Winner, Loser, or Innocent Victim? Has Renewable Energy Performed As Expected?

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Abstract

This study provides an evaluation of the performance of five renewable energy technologies used to generate electricity: biomass, geothermal, solar photovoltaics, solar thermal, and wind. We compared the actual performance of these technologies against stated projections that helped shape public policy goals over the last three decades. Our findings document a significant difference between the success of renewable technologies in penetrating the U.S. electricity generation market and in meeting cost-related goals, when compared with historic projections. In general, renewable technologies have failed to meet expectations with respect to market penetration. They have succeeded, however, in meeting or exceeding expectations with respect to their cost. To a significant degree, the difference in performance in meeting projections of penetration and cost stem from the declining price of conventional generation, which constitutes a moving baseline against which renewable technologies have had to compete.

Key Words: renewable energy, regulation, electricity generation, energy cost

JEL Classification Numbers: Q42, L94

Table of Contents

List of Tables and Figures

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EXECUTIVE SUMMARY

Public support for renewable energy technologies has been part of U.S. energy policy for nearly 30 years. Yet these technologies have failed to emerge as a prominent component of the U.S. energy infrastructure. This failure has created the impression that renewable technologies have not met the goals and claims of proponents, and that therefore after several decades of support without success, it is time to pull the plug on renewables.

This study evaluates the performance of renewable technologies for electricity generation measured against stated projections that helped shape public policy goals over the last three decades, and we evaluate this performance against projections and trends in conventional electric power generation. We propose two measures for evaluation. One is performance relative to projections for the contribution of renewable technologies to total electricity generation. The second is their performance relative to projections of cost.

The renewable energy technologies investigated are biomass, geothermal, solar photovoltaics, solar thermal, and wind. We reviewed 25 studies conducted over the last three decades that contained projections of the costs and market penetration of some or all of these technologies. All the studies included could not be given equal weighting, because the rigor of the analyses varied tremendously. To account for this variation, we developed several qualitative criteria related to the projections of both electricity production and cost. We then evaluated the studies according to these criteria.

Our findings document a significant difference between the success of renewable technologies in penetrating the U.S. electricity generation market and in meeting cost-related goals, when compared with historic projections.

For **market penetration**, we find:

- In general, renewable technologies have failed to meet expectations with respect to market penetration. One exception to this trend is wind, which has met projections from the 1980s, although earlier projections were overly optimistic. The other exception is biomass applications, for which market penetration has exceeded previous projections.
- For three of five of the renewable technologies reviewed, projections of installed capacity and generation have generally been revised downward over the past three decades. Graphs of these three sets of projections take the form of a "fan diagram" resulting from successive revisions downward of the projections.

- Nongovernmental organizations were generally more conservative than government, industry, or research organizations in their projections of capacity and generation of the various renewable technologies.

With respect to **cost**, however, the performance of renewable technologies is significantly different.

- Renewable technologies have succeeded in meeting expectations with respect to cost. For every technology analyzed, successive generations of projections of cost have either agreed with previous projections or have declined relative to them.
- In virtually every case, the path of actual cost has equaled or been below the projections for that period in time. The only exception appears in the case of capital costs for photovoltaics, where expectations from the 1970s and 1980s underestimated actual realized costs in the 1980s and 1990s.
- Retail prices of electricity from conventional sources have also been overestimated historically, yielding another fan diagram of projections from successive time periods.

These findings refute the premise that renewable technologies have failed to meet public policy goals, especially with respect to projections of cost, which we perceive to be the more important measure. This is remarkable, given that renewable technologies have not significantly penetrated the market, nor have they attracted large-scale investment and production that can contribute to technological development or economies of scale in production, as many analysts anticipated when forming their cost projections. The small market share of renewables appears to have more to do with changes outside their own development--principally regulatory reform and changes in conventional technologies--than with their technological performance. The industry appears to have been most successful with respect to factors most within their control.

Our analysis indicates the small market share of renewable technologies appears to have more to do with changes outside the development of renewable technologies than with their own technological performance. Over the roughly three decades we evaluate, regulatory reform has swept the energy industry. Prominent policy changes such as the deregulation of natural gas and oil coupled with declining technical costs of production have made these conventional energy fuels less expensive. An increasingly competitive world petroleum market has led to a decline and stabilization in the price of oil, such that currently the real price of oil is the lowest that has been observed since 1973. Deregulation of the railroads led to dramatic cost reductions for coal use in electricity generation. The Public Utility Regulatory Policies Act (PURPA) of 1978 opened the door for nonutility generation of electricity for resale, and the Energy Policy Act of 1992 opened the door for competitive wholesale generation. These changes and other technological developments have produced a dramatic decline in the price of fossil-fueled electricity generation. In addition, public policy and technological changes have led to a dramatic improvement in the environmental performance of these technologies (especially for newly constructed facilities).

The ultimate impacts of these changes in the regulation, technology and market structure of fossil fuels have been mostly favorable for electricity consumers; they have also been frustratingly disappointing for the fate of renewable technologies. Renewable technologies have had to compete in this changing environment. Hence, renewable technologies may be seen as a relative loser--perhaps the innocent victim--amidst the widespread success of a wide array of public policies aimed at energy markets.

We conclude that many significant expectations and public policy goals regarding development of renewable technologies for electricity generation have been achieved. Any argument that public policy support for renewable technologies should be ended because "past efforts have been unsuccessful" is based on a faulty premise. These findings should be of interest in the policy debate about the possible future role of renewable energy technologies, and about whether public policy can contribute effectively to the direction and pace of technological change.

While rejecting the negative, we can not make an unambiguously positive assertion. That is, we do not attempt to attribute the successful achievement of projected technological development and cost declines to a specific government policy or any other factor. We do not make a direct case for continued government support of these technologies. Nonetheless, the successful achievement of cost-related goals provides some reason for optimism with respect to the role of renewable technologies and of public policy in meeting future challenges such as the reduction in greenhouse gas emissions.

WINNER, LOSER, OR INNOCENT VICTIM?
HAS RENEWABLE ENERGY PERFORMED AS EXPECTED?

James McVeigh, Dallas Burtraw,
Joel Darmstadter, and Karen Palmer*

INTRODUCTION AND OVERVIEW

At least since the oil spill off the coast of Santa Barbara, California in 1969, the energy price upheavals of the 1970s, and the Three Mile Island meltdown of 1979, the choice of technologies to meet U.S. energy demand has appeared prominently on the agenda of U.S. public opinion and policy. Concerns about the environment, the economy, equity, monopoly power, and the role of the public sector have been manifest in the public debate. One outcome has been public policy and public-sector support, albeit sometimes faltering support, for the development of renewable energy technologies.

Nearly 30 years into this public discussion, the reality is that renewable technologies have failed to emerge as a prominent component of the U.S. energy infrastructure. This has created the perception that renewables have not met the goals and claims of proponents. The implication is that after several decades of support without success, it is time to *pull the plug* on renewables.[1]

This study does not address the merits of this claim nor its implication for public policy; instead it focuses on the premise of the argument--that renewable technologies have not met the goals and claims of their proponents. We evaluate the performance of renewable technologies for electricity generation measured against stated timetables that helped shape public policy goals, and we also evaluate these technologies against projections and trends in conventional electric power generation. The renewable energy technologies we investigated are biomass, geothermal, solar photovoltaics, solar thermal, and wind.

Our findings refute the premise that renewable technologies have failed to meet public policy goals. To summarize briefly, we confirm that *penetration* into the market has fallen far short of projections. However, the *costs* of these technologies generally have fallen in accordance with the projections of their proponents, sometimes exceeding the projected

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[1] For example, see: MISI (1998), and Bradley (1997).

decline. This is remarkable, given that renewable technologies have not significantly penetrated the market, nor have they attracted large-scale investment and production that can contribute to technological development or economies of scale in production, as many analysts anticipated when forming their cost projections.

Our analysis indicates that the small market share of renewable technologies appears to have more to do with changes outside their development than with their own technological performance. Over roughly three decades, regulatory reform has swept the energy industry. Prominent policy changes such as the deregulation of natural gas and oil coupled with declining technical costs of production have made these conventional energy fuels less expensive. An increasingly competitive world petroleum market has led to a decline and stabilization in the price of oil, such that currently the real price of oil is at its lowest since 1973.[2] Deregulation of the railroads led to dramatic cost reductions for coal use in electricity generation. The Public Utility Regulatory Policies Act (PURPA) of 1978 opened the door for nonutility generation of electricity for resale, and the Energy Policy Act of 1992 paved the way for competitive wholesale generation. These changes and other technological developments have produced a dramatic decline in the price of fossil-fueled electricity generation. In addition, public policy and technological changes have led to a dramatic improvement in the environmental performance of these technologies (especially for newly constructed facilities).

The ultimate impacts of these changes in the regulation, technology and market structure of fossil fuels have been mostly favorable for electricity consumers; they have also been frustratingly disappointing for the fate of renewable technologies. Renewable technologies have had to compete in this changing environment. Hence, renewable technologies may be seen as a relative loser--perhaps the innocent victim--amidst the widespread success of a wide array of public policies aimed at energy markets.

We conclude that many significant expectations and public policy goals regarding development of renewable technologies for electricity generation have been achieved. Any argument that public policy support for renewable technologies should be ended because "past efforts have been unsuccessful" is based on a faulty premise. These findings should be of interest in the policy debate about the possible future role of renewable energy technologies, and about whether public policy can contribute effectively to the direction and pace of technological change.

Although we reject the negative, we cannot make an unambiguously positive assertion. That is, we do not attempt to attribute the successful achievement of projected technological development and cost declines to a specific government policy or any other factor. We do not make a direct case for continued government support of these technologies.

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[2] Although the role of oil in electricity generation has diminished over time, it remained important to generation during peak periods of demand until recently. More important, in the 1970s and early 1980s the choice among conventional fuels was between oil and coal, as the availability of natural gas was in question. Hence, the decline in oil prices had an influence on the pace of technological change and cost reductions in the coal industry.

Nonetheless, the successful achievement of cost-related goals provides some reason for optimism with respect to the role of renewable technologies and of public policy in meeting future challenges such as reducing greenhouse gas emissions.

METHODS

To evaluate the performance of renewable technologies, we documented projections made by a variety of organizations (see List of Studies Reviewed) and compared them with what has actually transpired over the last three decades. These forecasts varied with respect to their intervals and ultimate time horizon. We report projections in five-year increments beginning in the 1970s, with forecasts as far as 2020. Our principal focus is performance to the mid-1990s. We follow up that discussion with a retrospective look at how projections for conventional power systems compare with actual outcomes over the same time horizon.[3]

Technologies

Each category of renewable energy technologies for electricity generation reviewed encompasses a variety of technologies, but for ease of discussion they have been aggregated into biomass, geothermal, solar photovoltaics, solar thermal, and wind. Hydropower has been excluded for two reasons: first, it has been developed so extensively that typically it is considered a conventional source of electricity, and, second, significant expansion of this resource would face severe opposition based on environmental concerns. Similar considerations apply to our exclusion of nuclear power, whose underlying resource base could, like geothermal energy, be viewed as virtually unlimited.

Subsidies and Incentives

The studies we reviewed differed in their level of sophistication of potentially important assumptions, including the treatment of subsidies and incentives for the development of renewable and nonrenewable technologies. On the federal level, these incentives included investment tax credits, production credits, and accelerated depreciation of capital. Many states offered various incentives for renewables, such as California's Interim Standard Offer contracts, which were offered to Qualifying Facilities and Cogenerators under PURPA, and additional investment tax credits of 10-15 percent. Direct expenditures by government on research and various other subsidies contributed to the development of not only renewable technologies but nonrenewable technologies as well.[4]

[3] Conventional power systems include all forms of generation, of which renewables are just a small portion.

[4] Expenditures through the Department of Energy on research, development, and demonstration projects for renewable and fossil technologies were about equal in 1980 and both were in excess of $1.3 billion. Both fell by nearly three-quarters by 1985, but by 1990 expenditures on renewables continued to fall to $129 million while expenditures on fossil rose to over $1.1 billion. In 1995 they were again similar, with renewables receiving $342 million and fossil receiving $504 (OTA, 1995, page 33; 1995 dollars).

The varied treatment of incentives in these studies is relevant in two ways. If possible, it would be best to control for the assumption about the level of public-sector incentives over the horizon contained in each study with respect to the cost projections and reported cost of each study, as well as with respect to projected market penetration. Unfortunately, most of the studies failed to make their assumptions explicit. Those that did so did not offer enough complementary detail to allow us to disentangle the effect of these assumptions from those of others in the study.

Therefore on this and many other issues we accept the projections at face value. That is, we do not adjust the projections for potential differences in their underlying assumptions.[5] Clearly, projections of cost and market penetration sometimes were built with anticipation of sustained high levels of government support. To the extent that this support did not materialize, was intermittent, or was dominated by support for conventional technologies, this could have weakened the performance of renewable technologies in comparison with the projections.

Characteristics of the Technologies

Another missing and potentially important piece of the analysis is an accounting of the special characteristics of renewable technologies that make their marginal cost in the delivery of energy services (and their environmental characteristics) differ in qualitative ways from other technologies. One aspect that detracts from their value to an electricity grid is the intermittent generation potential of solar and wind resources. Absent a technology such as hydroelectric pumped storage or batteries to store electricity and/or potential energy, the energy from the sun and the wind are only available a portion of each day. Often the availability coincides with periods of peak energy demand, but not always. The possible unavailability of these resources, especially at peak periods, detracts from their potential contribution to a system grid.

Yet these technologies have an offsetting virtue associated with their relatively small scale and independence from fuel supply. These attributes make siting easier and especially practical in remote areas not served by the electricity grid.[6] This feature enhances the "niche market" appeal of renewable technologies, particularly in remote areas of the Third World. Hence renewable energy will often compete not on the cost of energy, but on the basis of value provided to the customer. In addition, the distributed nature of these generation resources can be used to ease congestion and loop-flow problems on an electricity grid, thereby adding to their value within an electric system.

[5] Comments on preliminary versions of this paper have been on opposite sides of this issue. Renewable advocates have argued that we should look to contracting issues, subsidies, and market imperfections as obstacles to renewable technologies. A critic of renewables has argued the opposite, that we should look to these same issues to find preferential treatment of renewables. Indeed, these are important issues that have significant bearing on an evaluation of renewables, but they are not the focus of this study.

[6] There may be other impediments to siting of renewable generating facilities. For example, objections to noise levels and potential damages to migrating birds can complicate the siting of wind turbines (Gipe, 1995; Bradley, 1997).

Selecting Studies for Review

In designing the study, we tried to cover a wide range of the projections that were cast into the public debate, though of course we could not do so exhaustively. About 60 studies were located. Not all of those found could be given equal weighting, because the rigor of the analyses varied tremendously. To account for this variation we developed a qualitative scheme to evaluate the studies.

First, on subjective but fairly transparent grounds, we reduced the number of studies we reviewed in detail to 25.[7] Second, we constructed explicit criteria and evaluated the studies in light of these in order to develop weights that were applied to each study in the aggregate analysis. The criteria are listed in Tables 1 and 2.[8]

For each result, the median value among the studies (after accounting for the weighting) is the point used as an estimate.[9] It is noteworthy that the results are not highly sensitive to weights given to the studies. The overall results displayed in the next section are largely unaffected by our rating scheme compared with one that would have applied equal weights to each of the 25 studies. This is partly due to the use of a median value rather than a mean value of the weighted studies. This also indicates that the rigorous and not-so-rigorous studies were distributed about equally in the sample.

Also reported in Tables 1 and 2 is an affiliation of the author or authors by categories described below. The column Broad Technical Specification indicates whether the study addressed all, many, or just one of the renewable technologies we considered. Further, the Tables indicate the range of years covered in the study. These two columns were not used in weighting the studies.

We organized the studies in two different ways. Our primary focus is a chronological organization by the decade when the studies were written (1970s, 1980s, and 1990s). A secondary focus is the affiliation of the authors: government agencies, research institutions (including national labs and academic groups), the Electric Power Research Institute (EPRI), and nongovernmental organizations (NGOs). In our sample, projections from within the

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7 For example, several studies were excluded because we were unable to locate the entire report. Others were largely journalistic in nature, lacking the technical detail to make their inclusion useful.

8 Criteria concerning projections of electricity production involved whether the following assumptions were explicit: policy initiatives, total electricity/energy demand, cost of conventional generation/fuel, and the continued existence of tax credits. Also we considered whether the assumptions or results were specified by region, and whether the study was original work.

Criteria having to do with projections of cost involved whether the following were explicit: the discount rate, year in which dollars are denominated, operating and maintenance cost, and capacity utilization rates. Again, we considered whether the study was original work.

9 A "score" of 0.5, 1.0, or 1.5 was given to each study with respect to each of the criteria, and the scores were tallied to develop an overall weight for each study with respect to production projections, and separately with respect to cost projections. Weights for projections of cost of capital and cost of electricity differ because the studies differed with respect to whether this information was explicit. Similarly, the weights for projections of capacity and generation differ because of information that may not have been explicit in the study.

Table 1: Weighting of Studies in Cost Projections
(Weights: solid = 1.5, partially solid = 1.0, empty = 0.5)

					Criteria Considered					Final Weighting	
Study #	Group Affiliation	Study	Broad Technology Specification	Projected Years Given	Discount rate indicated	Dollar Year Specified	O&M	Capacity Factor	Original Work	Cost of Capital	Cost of Electricity
19,20	GOVT	FEA, 1974	●	80,85,90	●	●	●	○	●	●	●
18	GOVT	ERDA, 1975	○	85,00	○	○	○	○	●	○	○
21	GOVT	FEA, 1976	●	90,85,90	●	●	⊙	○	●	⊙	●
5	EPRI	EPRI 1977	○	1975-2022	●	●	○	○	⊙	⊙	⊙
24	NGO	Lovins, 1977	⊙	1975-1990	⊙	●	○	○	⊙	●	○
29	GOVT	OTA, 1978	○	80,00	○	●	⊙	⊙	⊙	⊙	⊙
26,28	GOVT	CONAES, 1979	●	80,85,90,00	●	●	⊙	●	●	●	●
36	Research	STANFORD, 1979	●	90,25	●	●	●	⊙	○	●	●
27	GOVT	CONAES, 1979	●	80,85,90,00	●	●	⊙	●	●	●	●
9	GOVT	EIA, 1980	●	1975-2020	○	●	○	○	●	⊙	○
35	Research	SERI, 1981	⊙	1980-2000	●	●	●	●	●	●	○
37	Research	Stoughbaugh and Yergin, 1981	⊙	1980-2000	○	○	○	●	○	●	○
6	EPRI	EPRI, 1982	⊙	82,86,90	●	●	○	○	⊙	●	○
38	GOVT	DOE, 1982	●	1985-2000	○	●	○	○	●	○	○
39	GOVT	DOE, 1983	●	1985-2010	○	●	○	○	●	○	○
4	NGO	Duedney & Flavin, 1983	●	1980-2000	○	○	○	⊙	⊙	●	⊙
30	GOVT	OTA, 1985	●	1990-2000	●	●	●	●	●	●	⊙
11	GOVT	EIA, 1990	●	1990-2030	⊙	●	●	●	⊙	●	○
22	NGO	WWI, 1990	●	1980-2030	○	●	○	○	⊙	○	●
31	GOVT	OTA, 1995	●	2000-2030	●	●	●	●	●	●	●
23	NGO	Gipe, 1995	○	1990-2000	●	●	⊙	●	⊙	●	●
14	GOVT	EIA, 1997	●	1995-2020	⊙	●	○	●	●	○	○
32	GOVT	PCAST, 1997	●	1995-2010	⊙	●	⊙	⊙	⊙	●	●
7	EPRI	EPRI-DOE, 1997	●	1997-2020	●	●	●	●	●	●	○
15	GOVT	EIA, 1997b	●	NONE	○	●	○	⊙	●	⊙	○

Table 2: Weighting of Studies in Production Projections

(Weights: solid = 1.5, partially solid = 1.0, empty = 0.5)

					Criteria Considered						Final Weighting	
Study #	Group Affiliation	Study	Broad Technology Specification	Projected Years Given	Policy Assumptions	Total Energy/ Electricity Needs	Cost of Conventional Generation/Fuel	Tax Credits/Prod Incentives	Regional Specifications	Original Work	Capacity	Production
19,20	GOVT	FEA, 1974	●	80,85,90	●	●	●	○	○	●	●	●
18	GOVT	ERDA, 1975	○	85,00	●	●	⊙	○	○	●	⊙	⊙
21	GOVT	FEA, 1976	●	90,85,90	●	●	●	⊙	○	●	●	○
5	EPRI	EPRI 1977	○	1975-2022	⊙	●	●	⊙	●	⊙	○	●
24	NGO	Lovins, 1977	⊙	1975-1990	⊙	●	●	⊙	○	⊙	○	○
29	GOVT	OTA, 1978	○	80,00	⊙	⊙	○	●	⊙	⊙	⊙	○
26,28	GOVT	CONAES, 1979	●	80,85,90,00	●	●	⊙	⊙	⊙	●	●	●
36	Research	STANFORD, 1979	●	90,25	●	●	●	⊙	⊙	○	○	●
27	GOVT	CONAES, 1979	●	80,85,90,00	●	●	⊙	⊙	⊙	●	●	●
9	GOVT	EIA, 1980	●	1975-2020	●	●	●	○	○	●	○	●
35	Research	SERI, 1981	⊙	1980-2000	●	●	●	⊙	●	●	●	⊙
37	Research	Stoughbaugh and Yergin, 1981	⊙	1980-2000	⊙	⊙	⊙	⊙	○	○	○	○
6	EPRI	EPRI, 1982	⊙	82,86,90	⊙	⊙	○	○	●	⊙	○	○
38	GOVT	DOE, 1982	●	1985-2000	●	●	●	○	○	●	○	●
39	GOVT	DOE, 1983	●	1985-2010	●	●	●	○	○	●	○	●
4	NGO	Duedney & Flavin, 1983	●	1980-2000	⊙	⊙	⊙	○	⊙	⊙	●	○
30	GOVT	OTA, 1985	●	1990-2000	●	●	●	●	●	●	⊙	○
11	GOVT	EIA, 1990	●	1990-2030	●	⊙	●	○	○	⊙	○	●
22	NGO	WWI, 1990	●	1980-2030	⊙	⊙	○	⊙	○	⊙	○	○
31	GOVT	OTA, 1995	●	2000-2030	●	⊙	⊙	●	⊙	●	○	○
23	NGO	Gipe, 1995	○	1990-2000	⊙	⊙	⊙	●	⊙	⊙	○	●
14	GOVT	EIA, 1997	●	1995-2020	●	●	●	●	●	●	●	●
32	GOVT	PCAST, 1997	●	1995-2010	●	⊙	⊙	●	●	⊙	⊙	○
7	EPRI	EPRI-DOE, 1997	●	1997-2020	●	⊙	⊙	⊙	●	●	○	○
15	GOVT	EIA, 1998	●	NONE	●	⊙	⊙	○	⊙	●	●	●

renewable energy technology industry itself are not represented due to our inability to locate original sources.[10]

Evaluation Criteria

Market Penetration

The first evaluation criterion we considered was penetration into the market or--the equivalent--the contribution of technologies to electricity supply. This is measured by electricity generation and installed capacity. We placed primary emphasis on electricity generation--the measure of how much energy is actually produced by a specific technology over the course of a year, reported in million kilowatt-hours, or gigawatt-hours (GWh). We occasionally refer to capacity, which is the measure of how much electricity is available at any one point in time reported in megawatts (MW), and is the sum of all nameplate ratings of the respective generation sources.[11]

Cost

The second evaluation criterion was cost, measured by the levelized cost of electricity generation and by capital costs. The cost of electricity at point of production was our primary measure, and it incorporates capital, fuel, and operation and maintenance (O/M) costs, as well as expected lifetime and capacity factors. The total costs of production over the lifetime of the facility were amortized in a straight-line fashion (just as payments for a standard home mortgage would be). This annual cost was divided by the average annual amount of electricity produced over that lifetime to calculate the levelized cost of electricity generation (COE). Levelized cost is reported in mills per kilowatt-hour (mills/kWh), where a mill is equal to one-tenth of one cent. We occasionally refer to capital costs, measured by the dollar expenditure for the rated capacity in dollars per kilowatt ($/kW). Cost data are reported in constant 1995 dollars. To normalize costs we used the consumer price index, and assumed values in each study were denominated in dollars for the year the study was published if no other information was given.

None of the studies reviewed offered a complete set of projections. Transformations were made from capacity to generation and vice versa, and from capital cost to the levelized cost of energy for each of the technologies using standard capacity and utilization factors. When data were plotted on a logarithmic scale, geometric means were used to interpolate estimates for missing time periods between projected years in each study; otherwise, arithmetic means were used.

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[10] A considerable effort was made to contact industry associations and individual firms, some of which provided us with technical background or served as reviewers of this study. However, off-the-shelf estimates by firms in the renewable technology industries were not readily available to us.

[11] We restrict our focus to the U.S. market, to the exclusion of the expanding opportunities for U.S. technology in foreign markets. However, we do not believe this was the primary context for public policy debates over the period we considered, nor was it a primary element of the studies we reviewed.

For each technology we also constructed a measure of actual generation and cost. For the early years, assessments by different organizations of the actual generation and costs of renewable technologies often disagreed. In such cases, we relied on whatever assessments were available from the Energy Information Administration (EIA).

FINDINGS

In this section we summarize projections and actual performance for each renewable technology, and end with a review of projections for electricity generation from conventional sources. Note that many of the graphs use a log scale to display results. Note also that sharp changes in the slopes of some of these graphs are in part an artifact of our chosen methodology, which selects a median value among projections for each five-year increment. There is considerable noise in the data (i.e., a random aspect to the estimates due to our interpretation of the studies and translation of their results into common forms of measurement) due to reasons we have outlined. Hence, we chose to report our findings as graphs, which communicate the qualitative nature of the findings better than data tables would. The data tables are sensitive to our assumptions and interpretations of previous studies; the trends illustrated in the graphs are much less sensitive.[12]

1. Wind

Production

In the 1970s, projections for wind generating capacity were high due to assumptions influenced by the energy market disruptions of that decade.[13] Projections were as high as 45,000 MW for 1995 and 140,000 MW by 2000 (CONAES, 1979c).

Studies of generation and capacity during the following decades offered projections that were lower by an order of magnitude, due in large part to declining fossil fuel prices. In Figure 1 (p. 10) this is illustrated by a large shift downward in projections of generation after the 1970s. Projections of generation and capacity from the 1990s are consistent with those from the 1980s. The industry experienced a brief decline in capacity in the early 1990s, due in part to retiring standard-offer contracts under PURPA and a decline in other public-sector incentives. Actual wind energy generation has been on the rise since the mid-1970s, but specific estimates prior to 1990 are quite uncertain and are not included in the graphs. In 1995, wind production was approximately 3,196 GWh.

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[12] Data tables and a larger set of graphs are available from the authors.

[13] This analysis does not include cost projections for small-scale wind turbines intended for distributed applications - that is, applications located close to the user that tend to be less than 50-kW in size.

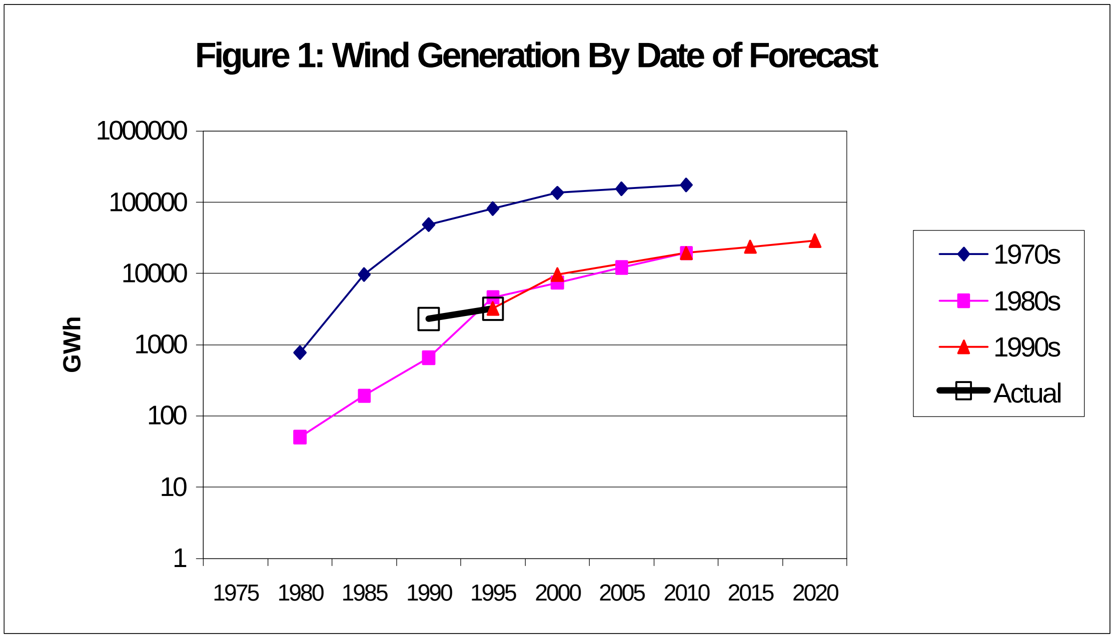
Figure 1: Wind Generation By Date of Forecast
GWh
1000000
100000
10000
1000
100
10
1
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970s
1980s
1990s
Actual

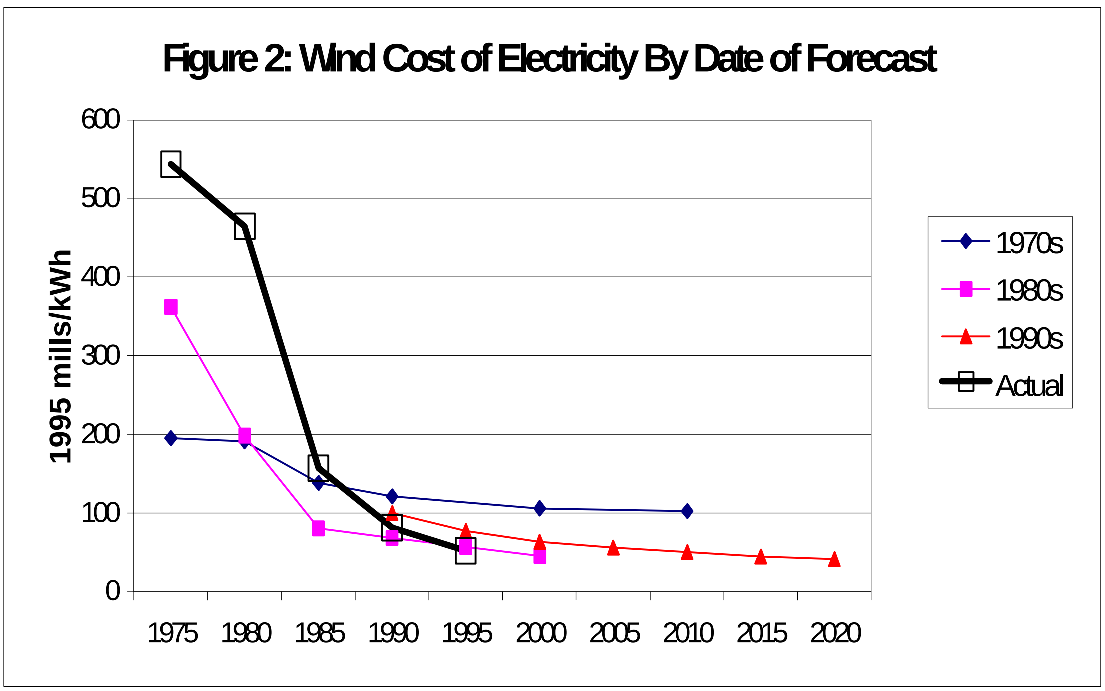
Figure 2: Wind Cost of Electricity By Date of Forecast
1995 mills/kWh
600
500
400
300
200
100
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970s
1980s
1990s
Actual

Costs

Figure 2 (p. 10) illustrates that projections of a decline in the capital cost and COE of wind have been realized or exceeded over time. Wind energy (along with geothermal) is the least-cost renewable technology currently, but its competitive standing depends on the availability of sites with strong wind resources and with access to transmission lines. Some early projections expected that the exhaustion of good wind resource sites early in the development of the technology would prevent costs from falling. For instance, the Committee on Nuclear and Alternative Energy Systems of the National Academy of Sciences envisioned rising capital costs and COE after 1995 for wind energy due to the need to use sites "with lower average wind speeds because the best sites have already been used" (CONAES, 1979c). The exhaustion of valued wind sites has not occurred, however, because of the unmet penetration of wind into the market and because the inventory of sites identified to have strong wind resources has expanded.[14] In addition, technological advances such as lower start-up speeds have improved profitability at lower wind speeds.

Wind has a current cost of about 52 mills/kWh at existing facilities (Resource Data Inernational, 1995); and a recent bid for 30 mills/kWh for a 100 MW wind farm was submitted to Northern States Power in Minnesota (Regulatory Assistance Project, 1998).[15] Current cost estimates are close to the average cost of generation from conventional sources.

2. Solar Photovoltaics

Production

Like wind, photovoltaic cost projections have been revised downward from the 1970s. Projections from the 1970s for solar photovoltaic range tremendously, as seen in Figure 3 (p. 12). Some authors forecast nearly 35,000 MW of capacity (FEA, 1974b) and 150,000 GWh of generation by 2000 (CONAES, 1979c); while others forecast nearly zero capacity and generation by 2020 (EPRI, 1977). Viewing the median value of projections of generation chronologically reveals a "fan diagram" that results from downward revisions of expected penetration. This pattern appears often in the Figures on other technologies as well. Capacity and generation have grown more than 10-fold since the early 1980s, but market penetration has been confined to niche markets and remote applications. In 1995, about 89.2 MW of capacity were installed in the United States.

Costs

Early studies were relatively optimistic regarding trends in costs for photovoltaic technology compared with those developed later. Stoughbaugh and Yergin (1979) projected

[14] The siting process includes a trade-off between the highest quality wind resource locations and proximity to transmission lines.

[15] Presumably this bid takes advantage of the 15 mills/kWh Renewable Energy Production Credit currently available to wind and closed-loop biomass, which would be reflected in the bid price.

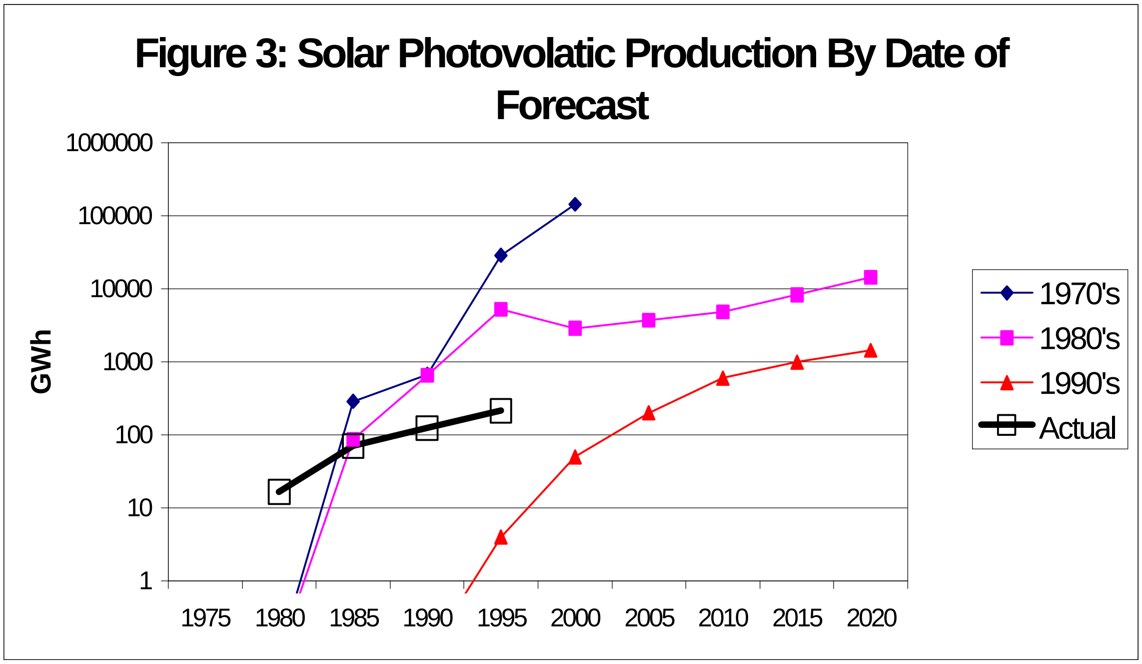

Figure 3: Solar Photovolatic Production By Date of Forecast
GWh
1000000
100000
10000
1000
100
10
1
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970's
1980's
1990's
Actual

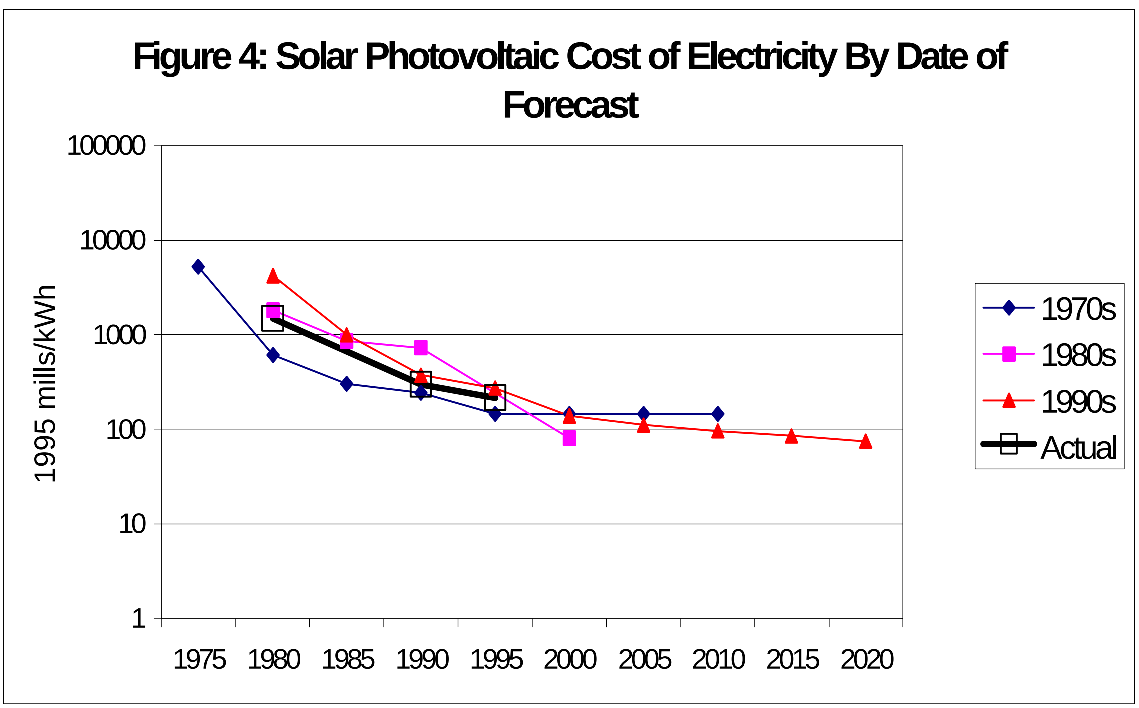

Figure 4: Solar Photovoltaic Cost of Electricity By Date of Forecast
1995 mills/kWh
100000
10000
1000
100
10
1
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970s
1980s
1990s
Actual

that by 1990 the cost of electricity from photovoltaic technology would be about 100 mills/kWh (Stoughbaugh and Yergin, 1979). Another early study projected an eventual leveling off of capital costs at around $3,000/kW and of COE at around 150 mills/kWh by 1990 (CONAES, 1979c). Figure 4 (p. 12) indicates these early projections of costs were not achieved.

Since the 1980s, however, projections of COE declines have been met or exceeded. Despite limited market penetration, capital costs and COE have dropped significantly. The current cost of capacity is about $7,000/kW, and the cost of generation is still over 200 mills/kWh. Recent studies project continuing declines in cost in coming decades due to efficiency improvements in both manufacturing the cells and capturing solar radiation and transforming it to electricity (OTA, 1995; PCAST, 1997; EPRI, 1997).

3. Solar Thermal

Production

Projections of solar thermal electricity production also form a fan diagram. Solar thermal electricity production began in the late 1970s with the 10-MW Solar One, a central station receiver, in the desert of southern California. Projections made during the late 1970s and early 1980s put solar thermal capacity at anywhere from 240 MW to 3,400 MW, and expected generation to range from 480 GWh to 5,400 GWh by the end of the 1980s (EIA, 1980; CONAES, 1979c). Luz International's facilities (SEGS I through IX) provided research on commercial adaptability of the technology, and demonstration of the first Stirling dish engine in 1984 signaled that these goals might be attainable by the end of the decade. Projections for capacity during the 1980s reflected this expectation.

However, reductions in public-sector financial incentives and government R&D spending on solar thermal hit this technology particularly hard. Luz International entered bankruptcy, contributing to a decline in production in the beginning of the 1990s. As with photovoltaics, the outcome is a fan diagram of declining forecasts of generation apparent in Figure 5 (p. 14). Recent projections anticipate capacity and generation to increase to twice current levels by 2020 (EIA, 1997a).

Costs

Few projections exist for the capital costs of solar thermal technology, and those we found varied greatly with regard to the type of technology modeled. There is also substantial variation in the measure of COE. Projections from the 1970s for 1990 ranged from 36 to 198 mills/kWh (FEA, 1976; CONAES, 1979c). Figure 6 (p. 14) illustrates that the median projections have been tracked closely by the actual COE.

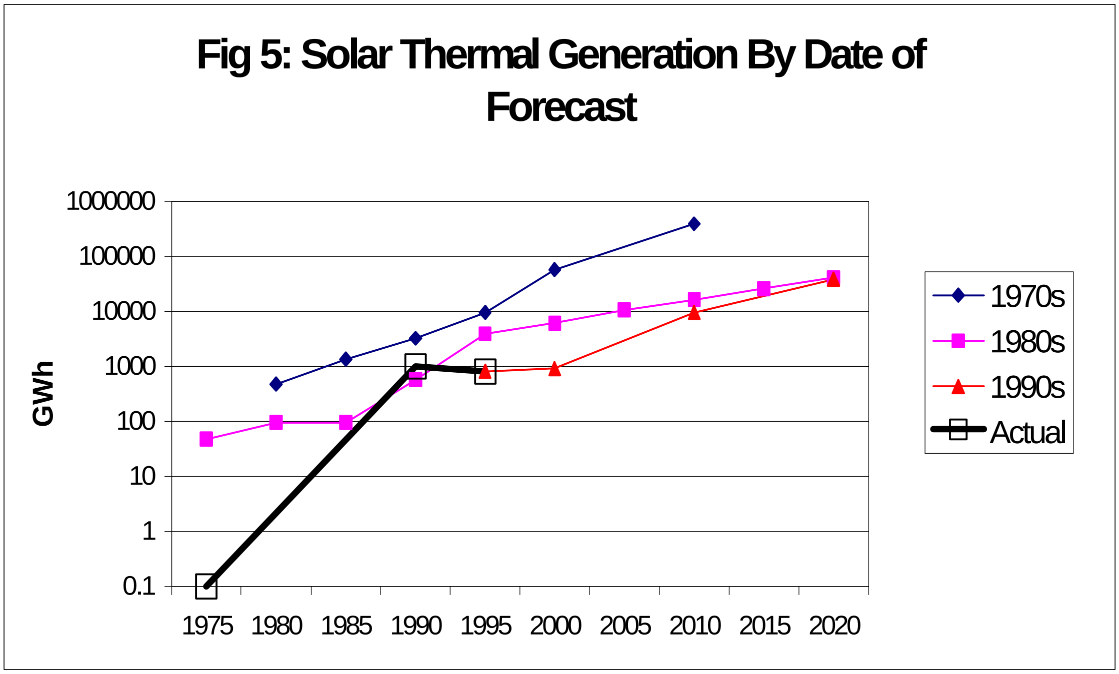
Fig 5: Solar Thermal Generation By Date of Forecast
GWh
1000000
100000
10000
1000
100
10
1
0.1
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970s
1980s
1990s
Actual

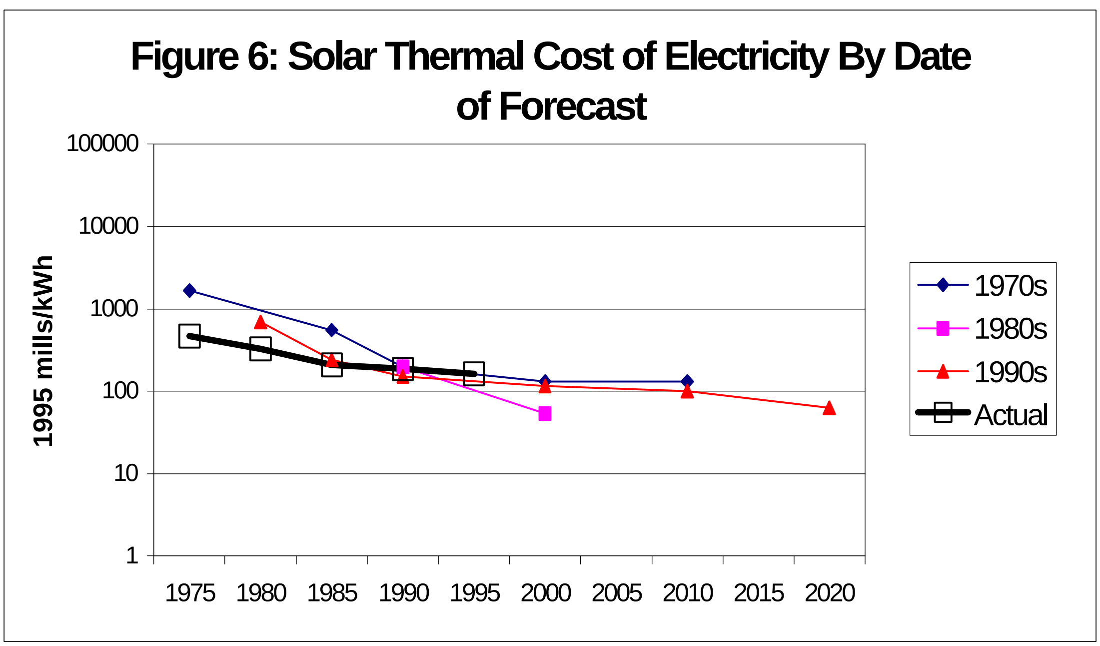
Figure 6: Solar Thermal Cost of Electricity By Date of Forecast
1995 mills/kWh
100000
10000
1000
100
10
1
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970s
1980s
1990s
Actual

4. Geothermal

Production

Projections of electricity production from geothermal produce a much weaker version of the familiar fan diagram. Generating electricity from geothermal energy involves capturing naturally heated steam to drive turbines. "Dry steam" is the easiest to use and cheapest, and is the resource type found at The Geysers, California, the largest geothermal electricity generation facility in the U.S. Increasingly, advances in geophysical theory and mapping, as well as more economical drilling technology, have increased the reservoir of geothermal energy that can be tapped cost-effectively. Also, valuable minerals (e.g., zinc) in the briny byproduct can be captured and sold to improve the economics of a geothermal project. These advances have not come quickly compared to expectations in the 1970s (CONAES, 1979a, 1979c). However, in a trend similar to petroleum extraction, they have enabled new installations in the outer areas of existing fields that compensate for the moderate decline in production at long-established facilities such as The Geysers.

Recent forecasts for new geothermal energy capacity and generation have been more moderate than previous ones (OTA, 1985; EIA,1997a). This produces in Figure 7 (p. 16) a weak version of the familiar fan diagram.

Costs

Many early reports from the 1970s forecast higher costs than those realized for generating electricity from geothermal in the future (EPRI, 1977; CONAES, 1979c).[16] The earliest development of geothermal resource and technology used dry steam resources, historically the least expensive form of the resource. It was anticipated that as dry resources were exhausted, subsequent development would have to turn to more expensive resources. However, technological advances have expanded the types of geologic settings that can be tapped. Figure 8 (p. 16) indicates that recent predictions have projected a declining path from 5.5 to 4 cents/kWh over the next 20 years, a smaller decline than projected today for other renewable technologies (EIA, 1990; Flavin and Lessen, 1990; EPRI/DOE, 1997).

5. Biomass

Production

Biomass resources can be converted into energy and can be divided into three categories: wood and agricultural wastes, municipal solid waste, and closed-loop biomass grown specifically for energy content. All three sources can be used for generating electricity ("biopower") as well as heat, while the last source also is frequently converted into fuel to power transportation (as in the blending of ethanol with gasoline). Currently wood and agricultural waste account for about 70 percent of biomass capacity.

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[16] The graph of COE displays an unusual pattern for the 1980s. This is because only one study is used (OTA, 1985), and it projected a significant drop in COE between 1990 and 2000 (150 to 77.8 mills/kWh).

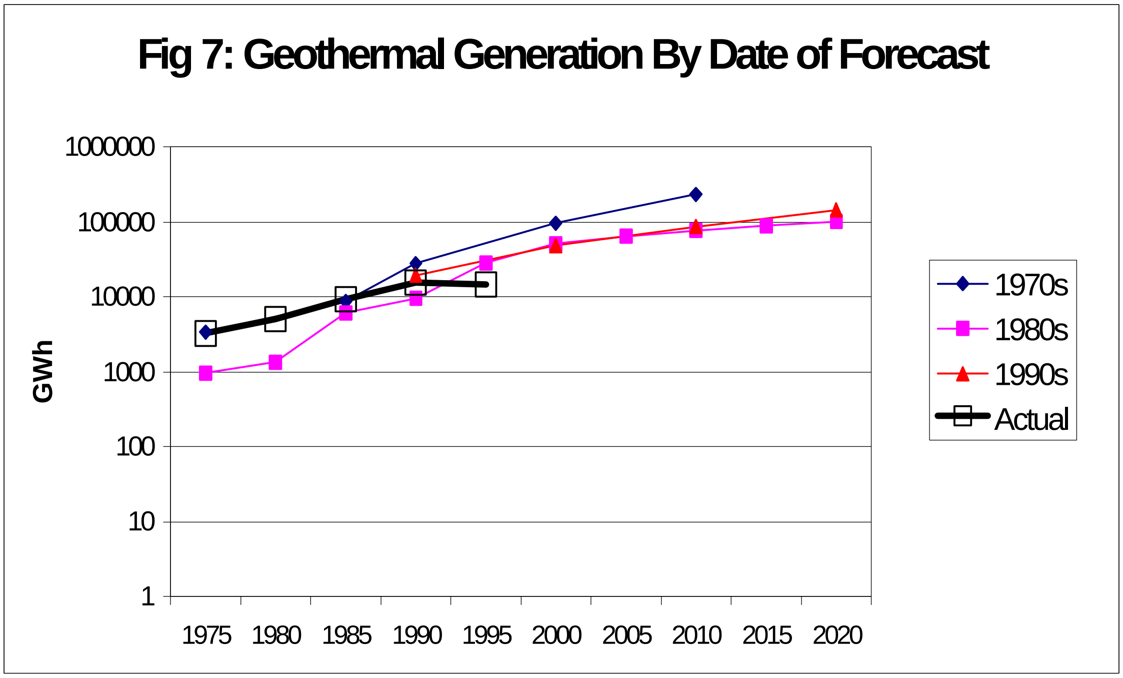
Fig 7: Geothermal Generation By Date of Forecast
GWh
1000000
100000
10000
1000
100
10
1
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970s
1980s
1990s
Actual

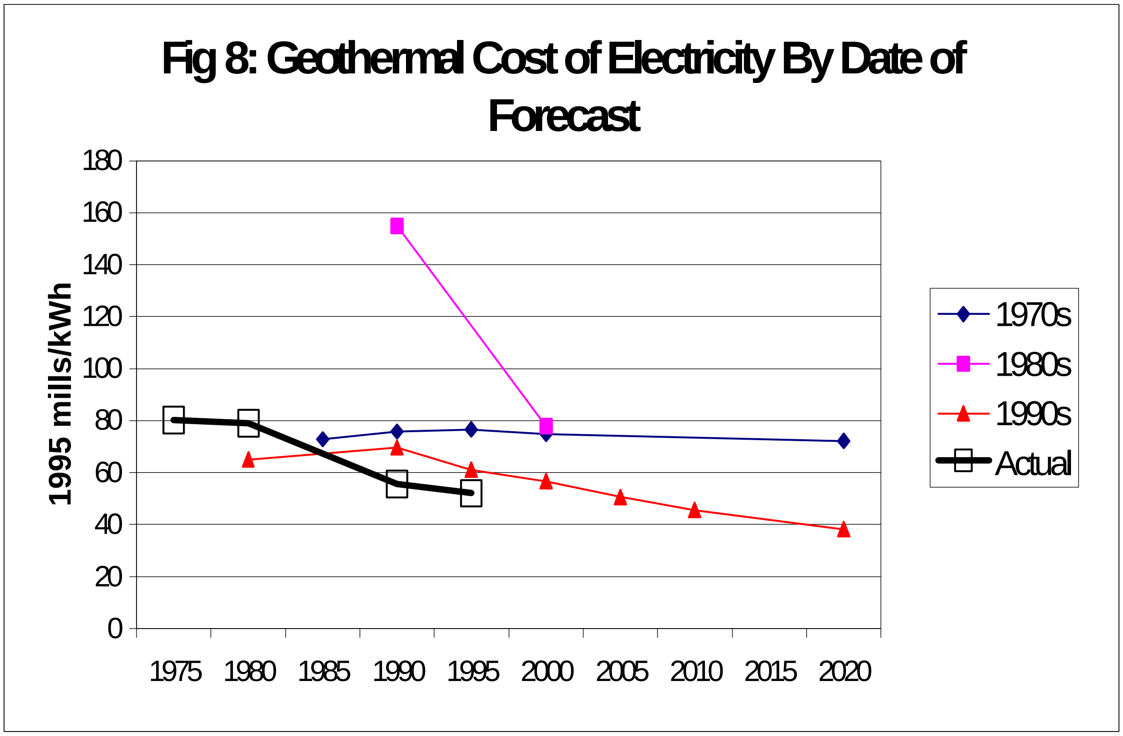
Fig 8: Geothermal Cost of Electricity By Date of Forecast
1995 mills/kWh
180
160
140
120
100
80
60
40
20
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970s
1980s
1990s
Actual

Unfortunately, few early studies dealt specifically with biopower. Instead, most early studies aggregated all the varied uses of the fuel and reported future market penetration as the energy content of the fuels it was to replace (including inputs to electricity generation). It is therefore difficult to separate the electricity contribution from the heat and fuel contribution of these projections, so few studies from before 1990 are included in our survey.

Figure 9 (p. 18) indicates that generation projections decreased from the 1970s to the 1980s, but then exceeded all prior levels in the 1990s. This is due to the advances in co-firing biomass with fossil fuels (e.g., replacing a small percentage of coal burned in a power plant with biomass), use of waste-to-energy plants to deal with municipal solid waste, and technological developments for closed-loop biomass generation systems, which has been developed but is not yet in use.

The actual production numbers used here are based on only utility generation until 1990. Nonutility data (such as the use of wood waste to generate electricity in pulp and paper production) were not collected by the EIA until 1989, and no reliable source could be found for estimation of the generation by these sources before that date. Both utility and nonutility generation are included after that, accounting for the jump in actual capacity and generation between 1985 and 1990.

Costs

As in the case of production statistics, few studies segregated the cost data among the various uses for biomass. Costs typically are reported in dollars per million Btu ($/mmBtu) to represent the cost of fuel input in biomass applications, including production of heat and electrical generation. For the evaluation of biopower, we converted these estimates to the standard mills/kWh to estimate the COE when it was appropriate to consider it as equivalent to electricity generation.[17]

Biomass costs as a whole parallel more closely those of conventional fossil fuels because this is the only renewable technology with fuel costs. A large portion of delivered biomass costs stems from the transportation of biomass resources for combustion or fuel production.[18] The capital costs of biomass are similar to those of fossil fuel generators. The other renewable technologies reviewed have high initial capital costs and no fuel costs.

Figure 10 (p. 18) shows that projections of biomass COE have fallen over time, and expectations have been met or exceeded. Currently, biomass costs are slightly higher than wind and geothermal, at about 70 mills/kWh. However, biomass is the largest provider of renewable energy due mainly to its availability 24 hours a day and its ability to co-fire with traditional fossil fuels.

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[17] The conversion rate was 10,353 Btu/kWh.

[18] This applies to dedicated feedstock fuel, and to wood and agricultural wastes if these are being purchased. Often for municipal solid wastes there is a tipping fee received by the plant for taking in the waste that offsets transportation costs.

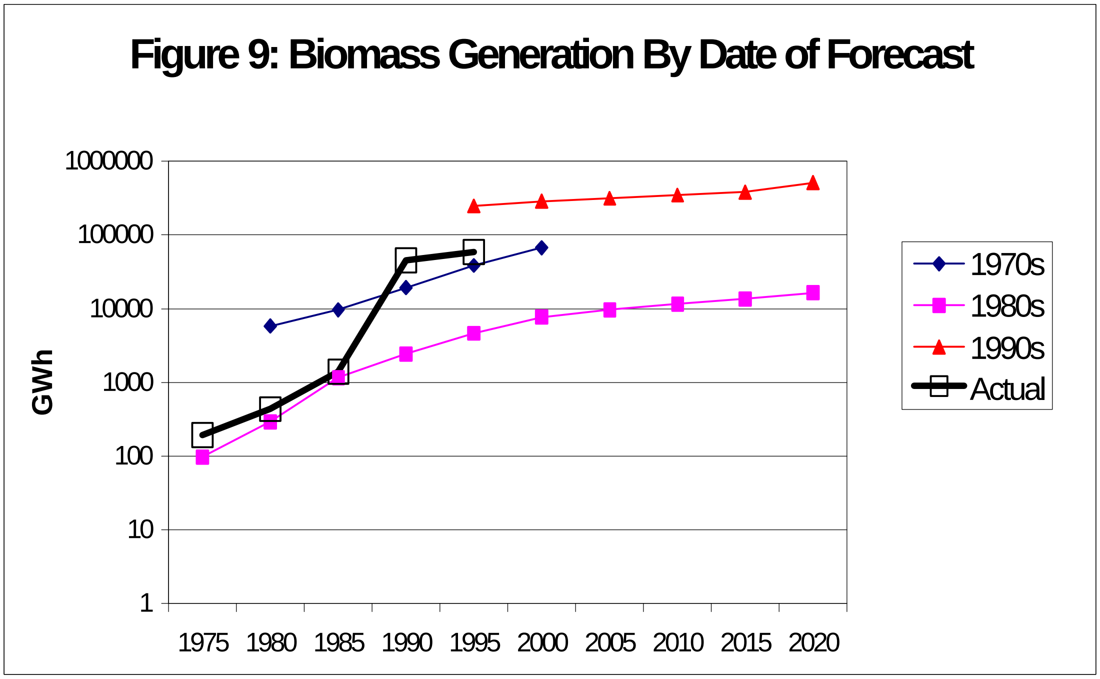


Figure 9: Biomass Generation By Date of Forecast
GWh
1000000
100000
10000
1000
100
10
1
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970s
1980s
1990s
Actual

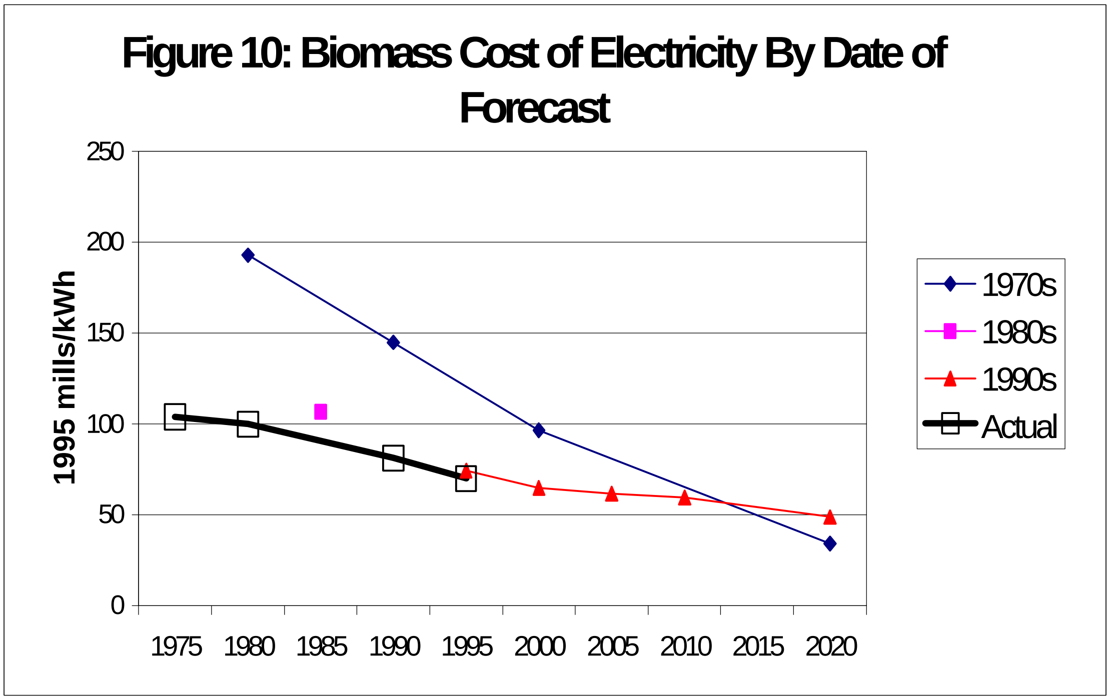
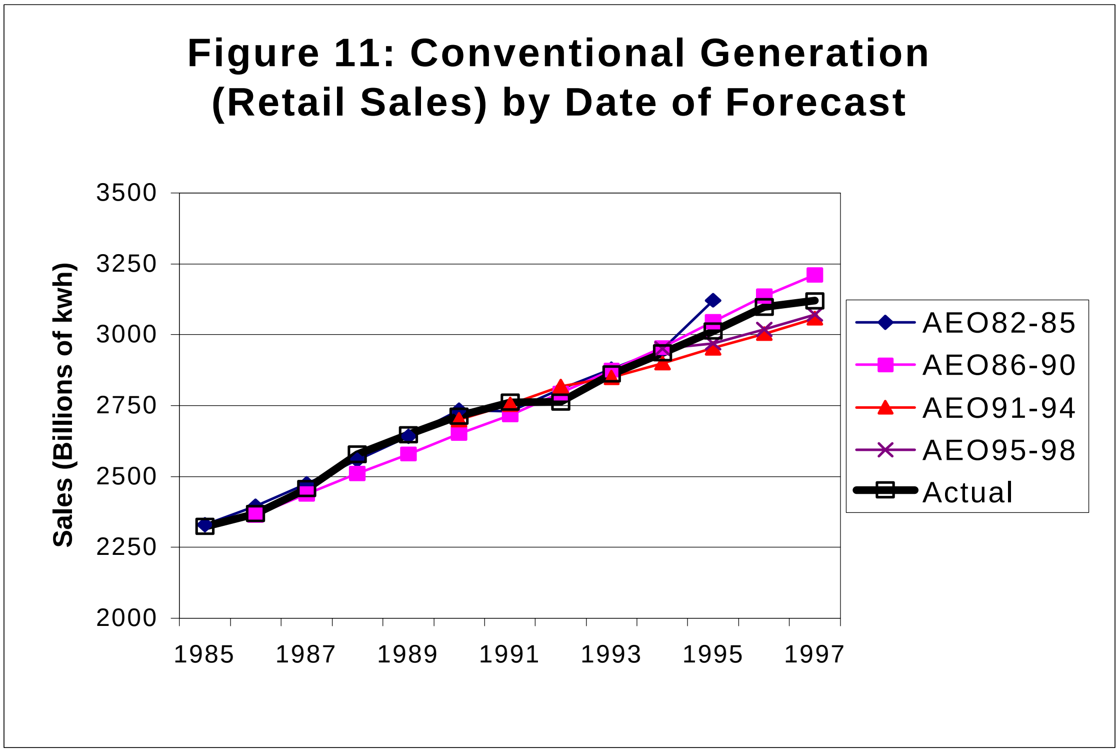


Figure 10: Biomass Cost of Electricity By Date of Forecast
1995 mills/kWh
250
200
150
100
50
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
1970s
1980s
1990s
Actual



6. Conventional Generation

To provide an estimate of projections for conventional technologies, we relied on a recent EIA document that evaluates forecasts over the last two decades (EIA, 1998a).[19] The EIA evaluation begins with forecasts made in the *1982 Annual Energy Outlook* for all electricity generation. This included nonhydroelectric renewable technologies, which made up a very small part of total generation (at most 0.3 percent in 1982). It also included hydroelectric (14 percent), nuclear (13 percent), and fossil-fired power production (73 percent).[20]

Production

Electricity sales increased by about 2.7 percent a year or about 80 percent overall from 1975 to 1997. Figure 11 indicates that from 1982 until now, government forecasts in the *Annual*

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[19] Cohen et al. (1995) provide a review of energy price and production projections for a number of sectors including electricity beginning in the 1970s. Their finding that price forecasts have been less accurate than production forecasts is reinforced in our review in this section.

[20] Based on data in EIA (1998b).

Energy Outlook of 2-3 percent a year annual growth have been largely accurate. The succession of forecasts displayed in the Figure appear mutually consistent and predict well the actual sales.[21]

Costs

In contrast to the agency's relatively accurate sales forecast, EIA projections in the 1980s significantly overestimated electricity costs in the future. For example, the 1982 *Annual Energy Outlook* forecast real electricity prices to rise by somewhat more than 8 percent during 1980-90; in fact, real prices declined by 10 percent. By the mid-1980s, the softening of world oil prices began to be reflected in EIA's updated forecasts, so that its 1984 *Annual Energy Outlook* (which serves as the basis for the observations that follow) foresaw a real price decline during 1983-95 of around 5 percent. The actual decline over the period was more than 25 percent.

It is instructive to dissect the components of that 12-year price change. The steady and increasingly sharp fall in world oil prices beginning in the early 1980s was of prime importance to the economics of electric power production, as it was to other sectors of the economy. Thus the entire difference between the projected and actual energy price in 1995 arises from the degree to which the fuel component of the price fell short of the forecast. During 1983-95, fuel costs were projected to rise 21 percent; they actually fell nearly 65 percent. Indeed, the drop in fuel prices exaggerates the overall decline in electricity prices, since operation-and-maintenance costs exceeded the forecast estimate, while the other major price component--capital charges--just about equaled the projected number. Table 3 summarizes the relevant data.

Table 3 also provides a rough estimate of the breakdown in real delivered electricity price between costs incurred at the electric generating plant (so-called busbar costs) and those accounted for by transmission/distribution (T/D) costs.[22] The former is of particular interest here, since it provides the more appropriate basis of comparison with renewable technologies, whose cost is measured at the point of electricity generation rather than delivery. In contrast to the 21 percent gap between projected and realized delivered electricity prices, Table 3 indicates that the actual outcome in 1995 with respect to real generation costs was about 44 percent below what had been forecast from a 1983 base. This larger difference is not

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[21] EIA (1998a) states that the reports published inthe years 1983 through 1988 were titled as the Annual Energy Outlook 1982 through the Annual Energy Outlook 1987. In 1989, the numbering scheme changed, and that year's report was titled the Annual Energy Outlook 1989. Thus, although a forecast has been published annually, there is no Annual Energy Outlook 1988. Hence, for AEO82-AEO87, the forecasts were based on data ending with the year identified in the title. For AEO89-AEO98, the forecasts were based on data ending with the year prior to the one identified in the title.

[22] This decomposition is crude. For instance, EIA 1997 (p. 11) presents a different estimate of the share of costs associated with T/D (EIA, 1997a). But we believe any bias implicit in our methodology to be relatively unimportant. We seek to find a rough baseline against which we can compare trends, in an order of magnitude that is roughly comparable to the costs of generation with renewable technologies.

surprising since the fuel component (whose costs are highlighted in Table 3) applies exclusively to the generation stage. In total, we estimate that about 51 percent of the cost of retail electricity costs is attributable to generation.[23]

To develop an estimate of cost projections for generation from all sources, which are predominantly nonrenewable, we relied on estimates of retail prices attributable to generation and aggregated these estimates into groups of four years each, over the period examined in EIA's 1998 *Annual Energy Outlook Forecast Evaluation*. Figure 12 (p. 22) indicates that the familiar fan diagram emerges especially clearly when viewing the projections compared with actual value for the generation portion of retail price projections.

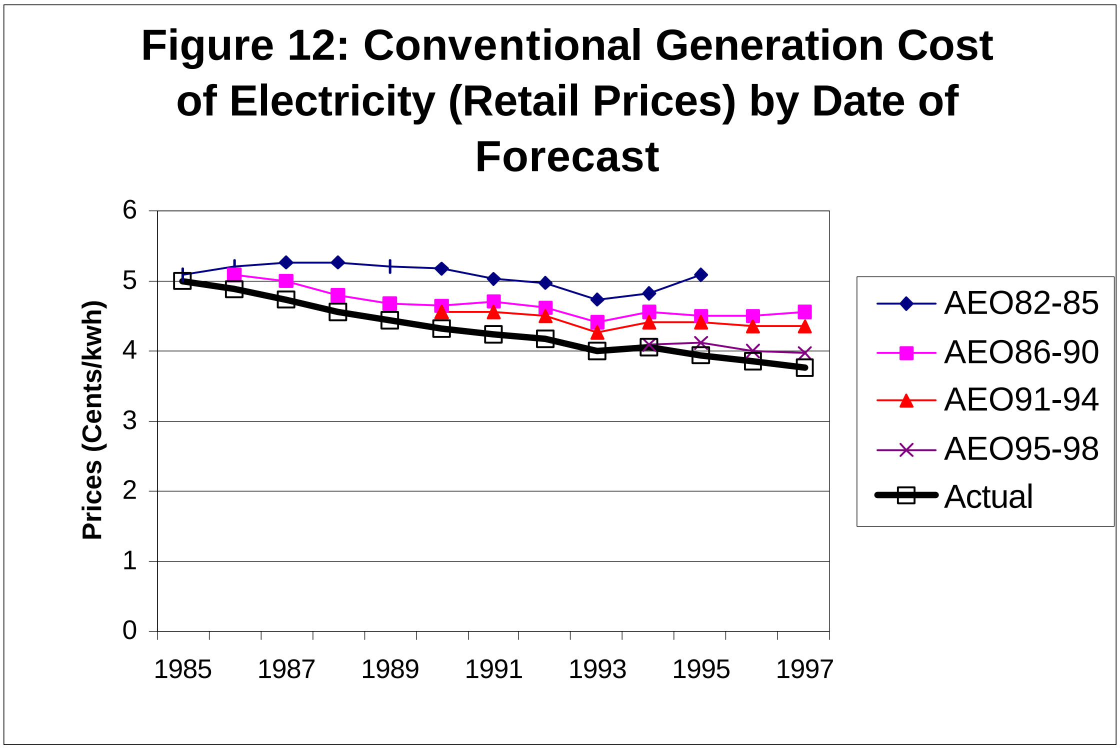
Table 3: Actual and Projected Electricity Prices (cents/kWh), 1983 and 1995, by Major Components (in 1995 dollars)

	Actual 1983		
	Generation	T/D	TOTAL
TOTAL	6.1	3.2	9.3
Capital	2.2	1.6	3.8
Fuel	3.3	-	3.3
O/M	0.6	1.6	2.2

	Actual 1995			**Forecast 1995**		
	Generation	T/D	TOTAL	Generation	T/D	TOTAL
TOTAL	3.6	3.5	7.1	6.4	2.4	8.8
Capital	1.7	1.1	2.8	1.7	1	2.7
Fuel	***1.1***	-	1.1	***4***	-	4
O/M	0.8	2.4	3.2	0.7	1.4	2.1

Sources and Notes: Total columns from EIA, *Annual Energy Outlook*, various issues. The split between plant and T/D is approximated on the basis of information in OECD/IEA, *Projected Costs of Generating Electricity: Update 1998* (Paris: 1998). See also: EIA, *Electricity Prices in a Competitive Environment* (August 1997); EIA, *Financial Statistics of Major U.S. Investor Owned Electric Utilities (1996)* (1997) and *Financial Statistics of Major U.S. Publicly Owned Utilities (1997)* (1997).

[23] The data suggest that 61 percent of total capital costs are attributable to generation and 39 percent to T/D. We apply 25 percent of total O/M costs to generation, and 75 percent to T/D. For 1995 actual, EIA shows a "wholesale power cost" of 0.4 cents/kWh in addition to the other three components shown. We allocated the 0.4 cents in proportion to the other three components. We apply the shares of costs attributable to generation and to T/D that are estimated for the year 1995 to the calculations for 1983 in Table 3, and the discussion in the remainder of this section.



Viewing Projections by Author Affiliation

Generation/Market Penetration

To the extent that NGOs have historically served as advocates for renewable technologies, these groups could presumably be expected to have been most optimistic with respect to the potential for renewables in general and market penetration in particular. We did not find this to be the case, however.

For wind, geothermal, and biomass, NGOs were the most conservative in their projections of capacity and generation, and in each case they were below levels actually realized. Projections by NGOs were relatively conservative with respect to generation from photovoltaics as well, with projections below realized levels. Only in the case of solar thermal technology were NGOs relatively high in their projections, although not the highest. (All groups overstated the market penetration of solar thermal to date.)

Studies sponsored or conducted by government (more than half of our sample) and independent research organizations (which include the national laboratories) have tended toward the highest projections of production and capacity. For all technologies except biomass, these studies have issued projections that erred on the high side when compared with actual installed capacity and generation. Studies associated with research organizations were almost accurate with respect to geothermal. These organizations also offered the highest projections for biomass, which turned out to be quite accurate.

Studies by EPRI usually, though not always, offered the most conservative projections across all technologies. These projections were on the low side for the solar technologies and biomass compared with actual outcomes, and fairly accurate for geothermal.

Costs

Overall, there is little systematic difference among the sponsors and authors of the studies with respect to projections of costs.

For **wind**, EPRI's projections have been lower than others, and consequently the most accurate.

For solar **photovoltaics**, NGOs were relatively optimistic regarding trends in cost of electricity compared with those offered by other groups, and they are the only ones to have erred on the optimistic (low-cost) side. Independent research organizations also erred on the optimistic side with respect to capital costs for solar photovoltaics.

All groups that conducted studies offered similar estimates for **solar thermal**, and these proved to be accurate or slightly pessimistic (high-cost) compared with actual outcomes. The different types of studies converged in their projections for 1985 and beyond for the costs of wind and solar technologies.

In the case of **geothermal**, NGO projections of cost were the lowest but nonetheless the closest to actual costs. Research groups have projected the highest costs and they are the only group to project increasing costs.

In the case of **biomass**, relatively few studies were included. Government estimates of COE were high compared with what has been realized.

DISCUSSION

The fan diagrams that emerge in the Figures from successive revisions in forecasts is a well known image in energy economics. It became familiar through revisions to projections for oil prices from the 1970s through the 1990s, as well as through revisions to forecast electricity and overall energy demand growth in the late 1960s through the 1970s. These projections often seemed to extrapolate historic rates of demand growth out into the future, thus failing to anticipate the dampening effect that higher energy prices would have on demand for energy.

Beginning in the early 1970s, the rate of growth for electricity demand deviated from historic trends. Indeed, the error in demand projections led to an overcommitment to capacity additions with vintages of technology--both nuclear and fossil--from earlier decades that has important lingering implications for the electricity industry today.

The fan diagram appears prominently in projections of generation for two out of five of the renewable technologies we surveyed. Early projections for solar photovoltaics and solar thermal proved to be too high, and they were reduced over time by dramatic margins. It is clear that these renewable technologies failed to meet expectations with respect to market penetration.

A modest fan diagram appears in two other cases: projections of generation from the 1970s were too high by significant amounts for wind, and early projections for geothermal proved to be too high by modest amounts. In both cases the technologies have come close to meeting revised projections from the 1980s and 1990s.

The exception to this pattern is biomass applications, for which market penetration has exceeded previous projections.

However, a different picture emerges in the assessment of projections for the cost of renewable technologies. In every case, successive generations of cost projections have either agreed with previous projections, or have declined relative to them. More important, in virtually every case the path of actual cost has equaled or been below the projections for that period in time.[24]

The story is reversed in our evaluation of projections of conventional technologies. Expectations generally were accurate with respect to generation from conventional technologies, and the cost projections for conventional generation were unambiguously overestimated. Hence, in the case of conventional technologies, forecasts of generation are accurate while successive revisions of cost create the familiar fan diagram. The appearance of the fan diagram in the projections of the cost of conventional generation has three implications worth noting.

First, projections of generation and cost, considered in tandem, are not necessarily more accurate for conventional generation than for renewable generation. Since quantity and price are related, it is not clear that the projections of sales for conventional generation are as accurate as indicated in Figure 11. Either the sales projections are built on an assumption of extremely price-inelastic (i.e., not sensitive to incremental changes in price) demand curves, or highly income-elastic (i.e., not sensitive to changes in income) demand curves, or both, or else there is an element of luck in their success. Had the projections with respect to price been accurate, sales would likely have been less than were actually achieved, according to most estimates of elasticity of demand. Were the errors in forecasting retail prices taken into account, a fan diagram conceivably would appear in the demand projections. That is, if forecast prices had turned out to be accurate, forecasts of electricity demand would have been too high compared with actual demand, continuing the trend from the 1970s.

Second, the rate of technological change might be expected to be far greater for an emerging technology than for mature technology. However, it is important to realize that such change continues for mature technologies. Technological progress has contributed to the decline in price experienced by all forms of generation (Bradley, 1997). Table 3 reports a 44 percent decrease in the cost of generation between 1983 and 1995. Changing fuel prices

[24] The only exception appears in the case of capital costs for photovoltaics, where expectations from the 1970s and 1980s were well below realized costs in the 1980s and 1990s. However, even in this case projections of the COE for photovoltaics were roughly accurate in comparison with realized costs.

are the dominant factor in explaining this decline but not the only factor. In a recent econometric study, Carlson et al. find significant technological improvement and reductions in the cost of production (holding input prices fixed) at coal-fired power plants between 1985 and 1994 (Carlson et al., 1998).[25] Indeed, the rate of improvement in relatively mature conventional technologies may accelerate in the increasingly competitive environment of wholesale and retail competition in the electricity industry that was launched by another public policy initiative--the 1992 Energy Policy Act.

Third, the advantageous changes in conventional generation created a difficult obstacle for renewable technologies. The declining price of conventional generation constituted a moving baseline against which renewable technologies had to compete. Energy policy initiatives including PURPA and the deregulation of natural gas, oil pipelines, and rail industries complemented technological and economic trends that directly affected conventional technologies. Collectively these regulatory, technological, and market structure changes served to reduce generation costs for conventional technologies.[26] To a significant degree, renewable technologies were an innocent victim of these other successes.

CONCLUSION

This evaluation has a strong bearing on the justification for continued public-sector support for the development of renewable technologies. Prior and sometimes faltering support has taken a variety of forms, from research funding to subsidies for investment and production. The public may well ask what the return has been on these investments. We do not provide evidence or attempt to evaluate the efficacy of public-sector programs as such, nor can we attribute the changes in technological development to government policies in general. The changes we observe may or may not be attributable to public-sector programs. But the claim that renewable technologies have failed to meet goals that influenced the nature of public-sector programs can be addressed directly.

A critical question is how to measure the success of renewable technologies. We propose two such measures. One is their performance relative to projections for their contribution to meeting electricity demand. A second is their performance relative to projections of cost. Regarding the first, renewable technologies seem to have failed in general, at least in terms of their contribution to grid-connected electricity generation, with

[25] Table 3 indicates capital costs have declined while O/M costs have risen over this timeframe. Part of this change could be realized by full depreciation of existing facilities ending capital charges accruing at those facilities. Although O/M costs would be expected to increase as facilities age, this is offset by technological change manifest through the advent of electronic controls in power plant management, as well as changing work relationships and articulation of work rules on site (Ellerman, 1998).

[26] Renewable technologies benefited indirectly from these trends, because construction costs through the entire industry were reduced.

perhaps a couple of exceptions (notably biomass).[27] With respect to the second measure, renewables seem to be a success.

The development of renewable technologies obviously has not occurred while the world otherwise stood still. In fact, over the time horizon we evaluated, dramatic changes have characterized energy markets in general. The ultimate impacts of these changes have been mostly favorable for electricity consumers; they have also been frustratingly disappointing for the fate of renewable technologies. The price of generation from conventional technologies has fallen precipitously, largely due to changes in fuel markets. This has raised the hurdle over which renewable technologies must pass in order to penetrate the electricity market in a significant way.

We view the confluence of changes in energy markets as an indication of the success of an array of changes in public policy, including, in particular, regulatory reform and deregulation of key energy markets and related industries such as railroads. Ironically, the perceived failure of renewable technologies to contribute importantly to electricity generation today is to a significant degree attributable to these successes.

This does not imply that public-sector support for renewable technologies has been misplaced. Public-sector financial incentives for renewable technologies (as well as other energy technologies) can be viewed as a precaution against rising energy prices, vulnerability to disruptions of foreign energy supply, and environmental concerns. After all, fire insurance is not judged as successful from the perspective of whether or not a person's house actually burns down. Similarly, the success of public-sector support for renewable technologies should not be viewed from the perspective of largely unrelated outcomes.

The most important measure of success would seem to us to be the cost of electricity generated from renewable technologies compared with the expectations that served as the justification for public-sector support. According to this measure, renewable technologies have met the goals set for them, and could be considered an important component of an ongoing movement toward sound energy policy. Whether the level of support has been adequate or should continue we leave to other investigators.

[27] As noted previously, in some niche markets apart from the electricity grid, renewable technologies have achieved significant penetration.

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