highly competent researchers, and significant resources. Rather, reviewing the past track record graphically illustrates how complex and difficult energy forecasting is. Thus, in future long-range energy forecasting efforts, considerable effort will be needed to avoid the types of failures of the past. Hopefully, this review and analysis of previous energy forecasting efforts will aid in this formidable task.

VI. CONCLUSION

In conclusion, a review of the past energy forecasts illustrates how complex and difficult such forecasting is. It is especially sobering to realize that projections of just 15 to 20 years into the future can end up very much in error. Future long-term energy forecasting efforts must therefore take great care to avoid many of the pitfalls of past attempts to peer into the future.

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