THE ECONOMICS OF NUCLEAR REACTORS: *RENAISSANCE OR RELAPSE?*

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ISSUE BRIEF

FINDINGS

Within the past year, estimates of the cost of nuclear power from a new generation of reactors have ranged from a low of 8.4 cents per kilowatt hour (kWh) to a high of 30 cents. This paper tackles the debate over the cost of building new nuclear reactors, with the key findings as follows:

- The initial cost projections put out early in today's so-called "nuclear renaissance" were about one-third of what one would have expected, based on the nuclear reactors completed in the 1990s.
- The most recent cost projections for new nuclear reactors are, on average, over four times as high as the initial "nuclear renaissance" projections.
- There are numerous options available to meet the need for electricity in a carbon-constrained environment that are superior to building nuclear reactors. Indeed, nuclear reactors are the worst option from the point of view of the consumer and society.
- The low carbon sources that are less costly than nuclear include efficiency, cogeneration, biomass, geothermal, wind, solar thermal and natural gas. Solar photovoltaics that are presently more costly than nuclear reactors are projected to decline dramatically in price in the next decade. Fossil fuels with carbon capture and storage, which are not presently available, are projected to be somewhat more costly than nuclear reactors.
- Numerous studies by Wall Street and independent energy analysts estimate efficiency and renewable costs at an average of 6 cents per kilowatt hour, while the cost of electricity from nuclear reactors is estimated in the range of 12 to 20 cents per kWh.
- The additional cost of building 100 new nuclear reactors, instead of pursuing a least cost efficiency-renewable strategy, would be in the range of $1.9-$4.4 trillion over the life the reactors.

Whether the burden falls on ratepayers (in electricity bills) or taxpayers (in large subsidies), incurring excess costs of that magnitude would be a substantial burden on the national economy and add immensely to the cost of electricity and the cost of reducing carbon emissions.

APPROACH

This paper arrives at these conclusions by viewing the cost of nuclear reactors through four analytic lenses.

- First, in an effort to pin down the likely cost of new nuclear reactors, the paper dissects three dozen recent cost projections.
- Second, it places those projections in the context of the history of the nuclear industry with a database of the costs of 100 reactors built in the U.S. between 1971 and 1996.

- Third, it examines those costs in comparison to the cost of alternatives available today to meet the need for electricity.
- Fourth, it considers a range of qualitative factors including environmental concerns, risks and subsidies that affect decisions about which technologies to utilize in an environment in which public policy requires constraints on carbon emissions.

The stakes for consumers and the nation are huge. While some have called for the construction of 200 to 300 new nuclear reactors over the next 40 years, the much more modest task of building 100 reactors, which has been proposed by some policymakers as a goal, is used to put the stakes in perspective. Over the expected forty-year life of a nuclear reactor, the excess cost compared to least-cost efficiency and renewables would range from $19 billion to $44 billion per plant, with the total for 100 reactors reaching the range of $1.9 trillion to $4.4 trillion over the life the reactors.

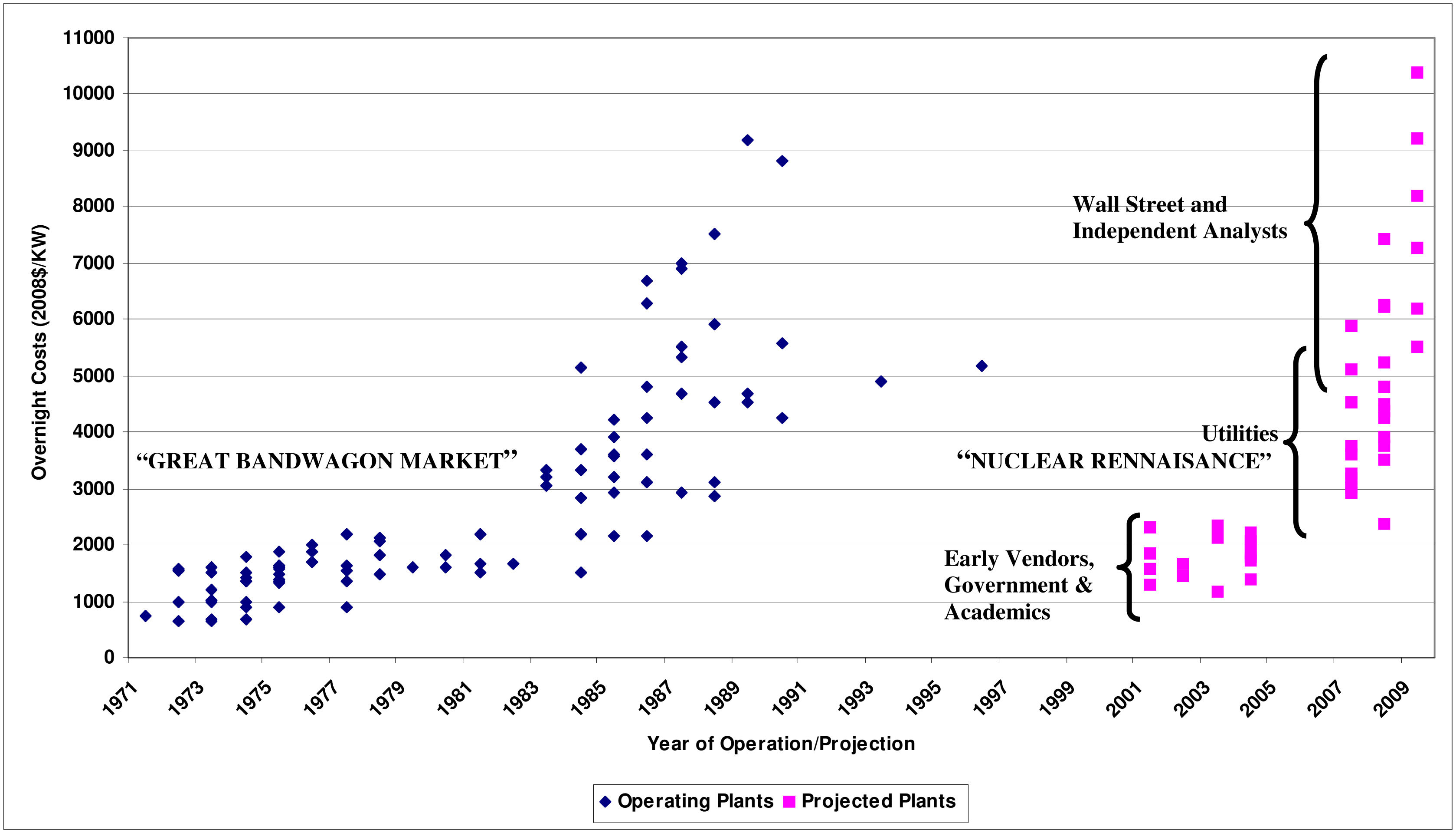
HOPE AND HYPE VS. REALITY IN NUCLEAR REACTOR COSTS

From the first fixed price turnkey reactors in the 1960s to the May 2009 cost projection of the Massachusetts Institute of Technology, the claim that nuclear power is or could be cost competitive with alternative technologies for generating electricity has been based on hope and hype. In the 1960s and 1970s, the hope and hype analyses prepared by reactor vendors and parroted by government officials helped to create what came to be known as the "great bandwagon market." In about a decade utilities ordered over 200 nuclear reactors of increasing size.

Unfortunately, reality did not deliver on the hope and the hype. Half of the reactors ordered in the 1960s and 1970s were cancelled, with abandoned costs in the tens of billions of dollars. Those reactors that were completed suffered dramatic cost overruns (see Figure ES-1). On average, the final cohort of great bandwagon market reactors cost seven times as much as the cost projection for the first reactor of the great bandwagon market. The great bandwagon market ended in fierce debates in the press and regulatory proceedings throughout the 1980s and 1990s over how such a huge mistake could have been made and who should pay for it.

In an eerie parallel to the great bandwagon market, a series of startlingly low-cost estimates prepared between 2001 and 2004 by vendors and academics and supported by government officials helped to create what has come to be known as the "nuclear renaissance." However, reflecting the poor track record of the nuclear industry in the U.S., the debate over the economics of the nuclear renaissance is being carried out *before* substantial sums of money are spent. Unlike the 1960s and 1970s, when the utility industry, reactor vendors and government officials monopolized the preparation of cost analyses, today Wall Street and independent energy analysts have come forward with much higher estimates of the cost of nuclear reactors.

Figure ES-1: Overnight Cost of Completed Nuclear Reactors Compared to Projected Costs of Future Reactors



Sources: Koomey and Hultman, 2007, Data Appendix; University of Chicago 2004, p. S-2, p. S-8; University of Chicago estimate, MIT, 2003, p. 42; Tennessee Valley Authority, 2005, p. I-7; Klein, p. 14; Keystone Center, 2007, p.42; Kaplan, 2008 Appendix B for utility estimates, p. 39; Harding, 2007, p. 71; Lovins and Shiekh, 2008b, p. 2; Congressional Budget Office, 2008, p. 13; Lazard, 2008, Lazard, p. 2; Moody's, 2008, p. 15; Standard and Poor, 2008, p. 11; Severance, 2009, pp. 35-36; Schlissel and Biewald, 2008, p. 2; Energy Information Administration, 2009, p. 89; Harding, 2009. PPL, 2009; Deutch, et al., 2009, p. 6. See Bibliography for full citations.

The most recent cost projections are, on average, over four times as high as the initial nuclear renaissance projections.

Even though the early estimates have been subsequently revised upward in the past year and utilities offered some estimates in regulatory proceedings that were twice as high as the initial projections, these estimates remain well below the projections from Wall Street and independent analysts. Moreover, in an ominous repeat of history, utilities are insisting on cost-plus treatment of their reactor projects and have steadfastly refused to shoulder the responsibility for cost overruns.

One thing that utilities and Wall Street analysts agree on is that nuclear reactors will not be built without massive direct subsidies either from the federal government or ratepayers, or from both.

In this sense, nuclear reactors remain as uneconomic today as they were in the 1980s when so many were cancelled or abandoned.

THE ECONOMIC COST OF LOW CARBON ALTERNATIVES

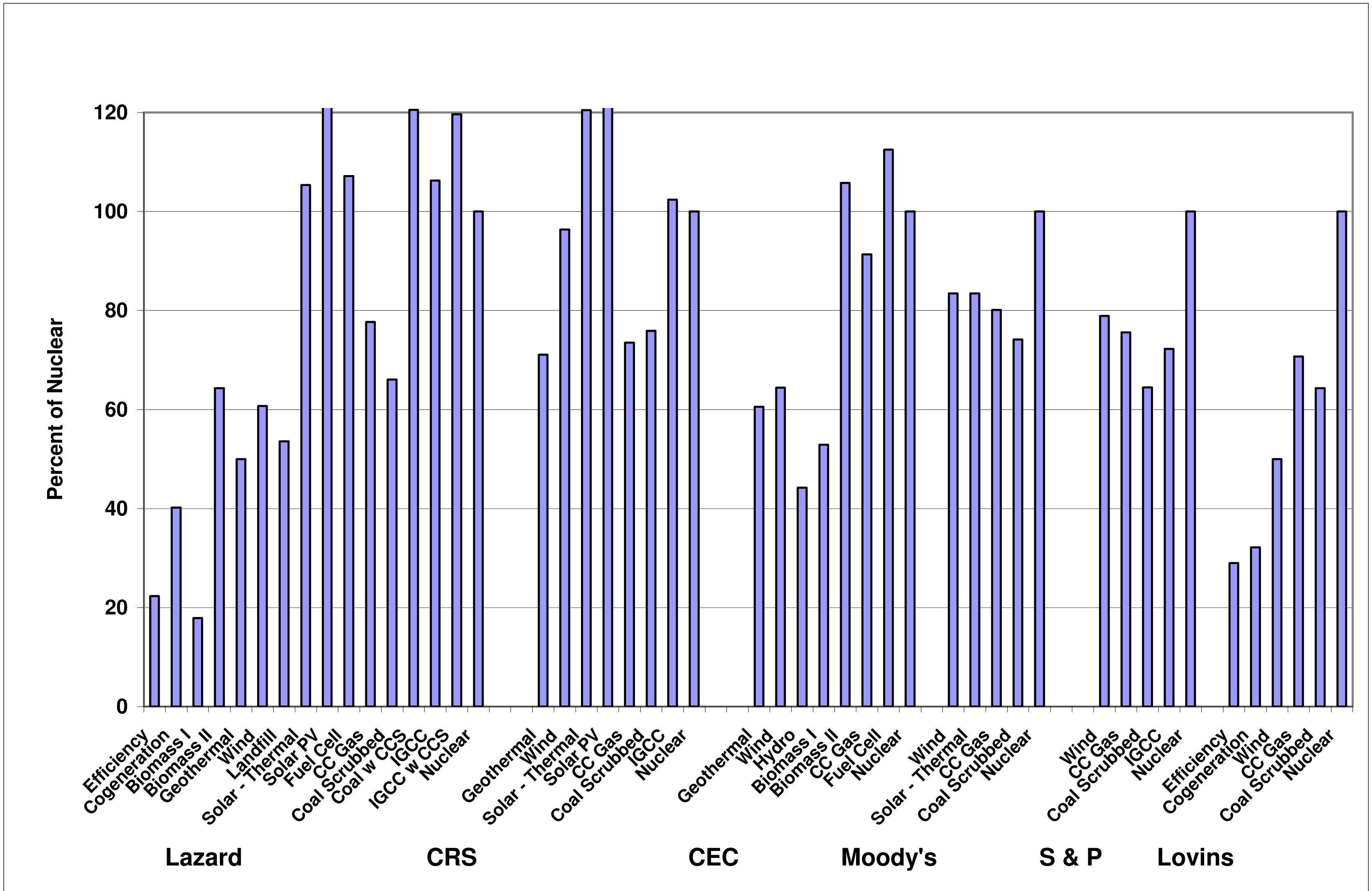
There is a second major difference between the debate today and the debate in the 1970s and 1980s. In the earlier debate, the competition was almost entirely between coal and nuclear power generation. Today, because the debate is being carried out in the context of policies to address climate change, a much wider array of alternatives is on the table. While future fossil fuel (coal and natural gas) plants with additional carbon capture and storage technologies that are not yet available are projected to be somewhat more costly than nuclear reactors (see Figure ES-2), efficiency and renewables are also primary competitors and their costs are projected to be much lower than nuclear reactors.

Figure ES-2 presents the results of half a dozen recent studies of the cost of alternatives, including two by government entities, three by Wall Street analysts and one by an independent analyst. Figure ES-2 expresses the cost estimated by each study for each technology as a percentage of the study's nuclear cost estimate. Every author identifies a number of alternatives that are less costly than nuclear reactors.

One of the central concerns about reliance on efficiency and renewables to meet future electricity needs is that they may not be available in sufficient supply. However, analysis of the technical potential to deliver economically practicable options for low-cost, low-carbon approaches indicates that the supply is ample to meet both electricity needs and carbon reduction targets for three decades or more based on efficiency, renewables and natural gas (see Figure ES-3).

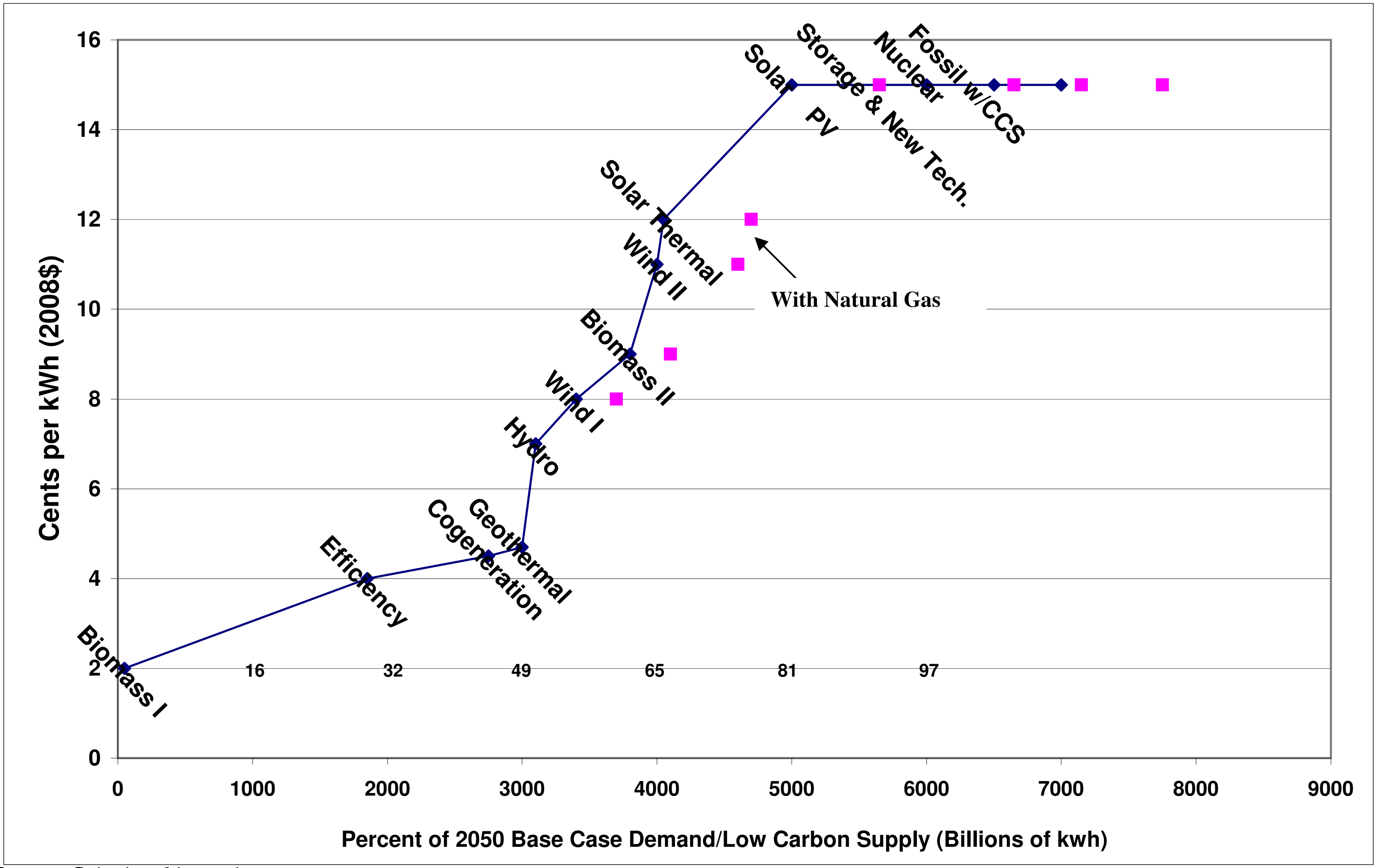
Figure ES-3 builds a "supply curve" of the potential contribution and cost of efficiency and renewables, based on analyses by the Rand Corporation, McKinsey and Company, the National Renewable Energy Laboratory, the Union of Concerned Scientists and the American Council for an Energy Efficient Economy. Clearly, there is huge potential for low carbon approaches to meet electricity needs. To put this potential into perspective, long-term targets call for emissions reductions below 2005 levels of slightly more than 40 percent by 2030 and 80 percent by 2050. Even assuming that all existing low carbon sources (about 30 percent of the current mix) have to be replaced by 2030, there is more than ample potential in the efficiency and renewables.

Figure ES-2: Busbar Costs of Alternatives by Estimating Entity (Nuclear Reactor Cost = 100 Percent)



Sources: See Figure I-1.

Figure ES-3: Meeting Electricity Needs in a Carbon Constrained Environment (Cost of Alternatives Substitution Curve)



Source: Calculated by author.

With continuing demand growth, it would still not be until 2040 that costly or as yet nonexistent technologies would be needed. Thus, pursuing these low cost options first meets the need for electricity and emissions reductions, while allowing time for technologies to be developed, such as electricity storage or carbon capture, that could meet electricity needs after 2040. The contending technologies that would have to be included in the long term are all shown with equal costs, above the technologies that have lower costs because it is difficult to project costs that far out in future and there will likely be a great deal of technological change before those technologies must be tapped to add substantial incremental supplies.

A COMPREHENSIVE VIEW OF OPTIONS FOR MEETING ELECTRICITY NEEDS

In addition to their cost, nuclear reactors possess two other characteristics that make them an inferior choice among the options available.

- The high capital costs and long construction lead times associated with nuclear reactors make them a risky source of electricity, vulnerable to market, financial, and technological change that strengthen the economic case against them.
- While nuclear power is a low carbon source of electricity, it is not an environmentally benign source. The uranium fuel cycle has significant safety, security, and waste issues that are far more damaging than the environmental impact of efficiency and renewables.

Figure ES-4 depicts three critical characteristics of the alternatives available for meeting electricity needs in a carbon-constrained environment. The horizontal axis represents the economic cost. The vertical axis represents the societal cost (with societal cost including environmental, safety, and security concerns). The size of the circles represents the risk. Public policy should exploit the options closest to the origin, as these are the least-cost alternatives. Where the alternatives are equal on economic cost and societal impact, the less risky should be pursued.

Nuclear reactors are shown straddling the positive/negative line on societal impact. If the uranium production cycle – mining, processing, use and waste disposal – were deemed to have a major societal impact, nuclear reactors would be moved much higher on the societal impact dimension. If one believes that nuclear reactors have a minor impact, reactors would be moved down on the societal impact dimension. In either case, there are numerous options that should be pursued first. Thus, viewed from a multidimensional perspective, including economic, environmental, and risk factors, there are numerous preferable alternatives.

THE IMPACT OF SUBSIDIES

As noted, nuclear reactors are very unlikely to be built without ratepayer and taxpayer subsidies. Many of the hope and hype analyses advance scenarios in which carbon is priced and nuclear reactors are the beneficiaries of large subsidies. Under those sets of extreme assumptions, nuclear reactors become less costly than fossil fuels with carbon capture and storage costs. However, they do not become less costly than efficiency and renewables. High carbon costs make efficiency and renewables more attractive.

Moreover, public policy has not tended to be quite so biased, although the supporters of nuclear power would like it to be. Imposing a price on carbon makes all low carbon options, including efficiency and renewables, more attractive as options. Subsidy programs tend to be applied to all low carbon technologies. As a result, although the carbon pricing and subsidy programs implemented and contemplated in recent years tend to impose cost on consumers or shift them from ratepayers to taxpayers; they do not change the order in which options enter the mix. In other words, given pricing and subsidies that simply values carbon emission or its abatement, the economic costs as estimated above dictate the order in which options are implemented. Nuclear reactors remain the worst option. It is possible to bias policies so severely that the order of priority changes, but that simply imposes unnecessary costs on consumers, taxpayers, and society.

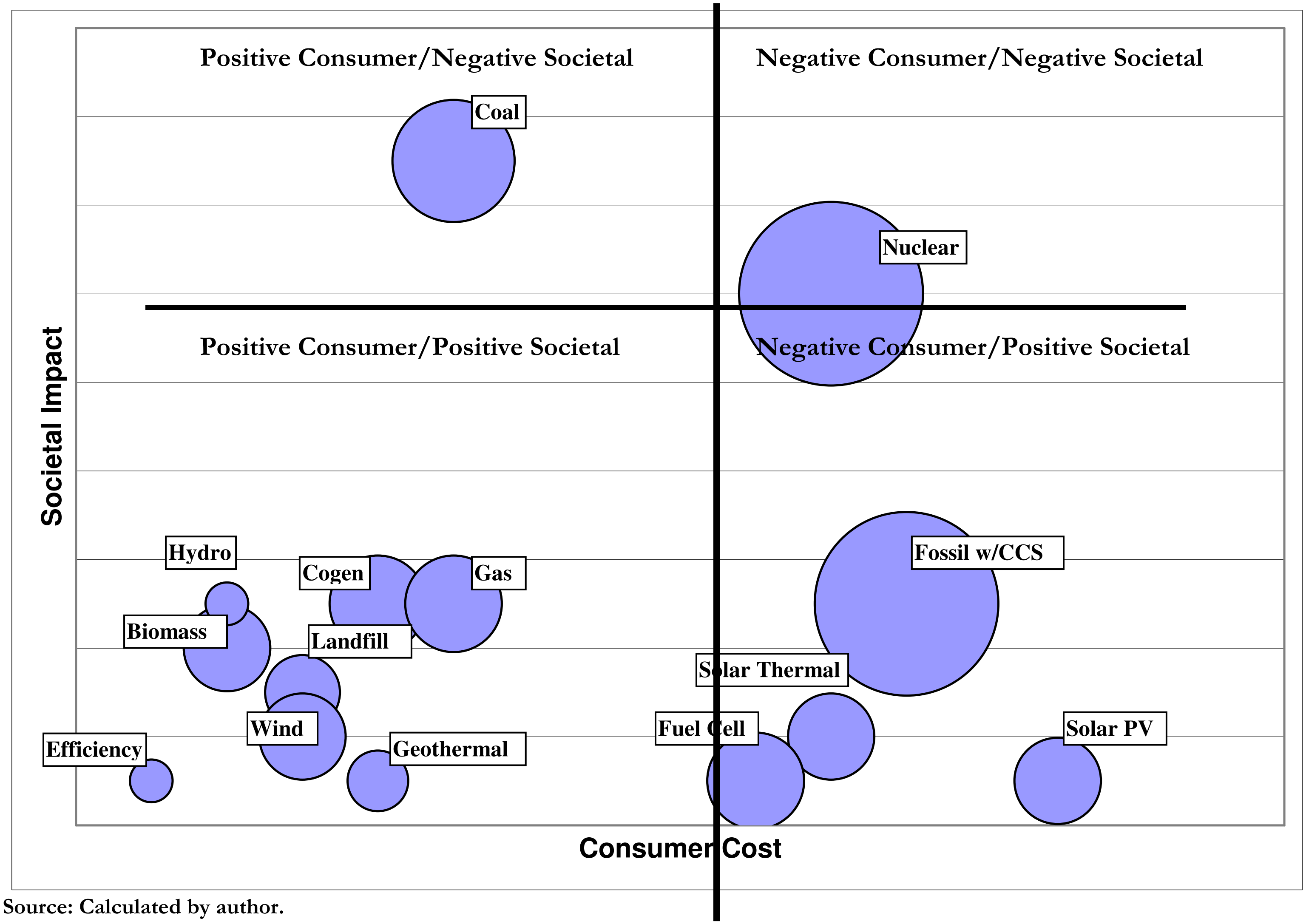
CONCLUSION

The highly touted renaissance of nuclear power is based on fiction, not fact. It got a significant part of its momentum in the early 2000s with a series of cost projections that vastly understated the direct costs of nuclear reactors. As those early cost estimates fell by the wayside and the extremely high direct costs of nuclear reactors became apparent, advocates for nuclear power turned to climate change as the rationale to offset the high cost. But introducing environmental externalities does not resuscitate the nuclear option for two reasons. First, consideration of externalities improves the prospects of non-fossil, non-nuclear options to respond to climate change. Second, introducing externalities so prominently into the analysis highlights nuclear power's own environmental problems. Even with climate change policy looming, nuclear power cannot stand on its own two feet in the marketplace, so its advocates are forced to seek to prop it up by shifting costs and risks to ratepayers and taxpayers.

The aspiration of the nuclear enthusiasts, embodied in early reports from academic institutions, like MIT, has become desperation, in the updated MIT report, precisely because their reactor cost numbers do not comport with reality. Notwithstanding their hope and hype, nuclear reactors are not economically competitive and would require massive subsidies to force them into the supply mix. It was only by ignoring the full range of alternatives -- above all efficiency and renewables -- that the MIT studies could pretend to see an economic future for nuclear reactors, but the analytic environment has changed from the early days of the great bandwagon market, so that it is much more difficult to get away with passing off hope and hype as reality.

The massive shift of costs necessary to render nuclear barely competitive with the most expensive alternatives and the huge amount of leverage (figurative and literal) that is necessary to make nuclear power palatable to Wall Street and less onerous on ratepayers is simply not worth it because the burden falls on taxpayers. Policymakers, regulators, and the public should turn their attention to and put their resources behind the lower-cost, more environmentally benign alternatives that are available. If nuclear power's time ever comes, it will be far in the future, after the potential of the superior alternatives available today has been exhausted.

Figure ES-4: A Multi-dimensional View of Alternatives (Size of Circles Denotes Risk)



Source: Calculated by author.

I. INTRODUCTION

A. THE TROUBLING HISTORY OF NUCLEAR REACTOR COSTS

Policy makers are being forced to evaluate alternative approaches to meeting the need for electricity in the decades ahead under extremely difficult circumstances. They must balance the importance of ensuring adequate supplies with the need to reduce greenhouse gas emissions from the electricity sector, which is the single largest sources of emissions in the United States. They must make decisions that will affect the flow of trillions of dollars of economic resource under conditions of extreme uncertainty.

One of the key aspects of that decision that is making the challenge so difficult is the need to assess the economics of nuclear reactors, none of which have been built in the U.S. in well over a decade. The uncertainty and lack of experience in the construction of nuclear reactors in the U.S. has not stopped advocates of nuclear reactor construction from declaring a "nuclear renaissance" and coming forward with optimistic projects of low cost electricity from nuclear reactors. Their initial projections put the cost of nuclear power far lower than the historical experience of the most recently completed U.S. reactors, as described in Figures I-1 and I-2.

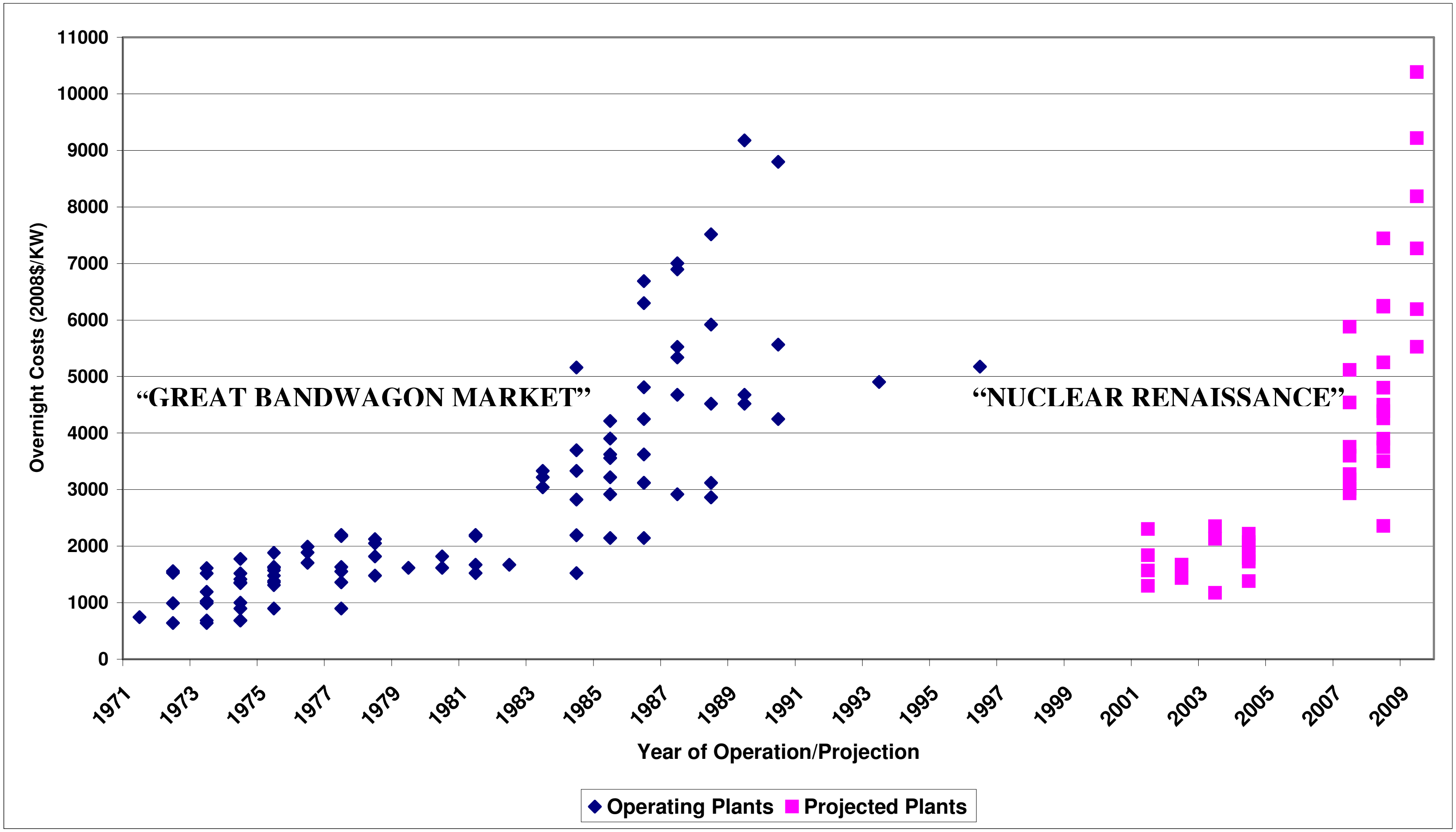
Figure I-1 uses "overnight" costs as the basis for comparison, while Figure I-2 uses "busbar" costs. Overnight costs are frequently used by industry analysts to describe the cost of building a power plant if it could be constructed instantaneously, or overnight. This isolates construction costs from the cost of financing construction and other costs. Busbar costs include all the costs necessary to operate a nuclear reactor. These are the costs passed on to the consumer. All costs are stated in 2008 dollars.

The Figures show the costs of the vast majority of nuclear reactors that were ordered during a flurry of activity that came to be known and the "Great Bandwagon Market" [1] and brought on-line between 1974 and 1996.[2] The Figures also show the projected costs that have been published in the past eight years, during what has been called the "nuclear renaissance." [3] These two Figures give a sense of the dramatic increase in both the actual cost of construction of nuclear reactors built in the U.S. during the "Great Bandwagon Market" and the current projections of cost of new nuclear reactors. The two graphs highlight the fact that the initial cost estimates early in this decade were quite low in comparison to both the historical trends and cost projections made in recent years. The more recent cost estimates have begun to come back in line with the historic pattern.

Cost estimates for new reactors have begun to take on considerable significance because it is no longer just a public relations or academic exercise. Utilities have begun to put them before public service commissions in an effort to receive certification to build reactors or to recover costs[4]. Interestingly, utility cost estimates are non-binding and utilities refuse to shoulder the responsibility of cost overruns, raising the specter of a process that could repeat the experience of the 1980s, when commissions struggled with cost overruns.

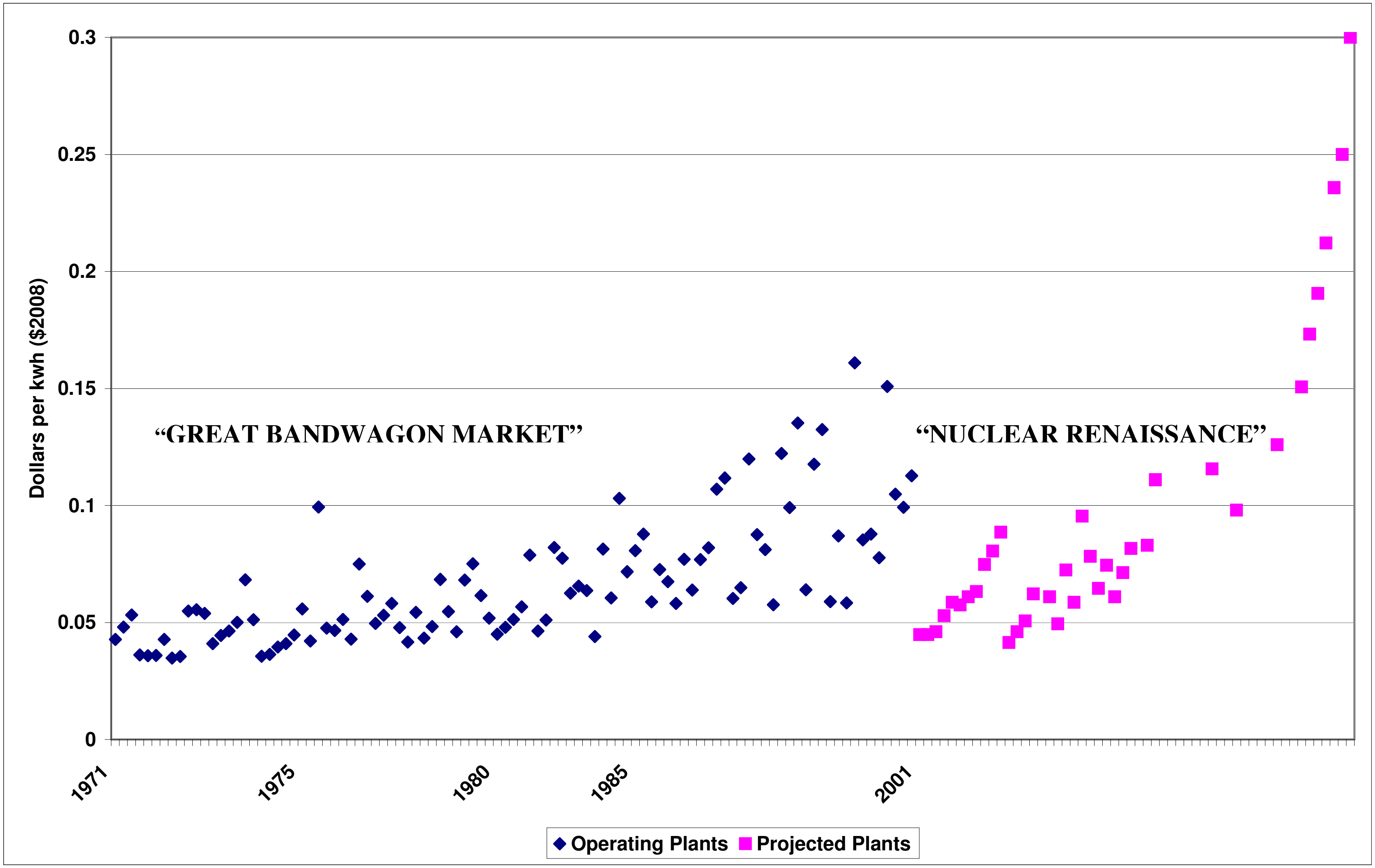
The stakes for consumers are huge. At the height of the regulatory proceedings to deal with the massive cost overruns in the 1980s, *Forbes* magazine opined as follows:

Figure I-1: Overnight Cost of Completed Nuclear Reactors Compared to Projected Costs of Future Reactors



Sources: Koomey and Hulttman, 2007, Data Appendix; University of Chicago 2004, p. S-2, p. S-8; University of Chicago estimate, MIT, 2003, p. 42; Tennessee Valley Authority, 2005, p. I-7; Klein, p. 14; Keystone Center, 2007, p.42; Kaplan, 2008 Appendix B for utility estimates, p. 39; Harding, 2007, p. 71; Lovins and Shiekh, 2008b, p. 2; Congressional Budget Office, 2008, p. 13; Lazard, 2008, Lazard, p. 2; Moody's, 2008, p. 15; Standard and Poor, 2008, p. 11; Severance, 2009, pp. 35-36; Schlissel and Biewald, 2008, p. 2; Energy Information Administration, 2009, p. 89; Harding, 2009. PPL, 2009; Deutch, et al., 2009, p. 6. See Bibliography for full citations.

Figure I-2: Busbar Costs of Completed Nuclear Reactors Compared to Projected Costs of Future Reactors



Sources: See Figure I-1.

> The failure of the U.S. nuclear power program ranks as the largest managerial disaster in business history, a disaster on a monumental scale. The utility industry has already invested $125 billion in nuclear power, with an additional $140 billion to come before the decade is out, and only the blind, or the biased, can now think that most of the money has been well spent. It is a defeat for the U.S. consumer and for the competitiveness of U.S. industry, for the utilities that undertook the program and for the private enterprise system that made it possible.[5]

Given that some analysts put the current cost estimates for nuclear reactors at the level of costs where the last cohort of reactors ended, the stakes for consumers and the nation could be even larger, rising to the trillions of dollars.

B. Purpose and Outline

To make these difficult decisions in a careful manner, policymakers need a rigorous analytic framework and good data. This paper provides both.

This analysis divided into five sections, each of which provides an important building block for sound decision making.

The next section, Section II, presents a comprehensive framework for dissecting nuclear reactor costs. It distinguishes two different cost analyses that should be applied to nuclear reactors in both the policy and public utility commission arenas – a direct, consumer pocketbook analysis and an indirect societal cost analysis.

The paper then reviews the empirical evidence on nuclear reactor costs in four areas.

Section III presents an analysis of three dozen recent estimates of the cost of nuclear reactors, dissecting their differences in an effort to understand why estimates vary so widely, as well as which entities appear to be making high and low estimates.

Section IV places those projections in the context of the long sweep of the history of the nuclear industry with a database of the cost of 100 reactors built in the U.S. between 1971 and 1996. Lacking contemporary experience with reactor construction in the U.S., the historical record becomes important as context.

Section V examines nuclear reactor costs in comparison to the cost of alternatives available today to meet the need for electricity in a carbon-constrained environment.

Section VI considers a range of qualitative factors, including environmental concerns, risks, and subsidies, that affect decisions about which technologies to utilize in a public policy environment that requires constraints on carbon emissions. This section also explains that public utility commissions should take both the direct consumer pocketbook and the indirect societal costs into account in their decision-making. Finally it examines the impact of subsidies on policy choices.

II. The Structure of Analysis

A. The Challenge of New Nuclear Reactor Cost Analysis

Answering the question – "how much will electricity from nuclear reactors cost?" – is extremely complex for several reasons, as suggested by Figure II-1. First, the direct economic costs of building and operating a nuclear reactor involve a large number of factors that are subject to a great deal of uncertainty. Second there are indirect costs that hang over the analysis that increase the societal costs and create even greater uncertainty.

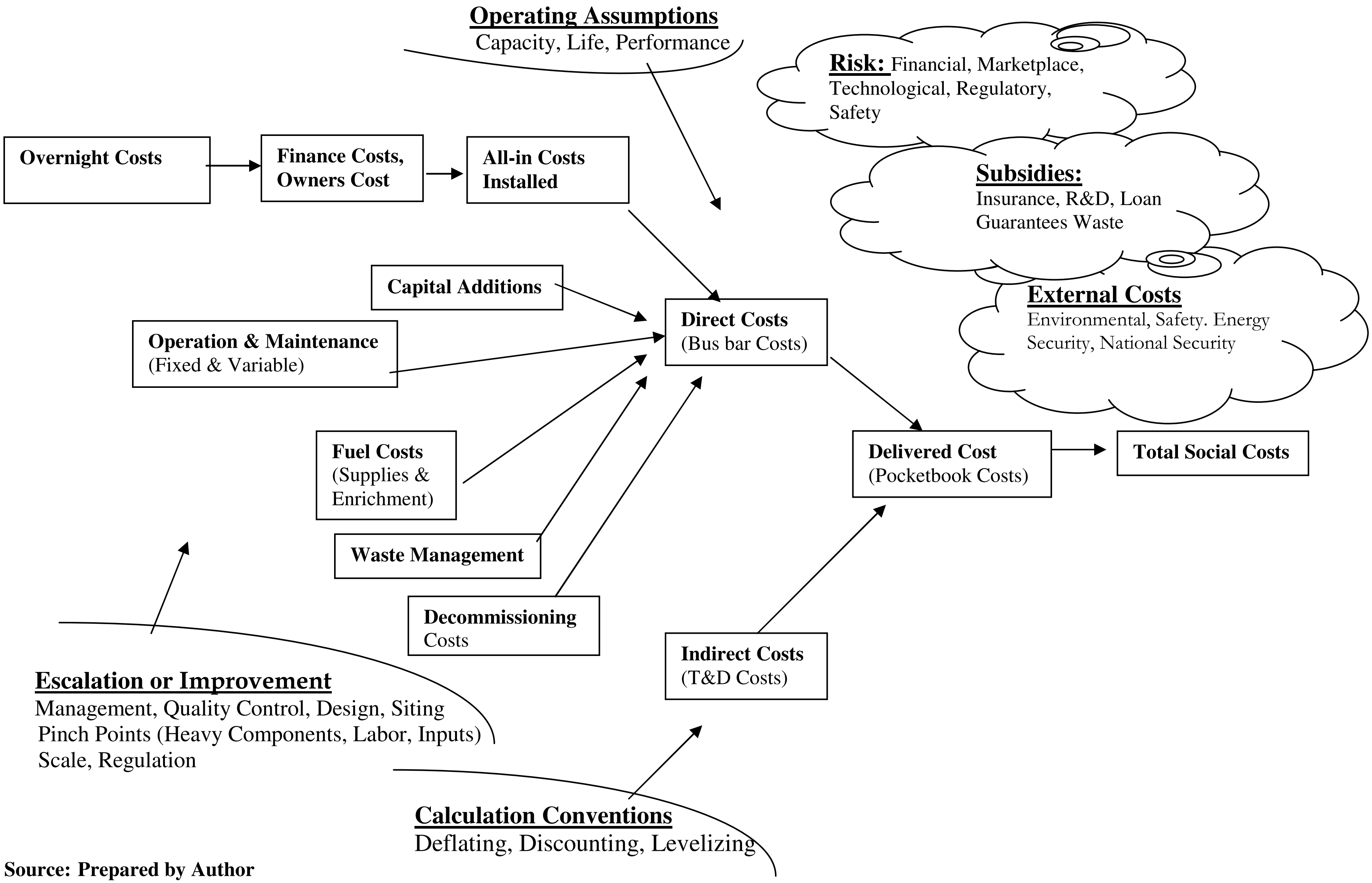
This uncertainty has not prevented dozens of analysts from making projections and it has resulted in a wide range of costs being put forward. In the last year alone, estimates of the cost of power from new nuclear reactors have varied from a low of 8.4 cents to a high of 30 cents, and that is for only the direct costs. Notwithstanding the uncertainty and diversity of the cost estimates, policy makers cannot just wait and see how things work out. They are being asked to make critical decisions in real time that will affect trillions of dollars of investment and consumer expenditures.

To understand the wide range of cost projections for new nuclear reactors, the analysis must isolate and examine the various elements that compose and affect the total cost. This section lays out a framework for dealing with the complexity of the cost analysis. First, it distinguishes between direct, consumer pocketbook costs and indirect, societal costs. Then, it identifies the key elements that affect the estimation of direct costs, which have been the focal point of so much recent analysis.

B. The Consumer Pocketbook and Societal Cost Benefit Analysis

Given the complexity of the nuclear reactor cost analysis, it is helpful to use two tests or standards in making decisions: a direct, consumer pocketbook test and an indirect, societal cost/benefit test. Total costs are the sum of direct and indirect costs. In a situation in which a commission will decide what the consumer will pay, the distinction between direct consumer pocketbook costs and indirect, societal costs is relatively easy to make. The commission reviews usually focus on the direct costs that consumers pay in their bills, but for the reasons given below, the indirect social costs should also be taken into account, particularly in the planning and prudence reviews that take place before construction begins. Policy analysis would make societal cost the focal point, but direct consumer pocketbook costs should also be considered. Thus, the distinction between the direct pocketbook and indirect cost analyses is a matter of degree.

Figure II-1: The Complex Structure of Nuclear Reactor Costs

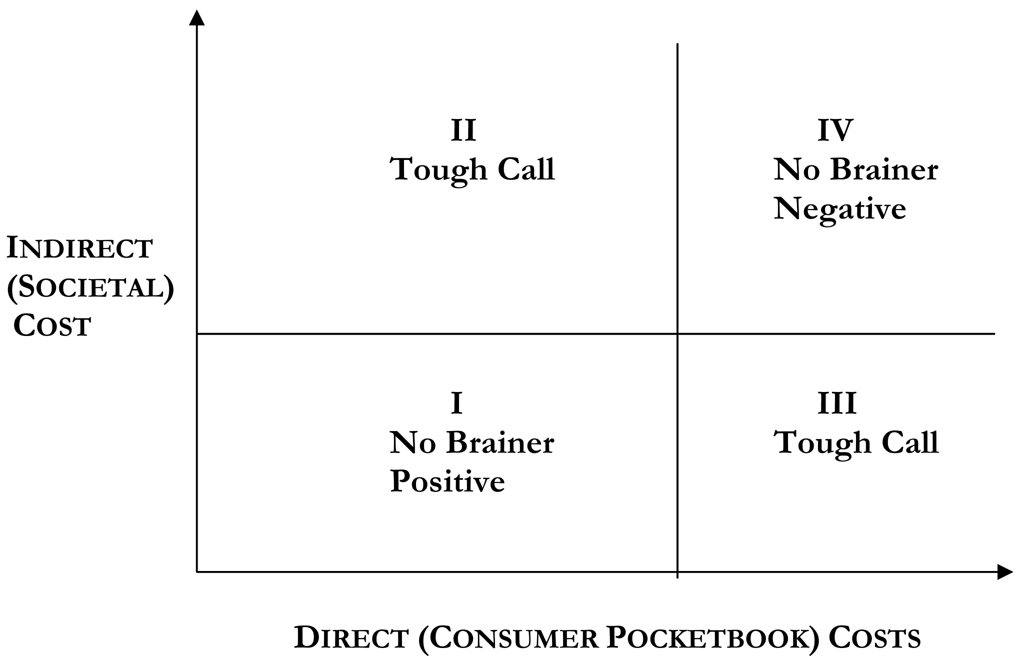


Source: Prepared by Author

Suggesting two separate analyses or distinguishing the two cost concepts sharply opens the door to a potentially complex set of outcomes. A project might pass one test, but fail the other. How do we decide? Conceptually, there are four possible outcomes of the two tests (see Figure II-3). Two outcomes are "no brainers." When the project fails both tests, it should not be pursued. When it passes both tests, it should be pursued. The challenge comes when there is a mixed result.

Conceptually, in the tough calls in Figure II-2, quadrants II and III, the costs and benefit should be quantified. If the benefits of the test that is passed are larger than the costs of the test that is failed, the project has a net benefit. If the winners and losers are different people (e.g. different generations of consumers or consumers in different areas), it is helpful if the losers can be compensated by the winners, but it usually takes explicit and complex public policy to transfer wealth from winners to losers.

Figure II-2: Outcomes in the Consumer and Societal Analysis



Source: Prepared by Author

Assessment of both the direct consumer pocketbook costs and the indirect societal costs should be made, quantified if possible, qualitatively if need be, in order to compare options. That is, the direct consumer pocketbook costs and the indirect societal cost of nuclear reactors should be compared to the direct consumer pocketbook costs and the indirect societal cost of alternatives available to meet the same level of need for electricity. Least-cost approaches should be pursued in all cases.

Framing the cost analysis is important. We must treat the analysis of nuclear-generated electricity as a debate over facts, assumptions, and economic models. With the huge challenge facing the electricity sector to meet a growing need for power while responding to the urgent need to address the problem of climate change, it is important to carefully evaluate the options. This requires policymakers to conduct rigorous analysis to ensure that the options chosen promote and protect the public interest. Thus, it is necessary to delve into the details of the cost analysis that are identified in Table II-1. Given the large number of issues and factors in play, it is important to identify which factors matter most.

C. MAIN ATTRIBUTES OF COST STUDIES

1. Study Characteristics

Table II-1 identifies the elements of the cost analysis in detail. A wide range of answers to the question have been published because the respondents use different costs and make different assumptions about the various elements that go into the cost estimates.

- Some of the variability in the cost estimates is a result of comparing apples to oranges, e.g. comparing different types of costs to one another, such as real to nominal dollars, comparing operating costs to total costs, etc.
- Some of the variability is the result of faulty methodology, e.g. failing to discount, omitting important cost elements, etc.
- A lot of the variability stems from "differences of opinion" about the level or rate of change of each of the cost elements, e.g. construction costs, operating costs (especially whether and how much carbon pricing will increase costs for some technologies), etc.

To evaluate cost estimates we need to know what kind of study it is and how the study was conducted, as well as the values for the cost elements included in the study. The key characteristics of cost estimates considered in this analysis are divided into three categories in Table II-1: assumptions, cost elements, and factors affecting societal cost.

Assumptions are major choices made in the study that affect the overall analysis. Cost elements are the discrete costs that must be incurred to build and operate a power plant (or in the case of energy efficiency, the cost of technologies that lower demand). Factors affecting societal cost are factors that are not included in the transaction and which tend not to be included in public utility rate cases where prices are set, but which influence the cost to society of the project. Traditionally, the latter category includes externalities, but in the case of nuclear reactors, it must include risks because they are large, pervasive, and also mask the true cost of a nuclear reactor.

Figure II-3 displays the structure of a Cost of Generation Model used by the California Energy Commission. It organizes the elements in a somewhat different manner but includes the same cost elements.

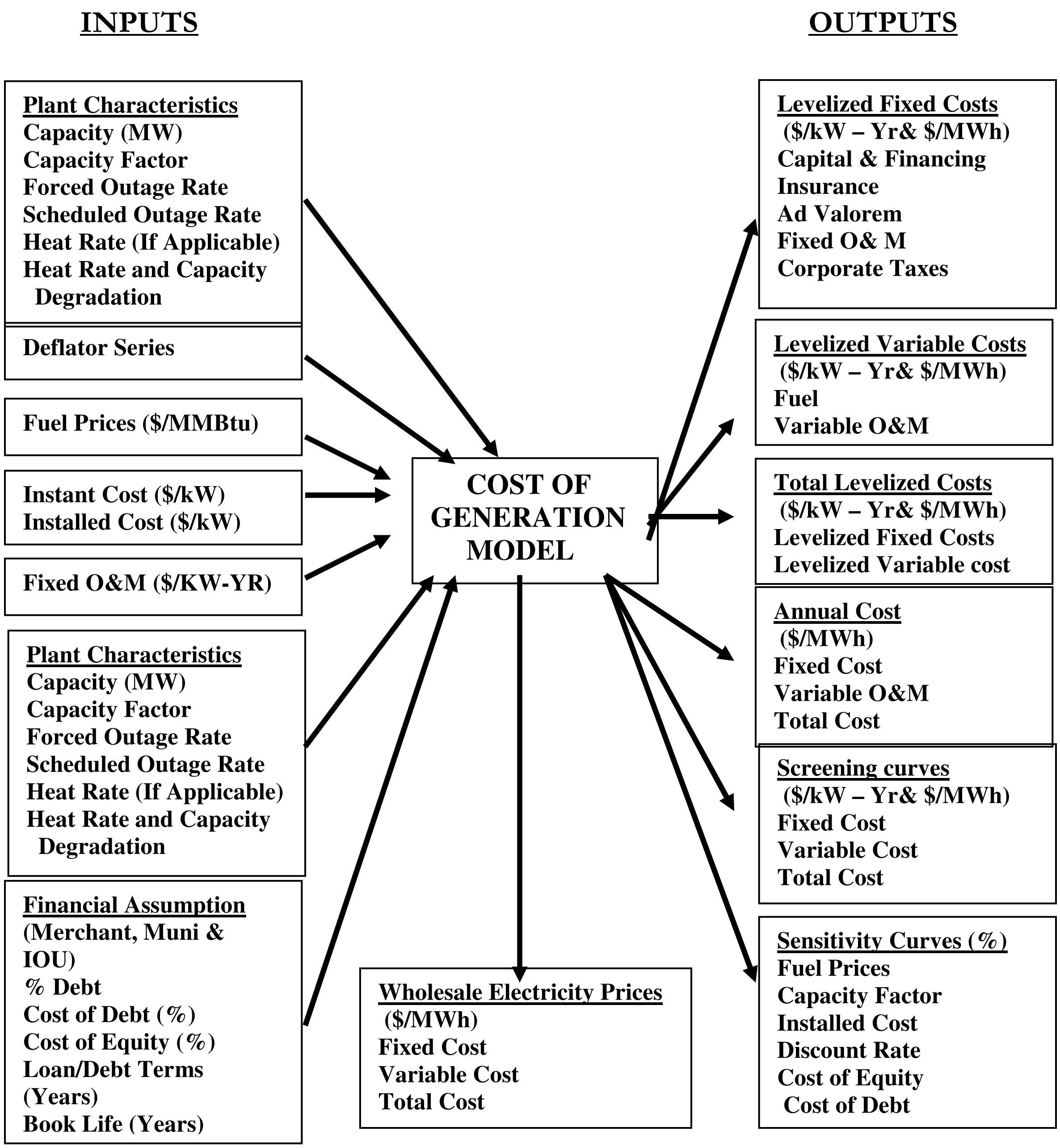
Type of Study: In assessing the cost projections from various sources, careful attention must be paid to exactly what the author is estimating. Giving the benefit of the doubt to the authors (i.e. assuming they are not trying to mislead policymakers and the public), there are three types of estimates: aspiration (hype), recommendation (hope), and projection (reality).

Table II-1: Critical Elements in the Comprehensive Cost Analysis

Assumptions		**Cost Elements**		**Societal Casts**	
Study	Type of Study	**Overnight**	Construction	**External Costs**	Environmental
Characteristics	Aspiration	**Vendor**	Period		Climate Change
	Recommendation		Inflation		Pollution
	Projection	**Finance**	Treatment of Construction		Air
	Date of Study		Debt/Equity Ratios		Land
	Scope of Analysis		Return on Equity		Water
	Nuclear only		Cost of Debt		Public Safety
	Comparative		Depreciation		Energy Security
			Taxes		National Security
Calculation	Deflating		Insurance	**Risks**	Financial;
Conventions	Discounting	**Owner**	Engineering		Marketplace
	Levelizing		Site Acquisition		Technological
	Cost of Debt		Spare Parts		Regulatory
	Depreciation		Regulatory		Safety
	Taxes		Site Acquisition		Accidents
	Insurance		Spare Parts		Attacks
			Regulatory	**Subsidies**	Insurance
Escalation/	Construction/	**Plant**	Capacity		R&D
Improvement	Operation	**Characteristics**	Capacity Factor		Core Costs
	Management		Performance		Loans
	Quality Control		Heat Rate		Production Credits
	Design	**Capital Additions**	Quantity		Tax Credits
	Siting		Timing		Waste
	Pinch Points				Decommissioning
	Heavy Component	**Operation &**	Fixed		
	Labor	**Maintenance**	Variable		
	Inputs		Escalation		
	Scale	**Fuel**	Cost		
	Vendor		Escalation		
	Construction Period		Supplies		
	Inflation		Availability		
		Waste mgmt	Cost		
		Decomissioning	Cost		
		Other Costs	Transmission		
			Distribution		

Source: Prepared by Author

Figure II-3: California Energy Commission Cost of Generation Model



Source: Klein, p 7.

- It is possible to hype future costs higher or lower by making differing and perhaps unrealistic assumptions about cost levels and their escalation or reduction over time.
- It is possible to hope that future costs will move in a particular direction and recommend policies or identify events that will push future costs in the desired direction.
- It is possible to project what the costs of construction are expected to be without hope or hype.

Recognizing what type of estimate is being made is important for both policy and rate analysis. Unfortunately, sometimes the estimates are not clearly labeled or explained in the studies. In these cases it is possible to identify the type of estimate that is being made only by comparing it to another type of estimate.

Study Characteristics: The time frame of the analysis is important, as costs have been changing rapidly in recent years. The scope of the analysis is important, particularly depending on whether alternatives are analyzed. If alternatives have not been analyzed in a study, then the analysis is not complete. When adding alternatives to the analysis, it is important to specify the structure of the cost study so that alternatives are evaluated using similar approaches and cost bases (e.g. hope, hype, or reality, capacity factors, etc.). Studies also use different calculation conventions (deflated, discounted, levelized.[6]). These must be recognized to make valid comparisons between studies. The studies have different opinions about the direction that costs are likely to move, given the past performance of the nuclear industry and the desire of the industry to ramp up construction.

2. Cost Elements

Overnight costs, all-in costs, and busbar costs are three different cost concepts that receive the most attention in the literature. Overnight costs (sometimes called instant costs) are a hypothetical construct, a form of virtual barn raising. They are an estimate of what it would cost if all the parts of the facility could be assembled and put together instantaneously. The concept isolates the raw material, manufacturing of components, and labor costs. But facilities are not built overnight, in a virtual world. They must be built physically and they take years to construct. Construction must be financed. Adding in finance and owner costs yields "all-in" costs (sometimes called installed costs).

There are other costs, in addition to the cost of installing the facility, which must be incurred to generate electricity. Fuel, operation and maintenance, and additional capital costs must be recovered, while provisions must also be made to dispose of waste and to ultimately decommission the facility. Combining these with the installed costs yields the busbar cost – the cost of delivering electricity to the point of interconnection with the grid. This cost of generation is the real world cost that is presented to the public utility commission for collection from ratepayers. In order to get the electricity to the consumer, transmission and distribution costs are also incurred.

This analysis identifies several key determinants of the cost of nuclear reactors. The most important element is the overnight cost and how it is treated financially. Capital costs account for about three-quarters of the cost of nuclear-generated electricity. Financial parameters have a large impact on nuclear costs because the reactors are capital-intensive and take a relatively long time to construct. Return on investment and cost recovery are major variables affecting the cost of a reactor.

Plant characteristics play an important part in the analysis with key parameters being plant life, capacity, and performance.

Operation and maintenance costs are the next most important, followed by fuel costs. The ultimate impact of waste disposal and decommissioning costs has yet to be determined, in part because they have not yet been fully realized with permanent storage facilities and fully decommissioned large reactors. Table II-1 organizes costs by function. Many discussions of costs focus on type – materials, labor, engineering services, etc. – but material and labor costs are actually spread across the categories and they affect different functions differently. Section III is devoted to a discussion of the key cost elements.

III. The High and Rising Cost of Nuclear Reactors

A. The Range of Current Cost Estimates

Table III-1 presents more than sixty estimates of nuclear reactor costs from over three dozen entities that have been published since 2001, when the nuclear industry first claimed a nuclear renaissance was imminent. The table shows the overnight, all-in, and busbar costs, where they are available, and attempts to impose order on the projections by stating costs in constant 2008 dollars, using the GDP deflator to restate the costs. When the dollar vintage was not specified in the study, it was assumed to be the year of the study. Figure III-1 shows the overnight costs for both the completed plants and the projections for future plants, repeating Figure I-1, but adding in types of institutions providing the estimates. The estimates are roughly equally divided between government consultants, utilities, government entities, utilities, and Wall Street/independent analysts, plus a small number of academic institutions. Many of the estimates are not very well explained or documented, while a few are analyzed in great detail.

Figure III-2 highlights how quickly the projected costs have escalated over the past decade. The low estimates from vendors, academics, and government agencies have approximately doubled. However, they remain below the estimates from many of the utilities and well below the estimates from Wall Street and independent analysts. Several aspects of the cost estimates are worthy of note.

- First, as noted in Section I, there has been a sharp increase in projected costs in a short period of time.
- Second, the early government and academic costs were quite low.
- Third, the recent utility cost estimates have doubled or tripled the first estimates but still tend to be lower than the estimates from Wall Street and the independent analysts.
- Fourth, the governmental entities tend to use the average of other analyses, particularly the utilities.
- Finally, the independent analysts tend to be the highest.

Even adjusting for inflation and stating all of the estimates in constant 2008 dollars, the projections are all over the map. However, it turns out that it is not very difficult to reconcile the estimates. A small number of variables account for the differences.

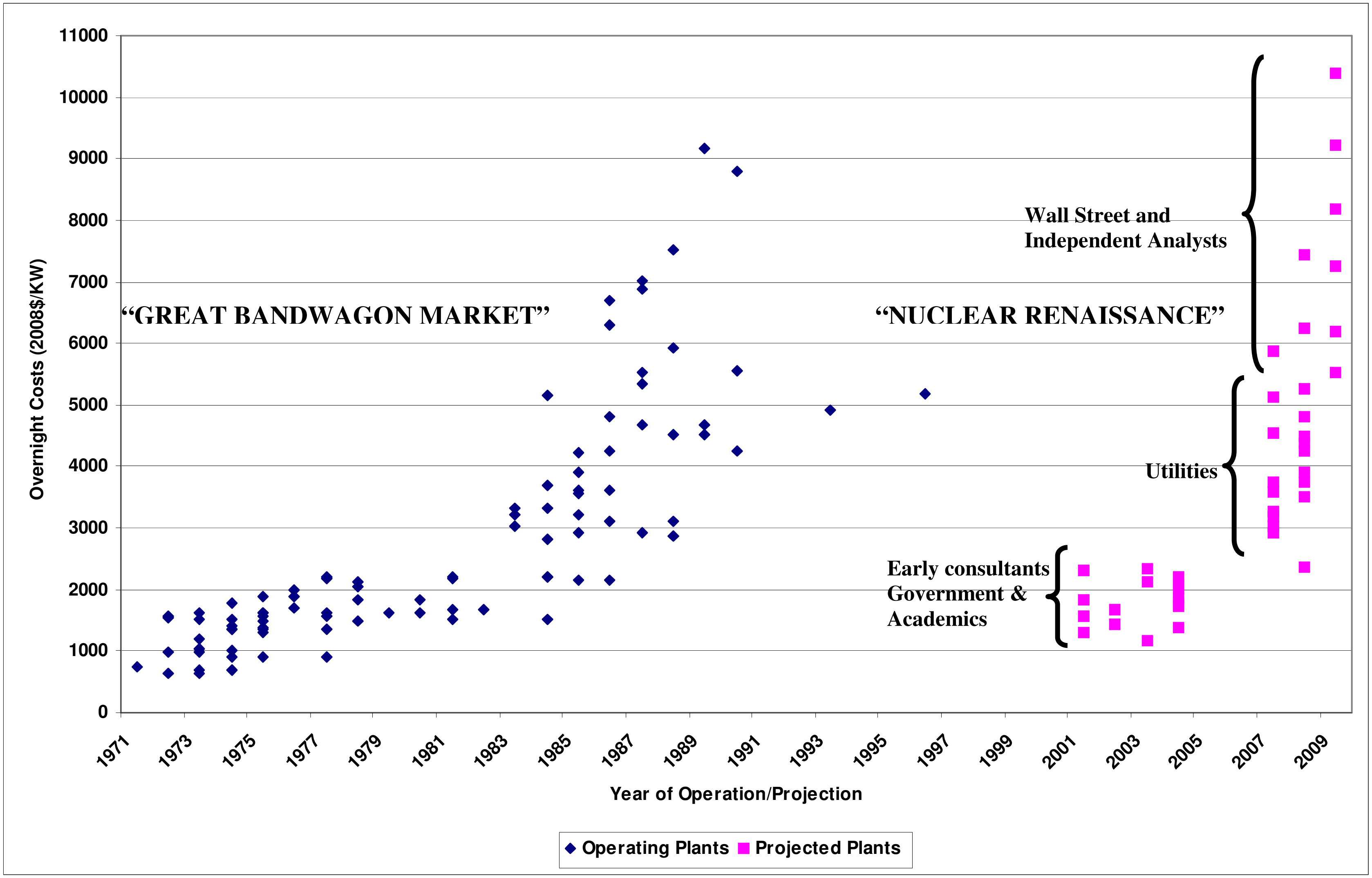
What these differences in estimates correlating with the type of institution making the estimate indicate is difficult to say. Utilities, especially in the early phase of the regulatory process, have an interest in understating costs, as long as the estimates are nonbinding. Low-balling the costs helps to get the power plant approved. In theory, Wall Street analysts are objective, but the recent crisis in the financial sector has called that into question. Wall Street analysts and rating agencies may have agendas related to their efforts to win clients.

Table III-1: Estimates of Nuclear Reactor Overnight, All-in and Busbar Costs: 2001-2008

Original Estimate	Date of Estimate	Source of Estimate	Overnight Cost 2008$/ kW			All-in Cost 2008$/kW			Busbar Costs (2008$/ mWh)		
			Low	Mid	High	Low	Mid	High	Low	Mid	High
SAIC	2001	U of C	2300	2300	2300				75	81	89
SAIC	2001	U of C	1840	1840	1840				69	61	63
SAIC	2001	U of C	1570	1570	1570				53	56	63
SAIC	2001	U of C	1295	12995	1295				45	52	74
Scully	2002	U of C	1434	1434	1674				41	46	51
Sandia	2002	U of C	2131	2131	2131				68		95
EIA	2003	U of C	215	2015	2217				72		78
EIA	2003	U of C	1241	1563	1784				49		61
MIT	2003	MIT	1175	2350					65	79	
U of C	2004	U of C	1380	1725	2070				61	71	82
TVA	2005	TVA		1853							
CEC	2007	CEC		3021			3840			106	
Keystone	2007	Keystone	3018		3018	3653		4092	85		114
Harding	2007	Harding		3329		4349		4655	96		125
South Texas 3&4	2007	CRS	2931	3214	3754						
Turkey Point 3&4	2007	CRS	3179	3179	4644						
Calvert 3	2007	CRS		5778							
Levy 1&2	2008	CRS		4260							
Summer 2&3	2008	CRS		4387							
Vogtle	2008	GA PUC		4381			6447				
Callaway 1	2008			4250			6125				
Duke	2008	Lovins		4800							
S&P	2008	S & P		4100							
DOE Loans	2008	DOE					6528				
EIA	2008	EIA		3400							
CRS	2008	CRS		3900						83	
CBO	2008	CBO		2358						74	
Lazard	2008	Lazard	3750		5250	5750		7550	100		126
Moody's	2008	Moody's		6250			7500			151	
Severance	2008	Severance	6233	7440		8858	10553		250	300	
MIT II	2009	MIT		4092						86	
Bell Bend	2009	PPL			9375						
Harding - Medium	2009	Harding 09	5524	7263	9217				137	173	212
Harding - High	2009	Harding 09	6189	8184	10383				150	190	235

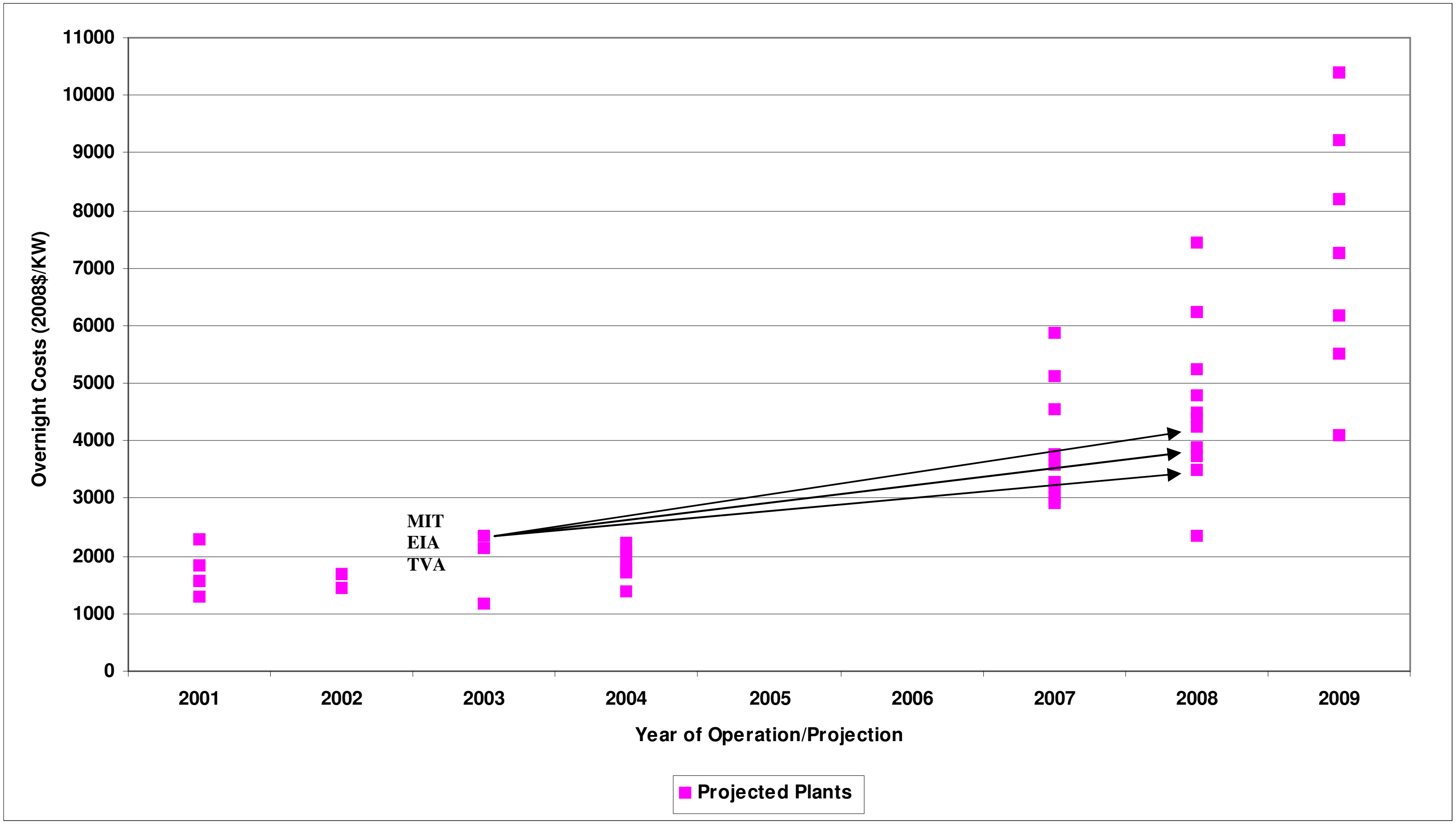
Sources: See Figure I-1.

Figure III-1: Institutional Origins and Levels of Recent Cost Projections



Sources: See Figure I-1.

Figure III-2: Escalating Overnight Cost Projections of Key Early Nuclear Renaissance Predictors



Sources: See Figure I-1.

B. CONSTRUCTION COSTS

Of the three dozen estimates included in Table III-1, several have publicly available and detailed documentation that enables us to isolate the key causes of differences in cost estimates. Most of the studies do not. Rather, they create high and low cost cases that assume different values for a number of variables simultaneously. These "high and low what if" scenarios may seem to bracket the range of possibilities, but if there is no reason to believe that the elements of the high or the low scenario should go together, the exercise may not be informative. It would be better to identify the individual impact of each cost element and project costs on a probabilistic basis.

1. Overnight and Busbar Costs

Overnight costs are the single most important cost element. Overnight costs exhibit a strong direct relationship to busbar costs. Some of the studies provide a basis for describing the impact of overnight costs on busbar costs holding other elements constant. Figure III-3 graphs the results of four such studies. Each of the studies included in Figure III-3 provided a narrow range of overnight costs with which the effect of overnight costs on busbar costs can be estimated, holding all other things constant. Those projections have been extended over a wider range of overnight costs estimates to assess the magnitude of the effect of overnight costs on busbar costs across the studies.

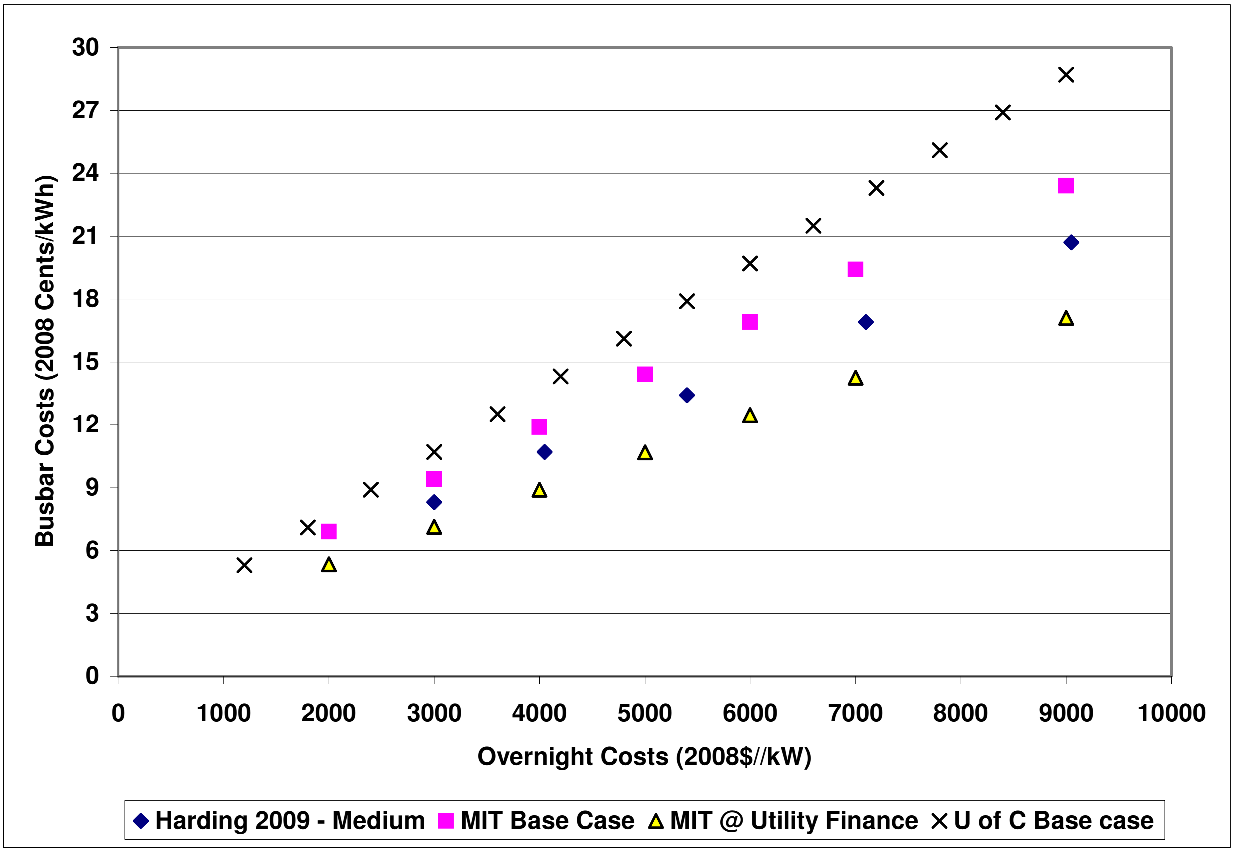
The MIT model suggests that for every $1,000 of increased overnight costs, the busbar costs go up by 1.8 cents in the utility finance model and 2.4 cents in the merchant finance model. Moving from overnight costs of about $2,000 to about $7,000 raises the estimated busbar costs around 8 cents/kWh in the utility model and about 12 cents in the merchant model. In the Harding study, busbar costs go up about 2.4 cents per kWh for every $1,000 increase in overnight costs. In the University of Chicago study, the increase in busbar costs per $1,000 in overnight costs was 3.0 cents per kWh.

2. Financial Models

There are two key elements that affect the extent to which financial costs magnify overnight cost differences. The higher the rate of return and cost of debt, the higher the financial costs. The larger the share of equity as compared to debt, the higher the financial cost.

Much of the impact of financial cost models can be encapsulated in the difference between utility and independent company finance. Some argue that independent power producers will build plants on a speculative basis.[7] Others argue that only utilities will build them, and only with clear guidance to public utility commissions about needs and cost recovery.[8] To date, the latter appears to be closer to the mark. Joskow and others do not believe that merchant nuclear reactors are very likely to be built, which is contrary to the assumption in the MIT analysis, so they applied a utility finance model to the MIT cost estimate. The Joskow numbers are shown in Figure III-3. With a lower cost of capital in utility finance version of the MIT analysis, nuclear reactors have lower capital costs and produce lower priced electricity.

Figure III-3: Reconciling Overnight and Busbar Costs of Selected Studies



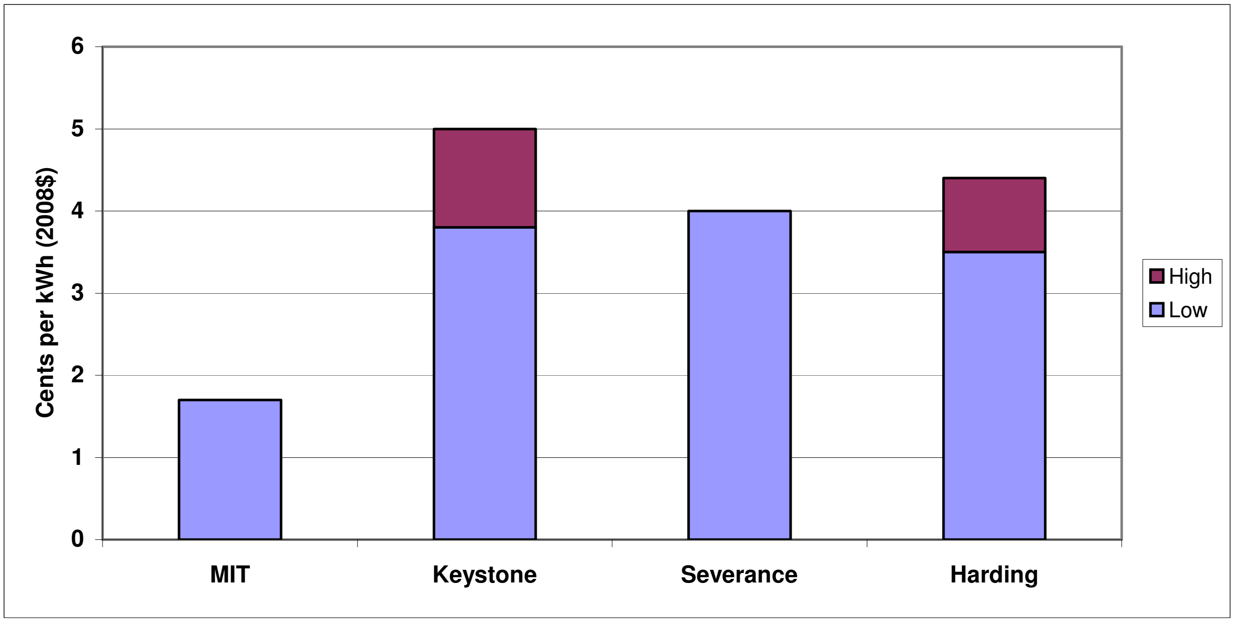
Source: See Figure I-1 and Joskow, 2006, Table 1.

The MIT model suggests that at $2,000 for overnight costs the difference between a utility and a merchant financial model is about 1.5 cents per kWh. The California Energy Commission Cost of Generation Model puts this figure at about 1.4 cents at an overnight cost of $2,950 per kW. As the overnight costs increase, the impact of the financial model is magnified. Thus, at $7,000 for overnight costs, the difference between the merchant and utility models in busbar costs is almost 5 cents per kWh.

C. Operating costs

Another cost element that can easily be factored into the framework of this analysis is the operating and maintenance costs. While construction and capital costs tend to attract the most attention, operating costs are significant. The MIT study used a low operating cost (including fuel) that it admitted was optimistic.[9] Others have estimated operating costs (including fuel) to be much higher (See Figure III-4). The difference is between about 1.5 cents per kWh to almost 3 cents per kWh. The Keystone base case for operation and maintenance costs (including fuel) was 2.1 cents higher than the MIT base case. Adding this operation and maintenance cost difference to the overnight costs in the MIT study, based on the utility finance model (which was the approach taken

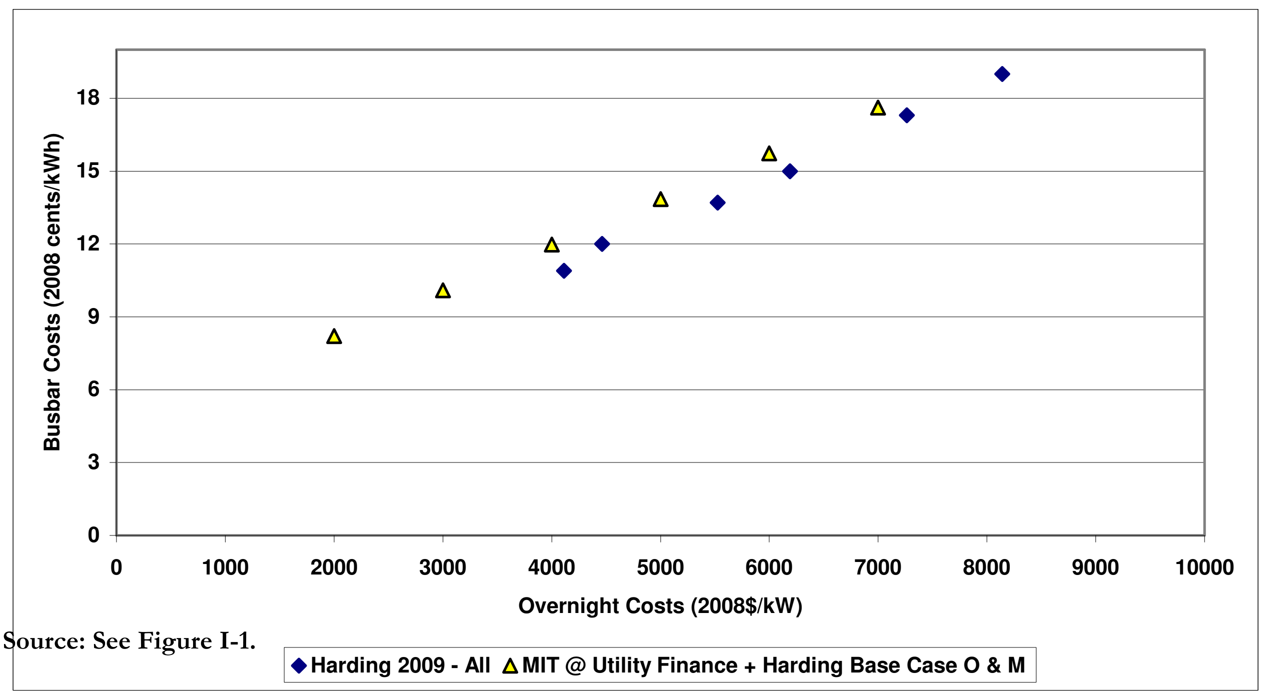
Figure III-4: Operating Cost Assumptions in Various Studies



Source: Figure I-1.

in the Keystone study), we largely resolve the difference between the projected busbar costs as shown in Figure III-5.

Figure III-5: Reconciling Overnight and Busbar Costs Including O&M Adjustment



Source: See Figure I-1.

D. Escalators

This analytic exercise is just arithmetic until it is tied to real world causes. The MIT study started with low overnight costs (as hypothesized by the earlier Department of Energy funded studies) and then hypothesized ways overnight costs might decline.[10] Many of the later studies derive their estimates by applying escalators to the early studies. In many of the studies since 2001, a wide range of overnight costs is presented as scenarios because there is uncertainty about construction costs, and construction costs have been rising.

The choice of an escalation rate for costs is an effort to properly inject reality into the model. Many of the discussions of escalation refer to the Cambridge Energy Research Associated (CERA) index of power plant construction costs. Harding points out that the CERA index for nuclear plant escalation has been as high as 14 percent per year.[11] Harding identifies four levels of escalation of costs: zero, 4%, 8%, and 14%. Harding's early analysis used the 4% figure and his later analysis argues that the 8% figure is closer to reality.[12] He points out that the heavy construction cost index calculated by American Electric Power has been increasing at a rate of 10.5% per year. Thus, his conclusion that the 8% figure is a better basis for estimating overnight costs is moderate. In the Harding mid-scenario, the 8% escalation puts the overnight costs at $7,100 and the busbar costs at 17.3 cents per kWh. In the Harding high scenario, the 8% escalator yields overnight costs of $8,000 per kWh and busbar costs of 19.0 cents. Harding's high model with high escalation puts the cost in the range of 21.2 to 23.5 cents. The MIT model with utility costs and Harding O&M costs predict the same busbar costs as specific overnight costs.

An update to the MIT study underscores how important these escalators can be.[13] It cites the CERA index showing an increase in nuclear construction costs of 22.5% per year between 2002 and 2007, the years for which it estimated costs. However, it escalated costs at 15% per year to arrive at a cost of $4,000 in 2007 dollars, which results in a cost in the low end of recent estimates from utilities. If it had used the higher observed escalation rate for 2002-2007, it would have arrived at a figure that was about $1,500 per kW higher, or more than one-third higher.[14]

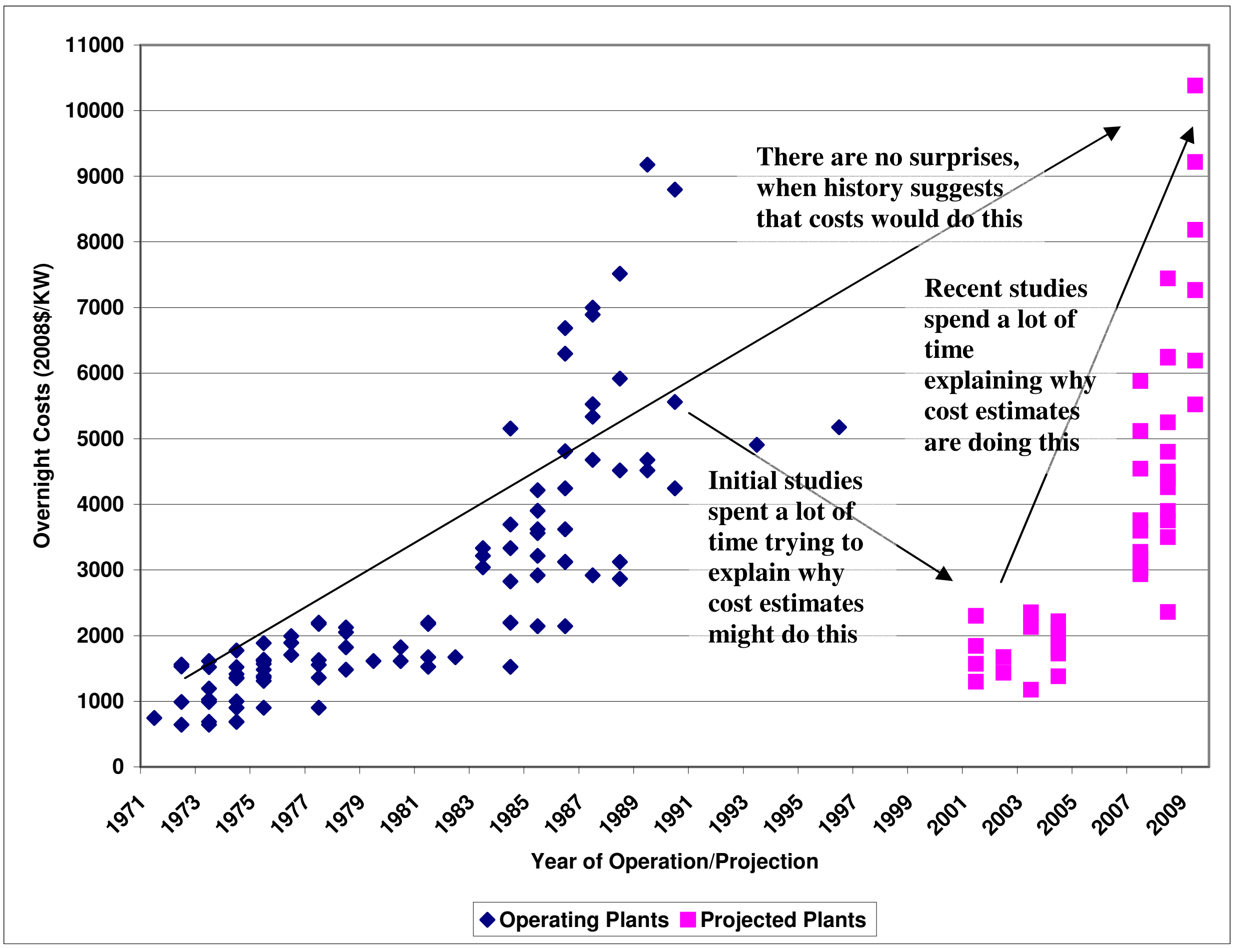
Similarly, Severance uses an 8.8% figure for escalation, which puts the overnight costs at $7,400 in his most likely case and the busbar costs at 25 cents per kWh. The Severance analysis yields high busbar costs because it includes two other costs not included in other analysis. Severance adds 2 cents for property taxes and 2 cents for decommissioning costs, which are higher costs than used by others. Excluding these, Severance's costs of 21 to 25 cents are close to Harding's high-end estimates (21.2 cents to 23.5 cents).

There are two different escalations that are being estimated in these studies. First is the increase in costs that is projected because of past escalation. Since many of the studies launch from the earlier low-ball estimates, they must deal with the increase in cost estimates that have already taken place. As the various cost indices suggest, that increase has already been substantial. Whether costs will continue to escalate in the future is a separate question.

The estimates by Florida Power and Light (FPL) illustrate this distinction. The non-binding cost estimate was derived by escalating and modifying the earlier cost estimate from TVA for its proposed Bellefonte reactors.[15] Moving from a 2004 estimate to a 2007 estimate, the projected cost of the plant doubled in real terms, suggesting an extremely high rate of escalation of 25% per year.[16] Looking forward, however, FPL projects only a 2.5% real rate of escalation to arrive at a mid-point overnight cost estimate of just under $3,600 per kW in 2007 dollars.[17] FPL acknowledges that Moody's has questioned the low figures being used by utilities.[18] If FPL used the rate of escalation of 8% for the next decade, its estimate would be well over $6,000, close to the number used by Moody's.

Ironically, much of the analysis in the early 21st century sought to explain how very low capital and busbar costs might come about, since the historical experience suggested much higher costs. More recent analysis has attempted to explain why the earlier cost estimates were too low and how quickly costs had escalated and could escalate in the future. The current estimates of construction costs, which are much higher than the early estimates, should not have been a surprise. They are perfectly consistent with the historical trend, as shown in Figure III-6.

Figure III-6: Price Trajectories and Explanations



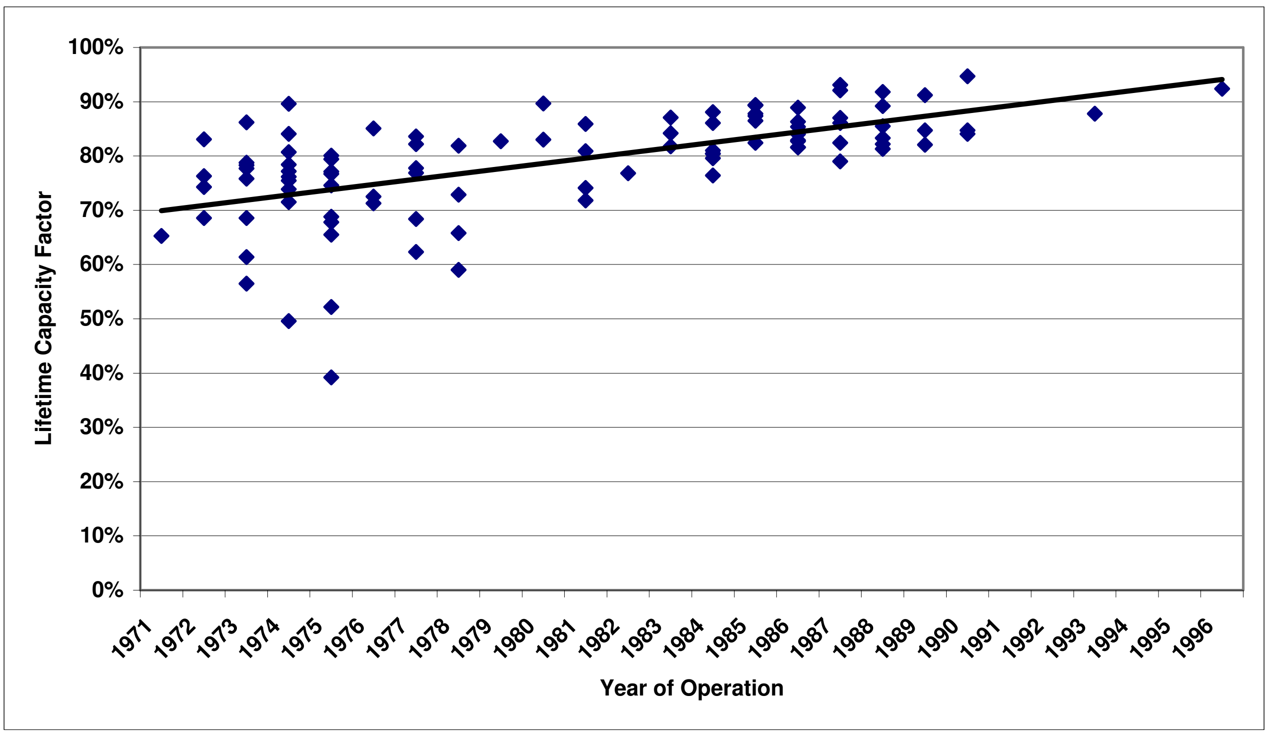
Sources: See Figure I-1.

There is a twist in the escalation of costs. The current recession has lowered material costs and reversed the dramatic upward trend in costs, but the CERA index shows only a moderate decline in the cost index.[19] The index is down by less than 10%. However, utilities, whose cost estimates in 2007-2008 failed to reflect the full impact of prior cost escalation, are suddenly offering assurances that the slack markets caused by the recession will moderate future cost increases.[20] They are admitting much higher numbers in their current statements than were used to launch their efforts to gain approval of the plants, but then attempting to cushion the impact with the assurance that declining commodity costs will lower costs. Although some have pointed out that commodity costs are a small part of total costs,[21] the utility approach renders nuclear construction cost almost as volatile as fossil fuel prices, leaving one to wonder what will happen when the recession ends or if a flurry of orders puts pressure on prices.

E. Capacity Factors and Plant Life of Nuclear Reactors

The methods used above to reconcile the differences between the various estimates have all relied on the base or mid-case estimates. We use these estimates for the comparative analysis because the studies' authors tend to run their scenarios as modifications of the base case. These base cases tend to use the high capacity factors and long facility lives that are observed at present, which is the end stage of the cohort of reactors (see Figure III-7).

Figure III-7: Date of Operation and Capacity Factors



Source: Koomey and Hultman, 2007.

Capacity factors are an important assumption. Capacity factors of 90% that are observed today took two decades to achieve. It may be a mistake to assume that new reactors will achieve those high capacity factors from day one. In so far as the reactors and technologies are new and unique, there may be a substantial learning process before such high levels of reliability are achieved. The average capacity factor for reactors that have been operating in the U.S. is about 79%. The average for the reactor brought on line in the ten years between 1989 and 1999 is 88%.

Although capacity factors and reactor operating lifetimes do not have as dramatic an impact as the construction and capital costs, they are important (see Table III-2). In the MIT study, with the base case assumption of a 40-year life for the reactor, decreasing the capacity factor from the base case assumption of 85% to 75% increases the busbar cost from 7.7 cents (2008 $) to 8.6 cents. Assuming the 85% base case capacity factor, lowering the lifespan of the reactor from 40 years to 25 years increases the cost from 7.7 cents to 8.6 cents. The worst case considered by MIT (75% capacity/25-year life) had a busbar cost of 9 cents, compared to the base case of 7.7 cents. The Keystone study varied both lifespan and capacity factor together. Moving from the base case of 40-year life and 90% capacity to the worst case, 30-year life and 75% capacity, raised the busbar cost from 9.7 cents to 11.4 cents. The busbar costs are higher in the Keystone study in large part because the overnight costs were assumed to be higher, as shown above in Table III-1.

Table III-2: Busbar Costs, Capacity Factors and Asset Lives (Cents per kWh, 2008$)

	MIT		**Keystone**	
	Reactor Life		**Reactor Life**	
Capacity Factor	**25-year**	**40- year**	**30- year**	**40-year**
75%	**9.0**	**8.6**	**11.4**	
85%	**8.6**	**7.7**		
90%				**9.7**

Source: MIT, *2003*, p. 43; Keystone, 2007, p. 42.

This review can be used to suggest the impact of various key variables that affect the cost of nuclear reactors, although a range of projected costs will not be specified until the history of the industry is reviewed in more detail in the next section. Here the relative importance of each of the key factors in the general context of a move from overnight costs of $2,000 to overnight costs of $7,000 can be explored. The analysis must start with the range of overnight costs because the impact of the financial and plant characteristic assumptions varies depending on those costs. Starting from the MIT utility model, adding $5,000 of overnight costs would add about 9.6 cents per kWh to the estimate. In the merchant model it would add 1.5 to 3 cents per kWh. Assumptions about plant life and capacity factors could add another 1.7 to 3.4 cents per kWh. O&M costs are independent of the other costs, but the difference between the studies runs in the range of 2 cents. Given these large differences in cost projections, it is easy to reconcile the low 5.2 cents per kWh estimate of a utility finance model based on the MIT 2003 overnight costs to the high estimate of 16 cents per kWh, based on the CEC utility finance model. Starting at 6.1 cents in Joskow's application of the utility model to the MIT base case, adding 9.6 cents for an additional $5,000/kW of overnight costs and 2.1 cents for operation and maintenance costs would yield an estimate of 17.8 cents, just above Harding's estimate of 17.3 cents.

IV. The Past as Prologue: The Persistent Upward Spiral of Nuclear Reactor Costs

A. The Vexing History of Nuclear Reactor Costs

The current cost controversy cannot be fully comprehended without placing it in the context of the history of reactor costs in the U.S. The cost of electricity generated by nuclear reactors in the United States has been a vexing problem for almost half a century.[22] Touted as producing power that would be "too cheap to meter,"[23] 240 reactors were ordered in about a decade from the late-1960s to the late-1970s.[24] If all of the reactors had been completed on time, well over half of all power generated in the U.S. by the mid-1980s would have been from nuclear reactors.[25]

Things did not work out that way. The "great bandwagon market" for nuclear reactors, as it came to be known, sputtered badly. Construction delays and cost overruns, as well as regulatory changes, drove the cost of reactors up dramatically.[26] "Too cheap to meter" quickly became "too expensive to build." More than half of all the orders for reactors were canceled. Many of the projects had incurred significant costs,[27] setting up lengthy fights over who should pay for facilities that were never used to supply electricity.[28] The cost overruns were also reviewed in lengthy, contentious state regulatory prudence proceedings, where the failures of management to control costs and to provide power at as reasonable cost were investigated.[29] As a result, no orders for nuclear reactors were placed in the U.S. after 1977. The last reactor brought on-line in the U.S. was completed in 1996. Construction on that reactor had begun in 1974.

The vexing nature of the cost of nuclear reactors has reemerged in what is now being called the "nuclear renaissance." Less than a decade after the last reactor was brought on-line, nuclear reactors were back in the news and at the center of public policy debates with calls for large subsidies to promote nuclear technology. Along with a number of other factors, very low cost estimates put forward by the industry and academics and funded by the Department of Energy helped to create the illusion of a nuclear renaissance. Those studies certainly gave the Department of Energy an opportunity to broadcast headlines such as "University of Chicago: Nuclear Power Competitive with Coal & Natural Gas."[30] The initial cost projections, however, have not held up. Much like the initial cost projections from the earlier round of nuclear reactors, projected costs escalated rapidly. By 2008, projected costs were three to four times higher than the initial cost projections in 2001-2004. Estimates that had put the cost of nuclear reactors as low as 6 cents per kilowatt hour (kWh) have been joined updated by estimates that put it as high as 30 cents.

Placing the ongoing conflict over projections of nuclear reactor costs in historic perspective takes on special importance. The management failure that *Forbes* refers to was much more than just the inability to execute massively complex construction projects. It was, first and foremost, a failure of analysis, a failure to distinguish hope and hype from reality.

For nearly a quarter of a century the theology of nuclear power – unchallenged and unchallengeable – was accepted by a variety of diverse interests to advance a variety of diverse causes. Rarely did those who seized on nuclear power as a means to their ends know its actual economic and technical status. Instead, the information available to them was part of a catechism whose basic function was to answer infidels and sustain the faith of the converted. The result, a circular flow of self-congratulatory claims, preserved the discrepancy between promise and performance.

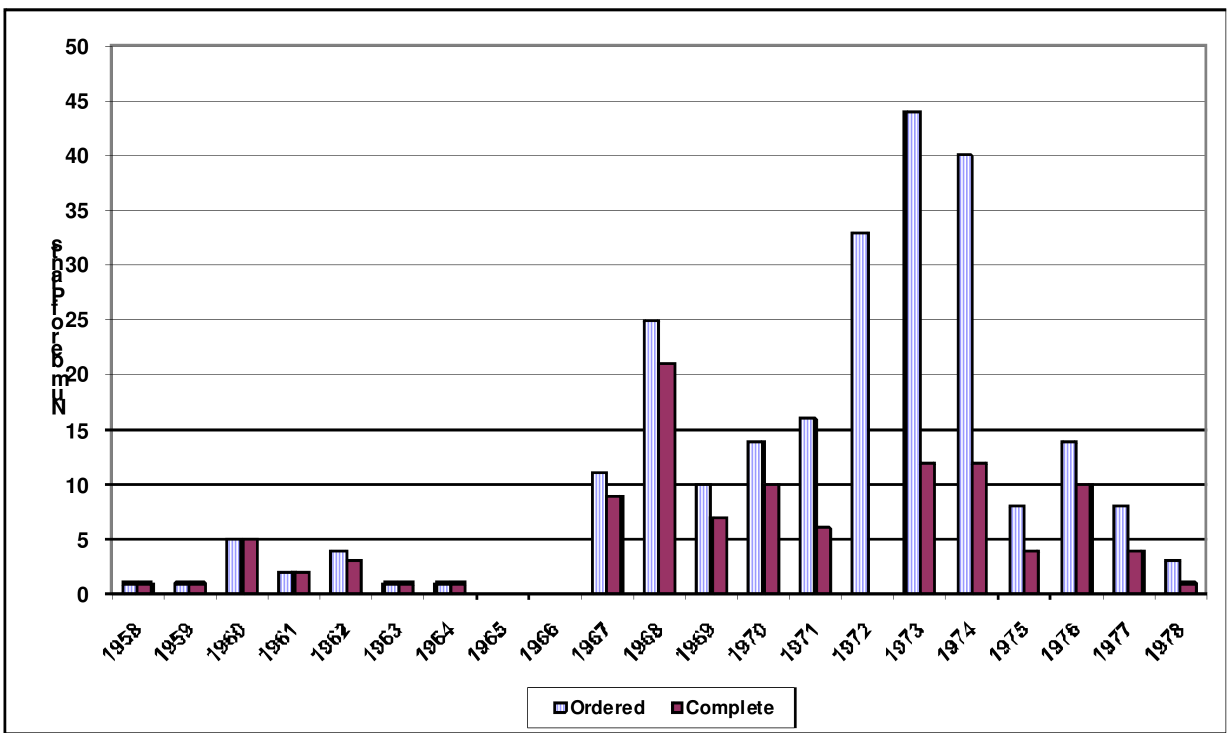
Systematic confusion of expectation with fact, of hope with reality, has been the most characteristic feature of the entire 30-year effort to develop nuclear power.

The identification of promise with performance began in the United States. The economic "analyses" which controlled discussion during the critical early years of light water commercial sales had nothing to do with the detached confrontation of proposition with evidence which we think of as analysis. The public agencies with putative responsibility for facing the facts had neither the means nor the motivation to respond critically to the nuclear industry's propaganda; they could only sanctify it. This they did with notable eagerness.[31]

B. Too Cheap to Meter Becomes Too Expensive to Build

The rapid escalation of cost projections for new reactors in recent years raises major concerns, especially in light of the history of cost escalation in the nuclear industry. The last time the industry tried to ramp up production in the U.S., costs skyrocketed. From the mid-1960s to the mid-1970s, a small number of turnkey reactors were brought on-line. From the mid-1970s onward, more than 200 reactors were ordered, but half of them were never completed (see Figure IV-1).

Figure IV-1: History of Reactor Orders and Cancellations

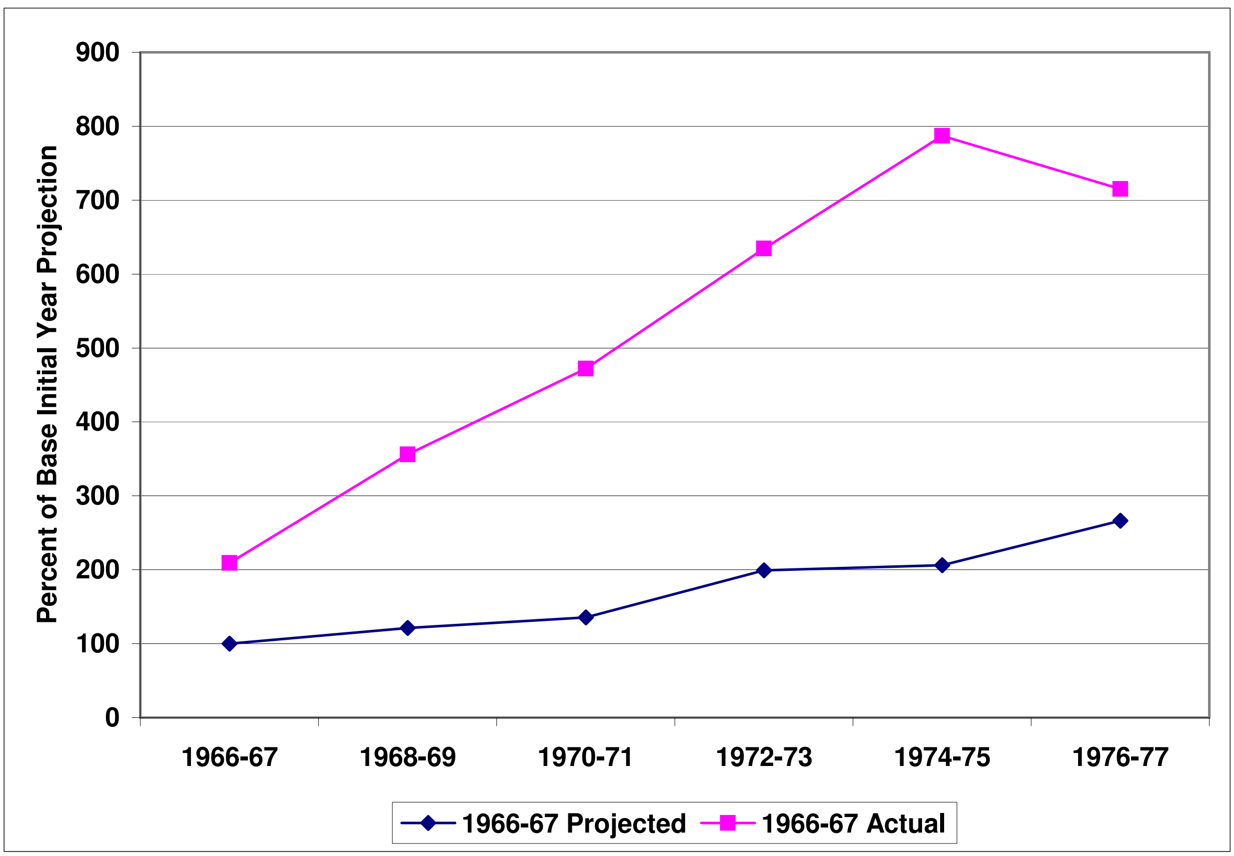


Source: Completed: Koomey and Hulttman, 2007; Cancelled: Cancelled Nuclear Units Ordered in the U.S., http://clonemaster.homestead.com/files/cancel.htm

The reactors that did make it on-line proved to be much more costly than originally projected. Figure IV-2 shows the increase in projected and actual costs by the date of commencement of construction for completed reactors, expressed as a percentage of the projected cost of the initial reactors. That is, Figure IV-2 uses the projected costs of the 1966-1967 reactors as the base and expresses all future projections and actual costs as a percentage of that base. This captures the fact that not only were projected costs increasing, but actual costs were increasing faster than projected costs.

The reactors commenced in 1966-1967 actually cost twice as much to build as originally estimated. The reactors commenced in 1968-1969 were projected to cost slightly more than the reactors commenced in 1966-1967, but they actually cost over three times as much as the projected costs of the reactors commenced in 1966-1967. Performance got worse, not better, over the decade:[32]

Figure IV-2: Actual and Projected Capital Costs by Date of Commencement of Construction, Completed Reactors



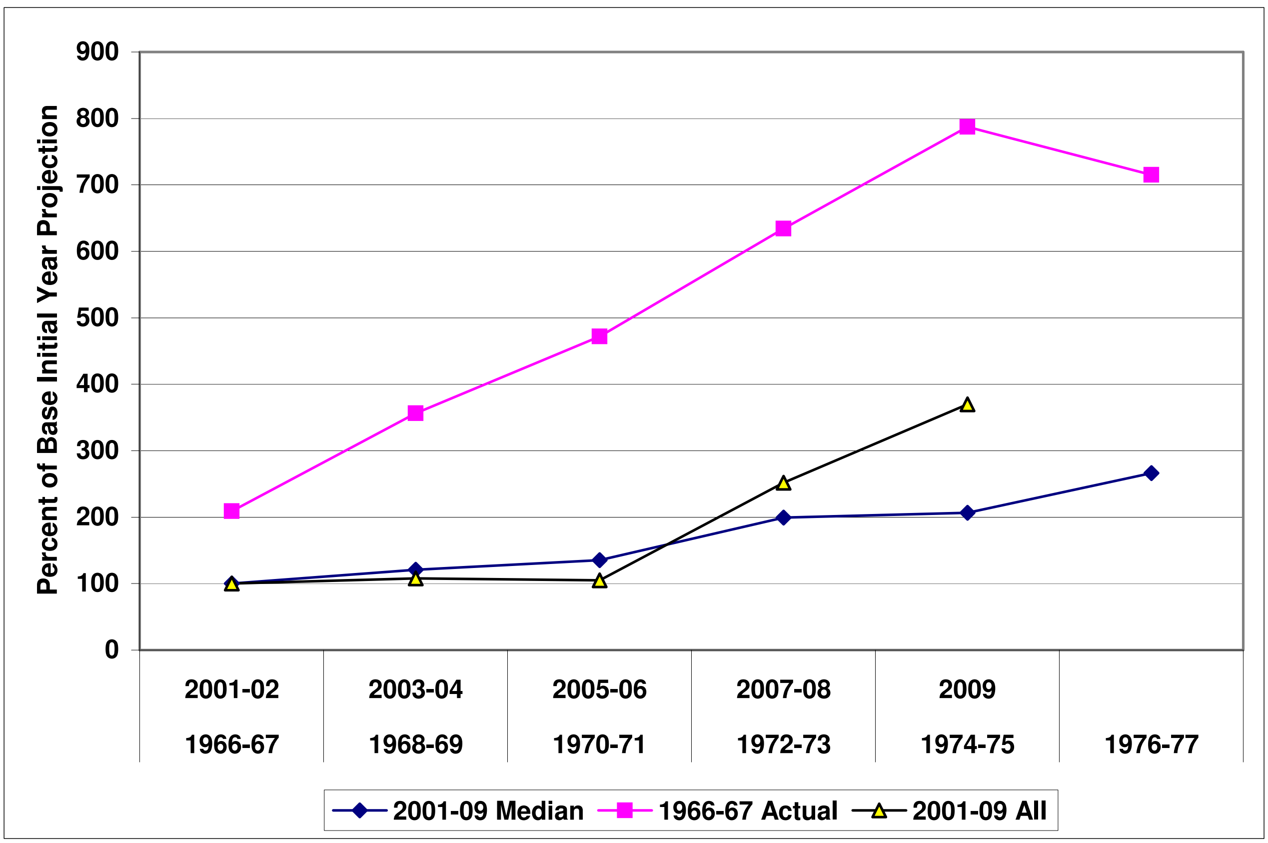
Source: Energy Information Administration, January 1, 1986.

The learning that usually lowers initial costs has not generally occurred in the nuclear power business. Contrary to the industry's own oft-repeated claims that reactor costs were "soon going to stabilize" and that "learning by doing" would soon produce cost declines just the opposite happened. The magnitude of cost underestimation was as large for reactors ordered in the early 1970s as it had been for much earlier commercial sales.[33]

On average, the actual costs for each reactor were almost three times higher than the original projection for that reactor. The final cohort of reactors cost seven times as much as the projected cost of the original cohort. In short, the first round of nuclear reactors went quickly from being "too cheap to meter" to being "too costly to build."

Figure IV-3 overlays the recent cost projections on the historical pattern completed reactor costs. It uses the estimates from 2001 as the base and then expresses all subsequent estimates as a percentage of that base. For each of the two year cohorts the graph shows two projections, one based on the average of the mid-point estimates for all of the studies completed in that year; the other based on the average of all projections in that two year cohort. The initial 2001-2002 midpoint estimates averaged about $1,761 per kW. The initial 2001-2002 estimates for all

Figure IV-3: Actual and Predicted Capital Costs, Completed Reactors, and Projected Costs of Future Reactors



Source: Energy Information Administration, January 1, 1986.

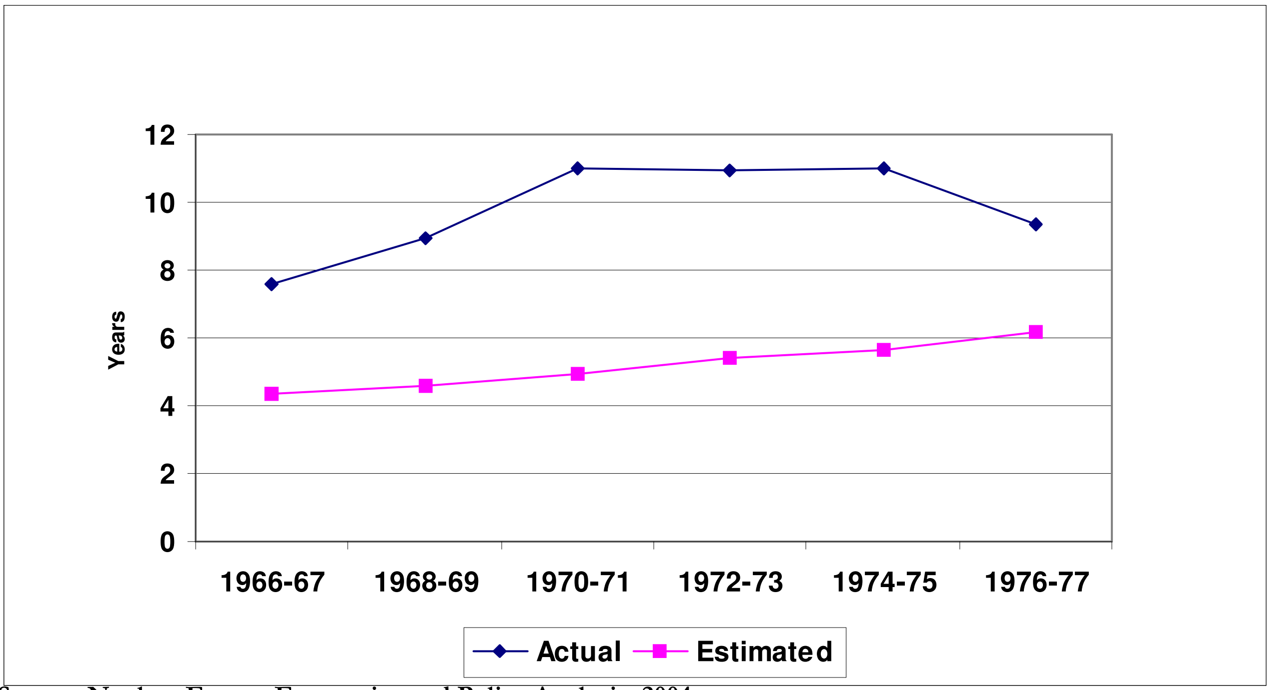
projections were about $1,775 per kW. The midpoint and the all estimates track closely until 2009, when a number of high estimates pull the all estimate average up. The estimate based only on midpoints for 2009 was $6,500. The estimate based on all projections for 2009 was over $8,000. Interestingly, one of the high estimates for 2009 comes from an independent analyst and one comes from a utility. The increase in projected prices falls about half way between the projections from the 1960s and 1970s and the actual increases in that period.

B. The Importance of Construction Periods

In the 1960s and 1970s, one of the major causes of the cost increases and missed projections was the inability of the industry to deliver reactors on time (see Figure IV-4). Large capital costs, sitting on the books, generated capital charges and a rate shock when the utilities finally finished the reactor. These charges cumulate, creating more and more expensive power.

By the end of the construction cycle that was started in the 1960s, the projected construction time increased by 50%, from just over 4 years to just over 6 years -- but actual construction periods

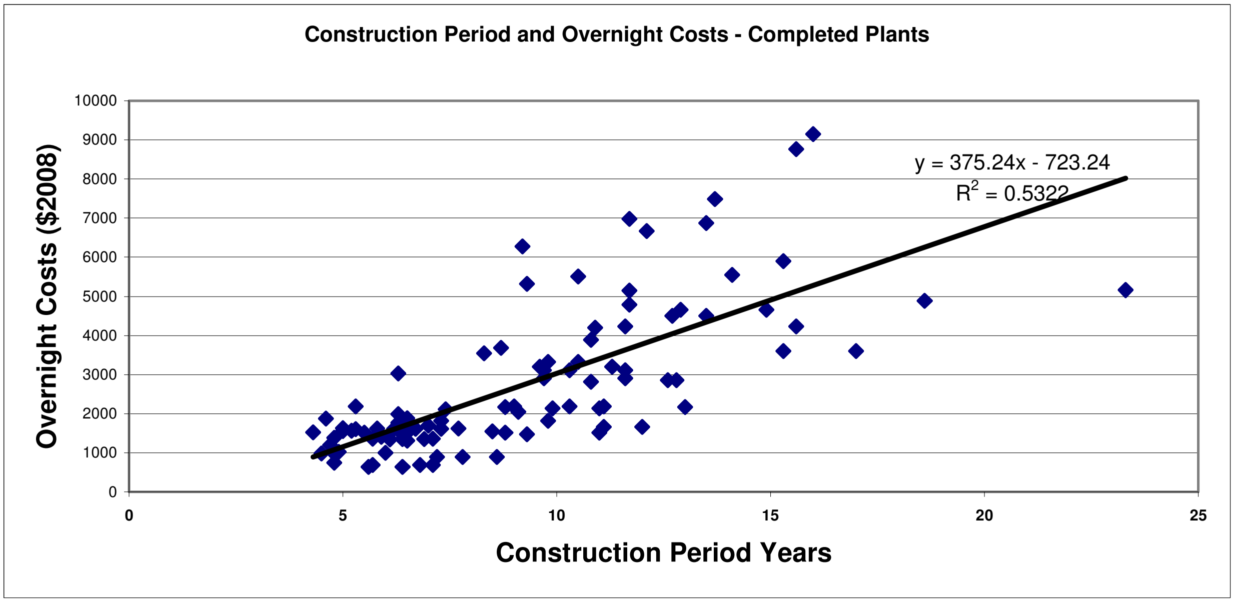
Figure IV-4: U.S. Nuclear Reactor Construction Periods



Source: Nuclear Energy Economics and Policy Analysis, 2004.

were almost 10 years. In other words, actual construction time at the end of the cycle was more than twice as long as the original projection. The correlation between construction periods and overnight costs is strong for both completed reactors and projections for future reactor costs (see Figure IV-5).

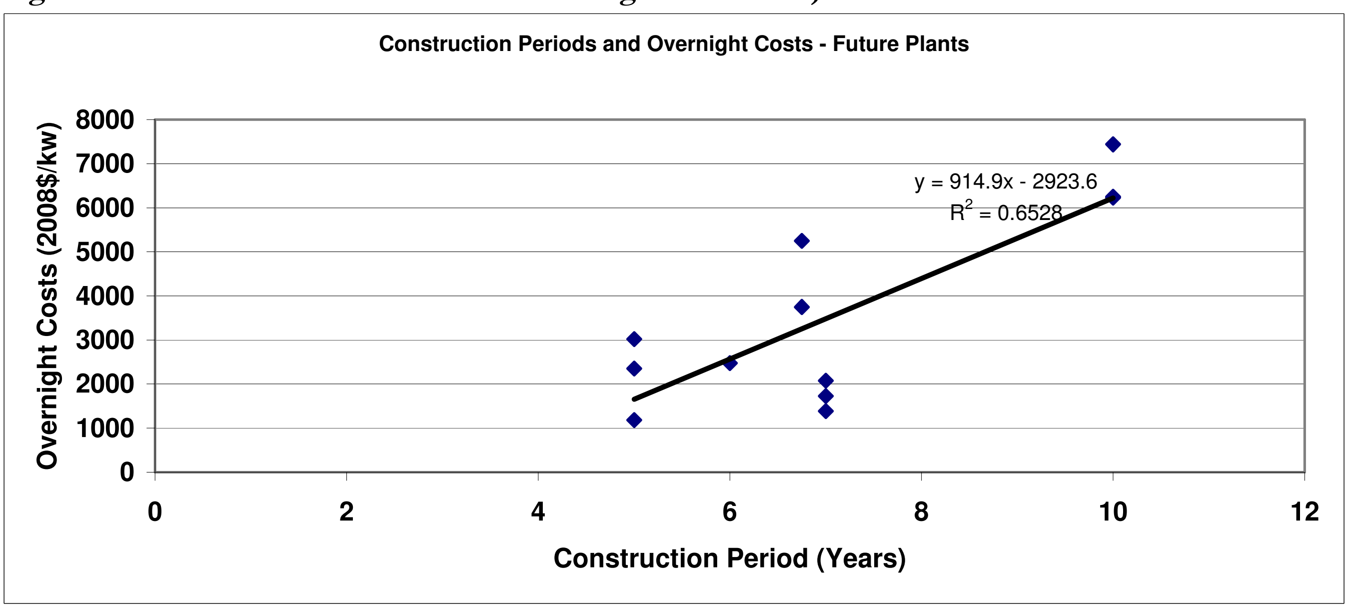
Figure IV-5: Construction Periods and Overnight Costs: Completed Plants



Source: Koomey and Hultman, 2007.

For the completed plants the length of the construction period explains just over half the variance in overnight cost projections. For the future projections, the length of the construction period explains almost two thirds of the variance in overnight cost projections (see Figure IV-6).

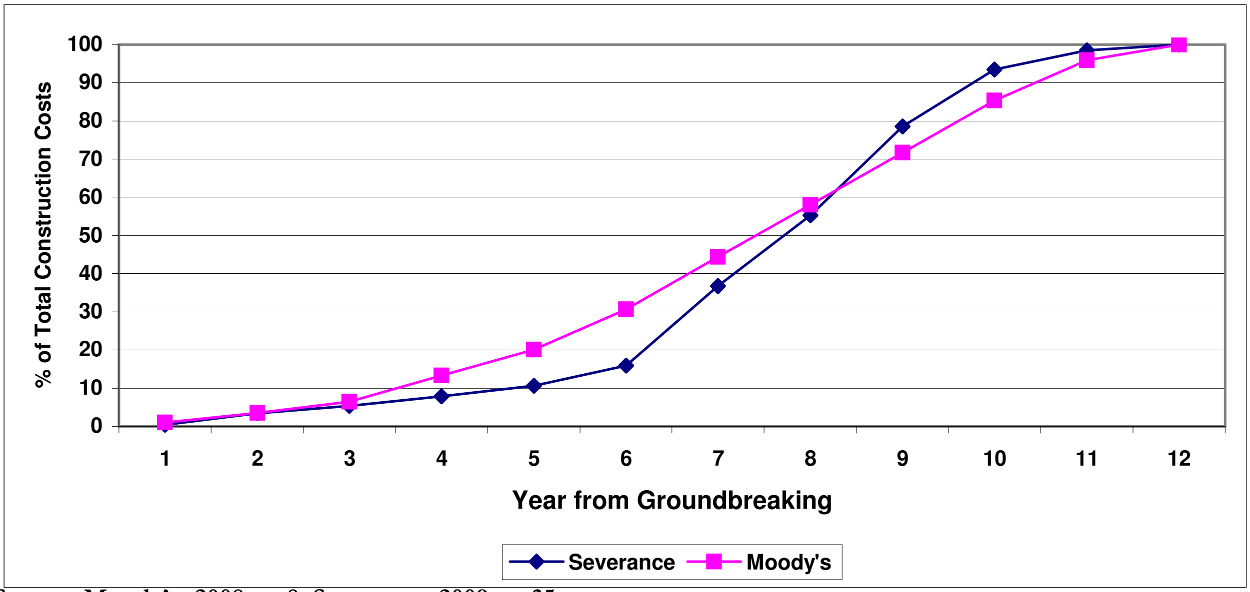
Figure IV-6: Construction Periods and Overnight Costs: Projections



Source: University of Chicago 2008; MIT 2003; Keystone 2007; CBO 2008; Lazard 2008; Severance 2008; Moody's 2008.

We are now witnessing a dispute over the projected construction periods. Some analysts project construction periods of five or six years, while others project construction periods of ten years or more.[34] Figure IV-7 shows the year-by-year construction expenditures in two recent studies with longer construction periods. Severance is for a two-unit project; Moody's is for a single unit.

Figure IV-7: Construction Expenditures across Time



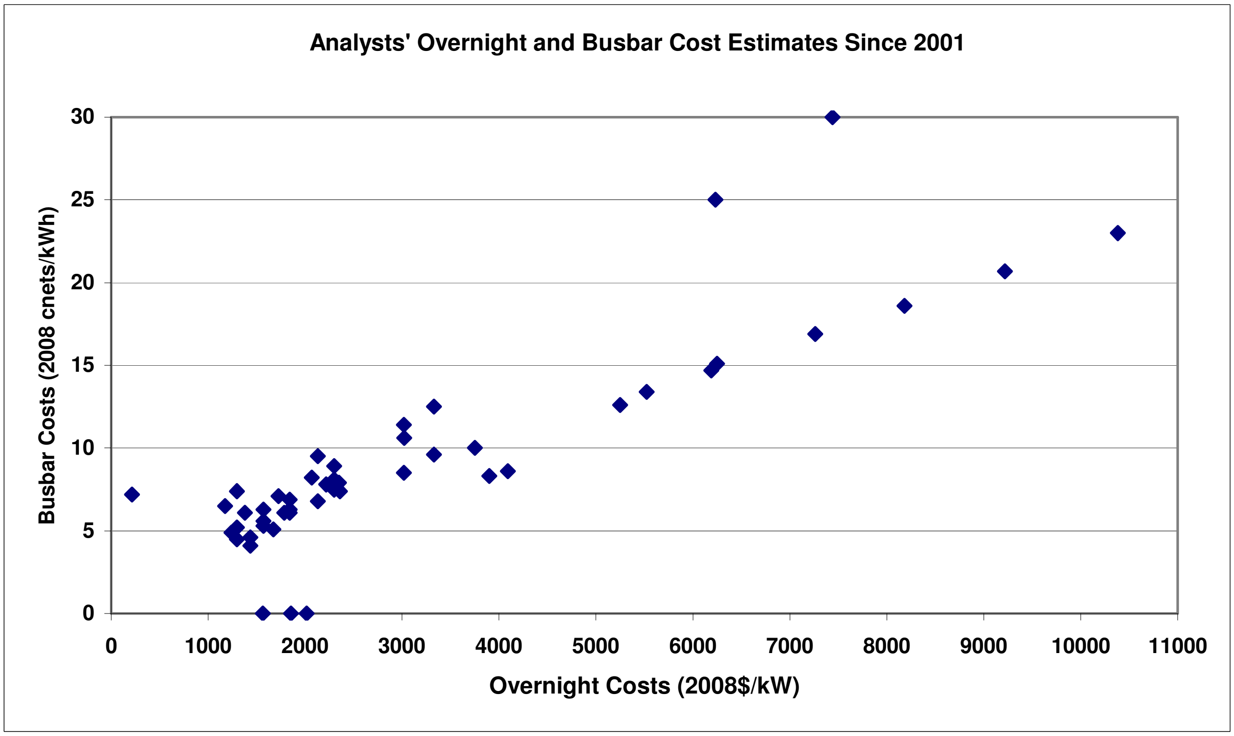
Source: Moody's, 2008, p. 8; Severance, 2009, p. 35.

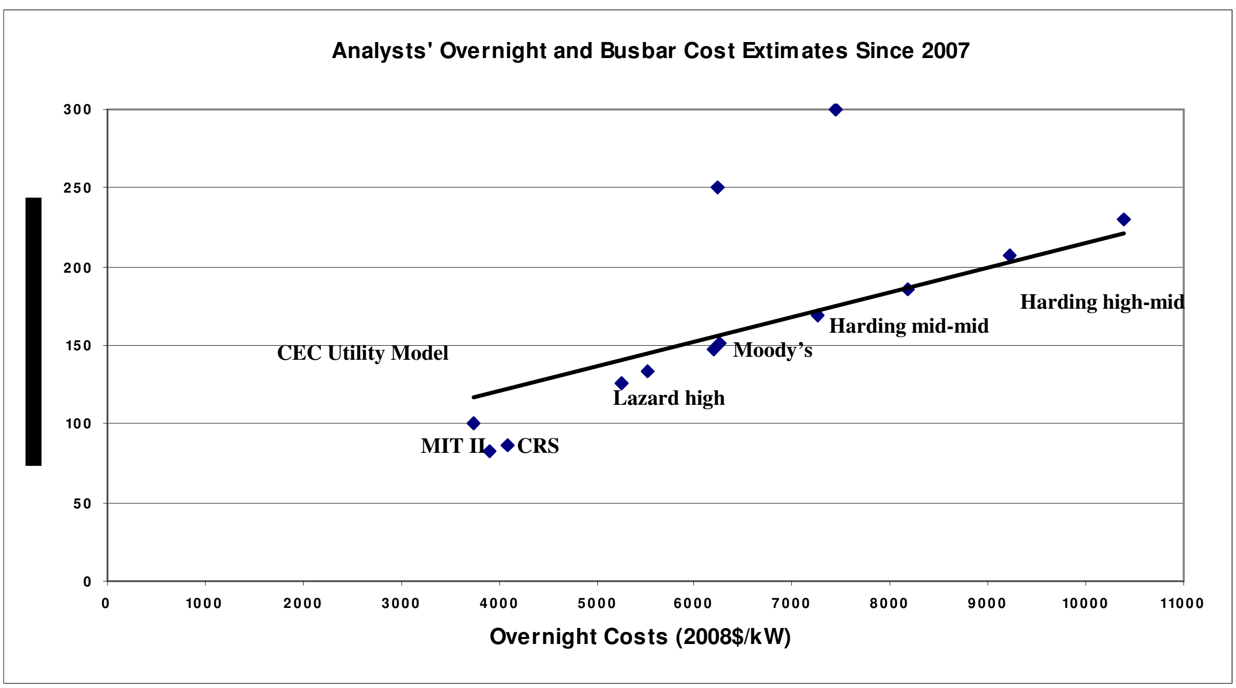
C. A RANGE OF COST ESTIMATES

Given this history, the initial low cost projections and their recent updates should be viewed with suspicion. Figure IV-8 shows the relationship between overnight and busbar costs for tow different sets of cost estimates in the "nuclear renaissance" period. The bottom panel presents the estimates since 2008. The two low cost estimates can be readily explained. The CRS study relied on the utility overnight costs and then applied a utility finance model. The MIT II study is the update of the 2003 MIT study, which was optimistic then and remains so. Wall Street and independent analysts provide much higher estimates. The high outliers are from the Severance study. The exhibit also includes an estimate of busbar costs based on the CEC utility cost of generation model.

The relationship between overnight costs and busbar costs is predictable. The MIT and CRS estimates appear to be low both because the overnight estimates are low and because they translate overnight costs into busbar costs at a lower rate. With overnight costs of about $4,000, the busbar costs in the CEC model are about 12 cents per kWh. The MIT II and CRS costs are about 3.5 cents lower. Thus, 12 cents per kWh would appear to be a lower bound. The Moody's estimate of about 15 cents is the midpoint. Harding's 2009 mid- estimate is 17.3 cents. Several of Harding's 2009 estimates are above 20 cents. Even adjusting for the unique costs that Severance includes, his estimates are above 20 cents as well. The range of reasonable estimates appears to be 12 cents to 20 cents, with a mid point of 16 cents.

Figure IV-8: Analysts' Overnight and Busbar Costs





Source: Figure I-1.

D. CONCLUSION

The 1960s and 1970s may seem like ancient history, but the new proposed cohort of reactors could easily be afflicted with the same problems of delay and cost overruns. Inherent characteristics of large complex nuclear reactors make them prone to these problems. Reactor design is complex, site-specific, and non-standardized. In extremely large, complex projects that are dependent on sequential and complementary activities, delays tend to turn into interruptions. Inherent cost escalation afflicts mega projects, a category into which nuclear reactors certainly fall.[35]

The endemic problems that afflict nuclear reactors take on particular importance in an industry in which the supply train is stretched thin. Material costs have been rising and skilled labor is in short supply. These one of a kind, specialized products have few suppliers. In some cases, there is only one potential supplier for critical parts. Any increase in demand sends prices skyrocketing. Any interruption or delay in delivery cannot be easily accommodated and ripples through the implementation of the project.[36]

The severe difficulties of Finland's Olkiluoto nuclear reactor being built by Areva SA, the French state-owned nuclear construction firm, provide a reminder of how these problems unfold.[37] Touted as the turnkey project to replace the aging cohort of nuclear reactors, the project has fallen three years behind schedule and more than 50% over budget.[38] The delay has caused the sponsors of the project to face the problem of purchasing expensive replacement power; the costs of which they are trying to recover from the reactor builder. The cost overruns and the cost of replacement power could more than double the cost of the reactor.[39]

A description of the process by which the U.S. ended up with hundreds of reactors that were "too expensive to build," written in 1978, before the accident at Three Mile Island changed the terrain of nuclear reactors in the U.S., bears an eerie resemblance to the past decade in the U.S.:

> At the beginning of 1970, none of the plants ordered during the Great Bandwagon Market was yet operating in the United States.
>
> This meant that virtually all of the economic information about the status of light water reactors in the early 1970s was based upon expectation rather than actual experience. The distinction between cost records and cost estimation may seem obvious, but apparently it eluded many in government and industry for years…
>
> In the first half of this crucial 10-year period, the buyers of nuclear power plants had to accept, more or less on faith, the seller's claims about the economic performance of their product. Meanwhile, each additional buyer was cited by the reactor manufacturers as proof of the soundness of their product…The rush to nuclear power had become a self-sustaining process...
>
> There were few, if any, credible challenges to this natural conclusion. Indeed, quite the contrary. Government officials regularly cited the nuclear industry's analyses of light water plants as proof of the success of their own research and development policies. The industry, in turn, cited those same government statements as official confirmation. The result was a circular flow of mutually reinforcing assertion that

> apparently intoxicated both parties and inhibited normal commercial skepticism about advertisements which purported to be analyses. As intoxication with promises about light water reactors grew during the late 1960s and crossed national and even ideological boundaries, the distinction between promotional prospectus and critical evaluation become progressively more obscure.
>
> From the available cost records about changing light water reactor capital costs, it is possible to show that on average, plants that entered operation in 1975 were about three times more costly in constant dollars than the early commercial plants competed five years earlier. [40]

The similarities between the great bandwagon market and the nuclear renaissance, and the fact that utilities not only steadfastly refuse to accept the risk of cost overruns but also are demanding massive taxpayer and ratepayer subsidies to build the next generation of reactors, should give policy makers pause. The one major difference between the great bandwagon market and the nuclear renaissance is that there has been an extensive challenge to the extremely optimistic cost estimates of the early phase, a challenge from Wall Street and independent analysts. It may be impossible to escape the uncertainty of cost estimation, but it is possible to avoid past mistakes.

Reflecting the poor track record of the nuclear industry in the U.S., the debate over the economics of the nuclear renaissance is being carried out *before* substantial sums of money are spent. Unlike the 1960s and 1970s, when the vendors and government officials monopolized the preparation of cost analyses, today Wall Street and independent analysts have come forward with much higher estimates of the cost of new nuclear reactors. And, because the stranglehold of the vendors and utilities on analysis has been broken, the current debate includes a much wider range of options.

As important as bad analysis was, it might have had little impact if it had not been combined with another critical mistake. The nuclear reactor vendors had delivered a small number of reactors at fixed prices and eaten massive cost overruns. After a few loss leaders were delivered, they shifted tactics. Unwilling and unable to sustain those losses, as the *Forbes* article put it, the

> Great Bandwagon Market was impelled by evangelisms, optimism and seemingly irresistible economics… But the suppliers had learned their lesson. The new generation of plants would be built under reimbursable-cost-plus-fixed-fee contracts. Without that, the nuclear power program would probably have sputtered out in the mid-Seventies, when cost lurched out of control.[41]

The contemporary policy debate takes the effort to insulate utilities from the high cost of nuclear reactors even farther. In addition to a broad range of general subsidies and the cost plus rate treatment, they are seeking large federal loan guarantees and treatment by state public utility commissions that would grant preapproval and recovery of construction costs.

V. NUCLEAR REACTOR COSTS COMPARED TO OTHER OPTIONS

A. COSTS OF ALTERNATIVES

Many of the more detailed analyses of nuclear reactor costs described in Section III also review the cost of some alternative sources of power. However, they tend to focus on the traditional central station options (i.e. coal, gas) as alternatives to nuclear reactors. The actual range of options is much wider. Utilities promote the narrow frame because large base load power is what they know and they profit by increasing the rate base, but ratepayer interests can only be protected by considering all options.

Analyzing the cost of alternatives can be even more complex than analyzing the cost of nuclear reactors. However, as described below, compared to the diversity of nuclear costs, there is much less diversity in the estimates of the cost of the alternatives.

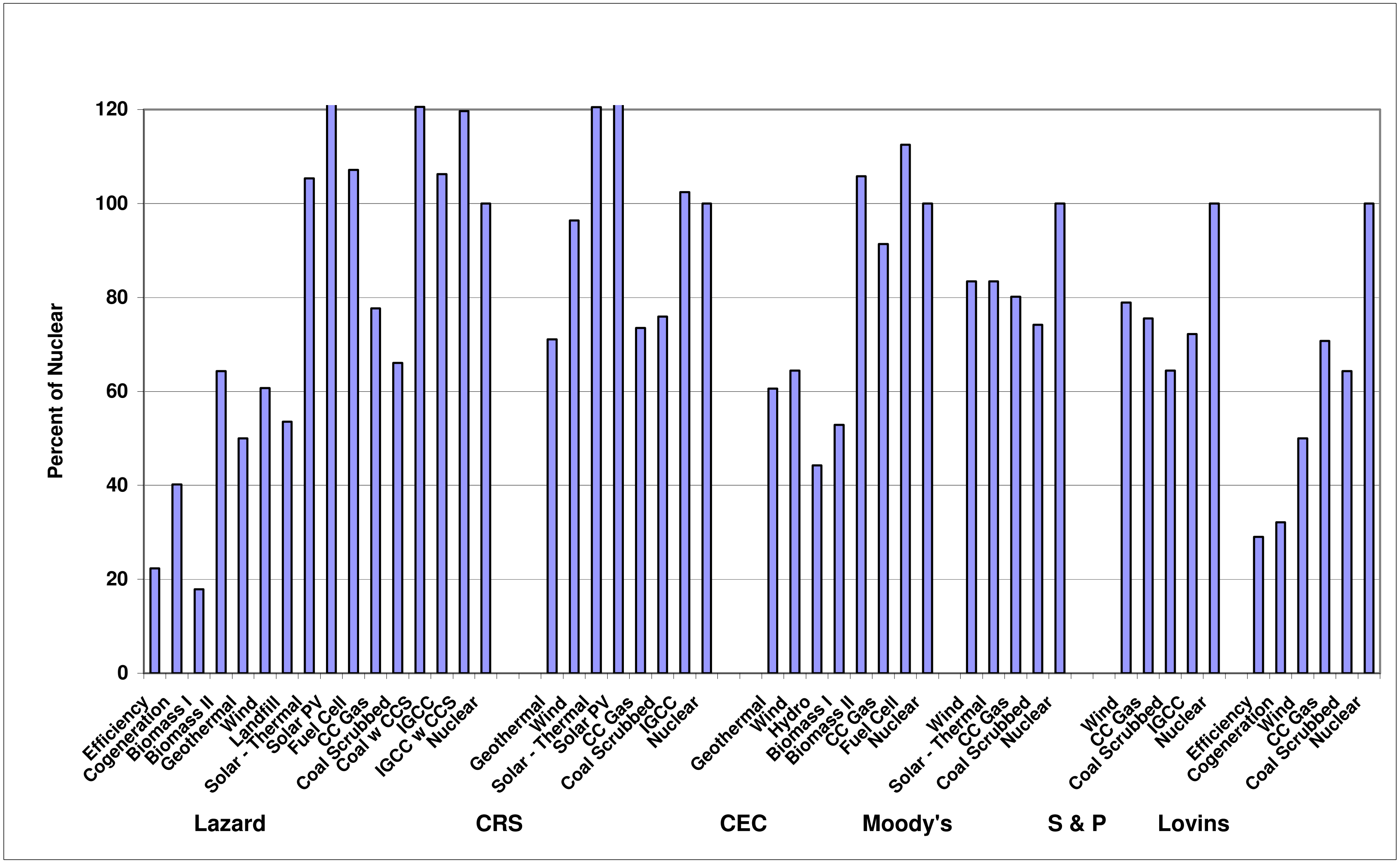
This assessment simply accepts the analyses in these studies and preserves their integrity by not adjusting the underlying analysis as the starting point for a comparative assessment. To begin the analysis, the base case (midpoint relative cost of each of the alternatives) is calculated within the individual studies. This preserves the author's original framework.

Figure V-1 shows the results across half a dozen recent studies that analyzed multiple technologies in one framework. In other words, the base case nuclear costs are the denominator of the fraction and the cost of the alternatives is calculated as a percentage of that base. Figure V-2 shows the same results rearranged by technology. Both figures do not include solar photovoltaics. Solar photovoltaics are not cost competitive at present, with several studies finding them two to five times as expensive as nuclear reactors. They are not included in Figures V-1 and V-2. Thus, this analysis focuses on the more cost competitive alternatives in the near term.

New nuclear reactors are estimated to be substantially more expensive than a variety of alternatives, including biomass, wind, geothermal, landfill, and some solar and conventional fossil fuels. The studies find that nuclear is cost competitive with advanced coal, natural gas, and some solar.

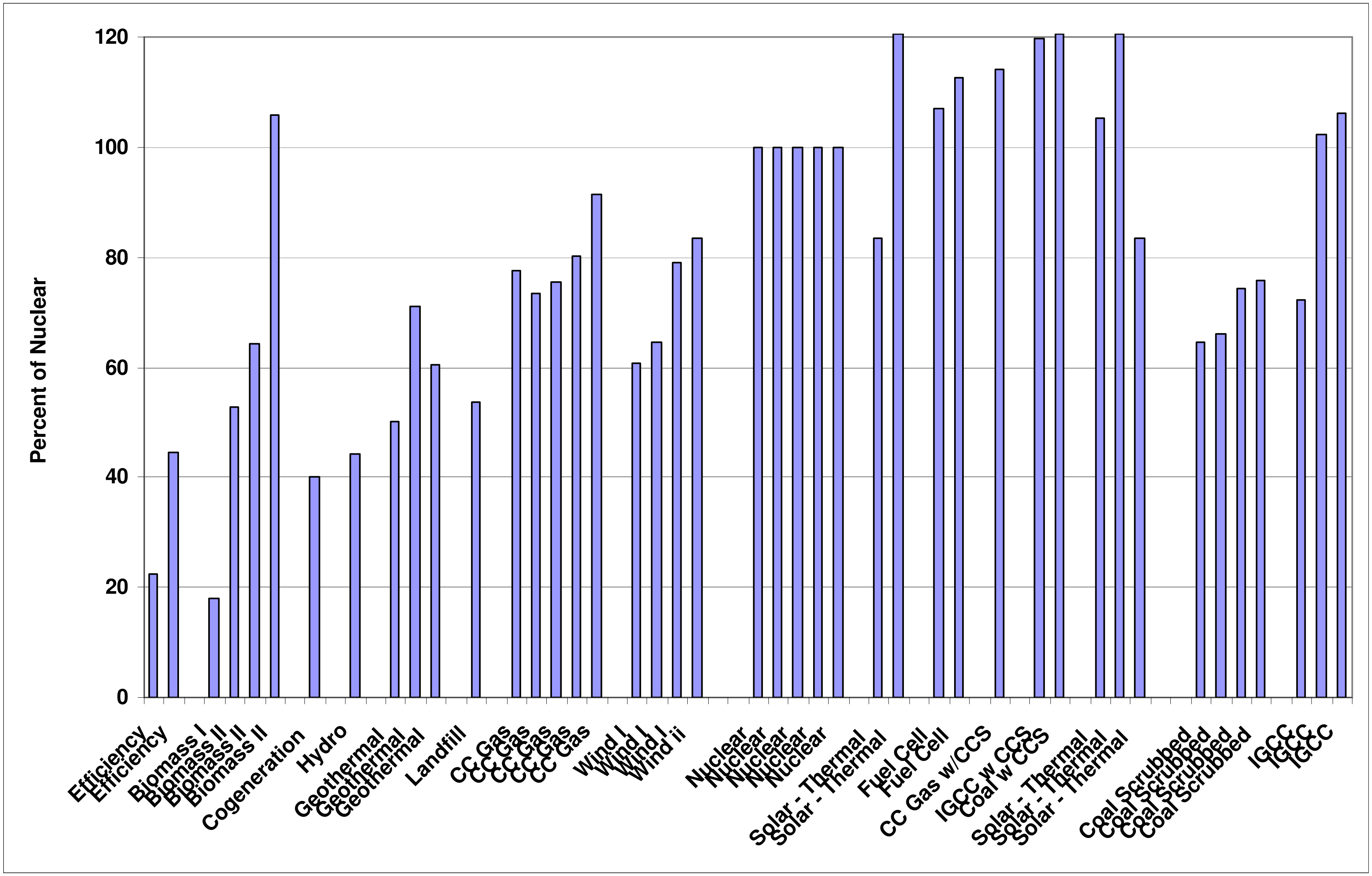
Figure V-3 shows the results from the California Energy Commission Cost of Generation Model. It presents the results in cents per kWh for a large number of alternatives. It is based on some California specific features. It includes three additional numbers. The overnight cost for nuclear in the CEC study was less than $3,000, a very low figure. Figure V-3 includes a higher cost estimate for nuclear in addition to the CEC scenario. This is the mid-point estimate of 16 cents per kWh from Section IV. It also includes fossil fuels with CCS from the earlier studies.

Figure V-1: Busbar Costs of Alternatives by Estimating Entity (Nuclear Reactor Cost = 100%)



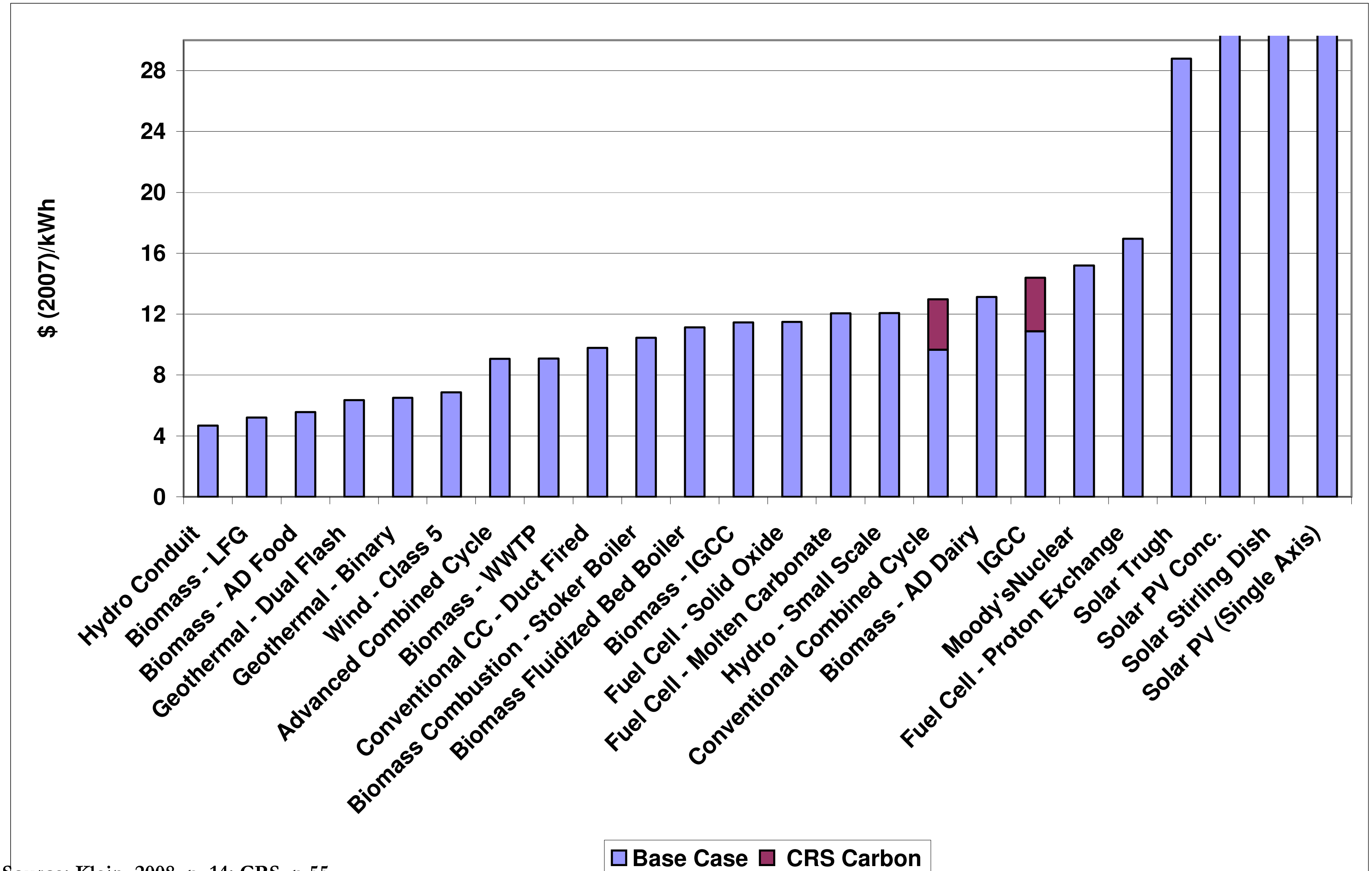
Source: See Figure I-1.

Figure V-2: Busbar Costs of Alternatives Arranged by Technologies (Nuclear Reactor Cost = 100%)



Source: See Figure I-1.

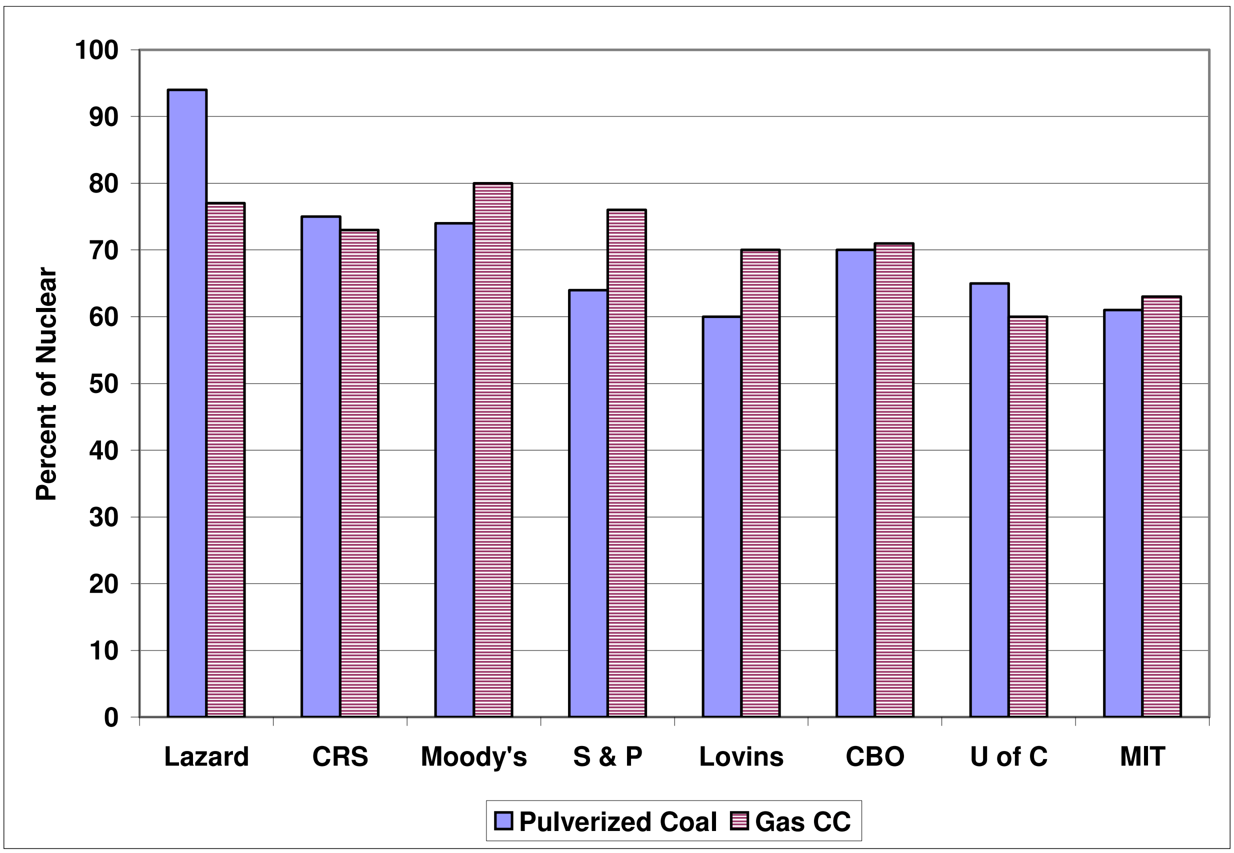
Figure V-3: California Energy Commission Cost of Generation Model (With Nuclear at Moody's and CCS at CRS)



Source: Klein, 2008, p. 14; CRS, p.55.

It is interesting to note, as shown in Figure V-4, that the early studies that found very low costs for nuclear also found very low costs for conventional central station fossil fuel plants. For example, the CBO study, which had the lowest cost estimate for nuclear of any of the studies reviewed, also estimated the cost of power from conventional fossil fuel plants to be substantially less than nuclear. The hope and hype of these early studies came in the projection of what would happen to future costs of nuclear reactors, with studies projecting or discussing declines in nuclear reactor construction costs and modeling the impact of policies to reduce greenhouse gas emissions on fossil fuel plants. As we have seen above, construction costs have moved in the opposite direction from these early studies, with nuclear construction costs escalating more rapidly than conventional plant costs.

Figure V-4: Fossil Busbar Costs as a Percent of Nuclear

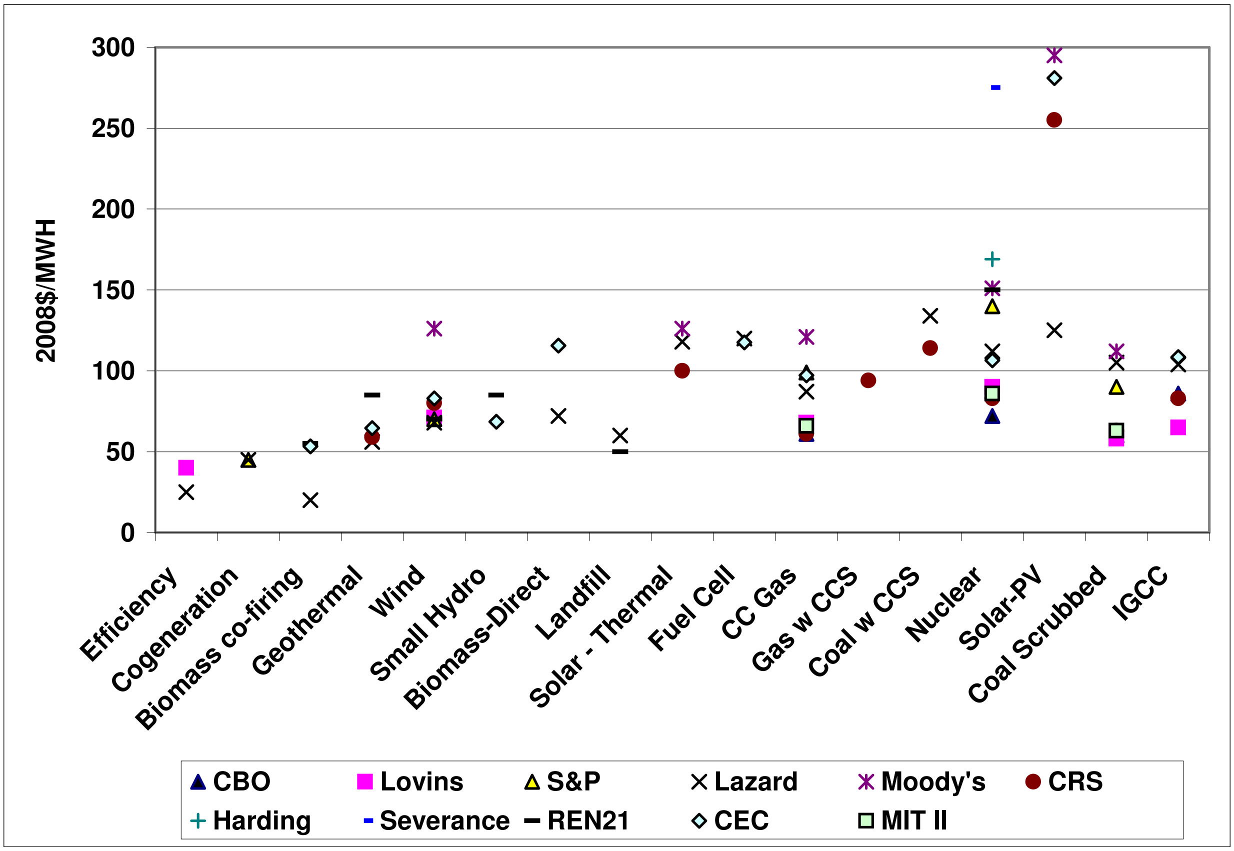


Source: Figure I-1.

The striking thing about the estimates of the options in these studies is the close agreement on costs, with two exceptions: solar photovoltaics and nuclear (see Figure V-5). The costs of nuclear and solar are high and uncertain; the other alternatives are lower and appear to be more certain.

These studies leave little doubt that there is a range of low-cost renewables and efficiency options available to meet the need for electricity. Given the history of the industry, the recent increase in construction cost indices, the higher overnight cost numbers that the utilities have begun to use, and the fact that the utilities and Wall Street are unable to finance these reactors in the capital markets, the low-cost projections seem implausible at best.

Figure V-5: Busbar Costs of Alternatives to Meet Electricity Needs



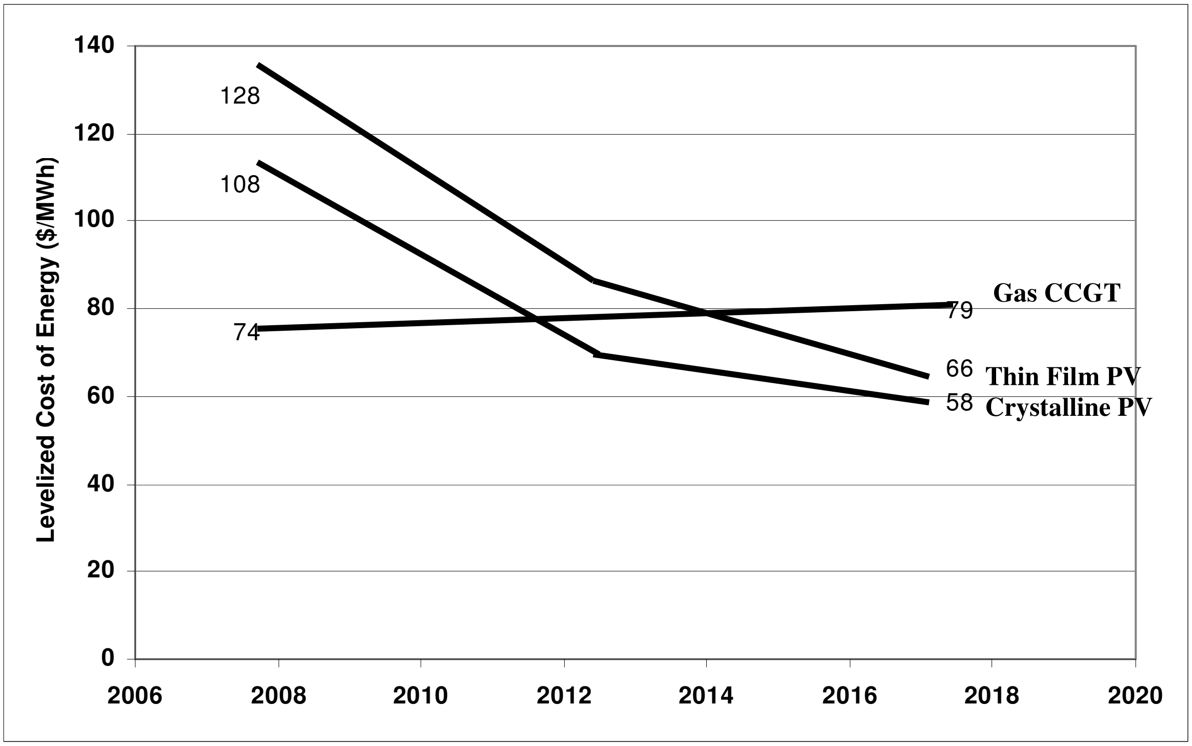
Source: See Figure I-1, Renewables.

While the nuclear hope and hype studies focus a great deal of attention on the possibility for declining costs, some analysts argue that the real potential for cost reduction lies on the side of the alternatives. For example, Lazard offers an analysis that sees a very steep decline in the cost of some photovoltaics (see Figure V-6). It sees the potential for the cost to be cut in half, rendering thin film and Crystalline Solar photovoltaic competitive with conventional natural gas and any of the other renewables.

B. Availability

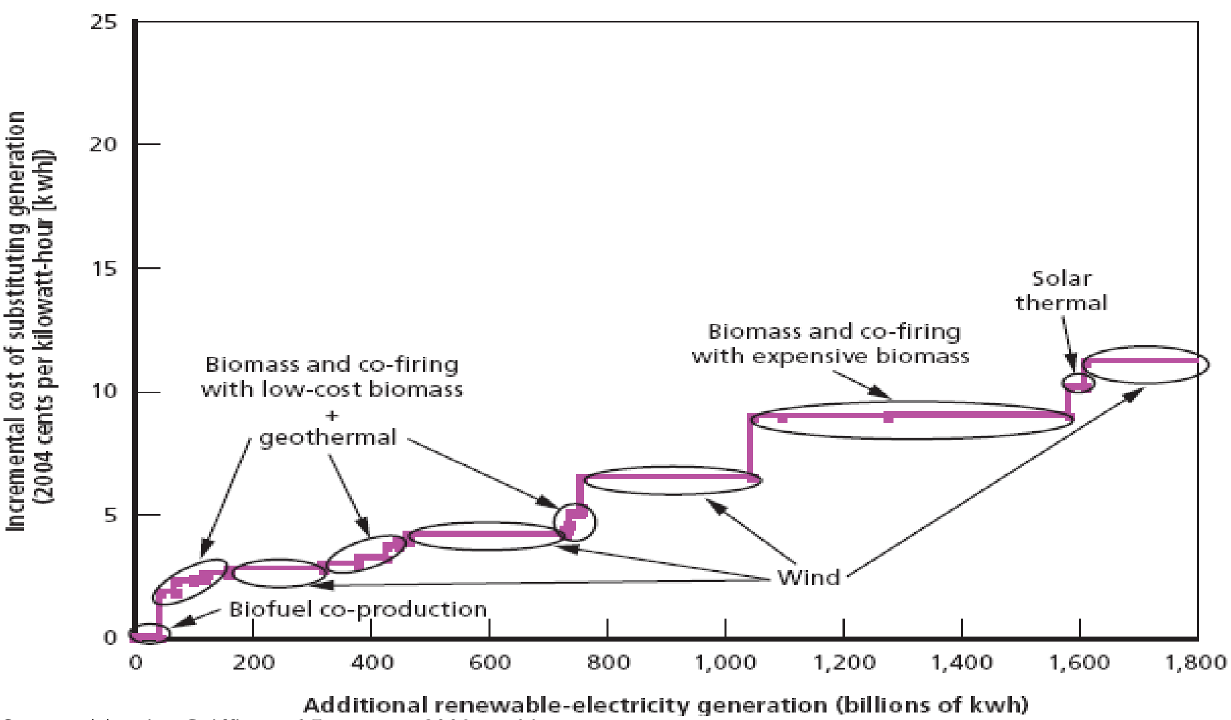
With so many options that are clearly lower in cost, the question arises as to whether we need debate the cost of nuclear reactors. A recent study from the Rand Corporation focuses on the supply-side sources that are carbon free. It clearly shows that a large portion of the need for electricity can be met without relying on the higher cost central station options (See Figure V-7).

Figure V-6: The Potential for Cost Reductions in Solar PV



Source: Lazard, p. 6.

Figure V-7: Sample Incremental Cost of Renewables Substitution Curve

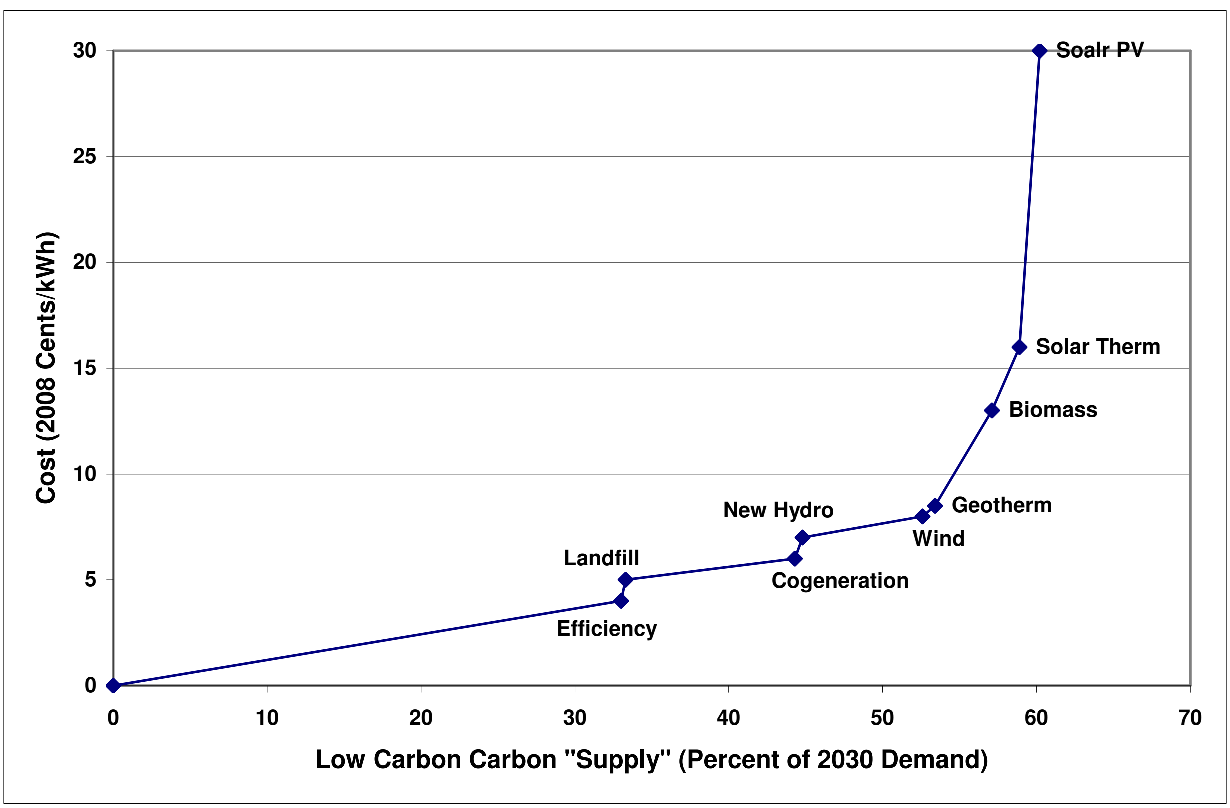


Source: Tomin, Griffin and Lempert, 2008, p. 14.

The Rand Study arranged the technologies in exactly the same order and at about the same level of cost as in the earlier cost analysis. Biomass, geothermal, wind, and solar thermal all cost less than nuclear, with solar thermal and high cost wind being just slightly less expensive than nuclear. The study looks at two different tranches of biomass and three different tranches of wind reflecting onshore and offshore opportunities. This supply curve is well defined in the literature. What is interesting is the quantity of electricity that Rand projects can be supplied at these costs. The estimate of 1,800 GWh is equal to 35% of the Energy Information Administration's base case forecast for the total amount of electricity that will be consumed in 2030.

As is frequently the case in such supply-side studies, the Rand analysis does not include any efficiency reduction in demand. Efficiency is the least costly and one of the largest alternatives available to meet electricity needs. A number of studies of individual states and of the nation as a whole find that a 30% reduction in electricity demand is technically feasible and economically practicable in the residential, commercial, and industrial sectors at an average cost of 5 cents per kWh.[42] Counting efficiency as a resource results in a dramatic shift in the supply curve. Figure V-8 presents the supply curve in a recent study from the Union of Concerned Scientists that includes efficiency. It expresses the quantity supplied as a percentage of the base case demand. Thus, in 2030, one third of the projected demand would be met by increasing energy efficiency; the need for generation would be cut by one-third. New sources of renewables would meet about one-quarter of the remaining demand. Meeting more than 50 percent of the need for electricity with efficiency and renewables beats the target in recent climate change proposals.

Figure V-8: UCS Incremental Low Carbon Sources of "Supply"



Source: Cleetus, 2009, p. 141.

Figure V-9 combines these and several other estimates for efficiency and renewables, using the costs discussed earlier into a "supply" curve.[43] It expresses the quantity of low carbon supply in two forms – billions of kWh and as a percentage of the base case demand in 2050. The 2050 base case demand is projected from the most recent Energy Information Administration projection of demand in 2030 by assuming the same underlying growth rate of demand from 2030 to 2050 as EIA assumed between 2010 and 2030. This calculation assumes that all existing low carbon sources of electricity must be replaced in the long-term. In other words, by 2050 there will be an entirely new set of resources meeting the need for electricity, none of which is online today.

Figure V-9 also shows a case with natural gas assumed to be needed to be integrated with low load factor renewables (wind and solar) on a one-for-one basis. This may not be necessary until higher levels of contribution from wind and solar are reached. Other options, particularly new storage technologies, may also fill this need to balance out low load factor renewables. Nevertheless, the quantity of gas needed to play the balancing role in the alternative supply curve is well within the range of EIA gas projections for 2030, especially when one considers that efficiency will free up a significant quantity of gas for other uses.

The goals put forward in the climate policy debate put this supply curve in perspective. The current goal is a reduction of more than 80% below 2005 levels by 2050. The interim goal is to achieve about half that reduction by 2030. The least cost efficiency-renewables approach meets the targets for three decades before the more costly central station and renewable alternatives come into play, if they ever do. The efficiency-renewables approach is the cornerstone of the long-term solution and it buys a great deal of time for new technologies to finish the job.

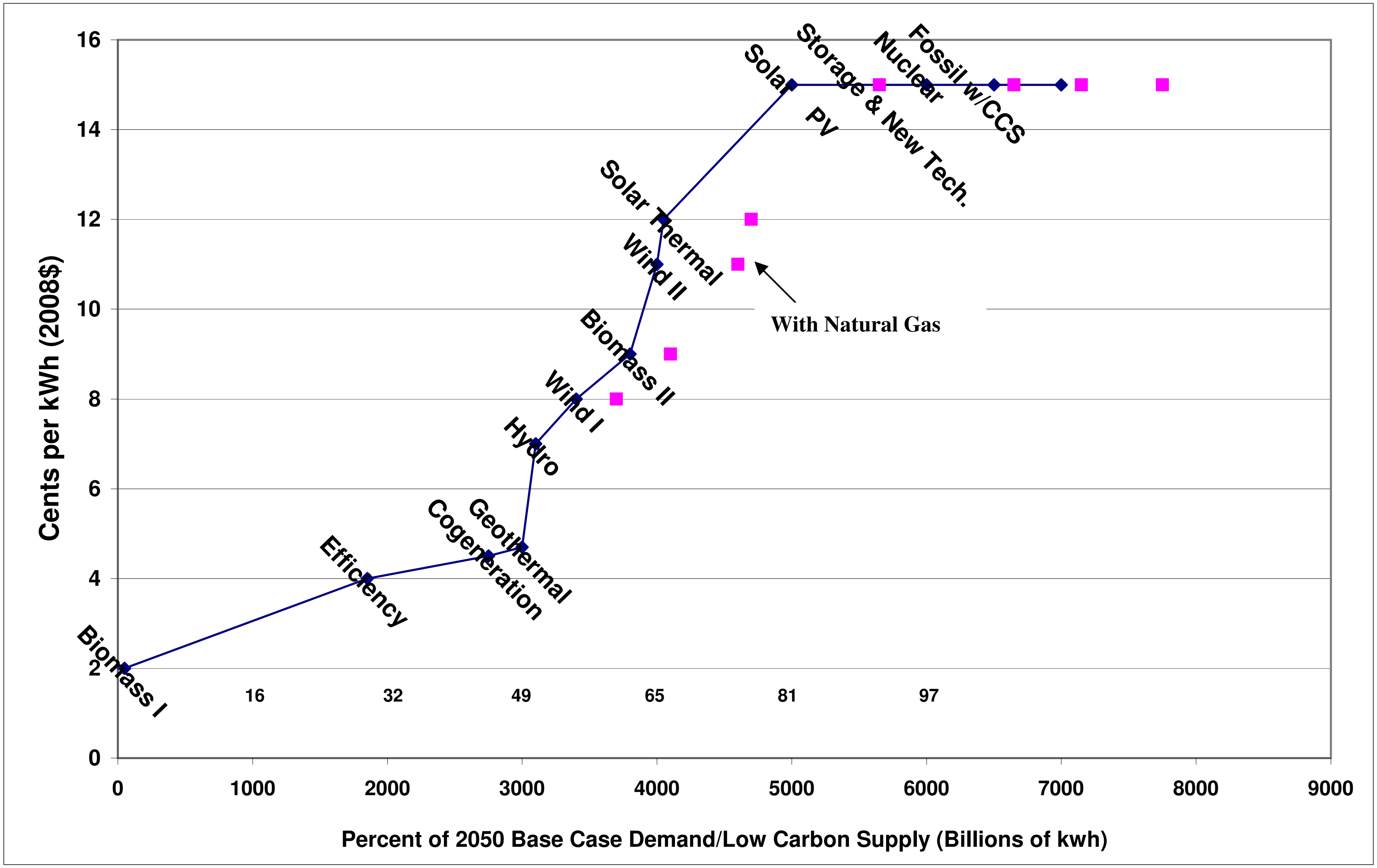
The costs of achieving the goal with the efficiency-renewables approach are low, a fact that has been recognized by a number of analysts.[44] With efficiency in the range of 2.5 to 5 cents and renewables in the range of 7 to 10 cents, the average cost of these alternatives is likely to be less than 6 cents per kWh.

C. The Consumer Cost of Premature Adoption of Nuclear Power

While this analysis suggests that we do not need to debate new nuclear reactors at present or for decades, the political reality is that we are having that debate. The stakes for the consumer are huge. Figure V-10 uses the estimates of the relationship between overnight costs and busbar costs observed in recent analyst studies to identify the range of busbar costs that seem likely. Given the overnight costs put forward by utilities, busbar costs would be in the range of 12 cents to 20 cents per kWh. Moody's and Harding medium costs are about 16 cents per kWh. Harding's high cost estimates suggest 20 cents or more.

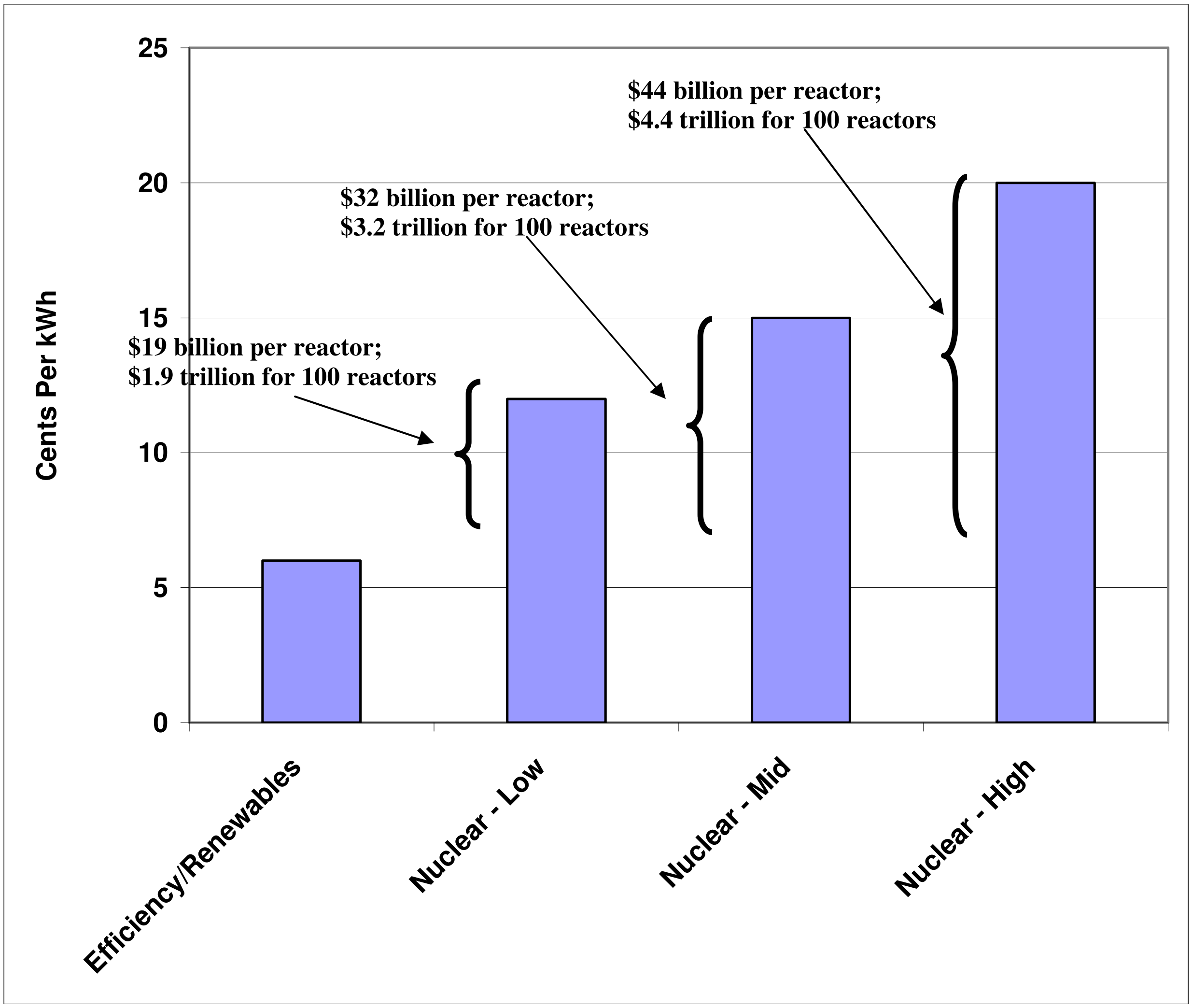
Comparing this range of costs to the cost of alternatives suggests that there are huge stakes for consumers. A 1,000 MW nuclear reactor at 12 cents per kWh and a 90% load factor would cost over $470 million more per year than the alternatives at 6 cents per kWh. Over the 40-year life of the reactor the excess cost would be $1.9 billion (see Figure V-9). One hundred plants would have an excess cost of $1.9 trillion. With nuclear costs estimated at 20 cents, the excess costs would be $1.1 billion per year or $44 billion over the life of the reactor; 100 reactors would have excess costs of $4.4 trillion.

Figure V-9: Electricity Supply Curve in a Carbon Constrained Environment



Source: Calculated by author.

Figure V-10: Ratepayer Cost of Nuclear Reactors Compared to Efficiency and Renewables



Source: Calculated by author.

VI. ASSESSING THE NUCLEAR OPTION

The answer to the question "how much will electricity from nuclear reactors cost?" is simple from the consumer economic point of view – nuclear reactors are likely to be much more costly than a range of alternatives. Those alternatives are available in sufficient supply so there is no reason to contemplate building nuclear reactors. The analysis of indirect costs does not alter that conclusion. While these factors make the picture more complex, they make the conclusion even stronger.

The following discussion makes the case that risk, externalities, and subsidies should be taken into consideration in both the public utility commission regulatory and policy arenas based on economic grounds. Making the case this way does not preclude us from noting that there are other grounds on which these factors could affect ratepayers. Most state statutes have broad language charging the public utility commission with protecting the general interest of the public. The narrow economic view is frequently chosen by the public utility commission, but with externalities and subsidies playing such a large part in the economics of nuclear reactors, that choice is less and less reasonable. In some states there are other statutes – environmental in particular – that force environmental issues into the public utility commission decision-making.

A. RISK

Risk plays an important role in the nuclear analysis because of the history, long lead-times, and economic and technological uncertainties involved in reactor construction and operation. The decision to commit to a reactor that requires a long lead-time and produces a large quantity of power creates sunk costs and results in rigidities that are vulnerable to changing economic, regulatory, or financial conditions. Over the long construction and operation period, things can change, rendering the initial decision uneconomic.

Regulators should not assume that ratepayers should bear the real risks of building nuclear reactors. A decision to authorize a reactor that has the risks identified above can impose severe costs on ratepayers, the utility, and the local economy. In addition to imposing excessive costs on consumers, a reactor may become uneconomic during its long construction cycle due to the development of alternative technologies, thus weakening the economy of the service area and the financial status of the utility.[45]

In the regulatory context, there is a tendency to try to shift the risk to ratepayers before and after the construction decision is made. Before the decision is made, utilities try to shift risks to ratepayers by seeking recovery of costs before the plant is in service. After a decision is made, if something goes wrong, the utilities will argue that they made the best decision they could at the time and therefore should not be held accountable when things change. In a competitive marketplace, however, they would bear the risk of their decisions, but also reap the rewards if the costs they incurred were lower than other alternatives available.

Beyond the risk of cost overruns, marketplace and technological risk should be taken into account in the resource planning process. Extensive assessment of the cost and availability of alternatives should be made to ascertain whether the proposed plant is likely to be the least costly alternative. At a minimum, the public utility commission should consider the likely technological developments during the construction and early operation phase of the nuclear reactor, identifying alternative technologies that could meet the need for electricity in that time frame.

A variety of mechanisms are available for incorporating risk into the decision-making process and allocating the risk to various stakeholders. For example, commissions can put a cap on costs, forcing utilities to bear the burden of cost overruns. The important point is to recognize the risk and make its allocation explicit and transparent.

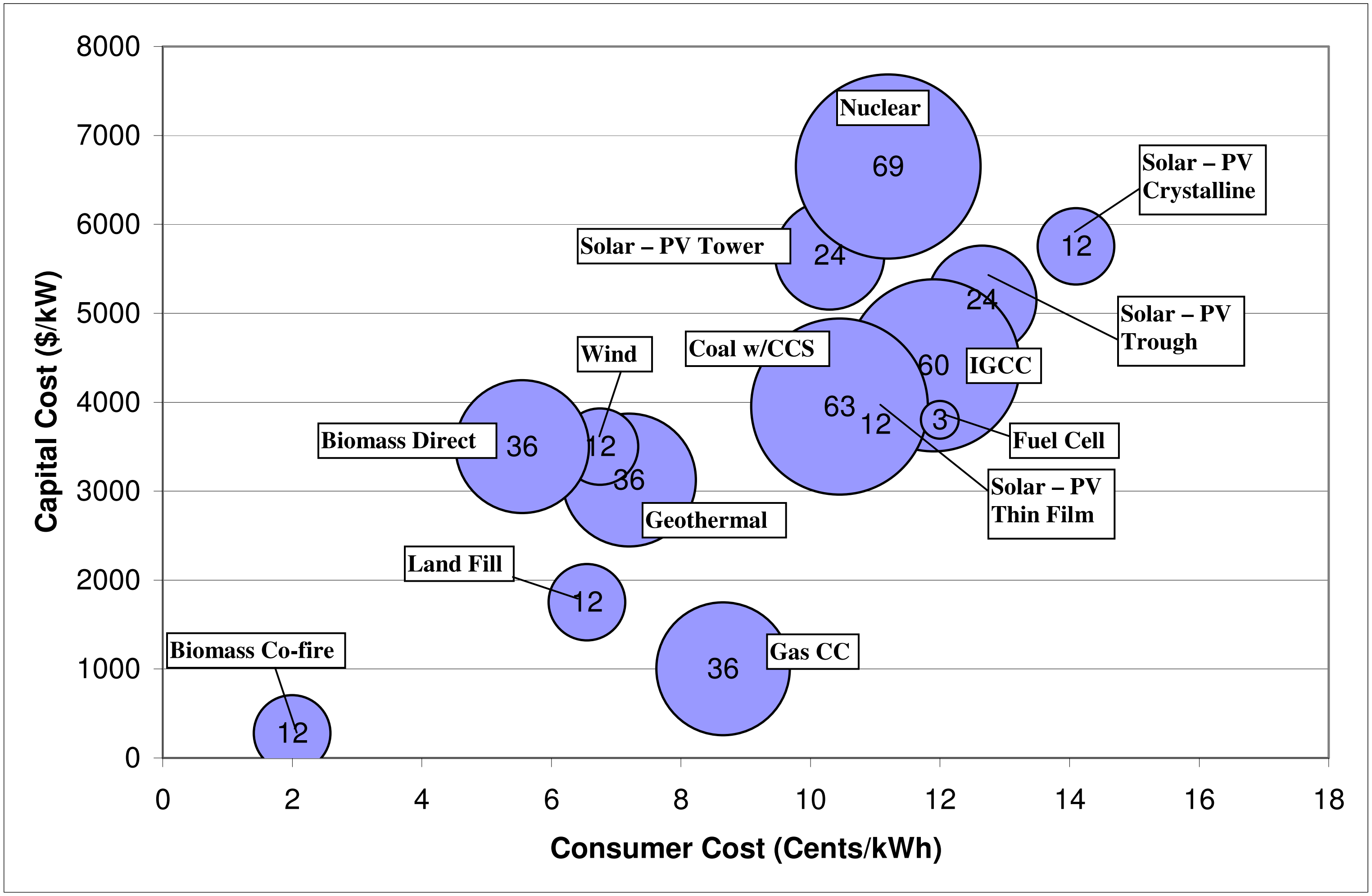
Figure VI-1 presents three characteristics of generation alternatives from the Lazard study that, as we have noted, underestimates nuclear costs significantly. Nevertheless, it shows that nuclear reactors are not the preferred option by a long shot. It shows the consumer cost, capital cost, and the construction period. These are three key determinants of risk, as discussed above. Capital costs are sunk costs, which render the option inflexible; long lead-times not only allow consumer costs to escalate, but also give alternatives more time to develop, thus improving their competitiveness. Finally, high consumer costs may reduce demand. The smaller the circle and the closer to the origin, the lower the cost and the less risk.

The Lazard study used a construction period of 69 months for nuclear, but others have used much longer time periods. Even with the underestimation of capital costs and the relatively short construction period, nuclear has a unique set of characteristics that are unattractive from the risk point of view – combining high costs, large capital outlays, and a long construction period. The coal based alternatives present about the same risk profile as nuclear reactors. There are half a dozen options that are clearly superior to nuclear reactors on all three risk dimensions, and the lowest risk alternative. Efficiency is not shown because Lazard estimated only the cost, which, as we have seen, is quite low. Efficiency would certainly have a short lead time and a low capital cost. If it were included it would be the most attractive on all three risk dimensions.

B. EXTERNALITIES

External costs have a complex relationship to the costs that are included in electricity rates. On the one hand, it can be argued that since ratepayers will not pay the external costs in their rates, they should not be included. On the other hand, to the extent that ratepayers bear those costs as taxpayers (where they are monetized outside of rates) and as inhabitants of the area affected (where they are not monetized), the public utility commission does bear responsibility. It is no longer possible to pretend that external costs are not being caused by the decision of the public utility commission and should not be recognized in the decision making process. Many of the nuclear reactor cost analyses and policy analyses that are building the case for nuclear power include the potential for the monetization of some external costs (i.e. carbon taxes). The utility industry seems to be responding to this possibility in its decision-making, at least with regard to CO_2, while the externalities associated with nuclear reactors such as environmental impacts receive much less attention.

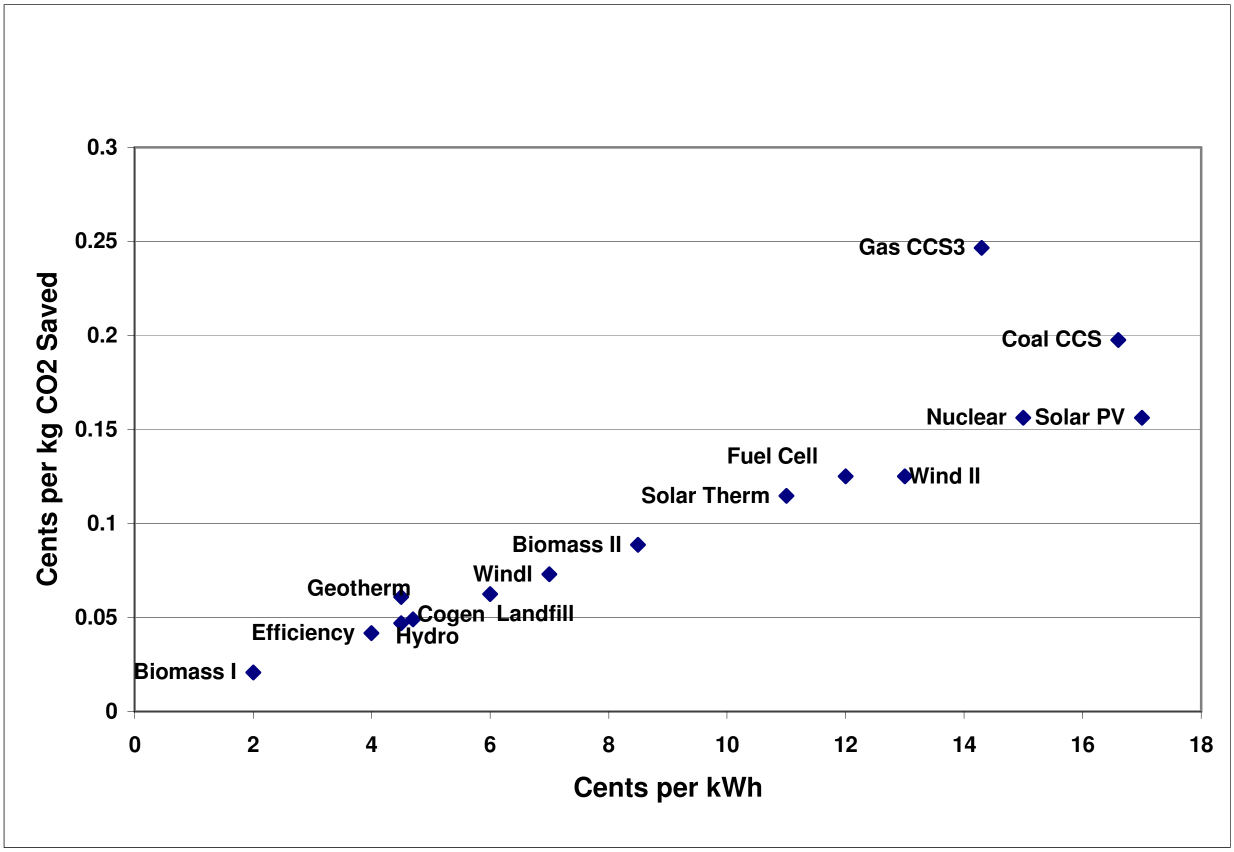
Figure VI-1: Consumer Cost, Capital Cost, and Construction Times, Various Supply-Side Alternatives (Circle Size Indicates Construction Time in Months)



Source: Lazard, 2008, pp. 11-13.

Within the narrow confines of the climate change policy debate, nuclear reactors are not a very attractive solution from the consumer point of view. They are not only an extremely expensive way to meet the need for electricity; they are also an extremely expensive way to lower carbon emissions, as shown in Figure VI-2. Since we know what it costs to produce or save a kWh of electricity, and we know how much carbon generating a kWh of electricity from coal produces, we can calculate the cost of reducing carbon compared to coal for each of the alternatives. Nuclear reactors are among the most expensive options.

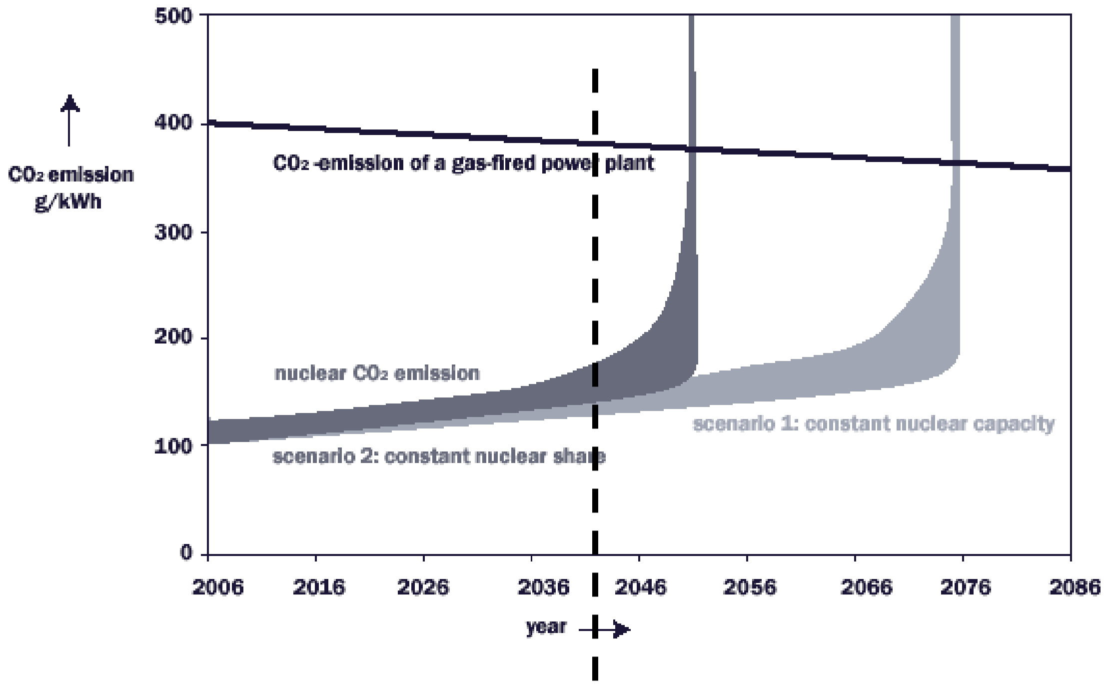
Figure VI-2: The Energy and Environmental Cost Effectiveness of Alternative Means of Meeting the Need for Electricity



Source: Calculated by author.

There is also some dispute over the size of the carbon footprint of nuclear energy. The construction, decommissioning, and especially the front end of the fuel cycle of nuclear reactors (mining, processing, waste disposal) are very energy intensive and likely to have a substantial carbon footprint. Storm van Leeuwen argues that the uranium production cycle has a significant carbon footprint that could become much more carbon intensive over time with an increase in nuclear power production. Interestingly, for nuclear reactors commissioned in the next few years, the differences between the carbon footprint scenarios are not that important, but in the second half of the life of the reactors it could be much larger (see Figure VI-3).[46] The midpoint production year for nuclear reactors commissioned in the near future would be around 2040 and the CO_2 emissions per kWh in this analysis would be in the range of 130 g/kWh – 180 g/kWh. This is about one-third of the carbon footprint of natural gas and about one-sixth of the carbon footprint of coal.

Figure VI-3: CO_2 Emissions over Time



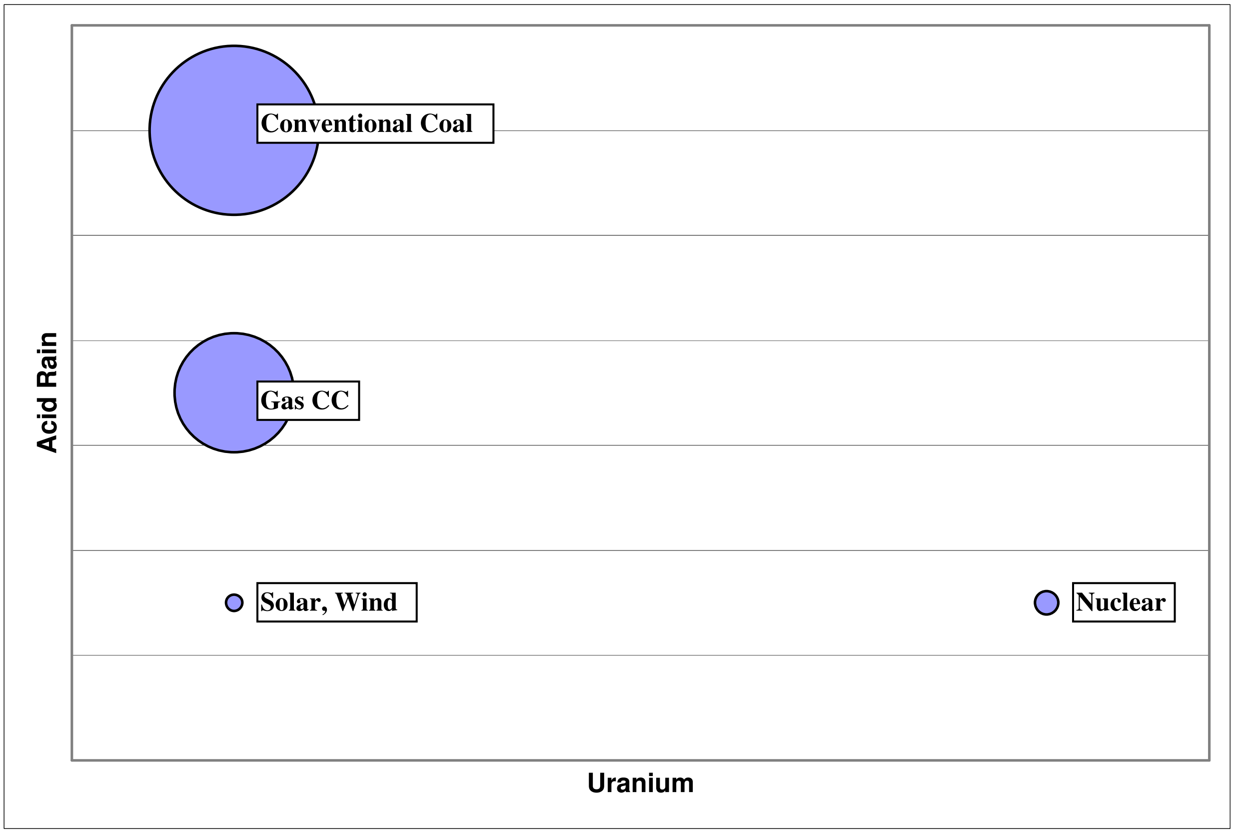
Median production year for nuclear reactor commissioned in 2010

Source: Frank Barnaby and James Kemp, "CO_2 Emission from Nuclear Power," Secure Energy? Civilian Nuclear Power, Security and Global Warming (Oxford Research Group, 2007), p. 43.

CO_2 is not the only environmental externality to consider. Moody's identifies three sets of environmental impacts associated with supply-side alternatives: carbon, precursors to acid rain, and uranium waste. It uses three simple categories of impacts: none, some, and substantial. Figure VI-4 depicts the Moody's assessment.

However, the problem with nuclear reactors goes beyond uranium waste and plant decommissioning. There are safety and security concerns in addition to the environmental impact associated with waste and decommissioning. Nuclear energy may have a large environmental impact because of uranium production, use, and waste considerations. Coal contributes significantly to acid rain and has other environmental impacts in addition to high carbon emissions. Natural gas has some impact on acid rain and carbon. Solar and wind are the only renewables considered by Moody's and they have no environmental impacts. The point is that nuclear has significant external costs.

Figure VI-4: Major Environmental Impacts of Alternative Generation Technologies (Circles Represent CO_2 Emissions)



Source: Moody's, 2008, p. 15.

The external costs associated with nuclear power raise another risk for ratepayers. If more nuclear reactors are commissioned and built, ratepayers and policy makers may consider the possibility of internalizing the external costs and subsidies. In the future, the current effort to internalize CO_2 costs could be extended to other externalities, especially if there is a surge in construction of nuclear reactors. Just as many studies ask, "what if CO_2 costs are internalized?" regulators should ask "what if the waste, decommissioning, and safety costs of nuclear reactors or their subsidies are internalized?" and "what if the subsidies become so onerous that they are shifted back to the reactors?"

There is another way that the "what if" analysis of externalities needs to be broadly drawn. Many of the "what if" discussions in the context of climate change policy ask "what if a tax or other pricing mechanism is used to induce reduction of greenhouse gases?" This has the effect of raising the cost of fossil fuel generation and making non-fossil fuel-generated power more competitive, but the analysis is frequently incomplete because it does not consider energy efficiency. Thus there is another "what if" that needs to be given full consideration: "What if efficiency reduces the need for generation altogether?" Whether through an explicit mandate or the operation of least-cost integrated resource planning, the possibility that demand will be reduced to such an extent that the need for generation is sharply reduced should be taken into account in any analysis that considers environmental externalities.

To some extent, these complexities afflict the calculation of the cost of all alternatives for meeting power needs. Projecting the cost of any large, long-term project is a difficult exercise saddled with uncertainties, but some projects are afflicted with more uncertainty than others. The challenges in the case of nuclear reactors are particularly intense because of their very large size and long lead-times, the checkered history of the industry, the paucity of contemporary experience in building these reactors, and uncertainties about the external costs.

As discussed in Section II, the concern about climate change is frequently cited and used to attempt to move nuclear reactors, which are much more costly for the consumer, into the "tough call" category in which societal costs are low and the consumer pocketbook costs are high. However, taking the full range of externalities into account, it is highly unlikely that it falls into the category of a "tough call." Even if the claim could be made that the net societal impact is positive, the societal benefits would not outweigh the consumer pocketbook costs. Assuming zero cost for nuclear externalities and a high cost for carbon, nuclear power is still substantially more expensive than the alternatives now available, but the matter does not stop there.

C. SUBSIDIES

The issue of subsidies is another cloud that hangs over the analysis. Subsidies feed into the societal costs analysis in a major way. Direct pocketbook costs may be lowered dramatically by subsidies, but that does not mean that resources are not consumed to support the production and operation of a reactor. Subsidies must be added to the pocketbook costs to arrive at a complete estimate of societal costs. These costs should also be identified by the public utility commission. Ratepayers bear a portion of these costs as taxpayers. By choosing to build a specific reactor, the utility commission is deciding to incur the costs. It bears responsibility for those costs, whether they fall on ratepayers, taxpayers, or residents. While subsidies are "socialized" reactor costs, that does not mean they are small or irrelevant.

1. Taxpayer Subsidies for Capital Costs

Some of the primary subsidies sought by the nuclear industry are loan guarantees and other taxpayer funded mechanisms to lower capital costs. Indeed, Wall Street and the nuclear industry itself have made it clear that without taxpayer funded loan guarantees, new reactors will not be built.[47]

Historically, when Congress has tried to pick winners by giving subsidies to one technology over another, it has done a poor job. The massive subsidies directed toward the nuclear reactor industry in various forms are a case in point. They certainly did not protect consumers from large cost overruns and excess costs in the 1970s and 1980s. In the current policy environment, Congress takes a different tack. It claims technological neutrality in its subsidy largesse. We are told that the playing field will be level for all low carbon alternatives. Prominent vehicles for implementing this type of subsidy are loan guarantees and tax incentives that lower the cost of capital or make capital available.

If Congress accomplishes its goal of being technology neutral, even huge capital cost subsidies will have no effect on the order in which technologies enter the supply mix. In other words, Congress will merely shift costs out of the market and into the federal budget, shifting costs from ratepayer to taxpayers. Of course, if some sectors are institutionally better able to game the subsidy system, or Congress is not neutral in its policies, then the supply curve will be distorted.

The hypothesis that lowering the cost of capital in a technology-neutral way does not alter the sequence in which technologies should enter the supply mix can be demonstrated with the results of the California Energy Commission Cost of Generation Model. The model includes four sets of financial assumptions. It utilizes four different weighted costs of capital estimates as described in Table VI-1. It calculated the weighted average cost of capital based on debt/equity ratios and the costs of debt and equity, as well as the favorable tax treatment offered to some technologies in California. The publicly owned utilities have a very low weight average cost of capital because they have access to tax free bonds that are backed by a government entity. The weighted average cost of capital for investor owned utilities and merchants is much higher -- in the range of twice as high. Non-gas fired sources of electricity are favored over gas-fired sources.

Table VI-1: California Energy Commission Cost of Generation Model Financial Assumptions

	Merchant Gas-fired	**Merchant Non-gas**	**Investor Owned**	**Publicly Owned**
% Debt	**40.0**	**60.0**	**50.0**	**100.0**
% Equity	**60.0**	**40.0**	**50.0**	**0.0**
Cost of Debt	**6.5**	**6.5**	**5.3**	**4.35**
Cost of Equity	**15.9**	**15.9**	**11.74**	**0.0**
Cost of Capital				
Weighted Avg.	**12.14**	**10.26**	**8.74**	**4.35**
With Tax Savings	**10.65**	**8.39**	**7.57**	**4.35**

Source: Klein, 2008, p. 32.

As Figure VI-5 shows, the huge difference in the cost of capital does not change the order in which the technologies enter the supply mix. We have cautioned that the 2007 cost of generation analysis by the California Energy Commission relied on the very low estimate of overnight cost for nuclear reactors from Keystone, of only $2,950 per kW. Current estimates are much higher. The Moody's analysis uses $6,250 per kW. If we double the overnight cost estimate to $5,900 per kW and analyze the impact of the much lower cost of capital for publicly owned utilities, we find that the impact of the financial model differences grows as overnight costs do. At an assumed overnight cost of $2,950 per kW, the lower cost of capital for the publicly owned utility lowers the busbar cost by just under 3 cents per kWh. At an assumed overnight cost of $5,900 per kW, the lower cost of capital lowers the busbar cost by just over 5 cents. However, the increase in the overnight cost is so large that the relative ranking of nuclear reactors is much lower.

Therefore, a technology-neutral subsidy does not change the consumer economics much. The simple average cost advantage of the 18 options that are lower in cost than nuclear reactors is 4 cents per kWh under the public utility model and 6 cents per kWh under the investor-owned utility finance model. A technology-neutral subsidy still leaves nuclear between 7 and 9 cents per kWh more costly than a mix of efficiency and renewables.

2. Ratepayer Subsidies of Utilities Construction Work In Progress (CWIP)

The cost problems of nuclear reactors are so severe that many companies contemplating building them are not only compelled to demand that they be treated under a utility finance model (when many were recently enamored of the merchant model, since they thought that would increase their profits), but they ask for special treatment – to be granted the highly unusual status of Construction Work in Progress (CWIP). CWIP allows the utility to start being paid for the plant or reactor before it is completed and producing power.

This violates one of the most basic tenets of utility regulation and is allowed in only a handful of states. Generally, public utility commission practice dictates that consumers pay only for a utility plant that is used and useful. Before a power plant is put in service, it cannot be considered useful because it is not being used. In the competitive marketplace, consumers generally pay for things when they are received.

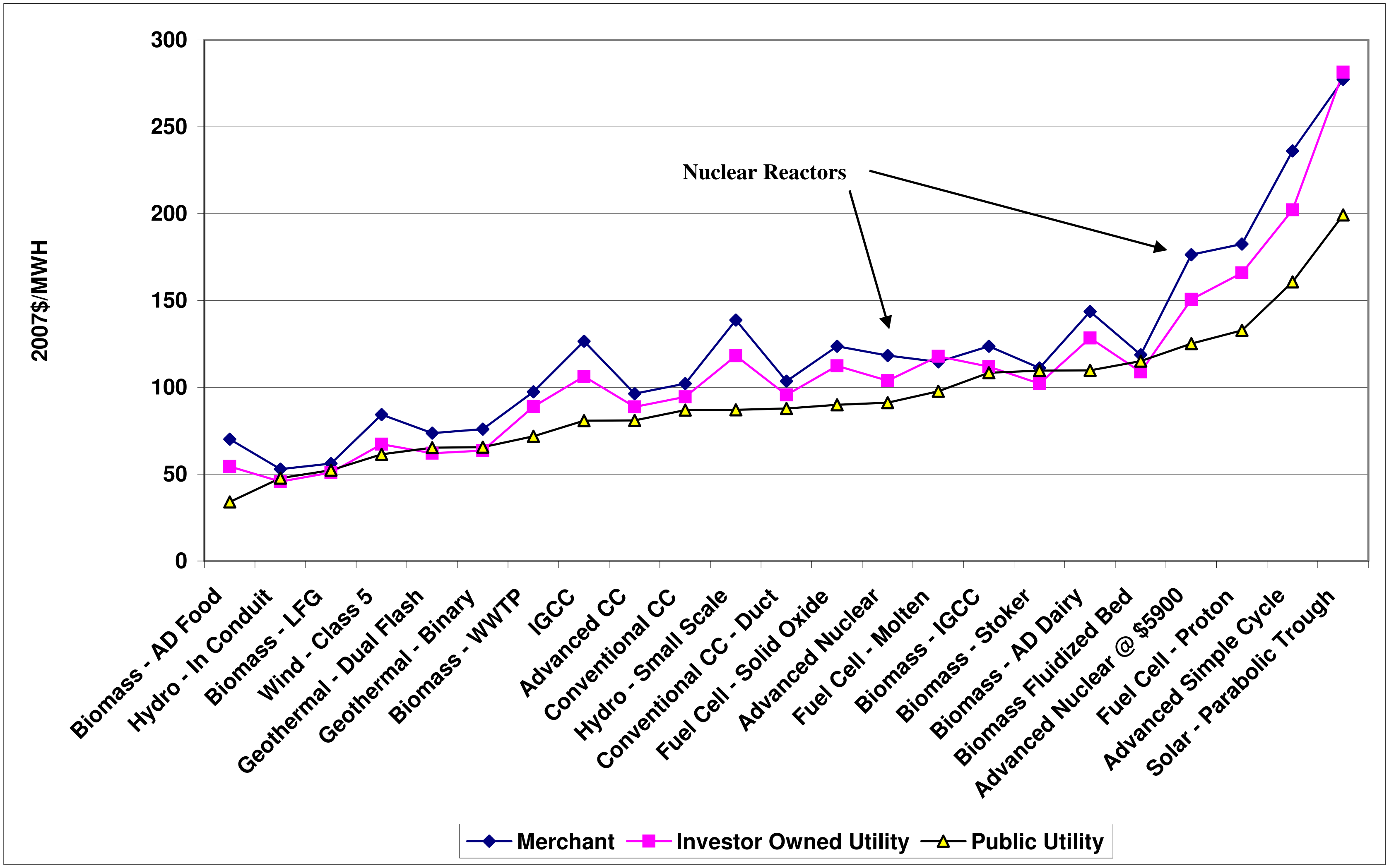
By charging consumers for capital expenditures before assets are used, utilities can claim to lower total costs because capital charges do not build up during construction, but the consumer "benefits" come at a cost.

First, if the plant is not completed, the consumers are left holding the bag.

Second, while CWIP may make nuclear power reactors slightly more palatable (from a lower financing cost standpoint), that does not change the fact that they are much more expensive than other options. The "benefits" to consumers are small, a few hundred million dollars, compared to the additional billions of dollars imposed on consumers as a result of the public utility making an uneconomical decision.

Third, the timing of the benefits is striking. The recent CWIP dispute in Georgia around the Vogtle plant shines a bright light on the issue. According to the utility's own numbers, consumers pay $2 billion more in rates during the seven year construction of the plant and the utility earns $1 billion sooner. Over the next sixty years consumers pay slightly lower rates so that after being put in the hole for $2 billion, the utility claimed consumers would eventually come out $300 million ahead. Utilities earn a lot more a lot sooner than consumers do because of the pattern of cost recovery. Even if consumers place no time value on their money, they do not break even for seventeen years. If the consumer discount rate equals the utility cost of capital, it is a wash, and if consumers have a higher discount rate, they never come out ahead. Consumers get little if any benefit, but the utility gets guaranteed income for years.

Figure VI-5: Busbar Costs for Alternative Technologies and Financial Models (Peakers, Pilot Technologies, and Solar PV excluded, 2007$)



Source: Klein, 2008, pp. 14.

Other utilities claim somewhat higher consumer savings but these debates over CWIP must not be allowed to be a diversion from the fundamental consumer issue. Making a nuclear reactor less expensive by $0.0006 cents or $.005 cents should not be allowed to obscure the fact that choosing to build the nuclear reactor makes electricity more expensive by $0.06 to $0.14 cents (see Table VI-2). In other words, cushioning the rate sticker shock is a far less consumer-friendly approach than choosing cost-advantageous efficiency and renewables. The policy choice is between CWIPing the reactor and not building it. Consumers will be better off by far if the reactors are not built.

Table VI-2: Consumer Cost Benefit Analysis of CWIP Nuclear Reactors vs. Relying on Efficiency and Renewables

CWIP Benefit	Efficiency and Renewables Benefit
Lowers the risk of a credit downgrade	Poses no risk of a credit downgrade
Lowers consumer cost by $0.0006 to $.005	Lowers consumer cost by $0.05 to $0.14

D. The Bottom Line on Nuclear Power

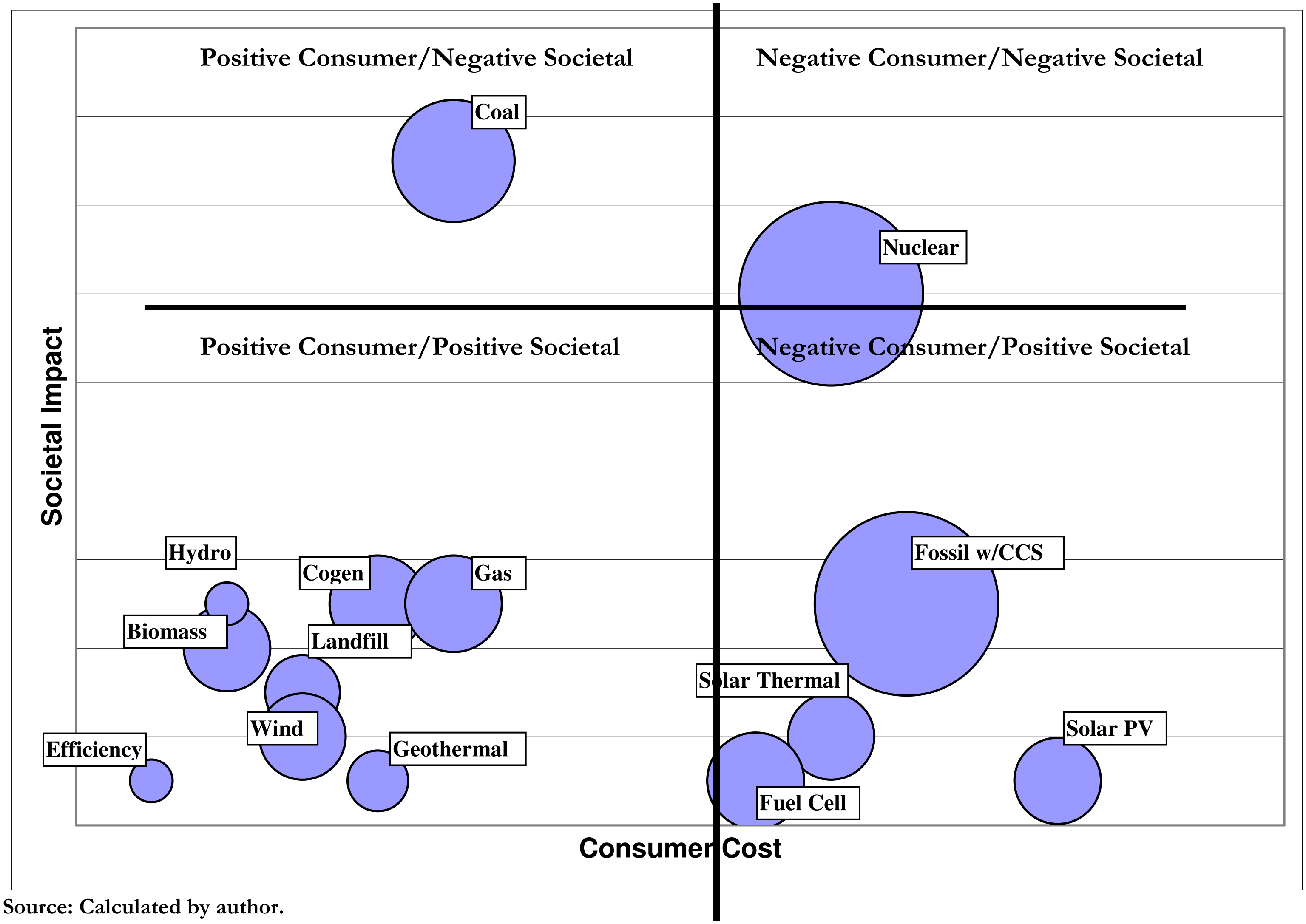
In establishing the analytic framework, the operating premise of this paper is that the direct consumer pocketbook cost should be the primary consideration, but indirect costs like environmental and risk factors should also be considered. Figure VI-6 presents that analysis in terms of the four quadrants identified in Section II. Alternatives clearly have more attractive profiles on all three dimensions of the analysis. Thus, there are three clusters of alternatives that are economically preferable to new nuclear reactors:

1. Efficiency and a set of low cost/high load factor renewable alternatives;
2. Moderate cost/low load factor renewables;
3. Natural gas plants especially combined with renewables.

Nuclear power is found to be a negative "no brainer," failing both the consumer pocketbook and the societal cost tests. It fails the societal cost benefit test on the grounds of both risk and externalities. This same comparative assessment finds that efficiency, low cost renewables, and natural gas based options are positive "no brainers." They are positive for the consumer pocketbook and society. The tough calls are expensive solar (because of its direct costs) and coal with carbon capture and storage, because of its direct costs and the risks associated with implementing an untested technology. Expensive solar costs are seen as declining, however, while coal sequestration and storage costs are unknown.

In Figure VI-6, nuclear reactors are located straddling the environmental issue. If one believes that the various environmental, safety, and security issues with uranium are important, it could be argued that nuclear energy has a larger environmental impact than coal and therefore

Figure VI-6: A Multi-dimensional View of Alternatives (Size of Circles Denotes Risk)



Source: Calculated by author.

belongs way up on the environmental dimension. If one does not see uranium as having important environmental and societal impact, one would move it down. That would not change the policy choices. Nuclear reactors would still be inferior to many other options.

The logical path for policymakers and regulators is to meet energy needs by starting from the origin in Figure VI-6 and working outward. The bevy of options in the positive/positive quadrant provides fertile near-term options, buying time for technological development, as many of the options are as yet not fully developed in the U.S. The options in the negative consumer/positive societal quadrant are the next place to look. The high cost renewables have prospects for significant cost reduction. Coal with carbon capture and storage requires extensive research and new infrastructure before it is a feasible option, but it taps an abundant domestic resource. The choice between the worst options comes down to a choice about which externalities and risks one values most – coal with its massive carbon output and other environmental externalities, nuclear with its high cost, high risk, and radioactive waste, safety, and proliferation externalities. The ultimate goal of policy should be to meet consumer, social, and environmental needs with the best possible alternatives. If we make the right choices in the near-term, these hard choices are decades away.

E. CONCLUSION

Policymakers should refuse to allow taxpayers and ratepayers to be put at risk. If nuclear reactors cannot stand on their own in the marketplace, they should not be propped up by subsidies. This analysis has shown that there is a range of alternatives that can meet the need for electricity at a lower cost and with a more benign environmental impact. The aspiration of the nuclear enthusiasts symbolized in the first MIT report has become desperation in the second MIT report precisely because their cost estimates do not comport with reality. Notwithstanding their hope and hype, nuclear reactors are not economically competitive and would require massive subsidies to force them into the supply mix. It was only by ignoring the full range of alternatives -- above all efficiency and renewables -- that the MIT studies could predict a feasible economic future for nuclear reactors. Today the analytic environment has changed from the early days of the great bandwagon market, so that it is much more difficult get away with the "systematic confusion of expectation with fact, of hope with reality."

The highly touted nuclear renaissance is based on fiction, not fact. It gargered a significant part of its traction in the early 2000s with a series of cost projections that vastly understated the direct costs of nuclear reactors. As those early cost estimates fell by the wayside and the extremely high direct costs of nuclear reactors became apparent, advocates for nuclear power turned to climate change as the rationale to offset the high cost. But introducing environmental externalities does not resuscitate the nuclear option for two reasons. First, consideration of externalities improves the prospects of non-fossil, non-nuclear options to respond to climate change. Second, introducing externalities so prominently into the analysis highlights nuclear power's own environmental and external problems. Even with climate change policy looming, nuclear power cannot compete in the marketplace, so its advocates are forced to seek to prop it up by shifting costs and risks to ratepayers and taxpayers.

The massive shift of costs necessary to render nuclear barely competitive with the most expensive alternatives, and the huge amount of leverage (figurative and literal) that is necessary to make nuclear power palatable to Wall Street and ratepayers is simply not worth it. The burden will fall on taxpayers. Policymakers, regulators, and the public should turn their attention to and put their resources behind the lower-cost, more environmentally benign alternatives that are available. If nuclear power's time ever comes, it will be far in the future -- after the potential of the superior alternatives available today has been exhausted.

ENDNOTES

[1] Bupp and Derian, 1978, Chapter 2, describing the origin of the great bandwagon market.

[2] Sixteen reactors brought on line prior to the ramp up in construction were turnkey projects, whose costs were not publicly revealed, although the vendors appear to have taken substantial losses (Cook, 1985, p. 84). There are a handful of plants for which cost data has not been made available (Koomey and Hultman, 2007).

[3] The precise origins of use of the term in America are unclear. A Google search on the term reveals the following history. The origin of the movement is in the early days of the Bush Administration with the formation of the Near Term Development Group and Vice President Cheney's National Energy Policy Task Force (Lake, 2008). The consultant and national laboratory studies summarized in the University of Chicago, 2003, study were part of the effort. In late 2001, the Department of Energy issued "A Roadmap to Deploy New Nuclear Plants in the United States by 2010." A conference at the Belfer Center at Harvard in February, 2002, was entitled "Nuclear Energy Renaissance in the United States: What Would be Required." A conference in Washington D.C. in September, 2002, used the term "nuclear renaissance," and one month earlier the chairman of British Energy had called for a nuclear renaissance (Grossman, 2002). Grossman (2002) indicates that the word "renaissance" had replaced the word "revival" in the lexicon "used by nuclear proponents in the U.S. and around the world to describe their desired recovery of the nuclear industry." The "World Nuclear Association," Annual Symposium in 2002 included a paper by Spurgeon (2002) entitled "Fuelling the Nuclear Renaissance." A 2003 article in *Los Alamos Quarterly* is entitled "Nuclear Renaissance" (Fisbine, 2003). By 2004, there is a book entitled *Nuclear Renaissance* (Nuttall, 2004). In 2004, the Department of Energy provided matching funds to three nuclear consortia under the 2010 program (Wikipedia, http://en.wikipedia.org/wiki/Nuclear_Power_2010_Program)

[4] Proceedings dealing with specific reactor proposals are active in Florida, Georgia Maryland, South Carolina, and Texas. General activity to secure a more favorable policy environment for nuclear reactors is more widespread.

[5] Cook, 1985, cover.

[6] Levelized cost is the real present value of the total cost of building and operating a generating plant over its economic life, converted to equal annual payments.

[7] MIT, 2003, uses merchant financing for nuclear reactors and utility financing for coal and natural gas. Klein, 2007, models merchant, investor owned utility, and publicly owned utility financing for all technologies.

[8] Joskow, 2006.

[9] The MIT update appears to forget that the operating costs assumptions were optimistic, far lower than the estimates of other studies and then it lowers it operating cost estimate even further. In essence, it has double counted the optimism. The original study said, we expect/hope that O& M costs will decline so we will use a low number. The later study says, see, operating costs at existing plants have gone down, so we will lower the number some more.

[10] MIT, 2003. All of the scenarios involved cost reductions. No cost increases were considered.

[11] Harding 2009.

[12] Harding, 2009, p. 5, "utility data suggests 8% real might be more realistic."

[13] Du and Parsons, 2009, p. 17.

[14] The study is much more optimistic about the construction cost of nuclear reactors than about the construction cost of coal plants. In the case of nuclear, it assumed an escalation rate that was far below the escalation in the most frequently cited cost index. On the other hand, it assumed an escalation for coal slightly above the escalation for non-nuclear plant construction costs in that index. The potential distortion that results is striking.

Differential Assumptions about Capital Costs:

	Base 2003 Assumption	Updated Cost at Assumption	Full Index Escalation
Nuclear	2000	4000	5520
Coal	1300	2300	2080

[15] TVA later demurred from building this reactor, Brewer, 2009.

[16] This is slightly above the rate of increase observed by MIT 2009 for the same period.

[17] Scoggs, 2007, Exhibit SD-8.

[18] Scoggs, 2007, p. 47.

[19] The HIS/CERA Power Plant Capital Cost index shows a decline of 5 percent in the most recent quarter.

[20] *Electric Utility Week*, May 25, 2009, reporting costs for the V.C. Summer nuclear reactors as high as $12.5 billion compared to the cost laid before the South Carolina PUC of $9.8 billion, with assurances that declines in commodity prices will return the reactor to its original estimate; Thomas Content, "Nuclear Plant Foes Prepare for Fight; Groups Rail at Lobbying to Change Moratorium," *Milwaukee Journal Sentinel,* May 23, 2009, reporting prices having risen as high as high as $71,000 per KW then falling back to $4,138.

[21] Keystone, 2007; Harding, 2007.

[22] See Bupp and Derian, 1978, Komanoff, 1981.

[23] Attributed to Levi Straus in 1954. See Ford, 1982. See also Makhajani, 2007, Appendix A; Smith, 2006, Chapter 1.

[24] Koomey and Hultman, 2007.

[25] In 1990, nuclear reactors accounted for approximately 20 percent of all generation. If all the cancelled plants had been completed, the amount of capacity that nuclear reactors would have represented would have been 2.5 times as great.

[26] Komanoff, 1981, Chapter 6.

[27] See Kopolow 2005, for nuclear; Kopolow 2006 for a comparison across energy sectors; and Kopolow 2009 for the discussion of a specific reactor. See Schlissel, et al., 2009, for a discussion of pending loan guarantees.

[28] Tomain, 1988, Federal Reserve Bank of New York, 1984.

[29] Tomain, 1988.

[30] U.S. Department of Energy, Press Release, September 20, 2004.

[31] Bupp and Dernier, 1978, pp. 188-189.

[32] Bupp and Dernier, 1978, pp. 78-79 see this as an important indication that learning was not taking place.

[33] Bupp and Derian, 1978, pp.71… 72…74…75…76…78…79.

[34] For example contrast Severance, 2008 and Moody's, 2008, v. MIT 2003 and University of Chicago, 2003.

[35] Interestingly, during the 1970s, large, complex software programs suffered similar problems. As programs grew larger and more complex, they began to bog down. Throwing more programmers at the problem did not solve the problem and the dilemma came to be known as the "Mythical Man Month." The solution was to modularize, standardize, and offer smaller programs. The nuclear industry has attempted some of these fixes, but the nature of the projects simply does not allow similar changes.

[36] Harding 2007.

[37] Areva's difficulties are not limited to this plant, Schneider, 2009.

[38] *International Herald Tribune*, "France: Areva Profit Falls Due to New Reactor," February 25, 2009.

[39] Kanter, 2009;

[40] Bupp and Derian, 1978, pp.71… 72…74…75…76…78…79.

[41] Cook, 1985, p. 84.

[42] Cooper, 2009, reviews several dozen studies that demonstrate the historical achievement of reduced demand as well as the technical potential.

[43] National Renewable Electricity Laboratory, 2009; Cleetus, Clemmer and Friedman, 2009.

[44] McKinsey, 2007; McKinsey, 2008; Rosenfeld.2008, Lovins 2008, Nadel, 2004. The American Council for an Energy Efficient Economy has done a series of state studies assessing efficiency potential in detail.

[45] Severance, 2008; Moody's 2008.

[46] Kleiner 2008.

[47] David Schlissel, Michael Mullett and Robert Alvarez, *Nuclear Loan Guarantees: Another Taxpayer Bailout,* Union of Concerned Scientists, March 2009, p. 19.

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