POWER SHIFT:

THE DEPLOYMENT OF A 21ST CENTURY ELECTRICITY SECTOR AND THE NUCLEAR WAR TO STOP IT

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EXECUTIVE SUMMARY

This paper presents a comprehensive analysis of the ongoing battle between two very different visions for the future of the electricity sector:

- the 20th century model of central station, baseload/peak-load generation that passively follows demand,
- the emerging 21st century, decentralized model based on coordinating and actively integrating distributed supply with managed demand using advanced information, communications, and control technologies.

The paper demonstrates that the current conflict between the dominant incumbents, led by nuclear power on the one side, and the new entrants, on the other, has reached a crucial turning point that will deeply affect the speed of the transformation and the ultimate structure of the 21st century electricity system.

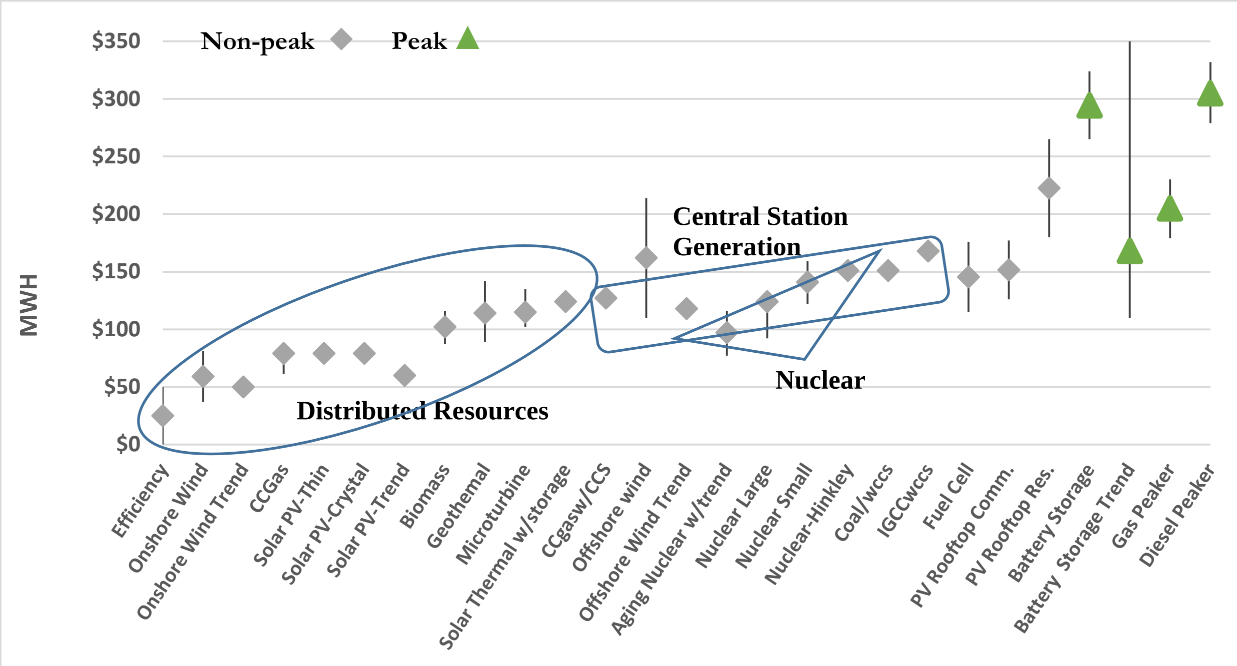
RESOURCE ECONOMICS

Part I of the analysis reviews the cost estimates for almost two dozen resources, estimates that continually change significantly because of rapid technological developments. The analysis includes demand-side efficiency as a resource of equal importance with supply-side resources.

Section II: The dramatic technological development of the past two decades has expanded the range of options available to meet the need for electricity in a low carbon environment. Wind is now cost competitive with natural gas, solar is rapidly becoming so, and storage technologies are rapidly advancing to reinforce this trend. Efficiency deserves full consideration as a resource because it has long been the least cost resource, costing substantially less than adding new supply (one-third to one-half). In contrast, construction of new nuclear reactors has continued it historic pattern of escalating construction cost, to the point where it is substantially more costly than the available alternatives. The operating costs of aging nuclear reactors have also been afflicted by the cost escalation disease. The most recent estimates indicate that low costs for decentralized alternatives, efficiency, wind, solar, and storage technologies, combined with the rising costs of nuclear power, have rendered power from new nuclear reactors two to three times more costly than the alternatives (see Exhibit ES-1). Indeed, it shows that nuclear economics have deteriorated so badly that even aging nuclear reactors are no longer competitive with new distributed alternatives.

Section III: The economic characteristics of the alternatives – size, construction period and cost – combine to make them much more attractive from the point of view of risk. With smaller, quicker to market assets with much smaller sunk costs available, a portfolio approach to acquiring low carbon resources that minimizes risk or price leaves nuclear power and "clean" coal out of the mix. Section III also shows that traditional measures of environmental impact and contemporary measures of sustainability indicate that the alternatives are vastly superior to nuclear power and "clean" coal.

EXHIBIT ES-1: LEVELIZED COST (LCOE) OF LOW CARBON OPTIONS WITH TRENDS



Source: See Section II, Figure II-3 and accompanying text.

BUILDING THE 21ST CENTURY ELECTRICITY SYSTEM

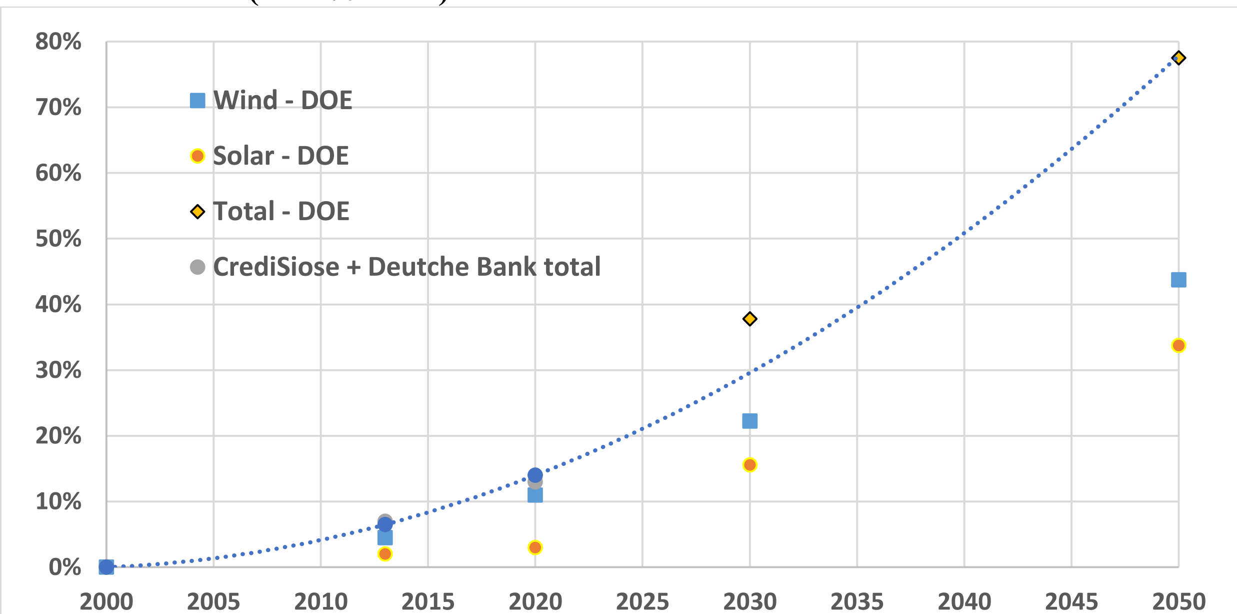
Beyond the fact that the alternative resources are less costly, the analysis in Part II shows that two other key conditions for the successful transformation of the electricity sector are met.

Section IV shows that the technical resource base is huge. It is orders of magnitude larger than the projection of need. As a recent MIT study on *The Future of Solar* succinctly put it: "Solar electricity generation is one of very few low-carbon energy technologies with the potential to grow to very large scale…. massive expansion of global solar generating capacity to multi-terawatt scale is very likely an essential component of a workable strategy to mitigate climate change risk. (MIT, *The Future of Solar*, 2015, pp. xi… xiii). Section V also shows that "Interest in wind power is stimulated by its abundant resource potential (more than 10 times current electricity demand); competitive, long-term stable pricing; economic development potential; and environmental attributes, including its ability to support reduced carbon emissions, improved air quality, and reduced water use (U.D. Department of Energy, *Wind Vision*,, p. xxvii.)" As shown in Exhibit ES-2, combining the two, non-hydro renewables yields a technical potential resource base that is more than adequate to meet demand, particularly when regional transmission grids are considered. Converting technical potential into a resource portfolio and a stable, working system is the challenge for policy

Section V shows there is a strong consensus in the financial, academic and trade literatures that the tools to operate the 21st century electricity system are in hand. There is a clear path to the full deployment of the new system, based on the practices identified in Exhibit ES-3. In the mid-term, expansion of renewables to the 30% - 40% range can be easily accommodated with the existing physical assets and management tools with no negative impact on reliability. The electricity system only needs to be operated with policies that allow the renewables to enter.

In the long-term, a wide range of measures to support the penetration of alternatives to much higher levels (80% or more) has been identified. Building an electricity system on principles of dynamic flexibility requires an institutional transformation and the deployment of supporting physical infrastructure. Given the need to respond to climate change and the cost of the alternatives, the 21st century model for the electricity system is the least-cost approach by a wide margin.

EXHIBIT ES-2: RESOURCES AS A PERCENT OF DEMAND, EFFICIENCY ASSUMED TO CUT GROWTH IN HALF (TO .5%/YEAR) TREND LINE BASED ON 2000-2020



Source: See Figure IV-3 and accompanying text.

EXHIBIT ES-3: MEASURES TO MANAGE AN INTELLIGENT, DECENTRALIZED ELECTRICITY SECTOR AND REDUCE PEAK LOAD

Demand: Efficiency
- **Demand Response**
  - **Target efficiency to peak reduction**
  - **Aggressive demand response**
  - **Manage water heater loads to reduce peak**
  - **Smart controllers**
    - **Rates**
    - **Target fixed-cost recovery to ramping hours**
    - **Time of us rates**

Supply: Diversify renewable supply
  - **Geographic (particularly wind)**
  - **Technological (wind & solar**
  - **Target solar to peak supply (west orientation)**
- **Re-orient conventional supply**
- **Shed inflexible baseload**
- **Deploy fast-ramp generation**

Grid management
- **Expand balance area**
- **Improve forecasting**
- **Integrated power transactions**
- **Import/export**

Storage:
- **Dispatchable**
  - **Solar thermal with storage**
  - **Utility storage in strategic locations**
- **Distributed storage**
  - **Community & individual storage**
  - **Air conditioning water heating**
    - **With storage**
  - **Electric vehicles**

Sources: See Section V, Table V-2 and accompanying text

THE NUCLEAR WAR AGAINST THE FUTURE

Part III of the analysis examines the reaction of central station utilities to the powerful technological development of alternatives. Not surprisingly, utilities that are deeply invested in large central station generation see the distributed alternatives as a severe threat to their interest. They have responded by launching an all-out attack on the alternatives on several fronts.

Section VI begins with a general description of the efforts of the incumbent utilities to slow the alternatives at the federal and state levels. On one front, they seek to undermine and reverse current and future policies that would be the building blocks of the 21st century electricity system. On the second front, they are seeking direct subsidies to support their uneconomic assets by jerry-rigging the market process by which resources are acquired and dispatched (see Exhibit ES-4).

EXHIBIT ES-4: THE NUCLEAR INDUSTRY'S BROAD ATTACK ON RENEWABLES

	Federal	States
Direct (Attack Programs that Support Renewables)		
Renewable Energy Production Credit[1]	X	X
Renewable Energy Portfolio Standard[2]	X	X
Efficiency Portfolio Standard[3]	X	X
Net Metering		X
Taxes and Fees[4]	X	X
Indirect (Implement Programs to Support Nuclear)		
EPA Rule Bias[5]	X	X
Wholesale market manipulation		
Above Market/Guaranteed Rates	X	X
Alter dispatch order to favor base load [6]	X	X
Restrict Demand Response[7]	X	X

Notes:
1 General opposition to and specific cutbacks in renewable commitments.
2 Includes shifting from "renewable" to "clean" standard.
3 General opposition to and specific cutbacks in utility efficiency programs.
4 Taxes on renewables, Minimum Offer Price Rules.
5 Allowing subsidies and incentives for nuclear. Giving system benefits for reliability, onsite fuel storage.
6 Must run rules/Take or pay clauses.
7 Opposition to bidding demand response in wholesale markets.

Source: See Section VI, Table V-1 and accompanying text.

The unifying theme of these two attacks is the claim that distributed resources cannot deliver sufficient, reliable power to meet the need for electricity. Section VI shows that the challenge of reliability, far from being the liability that the advocates of the central station model claim it is, can be a major advantage for the decentralized approach because it saves on vital resources.

These points are demonstrated in Section VI by a detailed examination of the key issues in the current debate in two specific examples, nuclear power efforts to obtain subsidies and extend the licenses of existing reactors. The effort to slow the development of alternatives and secure the future of central station baseload power is being pressed by threats to retire a number of the most uneconomic ageing reactors early. The claim is that, if policy makers allow them to retire, both the reliability of the electricity system and the ability to meet carbon emission reductions will be undermined. Careful examination of those claims shows that they are simply false. Detailed analysis of the threat of the closure of a large number of reactors in Illinois shows that under the current rules and given the current assets, the reliability of the system will not be undermined by early retirement. Alternatives will replace the power. A review of the pending license extension for Diablo Canyon shows that there are more than adequate resources to keep the system running and meet carbon reduction goals. These local level findings replicate the national level analysis.

Section VII: Section VII examines two sets of issues that are tangential to the core evaluation of resources and used by opponents of the transformation as diversions. The analysis of subsidies shows that nuclear has been the recipient of much larger subsidies than renewables, with little to show for it. In contrast to nuclear power, renewables have made much more progress, more quickly with much smaller subsidies, and there are good reasons to expect these trends to continue. Subsidizing mature aging reactors is shown to make even less sense than subsidizing the construction of uneconomic new reactors.

Claims by nuclear advocates that nuclear is a clean job creator do not withstand close scrutiny either. The alternatives are preferable from both the macroeconomic and environmental points of view. The number of jobs created by building alternatives to replace nuclear exceeds the number of jobs "lost" due to early retirement over the first half decade. Factoring in decommissioning jobs, there is no net "loss" of jobs for well over a decade. Estimates of the potential for deployment of alternatives would exceed carbon reduction targets by a substantial margin, even if nuclear reactors are retired.

RECOMMENDATIONS

In summary, the 21st century model has strong advantages over the 20th century model in a low carbon environment on every key policy criteria. It has lower resource and total system costs, less investment risk, a larger resource base, yields more macroeconomic benefits and is more environmentally responsible and sustainable. It is the equal of the 20th century model in terms of reliability.

Given the powerful economic trends operating against nuclear and central station power, the retirement of uneconomic aging reactors and the abandonment of ongoing new reactor construction can be a non-event. An orderly exit from nuclear and central station power is not only possible but crucial to ensure a least-cost, low-carbon future that is economically more beneficial, environmentally more responsible and kinder to consumers and the nation.

This analysis leads to three interrelated recommendations for policymakers.

- Policy should move to quickly adopt the necessary institutional and physical infrastructure changes needed to transform the electricity system into the 21st century model.
- Policy should not subsidize nuclear reactors, old or new. In the long run, their large size and inflexible operation make them a burden, not a benefit in the 21st century system.
- Combining the technological characteristics of central station power with the political efforts of central station incumbents to undermine the development of the 21st century system makes them a part of the problem, not the solution.

I. INTRODUCTION

A. PURPOSE

This paper examines the political economy of the ongoing transformation of the electricity sector.[1] It argues that the struggle over the future of the electric utility sector has reached a critical, political phase because the technologies are in hand to replace the 20th century model – powered by large, centralized baseload and peak-load generation that passively follows demand – with a decentralized model that uses advanced intelligence, communications, and control technologies to integrate distributed generation with actively managed demand.

Although distributed technologies have already put a great deal of economic pressure on the 20th century model, centering the electricity system on new technologies with new organizational principles requires a thorough transformation of the physical and institutional infrastructure of the sector. Dominant incumbent interests naturally resist such a transformation since their assets and skill sets do not fit well within the new model and would be significantly devalued if the alternative model were to become dominant. As UBS succinctly put it in a recent report, if the alternatives are allowed to expand and the electricity system is transformed to support their leading role, "Large-scale power generation, however, will be the dinosaur of the future energy system: Too big, too inflexible, not even relevant for backup power in the long run."[2]

In response to the threat of the alternatives, the incumbent interests have launched a "war against the future" on two primary fronts. The two most severely threatened incumbents are grounded in the largest and most inflexible sources of power generation in the 20th century electricity sector: coal and nuclear power. Each has taken a different tack in its resistance to the transformation of the sector.

As the single largest emitter of greenhouse gases both globally and in the United States, coal is saddled with an increasingly desperate fight against climate change policy. Therefore, the burden of resisting the broader transformation of the electricity sector has fallen on nuclear power, which can claim to be a low-carbon resource. However, the campaign to preserve the existing nuclear baseload model is hampered by two factors. Nuclear power is the largest and most inflexible of the central station resources, which makes it incompatible with the alternative technologies and it suffers a severe economic disadvantages that make it unable to compete with low-carbon alternatives.

The conflict between nuclear and the alternatives is not only the most important of the fronts in the war against the future, it also has a long history. An inability to compete has been at the center of the 50-year battle between nuclear power and the alternatives (first coal and gas, now efficiency, renewables, and gas). Today, the fight is over the fundamental structure and organizing principles of the electricity system and the selection of the technologies that will be the core resource on which the sector relies. Thus, today the stakes are much higher than ever.

The current battlefield between nuclear power and distributed alternative energy is focused on the EPA's proposed Clean Power Rule (CPP),[3] although nuclear advocates launched a vigorous assault on alternatives at the federal and state levels several years ahead of the CPP. The EPA CPP has intensified the struggle for three reasons:

- It can be used to obscure the economic fundamentals of resource acquisition.
- It could provide a boost to the transformation process supporting the alternatives.
- It has singled out "at-risk" aging reactors for potential subsidies.

The last point highlights a remarkable turn of events in the history of commercial nuclear power in the United States: the rapidly deteriorating economics of aging reactors. After decades of claiming to be a low-cost source of power because of low operating costs, aging reactors are no longer cost competitive even in that narrow view of operating cost. Not even the full implementation of the EPA Clean Power Rule would save aging reactors from early retirement, so the owners of those reactors have launched a major campaign to increase revenues with direct subsidies from state and federal policymakers and secure Jerry-rigged market pricing rules that undermine alternatives.

This paper shows that the fundamental critiques of new nuclear reactor construction that have been made throughout the history of the commercial nuclear power sector in the United States now apply to aging reactors as well.[4] Nuclear reactors old and new, particularly when they are used as a wedge for fighting the transformation of the electricity sector, are far from a necessary part of a low-carbon solution. On the contrary, nuclear power, with its war against the transformation of the electricity system, is part of the problem, not the solution.

Although the speed and extent of the transformation of the electricity sector will be decided by the political struggle between advocates of central station technologies and the alternatives, the driving force for change is economic. This paper examines the economic fundamentals underlying the transformation and conflict between the 20th and 21st century models of the electricity sector.

B. OUTLINE

The paper is divided into three parts.

Part I examines the "basic" economics of developing electricity resources. It shows that the economics strongly favor distributed resources and the transformation of the system.

- Section II examines generation resources. Resource acquisition begins with estimates of how much it will cost to produce electricity over the life of a facility. The section examines energy efficiency as a resource on equal footing with generation. The calculation is never simple, however. To ensure the cost estimates are comparable, the analysis uses levelized cost.
- Section III examines the economic risks associated with the various low-carbon resources. It shows that nuclear reactors old and new have higher risks than the alternatives. It also shows that the alternative are far more attractive from the point of view of environmental impacts.

A resources is not a system and resource costs are not the only consideration in building a resources portfolio or a system. Part II addresses two other key questions in building the 21st century electricity system.

- Section IV, addresses the question of whether the resource base is adequate to provide a long-term stable basis for the alternative model.
- Section V discusses the key challenges of deploying a 21st century electricity system, focusing on the issue of reliable power, which is the main focal point of the nuclear war against the future.

Part III analyzes the current battle between central station and alternative generation by examining key issues through the lens of ongoing efforts by nuclear advocates to increase their subsidies and reverse policies that support alternatives.

- Section VI examines the attack on alternatives through two case studies – the threat to precipitously retire ageing reactors and the extension of licenses for existing reactors – with respect to the reliability and carbon emission reductions.
- Section VII examines two diversionary tactics in the battle being waged by nuclear advocates in the "war against the future," the skirmish over subsidies, the potential impact on jobs and the ability to meet the goals of carbon reduction.

C. FINDINGS

1. Part I: Resource Economics

Section II: The dramatic technological development of the past two decades has expanded the range of options available to meet the need for electricity in a low carbon environment. Wind is now cost competitive with natural gas, solar is rapidly becoming so, and storage technologies are rapidly advancing to reinforce this trend. Efficiency has long been the least cost resource. Efficiency improvements that cost less than adding new supply can cut demand by 20-30% in the mid-term. In contrast, construction of new nuclear reactors has continued it historic pattern of escalating construction cost, to the point where it is substantially more costly than the available alternatives. The operating costs of aging nuclear reactors have also been afflicted by the cost escalation disease.

Section III: The economic characteristics of the alternatives – size, construction period and cost – combine to make them much more attractive from the point of view of risk. A portfolio approach to acquiring low carbon resources that minimizes risk or price leaves nuclear power out of the mix. Reliance on efficiency and renewables is also far more environmentally benign.

2. Part II: Building the 21st Century Electricity System

Section IV shows that the technical resource base on which the 21st century electricity system would rely is huge. Converting technical potential into resource portfolio and a working system is the challenge for policy. The short term projection of several financial analyses and the long term “vision” scenarios of U.S. Department of Energy studies reflect strong consensus in the financial, academic and trade literatures that the conversion of the technical potential and the building of the system is economically feasible.

Section V: The trade and financial literature and real world experience indicate that the tools are in hand to integrate the alternative new resources using advance information, communications and control technologies that actively manage supply and demand. The existing system can handle penetration of alternatives to 30% - 40% with no negative impact on reliability. A wide range of measures to support the penetration of alternatives to much higher levels of penetration (in the range of 80% or more) has been identified. Adopting policies to build an electricity system on principles of dynamic flexibility represents an institutional transformation that requires new physical infrastructure.

3. Part III: The Nuclear War against the Future

Part III of the analysis examines the reaction of central station utilities to the powerful technological development of alternatives. Not surprisingly, utilities that are deeply invested in large central station generation see this potential development as a severe threat to their interest and they have responded by launching an all-out attack on the alternatives with two fronts.

Section VI describes the efforts of the incumbent utilities to slow the alternatives at the federal and state levels, while they seek subsidies for their preferred resources. Following from the earlier analysis, it shows that the challenge of reliability, far from being the liability that the advocates of the central station model claim it is, can be a major advantage for the decentralized approach because it saves on vital resources.

Section VII examines the issue of subsidies, showing that nuclear has been the recipient of much larger subsidies, with little to show for it. In contrast, renewables have made much more progress, more quickly with much smaller subsidies, and there are good reasons to expect these trends to continue. Subsidizing mature aging reactors is shown to make even less sense than subsidizing new reactors. Section VII also shows that claims by nuclear advocates that nuclear is a job creator that is indispensable to meeting the carbon reduction goal do not withstand close scrutiny. The number of jobs created by building alternatives to replace nuclear exceeds the number of jobs “lost” due to early retirement over the first half decade. Factoring in decommissioning jobs, there is no net “loss” of jobs for well over a decade. Estimates of the potential for deployment of alternatives would exceed carbon reduction targets by a substantial margin, even if nuclear reactors are retired.

4. Recommendations

Given the powerful economic trends operating against nuclear power, the retirement of uneconomic aging reactors and the abandonment of ongoing construction of new reactors can be a non-event. An orderly exit from nuclear power is not only possible but crucial to ensure a least-cost, low-carbon future that is economically more beneficial and environmentally kinder to consumers and the nation.

This analysis leads to three interrelated recommendations for policymakers.

- Policy should move to quickly adopt the necessary institutional and physical infrastructure changes needed to transform the electricity system into the 21st century model.
- Policy should not subsidize nuclear reactors, old or new. In the long run, their large size and inflexible operation makes them a burden, not a benefit in the 21st century system.
- Combining the technoeconomic characteristics of central station technologies with the political efforts of the incumbents to undermine the development of the 21st century system makes them a part of the problem, not the solution.

PART I. RESOURCE ECONOMICS

II. ECONOMICS OF LOW-CARBON RESOURCES

A. THE FLASHPOINT OF TRANSFORMATION: OPERATING COSTS AND MERIT ORDER DISPATCH

The flashpoint of the conflict over the transformation of the electricity sector has been widely recognized in the industry and among analysts. It centers on the market clearing price of electricity in those areas where markets, as opposed to regulators, set that price.

The 20th century electricity industry relied on baseload facilities that had to run constantly to meet off-peak demand. Rather than store electricity itself, which was costly, utilities chose to meet higher demand (shoulder and peak) by storing raw energy that could be used to quickly generate electricity (primarily fossil fuels like natural gas and diesel, but also a small amount of water pumped above a generator). For fossil-fuel peak power, operating costs were high, but capital costs were low, so it made sense to run these facilities for a small number of peak hours. By allowing peak prices to skyrocket (known as hockey-stick price increases) and paying those prices to all generators, scarcity rents were created that could be used to pay the high capital cost of baseload facilities.[5] Where prices were set by regulators, they were put far above marginal costs for the same reason.

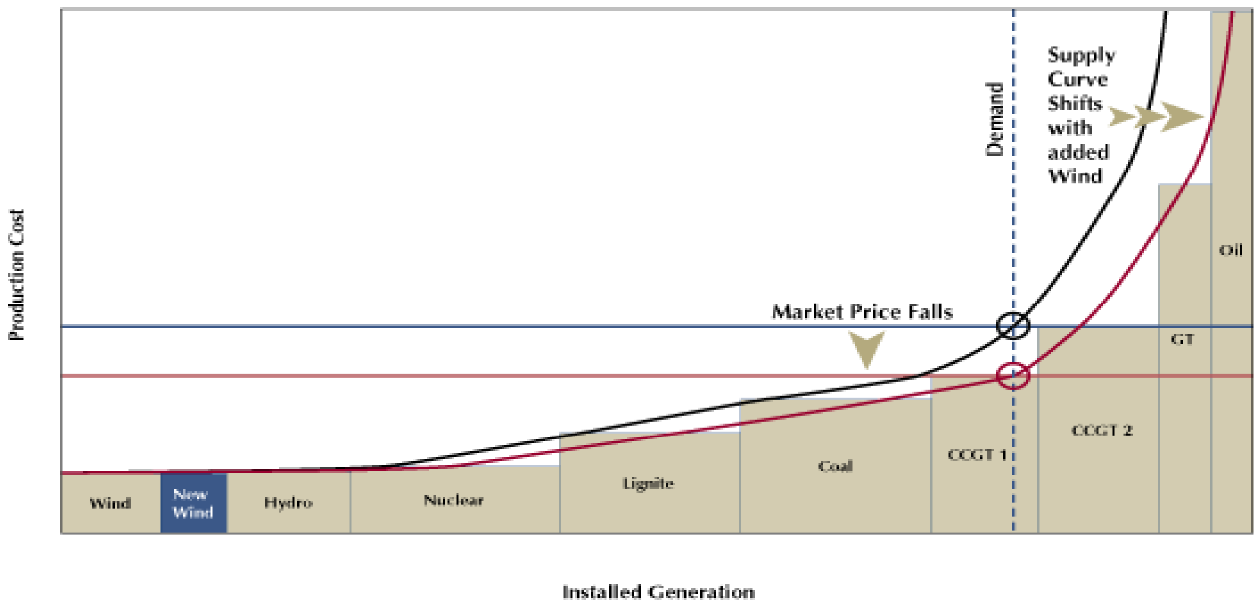
Over the past two decades it has become much more costly to meet demand in the old way. First, diesel became expensive and volatile. Second, the social costs of fossil fuels have been recognized. Third, carbon emissions have become a major concern. The search for low-carbon alternatives to replace coal baseload generation has unleashed a wave of innovation. Innovation has led not only to a dramatic lowering of the cost of renewable alternatives, but also to the use of resources that are likely to be dispatched on-peak because they have very low operating costs. As these resources come online, they shift the supply curve, putting downward pressure on the market clearing price and the scarcity rents available for capital recovery.

Figure II-1 is taken from a recent analysis by a group advocating for nuclear power. It shows how the addition of wind lowers the market clearing price, which is undermining the economics of aging nuclear reactors. In the "merit order effect," an effect that has been documented in every nation in which the use of wind has increased significantly,[6] wind backs inefficient natural gas (and some coal) plants out of the supply needed to clear the market at the peak. This lowers the market clearing price. The upper graph shows the current situation as lamented by the nuclear industry. The downward pressure on market clearing prices has led to a number of years of losses for the aging, high-cost nuclear reactors. They cost more to run than the alternatives, so they cannot cover their operating costs or make any contribution to their capital costs

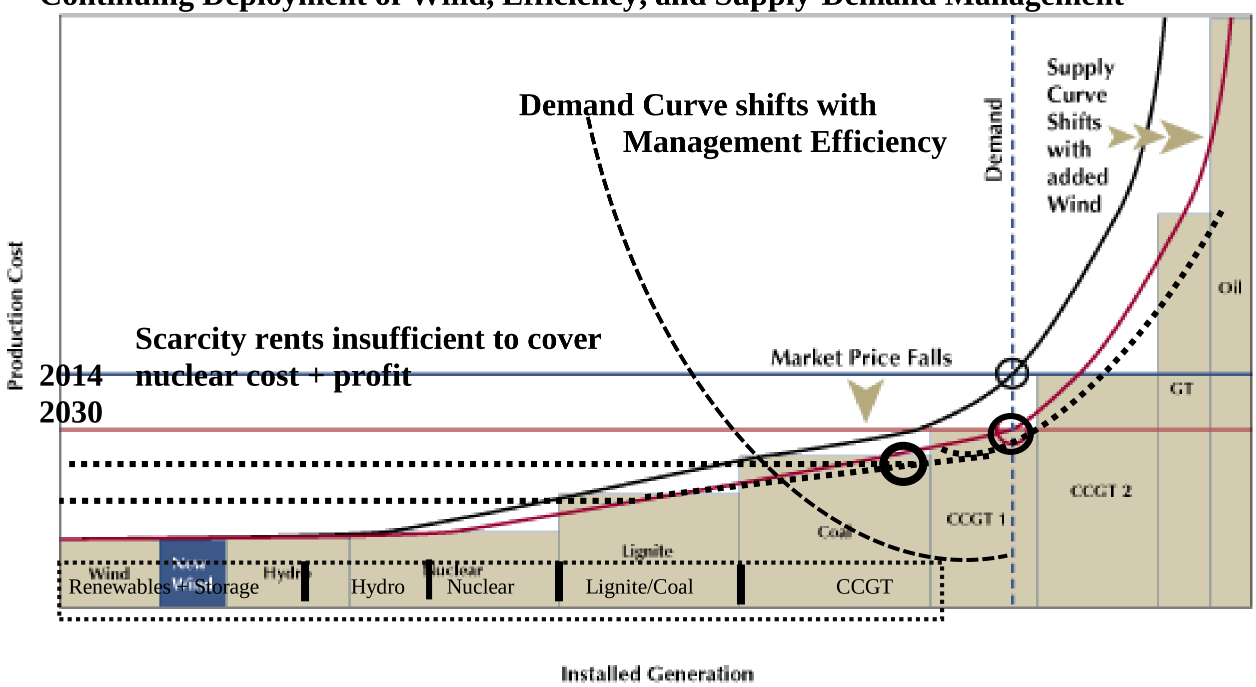
The lower graph shows the potential impact of continuing deployment of low-cost renewables and the development of a 21st century low-carbon electricity system. Renewables squeeze out more fossil fuels. Efficiency lowers demand, and demand management makes demand more responsive at the peak. The market clears at a lower price. A utility sector that moves toward a more diversified, distributed resource base and directly addresses the storage issue will put further pressure on high capital cost resources. The process of innovation for distributed alternatives such as wind and efficiency is advanced while for solar it is midstream. For others, like storage, it is just beginning. The pressure will continue to mount.

FIGURE II-1: THE MERIT ORDER EFFECT OF ADDING NEW WIND CAPACITY ON PEAK PRICES

Current Wholesale Market



Continuing Deployment of Wind, Efficiency, and Supply-Demand Management

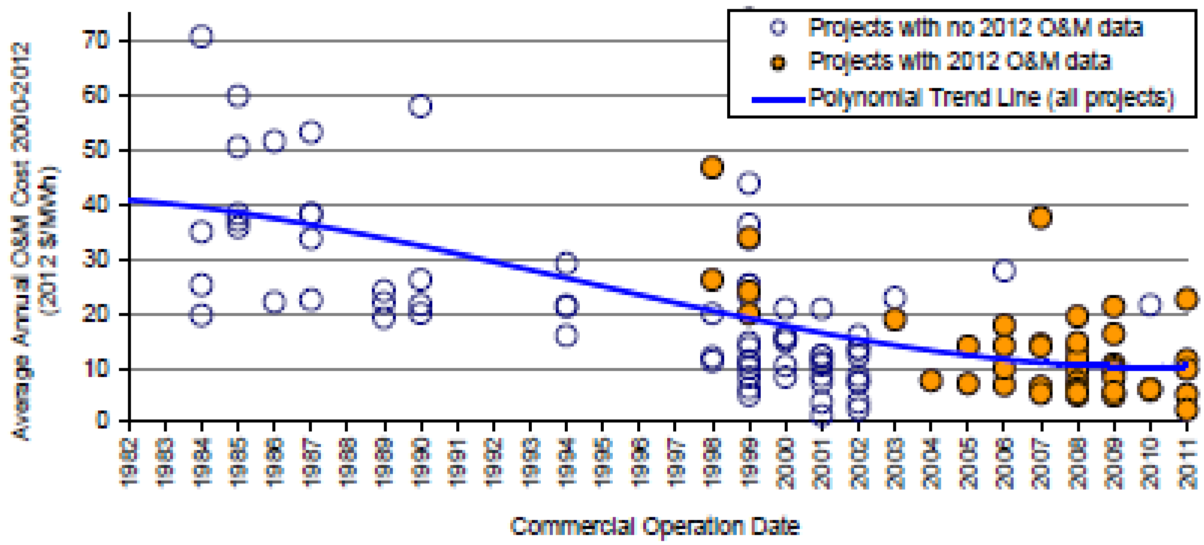


Source: Doug Vine and Timothy Juliant, 2014, *Climate Solutions: The Role of Nuclear Power,* Center for Climate and Energy Solutions, April, p. 6, with author's additions.

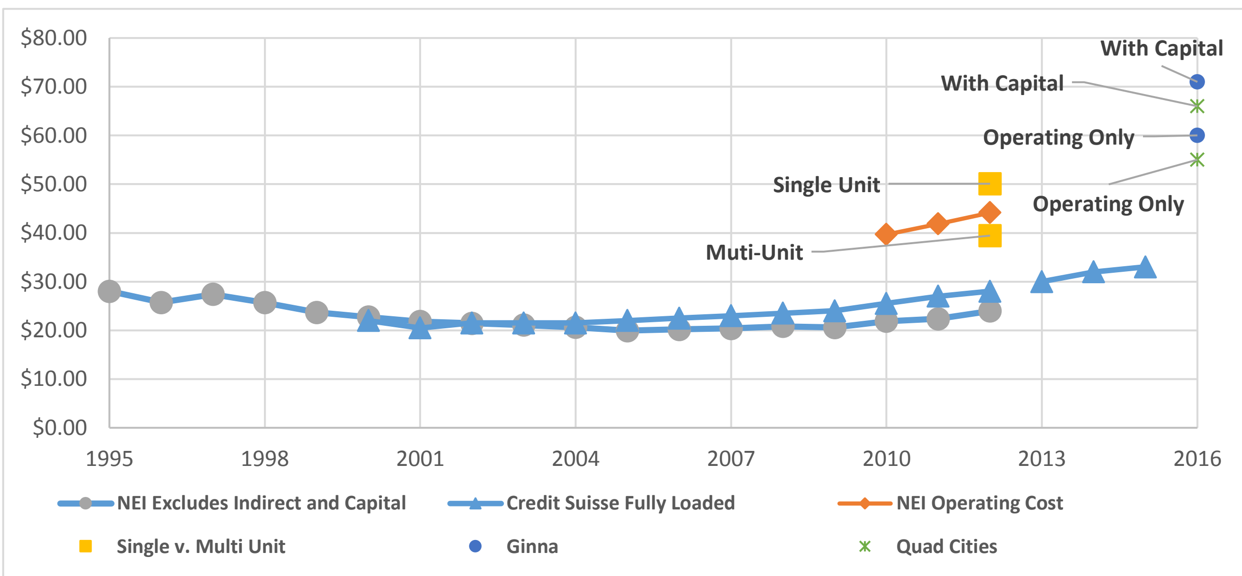
The "merit order" predicament in which nuclear power finds itself is deeply ironic. Historically, nuclear power represented itself as a low-cost option by emphasizing low operating costs and downplaying its very high fixed, capital costs. As shown in Figure II-2, dramatic increases in nuclear operating costs and reductions in the cost of alternative technologies have unmasked that sleight of hand.

FIGURE II-2: AVERAGE O&M COASTS ($/MWH)

Wind



Nuclear



Sources: NEI Operating Cost (Nuclear Street News Team. "NEI Lays Out the State of Nuclear Power." Nuclearstreet.com. February 26, 2014); NEI Excludes Indirect (Nuclear Energy Institute, Operating Costs, http://www.nei.org/Knowledge-Center/Nuclear-Statistics/Costs-Fuel,-Operation,-Waste-Disposal-Life-Cycle/US-Electricity-Production-Costs-and-Components); Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality*, February 19, 2013, p. 9; Naureen S. Malik and Jim Poulson, "New York Reactors Survival Tests Pricey Nuclear," *Bloomberg*, January 5, 2015, p. 2. Quad Cities is based on a $580 million subsidy (Steve Daniels, "Exelon Puts an Opening Price Tag on Nuclear Rescue: $580 Million," *Crains Chicago Business*, September 24, 2014), converted to $25/MWH for output at risk reactors. Illinois Commerce Commission, Illinois Power Agency, Illinois Environmental Protection Agency, Illinois Department Commerce And Economic Opportunity, 2015, *Response To The Illinois General Assembly Concerning House Resolution 1146*, January 5, real price increase to break even, plus $11/MWH for capital.

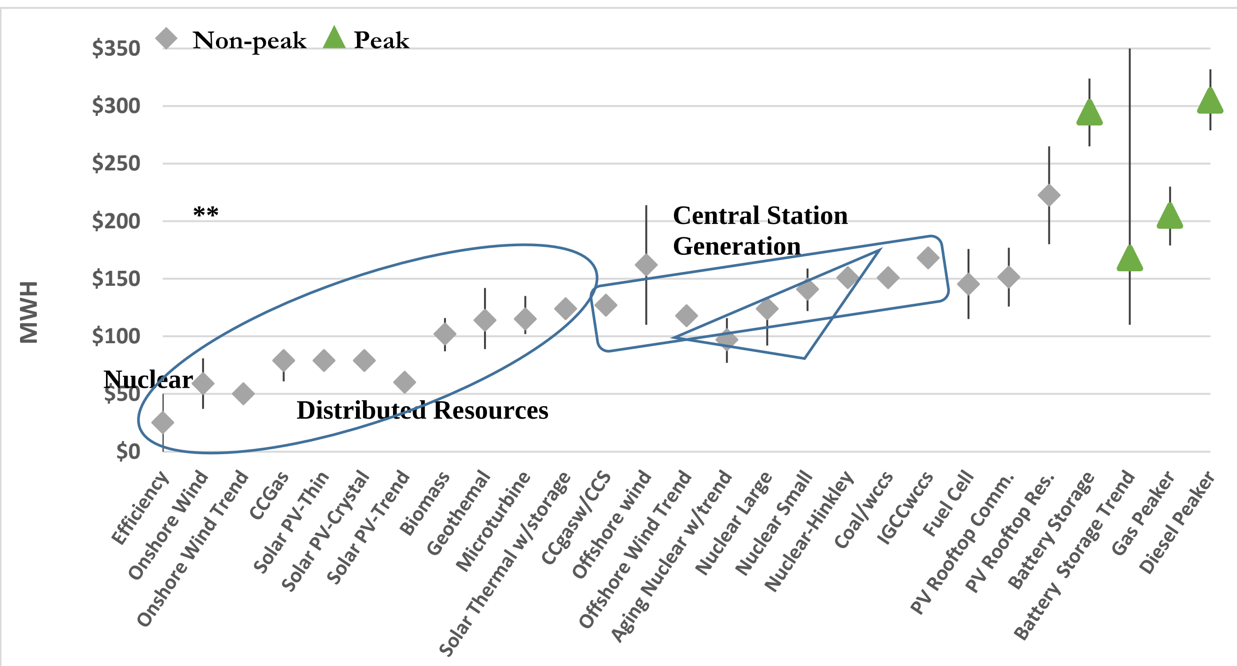
In contrast to the increasing operating costs of nuclear reactors, operating costs for wind have been declining. In the mid-1990s nuclear reactors would have been dispatched before wind with a substantial operating cost advantage. Two decades later, wind has a substantial advantage which is likely to grow in the years ahead. Thus, it is not coal, gas, and subsidies that are giving aging nuclear reactors heartburn, it is the superior economics of wind and efficiency combined with the increasing operating costs of aging nuclear reactors that has made the aging reactors uneconomic.

The lower graph in Figure II-2 includes estimates for the cost of keeping aging reactors online. Ginna is a New York reactor and Quad Cities is a two-reactor site in Illinois for which Exelon has stated specific revenue increases are needed, although these estimates are shrouded in uncertainty.[7] The operating costs are quite high and total costs are higher still, well above recent market clearing prices. In the near term, the subsidy necessary to keep these aging reactors online is substantial but will vary from market-to -market. Operating costs alone are almost twice the current market clearing price of electricity and, as the discussion below shows, things are likely to get worse rather than better over time.

B. Full (Levelized) Cost

While the merit order effect has an important impact once renewables are deployed, it is not the primary cause of the underlying deployment. If renewable resources were at a severe cost disadvantage, it is unlikely they would have gained sufficient market share to so dramatically affect market clearing prices. Declining total (levelized) costs are the ultimate driver of change. Figure II-3 combines the results of the two most recent estimates of levelized cost of electricity from Lazard to underscore this point.

Figure II-3: Levelized Cost (LCOE) of Low Carbon Options with Trends



Source: ***Lazard's Levelized Cost of Energy Analysis – Version 8.0, Version 7.0.***

Needless to say there are several such estimates available.[8] I choose Lazard as a single source for this discussion to preserve consistency in assumptions and because I believe the Lazard analysis is superior to most and provides the basis for important and useful observations.

- From the outset, the Lazard analysis included efficiency, which is the least cost resource by far. None of the other major studies of electricity resources do this.
- Lazard's was among the first of the comprehensive analyses to note the strong downward trend in the cost of solar and to begin arguing that solar was cost competitive in some major markets and for peak power. As discussed below, many have joined Lazard in projecting that solar will be broadly cost competitive with natural gas by the middle of the second decade of the 21st century, if not sooner.
- The Lazard analysis always included estimates for coal with carbon capture and storage and has recently added an estimate for the cost of natural gas with carbon capture and storage.
- The most recent analysis adds important storage technologies, utility scale solar with storage, and utility scale battery storage. It also presents a cost trend for storage that is similar to the trends from other sources.
- The current analysis presents "unsubsidized" costs strictly for generation (no transmission, system integration, or waste disposal and decommissioning).
- The analysis always included natural gas peaking capacity costs and, in a recent analysis, added a cross-national comparison of technologies that might displace gas as the peaker resource.

To ensure an apples-to-apples comparison, I highlight Lazard's mid-point, unsubsidized cost projection and compare it to the other mid-points, unsubsidized. I also present the range. I have included trend projections for solar, wind, and storage (from Lazard). For storage I use Lazard as the point estimate, an upper bound from the Brattle Group, and a lower bound from Navigant.[9]

I have included three additional estimates of nuclear costs. Because Lazard continues to use a construction period of just under six years — the U.S. average was 10 and the reactors currently under construction are well past six — I include two other estimates of the cost of power from new nuclear reactors. The official cost of the U.K. Hinkley reactor provides an estimate that reflects the higher cost projections of current technologies.[10] I then include my estimate of the long-run cost of Small Modular Reactors, which have recently received a lot of attention.[11] Finally, I include an estimate of the cost of power from aging reactors for the mid-term based on the most costly (Ginna) and least costly (Byron) estimates for the at-risk reactors. The estimate incorporates the underlying cost escalation assumed by Credit Suisse in its study of aging reactors.[12]

Figure II-3 delivers a message that has been clear to energy analysts for quite some time. There are a number of alternatives that are likely to be competitive with natural gas-fired generation. Therefore, many alternatives are likely to be considerably less costly than nuclear, even in a low-carbon environment. Efficiency and wind are already less costly than aging reactors. Solar is likely to join that club in the near future, as are several other technologies that play a smaller role in the resource debate (biomass, geothermal, microturbines). Unabated gas is much less costly, while gas with carbon capture and storage is competitive with new nuclear.

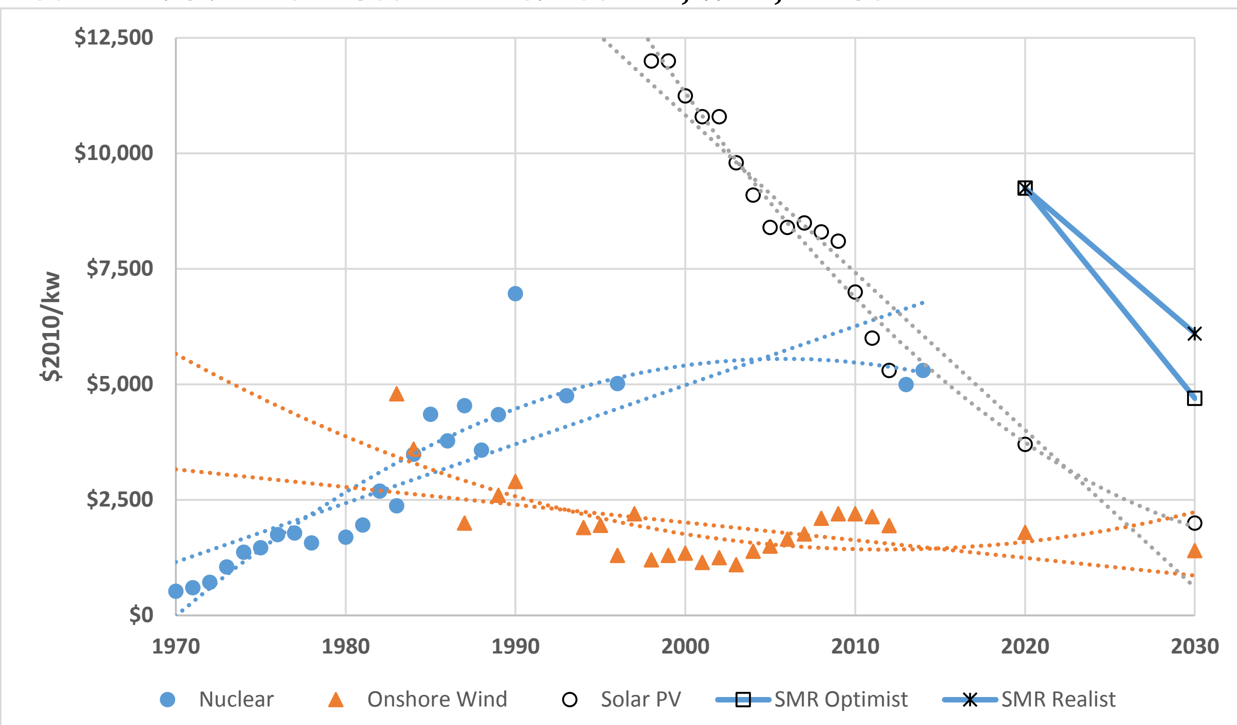
The EPA's Clean Power Rule focuses its attention on unabated gas, efficiency, and non-hydro renewables, which are clearly lower in cost than nuclear.

Figure II-3 also reminds us that reducing peaks is a very valuable undertaking since peaking power is so costly and tends to be fossil fuel-fired. This is the reason that storage, which had not been a focal point of investment and innovation, is now such a hotbed of activity.

C. KEY COST TRENDS

The economic characteristics of the mid-term options behind the energy cost analysis in Figure II-3 reflect dramatic technological and economic developments over the course of the past two decades. Figure II-4 shows long-term cost trends for three of the most frequently discussed supply-side, low-carbon options: nuclear, wind, and solar.

FIGURE II-4: OVERNIGHT COST TRENDS: NUCLEAR, WIND, AND SOLAR



Sources: Galen Barbose, Naïm Darghouth, Samantha Weaver, and Ryan Wiser, 2013, *Tracking the Sun VI: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2012*, Lawrence Berkeley National Laboratory, July; Ryan Wiser, Mark Bolinger, 2013, *2012 Wind Technologies Market Report*, U.S. Department of Energy, August; Mark Cooper, 2014, Small Modular Reactors and the Future of Nuclear Power in the United States," *Energy Research & Social Science*, 3.

The economic competitiveness of renewable resources reflects technological and economic progress. Wind already exhibits much lower overnight costs than nuclear and solar will in the near term. Declining construction costs are reinforce by rising capacity factors. For wind, utilization has increased dramatically and achieved capacity factors above 50 percent in some cases, with costs per kilowatt hour plummeting as the result of increasing tower height, longer and larger blades, better gearbox reliability, material optimization, and more efficient computer programming.[13] The long-term declining cost trend for solar has been driven by both economies of scale and innovation. Each of these factors has made a substantial contribution to declining cost and both are likely to continue to do so.[14] Solar costs have been falling because of economies of scale in production, reduced utilization of key component materials, increasing cell efficiency, and other system cost savings and streamlining of siting, all of which have lowered the cost of capital. [15]

Storage is projected to be the least cost-peaking power source, just 10 percent more costly than the higher nuclear projections.[16] Rapid declines in storage costs reinforce the importance of rapid declines in renewable costs as low-cost storage can dramatically boost the effective load factor of renewables. Lazard's estimate of a rapid decline in storage costs is consistent with other estimates.[17]

Although important local conditions can affect the cost estimates of power from alternatives — such as the richness of wind and solar resources — the broad technology cost trends tend to be global because technology is exportable. In fact, as shown in the upper graph of Figure II-5, declining costs abroad have been greater than those in the United States despite the fact that the United States has richer resources. For example, solar costs declined almost twice as fast in Germany as in the United States after Germany made a strong commitment to increase reliance on renewables and decrease reliance on nuclear. As shown in the lower graph of Figure I-5, cost trends for wind and solar in South Africa exhibit a similar pattern.[18]

In contrast to the non-hydro renewables, over the course of 50 years of commercial nuclear power in the United States, construction costs have risen persistently without any indication of abatement. Small modular reactors (SMRs), which have been touted as the next big thing to save nuclear power, are likely to be much more costly than the renewables. Investment in SMRs has collapsed, with both Westinghouse and B&W, the two largest firms pursuing the technology in the United States, throttling investment.[19]

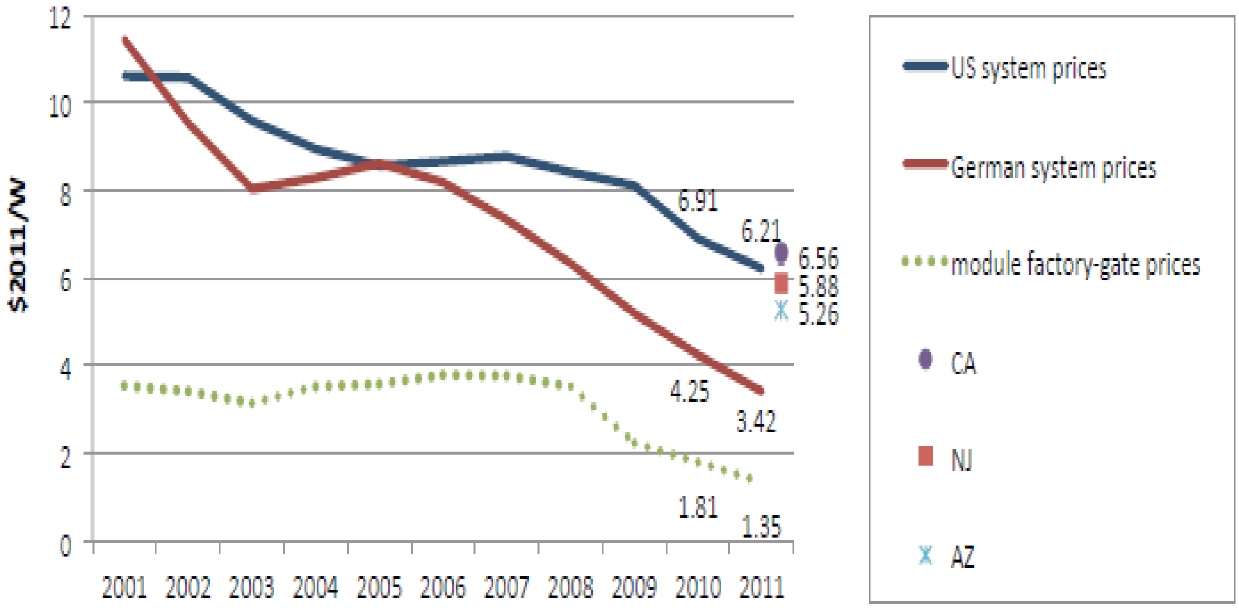
The combined effect and pay-off of the rapid improvement in technologies resulting in declining operating, construction and life cycles costs is to deliver much lower cost, low carbon energy to the market. As Figure II-6 shows, there has been a strong downward trend in purchased power agreement prices. The Figure is constructed to align the dates, which shows that the break point came in 2009. We observe wind and solar price declines of 50% in half a decade. Recent wind prices are in the range of \$20-\$40/kwh; solar prices are in the range of \$50-\$80/kwh.

In an analysis that projects renewables will account for the overwhelming majority of U.S. capacity addition in the next decade, Credit Suisse notes that the prices being paid in Purchased Power Contracts (PPAs) are already lower than the numbers used in Figure II-3 above, making them cost competitive with conventional generation options.

> Renewables are cost competitive to even cheap against conventional generation. The clearing price for new wind and solar continues to fall with improvements in utilization and falling capital costs. For wind we are seeing utilization rates 15–20 percentage points higher than 2007 vintage turbines, regularly supporting PPA pricing at or below \$30/MWH that effectively 'creates' long-term equivalent natural gas at <\$3/MMBtu. Lower capital costs for solar have dropped PPA pricing to \$65–80/MWH from well over \$100/MWH, making solar competitive with new build gas peaking generation.[20]

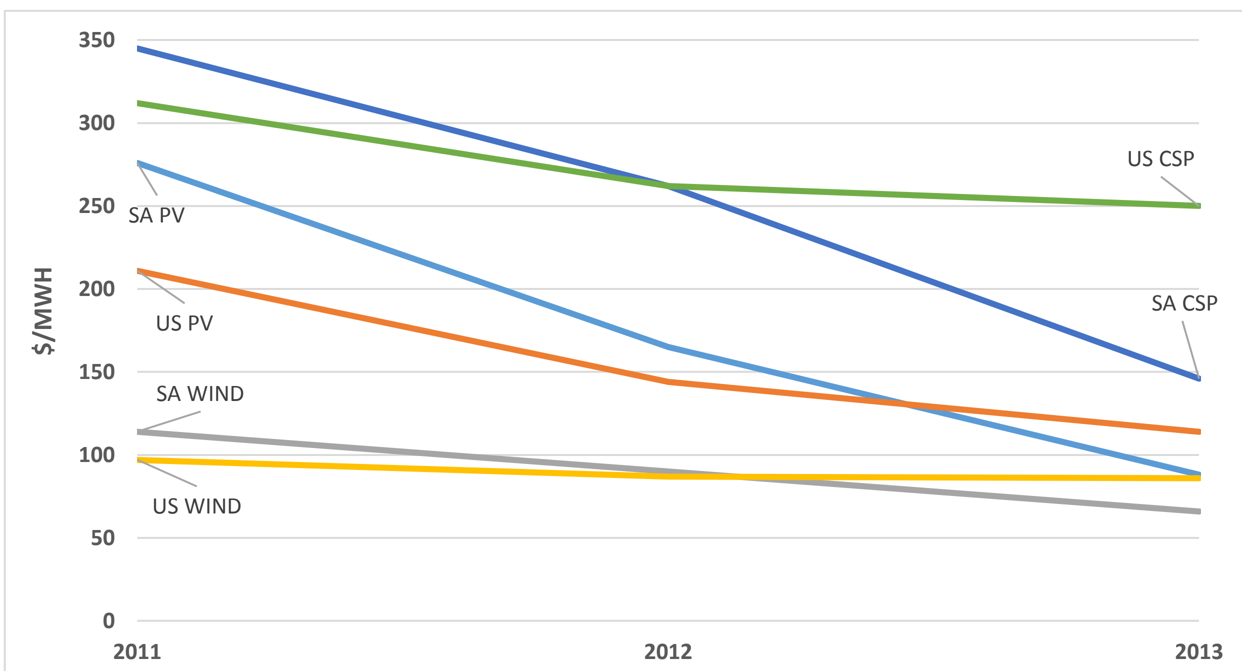
FIGURE II-5: CROSS-NATIONAL COMPARISON OF RENEWABLE COST TRENDS

Median Installed Price of Customer-Owned PV Systems ≤10 kW: U.S. v. Germany



Source: Joachim Seel, Galen Barbose, and Ryan Wiser, *Why Are Residential PV Prices in Germany So Much Lower Than in the United States?*, February 2013, U.S. Department of Energy, SunSpot, p. 9.

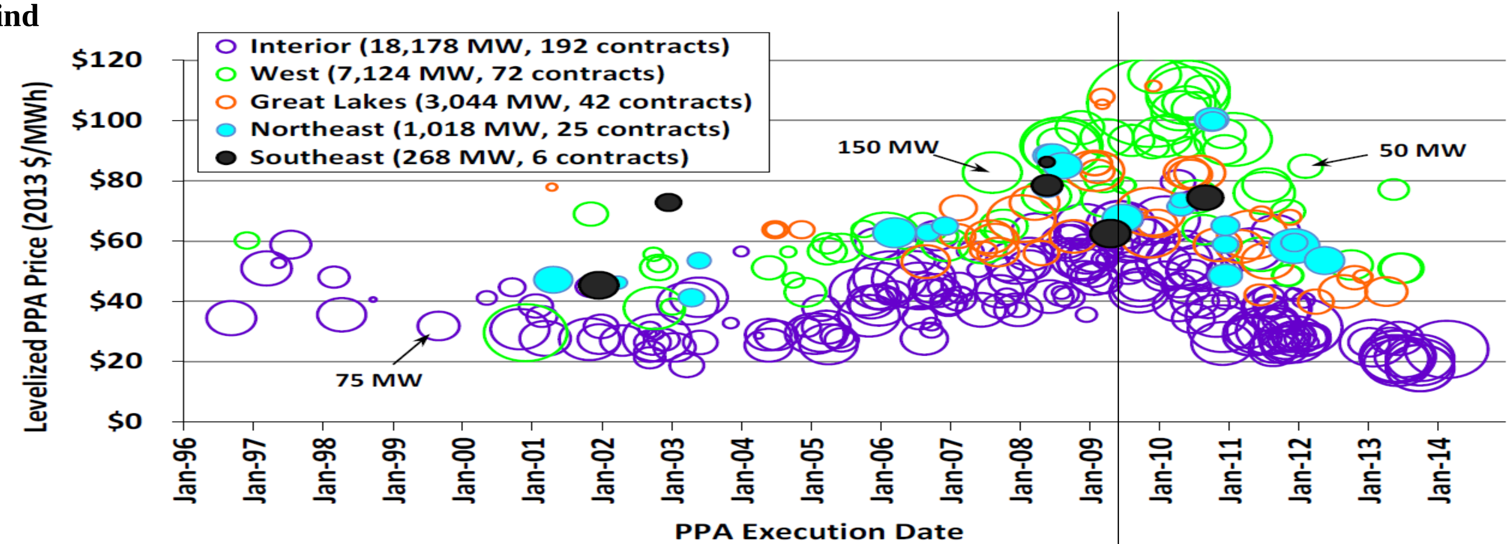
South Africa Bid Prices v. U.S. EIA Cost Projections



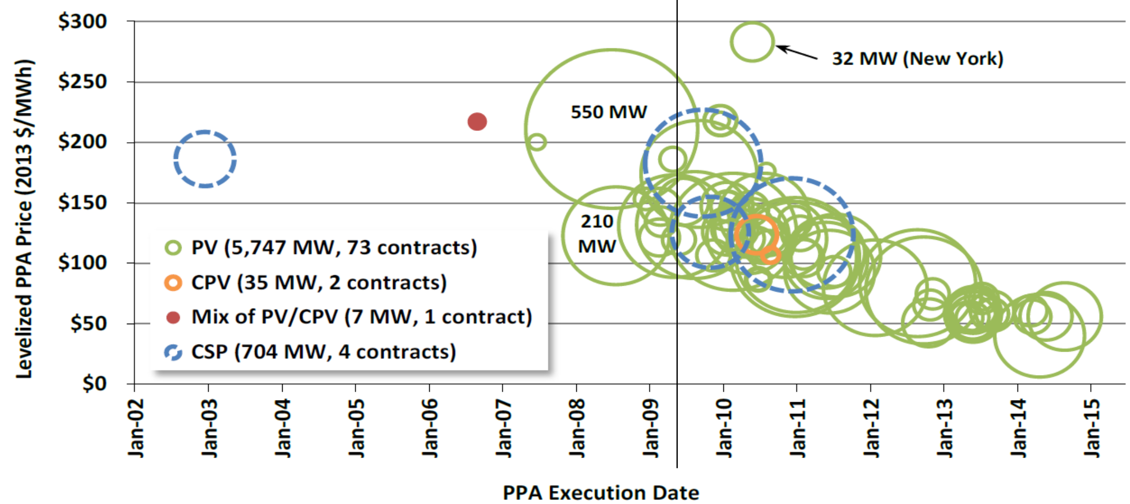
Source: David Richard Walwyn and Alan Colin Brent, "Renewable Energy Gathers Steam in South Africa," *Renewable and Sustainable Energy Reviews*, 41 (2015)

FIGURE II-6: WIND AND SOLAR PURCHASE POWER AGREEMENT PRICEA ACROSS TIME

Wind



Solar



Sources: U. S. Department of Energy, *2013, Wind Technologies Market Report,* p. 58; Sunspot, *Utility Scale Solar*, 2013, p. 28

Wind and solar not only costs substantially less than power from new nuclear reactors, they are less costly than power from aging reactors. The market fundamentals on the supply-side are running strongly against nuclear power.

D. EFFICIENCY AS A RESOURCE

In the above analysis of cost, efficiency is the least costly resource that anchors the supply-curve of low-carbon resources. Yet, as noted, most analyses of levelized cost of resources focus on generation alternatives and do not include efficiency. The cost of efficiency deserves much more attention. This section explains the availability of efficiency as a resource to meet the need for electricity in a low-carbon environment by examining why untapped opportunities to invest in efficiency are available and how much efficiency costs. The next section examines how much of the resource is available.

1. Market Imperfections and Barriers as the Cause of the Efficiency Gap

To recognize efficiency as a low-carbon resource I turn to a phenomenon that economists, engineers, and policy analysts have for 30 years described as the "energy paradox" or "efficiency gap."[21] Engineering/economic analyses showed that technologies exist to potentially reduce the energy use of consumer durables (from lightbulbs to air conditioners, water heaters, furnaces, building shells, and automobiles) and producer goods (motors, HVAC, and heavy duty trucks). Because the reduction in operating costs more than offsets the initial cost of the technology, resulting in substantial potential net economic benefits, we confront the paradox: "Why don't consumers purchase more economically efficient durable goods that result in net economic savings?"

The answer to the question is well documented in hundreds (if not thousands) of empirical studies. Energy markets are imperfect and riddled with barriers and obstacles to efficiency, especially in the electricity sector. Market imperfections lead to underinvestment in energy-saving technologies. McKinsey & Company offered the following framing in a series of analyses addressing various aspects of the ongoing transformation of the electricity sector.

> The highly compelling nature of energy efficiency raises the question of why the economy has not already captured this potential, since it is so large and attractive. In fact, much progress has been made over the past few decades throughout the U.S., with even greater results in select regions and applications. Since 1980, energy consumption per unit of floor space has decreased 11 percent in residential and 21 percent in commercial sectors, while industrial energy consumption per real dollar of GDP output has decreased 41 percent. As impressive as the gains have been, however, an even greater potential remains due to multiple and persistent barriers present at both the individual opportunity level and overall system level. By their nature, energy efficiency measures typically require a substantial upfront investment in exchange for savings that accrue over the lifetime of the deployed measures. Additionally, efficiency potential is highly fragmented, spread across more than 100 million locations and billions of devices used in residential, commercial, and industrial settings. This dispersion ensures that efficiency is the highest priority for virtually no one. Finally, measuring and verifying energy not consumed is by its nature difficult. Fundamentally, these attributes of energy efficiency give rise to specific barriers that require opportunity-specific solution strategies and suggest components of an overarching strategy.[22]

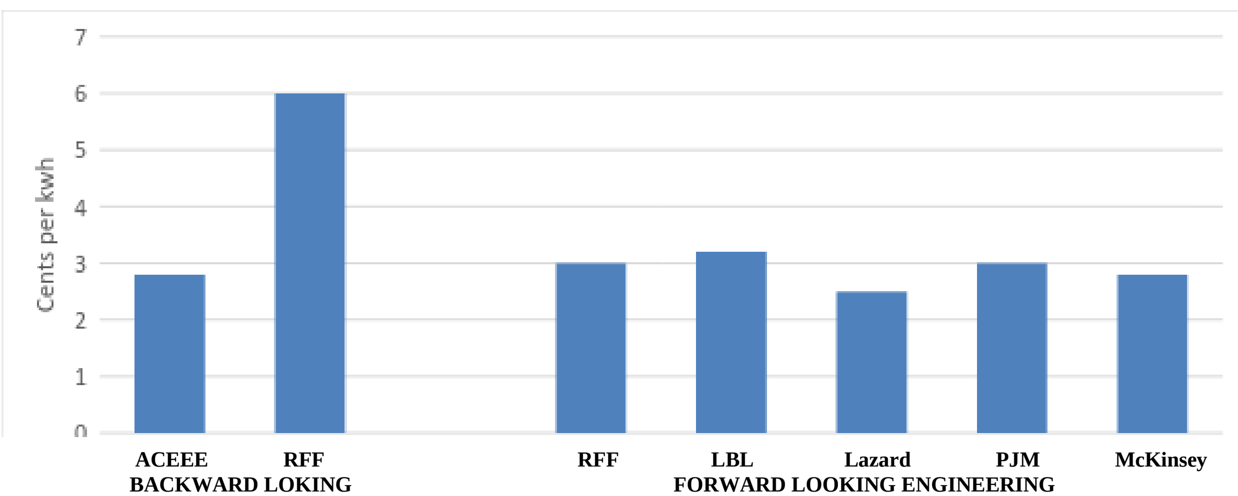
Even in the industrial sector, where firms are considered to be motivated primarily by economic profitability incentives, the efficiency gap is evident. A recent United Nations Industrial Development Organization (UNIDO) review of 160 studies of industrial energy efficiency investments framed the analytic issues by posing and answering key questions in exactly the same way as McKinsey and Company.[23] I have discussed at length the specific factors and processes that create the efficiency gap.[24] Treating the efficiency gap as real, I focus on the question of how much it costs to save energy and how much can be saved.

2. The Cost of Saved Energy

The engineering economic analyses that provided the initial evidence for the efficiency gap showed that saving energy was significantly less costly than consuming it. *Ex ante* analyses indicated that there would be substantial net benefits from including technologies to reduce energy consumption in durable goods. As policies to spur investment in and deployment of energy-saving technologies were implemented, *ex post* analyses were conducted to ascertain whether the *ex ante* expectations were borne out. Those analyses strongly support the *ex ante* engineering analyses, as shown in Figure II-1.

Several efforts to look back at achieved costs conclude it is well below the cost of energy, including estimates from Resources for the Future and the U.S. Department of Energy. The forward-looking estimates from research institutions such as Lawrence Berkeley Labs and McKinsey & Company are similar. In fact, utilities and Wall Street analysts use similar estimates.

FIGURE II-7: THE COST OF SAVED ELECTRICITY



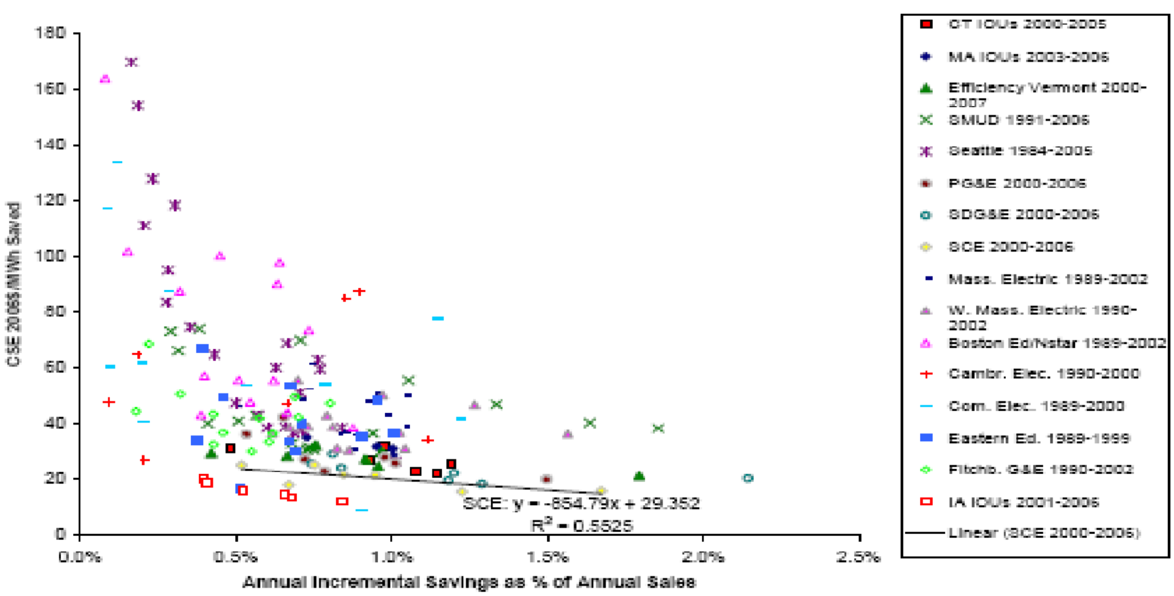
Sources: Kenji Takahasi and David Nichols, "Sustainability and Costs of Increasing Efficiency Impact: Evidence from Experience to Date," *ACEEE Summer Study on Energy Efficient Buildings* (Washington, D.C., 2008), pp. 8–363, McKinsey Global Energy and Material, *Unlocking Energy Efficiency in the U.S. Economy* (McKinsey & Company, 2009); National Research Council of the National Academies, *America's Energy Future: Technology and Transformation, Summary Edition* (Washington, D.C.: 2009). The NRC relies on a study by Lawrence Berkeley Laboratory for its assessment (Richard Brown, Sam Borgeson, Jon Koomey, and Peter Biermayer, *U.S. Building-Sector Energy Efficiency Potential* (Lawrence Berkeley National Laboratory, September 2008).

The most intense and detailed studies were conducted by utilities subject to regulation. Figure II-8 shows the results of analyses of the cost of efficiency in 16 states over various periods covering the last 20 years. The data points are the annual average results obtained in various years at various levels of energy savings. The graph demonstrates two points that are important for the current analysis.

- The vast majority of costs fall in the range of $20/MWH to $50/MWH (i.e., 2 to 5 cents/kwh). The average is about $27/MWH, consistent with the estimate in Figure II-3, above.
- The higher the level of energy savings, the lower the level of costs. There is certainly no suggestion that costs will rise at high levels of efficiency.

While the aggregate data in Figure II-8 appear to suggest a very strong downward trend, the data for individual utilities suggest a moderate downward trend. Figure II-8 shows the trend line for one individual utility. The trend is very slightly negative. The authors suggest that declining costs for higher levels of efficiency can be explained by economies of scale, learning, and synergies in technologies.[25] As utilities implement more of the cost-effective measures, costs decline. In addition, when technical potential is higher than achievable savings then economies of scale, scope, and learning can pull more measures in without raising costs. This analysis supports the assumption that the cost of efficiency will not increase in the mid-term.

FIGURE II-8: UTILITY COST OF SAVED ENERGY (2006$/MWH) VS. INCREMENTAL ANNUAL SAVINGS AS A PERCENT OF SALES



Source: Kenji Takahasi and David Nichols, "Sustainability and Costs of Increasing Efficiency Impact: Evidence from Experience to Date," *ACEEE Summer Study on Energy Efficient Buildings* (Washington, D.C., 2008), pp. 8–363.

3. Cost Trends with Standards

This explanation introduces an important area of analysis in the "energy gap" debate: learning curves and regulatory programs to achieve increased efficiency. Policies to reduce the efficiency gap, like performance standards, are intended to overcome market barriers and imperfections that have inhibited investment in efficiency. They have the effect of improving market performance. By overcoming barriers and imperfections, well-designed performance standards will stimulate investment and innovation in new energy efficient technologies. A natural outcome of this process will be to lower the level of energy consumption as well as the cost of energy savings.

One of the strongest findings of the empirical literature is its support of the theoretical expectation that technological innovation will drive down the cost of improving energy efficiency and reducing greenhouse gas emissions. A comprehensive review of *Technology Learning in the Energy Sector* found that energy efficiency technologies are particularly sensitive to learning effects and policy.

> For demand-side technologies the experience curve approach also seems applicable to measure autonomous energy efficiency improvements. Interestingly, we do find strong indications that in this case, policy can bend down (at least temporarily) the experience curve and increase the speed with which energy efficiency improvements are implemented.[26]

Analyses that fail to take into account the powerful process of technological innovation that lowers costs will overestimate costs, undervalue innovation, and perpetuate market failure. Detailed analyses of major consumer durables — including vehicles, air conditioners, and refrigerators — find that technological change and pricing strategies of producers lower the cost of increasing efficiency in response to standards.

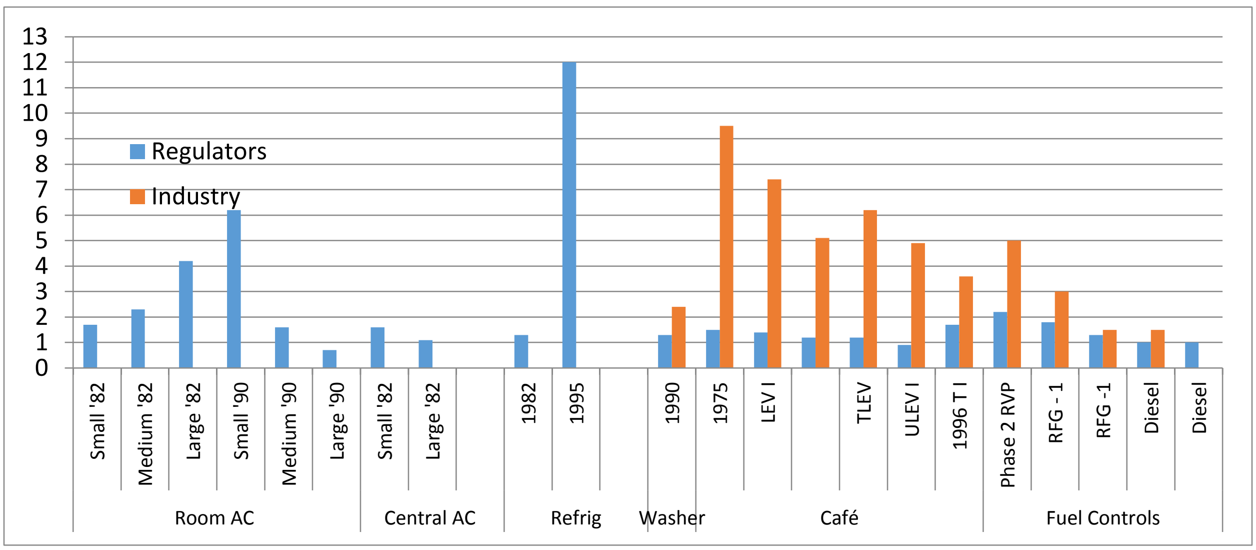
> 1. For the past several decades, the retail price of appliances has been steadily falling while efficiency has been increasing.
>
> 2. Past retail price predictions made by the DOE [U.S. Department of Energy] analysis of efficiency standards, assuming constant price over time, have tended to overestimate retail prices.
>
> 3. The average incremental price to increase appliance efficiency has declined over time. DOE technical support documents have typically overestimated the incremental price and retail prices.
>
> 4. Changes in retail markups and economies of scale in production of more efficient appliances may have contributed to declines in prices of efficiency appliances.[27]
>
> The more specific point here is that, while regulatory compliance costs have been substantial and influential, they have not played a significant role in the pricing of vehicles. …
>
> As with any new products or technologies, with time and experience, engineers learn to design the products to use less space, operate more efficiently, use less material, and facilitate manufacturing. They also learn to build factories in ways that reduce manufacturing cost. This has been the experience with semiconductors, computers, cellphones, DVD players, microwave ovens – and also catalytic converters.
>
> Experience curves, sometimes referred to as "learning curves," are a useful analytical construct

> for understanding the magnitude of these improvements. Analysts have long observed that products show a consistent pattern of cost reduction with increases in cumulative production volume. …
>
> In the case of emissions, learning improvements have been so substantial, as indicated earlier, that emission control costs per vehicle (for gasoline internal combustion engine vehicles) are no greater, and possibly less, than they were in the early 1980s, when emission reductions were far less.[28]

A comparative study of European, Japanese, and American automakers, prepared in 2006 before the recent reform and reinvigoration of the U.S. fuel economy program, found that standards had an effect on technological innovation. The United States had lagged because of a dormant U.S. standards program and the fact that U.S. automakers did not compete in the world market for sales (i.e., it did not export vehicles to Europe or Japan, where efficiency was improving). [29]

Figure II-9 shows the systematic overestimation by regulators of the cost of efficiency-improving regulations in consumer durables. The cost for household appliance regulations was overestimated by more than 100 percent and the costs for automobiles were overestimated by roughly 50 percent. The cost estimates from industry players were even further off the mark, running three times higher for auto technologies.[30] Broader studies of the cost of environmental regulation find a similar phenomenon, with overestimates of cost outnumbering underestimates by almost five to one. Industry figures are considered a "serious overestimate."[31]

FIGURE II-9: THE PROJECTED COSTS OF REGULATION EXCEED THE ACTUAL COSTS: RATIO OF ESTIMATED COST TO ACTUAL COST BY SOURCE



Sources: Winston Harrington, Richard Morgenstern, and Peter Nelson, "On the Accuracy of Regulatory Cost Estimates," ***Journal of Policy Analysis and Management*** **19(2) 2000,** ***How Accurate Are Regulatory Costs Estimates?,*** **Resources for the Future, March 5, 2010; ; Winston Harrington,** ***Grading Estimates of the Benefits and Costs of Federal Regulation: A Review of Reviews,*** **Resources for the Future, 2006; Roland Hwang and Matt Peak,** ***Innovation and Regulation in the Automobile Sector: Lessons Learned and Implications for California's CO_2 Standard,*** **Natural Resources Defense Council, April 2006; Larry Dale, et al., "Retrospective Evaluation of Appliance Price Trends,"** ***Energy Policy*** **37, 2009.**

While the very high estimates of compliance costs offered by industry can be readily dismissed as self-interested political efforts to avoid regulation, they can also be seen as a worst-case scenario in which the manufacturers take the most irrational approach to compliance under an assumption that there is no possibility of technological progress or strategic response. Consistent with the empirical record on cost, a simulation of the cost of the 2008 increase in fuel economy standards found that a technologically static response was three times more costly than a technologically astute response. [32]

A recent analysis of major appliance standards adopted since 2000 shows a similar, even stronger pattern. Estimated cost increases are far too high. There may be a number of factors, beyond an upward bias in the original estimate and learning in the implementation, that produce this result, including pricing and marketing strategies.[33] Thus, the empirical evidence suggests that efficiency is the least costly low-carbon resource and is likely to remain so at least through the mid-term. Given the 30-year track record of increasing efficiency and declining cost driven by technological innovation, there is no reason to believe this will change, even in the long-term.

4. Conclusion

While these traditional studies of the cost of saved energy reach a strong consensus there are other strands in the literature and factors that should be considered. On the one hand, the studies of utility-centered efficiency programs show somewhat higher costs. For example, a review by LBL[34] that adds in the administrative costs of these programs yield some results in range of $0.05/kwh for the residential sector. Since these estimate include administrative costs of programs that involve significant interventions to stimulate uptake, they may not be comparable to the resource cost estimates discussed early. In fact, simple rebate programs are very low in cost. Assumptions about discount rates may also contribute to the higher estimates. The finding about rebate programs points to another importance consideration. The utility-based analysis does not include other lower cost approaches, like appliance efficiency standards, building codes and combined heat and power projects. These can significantly reduce energy consumption without the heavy implementation costs of utility programs.

On the other hand, over the course of more than a decade the analyses by ACEEE,[35] which has repeatedly examined utility-based program show no trend of increase. It continues to find the range of costs from $0.02 to $0.05 per kWh, with the average around $.025.

An extension of this argument points out that, while the historic data supports the hypothesis that there might be mild learning effects and economies of scale working, the transformation of the electricity sector may have a much larger effect on the cost of efficiency (see Table III-1). Some have argued that changes in the relationship between the utility and the customer and the broader range of approaches to efficiency that is made possible by the new ICT technology could significantly lower costs. A reduction in transaction costs, improved targeting and better monitoring of results can dramatically lower costs and improve the effectiveness of efficiency efforts. These effects are similar to the impact of the application of ICT technologies in other sectors.[36]

TABLE II-1: POTENTIAL SOURCES OF LOWER COST/MORE EFFECTIVE EFFICIENCY IN THE 21ST CENTURY ELECTRICITY SECTOR

Traditional Approach	ICT-driven Approach	Benefit
Narrowly targeted	Broad reach	Economies of Scale
	Data-driven selection	Higher yield from better targeting
Time-intensive on-site Assessment	Remote assessment	Lower cost
Capital intensive retrofits	Operational measures	Low cost, low hanging fruit
"Measure by Measure"	Holistic	Higher yield
Sporadic follow-up	Ongoing monitoring	More effective evaluation

Source: Grueneich, Dian and David Joust, 2014, "Scale, Speed, and Persistence in an Analytics Age of Efficiency: How Deep Data Meets Big Savings to Deliver Comprehensive Efficiency," ***The Electricity Journal,*** **April.**

III. ECONOMIC RISK

While cost is the focal point of resource selection, economic cost has never been the sole criteria by which electricity resources are selected. Other economic and non-economic characteristics factor into which resource should be included in the portfolio of low-carbon resources. The list of performance criteria by which the electricity system is evaluated varies from study to study, as Figure III-1 shows, but it generally includes the following: economic costs (including financial, capital and operating cost), price volatility, reliability (including operational characteristics), variety, security (including availability and origin of fuel supply), flexibility (including operation and construction lead time), environmental impacts (including greenhouse gases, pollutants, waste, water, and land use) and social well-being (including health and consumption externalities).

FIGURE III-1: ELECTRICITY SYSTEM PERFORMANCE, CHARACTERISTICS, AND STRATEGIES

Multiple Performance Criteria →	**Key System Characteristics** →	**Coping Strategies** →	**Strategy Effects**
Stirling, 2010 Financial Operational Supply security Environmental Health Social Wellbeing	Stirling, 2010 Technology Combustion Fossil v. Other Non-combustion Geographic Scale Local, Regional, National, Global Resource Depleting Non-depletable Renewable	Stirling, 2010, Risk Management Real Options Portfolio Hedging Diversity	Stirling, 2010 Portfolio Benefits Hedging ignorance Mitigating lock-in Fostering innovation Accommodating pluralism Positive Synergies Portfolio Challenges Negative Feedback Crowding out
Costello, 2005 Economic Operational Supply security Environmental Social Wellbeing	Costello, 2005 Technology Type Lead Time Intermittency Geographic Domestic Resource Abundance Supply security	Costello, 2005 Hedge Against Price Supply Reliability Regulatory Risk Fuel Diversity	Costello, 2005 Portfolio theory Real Options theory

Sources: Stirling, Andrew, 2010, Multicriteria Diversity Analysis; A Novel Heuristic Framework for Appraising energy Portfolios, *Energy Policy*, 38; Costello, Ken, 2005, *Making the Most of Alternative Generation Technologies: A Perspective on Fuel Diversity*, NRRI, March.

This section considers two sets of factors beyond "simple" resource economics that frequently affect the acquisition of resources, investment risk and environmental impacts. Part II examines resource adequacy, operational factors and system reliability.

A. NEW BUILDS: INVESTMENT RISK

The factors that expose investors to risk are playing an increasingly important role in resource selection. The size of projects, time to market, and sunk capital costs become an important consideration in an uncertain world with volatile prices. These concerns are reinforced by the urgency of dealing with the challenge of climate change.

The Lazard analysis discussed above provides estimates for key characteristics of deploying various low-carbon technologies that have played an important part in the ongoing debate over resource selection. Small, nimble, quick-to-market assets are considered much more attractive investments. As shown in Figure III-2, there is a sharp distinction between central station resources and decentralized resources. The top graph displays cost and capacity. The bottom graph displays the construction period and sunk costs. Lazard uses a 69 month construction period, but the actual construction period for U.S. reactors is closer to ten years; off the charts of Exhibit III-2.

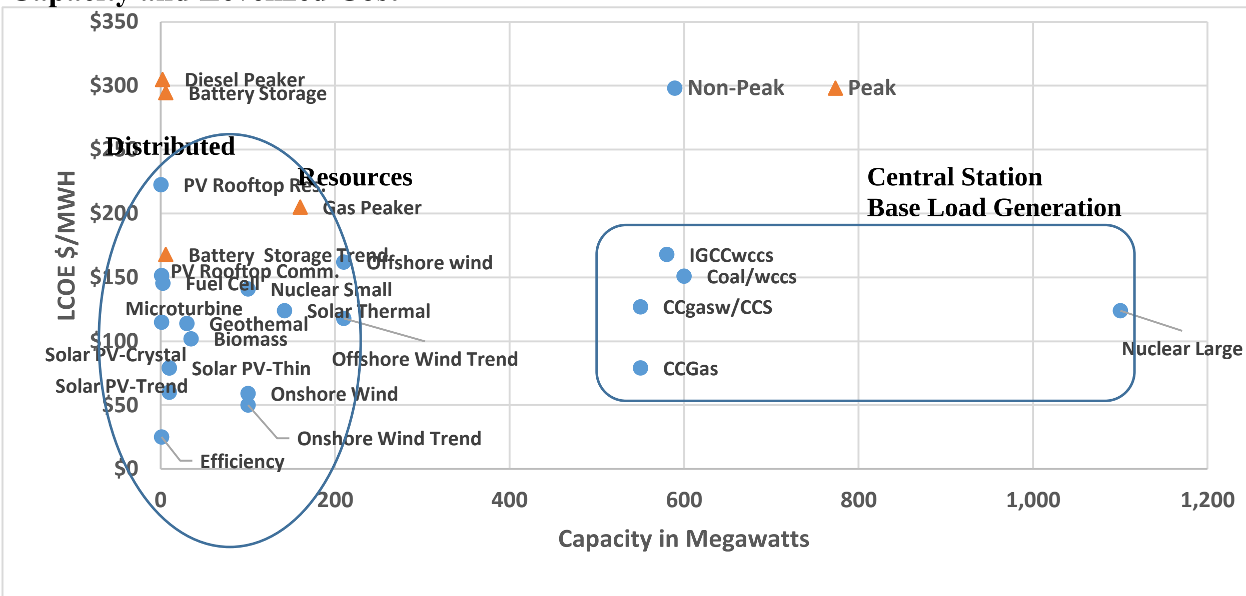
Central station, baseload facilities in general, and nuclear reactor construction in particular, are at a disadvantage compared to alternatives which are more flexible and better able to meet small-load increases more quickly. As a result, the alternatives are easier to finance. The slowing of growth in demand, caused in the short term by the severe global recession and reinforced in the long term by improvements in energy efficiency, magnify the importance of small size and flexibility. The importance of climate change and niche applications is also magnified. In fact, small modular reactors were pitched as a response to these challenges but the technology was still on the drawing board.[37] SMR deployment was a decade or more away and numerous alternatives were already available that had more desirable characteristics. Thus, nuclear technology was again not competitive.

The investment characteristics discussed above — size, cost, and construction period — are presumed to expose the investor to several forms of risk, e.g., technology, marketplace, policy, and financial. Another form of risk that plays a particularly important role in the case of nuclear power is execution risk. Throughout its history, the construction of highly complex nuclear facilities has been plagued by construction delays and cost overruns, particularly in market economies. The current cohort of nuclear reactors under construction have experienced this problem.

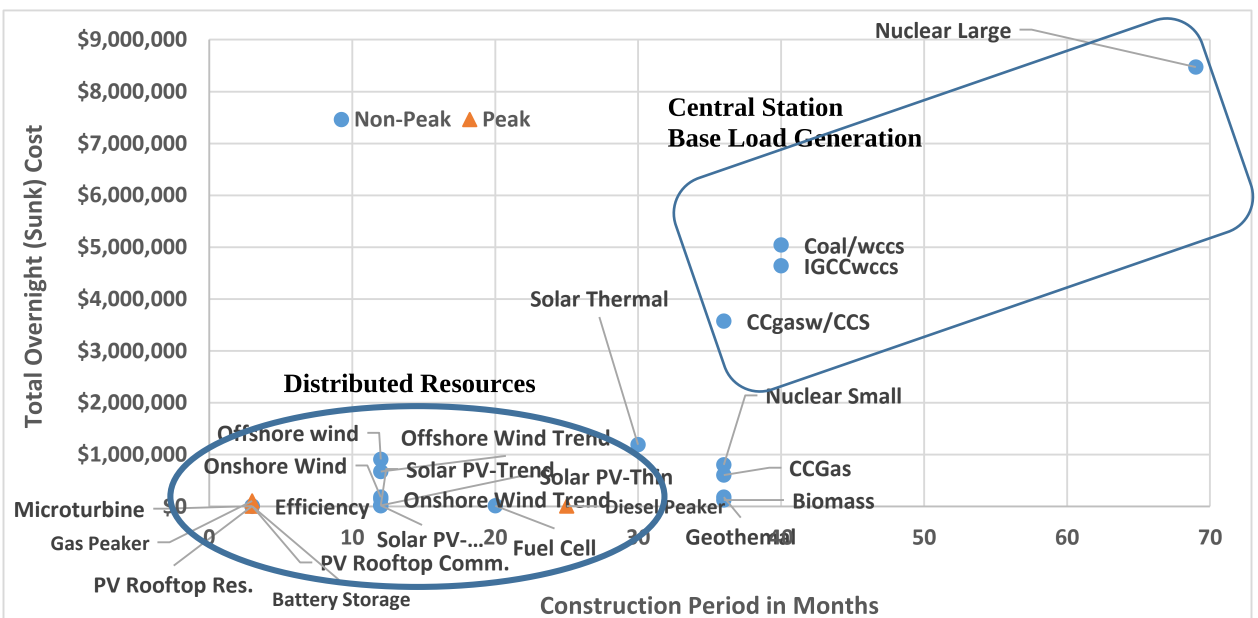
While a great deal of analysis of the nuclear construction problem exists, there has not been much analysis that compares nuclear construction to other technologies. A recent data set prepared by Sovacool et al. fills that gap. They compiled a cross-national data set including more than 400 projects across several technologies – nuclear, wind, solar, thermal, hydro and transmission. They gathered data on cost, cost overruns, construction period, and construction delays and reported bivariate relationships to test a number of hypotheses about the causes of cost overruns.

FIGURE III-2: COST, CAPACITY, AND CONSTRUCTION PERIODS OF LOW CARBON RESOURCES

Capacity and Levelized Cost



Construction Period and Total Overnight (Sunk) Cost*



Source: *Lazard's Levelized Cost of Energy Analysis – Version 8.0, Version 7.0.*

For the purposes of this analysis, I focus on nuclear v. non-hydro renewables (wind and solar) since these are the key low-carbon technologies at play in the U.S. (Table III-1). I include both U.S. and non-U.S. projects to gain insight into whether observed problems are unique to the United States or general to technologies across nations.

TABLE III-1: NUCLEAR COMPARED TO NON-HYDRO RENEWABLES: CONSTRUCTION PERIOD STATISTICS

Governance	Technology	Mean	St. Dev.
Non-U.S.	Nuclear		
	Cost Overrun (%)	44	66
	Construction Period (Mos.)	80	25
	Construction Delay (Mos.)	54	44
	Non-Hydro		
	Renewables Cost Overrun (%)	4	16
	Construction Period (Mos.)	21	12
	Construction Delay (Mos.)	5	17
U.S.	Nuclear		
	Cost Overrun (%)	202	129
	Construction Period (Mos.)	104	34
	Construction Delay (Mos.)	74	58
	Non-Hydro		
	Renewables Cost Overrun (%)	4	13
	Construction Period (Mos.)	17	8
	Construction Delay (Mos.)	-2	4

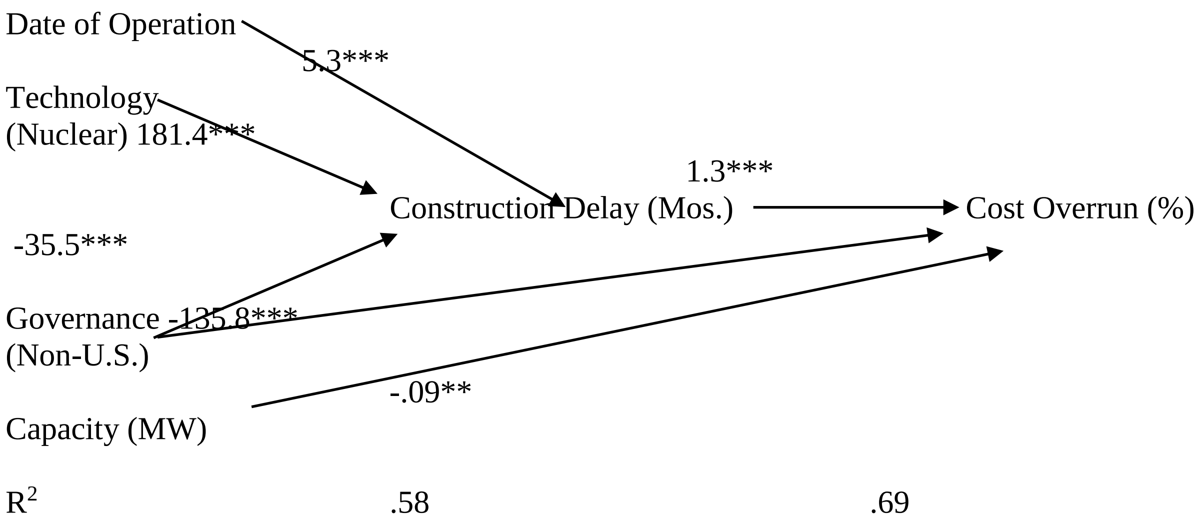
Source: Benjamin K. Sovacool, Alex Gilbert, and Daniel Nugent, 2014, "An International Comparative Assessment of Construction Cost Overruns for Electricity Infrastructure," ***Energy Research and Social Science,*** **3.**

Table III-1 captures all of the variables used in the Sovacool et al. studies in a way that highlights the bivariate relationships between the causal factors of construction delays and cost overruns. Table III-1 presents the means and standard deviations for each of the variables of interest. We observe that for the United States and globally, nuclear is much more likely to suffer large construction delays and cost overruns than non-hydro renewables. While the problem of nuclear construction delays and cost overruns is much greater in the United States, it is also quite large globally. Note that nuclear cost overruns in the United States are more than 350 percent higher than non-U.S. counterparts, but construction delays are only about 30 percent greater. Recently released French data may provide a partial explanation for the difference: many of France's cost overruns were hidden.[38]

In contrast to severe construction delays and cost overruns for nuclear, non-hydro renewables have much smaller delays and overruns which are relatively uniform across the globe.

Figure III-3 constructs a multivariate model that explains a large part of the variance in construction delays (58%) and cost overruns (69%). All of the signs are in the expected direction with the exception of the direct link between capacity and cost overruns. Construction period is the primary determinant of cost. Older, nuclear technologies in the United States took much longer to construct. Once we control for technology, governance, and construction delays, the large capacities are associated with lower cost overruns. However, the indirect effect of capacity on cost overruns through the impact of capacity on construction delay offsets the direct effect. Simply put, nuclear power poses a great deal more execution risk.

FIGURE III-3: A MULTIVARIATE MODEL OF CONSTRUCTION DELAYS AND COST OVERRUNS FOR NUCLEAR AND NON-HYDRO RENEWABLES

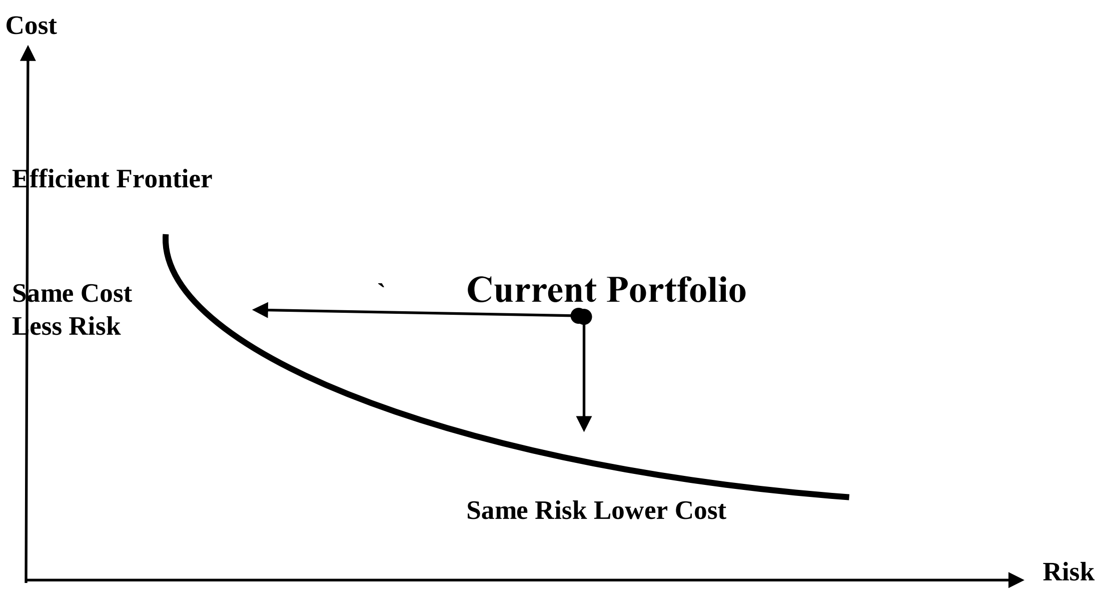


Note: Beta Coefficients with Robust Standard Errors, * = Sig. p< .000, **= Sig. p< .00; only statistically significant Betas shown, but all variables are included**

B. MULTI-CRITERIA ANALYSIS OF COST AND RISK

The investment risk aspect of resource acquisition is increasingly dealt with by applying a portfolio approach to decision making. The key concept is to reduce the overall risk of the portfolio by including assets that have different levels of risk, particularly when the risks are not positively correlated. Figure III-4 illustrates the concept from a publication targeted at energy regulators.

FIGURE III-4: RISK/COST REWARD



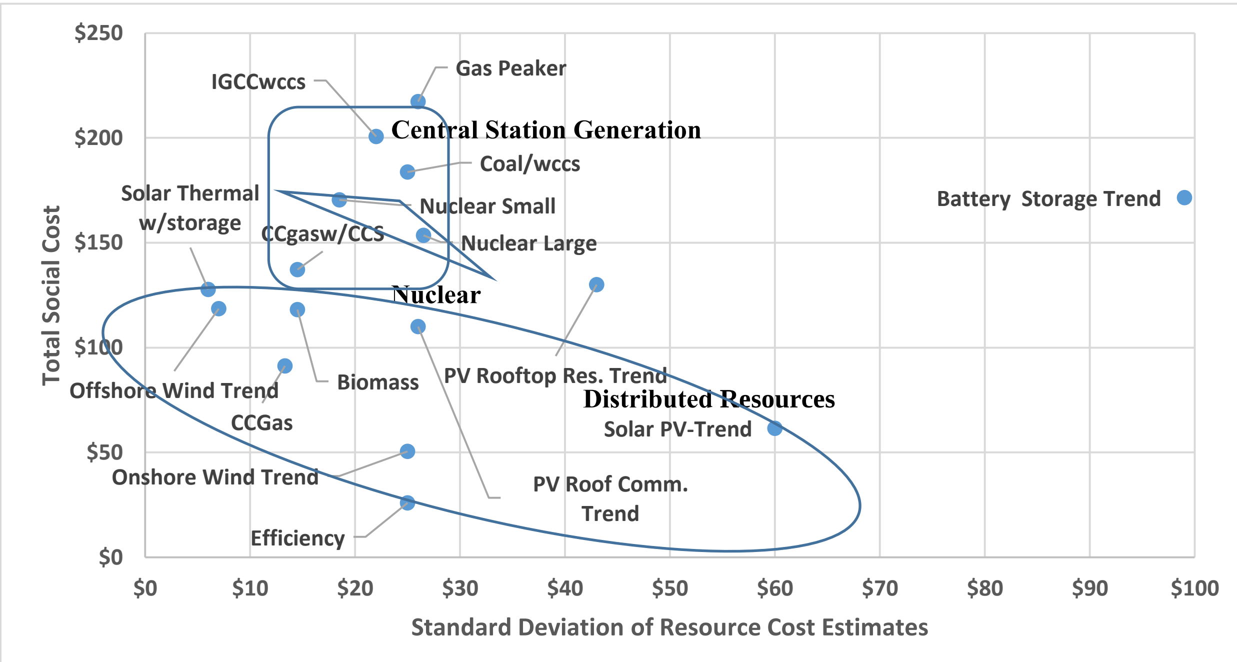
Source: Ken Costello, *Making the Most of Alternative Generation Technologies: A Perspective on Fuel Diversity*, (NRRI, March (2005), p. 12.

The assumption is that there is a risk/cost trade-off that defines an efficient frontier. Investors want to be on the efficient frontier where risk and reward are balanced. They can improve their expected returns if they can increase their reward without increasing their risk, or they can lower their risk without reducing their reward. In the financial literature, risk is measured by the standard deviation of the reward. In applying this framework to the evaluation of generation options, analysts frequently measure reward as kilowatts per dollar (a measure of economic efficiency). This is the inverse of cost. Indeed, they use efficiency and cost interchangeably.[39] Options that would move the portfolio toward the efficient frontier and assets that are closer to the origin) should be adopted since they embody lower cost and/or risk.[40]

The expected value (cost) of the portfolio reflects the cost and risk of each resource and the extent to which the costs co-vary. Lowering risk without raising cost or lowering cost without raising risk are attractive strategies. Above all, the portfolio's risk can be reduced by including resources with negatively correlated prices. Adding assets which exhibit cost volatility that is negatively correlated with the other assets in the portfolio (when X is up Y is down, or vice versa) can lower the overall risk (and therefore the expected price) even though it presents a higher cost.

Figure III-5 shows the risk/cost array based on the levelized cost estimates from Figure II-3 (above). I base the standard deviation on the full range of costs, including not only the basic cases but all scenarios in Lazard in the full analysis. This is the data that can be used to identify the optimum portfolio, as I have shown in earlier analyses of national average data.[41] The rank order of the resources based on expected costs is identical to the rank order based on levelized cost.

FIGURE III-5: U.S. RISK/COST ARRAY BASED ON LAZARD



Source: see Figure II-3

The bottom line for nuclear is clear; it is not a very attractive asset. Given the lack of correlation between the variability among other low-carbon assets, one would not expect nuclear to enter optimum portfolios.

A recent study by Jason Rauch uses this approach to identify the optimal portfolio for generation resources in New England and corroborates my findings with detailed regional data. The purpose of his paper is to show that taking risk into account is important to arrive at optimal decisions and to demonstrate a rigorous methodology that can be easily implemented by public utility commissions.[42] Here I move beyond that laudable goal and draw policy conclusions that address big questions in the ongoing debate about low-carbon resource acquisition:

- How does carbon regulation affect the attractiveness of the alternatives? How much gas is needed? How large are the cost increases? How much nuclear belongs in the portfolio?

The makeup of the optimal portfolio provides clear answers to these question. Nuclear is not included in any optimal portfolio.

- Gas is 15–16 percent of the optimal portfolio.
- Wind accounts for 34–48 percent, depending on the cost of integration.
- Hydro is in the range of 21–34 percent (hydro is up when wind is down)
- If the decision maker ignores both risk and carbon mitigation, the preferred portfolio is 96 percent gas, but if the decision maker considers either **risk or carbon mitigation**, the gas share is reduced by five-sixths.

Carbon regulation has little impact on the mix of generation in the optimal risk-adjusted price portfolio.

- The optimum resource mix is roughly the same in both the base case and the zero carbon case.
- However, once one moves to decarbonize the electricity sector, optimal portfolio analysis becomes particularly important.
- An approach to zero carbon emissions that is risk aware decreases the expected cost by just under 20 percent.
- An optimal portfolio strategy keeps the cost increase under 13 percent.
- Controlling the cost of integrating large shares of wind is important, as it can add 2 to 4 percent to the cost of the optimal portfolio.

Combined, these observations give a clear conclusions for policy makers. A well-designed transition to low-carbon resources that controls the cost of integrating renewables and is optimized for price and risk can cut cost increases by 40 to 50 percent. Spread across a decade and a half, as in the EPA Clean Power Rule, the impact would be less than 1 percent per year, in line with the EPA's estimates. Nuclear power is not needed to achieve these results.

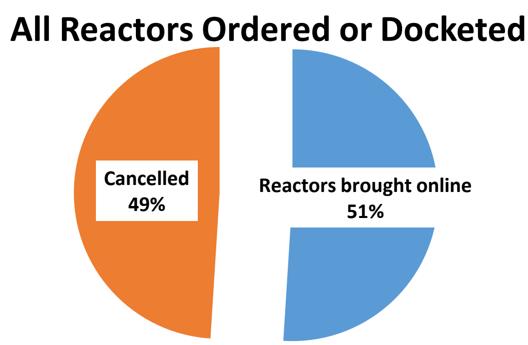
C. Operating Risk of Aging Reactors

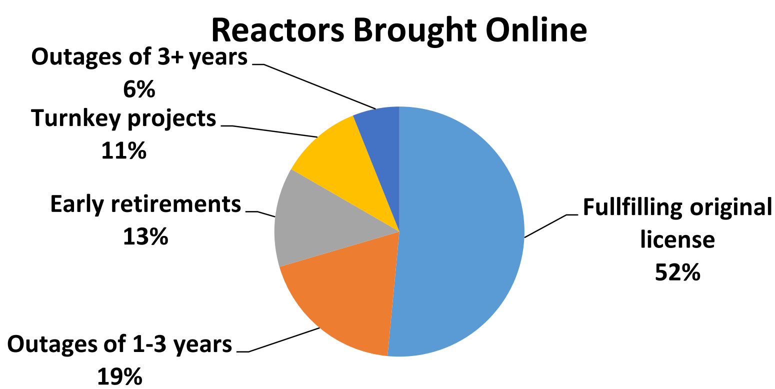
The complexity and challenge of nuclear technology does not end with the construction cycle. Throughout their operating life, reactors exhibit ongoing problems. As noted above, the maintenance of aging facilities has also grown more challenging, as shown by a number of recent events.[43]

- The rising cost of operating aging reactors.
- The early retirement of San Onofre and Crystal River which resulted from botched maintenance activity.
- The severe cost overrun experience of recent uprates.

In fact, the entire history of commercial nuclear power in the United States exhibits a persistent pattern of difficulty operating and managing reactors (see Figure III-6).[44] While it is widely recognized that half of the reactors ordered or docketed at the NRC in the 1960s and 1970s were cancelled, what is not as well-known is that the half that were brought online did not perform as advertised

Figure III-6: U.S. Nuclear Reactors: Financial and Online Status (as of 2012)





Sources: Fred A. Heddleson, *Summary Data for US Commercial Nuclear Power Plants in the United States*, Nuclear Safety Information Center, April 1978; US Energy Information Administration, *Nuclear Generating Units, 1955-2009; Nuclear Power Plant Operations, 1957-2009*; David Lochbaum, *Walking a Nuclear Tightrope: Unlearned Lessons of Year-Plus Reactor Outages*, September 2006; Jonathan Koomey, *Was the Three Mile Island Accident in 1979 the Main Cause of US Nuclear Power's Woes?*, June 24, 2011.

Ultimately, one-quarter of all U.S. reactors that came online had outages of more than 1 year. My quantitative and qualitative analysis of long outages and early retirements (before the recent round) provides insight into the decision to retire reactors (see Table III-2). There are three causes of these outages:

- Replacement—to refresh parts that have worn out.
- Retrofit—to meet new standards that are developed as the result of new knowledge and operating experience (e.g., beyond-design events).
- Recovery—necessitated by breakage of major components.

TABLE III-2: SIGNIFICANT EARLY RETIREMENTS AND REACTORS WITH OUTAGES EXCEEDING 5 YEARS

Reactor (Location)	Shutdown (Outage)	Years of Operation	Cause of Shutdown
Shoreham (NY)	1987	0	Local opposition and concerns about evacuation plan. Closed before commercial operation began.
Three Mile Island 2	1979	0.33	Partial core meltdown caused by loss of coolant, rated a 5 on the INES scale. Cleanup took 14 years and cost about $1 billion.
Fermi I (MI)	1972	2	In 1966, a loose zirconium plate at the bottom of the reactor vessel blocked sodium coolant flow, and two fuel subassemblies started to melt. Less than three years after cleanup was completed and the reactor restarted, the core was approaching the burnup limit.
Peach Bottom 1 (PA)	1974	7	This was a small, experimental, helium-cooled, graphite-moderated reactor.
Indian Point 1 (NY)	1974	12	The emergency core cooling system did not meet regulatory requirements.
Fort St. Vrain (CO)	1989	13	Control rod drive assemblies, steam generator ring headers, low plant availability, and prohibitive fuel costs.
Humboldt Bay (CA)	1976	16	During a shutdown for seismic modifications, updated economic analyses showed that restarting would probably not be cost-effective.
Rancho Seco (CA)	1989	15	Concern about safety coupled with poor performance. Closed by popular vote.
La Crosse (WI)	1987	17	The small size of the plant made it no longer economically viable.
Trojan (OR)	1992	17	Tube leaks requiring replacement of steam generator, regulatory uncertainty
Dresden I (IL)	1978	18	Minor steam leaks and erosion in steam piping, fuel failures, and corrosion of admiralty brass that led to elevated radionuclide levels. While the reactor was offline for decontamination and retrofitting, new regulations were issued, and compliance would have cost more than $300 million.
Browns Ferry 1 (AL) (21-year outage)		18	Unit One was shut down for a year after fire damage in 1975. It was repaired
Browns Ferry 2 (6.7-year outage)		29	and operated from 1976 to 1985, when all three units were shut down
Maine Yankee (ME)	1996	23	NRC staff identified so many problems that "it would be too costly to correct these deficiencies to the extent required."
San Onofre 1 (CA)	1992	24	Economic analysis of costs and benefits, steam generator degradation, and seismic retrofit requirements.
Zion 1 & 2 (IL)	1998	25	Control-room operator accidentally shut down Unit 1 and tried to restart it without following procedures. Utility later concluded that repairing steam
Brown Ferry 3 (10.7-year outage)		25	operational and management issues. TVA spent $1.8 billion to restore Unit One to operational status. Generators would be uneconomical.
Millstone 1 (CT)	1998	28	After a leaking valve forced a shutdown in 1996, multiple equipment failures were discovered.
Three Mile Island 1 (NY)	(6.6-year outage)	29	Offline for refueling during 1979 accident at Three Mile Island 2, brought back online in 1986
Connecticut Yankee (CT)	1996	29	Economic study showed customers would save money if the plant closed. Other considerations included long-term maintenance costs and the availability of low-level waste disposal.
Yankee Rowe (MA)	1991	32	Reactor vessel embrittlement, steam generator tube damage
San Onofre 2 & 3	2012	30	Steam generator flaw
Crystal River	2009	32	Containment shell flaw and botched repair
Kewaunee	2013	39	Uneconomic
Vermont Yankee	2014	42	Uneconomic

Sources: NRC Web site; licensee Web sites; Wikipedia; Office of Technology Assessment, *Aging Nuclear Power Plants: Managing Plant Life and Decommissioning,* September 1993.

Even before the recent round of early retirements, almost one-seventh of the reactors brought online were retired early. The recent retirements mean that almost one in five reactors brought online have retired before the expiration of their licenses.

Early-retirement reactors are typically older, smaller reactors built before the ramp-up in safety regulation. They are not worth repairing or keeping online when new safety requirements are imposed or when the reactors are in need of significant repair. On average, compared with reactors that were not retired early, early retirements were:

- Less likely to be pressurized water reactors (53% v. 63%)
- Brought online earlier (on average, 1972 v. 1979)
- Smaller (558 megawatts v. 964 megawatts)
- Less likely to have suffered a safety-related outage (12% v. 33%)
- More likely to have suffered damage or a component-related outage (24% v. 11%)

Qualitatively, the decision to retire a reactor early usually involves a combination of factors such as major equipment failure, system deterioration, repeated accidents, and increased safety requirements. Economics is the most frequent proximate cause and safety is the most frequent factor that triggers the economic reevaluation. Although popular opposition "caused" a couple of early retirements (a referendum in the case of Rancho Seco; state and local government in the case of Shoreham), this was far from the primary factor. In some cases, local opposition clearly failed (referenda failed to close Trojan or Maine Yankee). External economic factors such as declining demand or more-cost-competitive resources can render existing reactors uneconomic on a "stand-alone" basis or in conjunction with one of the other factors (the latter is more common).

In addition to this long-term analysis I have conducted an in-depth analysis of the recent early retirements of reactors. Table III-3 shows the characteristics that I identified as causes of early retirement for aging reactors. Among the five that have been retired recently, three were broken and repairs were too costly to fix; two were small and commissioned early. I include in this table the subset of characteristics that are relevant to the reactors for which utilities are currently seeking subsidies, as discussed in Part III. All but Byron were on my earlier list of at-risk reactors. I contrast these at-risk reactors to the reactors that retired early in the past two years. For these reactors the problem is primarily economic, which is what the utilities would like to reverse by seeking subsidies and other increases in their revenues. However, several of the reactors have other problems.

D. ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS

To approach the analysis of environmental impacts, it is useful to start from efficiency because it highlights the complete array of positive and negative impacts of energy choice that is becoming widely recognized and consistently modeled. The fullest expression of externalities can be recognized in the decision not to consume.[45]

TABLE III-3: RECENT EARLY RETIREMENTS AND CHARACTERISTICS OF "AT-RISK" REACTORS

Reactor	Economic Factors						Operational Factors			Safety Issues	
	Cost	Small	Old	Merchant	20yr< w/o Ext.	25yr< w/ Ext.	Broken	Reliability	Long term Outage	Multiple Safety Issues	Fukushima Retrofit
RETIRED, 2013											
Kewaunee	X	X	X	X						X	
Crystal River	X		O				X		O	X	
San Onofre				X	X		X		O	X	
AT RISK											
Ginna	X	X	X	X		O				X	
Davis-Besse	X		O	X		O		X	X	X	
Quad Cities	X			X		O					X
Clinton	X			X	X						
Byron	X			X	X	O				X	

Sources and Notes: Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality,* February 19, 2013; UBS Investment Research, *In Search of Washington's Latest Realities (DC Field Trip Takeaways*), February 20, 2013; Platts, January 9, 2013, "Some Merchant Nuclear Reactors Could Face Early Retirement: UBS," reporting on a UBS report for shareholders; Moody's, *Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues,* Special Comment, November 8, 2012.; David Lochbaum, *Walking a Nuclear Tightrope: Unlearned Lessons of Year-Plus Reactor Outages,* September 2006, "*The NRC and Nuclear Power Plant Safety in 2011*, 2012, and UCS Tracker); NRC Reactor pages.

Operational Factors: Broken/reliability (Moody's for broken and reliability); Long Term Outages (Lochbaum, supplemented by Moody's, o-current, x=past); Near Miss (Lochbaum 2012); Fukushima Retrofit (UBS, Field Trip, 2013).

Economic Factors: Cost, Wholesale markets (Credit Suisse) Age (Moody's and NRC reactor pages with oldest unit X=as old or older than Kewaunee, i.e. 1974 or earlier commissioning, O= Commissioned 1975-1979, i.e. other pre-TMI); Small (Moody's and NRC Reactor pages, less than 700 MW at commissioning); Stand Alone (Moody's and NRC Reactor pages); Short License (Credit Suisse and NRC Reactor pages). Some of the characteristics are site specific, some are reactor specific.

The reactors at a specific plant can differ by age, size, technology and the current safety issues they face. Historically, in some cases there were long outages at one, but not all of the reactors at a plant. Similarly, there are numerous examples of a single reactor being retired early at a multi-reactor site. Given the complexity of an analysis of individual reactors across the eleven risk factors and the fact that unique precipitating events are the primary cause of early retirements, I count only one potential reactor retirement per plant.

A comprehensive list of non-energy impacts can be found in the analysis of energy efficiency (see Tale III-4). This is the correct place to start since it would include all of the impacts of energy consumption and avoided production. An evaluation of the non-energy benefits of whole house retrofits produces a similar, long list of benefits.[46]

TABLE III-4: TWO VIEWS OF BENEFITS OF EFFICIENCY AS EXTERNALITIES

	REGULATORY ANALYSIS PROJECT		
OECD/IEA	Utility System	Participant	Societal Non-energy
Economic			
Provider Benefit	Generation,		Reduced Terminations
& Infrastructure	Transmission,		Reduced Uncollectibles
	Distribution,		
	Line Loss, Reserves		
	Credit & Collections		
Energy Prices	Demand Response		
	Price Effect		
Public Budgets			
Energy Security	Reduced Risk	Societal Risk & Security	
Macro-economic		Employment, Development	
		Productivity, Other economic	
Social			
Health		Health, Comfort, Bill Savings	
Affordability		O&M, Other resource Savings	
Access		Low Income Consumer Needs	
Development	Development		
Job Creation		Employment	
Asset Values		Property Values	
Disposable Income			
Productivity		Productivity	
Environment	Avoided Regulatory		Avoided Regulatory
GHG Emissions	Obligations & Costs		Obligations & Costs
Resource Mgmt.			Electricity/Water Nexus
Air/Water			Air quality
Pollutants			Water Quantity & Quality
			Coal Ash & Residuals

Sources: James Lazar and Ken Colburn, *Recognizing the Full Value of Energy Efficiency* (Regulatory Analysis Project, September 2013), p. 6; Lisa Ryan and Nina Campbell, *Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements* (International Energy Agency, Insight Series 2012), p. 25.

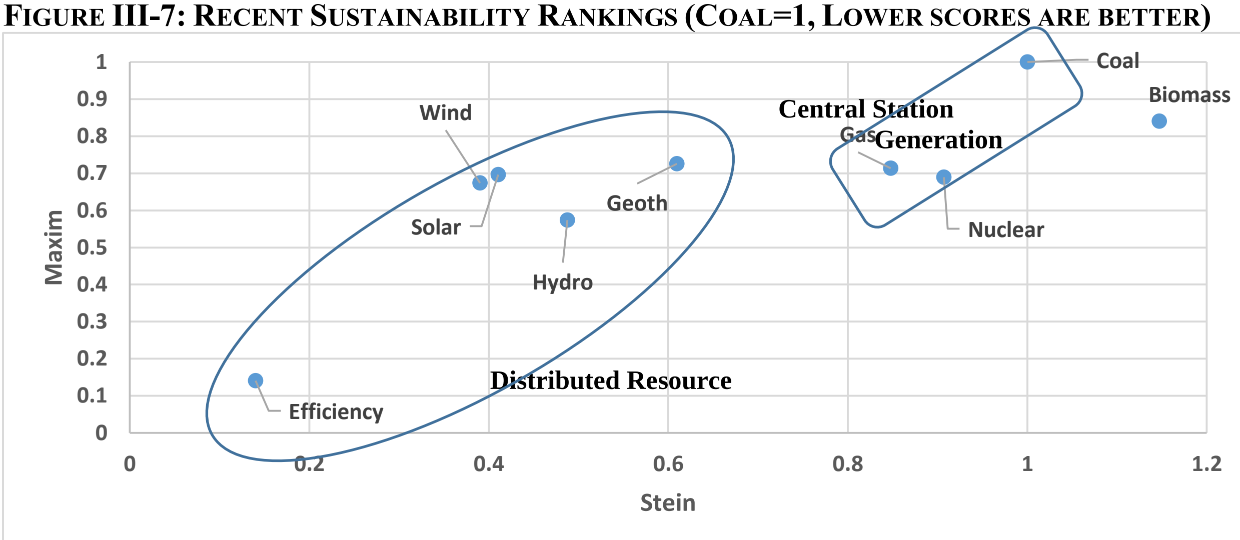
The magnitude of these potential gains is difficult to estimate but likely to be substantial. Direct estimates of the non-economic benefit are estimated to be 50–300 percent of the underlying energy bill savings.[47] The broad benefits of efficiency reinforce its role as the cornerstone of the low carbon resource portfolio. I also note that this comprehensive view of the benefits of efficiency includes many of the key system operation issues that will be discussed in the next section (e.g. demand response, reduced investment in all types of facilities, more efficient generation).

The broad view of externalities has extended to the broader issue of sustainability of generation resources[48] and it has also begun to look at important interactions between climate change and non-carbon externalities, like heat waves and water use.[49] A broad concept of sustainability is being used more frequently to describe the non-energy impacts of different technologies and resources.

> Evaluation of each technology was based on the application of four primary criteria:
>
> - Financial (FC): financial value of the technology and return on investment.
> - Technical (TC): characteristics of the technology as a power source and its production capabilities.
> - Environmental (EN): impact of power plant on local and regional environment, as well as human health.
> - Social/Economic/Political (SEP): impact on local economy and communities, as well as congruence with overall national policies. [50]

This definition is used to calculate both of the axes in Figure III-7. Each axis is based on a recent study of the sustainability of resources, which have a strong correlation (r=.86). Figure III-7 sets coal as the base (equal to 1) and then calculates the ratio of the other resources compared to coal, where lower scores mean more preferable rankings. I have also included efficiency as it is ranked in earlier studies. The sharp break between efficiency/renewables on the hand and the conventional resources (fossil fuels and nuclear) on the other is readily apparent in both sets of rankings,

FIGURE III-7: RECENT SUSTAINABILITY RANKINGS (COAL=1, LOWER SCORES ARE BETTER)



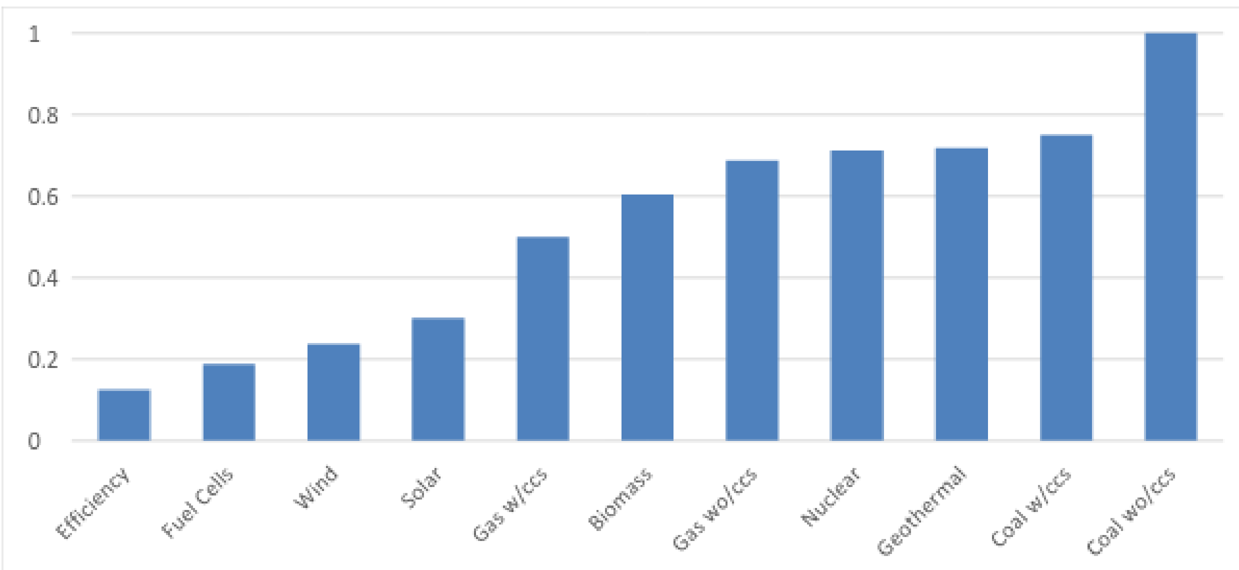
Sources: Eric W., Stein, 2013, "A Comprehensive Multi-Criteria Model to Rank Electric Energy Production Technologies," *Renewable and Sustainable Energy Reviews*, 22; Alexandra Maxim, "Sustainability Assessment of Electricity Generation Technologies Using Weighted Multi-Criteria Decision Analysis," *Energy Policy*, 65: 2014, Figure 2.

Once we move into the broader realm of the electricity system's non-economic goals, nuclear power fares very poorly. Nuclear power has significant disadvantages in terms of security [51] and proliferation risks[52] and continues to suffer from unique environmental problems.[53] As a result, in multi-attribute rankings and evaluations the main renewables (wind, solar, hydro) and efficiency are much more highly rated[54] and have consistently been so for decades.[55]

> The results indicate that wind, solar, hydropower and geothermal provide significantly more overall benefits than the rest even when the weights of the primary criteria clusters are adjusted during sensitivity analysis. The only non-renewable sources that appear in three of the 20 top rank positions are gas and oil, while the rest are populated with renewable energy technologies. These results have implications for policy development and for decision makers in the public and private sectors. One conclusion is that financial incentives for solar, wind, hydropower and geothermal are sound and should be expanded. Conversely, subsidies for non-renewable sources could be diminished.[56]

Figure III-8 shows the results of an older set of environmental evaluations conducted before climate change was a focal point of concern. Nuclear is seen as having a greater impact than gas but a smaller impact than coal. The rank order of resources with respect to their non-carbon environmental impact is identical to that of the resource economics, which confirms the earlier finding. Efficiency, wind, solar, and natural gas are much more attractive resources.

FIGURE III-8: OLDER RANKINGS OF THE ENVIRONMENTAL COST OF ELECTRICITY RESOURCES (COAL=1, LOWER SCORES ARE BETTER)



Sources: Wilson B. Goddard, *A Comparative Study of the Total Environmental Costs Associated with Electrical Generation Systems* (G&GE Applied Research, 1997); *U.S* Congressional Office of Technology Assessment, *Studies of the Environmental Costs of Electricity* (Washington, D.C. September 1994), evaluating Richard Ottinger, et al., Pace University Center for Environmental Legal Studies, *Environmental Costs of Electricity* (New York,: Oceana, 1990), Paul Chernik and Emily Caverhill, "The Valuation of Externalities from Energy Production, Delivery and Use" (Fall 1989); Olave Hohmeyer, *Social Costs of Energy Consumption: External Effects of Electricity Generation in the Federal Republic of Germany* (Berlin: Springer-Verlag, 1988); Michael Shuman and Ralph Cavanagh, *A Model of Conservation and Electric Power Plan for the Pacific Northwest: Appendix 2: Environmental Costs* (Seattle, WA: Northwest Conservation Act coalition, November 1982).

These broader perspectives on resource acquisition reinforce the conclusions reached on the basis of "simple" resource economics. Efficiency and renewables are the preferred choices by far.

PART II. BUILDING THE 21ST CENTURY ELECTRICITY SYSTEM

IV. ENERGY RESOURCE POTENTIAL

Assuming the urgent need for decarbonization, Part I demonstrated that from three different points of view nuclear power and central station generation are at a severe economic disadvantage as the technologies of distributed generation continue to develop and deploy. The challenge is magnified for fossil fuels in a low carbon world, but it confronts nuclear power as well. The economics that point toward renewables and efficiency include:

- Short-term operating (variable) costs,
- Long terms total (resource) costs, including efficiency as a resource, and
- Market risk, portfolio management, and environmental impacts.

A resource is not a system, however, and resource costs are not the only factor that must be considered. First and foremost, the resource base must be sufficient to meet the needs for electricity over the long term. Second, the resources must be combined and operated to yield a stable, reliable system of supply. The commanding positions of efficiency and renewables in terms of the resource economics and other factors is one of the major forces driving change in the electricity sector, but it is not the only force. The top part of Table IV-1 describes additional factors that have been driving change and combined to raise the possibility that an alternative system can be constructed to meet the need for electricity.

TABLE IV-1: TRENDS AND STATE OF PLAY IN THE SYSTEM TRANSFORMATION

	Resources Potential	Systemic Operation
Trends:	Renewable cost reduction Rising cost of conventional Slow demand growth Self-supply	Growth of Decentralized supply Diverse participation in markets Customer engagement Interaction with other sectors and power suppliers Growth if ICT in grid operation
State of Play:		
Near/md term	Cost competitive Adequate for steady path to long term goal	Costs and benefits under intense analysis Demonstrated to moderate levels (30-40%)
Long-term	Solar: Resource dwarfs need Wind: Resource exceeds need	Tools for high levels (65%+) identified.
Challenges	Incumbent resistance New business models needed Regulatory inertia Rate structure Investment incentives Wind: Offshore cost Solar: storage, balance of system costs, common element resource base Beyond resource economics: security, reliability, resilience, environment	Incumbent resistance New business models needed Regulatory inertia Rate structure Investment incentives Deployment of Intelligent infrastructure Physical Institutional

The performance standards (goals) will be much the same as in the past – adequate, reliable, affordable, power that meets the growing need – but there are three sources of change, beyond resource economics. There is greater emphasis placed on concerns about the environmental and energy security qualities of the system. The system will have to move away from reliance on unabated use of fossil fuels as the primary resource. The core logic of the system could also change -- move away from central station load following to distributed active integration of supply and demand.

This Part examines the next two pressing questions about the future direction of the electricity sector.

- Section V, Are there adequate resources to sustain the alternative model?
- Section VI, Do the organizational and institutional tools exist to operate the system?

A. Renewables

1. Long Term Potential

The possibility that renewables could become the primary source of energy in the decarbonized electricity sector has been recognized by major research institutions. As the MIT study on *The Future of Solar* put it,

> Massive expansion of solar generation worldwide by mid-century is likely a necessary component of any serious strategy to mitigate climate change. Fortunately, the solar resource dwarfs current and projected future electricity demand…
>
> Solar electricity generation is one of very few low-carbon energy technologies with the potential to grow to very large scale. As a consequence, massive expansion of global solar generating capacity to multi-terawatt scale is very likely an essential component of a workable strategy to mitigate climate change risk.[57]

The Department of Energy said much the same about the potential for wind in its *Wind Vision Report*,

> Interest in wind power is stimulated by its abundant resource potential (more than 10 times current electricity demand); competitive, long-term stable pricing; economic development potential; and environmental attributes, including its ability to support reduced carbon emissions, improved air quality, and reduced water use.[58]

Both of these analyses recognize key challenges that must be overcome to achieve high levels of reliance on renewables. However, both of the analyses are optimistic about the ability to do so.

MIT identified three key challenges –

> We focus in particular on three preeminent challenges for solar generation: reducing the cost of installed solar capacity, ensuring the availability of technologies that can support expansion to very large scale at low cost, and easing the integration of solar generation into existing electric

> systems. Progress on these fronts will contribute to greenhouse-gas reduction efforts, not only in the United States but also in other nations with developed electric systems. It will also help bring light and power to the more than one billion people worldwide who now live without access to electricity.[59]

At the same time, the MIT study pointed to real world experience that suggested the path to overcome the challenges is clear, adding recommendations for public policy to support that effort.

> A number of emerging thin-film technologies that are in the research stage today use novel material systems and device structures and have the potential to provide superior performance with lower manufacturing complexity and module cost. Several of these technologies use Earth-abundant materials (even silicon in some cases)…
>
> Experience in Germany suggests that several components of BOS [Balance of System cost, other than solar panels], such as the cost of customer acquisition and installation labor, should come down as the market matures…
>
> net load peaks can be reduced — and corresponding cycling requirements on thermal generators can be limited — by coordinating solar generation with hydroelectric output, pumped storage, other available forms of energy storage, and techniques of demand management. Because of the potential importance of energy storage in facilitating high levels of solar penetration, large-scale storage technologies are an attractive focus for federal R&D spending. [60]

Given the much lower current cost of wind and its much higher levels of penetration at present, it is not surprising to find that the DOE *Wind Vision* analysis argues that "Wind generation variability has a minimal and manageable impact on grid reliability and related costs."[61] DOE believes that operational challenges that could arise with much higher levels of wind penetration can be easily overcome by expanding the use of techniques that have been found effective in the past. "Such challenges can be mitigated by various means including increased system flexibility, greater electric system coordination, faster dispatch schedules, improved forecasting, demand response, greater power plant cycling, and—in some cases—storage options."[62]

These two recent studies from prominent institutions come at the end of a long debate about the ability of renewable energy to keep the lights on while virtually eliminating all fossil generation and even all central station generation. While the prospect of that ultimate outcome is increasingly seen as quite good,[63] the near- and mid-term challenge in resource acquisition falls far short of the elimination of all fossil fuels and central station generation. The analysis of integrating much higher levels of wind and solar has progressed to detailed, utility-sponsored studies highlighting the impact and necessity of changes to the grid, as discussed in the next section.[64]

2. Mid-Term Potential

While academics and government agencies have been looking at the long term resource potential for quite some time, the new voices in the conversation are the financial analysts who focus on the near and mid-terms, since that is the time frame in which the advice to investors is most relevant. In this paper and earlier analyses I have shown that these financial analysts have been at the forefront of raising important issues when it comes to nuclear power including

- questioning the unrealistically optimistic cost projections offered by advocates in the early days of the "nuclear renaissance" and warning that new reactor construction would place severe burdens on utility finance,[65]
- identifying the implications of the dramatically declining cost of alternatives – wind, solar and storage,[66] and
- recognizing the economic problems of aging reactors in wholesale markets where renewables and efficiency are putting downward pressure on prices.[67]

Therefore, we should not be surprised to find many of these analysts signaling the potential for dramatic change in the structure of the utility industry. That analysis begins with the economic building blocks for a transformation of the electricity sector, centered on renewables, distributed resources and efficiency.

A late 2012 analysis from Citi Research concluded that "residential-scale solar is already competitive with electricity off the grid…Utility-scale solar will be competitive with gas-fired power in the medium term… Utility-scale wind is already competitive with gas-fired power."[68]

Credit Suisse takes an even more aggressive view of the development of renewables. They argue that over the next decade renewable deployment will be so substantial it will meet five-sixths of the need for generation, resulting in reduced pressure on gas supply. While Credit Suisse cites policies that are promoting renewables as the context for its transformational impact on supply, as noted above, it also argues that renewables have become cost-competitive with conventional baseload generation.[69]

> We see an opportunity for renewable energy to take an increasing share of total US power generation, coming in response to state Renewable Portfolio Standards (RPS) and propelled by more competitive costs against conventional generation. We can see the growth in renewables being transformative against conventional expectations with renewables meeting the vast majority of future power demand growth, weighing on market clearing power prices in competitive power markets, appreciably slowing the rate of demand growth for natural gas. [70]

McKinsey & Company reach the same conclusion as Citi and Credit Suisse in projecting cost parity for solar and conventional generation within the next decade. They argue that the growth of solar could have an "outsize" effect on the demand for baseload generation and "seriously threaten" utilities "because its growth undermines the utilities' ability to count on capturing all new demand, which historically has fueled a large share of annual revenue growth. (Price increases have accounted for the rest.)" [71] The net effect is to shift the demand for resources and undermine the ability to raise capital for baseload generation.

> By altering the demand side of the equation, solar directly affects the amount of new capital that utilities can deploy at their predetermined return on equity. In effect, though solar will continue to generate a small share of the overall US energy supply, it could well have an outsize effect on the economics of utilities—and therefore on the industry's structure and future.[72]

The importance of the impact of renewables at the margin was also emphasized by analysts at Sanford Bernstein. Reflecting on a debate in California, they note that the effect at the margin is much larger than one might think given relatively small market share: "Two things stand out. First, this is a live issue in one of the largest power markets in the world, with solar at .17 percent of global demand. Second, trends that start in California tend to travel well."[73]

> We think it is realistic to expect at least 30-40% reduction in cost per watt in key solar markets, while the greatest cost reductions are likely to come from the residential segments as scale and operating efficiencies improve. There is historical precedent for this in the oldest major solar market in the world – Germany….
>
> Lastly, the power of all in cost should not be underestimated. A typical residential US-based system costs around ~$25-35K today, but we believe that comparable residential systems could easily dip into the $10-15K range over the next 5 years if market forces driving cost reduction are allowed to progress without substantial policy/exogenous shocks. If interest rates are reasonable and a homeowner takes out a loan, upfront capital investment would be as little as a few thousand dollars. (35-39)

B. Energy Savings

Many financial analysts who project the important role that renewables can play in meeting the need for electricity in the mid-term note a similar role for efficiency. Credit Suisse suggests that declining demand growth helps to drive the transition of the electricity sector.

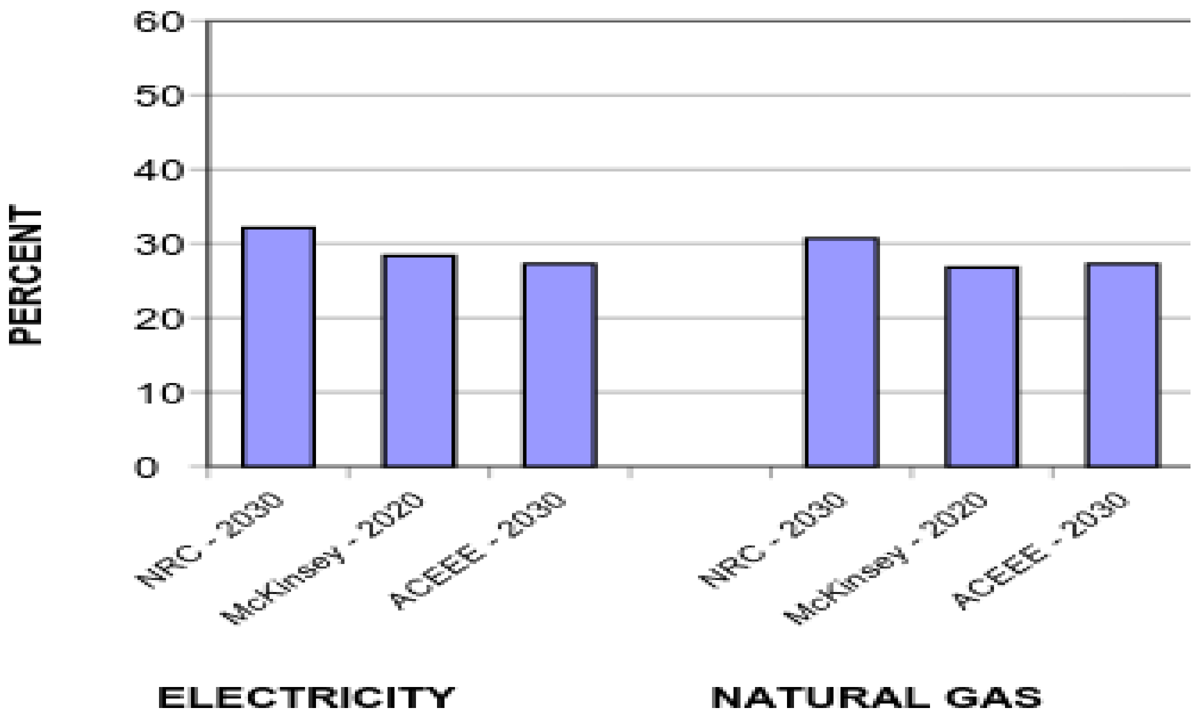
> The impact of energy efficiency has become more of a focal point after another year of lackluster power demand growth in 2013 and disappointing usage trends across customer classes.[74]
>
> Our take: Energy efficiency remains an under-appreciated but very important trend in power markets that will lead to structural drags on power demand growth impacting the outlook for competitive power market recovery and where utility capex will need to be allocated. We model efficiency lowering annual demand growth by ~70 bp (.7%) a year from a 'normal' baseline, putting core growth at +0.5-1.0% with downside risk barring better economic recovery…
>
> Our outlook for slower demand growth relative to a 'normal' +1.5% pushes out reserve margin equilibrium by 1–3 years, creating another unwanted headwind for competitive power.[75]

Credit Suisse explains that the slowing of demand growth places a great deal of pressure on the economics of utilities, not only where it adds to the downward pressure on prices set in markets but also in regulated states where rate structures have relied on growing demand to ensure recovery of fixed costs.[76]

McKinsey & Company were among the first to propose the important role of efficiency.[77] However, beyond the fact that efficiency lowers the cost of carbon reduction, efficiency has two impacts on the economics of resource acquisition. First, as demand growth slows, the addition of large, central station facilities adds very large increments of supply that may result in excess capacity. Second, in the near-term, efficiency is a response that buys time for alternative technologies to develop. Given cost trends, this improves the prospects for renewables, whose costs have been falling.

The potential for energy savings is substantial, as shown in Figure IV-1. Several major research institutions estimate that there is great potential to reduce the consumption of each of the forms of energy (electricity, natural gas, gasoline, and diesel), all of which are substantial emitters of carbon, by most households. Figure IV-1 shows that a 20–30 percent reduction in consumption of energy sources consumed directly by households is technically feasible and economically practicable.

FIGURE IV-1: THE SIZE OF THE EFFICIENCY GAP ACROSS ENERGY MARKETS: TECHNICALLY FEASIBLE, ECONOMICALLY PRACTICABLE POTENTIAL ENERGY SAVINGS



Sources and Notes: Electricity and natural gas savings based on Gold, Rachel, Laura, et. al., *Energy Efficiency in the American Clean Energy and Security Act of 2009: Impact of Current Provisions and Opportunities to Enhance the Legislation*, American Council for an Energy Efficient Economy, September 2009), McKinsey Global Energy and Material, *Unlocking Energy Efficiency in the U.S. Economy* (McKinsey & Company, 2009); National Research Council of the National Academies, *America's Energy Future: Technology and Transformation, Summary Edition* (Washington, D.C.: 2009). The NRC relies on a study by Lawrence Berkeley Laboratory for its assessment (Richard Brown, Sam Borgeson, Jon Koomey and Peter Biermayer, *U.S. Building-Sector Energy Efficiency Potential* (Lawrence Berkeley National Laboratory, September 2008).

Figure IV-1 also shows the potential for natural gas savings through increased efficiency. I show the natural gas sector because it is closely tied to the electricity sector in terms of recent additions to generation. The natural gas estimates in Figure IV-1 are generally estimates of the reduction in appliances and equipment that consume natural gas, but not the electricity sector. This means that Figure IV-1 captures a multiplicative reduction in the demand for gas. Lower electricity consumption will lower demand for gas from utilities and improved appliance efficiency will lower demand for gas from consumers.

This analysis also implies a third effect that will lower demand for gas. Several of the analyses that project a large increase in renewable capacity point out that this will have the effect of dramatically reducing the demand for natural gas.[78] These observations counter the price volatility fear campaign that incumbent utilities and nuclear advocates rely on to discredit natural gas. Reducing supply pressures with direct efficiency, indirect reduction in electricity consumptions and deployment of renewables would dampen any identifiable volatility,[79] which has always been overstated in any case.[80]

These estimates of electricity savings involve the near-term energy savings resources that can be tapped at current projected costs. There is technical potential well beyond these resources, which will become economic as the cost of electricity rises and the cost of efficiency drops. Figure IV-2 presents two perspectives on this proposition. The top graph shows the results of a number of state studies that fall in the mid-term time range. The technical potential is considerably higher than the near-term economic potential. The bottom graph presents the estimates of a mid-1990s review of efficiency potential. The technical potential could be substantially larger than 30 percent.

C. "NEW" RESOURCES: DEMAND RESPONSE, STORAGE AND INTELLIGENT INTEGRATION

I placed quotation marks around "new" in the title of this section to underscore the fact that, while demand response and storage have been around for quite some time, they were a small part of the 20th century model and played a minor role. In the introduction I argued that the potential transformation of the electricity system involves the movement of resources that were marginal, at best, into leading roles. The same is true of demand response, storage and intelligent integration. They move from being bit players to being important supporting actors. Their impact and importance would not only come from a much larger role, but also from providing much more important functions.

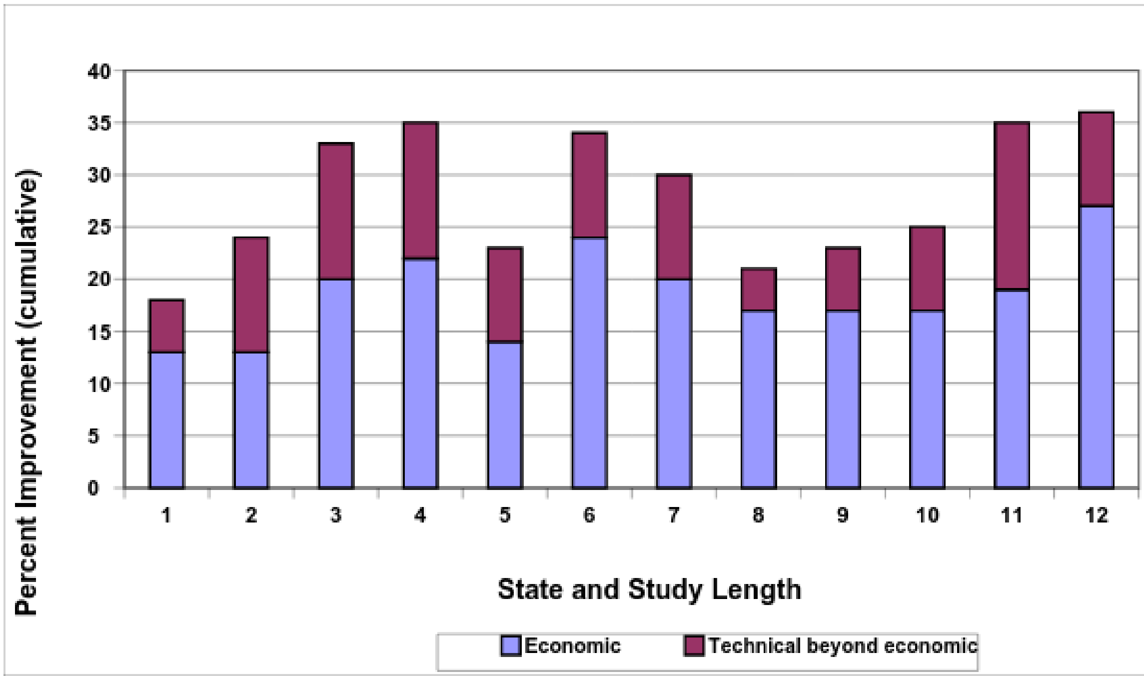
I believe that the discussion of these elements of the 21st century electricity system belong in a discussion of resources because they are closely intertwined and they produce an effective resource, sometimes referred to as a virtual power plant.[81] As a UBS analysis put

> We note some discussion in the industry around tapping multiple revenue streams for interconnected batteries. We suspect improving tariffs from power markets will continue to make such compensation possible for both the DR-like attributes in reducing peak during emergency events alongside compensation for energy and ancillary benefits provided. We suspect much of this focus will eventually mesh into the wider question of Demand Response Compensation….
>
> An alternative way to think of storage market penetration is effectively bidding into existing Demand response regimes…[82]

Demand response and storage have been around for decades, growing out of a need to manage peaks that became more intense as air conditioning spread. However, their 20th century manifestation was small, slow, inconsistent, uncertain and an afterthought. Their contemporary manifestation is quite different and widely recognized as one of the key building blocks of the 21st century electricity model. It embodies the essential active feature of the system,[83] relying on information about the state of the network delivered on a real time basis to technologies that can instantaneously control and match load with resources. As demand response and storage are built into the heart of the electricity system, they provides a range of functions, i.e. have a

FIGURE IV-2: TECHNICAL AND ECONOMIC POTENTIAL OF EFFICIENCY GAINS

State-by-State Mid-term Estimates, Circa 2005



Sources: Nadel, Steve, Anna Shipley, and R. Neal Elliot, *Technical, Economic and Achievable Potential for Energy-Efficiency in the U.S. – A Meta-Analysis of Recent Studies* (American Council for an Energy-Efficient Economy, 2004); Kushler, Marty and Dan York, *A Review of Energy Efficiency Potential Studies in the Midwest* (American Council for an Energy-Efficient Economy, December 16, 2008); Sharon (Jess) Chandler and Marilyn A. Brown, *Meta-Review of Efficiency Potential Studies and Their Implications for the South,* Ivan Allen College School of Public Policy, Georgia Tech, August 2009), p. 39.

National Long-Term Estimates, Circa 1995

Electric Efficiency Measure	Percent Reduction in Consumption
White Surfaces/Vegetation for Air Conditioning	25–50
Residential Lighting	50
Residential Water Heating	40–70
Residential Space Heating	40–60
Residential Appliances	40–60
Commercial Water Heating	40–60
Commercial Lighting	30–60
Commercial Cooking	20–30
Commercial Cooling	30–70
Commercial Refrigeration	20–40
Commercial & Industrial Space Heating	20–30
Commercial Ventilation	30–50

Source: National Academy of Sciences, Panel on Policy Implications of Greenhouse Warming, *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base* (National Academy Press, 1995), p. 55–56.

number of sources of value that are recognized in the trade[84] and academic literatures.[85]

- Demand reduction overall and at the peak through both reduction and load shifting.
- Avoided capital cost in generation, transmission and distribution.
- Efficiency through reduction of line loses, reduced congestions and transmission reinforcement.
- Ancillary services by providing reserve support for energy, standby and balancing
- Market structure, through support for renewables, reduced concentration of suppliers

The circumstances of demand response are similar to those that apply to the deployment of renewable resources described above. There is readily achievable progress in the short term and much greater potential in the long term.

> Importantly the level of DR does not have to be huge in order to realise many of the estimated benefits of this paper (e.g. 2.8% reduction in overall electricity use and a 1.3% shift in peak demand). The evidence from the literature suggests that such reductions are achievable and that there is actually potential for electricity reductions and shifts to be much greater given the right environment.[86]

The intense interest in and debate over storage highlights two critical characteristics of the current development of storage technology. Because it is important, it is attracting an immense amount of resources and entrepreneurial activity. As a result, an extremely rich technology palate of options is being created from which all the key stakeholders (consumers utilities, grid operators and policy makers) in the electricity space can choose.

Tesla's announcement of the opening of its book of orders for its "giga" battery factory stimulated a flood of articles about the imminent demise of the utility sector [87]and nuclear, in particular.[88] Talk of the threat of a death spiral of utilities had been in the air for several years.[89] While much of the press focused on the residential sector, UBS sees the near term impact of storage in the commercial and industrial sectors.[90] As UBS put it, residential deployment is more dependent on continued cost reduction and supportive policy.

> Batteries delivered at an economically competitive price are the holy grail of solar penetration, and we believe the industry will begin deploying on a large scale within the next ~5 years or less. We expect battery deployment to occur primarily where there is a clear economic rationale. One of the clearest examples is commercial scale battery deployment, which is already occurring today in several countries. Commercial customers are often subject to demand based charges, which can account for as much as half of the electric bill in some months. We think companies with differentiated battery solutions coupled with intelligent software and predictive analytics that work with the grid to avoid these charges and smooth electric demand will pave the way for mass adoption. Additionally, we expect utilities worldwide to pursue batteries on a large scale as costs drop over the next several years and renewable/intermittent generation deployments increase. Residential customers without proper pricing mechanisms in place (for example, peak demand charges) are unlikely to pursue energy storage in the short term,

> although we believe solar leasing companies and other energy service companies could shift towards offering batteries as part of energy packages designed to integrate more intelligently with the grid and address utility concerns around distributed generation.[91]

RMI looked at the economics in all sectors as building the potential for grid defection. [92] While others like RMI also see commercial PV with storage as leading, they do not see residential all that far behind. Deutsche Bank takes a similar view. It sees grid parity in two-thirds of the states with over three quarters of demand in 5 to 10 years. Both of these analyses that are optimistic about residential solar underscore the importance of policy.

The debate over which storage technologies tied to which renewable resources will be the leading edge is instructive not because of the uncertainty between different types of storage technologies. Its import lies in the existence of multiple applications and services that storage provides, driven by dramatically declining costs, and the resulting confidence that storage can play a much larger roles in in the 21^{st} century electricity system. Regardless of which technologies, among a dozen, takes hold and which sector leads, there is in no doubt that storage will play an important role in the 21^{st} century electricity system.[93]

Moreover, while much of the analysis of storage (certainly when it is tied to residential PV systems) focuses on the private costs and benefits, some have argued that there are public benefits that need to be considered.[94] These benefits include reduction in production, investment and outage costs and improved reliability. The analysis conducted by the Brattle group for a Texas distribution utility found that the system-wide benefits constituted a significant part of the total benefit (30%-40%), enough to tip the scale in favor of much larger investment than would be driven by private incentives alone. Policy to capture those benefits in an effective manner and share them "fairly" is the focal point of attention in a vigorous debate over rate structure, incentives and stranded costs.

Demand response and storage are two of the key elements in the active 21^{st} century electricity system. In the next section I will discuss the full array of elements. Here it suffices to say that the reduction of use of generation through intelligent management is estimated to be in the range of 10–20 of aggregate demand and a higher percentage of peak demand. This should be considered a transformation dividend with respect to carbon reduction. The downward pressure on peak and average prices, which has been observed in systems that are partially designed (at best) to exploit this aspect of the emerging electricity system, are an economic dividend that would be reinforced by a successful transformation of the system. Thus, virtual power plants can have a substantial impact and value.

The emerging consensus is that the current physical and institutional infrastructure can handle the growth of renewables to 30–40% quite well. For example, a study conducted for PJM members that included only one of the many grid management strategies – i.e. geographic diversity of renewables, which is a natural occurrence if high levels of renewables are pursued since the resource is generally dispersed – found that 30 percent penetration of renewables is easily manageable.[95] Half-a-dozen advanced industrial countries (Denmark, Germany, Ireland, Spain, Sweden and Portugal) have achieved three times the current penetration of renewables in the United States.[96] A recent study for the European Commission found a 60% penetration of renewables to be manageable.[97] Thus, the sense of short-term crisis that utilities have sought to create by threatening to retire several reactors is contradicted by these findings and developments, but feeds into and off of the larger debate about reliability without central station generation.

The analysis of this potential transformation has progressed greatly and includes modeling a sector that captures the synergies of geographically diverse and widespread renewables combined with key infrastructure components of transmission, the tradeoff[98] with storage, [99]and demand response,[100] which can lower costs and meet demand. Moreover, the magnitude of these benefits projected in these analyses are early in the process of transformation. A wide range of opportunities is opening up that can eliminate the wall between supply and demand behind which the 20th century baseload model was built. Doing so relies on the interrelationship of battery powered vehicles[101] and the smart grid,[102] the Internet of things,[103] and having multiple roles for solar power.[104]

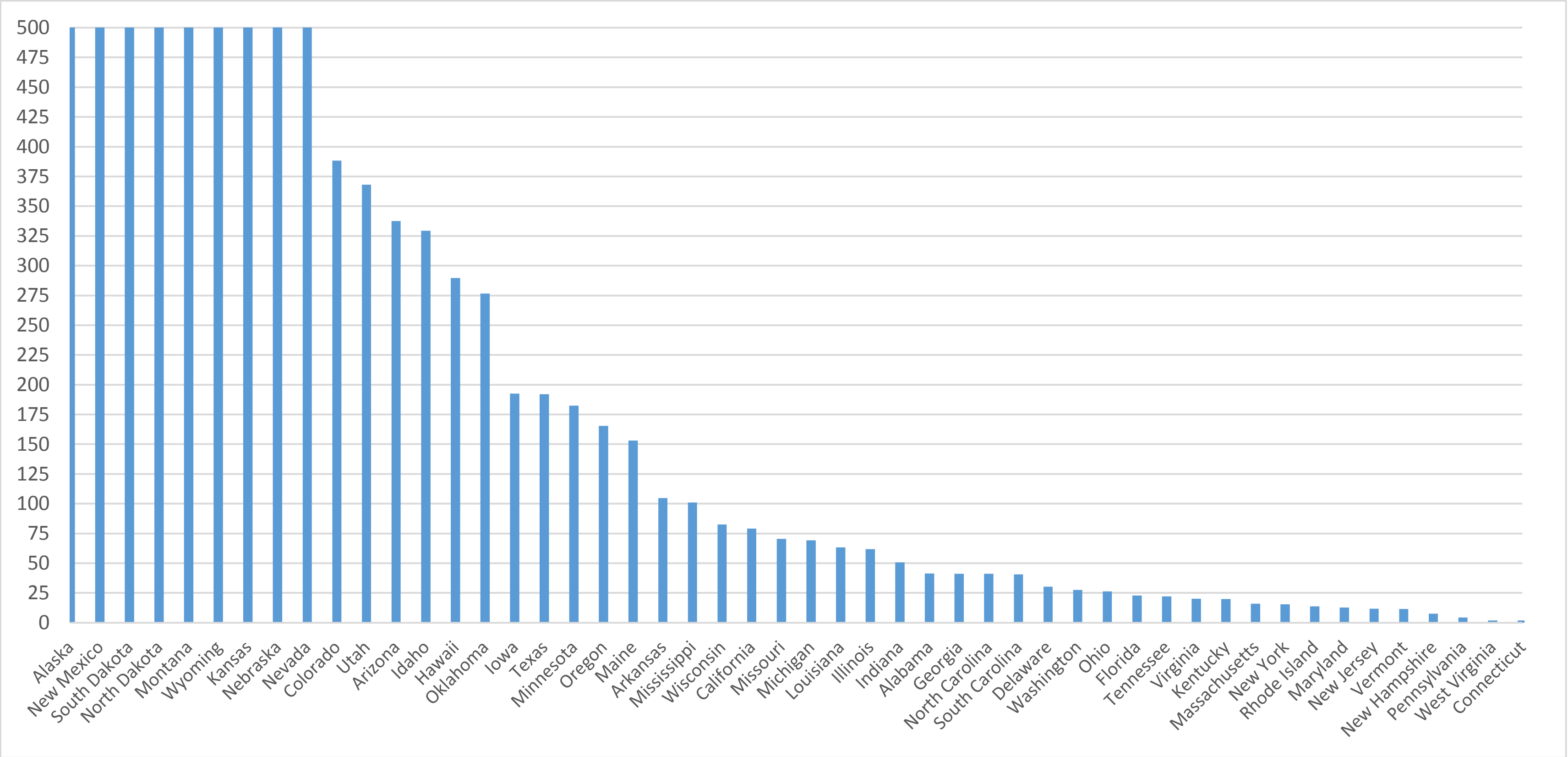
D. The Immense Technical and Economic Resource Base for a 21st Century Electricity System

As noted above, individually the technical potential of each of the resources is huge compared to the current and projected need for electricity. While the geographic distribution of resources is not uniform, combining the two major resources (solar and wind) shows that there is a wide availability of resources. Figure IV-3 presents the result of a 2012 study done by the National Renewable Energy Laboratory which is consistent with the observations of the Department of Energy and the academic literature. It shows the ratio of potential resources compared to electricity sales in 2010. The calculation of the potential was based purely on technical considerations. The load factors that underlie the study are about 20% for solar and 30%-40% for wind, which are consistent with real world experience and likely to improve over time.

For half the states the resource is more than 50 time consumption. For two thirds of the states the available resources is more than 25 times the level of consumption. There are only four states where the ratio is less than ten. However, the states that are on the lower end of the range are located in service areas (RTOs/reliability regions) with states that have much higher levels of potential resource.

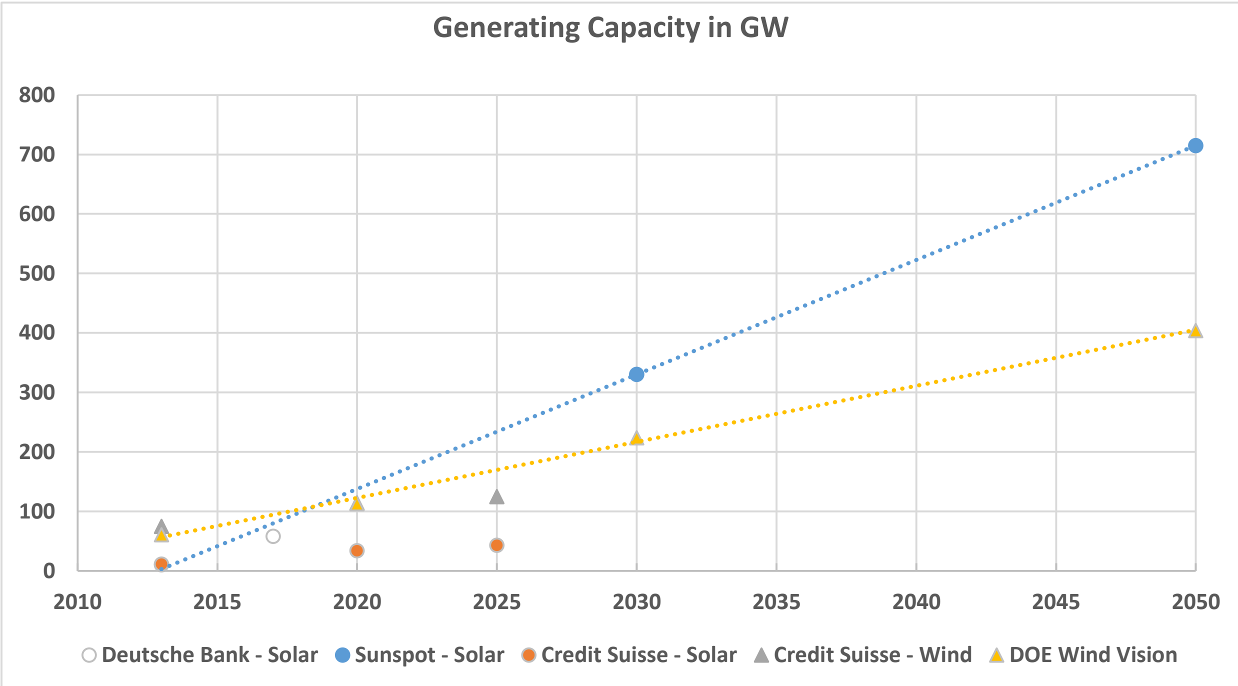
Technical potential is only the starting point for the sufficiency analysis. The economics of exploiting the resources is a vital consideration. The above discussion indicates that the role of renewables is set to expand rapidly. Figure IV-4 quantifies this conclusion. The upper graph of Figure IV-4 presents the projections of the financial analysts and the two Department of Energy “Vision” analyses in terms of capacity additions, while the lower graph presents the penetration of resources compared to demand. There is agreement in the mid-term about the deployment of capacity. In calculating the percentage of demand met by wind and solar in the lower graph of Figure IV-4, I have adjusted the projected deployment of renewable generating capacity to a projected demand that assumes efficiency cuts the rate of demand growth in half (from about 1% per year to about .5% per year). The combination of efficiency, the intelligent integration dividend and storage make this a very cautious estimate of the long term potential reduction in demand. The projected level of wind and solar for 2030 is just under 40%, which is

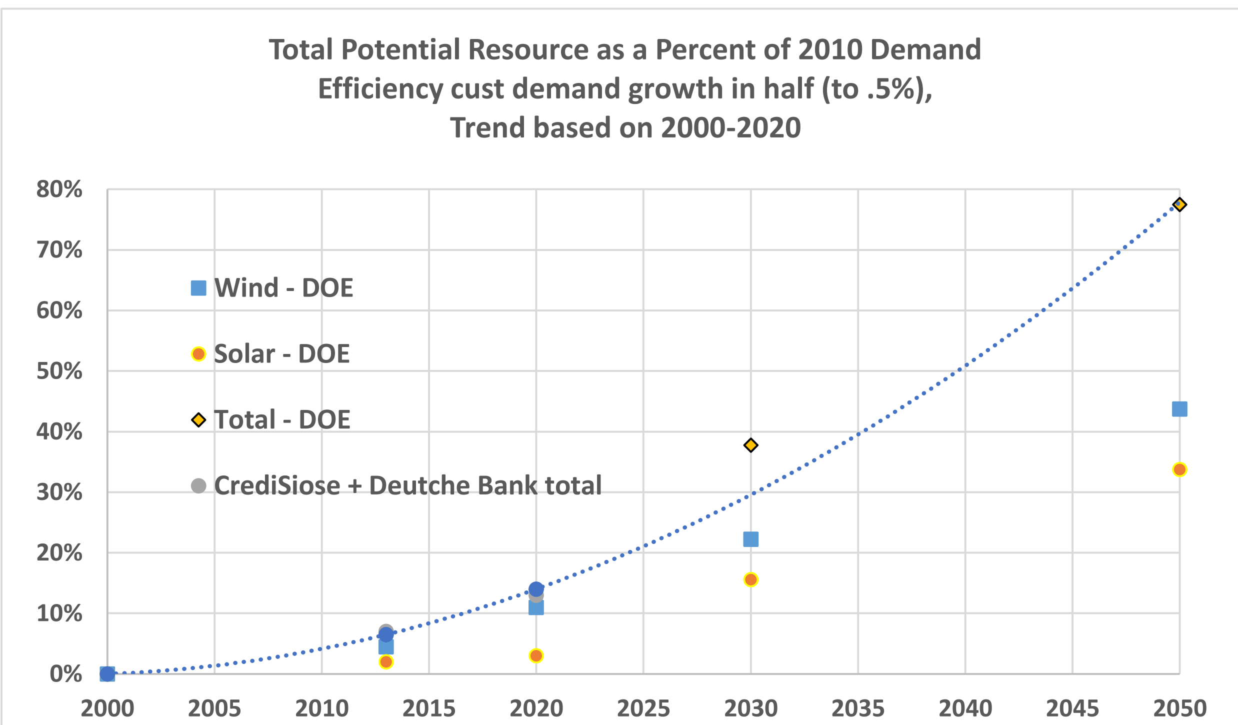
FIGURE IV-3: RATIO OF U.S. RENEWABLE ENERGY TECHNICAL POTENTIALS TO 2010 ELECTRICITY SALES



Source: Lopez, Anthony, et al., 2012, *U.S. Renewable Energy Technical Potential: A GIS-Based analysis,* NREL, July.

FIGURE IV-4: PROJECTIONS OF RENEWABLE GENERATION CAPACITY AND ENERGY





Sources: Eggers, Dan, Kevin Cole, Matthew Davis, 2014, *The Transformational Impact of Renewables*, Credit Suisse, December 20, p. 3; U.S. Department of Energy, 2015, Wind *Vision: A New Era for Wind Power in the United States*, pp. xvi, xxii; U.S. Department of Energy, 2012, *SunShot Vision Study*, February, pp. xix, xx; Shah, Vishal and Jerimiah Booream-Phelps, 2015, *Crossing the Chasm Solar Grid Parity in a Low Oil Price Era*, Deutsche Bank, February 27, p. 56; 2000 data from EIA, *Electricity Annual.*

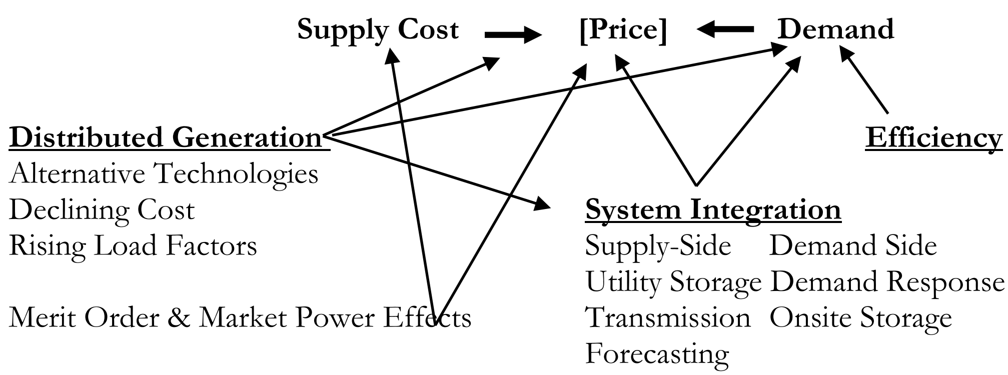
in the range in which the analysis finds is easily accomplished. The 2050 figure is just under 80%, which requires a significant degree of transformation of the system, but is deemed to be achievable.

There is no doubt that the technical potential vastly exceeds the long-term need and the economic potential is adequate to meet mid-term needs. The uncertainty comes in the continued development and declining cost of the alternative technologies and the implementation of policies to integrate the resources into a stable, reliable electricity system. These observations support the conclusion that the electricity sector is on the cusp of a major transformation. Independent financial analysts are also signaling the dramatic impact that the emergence of the 21^{st} century electricity market could have on the 20^{th} century utility business model.

V. INSTITUTIONAL RESOURCE NEEDS

Capturing the substantial economic dividend of the intelligent management on which the 21st century system rests requires that the system be built. While falling costs and rising renewable load factors are the engines that are driving change at present, as shown in Figure V-1, building a 21st century electricity system with high levels of penetration of renewables requires substantial new physical and institutional infrastructure that is centered on system integration and management.[105]

FIGURE V-1: THE TRANSFORMATION LEADING TO THE 21ST CENTURY ELECTRICITY SYSTEM



Infrastructure needs for the active, decentralized, intelligent two-way electricity system

Open resource acquisition	**True economic dispatch & net metering**	**Two-way intensive physical, informational infrastructure & smart grid management for integration & demand response**	**Cost Recovery Adequacy for Utilities Infrastructure and Management; Downsizing Benefits for Consumers**

Source: Author

Cost recovery to ensure the deployment of adequate facilities, a problem that plagues electricity markets in general,[106] can be compounded by the expanding role of decentralized resources with low operating costs. Incentives to innovate and compensation for intensive system management is a new challenge. Open resources acquisition, economic dispatch, and net metering dramatically reduce the rents available to fund nuclear construction and sustain its high capital costs. Capital outlays for new transmission assets must also be supported. The two-way, information-intensive system that allows integration and management of supply-side and demand-side resources involve an entirely different set of skills and assets that are irrelevant to central station and nuclear resources. Indeed they replace central station generation.

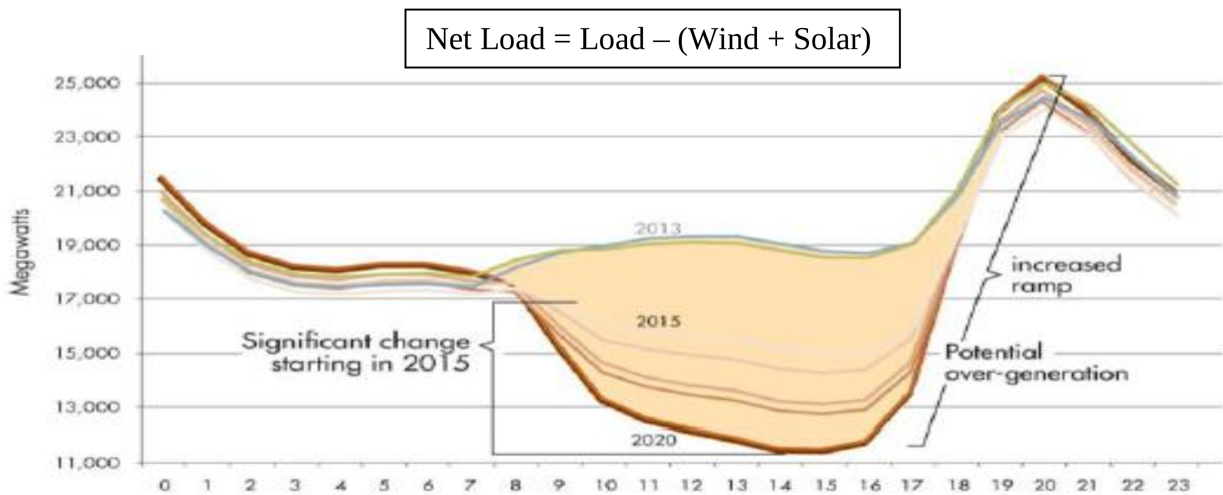
In short, the 21st century electricity system needs new regulatory structures with more sophisticated rate structures and business models to support active management and integration of decentralized, and flexible resources. The legitimate challenges of building these institutions can be exacerbated by the opposition of powerful incumbents.

One of the main challenges and fronts in the battle for the future stems from concerns about the ability of a decentralized electricity system to meet the need for electricity in a manner that matches the reliability of the 20th century model. In fact, building an electricity system around the intelligent network is not only a challenge that can be overcome, meeting that challenge yields substantial benefits, beyond just maintaining reliability. The new organizational form can actually be seen as adding resources, when viewed in the light of replacing the central station, baseload, load-following system of the 20th century. It is a better way to meet the need for electricity in a low-carbon environment.

A. MEETING THE NEED FOR RELIABLE ELECTRICITY IN THE 21ST CENTURY

The broader operational challenge of implementing the new system of active management with an expanding role for renewables has come to be symbolized in a graph that depicts the load profile of the system (it resembles a "duck," as seen in Figure V-2). When renewables enter a grid that has been built around and operated to support central station facilities and load-following peaking power, the demand for baseload power falls (the belly of the duck) while the demand for peaking power rises slightly (the head of the duck). The steep climb (ramp) from the bottom of the belly to the top of the neck of the duck is a double-edged challenge for the system.

FIGURE V-2: SOLAR'S EFFECT ON ON-GRID POWER DEMAND: THE CAISO PEAKING DUCK TRIGGERS A GROWING NEED OF FOR FLEXIBILITY STARTING IN 2015



Sources: Parker, et al., *Bernstein Energy & Power Blast: Equal and Opposite… If Solar Wind, Who Loses?* April 4, 2012, p.2; Chet Lyons, Energy Strategies Group, Guide to Procurement of Flexible Peaking Capacity: Energy Storage or Combustion Turbines?

Bernstein's research described one side of the challenge with respect to the graph in Figure V-2.

> CAISO [California Independent System Operator] Peaking Duck sounds like a delicious Asian-Latino inspired poultry dish. Instead it is the future of merchant power markets globally. The Top blue line (the buck's back) represents 24-hour demand for electricity in California in 2012. Daytime demand for power from sources other than wind and solar in 2012 peaked around midday. As more solar capacity is installed, that peak is lower in 2013 (the red line) and the forecast is that by 2020 that demand profile will resemble the green line (the duck's belly). Daytime power demand collapses.

Even in the Bernstein example, the net load to be met by non-solar resources declines by about 17 percent. Assuming that most of that load is met by fossil fuels, this represents a major reduction in CO_2 emissions. This is a feature, not a bug. The big challenge involves meeting the slightly higher peak and, more importantly, climbing the much steeper grade to reach the peak.

The solution to the steep climb that has been offered by a number of analysts and implemented in a number of nations is the use of intelligent, active management to raise the duck's belly and lower its neck (see Table V-1). NREL identifies eleven integration strategies. Lovins identifies nine measures. The Regulatory Analysis Project identifies ten policies that can be implemented in a dynamic electricity system that actively manages supply and demand, which can lower the peak by 30 percent and dramatically increase the system-wide load factor.[107] In fact, the Regulatory Analysis Project (RAP) counts "Retire inflexible generating plants with high off-peak must run requirements" as a benefit to developing the integrated system of supply and demand management. Across the studies in Table V-1 there are two dozen policies.

TABLE V-1: MEASURES TO MANAGE AN INTELLIGENT, DECENTRALIZED ELECTRICITY SECTOR AND REDUCE PEAK LOAD

Demand	**System Integration**
Efficiency	**Grid management**
Target efficiency to peak reduction	**Expand balance area**
Aggressive demand response	**Improve forecasting**
Manage water heater loads to reduce peak	**Integrated power transactions**
Smart controllers	**Import/export**
Rates	**Dispatchable storage**
Target fixed-cost recovery to ramping hours	**Solar thermal with storage**
Time of use rates	**Utility storage in strategic locations**
Supply	**Distributed storage**
Diversify renewable supply	**Community & individual storage**
Geographic (particularly wind)	**Air conditioning water heating with storage**
Technological (wind & solar)	**Electric vehicles**
Target solar to peak supply (west orientation)	**Deploy fast-ramp generation**
Re-orient conventional supply	
Shed inflexible baseload	

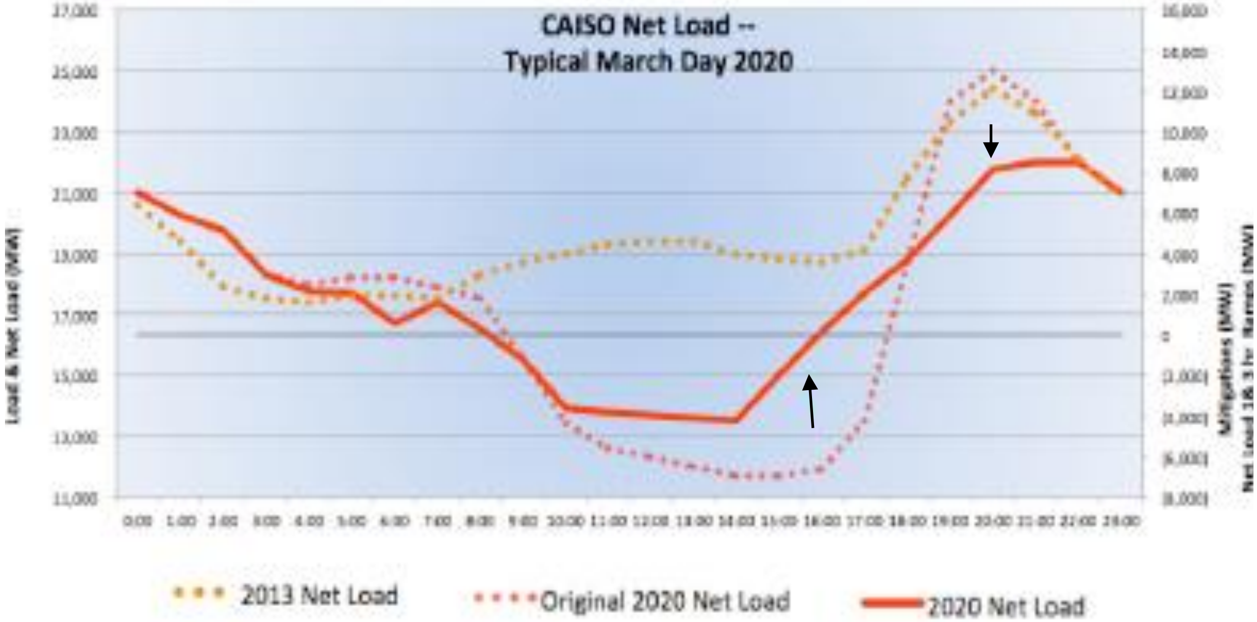
Sources: U.S. Department of Energy, *Wind Vision: A New Era for Wind Power in the United States*, 2015, p. 90, citing M. Milligan, et al., *Impact of Electric Industry Structure on High Wind Penetration Potential*, NREL, July 2009 (p. 23), E3, *Investigating a Higher Renewables Portfolio Standard in California,* January 2014. Amory Lovins, *An initial critique of Dr. Charles R. Frank, Jr.'s working paper "The Net Benefits of Low and No-Carbon Electricity Technologies," summarized in the Economist as "Free exchange: Sun, Wind and Drain,* Rocky Mountain Institute, August 7, 2014. Jim Lazar, *Teaching the "Duck" to Fly*, Regulatory Analysis Project, January 2014. Steve Nadel, 2014, *Conquering the Evening Peak,* ACEEE.

By implementing these management measures the shape of the duck becomes sleek and it is able to fly (see the upper graph in Figure V-3). The lower graph, from a study by Deutsche Bank presents the same result in a more traditional manner. The RAP Project describes the result as follows

> Thus, our modified post-renewable load is easier to serve than the actual load projected to exist would have been without the addition of renewable resources. This is desirable for almost any electric utility system, including those without significant renewable energy deployment issues.

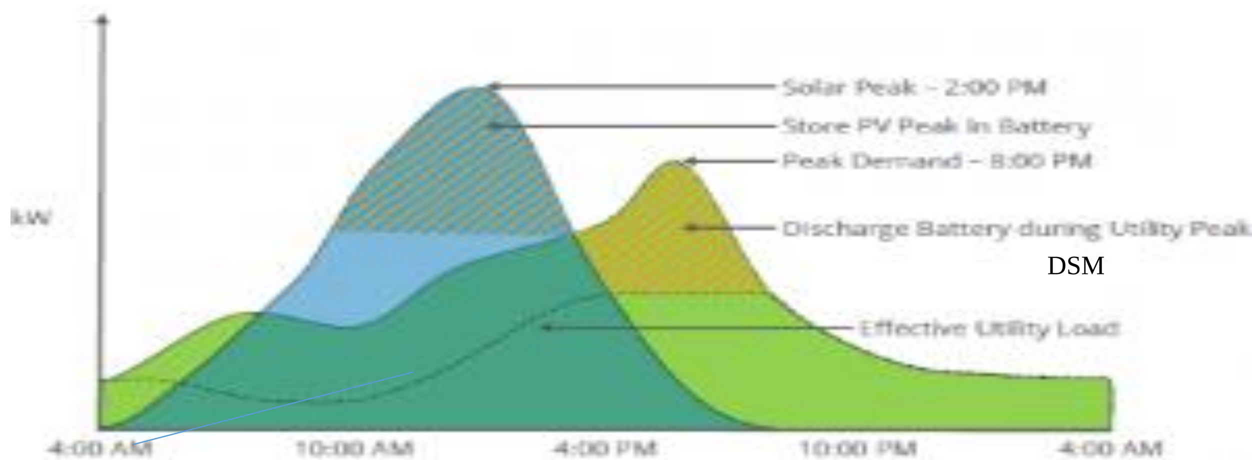
FIGURE V-3: THE BENEFITS OF ACTIVELY MANAGING RENEWABLE SUPPLY AND DEMAND

Slimming the Duck so it can fly



Sources: Clean Coalition, *Flattening the Duck,* December 16, 2013; Jim Lazar, *Teaching the "Duck" to Fly,* Regulatory Analysis Project, January 2014, pp. 21-22.

Theoretical Load Curve Reduction with Storage



Source: Shah, Vishal and Jerimiah Booream-Phelps, 2015, Crossing the Chasm Solar Grid Parity in a Low Oil Price Era, Deutsche Bank, February 27, p. 53.

It's evident that the net load (including solar and wind) after application of the ten strategies is a much more uniform load to serve from dispatchable resources even with the non-solar/wind resources than the load that was forecast for this period without solar and wind. The peaks have been lowered, the troughs raised, and the utility has control over a portion of the load to schedule when it can most economically charge water heaters, air conditioners, and batteries. In essence, the effect of the ten strategies is to reduce both peaking needs and ramping requirements.[108]

B. The Detailed Analysis of California

The evidence from detailed engineering studies and the real world experience of advanced industrial nations has continued to mount and is now overwhelming. Penetration of wind and solar to levels far beyond what is projected in base case U.S. Energy Information Administration (EIA) analysis of the U.S. or EPA's Clean Power Rule can be achieved without compromising system reliability at all. The more flexible the system is made with geographic diversity, low-cost storage, demand shaping, and technological diversity, short interval scheduling and "quick start" generation, the higher are the levels that can be achieved.

1. The LBL Analyses

The LBL has conducted a series of analyses of increasing penetration of renewables in California. Although the analysis does not include some important potential mitigation measures such as expanded trade over regional interties,[109] a series of detailed mitigation measures studied by Lawrence Berkeley national Laboratory concluded that

> Taken together, these scenarios indicate that relatively high penetrations of total VG [variable generation] can be achieved using combinations of wind and solar technologies while maintaining or even enhancing the value of the wind/solar generation compared with the value of using single wind and solar technologies in isolation.[110]

In the LBL analysis, a "relatively high level" is a mix of wind and photovoltaics to 30–40 percent, with wind generally making a contribution that is 2 or 3 times are large as solar,[111] and central station solar with 6 six hours of battery storage potentially adding an additional 20 percent, within the constraints of maintaining the reliable operation of the system as base case levels. This conclusion is based only on an evaluation of the economic value, measured as "avoiding the capital investment cost and variable fuel and O&M costs for other (fossil-fuel-based) power plants in the power system."[112] The baseline total cost for the fossil fuel plant is \$70/MWh, which is close to the "unabated" natural gas cost discussed in Section II. This is essentially the economic resource value of renewables, demand management and unabated gas base.

The analysis shows that the technical and economic processes by which policies work to mitigate the impact of variability are straight forward.

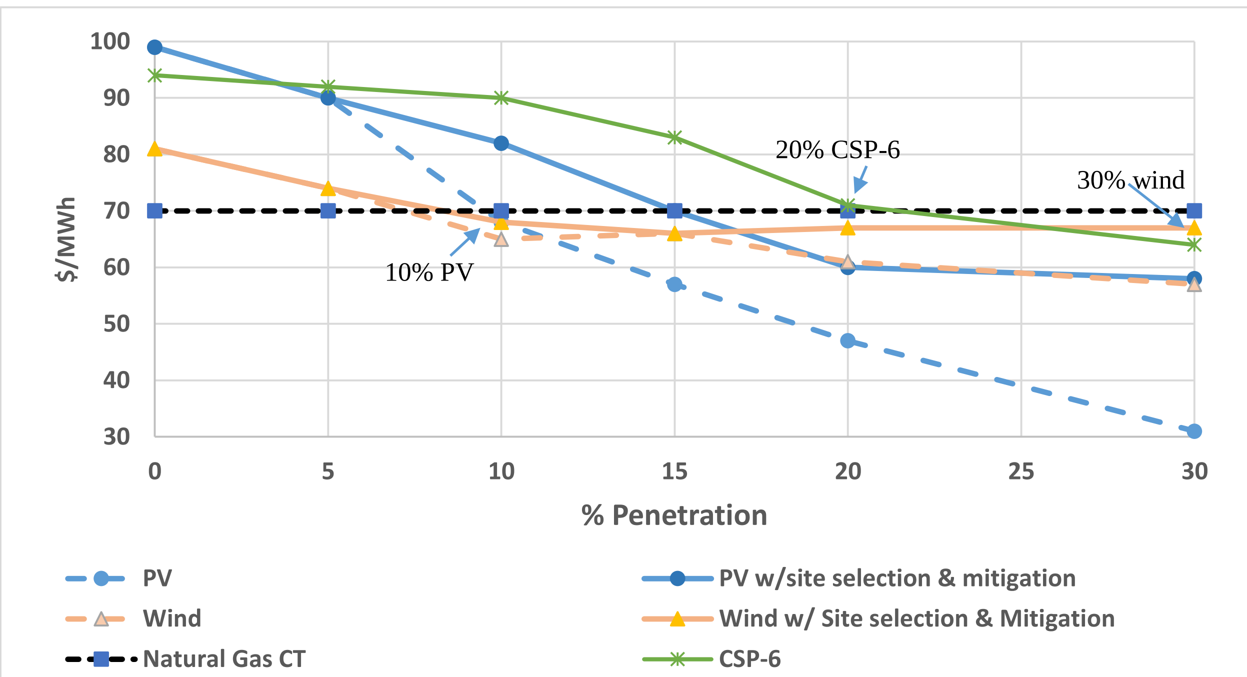
- Geographic diversity, particularly for wind, reduces extremes of generation, high or low output.[113]
- Technological diversity fosters a better fit with load.[114]
- Storage allows more energy to be captured and used when needed,[115] both by reducing curtailment[116] and by increasing demand (and therefore prices) during slack periods.[117]
- Demand shaping allows a better balance between supply and demand.[118]
- Flexibility is a key attribute, achieved by

- sub-hourly scheduling to reduce the magnitude and impact of forecasting error,[119]
- "quick start' generation[120] or
- through a portfolio approach that uses a mix of generation assets that can reduce the need for flexibility of individual assets.[121]

- Exploiting the best sites for renewable resources yields much larger economic value, three time the average.[122]
- The value of mitigation measures increases as the penetration of renewables does.[123]

Figure V-4, shows the value of renewables in the LBL study when sites are chosen economically (the best sites first for wind and solar) and mitigation measures are adopted and implemented to maximize value. The highest three valued mitigation measures are counted and assumed to be implemented in a manner that makes them additive, which is the same assumption used by the utilities in their California study.[124]

FIGURE V-4: VALUE OF WIND AND PV AT VARIOUS LEVELS OF PENETRATION AND UNDER DIFFERENT ASSUMPTION ABOUT POLICY: CALIFORNIA CASE STUDY



Sources: Andrew Mills and Ryan Wiser, *Changes in the Economic Value of Variable Generation at High Penetration Level: A Pilot Case Study of California, 2012, p. 7;* Andrew Mills and Ryan Wiser, *Strategies for Mitigating the Reduction in Economic Value of Variable Generation with Increasing Penetration Levels,* 2014, pp. 3, 5, 39, 40.

The declining "value" of renewables as penetration increases without mitigation is a common finding in these studies, since production is out of sync with load, but the dramatic increase in value with mitigation is also a common finding, since mitigation allows a better fit with load. Since the LBL study gives us a flat fossil baseline, we find that a combination of 30 percent wind and 10-15 percent PV yields a value close to the flat fossil baseline. Adding CSP with six hours of storage up to 20 percent puts renewables at almost two-thirds of total generation at a value equal to the flat fossil baseline, without reducing the value of the other renewables.

2. California Utility Studies

Although the utilities in California put together an analysis that takes a very different approach than the LBL analysis and seems much more ominous, close examination shows that when it introduces mitigation measures, it reaches a similar end point, as shown in Figure V-5. The utilities started with a base case of renewables at 33 percent and set up straw men of 40 percent and 50 percent PV scenarios. Not surprisingly, they find that this extreme approach produces major problems in matching supply and demand.

Consistent with the LBL analysis, however, the introduction of mitigating policies immediately solves the problem. The utility study identifies four "least regrets opportunities" and a number of opportunities for "research and development for technologies to address overgeneration."[125] Adding in three blocks of "flexibility solutions" reduces the curtailment of PV generation to the level of the 33 percent PS, which was virtually zero. The 15,000 MW of downward "flexibility solutions" is equal to 10 percent of the capacity in the "unmitigated" PV system and 15 percent of the capacity in the "mitigated" PV system. This is consistent with the RAP finding discussed above.

This level of "flexibility solutions" is in the range of the planning reserve, an equivalence that the literature generally notes. As the penetration of relatively small scale distributed technologies increases, the need for planning reserves may decline, since in the current baseload approach it is the threat of the loss of large units that drives up planning reserves. The potential for a trade-off between planning reserves and "flexibility solutions" could have a significant impact on the cost of meeting the need for electricity.

While the utility study does not model the specific "flexibility solutions" it does identify the likely primary candidates, which are the same as those modeled in the LBL analysis. The utility study represents significant challenges, but also opportunities. The four "least regrets" opportunities identified in the study include:

- Increase regional coordination,
- pursue a diverse portfolio of renewable resources,
- implement a long-term, sustainable solution to address overgeneration before the issue becomes more challenging and
- implement distributed generation solutions.

FIGURE V-5: THE IMPACT OF DOWNWARD FLEXIBILITY

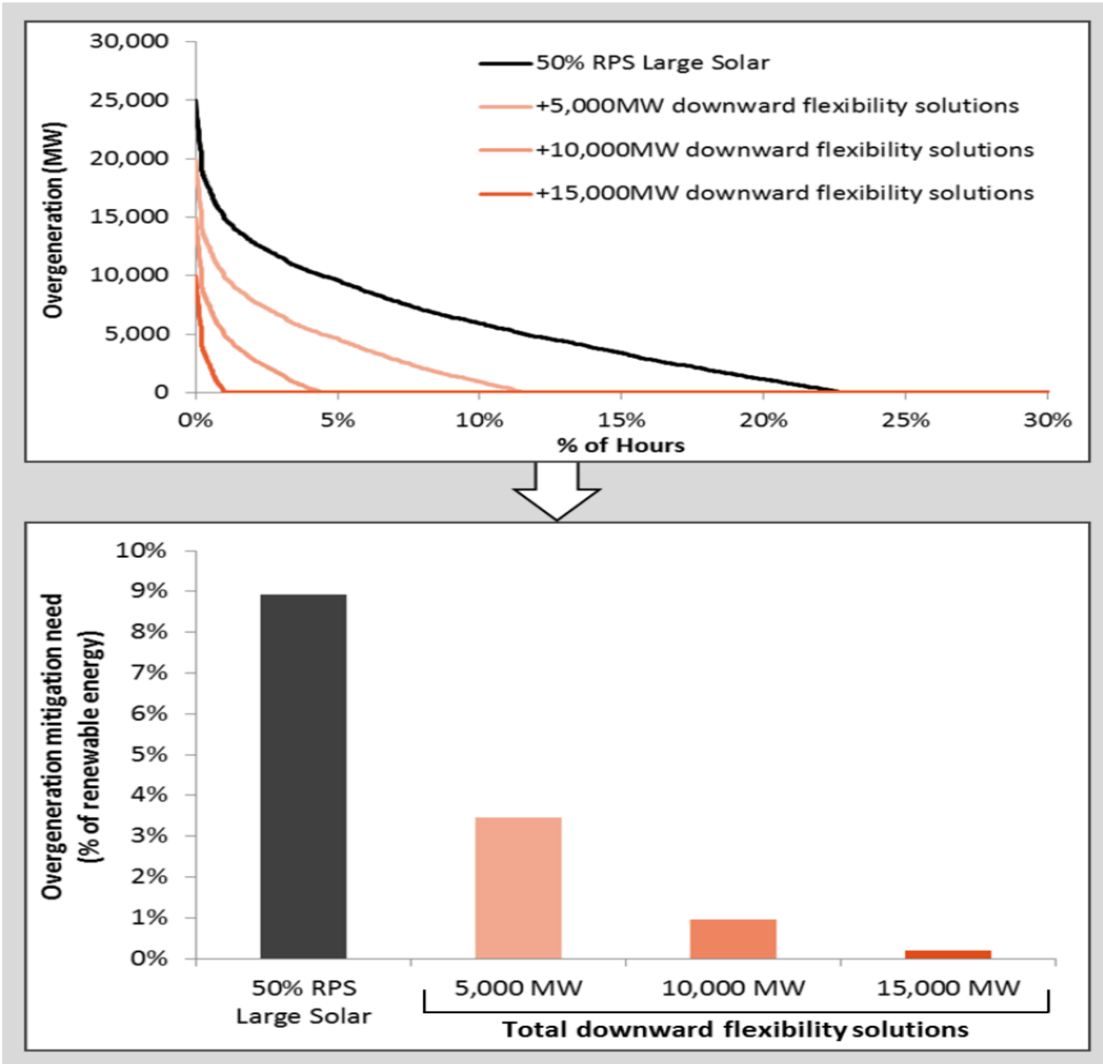


Figure 33: Adding 15,000 MW of downward flexibility solutions to the Large Solar Scenario results in roughly the same quantity of overgeneration as in the 33% RPS Scenario

Source: E3, *Investigating a Higher Renewables Portfolio Standard in California,* January 2014.

Research and development for technologies to address overgeneration are plentiful including

- promising technologies like storage (solar thermal with energy storage, pumped storage, other forms of energy storage including battery storage, electric vehicle charging, thermal energy storage) and
- flexible loads that can increase energy demand during daylight hours (advanced demand response and flexible loads).

Technical potential to implement new solutions are also available including

- sub-five minute operations,
- creating a large potential export markets for excess energy,
- changing the profile of daily energy demand and
- optimizing the thermal generation fleet under high RPS.[126]

The potential for extremely rapid balancing, innovative battery technologies and microgrids, which address the core problem of reliability in the digital age have only begun to be appreciated.[127]

The LBL study cautions that the choice of the level of renewable resources will depend on the relative cost of the resources, "determining whether to pursue technological diversity as a mitigation measure would require comparing the anticipated increase in value against the potential higher cost of building combinations of technologies to achieve the target penetration level."[128] Sections II and III showed that the current and projected costs of resources strongly favor efficiency and renewables, with the cost of storage plummeting.

The LBL analysis does "not consider many other costs and impacts that may be important, including environmental impacts, transmission and distribution costs or benefits, effects related to the "lumpiness" and irreversibility of investment decisions, and uncertainty in future fuel and investment capital costs."[129] I have shown in Section IV that the consideration of "lumpiness, irreversibility, and uncertainty" strongly favor investment in efficiency and renewables. Section VIII shows that environmental considerations do so as well. Increases in transmission costs, which might cut against renewables, are small and offset by potential distribution cost savings. The empirical evidence indicates that the cost of integration are not very large.[130]

The LBL study cautions that policy needs to be tailored to achieve some of the mitigation effects, particularly demand shaping,[131] and technology limitations need to be taken into account in system design (particularly storage).[132] The attention to specific needs, goals and limitations stems from the fact that there are so many options that can be used to ensure reliable supply. It is not a question of whether reliability can be maintained, but choosing the least cost way to do so and the costs can be quite small, far less than the resource cost difference between nuclear and the other low carbon alternatives.[133] In the face of this evidence, claims that renewables will harm the reliability of an electricity system that is designed to accommodate high levels of renewables are simply wrong. They ignore the real world and are driven entirely by politics, not scientific evidence.

I show in the next Section that efforts to create a crisis of reliability in the short term are also misguided. The electricity system is already designed to handle much larger shifts in the resource mix or demands placed on it than the orderly development of high penetration of renewables would impose on the system. Simply put, with sensible and efficient policy, the current electricity system can easily get to much higher levels of penetration of renewables and efficiency, while the physical and institutional foundation for much higher levels is built. In fact, the Department of Energy put it quite simply in concluding that wind could reach very high levels of penetration, "Wind generation variability has a minimal and manageable impact on grid reliability and related costs."[134] In sum, careful analysis shows that reliability is a non-issue; the conflict is about the future of the techno-economic structure of the electricity sector in the 21st century.

3. Other Studies

California attracts a great deal of attention because it is a large U.S. electricity market with a strong commitment to shifting to renewables. It is also of interest since it experienced the largest early retirement of nuclear reactors in almost two decades. In fact, it is the largest early retirement of nuclear reactors in U.S. history. The fact that it was handled with relative ease is a good indication that early retirements are manageable. In fact, the dozens of early retirements that have occurred throughout the history of the commercial nuclear sector in the U.S. suggest that, as a general proposition, the electricity system can manage them well.

The conclusion that high levels of penetration of renewables can be achieved without undermining reliability is supported in the literature in a variety of ways.

- First, there are other studies of California[135] that reach the same conclusions, while simultaneously analyzing other U.S. areas.[136]
- Second, I have already noted that there are numerous studies of other states that support the basic findings of these California studies including very diverse areas – Texas, Mid-America[137] and the Mid-Atlantic.[138]
- Third, there are numerous studies of other nations, particularly in Europe.[139]
- Fourth, there is a great deal of conceptual work on how integration can be accomplished.[140]

There are two important points made in these studies, in addition to the fact that they support the general proposition that high levels of penetration of renewables can be achieved without undermining reliability.

First, the finding spans different types of renewables. A study that focuses on California and the independent system operator in the Midwest, MISO, finds that policies to handle high level of penetration of renewables work in both cases. The only difference is that the leading renewable resources will differ between regions depending on the richness of the resource. In the upper Midwest, wind is the economically preferred option. Nevertheless, a mix of renewable resource is preferable as penetrations rise.

Second, the findings directly and indirectly support the proposition that the cost of building and operating a system that includes high levels of penetration of renewables is quite reasonable, when policies to manage the integration of renewable resources are implemented. The literature puts the cost well below $0.01 per kwh.[141] Recalling the cost advantage that renewables enjoy today and the even larger cost advantage that they are expected to enjoy in the mid-term, this makes the 21st century electricity system the least cost approach in a low carbon environment by a wide margin.

The finding that the cost of the integration of distributed supply and actively managed demand are quite small enjoys a strong consensus in the literature, which is reflected in the DOE

Wind Vision. The DOE analysis provides a simple explanation. In the early years of the transition, costs rise slightly because new generation resources are being deployed. The increasing cost of electricity is primarily the result of the need to decarbonize the sector because aging and polluting generation must be replaced. The new generation is more costly than depreciated plant that has been deployed without concern about the external costs of climate change. This is consistent with the analysis offered by the EPA in its Clean Power Plan, which shows a slight increase in real costs in the mid-term.[142]

However, in the mid and long terms, costs fall. The aging, polluting generation would have had to be replaced without decarbonization and the cost of the alternatives has been declining due to technological progress. In the long term the cost of electricity is lower.

The DOE explicitly laid out the process in the case of transmission.[143] The *Wind Vision* analysis argues that transmission costs are constantly being incurred by the electricity system. In the early years, those costs are reallocated from supporting the central station generation (which is shrinking) to supporting the new distributed resources. There is only a slight net increase in transmission investment. As time goes on and the share of renewables grows, the transmission costs increase. However, they are complementary to the deployment of renewables, whose capital and operating costs have been declining and are much lower than the non-renewable low carbon alternatives.

This is consistent with the analysis of cost in Part I. The capital cost of nuclear reactors was always high and gets higher, relative to the renewables over time. The capital cost of fossil fuel consumption increases dramatically, as carbon capture is required for decarbonization. Given the strong trends of declining cost, the savings on the capital cost of distributed resources more than offsets the increase in capital expenditures on transmission, distribution and operation, as suggested by the *Wind Vision* scenario.

C. INCUMBENT OPPOSITION TO THE TRANSFORMATION OF THE ELECTRICITY SECTOR: NERC'S RESPONSE TO THE CLEAN POWER PLAN

This analysis has shown that the trade and academic literature, as well as real world experience indicates that following a path toward a 21st century electricity system poses no serious threat to reliability up to a 30% - 40% penetration. The same analyses have identified the specific actions that can carry the system to much higher levels of reliance on renewables. Combining these measures which allow the system to operate at high levels of penetration with the implementation of aggressive efficiency measures meets 80% of business as usual or base case demand. Adding in the transformation dividend of reduced demand would put the total above 90%. Pursued aggressively, the magnitude and timing of the transformation meets the need for an effective response to climate change.

Given this conclusion, the analysis of the EPA's Clean Power Plan from the North American Electric Reliability Corporation (NERC) provides a useful link to the discussion of the battle the incumbent utilities, led by nuclear, are fighting against this transformation. The NERC analysis is a classic example of the static, backward looking industry analysis discussed in Section II that is routinely produced in the efficiency space in an effort to derail efforts to adopt beneficial regulations. By making a series of unrealistic assumptions and assuming the worst possible response by industry the analysis purports to show that the regulation are unworkable and/or will result in huge increases in cost (see Table V-2). When it actually comes to implementing the rules, market forces and regulators overseeing the process elicit much more efficient responses.

NERC purports to show that the Clean Power Rule will undermine the reliability of the electricity system.[144] The critique of the NERC analysis shows that one can only arrive at that conclusion by making erroneous assumptions about how the current state of the grid and assuming myopic reactions by utilities, as summarized in Table V-2.[145] The critique rests on many of the effective measure that have been identified in this section as readily available to ensure the reliability of an electricity system that relies on a much larger role for renewables and demand-side measures. The NERC analysis and the critique provide a useful transition to the discussion of the attack on the 21st century electricity system launched by nuclear power, since they invoke the same erroneous assumptions and myopic behaviors to advance their arguments.

TABLE V-2: RELIABILITY IMPACT OF THE CLEAN POWER PLAN

Weaknesses in the NERC analysis	Solutions not considered by NERC
Assumptions	
Slowing growth of renewables	Growing renewables, distributed generation to reduce transmission needs, storage,
Little demand side energy efficiency	Substantial efficiency potential in utility programs private efficiency, CHP, building codes
Myopic Utility Responses	
Bulk power only, constrained response	Excess capacity, Demand response
	Waivers where appropriate
	Alternatives
	Transmission: investment incentives, operational Improvement, e.g. dynamic line ratings, adaptive line rating, topoly control optimization
	Distribution: Advanced metering, distribution automation, advanced management, optimization
Little flexibility	Compliance flexibility
	Averaging across time and space
	Head start
	Regional response,
	Market-based strategies
Natural gas supply/delivery concerns	Natural gas market improvements
	Reinforced incentives for efficient operation and savings, investment in capacity
Little coal plant efficiency improvement	Fleet improvement or redispatch, Co-firing with biomass, waste heat recovery, Cogeneration

Sources: AEE Institute, NERC's Clean Power Plan 'Phase I' Reliability Assessment: A Critique, May 7, 2015, Jurgen Weiss, 2015, EPA's Clean Power Plan and Reliability: Assessing NERC's Initial Reliability Review, Brattle Group, February; Susan Tierney, Eric Svenson, Brian Parsons, 2015, Ensuring Electric Grid Reliability Under the Clean Power Plan: Addressing Key Themes From The FERC Technical Conferences, April 2015.

D. CONCLUSION

1. A Global Perspective

In this part I have looked intensively at the positive prospects for high levels of penetration of renewables in the U.S. I have noted that similar findings have been made for other nations. Throughout Part II I have shown that the intensive analyses of two areas – the U.S. and Western Europe – and the real world experience of states or nations within those regions – lead to the strong conclusion that high levels of penetration of the 21st century model are not only feasible, but also the least cost approach to meeting the need for electricity in a decarbonized sector. Another particularly interesting case of a continental ecosystem is Australia. The analysis of the potential for renewables in Australia produces similar results as the U.S.[146] It put the technical potential of wind at 30 times 2011 consumption and solar at 200-350 times 2001 consumption.[147] The estimated cost of integration is similar to the other U.S, and European estimates – in the range of $0.005 to $0.01/kWh including transmission costs.[148]

> **The high level operational review found that operational issues appear manageable,** but it is noted that several key considerations would require more detailed investigation. Overall, the transmission network would require significant expansion to transport renewable generation to customers and significant management of the transition to 100 per cent renewables.
>
> **Considerable PV generation in all four cases drives demand and load pattern changes**. Based on the modelled PV generation levels the NEM is likely to become winter peaking (in contrast to most regions' current summer peak), which means managing heating loads would be more critical than the current air-conditioning loads. The PV contribution levels also (typically) cause generation availability to peak around midday, so DSP would move demand into this period rather than the traditional late night off-peak periods.[149]

The parallel is also strongly evident in looking at the least cost penetration of renewables and their cost impact. High levels (~75%) yield lower cost and lower risk, low carbon portfolios.

> In 2030, the lowest expected cost generation portfolio includes 60% renewable energy. Increasing the renewable proportion to75% slightly increased expected cost (by$0.2/MWh), but significantly decreased the standard deviation of cost (representing the cost risk). Increasing the renewable proportion from the present 15% to 75% by 2030 is found to decrease expected wholesale electricity costs by $17/MWh. Fossil-fuel intensive portfolios have substantial cost risk associated with high uncertainty in future gas and carbon prices. Renewables can effectively mitigate cost risk associated with gas and carbon price uncertainty. This is found to be robust to a wide range of carbon pricing assumptions. This modelling suggests that policy mechanisms to promote an increase in renewable generation towards a level of 75% by 2030 would minimize costs to consumers, and mitigate the risk of extreme electricity prices due to uncertain gas and carbon prices.[150]
>
> Using a commercially available modelling package, PLEXOS, we model what a transition to gas fired generation in the year 2035 would deliver and compare that to a transition to power from renewable technologies. The results indicate that a transition to gas fired generation reduces emissions only marginally and that wholesale prices will be higher than the renewable energy option.[151]

The following global resource maps support several of the observations offered in this part and they return us to the MIT study conclusion that solar should play a leading role (see FigureV-6).

The very large solar resource is clear, but wind is also quite plentiful. The U.S. and Australia are quite well endowed with solar. The areas that lack solar resources in the U.S. have rich wind resources. The South Eastern U.S. is where the renewable resources base was somewhat less than 10 times demand. Europe, which has more limited solar resources in the Northern areas has richer wind resources. The regions of the world where the overwhelming majority of people reside generally have at least one of the major nonhydro renewables in abundance. Moreover, in many of the areas of the world where the wind resource is not rich, hydro is quite plentiful. Because the resources are widely distributed, they can strengthen local economies and contribute to local energy security. Thus, the palate of potential resources is rich. The optimum portfolio will vary according to which resource is richest in a given area, but geographic, technological and resource diversity are extremely valuable, which makes broad transmission areas crucial.

The pattern of development of the renewable potential, supported by the deployment of physical and institutional infrastructure, is not only the superior economic approach, it is also the most attractive approach with respect to the challenge of climate change. The long lead times needed for central station facilities (particularly where new technologies are needed) are a severe liability with respect to decarbonization. The near and mid-term deployment of renewables to 30% to 40%, fulfills the need to move quickly to decarbonize the electricity sector. The deployment of the necessary infrastructure will support the achievement of the long-term decarbonization goal with much higher levels of renewables and efficiency.

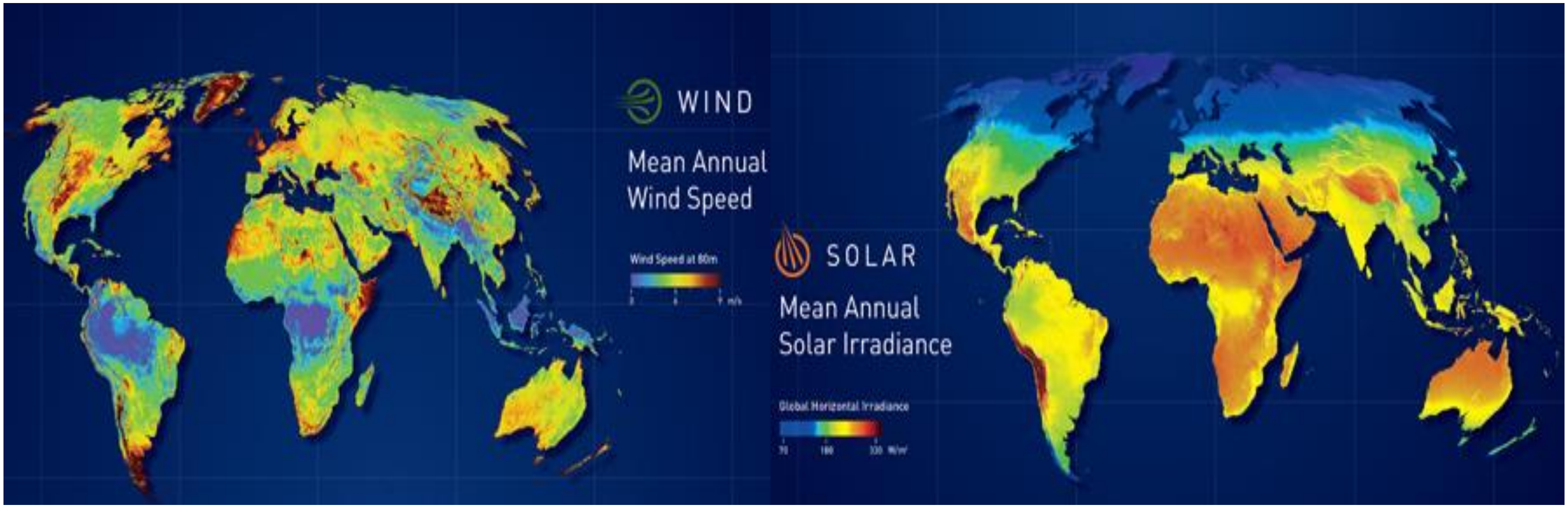
2. A Local Perspective

Jacobson and Delucchi, et al.,[152] among the early leaders of the analysis of electricity systems based on 100% renewable resources, have recently taken that analysis to a much more refined level, developing a model that uses current and projected resource costs, estimates of resource potential and the increasing knowledge of integration to specify 100% renewable scenarios for the 50 individual states, with models for 139 nations underdevelopment.

The upper graph in Figure V-7 shows the levelized cost for more than two dozen resources. These estimates include the cost of integration, particularly the expansion of transmission. Because efficiency plays an important role in the overall scenario, I have added in the cost of efficiency from the earlier analysis assuming a slight upward trend over the long term. I have also included, as earlier, two higher estimates of the cost of nuclear because the underlying assumptions involve a very short construction period and a declining cost trend that has no basis in the history of the commercial nuclear industry.

Efficiency and renewables are much lower in cost than the central station alternatives and result in a lower cost, low carbon sector. Renewable powered peak resources (solar thermal and CSP with storage) are low in cost. The scenarios also find that “stand alone” types of storage would be cost effective on an as needed basis. Even under the extremely optimistic nuclear cost

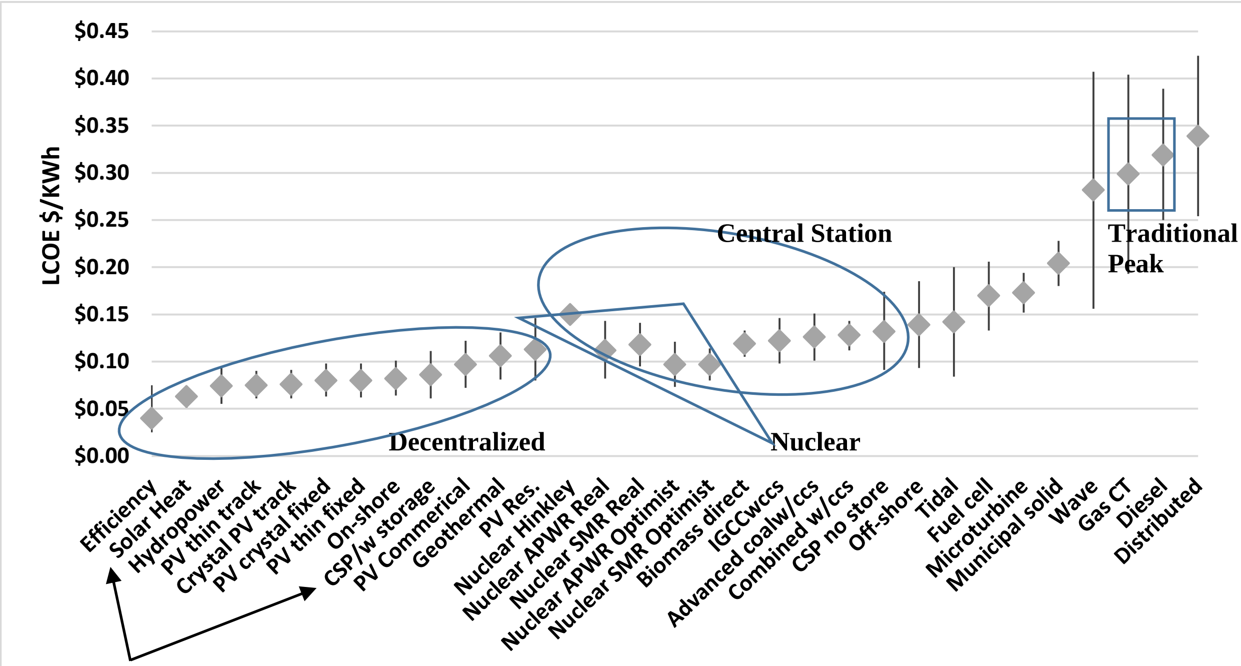
FIGURE V-6: GLOBAL WIND AND SOLAR RESOURCES



3tier.com/en/about/press-releases/3tier-completes-remapping-wo...

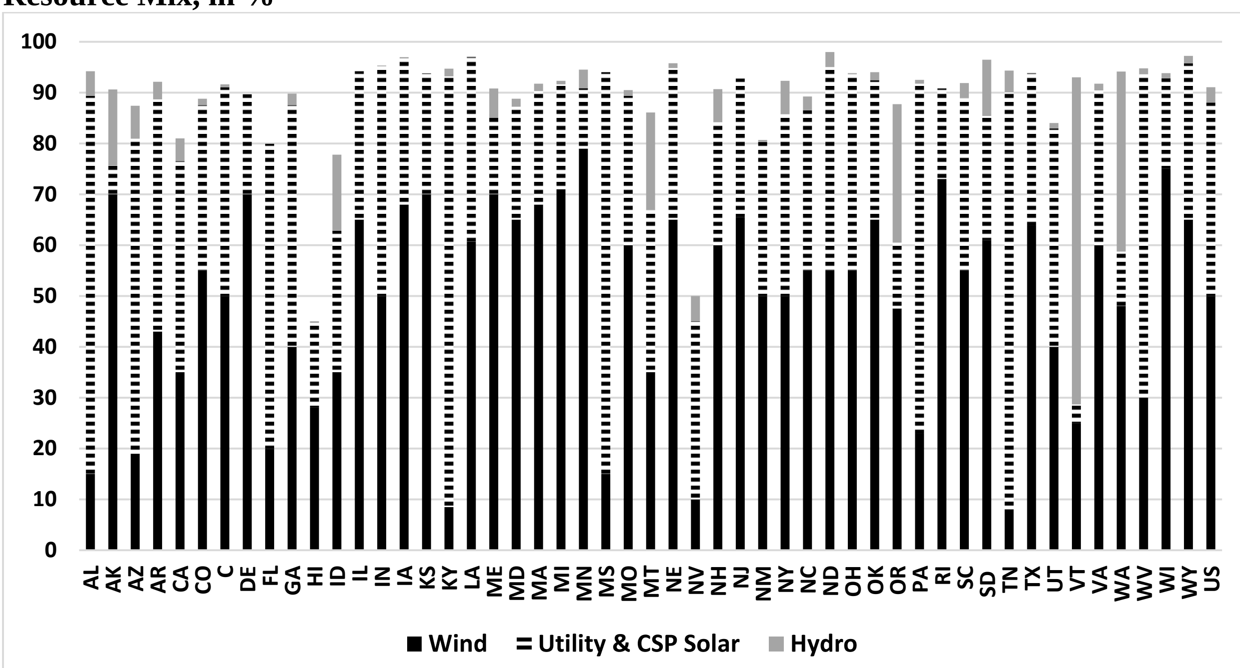
Figure V-7: Cost and Resource Mix for 100% Renewable Scenario

LCOE, 2050



Renewable Powered Peak

Resource Mix, in %



Mark Z. Jacobson, et al., 2015, "100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States," *Energy & Environmental Science,* Table 5,Table 3.

assumptions, the analysis builds 100% renewable portfolios that are 7% lower in cost than the conventional generation low carbon scenario.

The lower graph in Figure V-7 shows the mix of resources on a state-by-state basis. Wind, large solar (utility scale PV and CSP with storage), and hydro combine to meet the vast majority of the need in all but three states. The graph captures the important role that the richness of the local resource plays in defining the least-cost mix. The ratio of wind-to-solar varyies widely, which is what has been observed in studies of individual nations as noted above. The three states where those resources play a relatively small role occur where the geothermal resource is rich (Hawaii, Nevada and Idaho).

The opportunity to build the 21st century electricity system centered on distributed, renewable resources and actively managed demand is very real and very attractive. As discussed in the next section, it is also very threatening to and adamantly opposed by incumbent interests grounded in the central station model.

PART III. THE NUCLEAR WAR AGAINST THE FUTURE

VI. THE ATTACK ON RENEWABLES: THE PRIMARY DIVERSIONARY TACTIC, RELIABILITY

A. CREATIVE DESTRUCTION AND CONSTRUCTION

The analysis in Part II leads to the conclusion that the electricity sector is on the cusp of a major transformation, which will have major implications for the structure of the sector. It is part of the rapid and continuous process of creative destruction and construction that typifies advanced market economies, particularly as technological revolutions unfold.[153] The process of creating a new technology paradigm destroys the old one, although it can unfold over decades. Independent financial analysts are signaling the dramatic impact that the emergence of the 21st century electricity market could have on the 20th century utility business model.

> Investors beware: Distributed generation (DG) could kill utilities as we know them today. It could take a decade or more in the United States, but some European utilities already are facing change-or-die challenges due to DG. Technologies such as rooftop solar reduce the value of utilities' century-old centralized networks, and erode their efficient-scale competitive advantage. As more customers adopt DG, utilities' costs to maintain and operate the grid must be spread across a smaller customer base, raising customer rates and increasing the economic incentive to cut the cord. The death spiral ends when investors—equity and credit—are left holding an empty purse of dormant power plants and copper wires.
>
> We think the sector's imminent demise is premature, but DG is already starting to shrink some utilities' economic moats. The electric utilities industry group Edison Electric Institute (EEI) recently identified DG as the largest disruptive threat to utilities' business models and financial health. We agree. Utilities' efficient-scale competitive advantages rely on their centralized network monopolies, but that breaks down when customers become self-sufficient competitors. The cost-of-service regulatory model that allows utilities to earn at least their cost of capital in the long run also breaks down when fewer and fewer customers are bearing the costs of maintaining the centralized network. Ultimately, utilities' earnings will shrink, cash flows will suffer, ROIC will fall, and utilities' interest and dividend payments will become less certain.[154]
>
> Change is sweeping across the plains of our energy landscape. The combination of solar leasing, advances in renewable energy storage, and the brave new world of the "Internet of Things" spell doom for utilities as we know them. Utility shares could be worth a lot less, and sooner than investors would care to recognize.
>
> The electric utility business model has remained stubbornly unchanged for much of the last 50 years. While telecoms, health care, and other industry structures have hurtled ahead -- for better or worse -- in response to our modern technological and regulatory framework, the system that powers our homes and businesses seems almost anachronistic at this point. Utilities invest in building large-scale generation plants and a transmission and distribution architecture to move power from source to end user, and then recoup costs through the rates they charge customers.[155]

It is not only high-capital cost generation that is feeling the profit pressures. "Disruptive" has become the watchword for this analysis. The Edison Electric Institute document referred to in the first quote above recognized the potential disruption.

> Recent technological and economic changes are expected to challenge and transform the electric

> utility industry. These changes (or "disruptive challenges") arise due to a convergence of factors, including: falling costs of distributed generation and other distributed energy resources (DER); an enhanced focus on development of new DER technologies; increasing customer, regulatory, and political interest in demand side management technologies (DSM); government programs to incentivize selected technologies; the declining price of natural gas; slowing economic growth trends; and rising electricity prices in certain areas of the country… the industry and its stakeholders must proactively assess the impacts and alternatives available to address disruptive challenges in a timely manner.[156]

A year later, The Edison Electric Institute formed an alliance with a leading environmental group (NRDC–National Resources Defense Council) to call for changes in tariff and rates structures that recognize the emerging reality. Their joint statement recognizes the inability/inappropriateness of recovering capital costs in variable charges and the need to transform the grid and its operation into a two-way network that supports decentralized behaviors at the edge of the network to improve the efficiency of the sector, but requires a physical and institutional transformation.

The public effort to form alliances to come to grips with the transformation of the electricity system came a year after the launch of a private effort to control and slow its harmful effect. At the highest level meeting of the industry's trade association an "action plan" [157] was launched to deal with

> "Facing the challenge of a Distribution System in Transition
>
> - Transition creates new challenges for utilities:
> - Prospect of declining retail sales,
> - Financing of major investment in the T&D system; workforce issues,
> - Potential obsolescence of existing business and regulatory models."

For the chief executives, "the challenge: How do you grow earnings in this environment." The culprits were "loss of customers" and "competition." The target of the campaign was identified as "hidden subsidies like net metering allow higher income customers to avoid system costs (pay little distribution or other fixed costs, despite the fact that they impose new costs on the system), which are then paid by middle class and lower income customers." The strategy was to "raise concerns about net metering" among customers, policy makers and regulators. The ultimate goal was to secure the utilities central role in the future utility system

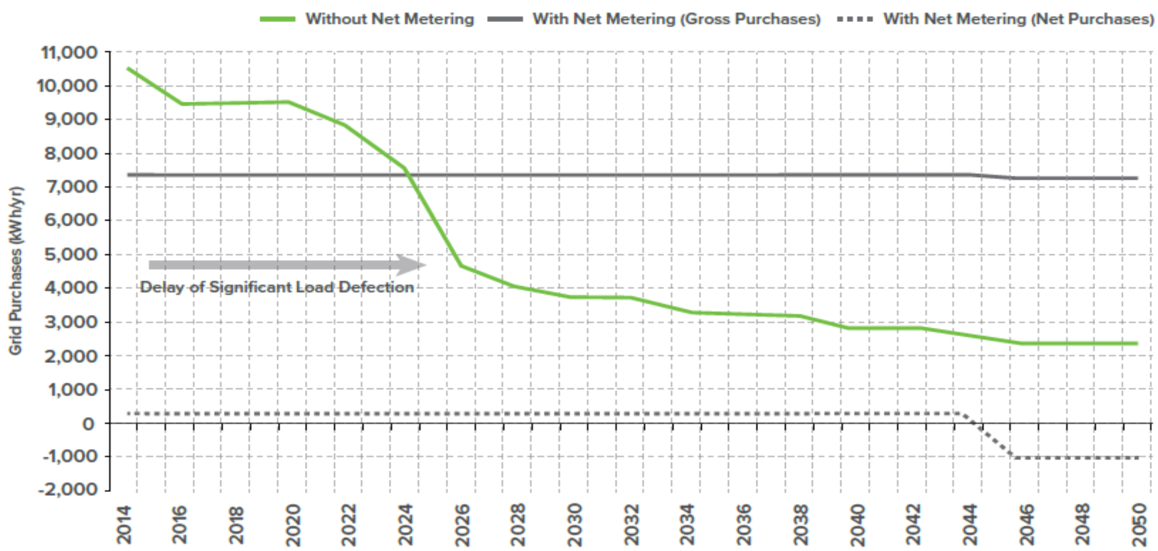
- "gain support for utility involvement in DG, microgrid space
- Promote fleet and off-road transportation applications
- Incorporate multi-site DC companies
- Provide members with DC market activities, best practices, competitive intelligence
- Siting utility-owned generation on DOD land
- Expand Utility Energy Services Contract, privatization initiatives."

The costs and benefits of photovoltaics are being hotly debated at all policy levels, but the “action plan” makes it clear that the primary goal of the response by the utilities is to defend and extend the utility role in the electricity system, not building a least cost electricity system.

B. THE NUCLEAR ATTACK ON RENEWABLES

Against this background, the Rocky Mountain Institute on *Grid Defection* is instructive. It presents an analysis that concludes that solar with battery storage will trigger a large wave of “grid defection” in 5 to 10 years. It shows that resistance to this trend by refusing to offer net metering could delay the impact by about a decade, but it will arrive in any event (see Figure VI-1). The message aimed at utilities is that their interests would be better served if they use the transition to build a system that accommodates and manages the transition, rather than being overwhelmed when it finally develops.

FIGURE VI-1: NET GRID PURCHASES WITH AND WITHOUT NET METERING: RESIDENTIAL



Source: Peter Bronski, et al., *The Economics of Load Defection,* Rocky Mountain Institute, April, 2015. p. 37.

However, one can take the opposite lesson from this analysis. If this one policy can delay the transition significantly for a decade, utilities might see this as an opportunity to protect their short-term interests and secure an alternative long-term structure. By layering a number of attacks on the alternatives and simultaneously securing policies that advance their economic interests, they can significantly delay and alter the shape of the future. This interpretation is more consistent with their behaviors and it suggests that the current battle over fundamental policies – subsidies, rate structures, deployment of physical facilities, etc., are strategic and will profoundly affect the future structure of the industry.

The Rocky Mountain Institute recognizes that whatever the ultimate outcome, if the path of greatest resistance is taken by the utility industry, there will be a significant cost and the key decision point is at hand.

These two pathways are not set in stone, and there is some room to navigate within their

> boundaries. But decisions made today will set us on a trajectory from which it will be more difficult to course correct in the future. The time frame for making such decisions with long-lasting implications for the future grid is relatively short, and is shorter and more urgent for some geographies than others.[158]

The Rocky Mountain Institute is certainly not the only one to suggest that there is a direct link between policy choices and industry structure. The baseload dominated electricity system was created by policy support and subsidies for physical and institutional infrastructure that favored a specific type of technology. The dominant incumbents will seek to slow or stop the spread of alternatives by deny their access to a similar process that they understand well.

> Their diffusion can be slowed by effects of path dependence and lock-in of earlier technology systems…. high carbon technologies and supporting institutional rule systems have co-evolved, leading to the current state of 'carbon lock-in'. For example, reductions in cost and the spread of infra- structure supporting coal- and gas-fired electricity generation enabled the diffusion of electricity-using devices and the creation of institutions, such as cost-plus regulation, which encouraged further investment in high carbon generation and networks. This created systemic barriers to investment in low carbon energy technologies….
>
> The proposition that industries or technologies whose ascendancy is threatened by new competition tend to respond, carries some weight. It also suggests that actors, such as large energy companies, with substantial investments in the current system and its technologies, and relatively strong political influence, are likely to act to frustrate the implementation of institutional changes that would support the implementation of low carbon technologies.[159]

The economic conflict of interest between nuclear power and the lower-cost, low-carbon alternatives is reinforced by fundamental differences between central station power and distributed resources in terms of technological competence and institutional requirements. In short, this clash is inevitable and has given rise to a frontal assault by nuclear advocates on the alternative resources and institutions that will support them (see Table VI-1).[160]

Lovins had earlier elaborated on the deep-seated sources of conflict, making it clear that a truce that tries to accommodate both sides is neither very likely, nor good policy.

> "All of the above" scenarios are… undesirable for several reasons…. First, central thermal plants are too inflexible to play well with variable renewables, and their market prices and profits drop as renewables gain market share. Second, if resources can compete fairly at all scales, some and perhaps much, of the transmission built for a centralized vision of the future grid could quickly become superfluous. Third, big, slow, lumpy costly investments can erode utilities' and other provider's financial stability, while small, fast granular investments can enhance it. Competition between those two kinds of investments can turn people trying to recover the former investments into foes of the latter – and threaten big-plant owners' financial stability. Fourth, renewable, and especially distributed renewable, futures require very different regulatory structures and business models. Finally, supply costs aren't independent of the scale of deployment, so PV systems installed in Germany in 2010 cost about 56–67% less than comparable U.S. systems, despite access to the same modules and other technologies at the same global prices.[161]

TABLE VI-1: THE NUCLEAR INDUSTRY'S BROAD ATTACK ON RENEWABLES

	Federal	States
Direct (Attack Programs that Support Renewables)		
Renewable Energy Production Credit[1]	X	X
Renewable Energy Portfolio Standard[2]	X	X
Efficiency Portfolio Standard[3]	X	X
Net Metering		X
Taxes and Fees[4]	X	X
Indirect (Implement Programs to Support Nuclear)		
EPA Rule Bias[5]	X	X
Wholesale market manipulation		
Above Market/Guaranteed Rates	X	X
Alter dispatch order to favor base load [6]	X	X
Restrict Demand Response[7]	X	X

Notes:
1 General opposition to and specific cutbacks in renewable commitments.
2 Includes shifting from "renewable" to "clean" standard.
3 General opposition to and specific cutbacks in utility efficiency programs.
4 Taxes on renewables, Minimum Offer Price Rules.
5 Allowing subsidies and incentives for nuclear. Giving system benefits for reliability, onsite fuel storage.
6 Must run rules/Take or pay clauses.
7 Opposition to bidding demand response in wholesale markets.

Source: Nuclear Information and Resource Service, *Killing the Competition: The Nuclear Industry Agenda to Block Climate Action, Stop Renewable Energy, and Subsidize Old Reactors,* September, 2014

Since marketplace evidence indicates clearly that new reactors have long been uneconomic and aging reactors have become uneconomic, nuclear advocates now couch the plea for above-market prices for nuclear and the attack on alternatives in other terms that divert attention from the both the short term (merit order) and the long term (levelized cost) measures of resource cost. They claim some "hidden" value for central station power, while rejecting alternative approaches to realizing that value. This is a diversionary tactic.

The most prominent is the claim that there is a need for baseload generation to maintain the reliability of service. This argument can even be expressed in a way that extends the support to coal-fired generation. Nuclear advocates combine the reliability claim with the need to reduce carbon emissions to reach the conclusion that nuclear is indispensable to the effort to respond to climate change. A second diversion is to debate current explicit subsidies enjoyed by alternatives, while ignoring the much larger explicit and implicit subsidies enjoyed by nuclear over more than half century. The third diversion involves claims about the non-energy benefits of nuclear power in terms of macroeconomic impacts and the effort to have nuclear defined as a clean, environmentally beneficial resource.

These efforts to divert attention from the economic fundamentals do not withstand close scrutiny. The reliability diversion is examined in this section. The subsidy diversion is discussed in the next section. The clean resource diversion is examined in the final section.

C. THE FALSE RELIABILITY CRISIS: EXELON'S NUCLEAR BLACKMAIL

In Part II I showed that reliability challenges are entirely manageable as the 21st century electricity system is deployed. In the context of the attack on renewables, the reliability issue has taken on two aspects. The threat to close several aging nuclear reactors immediately is intended to create a sense of immediate and urgent crisis, which gives the reactor owners leverage over policymakers. In the mid- and long-terms the reliability issue involves the ability of the grid to be managed with much higher levels of distributed generation and renewables. The previous section has looked at the long term issue. This section examines the short-term and mid-term issues. It leads to similar conclusions. In both cases the reliability crisis/challenge proves to be more fiction than fact. The two case studies in this section are: (1) Exelon's threat to close a number of nuclear reactors and its pursuit of subsidies, which triggered an intensive analytic exercise in Illinois that gives insight into the short term issues. (2) PG&E's application for a license renewal for Diablo Canyon, 10 years before the expiration of the current license, provides an ideal opportunity to look at the mid-term issues.

1. Responses to the Threat to Precipitate a Crisis

The refusal of the Illinois legislature to be stampeded into providing a new subsidy for aging reactors and the decision to get the facts before bailing out the aging nuclear reactors sheds a great deal of light on the problem. The State of Illinois agencies' analysis of the early retirement of aging nuclear reactors in response to Exelon's efforts to secure subsidies for its aging reactors indicates that there is no crisis that merits rate increases of billions of dollars over the next decade. The analyses commissioned by the legislature show that a prudent approach to the orderly, early retirement of uneconomic, aging reactors is preferable.

First, from either the reliability or carbon reduction points of view, the amount of at-risk nuclear power is not large enough to warrant immediate subsidization. At present, the level of distributed resources in the United States is well below the threshold where reliability concerns might arise. There are a host of approaches to managing the grid that would ensure reliability even as the share of distributed resources rises substantially.[162] Therefore, it takes a set of worst-case assumptions devoid of alternative foresight, planning, and preparation to yield a hint of concern about reliability in the near term.

> [R]esources in both RTOs are adequate in the "base case," and continue to be adequate when the at-risk nuclear plants are retired in the "nuclear retirement case." In MISO resources remain adequate if the nuclear plants are retired even if there is a "polar vortex" event, but not in the "high load and coal retirement" case. On the other hand, resource adequacy is substandard in PJM in both stress cases; but demand response mitigates the problem in the "high load and coal retirement" case. (Demand response is comprised of resources that can reduce demand during emergencies, such as interruptible load and direct control load management, and counts as capacity that can be used to maintain reliability.) Cases 3 and 4 are both extreme and would almost surely show degraded reliability even if the nuclear plants had not been modeled as retired prematurely…. The reliability index (LOLE) values for portions of MISO and PJM within Illinois – three MISO Local Balancing Areas and one PJM transmission zone… are not violated in Illinois in any case, except for the "high load and coal retirement" case in PJM, and in that case the problem is mitigated by demand response. The IPA attributes the superior resource adequacy in Illinois, even given the premature closures of the nuclear plants, to its initial capacity surplus and to its robust transmission system that enables Illinois to call on out of state capacity support.[163]

Second, to the extent that the early retirement of several reactors might put pressure on the electricity system, the Illinois analysis found that there are responses available and it is not an Illinois-specific problem, but a regional problem. In some senses, such an event immediately triggers mitigating responses. "Thus, the eventual closure of a generating facility could be accompanied by a variety of actions by the affected RTO to alleviate reliability concerns."[164]

Third, the regional transmission systems have rules that require notice about decisions to abandon generation, which affords the operator and market participants time to adjust, and imposes penalties for failing to deliver on existing commitments.[165] "Usually, nuclear plant closures are not sudden unheralded events. Rather they are planned and anticipated months or even years in advance. This would be particularly true of a closure prompted by low power prices rather than a serious accident or the unexpected failure of plant equipment."[166]

To the extent that a problem might be caused by the closure of multiple reactors, it would elicit responses from other market participants to mitigate the impact. In the mid-term there are even more actions that can be taken. At the same time, the analysis notes that the transmission system has built-in mechanisms that respond to the challenge. The list of immediate potential short-term responses is quite long.

> If the retirement or suspension of the generating unit creates a reliability issue, MISO shall: (1) begin negotiations of a potential System Support Resource ("SSR") Agreement with the owner or operator of the Generation Resource; and (2) use reasonable efforts to hold a stakeholder meeting to review alternatives. The list of alternatives to consider and expeditiously approve include (depending upon the type of reliability concern identified): (i) redispatch-reconfiguration through operator instruction; (ii) remedial action plans; (iii) special protection schemes initiated upon Generation Resource trips or unplanned Transmission Outages; (iv) contracted demand response or Generator alternatives; and (v) transmission expansions. A Generator alternative may be a new Generator, or an increase to existing Generator capacity. [167]

2. Economic Cost

In fact, the Illinois analysis went beyond the focus on reliability to consider the impact of a reactor closure on the economics of the system. Not only did it conclude that response mechanisms would be driven by basic economics, but it noted that the overall impact could be positive, if more economic resources are brought online.

> Such actions would also have the effect of increasing the supply or availability of other generating resources or the supply of demand response resources. Such actions would moderate what might otherwise have been a sudden increase in energy market prices.[168]
>
> Even if notification of a generation owner's intent to close a generating facility does not trigger any reliability concerns, the closure's actual or anticipated impact on electric energy and capacity prices would provide an incentive for firms to construct replacement generating facilities. It would also lead to an increase in the cost-effectiveness of energy efficiency measures, which would justify additional investment in such measures by retail customers (as well as utilities and government agencies that are subject to mandates to subsidize such measures through energy efficiency programs). Furthermore, it would increase congestion on the transmission system, which could justify the acceleration of transmission system upgrades by RTOs like PJM and MISO. Together, such reactions would expand supply, contract demand, and allow for more efficient utilization of resources, all of which would ameliorate or even overcome the increase in prices due to the closure of the plant by itself. That is, in the long run, the closure of a particular power plant could reduce rather than increase prices, as newer more efficient faculties are introduced to the power grid.[169]

In the case of Exelon Illinois, the threat to abandon a large amount of capacity represents an exercise of market power[170] which would raise prices for the facilities that remain online. In fact, there is presently a surplus[171] that Exelon may be trying to drive out of the market.

The finding that there is little impact on Illinois highlights the fact that the proper level of consideration is multi-state and reliability is not the primary concern.[172] Spreading the impact across a wide area and a significant period, which gives the system time to react, results in almost no cost or reliability damage. Simply put, nuclear reactor retirement can be a non-event.

The Illinois Department of Commerce expresses the belief that, "Eventually, market forces and national policies will fully compensate nuclear plant operators for their reliability and carbon-free emissions." I have shown that the market fundamentals are pressing in the opposite direction. Indeed, the more public policy relies on "effective market-based solutions" to solve the problem of reducing carbon emissions, the less likely nuclear reactors are to be supported. In the long run supply stack of low-carbon resources, nuclear is the most costly resource.

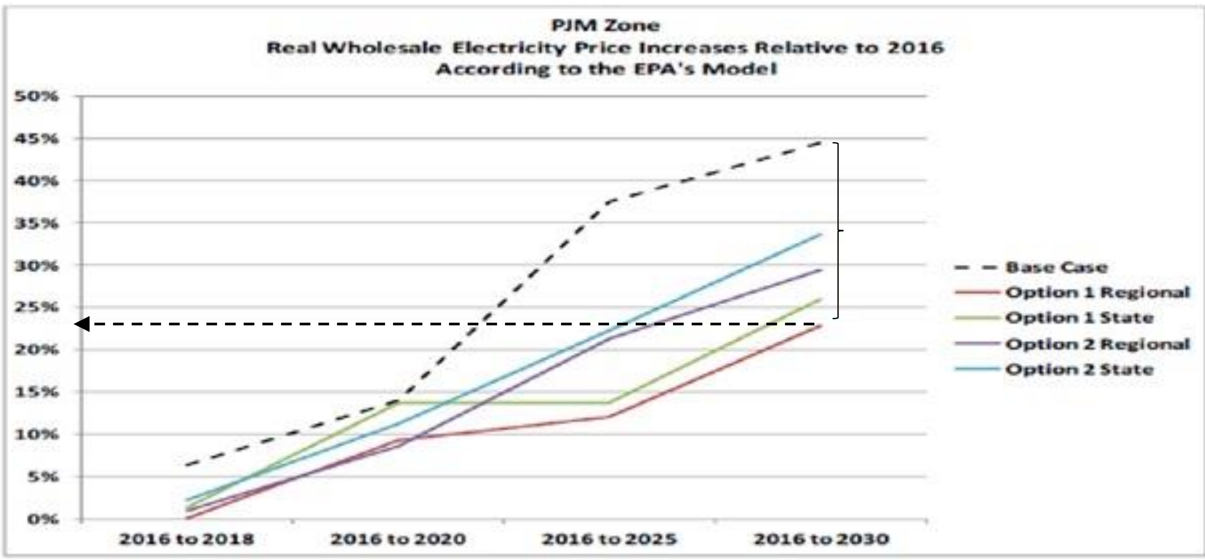
The ICC analysis provides important insight into this issue by citing an EPA analysis of the PJM Zone, into which the majority of the at-risk reactors in Illinois sell (see Figure VI-2). As the ICC notes: "The EPA conducted its own analysis of the costs of compliance with its proposed CO2 regulations." In the following chart, the "Base Case" line represents the EPA's projection of wholesale electricity prices without the rule. For the purpose of examining the early retirement of nuclear reactors, the implication drawn by the ICC is that more resources are in the offing for reactors, diminishing the need for Illinois to take state-specific action.

> Even in the Base Case, it appears that EPA modelers expect PJM Zone wholesale electricity prices to rise significantly above current price levels…. The EPA's wholesale electricity price forecasts reflect substantial increases, even relative to the first year of the EPA's own projections, as shown in the following chart: Assuming wholesale price increases of the magnitude shown above, it seems likely that eventually the profitability of Exelon's nuclear plants in Illinois would be restored.[173]

The other four line segments, which the ICC notes "represent projections of wholesale electricity prices under four different assumptions about how states achieve compliance," are of equal, if not greater importance. Keeping in mind that the EPA did not project any increase in nuclear reactor output, the fact that the other four lines are well below the base case suggests that the reduction of carbon emissions will lower the wholesale price of electricity. Emissions reduction is achieved by replacing coal using the following (in order based on the magnitude of the contribution): demand reduction, natural gas, improved coal efficiency, and hon-hydro renewables. The overall reduction in the wholesale price can be as high as 50 percent, achieved by more aggressive replacement of coal and a regional approach. An aggressive, least cost regional approach to meeting the climate keeps the price increase around 1% per year, substantially below the rate of increase in the cost of operating aging reactors. The burden of subsidizing aging reactors grows more onerous

The opportunity to reduce carbon emissions by adding resources with costs below the current average has long been recognized. In fact, the former head of Exelon, John Rowe, frequently made this argument using the carbon supply curves for Exelon and PJM.[174] The current efforts of Exelon to impair the alternatives and extract subsidies may reflect the continuing deterioration of nuclear economics. In the five years since Rowe began making the argument that there were many non-nuclear low cost approached available, the cost of wind and solar, measured by purchased power agreements, has declined dramatically, 50% or more. The cost of nuclear construction and aging reactor operation, on the other hand, has increased substantially. Rowe was ahead of his time, as efficiency has been joined by wind and some solar to be less costly or competitive with natural gas, not to mention nuclear.

FIGURE VI-2: THE EFFECT OF LOW-COST, LOW-CARBON RESOURCES ON PRICES



Source: Illinois Commerce Commission, Illinois Power Agency, Illinois Environmental Protection Agency, Illinois Department Commerce and Economic Opportunity, 2015, *Response To The Illinois General Assembly Concerning House Resolution 1146*, January 5, p. 46.

My cost analysis shows that the savings could be substantial if more efficiency and wind are used in the near-term and more solar is used in the mid-term. The fact that carbon reduction lowers expected costs without any increase in nuclear bodes ill for the hope that "market forces" and "effective market-based solutions" will bail out uneconomic aging reactors. The more likely outcome should policy makers choose to keep nuclear with its uneconomic costs in the low carbon portfolio would be to saddle Illinois ratepayers with permanent, increasing subsidies for aging reactors. The frantic push for states to bail out these reactors when a response at the regional level is more appropriate (if a reaction is needed at all) will saddle state ratepayers with much larger burdens.[175] The ICC analysis ends with a more precautionary note.

> When evaluating the solutions included in this report and any alternatives offered by stakeholders, holistic solutions aimed at solving fundamental market challenges are preferable. The right energy policy has the potential to minimize rate increases to families and businesses while positioning Illinois as a national leader in the development of clean energy. As neighboring states address Clean Power Plan compliance, new clean energy investments by Illinois may offer first-mover advantages in increasingly carbon-constrained energy markets. If Illinois is to move forward with a robust response, the full impact and potential of any such policy must be fully explored.[176]

D. Baseload Bias, Utility Scale Fetish and Short-Run Myopia in Nuclear License Renewal: PG&E's Diablo Canyon

1. The NRC Guidelines

The PG&E application for a license renewal for its Diablo Canyon reactors represents a different point in the reliability debate, a mid-term, general claim about reliability. Ten years in advance of the expiration of its current license the application covers a period 10–30 years into the future (2024-2044). The Nuclear Regulatory Commission's (NRC) Generic Environmental Impact Statement for License Renewal (GEIS, NUREG-1437, 2013) gives guidance to utilities on the general criteria the NRC will apply in license renewal.

In updating its GEIS in 2013 the NRC has recognized the energy field is evolving very rapidly, and therefore the NRC makes a case-by-case analysis of energy alternatives in license renewal proceedings, using "state-of-the-science" information:

> **Recent advances in (replacement power alternatives).** Several commenters asserted that much of the information describing replacement power alternatives did not reflect the state-of-the-science. In some cases, commenters noted facts and events that occurred after the publication date of the draft GEIS.
>
> The NRC has updated the final GEIS to incorporate the latest information on replacement power alternatives, but it is inevitable that rapidly evolving technologies will outpace information presented in the GEIS. Incorporation of this information is more appropriately made in the context of plant-specific license renewal reviews, rather than in the GEIS. As with renewable energy technologies, energy policies are evolving rapidly. While the NRC acknowledges that legislation, technological advancements, and public policy can underlie a fundamental paradigm shift in energy portfolios, the NRC cannot make decisions based on anticipated or speculative changes. Instead, the NRC considers the status of alternatives and energy policies when conducting plant-specific environmental reviews.[177]

In spite of this statement, a close look at the GEIS in the context of the contemporary industry shows quite clearly that two decades of rapid and dramatic economic and technological change have rendered even the modified standard that the NRC uses to evaluate request for license renewal obsolete. The NRC is still captive to the baseload point of view.

The NRC framework for evaluating license renewal requests under the 1996 Guidelines (NUREG, 1437) focused on nuclear reactors as baseload generation facilities. The first page of the section of "Alternatives to License Renewal," concluded by stating that "Therefore, NRC has determined that a reasonable set of alternatives should be limited to analysis of single, discrete electric generation sources and only electric generation sources that are technically feasible and commercially viable."[178] In the evaluation of the sources, the NRC invoked the concept of baseload over 30 times. The majority were references to the failure of renewables to meet the baseload criteria.

In the 2013 revision to NUREG 1437, the standard was revised somewhat. Utility scale replaces baseload as the central concept, while a reliable quantity of replacement capacity equal to the baseload capacity is the target. The development of the technology is also more flexibly defined to consider a longer term perspective.

> A reasonable alternative must be commercially viable on a utility scale and operational prior to the expiration of the reactor's, operating or expected to become commercially viable on a utility scale and operational prior to the expiration of the reactor's license. As technologies improve, the NRC expects that some alternatives not currently viable at some time in the future. The NRC will make that determination during plant-specific license renewal reviews. The amount of replacement power generated must equal the baseload capacity previously supplied by the nuclear plant and reliably operate at or near the nuclear plant's demonstrated capacity factor.
>
> Should the need arise to replace the generating capacity of a nuclear reactor, power could be provided by a suite of alternatives and combinations of alternatives, including expanding the capacities of one or more existing power generating plants within a region, delaying the scheduled retirement of one or more existing plants, or purchasing an equivalent amount of power. The number of possible combinations is potentially unlimited… [C]ombinations of alternatives may be considered during plant-specific license renewal reviews.

The NRC continues to exhibit an extremely narrow focus on utility-scale and baseload. In the current technological and economic environment this focus is tantamount to an irrational baseload bias and a utility-scale fetish that is out of touch with reality. Section 2 of the revised relicensing regulation (NUREG, 1428, 2013) invokes baseload and utility-scale 25 times in the 16 pages in which the alternatives are evaluated.[179] The assessment of the alternatives is defined by these two antiquated concepts. Moreover, the identification of alternatives does not include building new facilities, efficiency, or integrated management of supply and demand.

The failure of the NRC to adjust to the changes in the electricity sector is evident in the response to a contention challenging the Diablo Canyon license extension:

> A contention challenging PG&E's decision to exclude a particular alternative or combination of alternatives would be admissible only if it demonstrated that the proposed alternative(s) could supply baseload power sufficient to replace Diablo Canyon's generating capacity at the time the licenses expired in 2024 and 2025.[180]

Ironically, and reinforcing the lack of change in its point of view, the NRC suggests that the fact that PG&E is asking for the license renewal 10 years in advance is a matter of necessity and routine.[181] This suggests that it takes as long to implement the steps necessary to extend the life of a nuclear reactor as it does to build a new one. Thus, aging reactors suffer from the same drawback as was demonstrated for new reactors in the earlier discussion. They are a very bad investment in a dynamic environment.

Instead of biasing the analysis by targeting utility-scale alternatives that yield baseload quantities of reliable power and takes ten years to bring online, it could have referred to sufficient capacity to reliably meet the projected need for electricity. When pressed, the NRC says, essentially that the framework for decision making has not changed. There is a significant cost. An erroneous decision to approve the license extension under these circumstances imposes direct and immediate harm on consumers. It reinforces the utility's incentive and ability to resist the superior economic options that have become available and frustrate the transformation of the utility sector.

2. The PG&E Diablo Canyon Application

The harm of failing to give proper guidance to utilities can be seen clearly in the PG&E application for a license renewal for Diablo Canyon. PG&E has continued to apply the standard from the 1996 GEIS. Either it has failed to recognize the modest modification in the NRC guidelines, recognizes that there was little change in the NRC's thinking, or has purposefully ignored it.

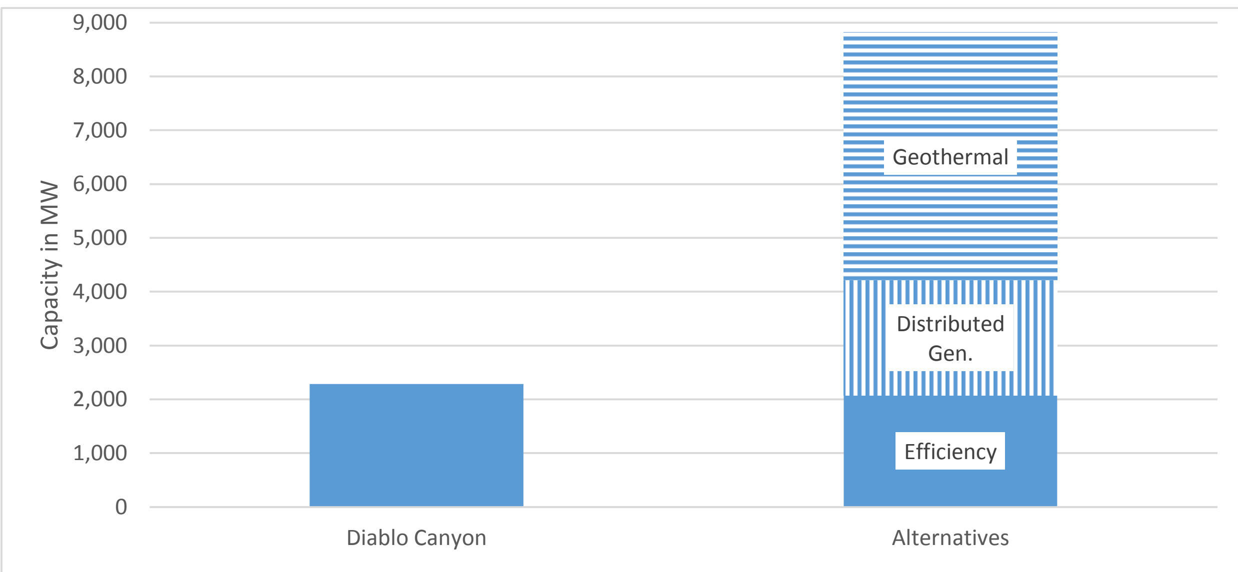
In a number of respects, PG&E's energy alternatives analysis is seriously outdated. First, in Section 7.2.1.2, PG&E focuses its analysis on "standalone" alternatives, using that to disqualify a number of renewable alternatives that have proven reliable and effective in providing electricity. PGE repeatedly cites the old standard to "disqualify" alternatives: [182]

> This section identifies *standalone* alternatives that PG&E deemed unreasonable, and the bases for these determinations. PG&E accounted for the fact that DCPP provides baseload generation and that any feasible alternative to DCPP would also need to be able to provide baseload power. In performing this evaluation, PG&E relied heavily upon NRC's GElS. 7-2.7
>
> *There may be insufficient operational flexibilities to both meet those renewable power requirements and replace DCPP baseload capacity with wind, solar, and geothermal generation.*
>
> Because the power output can only be intermittently generated during the day or during certain seasons, depending on the location, wind turbines are unsuitable for baseload applications.
>
> *Wind generation* – therefore, wind generation cannot be considered an adequate replacement of DCPP generation *absent sufficient energy storage to overcome wind's intermittency. Besides pumped-storage hydroelectricity, Compressed Air Energy Storage (CAES) is the technology most suited for storage of large amounts of energy; however, no combination of wind and CAES has yet been proposed at the scale necessary to replace DCPP generation. (7-2.8)*
>
> Because solar thermal power is not available 24 hours per day, it is typically not acceptable for baseload applications *absent sufficient energy storage to overcome solar's intermittency... As noted above, besides pumped-storage hydroelectricity, CAES is the technology most suited for storage of large amounts of energy; however, no combination of CSP and CAES has yet been proposed at the scale necessary to replace DCPP generation. 7-2.9*
>
> *While development of battery storage options is ongoing, none are currently available in quantities or capacities that would provide baseload amounts of power. In light of the large contribution of solar PV to potential OG in PG&E service area and limitations on its use as baseload capacity, DG cannot serve as* a *reasonable alternative to the baseload generation of DCPP. 7-2.11*
>
> Geothermal plants offer base load capacity similar to DCPP, but it is unlikely to be available *within PG&E's service area* on the scale required to replace the capacity of DCPP. 7-2.12

PG&E's focus on "standalone" energy sources reflects two irrational and unsupported biases: first, toward reliance on "baseload" generation by a single source, and second, toward "utility-scale" generation. PG&E also assumes that a significant amount of natural gas generation will be needed to replace the amount of electricity generated by Diablo Canyon. But, there are a large number of possible combinations of many resources that can meet the need for electricity in a low carbon environment. PG&E has chosen a single combination that relies on a large amount of gas, which increases the environmental impact of that alternative. More renewables, distributed generation, geothermal, and efficiency would achieve the same outcome with a much more environmental and consumer-friendly impact.

To appreciate why these developments deserve much more consideration than PG&E has given them, one need only compare PG&E's Amended Environmental Report with the California Energy Commission documents PG&E relies on. PG&E rejects the option of geothermal energy based on the assumption that a single new geothermal plant would have to be built in PG&E's service territory.[183] As Figure VI-3 shows, making the conservative assumption that the PG&E service territory includes half the geothermal resources in the state, geothermal resources are twice as large as Diablo Canyon capacity.

FIGURE VI-3: ALTERNATIVE POTENTIAL IS FOUR TIMES DIABLO CANYON CAPACITY



Source: Diablo Canyon Amended Environmental Report pp. 7.2-6, 7.2-11, 7.2-12

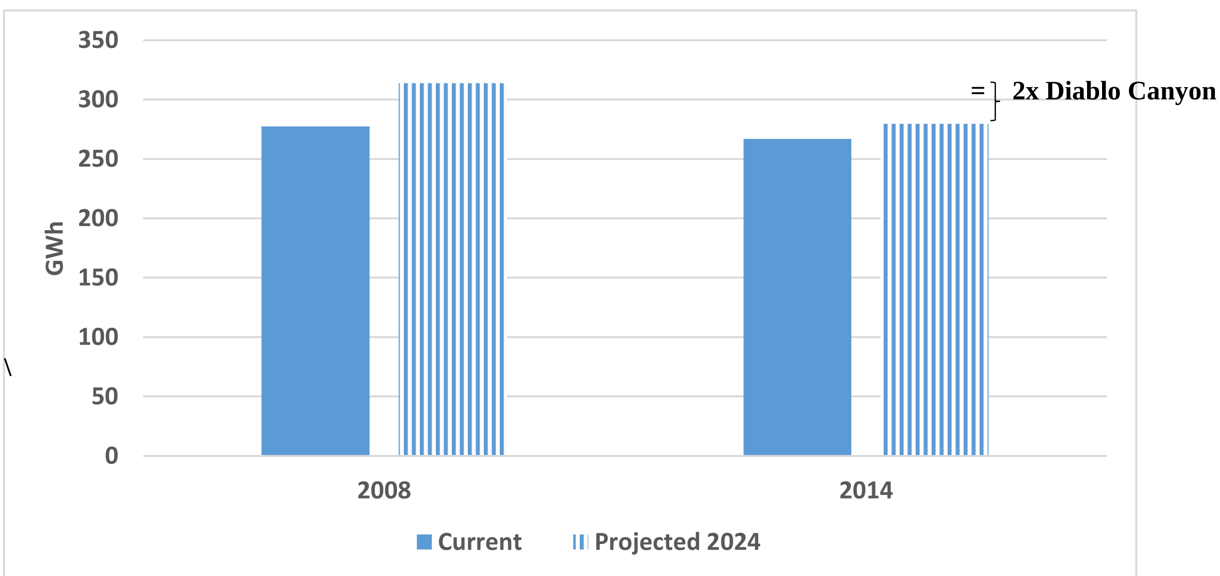
Adding in efficiency and other distributed resources, the alternative energy capacity would be four times the capacity of Diablo Canyon. Three quarters of this capacity (geothermal and efficiency) is not intermittent, meaning that the 24-hour energy supply provided by Diablo Canyon could be replaced three times. Adding in renewables with storage would increase 24-hour availability of capacity to 3.5 times the capacity of Diablo Canyon. As discussed above, a of a well-managed 21st century electricity grid has the ability to deliver reliable power while relying on renewable generation at much higher levels of penetration than would be necessary should Diablo Canyon retire.

Because PG&E is so focused on disqualifying alternatives based on the erroneous standard of "sufficient, single resource baseload power," it fails to conduct a responsible analysis of its own data. For example, in updating the Environmental Report from 2010 to 2015, PG&E provides data to show that the dramatic transformation of the sector is well under way. This trend includes reduced energy demand, greater capacity for managing demand, and greater reserve margins than existed even 10 years ago. The following quote, reproduced with PG&E's cross-outs and italicized additions preserved, provides clear evidence of the shift in electricity demand:

> In 2014, California *planning* reserve margins were ~~approximately~~ *projected to be* ~~22~~ *34* percent (Reference 8). The California Energy Commission defines planning reserve margin as the minimum level of electricity supplies needed to cover a range of unexpected contingencies, such as increased air conditioning demand on a hotter than average day, or an unplanned maintenance outage at a power plant. California energy demand is projected to increase from ~~277,479~~ *266,754* GWh in 2014 to ~~313,671~~ *279,632* GWh in ~~2018~~ *2024* (Reference 5, Form 1.1c). Of these statewide energy demand projections, PG&E would comprise approximately ~~37~~ *38* percent of the energy (Reference 5, Form 1.1c). [184]

The dramatic decrease in demand and sharp increase in reserve margins (over 50%) between 2008 and 2014 suggests that there is a lot more leeway to retire large, costly, inflexible reactors like those at Diablo Canyon. As shown in Figure VI-4, the reduction in projected peak demand in a short six years equals almost twice the total output of Diablo Canyon.

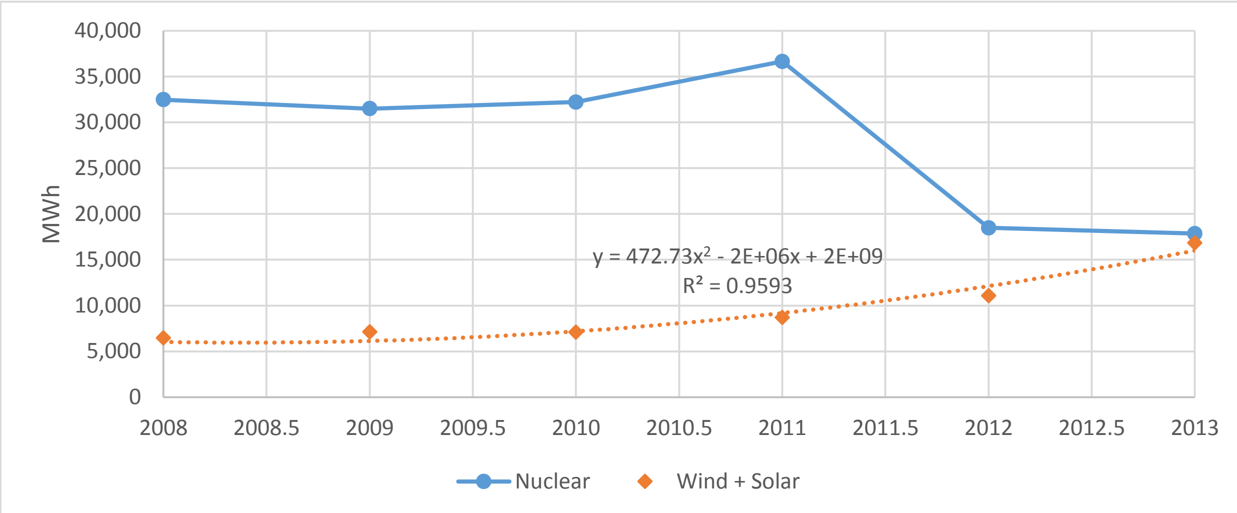
FIGURE VI-4: DECLINING DEMAND REDUCES THE NEED FOR DIABLO CANYON CAPACITY



Source: Diablo Canyon Amended Environmental Report, p. 7.2-1

PG&E's analysis of the supply-side of the California electricity sector also obscures a simple fact: non-hydro renewables, i.e. wind and solar, have increased dramatically and are poised to surpass nuclear generation, which has been in decline, as shown in Figure VI-5.

FIGURE VI-5: CALIFORNIA GENERATION



Source: http://www.energy.ca.gov/renewables/tracking_progress/documents/installed_capacity.pdf

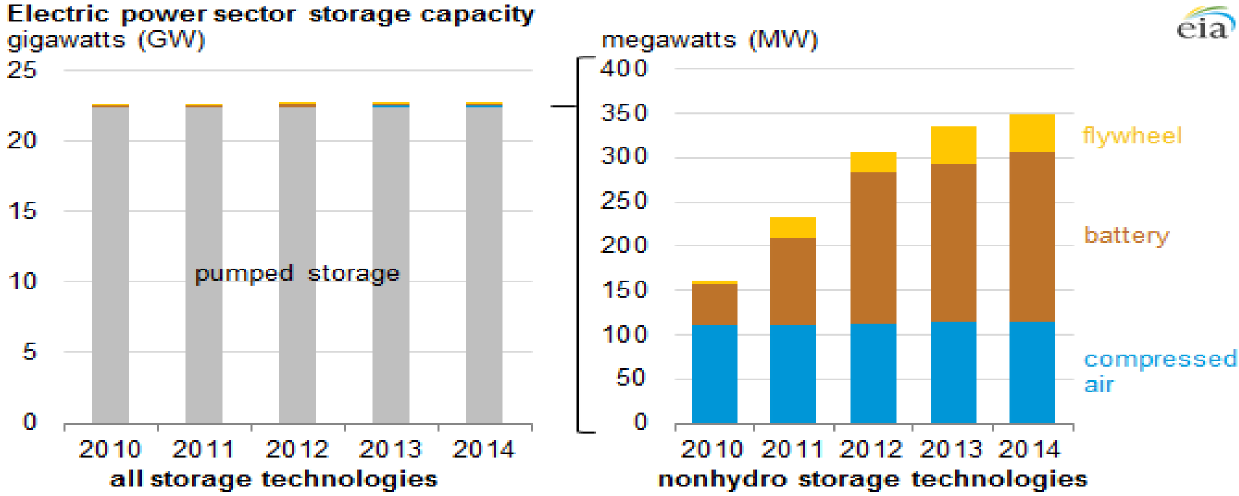
PG&E's analysis is also fundamentally weakened because it fails to recognize the dramatic development in battery technology that has been occurring over the past several years. Instead, PG&E focuses on pumped storage and compressed air. PG&E's failure to address battery technology is particularly egregious in light of the fact that many analysts conclude that batteries will play a key role in the transformation of the electricity system. Declining costs are a key driver, as discussed above, but so too is the increasing array of technologies and applications, not to mention the additional critical and valuable functions they provide with increasing renewables. Lazard and others see batteries as becoming the lowest cost peak resource, which will team with renewables. For these reasons, as shown in Figure VI-6, batteries have already surpassed compressed air and are rapidly expanding, as a storage medium.

Finally, PG&E makes the argument that Diablo Canyon is needed to reduce carbon emissions:

> Finally, overlaying these concerns about the alternative generation technologies are federal and state greenhouse gas emissions reduction goals. According to EPRI, even while adding renewable capacity equal to 4 times today's wind and solar capacity in 2008, the United States would need to maintain all of its current nuclear capacity, and add 45 more nuclear facilities, to meet greenhouse gas emissions reduction goals.[185]

But PG&E relies on the results of a dated, 2009 EPRI analysis with no effort to consider its relevance to the current market situation. When change is as rapid as is taking place in the electricity sector at present, half a decade is a long time. In 2009 EPRI may well have still been under the spell of the "nuclear renaissance." The challenge of building 45 nuclear reactors in less than three decades in a nation that has not brought one online in the past two decades suggests the utter impossibility of this scenario.

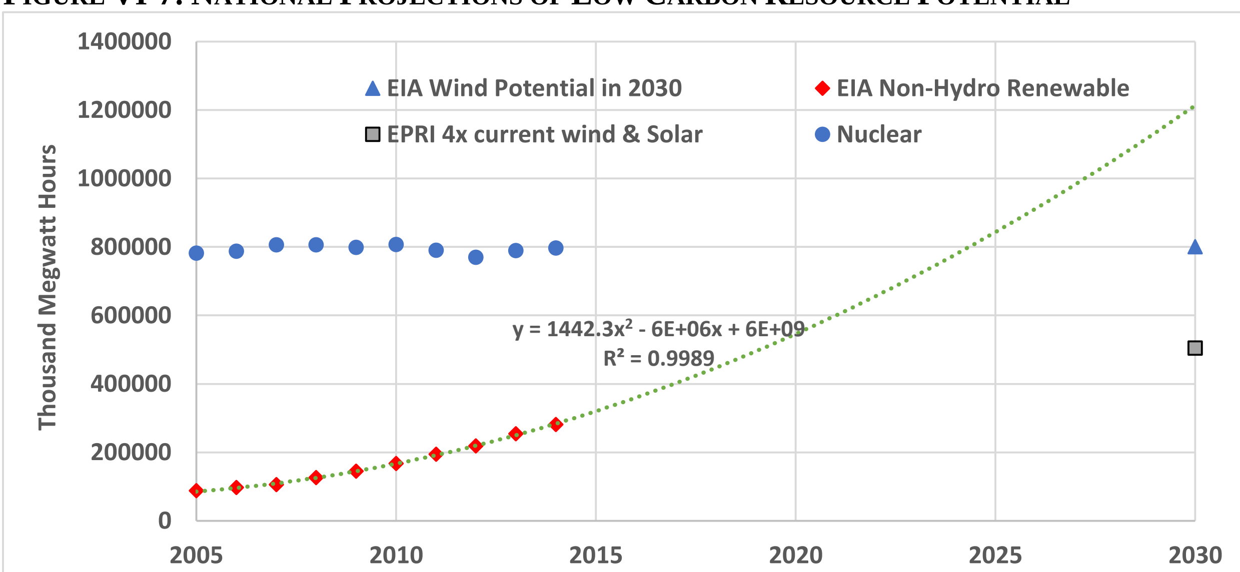
FIGURE VI-6: BATTERY STORAGE IS EXPANDING RAPIDLY, OTHER STORAGE TECHNOLOGIES ARE STATIC



Source: EIA, Nonhydro Electricity Storage Increasing as New Policies Are Implemented, *Energy Today*, April 3, 2015

More importantly, that scenario is not the only approach to reaching climate change goals by any stretch of the imagination. Since 2008, the wind and solar capacity brought online in the United States has increased its total seven fold. Moreover, as noted above and shown in Figure VI-7, many analysts think that much larger contributions from these resources are possible. The recent analysis from the Department of Energy suggested that wind alone could grow sufficiently to cover three-quarters of the amount of nuclear capacity EPRI suggested was needed. A simple projection of recent deployments would not only cover the shortfall, but retire a substantial part of the aging nuclear fleet.

FIGURE VI-7: NATIONAL PROJECTIONS OF LOW CARBON RESOURCE POTENTIAL



Sources: EPRI 4x current wind and solar cited at Diablo Canyon Amended Environmental Report, p. 7.2-2; Nuclear and EIA Non, from EI A electricity data.

VII. DIVERSIONARY TACTICS IN THE NUCLEAR WAR AGAINST THE FUTURE

A. SUBSIDIES AND BAILOUTS, PAST, PRESENT, AND FUTURE

1. Forward-Looking Subsidies: Inertia, Subsidies and System Transformation

Implicit and explicit subsidies play a prominent role in the nuclear attack on renewables identified in Table VI-1, above. This is not surprising considering that subsidies routinely play a crucial and unavoidable role in energy policy decisions. One of the most important battles in the struggle between technologies will inevitably be the struggle over subsidies.

The baseload-dominated electricity system of the 20th century was created by policy support and subsidies for physical and institutional infrastructure that favored a specific type of technology. [186] The dominant incumbents will seek to slow or stop the spread of alternatives to defend these trillion-dollar investments and assets sunk into central station facilities.[187] Recent climate-change analysis highlights how the inertia of a century of domination by central-station, fossil-fuel-focused institutions has created a unique challenge — carbon lock-in — which is magnified by the need to rapidly reduce carbon emissions.

Because the potential external costs are so large and the need to overcome inertia is so great, climate change puts a spotlight on technological innovation. The evidence suggests that the cost of inertia is quite large, whereas targeted approaches that speed and smooth the transition to low carbon resources can have many benefits.[188] The growing concern over adjustment leads to concern over an "innovation gap."[189]

Beyond inertia, many of the benefits of alternative generation technology resources or the processes by which their costs would be reduced – e.g., learning by doing, network effects – are externalities themselves, which means the private sector will underinvest in them.[190] Returns to R&D can be high.[191] Accelerating innovation can speed the transition, saving a decade or two[192] while reducing economic disruption.[193]

One of the obvious ways to overcome inertia, fill the "innovation gap" and speed the transition is to shift subsidies away from incumbents to the low-carbon alternatives. In fact, some have argued that the benefits of stimulating innovation are so large that they can offset the apparent "cost" of phasing out nuclear power altogether.[194]

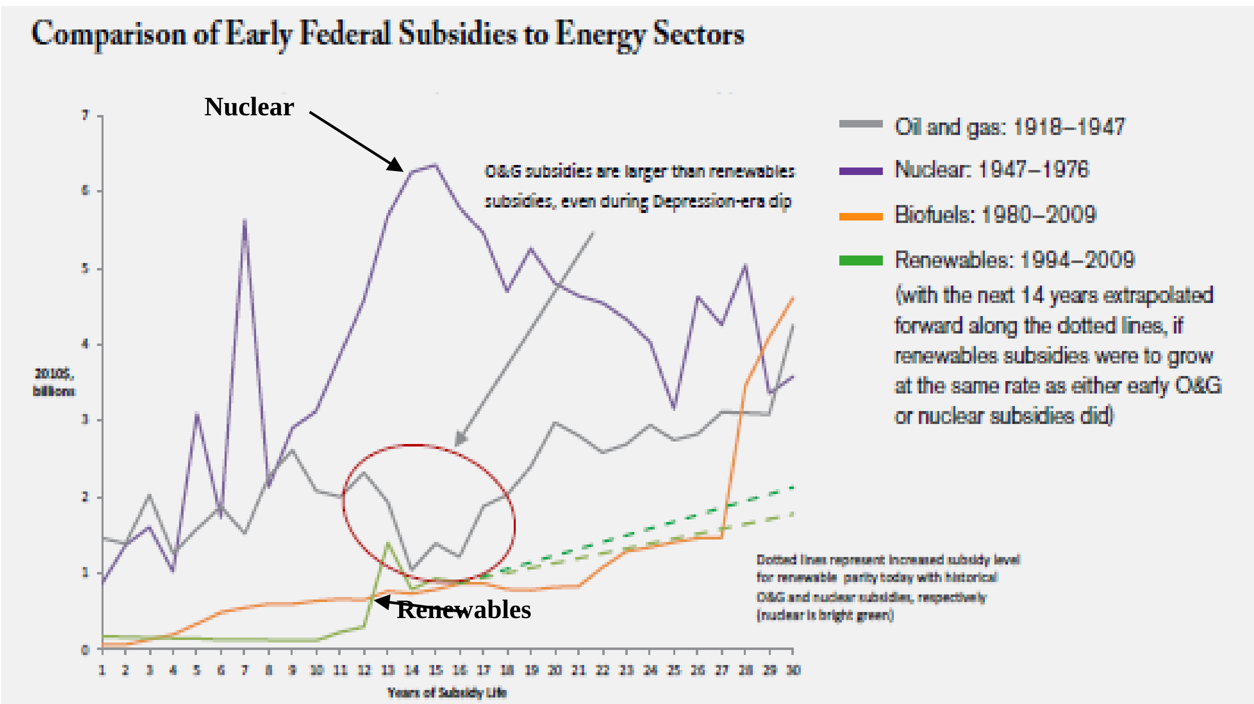
> Our results show that phasing out nuclear power would stimulate investment in R&D and deployment of infant technologies with large learning potentials. This could bring about economic benefits, given the under provision of innovation due to market failures related to both intertemporal and international externalities.[195]
>
> The evolution of the renewables costs in the coming years will not be independent of the future of nuclear power, as well as of energy and climate policies. In this context of uncertainty, policymakers need to understand the economic consequences of nuclear power scenarios when accounting for its interplay with innovation and cost reduction in renewables.[196]

Analyzing past subsidies strongly supports the proposition that shifting subsidies from nuclear to other resources will lower the cost and accelerate the speed of transition (see

FigureVII-1). It strongly rejects the notion that new subsidies should be showered on mature old technologies like aging reactors.

While the nuclear industry complains about the subsidies that are bringing renewables into the market today and resists programs to promote energy efficiency, analysis of the historical pattern demonstrates that the cumulative value of federal subsidies for nuclear power dwarfs the value of subsidies for renewables and efficiency.[197] Renewables are in the early stage of development, as shown in FigureVII-1. Nuclear received much larger subsidies in its developmental stage and enjoyed truly massive subsidies compared to other resources as it grew. The graph calculates the rate of growth in subsidies that would be necessary to bring renewables into parity with the early rate of growth in subsidies enjoyed by central station resources. Renewables are more than a dozen years behind the central station resources, but given the importance of inertia, parity may not be enough to overcome the advantages of incumbency.

FIGUREVII-1: FEDERAL SUBSIDIES FOR INFANT ENERGY INDUSTRIES AND BEYOND

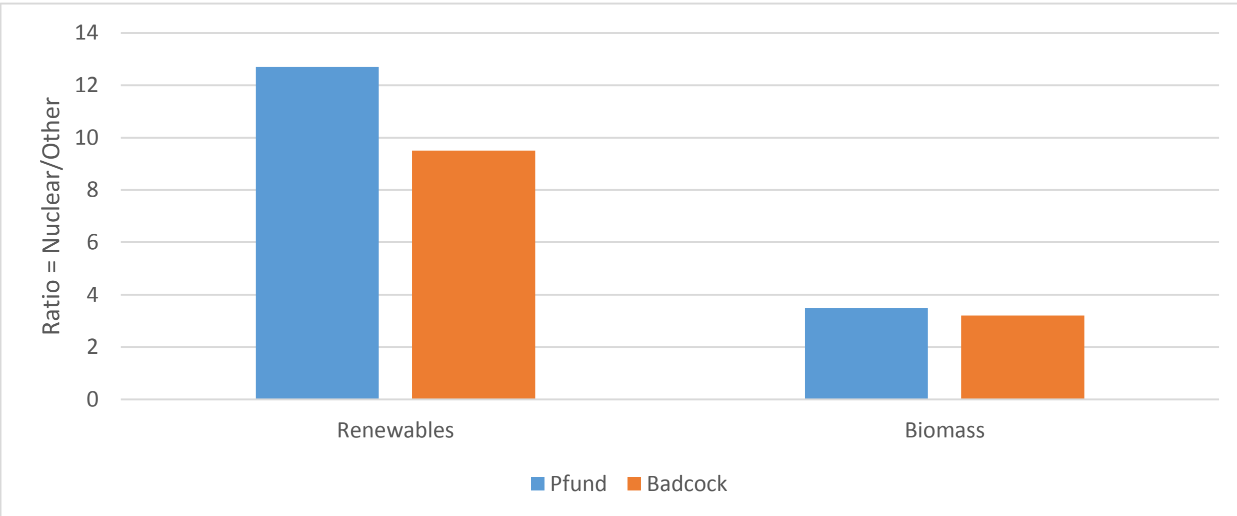


Source: Nancy Pfund and Ben Healey, *What Would Jefferson Do? The Historical Role of Federal Subsidies in Shaping America's Energy Future*, Double Bottom Line Investors, September 2011, pp. 29–30.

There can be debate about the current level of subsidies, particularly given the difficulty of valuing the nuclear insurance and waste subsidies which are existential rather than material (i.e., without the socialization of liability and waste disposal the industry would not exist). However, there is no doubt that the long-term subsidization of nuclear power vastly exceeds the subsidization of renewables and efficiency by an order of magnitude of 10 to 1 (as shown in FigureVII-2).[198]

A decision to shift subsidies to the alternatives should have nothing to do with fairness, however, it should be based on the likely payoff of the investment. Analyses of past subsidies globally and in the United States make it clear that renewables are a much better bet[199] even though the estimates do not include the very large implicit subsidies nuclear enjoys from the socialization of the cost of risk and waste management.[200]

FIGUREVII-2: RATIO OF TOTAL SUBSIDIES: NUCLEAR COMPARED TO OTHERS



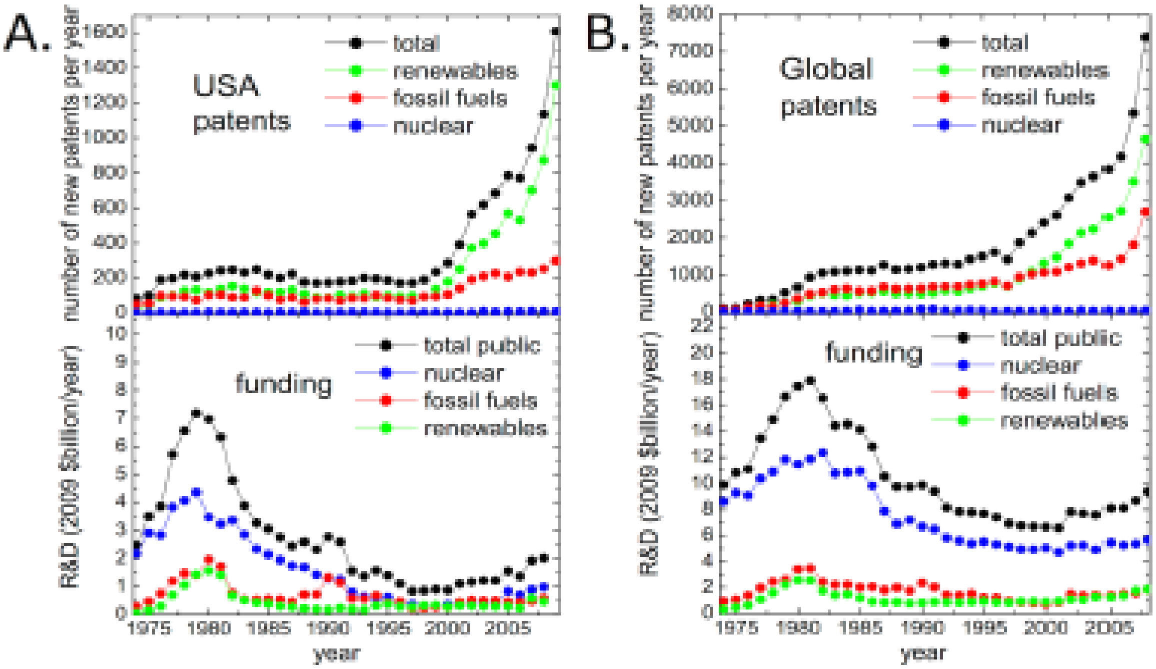
Sources: Nancy Pfund and Ben Healey, *What Would Jefferson Do? The Historical Role of Federal Subsidies in Shaping America's Energy Future*, Double Bottom Line Investors, September 2011, pp. 29–30; Badcock, Jeremy and Manfred Lenzen, 2010, "Subsidies for Electricity-Generating Technologies: A Review" *Energy Policy,* 38, Table 4.

It is clear that with a much smaller level of subsidy to drive innovation and economies of scale, the renewables have achieved dramatically declining costs in a little over a decade, which is exactly the economic process that has eluded the nuclear industry for half a century. FigureVII-3 captures the essence of the subsidy issue by juxtaposing the magnitude and timing of subsidies and the extent of innovation, as measured by patents issued. The ultimate irony is that despite much smaller subsidies to drive innovation and economies of scale, renewables have achieved dramatically declining costs in just over half a decade, as discussed in Section II.

The dramatic increase in innovative activity despite relatively low levels of R&D subsidy and much lower cumulative subsidization reflects the decentralized nature of innovation in the renewable space. It leads to the dramatic payoff in terms of declining price. As we have seen, wind had the earlier success and solar is now catching up.[201] Nuclear power has failed to show these results because it lacks the necessary characteristics.

The nature of the renewable technologies involved affords the opportunity for a great deal of real world development and demonstration work before it is deployed on a wide scale. This is the antithesis of past nuclear development and the program that SMR advocates have proposed. The alternatives are moving rapidly along their learning curves, which can be explained by the fact that these technologies actually possess the characteristics that stimulate innovation and allow for the capture of economies of mass production. They involve the production of large numbers of units under conditions of competition. Nuclear power, even SMR technology, involves an extremely small number of units from a very small number of firms, with the monopoly model offered as the best approach.

FIGURE VII-3: INNOVATION AND PUBLIC SUPPORT FOR R&D



Source: Bettencourt, Luı´s M.A., Jessika E. Trancik, and Jasleen Kaur, 2013, "Determinants of the pace of global innovation in energy technologies," ***PLoS ONE*****, October 8, p. 10.**

If policymakers have to bet on subsidies to accelerate innovation, limit cost, and reduce carbon emissions, then the performance history of the nuclear and alternative industries gives them extremely good reason to expect a single outcome: alternatives will overcome their challenges more quickly and efficiently than nuclear technology.

2. Backward-Looking subsidies: Keeping Aging Reactors Online

Having concluded that forward-looking subsidies should focus on renewables rather than new nuclear technology, we next address the question of whether or not it makes economic sense to use backward-looking subsidies to keep aging reactors online. This has become a focal point of debate in both the EPA's Clean Power Rule and the broader conflict between nuclear and the alternatives.

In Section II I included current and projected cost estimates for aging reactors in both the operating and total cost analyses. I showed that aging reactors are more costly than efficiency, wind, gas, and some solar in the near-term. In the mid-term more solar becomes competitive with aging reactors as do several other generation sources, including biomass, geothermal, micro-turbines, and even offshore wind. Specific proposals for subsidies of old reactors have now been made in states where wholesale prices are set in markets. They provide strong support for the proposition that aging reactors are uneconomic.

Utilities in New York,[202] Illinois[203], and Ohio[204] have asked for above market prices for six reactors. These reactors have lost hundreds of millions of dollars over the last couple of years, but the nuclear utilities claim that the low price of gas is the cause of the problem. This is incorrect in three respects. First, the rising cost of operating reactors accounts for about a third of the problem. Second, the addition of wind, which backs inefficient gas out of the market clearing price, contributes to the shift. And third, demand for nuclear has declined due to increased efficiency. The price of gas matters, too, but less than the other three factors. Two-thirds of the revenue shortfall that aging reactors are experiencing has nothing to do with natural gas prices. The bulk of the problem is caused by the rising cost of keeping nuclear reactors online, the superior economics of renewables, and the attractiveness of efficiency.

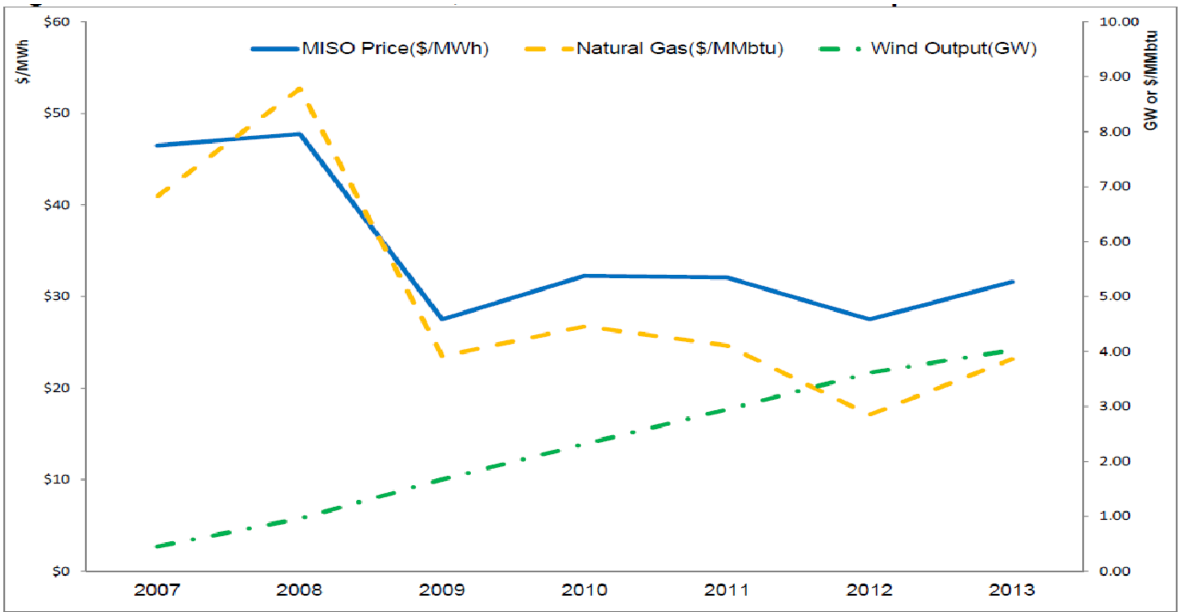
FigureVII-4 shows that market fundamentals are undermining the economics of aging reactors. The upper graph shows two aspects of the aging reactor problem. It shows that the price of gas price in 2009–2013 was relatively stable. The growth of wind power was substantial. The lower graph shows the magnitude of that shift in terms of net demand for load, the key concept discussed in Section VI. Between 2010 and 2013 the share of wind and other resources increased from 2–6 percent at the peak and 5–11 percent on average. The supply curve shifted to the right substantially. At the same time, demand declined by 12 percent at the peak and 14 percent on average. The demand curve shifted to the left. The overall effect of efficiency and wind penetration was to reduce the demand for fossil-fired load by 16 percent at the peak and 18 percent on average.

FigureVII-5 shows the core cost problem that the aging reactors face taken from the Illinois analysis. It provides more detail than was provided in the general discussion in Section II. The left graphs shows that several of the aging reactors in the Exelon Illinois fleet showed losses in 2009 after running significant surpluses in 2007 and 2008. As natural gas prices rose in 2010, they again broke even. In fact, the price of natural gas in 2013 was very similar to the price in 2010, but the reactors were again losing money. The right side graph in FigureVII-6 shows the merit order problem. As wind pushed the supply curve to the right, the market clearing price declined.

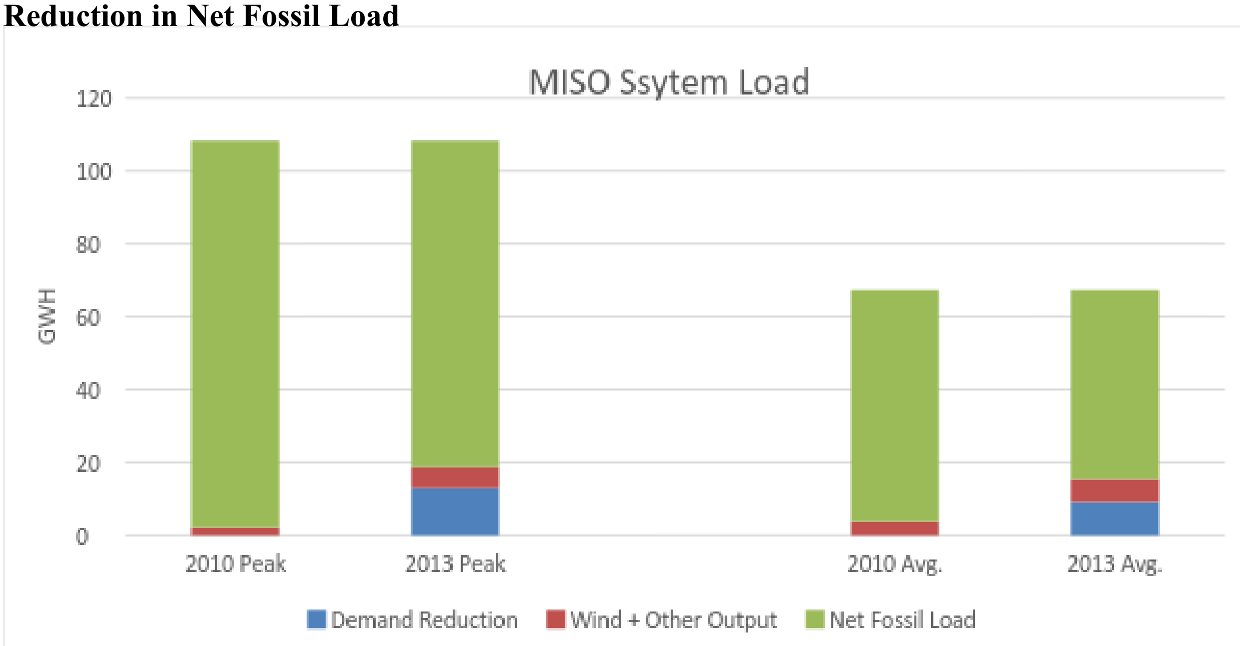
Putting the two graphs side-by-side enables us to highlight another aspect of the current situation that is often overlooked. Neither of the graphs show that costs of aging reactors were rising over this period. In fact, there is an inconsistency between the two graphs. The operating costs of some of the aging reactors in the left-hand graph are actually much higher than the position that nuclear power is given in the right-hand graph. In a true merit order dispatch they would be dispatched much later, if at all. They would come after some coal and even gas generators. They are uneconomic based on marginal cost.

FIGURE VII-4: MARKET FUNDAMENTALS PRESSURING MARKET CLEARING PRICES

Real-Time Market Price, Natural Gas Prices and Wind Output Since 2007

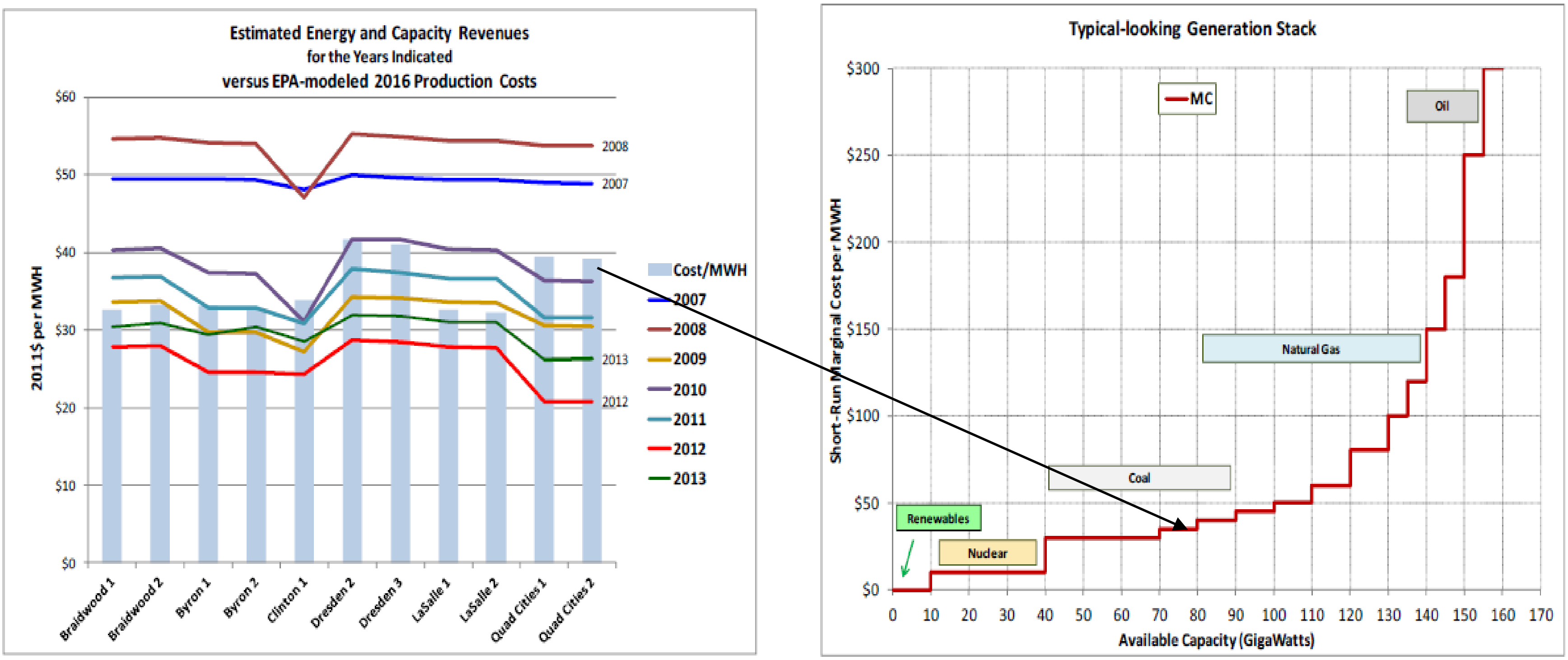


Reduction in Net Fossil Load



Source: MISO 2013 Annual Market Assessment Report Information Delivery and Market Analysis, June 2014, pp. 14, 16, 20.

FIGURE VII-5: MISREPRESENTATION OF THE LOCATION OF AGING REACTORS IN THE TYPICAL LOADING STACK



Price changes possibly needed to restore profitability

Source: Illinois Commerce Commission, Illinois Power Agency, Illinois Environmental Protection Agency, Illinois Department Of Commerce And Economic Opportunity, *Potential Nuclear Power Plant Closings In Illinois: Impacts And Market-Based Solutions, Response To The Illinois General Assembly Concerning House Resolution 1146*, January 5, 2015.

FigureVII-6 identifies the basic economics underlying the problem of aging reactors. The uneconomic cost of subsidizing them to stay online flows from the failure to properly analyze the causes of the problem. Ignoring cost increases as a partial cause of the aging problem and failing to recognize the continuing addition of low operating cost resources leads to underestimation of the ultimate size of the subsidies.

In the upper graph in Figure VII-6, I show the market clearing price declined dramatically due to these two fundamental economic factors. This brings us back to the core economic forces I introduced at the outset of the analysis in Figure II-1. Here we can calculate that at least two-thirds of the aging reactor problem can be attributed to the increasing cost of aging reactors and the declining market clearing price due to shifting supply and demand. It is also important to note the speed with which these changes took place. The ability of the electricity system to adjust is substantial. In the lower graph of Figure VII-6 we plot the rising cost of aging reactors in the Exelon fleet, which is close to the rate found in recent national studies, against the declining revenue in the Illinois example. It also assumes that the wholesale price increases at the rate projected for PJM under the efficient response to the EPA Clean Power Rule. The subsidy necessary to cover the total cost of the reactors starts at $25/MWH and almost doubles in a decade. The rising costs account for about one-third of the current subsidies**.**

From the point of view of economic fundamentals, resisting these economic forces is futile in the sense that the only way to keep aging reactors online is to impose more and more uneconomic costs on consumers. Rather than subsidize aging reactors, the sensible policy is to accelerate a transition to renewables and retire aging reactors in an orderly fashion. Because the primary cause of the revenue shortfall suffered by aging reactors is driven by market fundamentals that are likely to become even more adverse over time, the case for subsidizing their operation has not been made. It clearly costs more to keep them online than to retire them. That burden will only grow.

B. NON-ENERGY ECONOMIC IMPACTS

The analysis of resource economics, reliability, and carbon reduction all indicate that subsidizing nuclear power, old or new, is a mistake in the 21st century electricity system. But two non-energy impacts are also invoked in the effort to support subsidies for nuclear power: macroeconomic impacts and the 'indispensable" role of nuclear in carbon reduction.

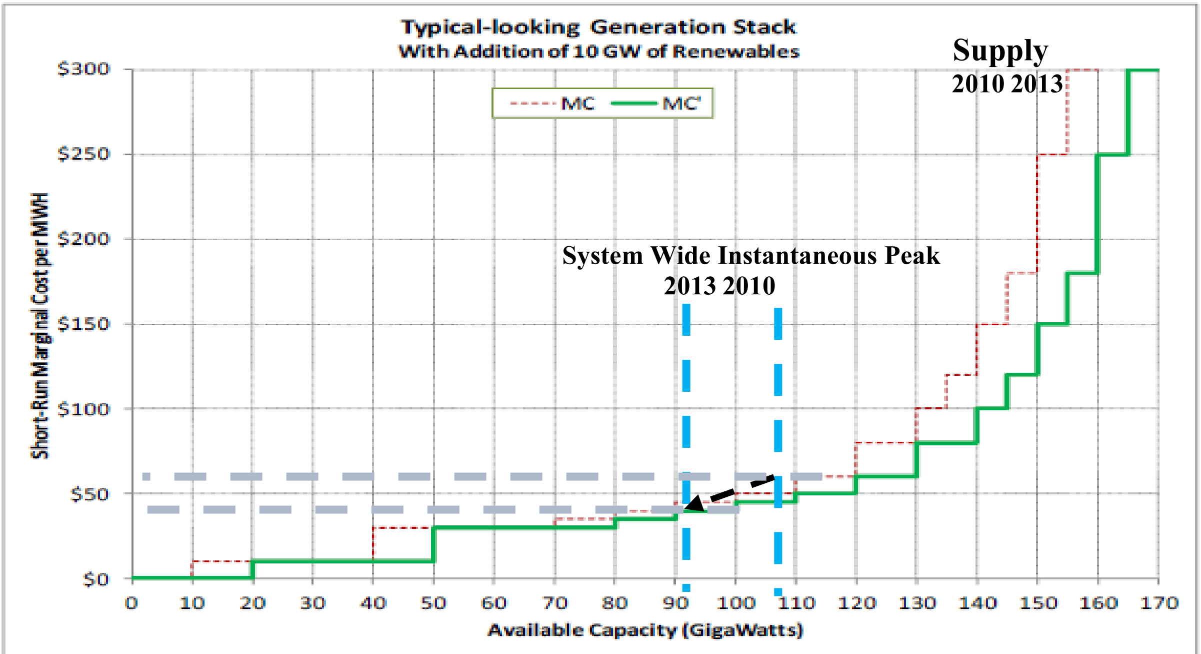
1. Employment and the Local Economy

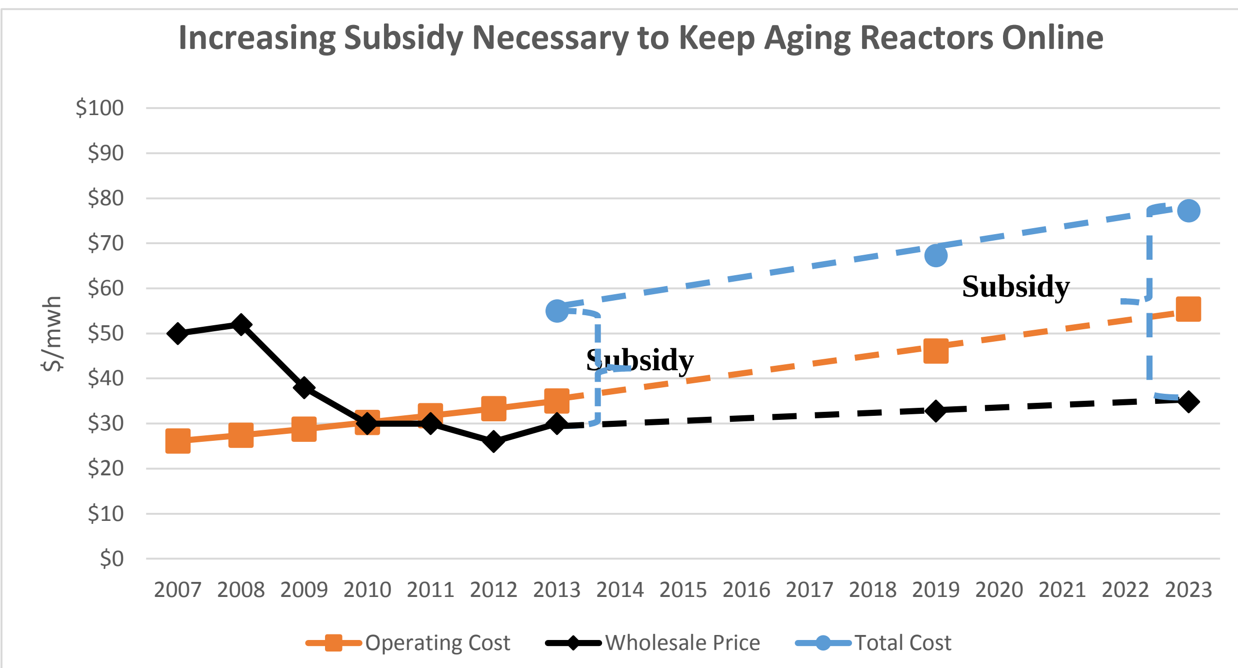
The non-energy impact that receives the most attention in the case of aging reactors is the impact on the local economy. A careful examination of this macro-economic impact does not lend much support to the case for subsidies.

The Illinois Department of Commerce analysis raises the question of the impact on the local and state economy. As shown in Figure VI-7, the loss of nuclear reactor-related jobs (direct and indirect) is offset in the early years by construction of alternatives. When the construction jobs expire, the loss of nuclear jobs exceeds the ongoing number of jobs added by the

FIGURE VII-6: THE ECONOMIC COST AND UNECONOMIC CONSEQUENCES OF BAILING OUT AGING NUCLEAR REACTORS

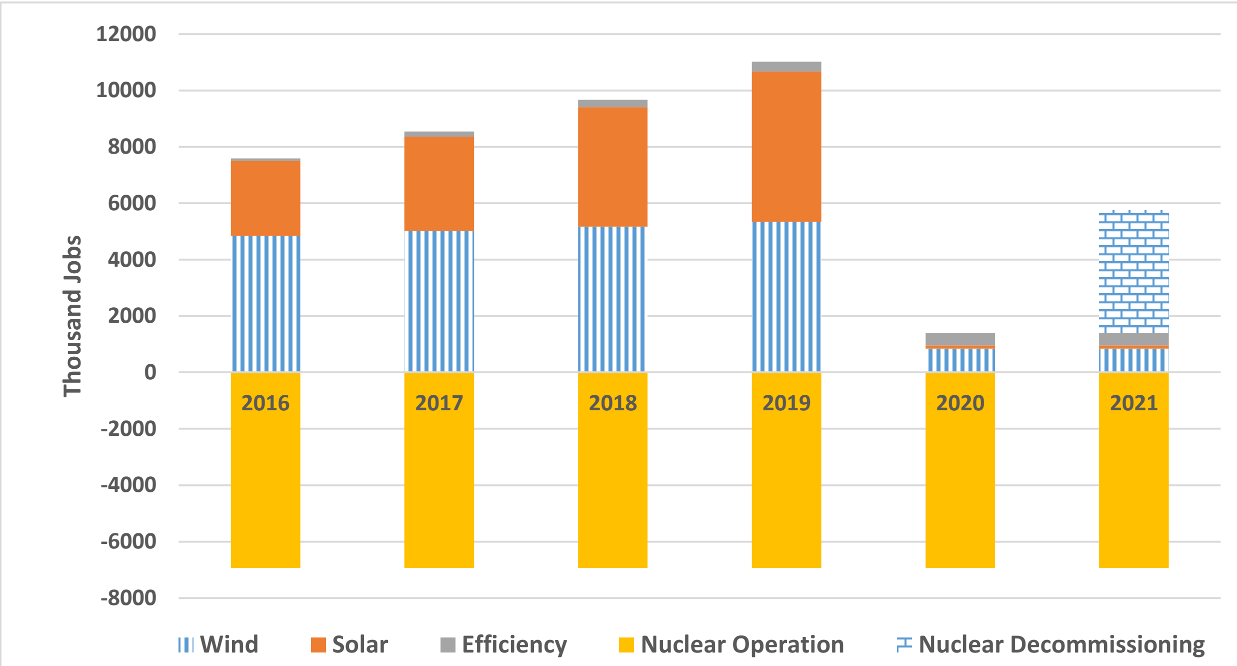
Impact of Merit Order and Declining Demand Based on MISO Changes





Source: Illinois Commerce Commission, Illinois Power Agency, Illinois Environmental Protection Agency, Illinois Department of Commerce and Economic Opportunity, ***Potential Nuclear Power Plant Closings In Illinois: Impacts And Market-Based Solutions, Response to the Illinois General Assembly Concerning House Resolution 1146*****, January 5, 2015, for the supply stack. Demand shift is for MISO from MISO 2013 Annual Market Assessment Report Information Delivery and Market Analysis, June 2014, pp. 14, 16, 20.**

FIGURE VII-7: JOBS IMPACT OF EARLY RETIREMENT AND REPLACEMENT, INCLUDING DECOMMISSIONING



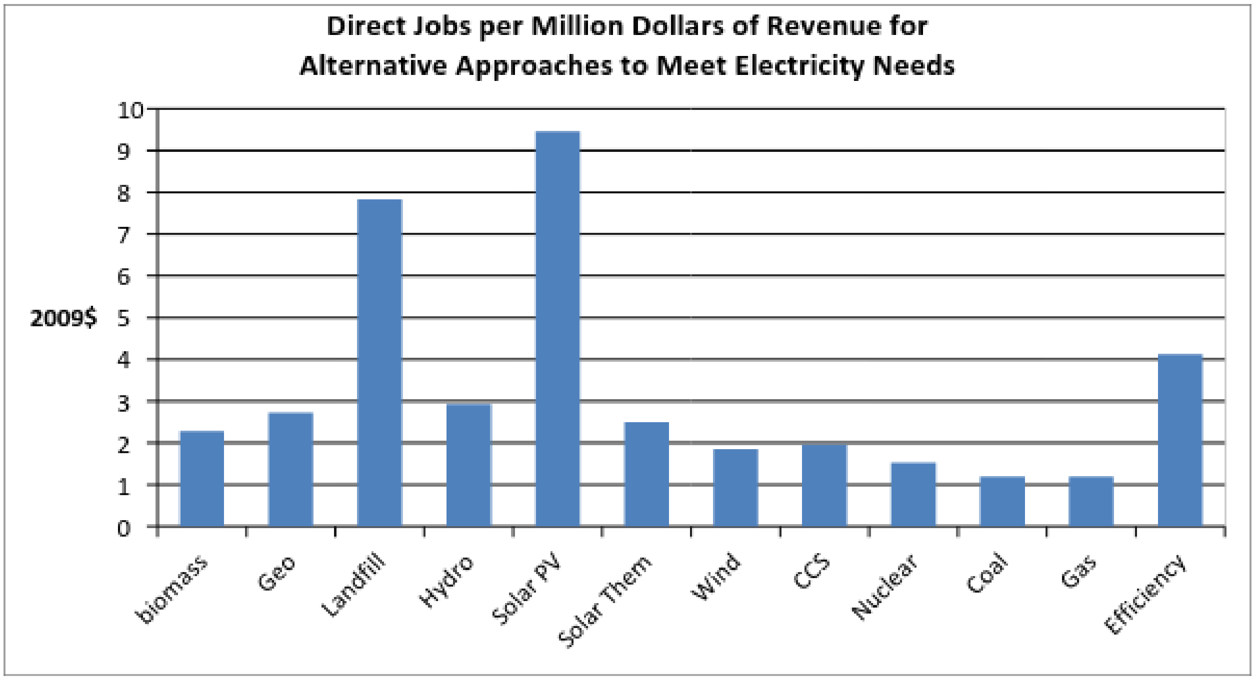
Sources: Illinois Commerce Commission, Illinois Power Agency, Illinois Environmental Protection Agency, Illinois Department Of Commerce And Economic Opportunity, *Potential Nuclear Power Plant Closings In Illinois: Impacts And Market-Based Solutions, Response To The Illinois General Assembly Concerning House Resolution 1146*, January 5, 2015, p. 139. Decommissioning is discussed on p. 134.

"operation" of replacement resources. However, this calculation does not include decommission activities at the reactors. Ironically, while the Department of Commerce does not include decommissioning jobs, it then criticizes the Nuclear Energy Institute analysis that failed to do so.[205] The oversight is substantial.

The direct jobs gained in decommissioning a reactor are equal to over three-fifths of the jobs lost in retiring the reactors. The Department of Commerce argues that they would not be immediately available, but that is not a reason to ignore them, particularly when the number of direct jobs added by replacing the reactors exceeds the number lost in early retirement. The timing of the decommissioning is uncertain, but if it begins in the fifth year that proves the relative importance of the decommissioning jobs. Their impact in terms of indirect jobs is also uncertain. Treating the decommissioning jobs as equivalent to the operating jobs in terms of indirect jobs, we find that there would be no net loss in jobs until the thirteenth year after closure. The combination of lower cost and the use of non-commodity, local power sources gives efficiency and renewables a large advantage in macroeconomic impacts.[206]

The calculations offered by the Department of Commerce show that operation of nuclear reactors is almost twice as labor intensive as the operation of the replacement resources of efficiency, wind, and solar. This assumption is at odds with other evidence in the electricity sector, which shows that nuclear creates many fewer jobs than efficiency and solar and about the same number of jobs as wind, as shown in Figure VII-8.[207]

FIGURE VII-8: JOB CREATION BY ALTERNATIVE APPROACHES TO MEETING ELECTRICITY NEEDS



Source: Direct jobs: Max Wei, Shana Patadia and Daniel Kammen, "Putting Renewables and Energy Efficiency to Work: How Many Jobs Can the Clean Energy Industry Generate in the US?" ***Energy Policy,*** **38 (2010);**

One explanation may be that the challenge of keeping aging reactors online, which has so dramatically increased their operating cost, might also increase the amount of labor needed. In other words, this leads to a perverse economic principle: the more inefficient the resource, the more it should be valued as a jobs project.

Another non-energy economic rationale teed up by the legislature and cited by the Department of Commerce is the "duty/desire" to maintain Illinois as an exporter of electricity. Exporting electricity at a loss is a problem for the utilities and a benefit to the importing states. Subsidizing the continued operation of the reactors shifts the burden from the utilities to Illinois ratepayers, while the benefits still flow to out-of-state consumers. A better solution to the problem would be regional, raising the price for everyone, in which case Illinois ratepayers would bear only their fair share of the burden. But, of course, the best solution would be to pursue least cost resources and recognize that baseload is an antiquated concept.

> The value of Illinois continuing to be a net exporter of electricity both now and in the future is an underlying impetus of House Resolution 1146 (HR 1146). If Illinois is to continue as a net exporter of energy under the USEPA proposed carbon dioxide reduction rule Illinois will have to act to maintain existing low or no carbon emissions energy assets as well as develop new low or no carbon emissions energy assets….

> wholesale electricity markets do yield benefits to Illinois, they also fail to fully compensate nuclear plant operators for the value they provide to the market….
>
> Eventually, market forces and national policies will fully compensate nuclear plant operators for their reliability and carbon-free emissions. Until that time, Illinois has the opportunity to craft effective market-based solutions that can support all forms of low-carbon power generation to be sited in Illinois for the benefit of Illinois' economy and citizens.[208]

2. Carbon Reduction

With nuclear power among the least attractive resources from every point of view, there is no compelling reason to subsidize the continuing operation of aging reactors, nuclear advocates resort to claims that nuclear is indispensable to the effort to reduce carbon emissions. Backward-looking analysis makes the obvious point that nuclear power has made up a large part of current and total low-carbon generation. However, forward-looking analysis shows that it is not needed to meet the goals of carbon reduction.

Pointing out that 60% of our current low carbon generation comes from nuclear as a basis for suggesting that nuclear must play a central role in the future decarbonization of the electricity sector is simply wrong as a matter of fundamental economics and totally irrelevant to policy making. The existence of nuclear power is a very old sunk cost and its deployment and its deployment had nothing to do with decarbonization.

- Backward looking analysis can only inform forward looking analysis if it has relevance to the future and sunk costs should not be considered unless they actually influence important future variables or prices, which the existing nuclear reactors do not (except perhaps in the fact that their operating costs are rising dramatically as they age).
- The existing nuclear reactors cannot grow their contribution to decarbonization (except at a huge cost of minor uprating). In the mid-term, the share of the existing reactors to the goal of decarbonization is closer to 10 percent. It is the future that matters.
- In the past twenty years, 95% of the low carbon resources deployed have been non-hydro renewables. The recent past is much more likely to be relevant to the future.
- In the mid- to long-term, none of the existing nuclear reactors will make any contribution to decarbonization. They will all have to be replaced and their future costs, compared to the available alternatives, are all that matters.

When a least cost approach is taken to meeting the need for electricity in a low-carbon environment, nuclear could easily be replaced by other low-carbon resources at little or no cost increase. The projected wholesale cost increases resulting from early retirement of the reactors are less than or equal to the subsidies being sought by the utilities to keep the reactors online. The relevant question is, are there enough low-carbon resources available to replace the aging reactors? As the earlier analysis of resource availability showed, when the near-term challenge of meeting the EPA Clean Power standards is the focus, the answer is yes.

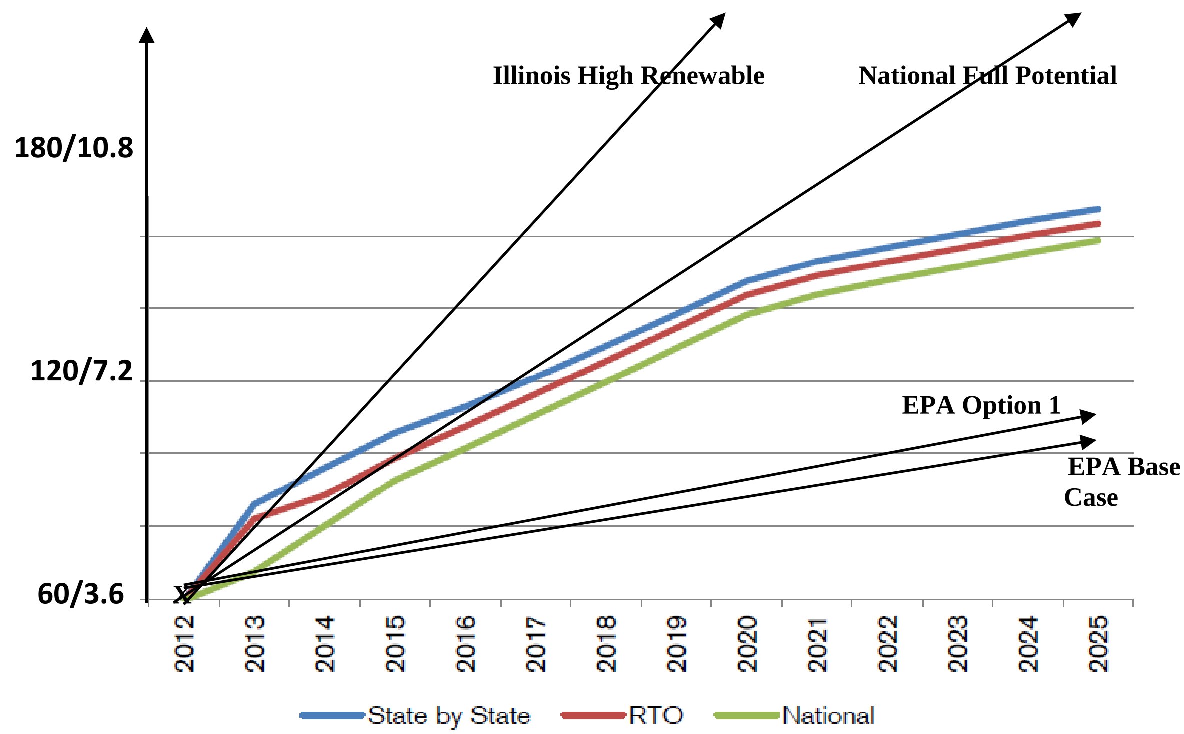
While the reduction of carbon emissions that results from the combination of the base case trends and the policy case in the EPA analysis is impressive, it is well below what the literature reviewed above deems economic and achievable for efficiency and renewables. According to the Citi projection of base case growth, which includes only existing state RPS programs, at least 60 percent more could be achieved with renewables (see Figure VII-9). Two-fifths of the states have yet to adopt RPS programs, so it is reasonable to assume that a policy case in which the remaining states sought to increase renewable energy to roughly the same level as the RPS states would nearly double renewables.

As shown in Figure VIII-10 the contribution of efficiency could also be double the EPA assumption, based on the estimates of the national experts discussed earlier. For both renewables and efficiency the projected costs are competitive with the current cost of natural gas, so these carbon reductions impose very little increase in the cost of electricity. This outcome results from the fact that policy helps to overcome the efficiency and innovation gaps.

The large potential for additional carbon emissions reductions from low-cost efficiency and renewables has a major implication for the EPA analysis, as shown in Figure VII-11. The aging reactors can be readily offset by the other low-carbon sources.

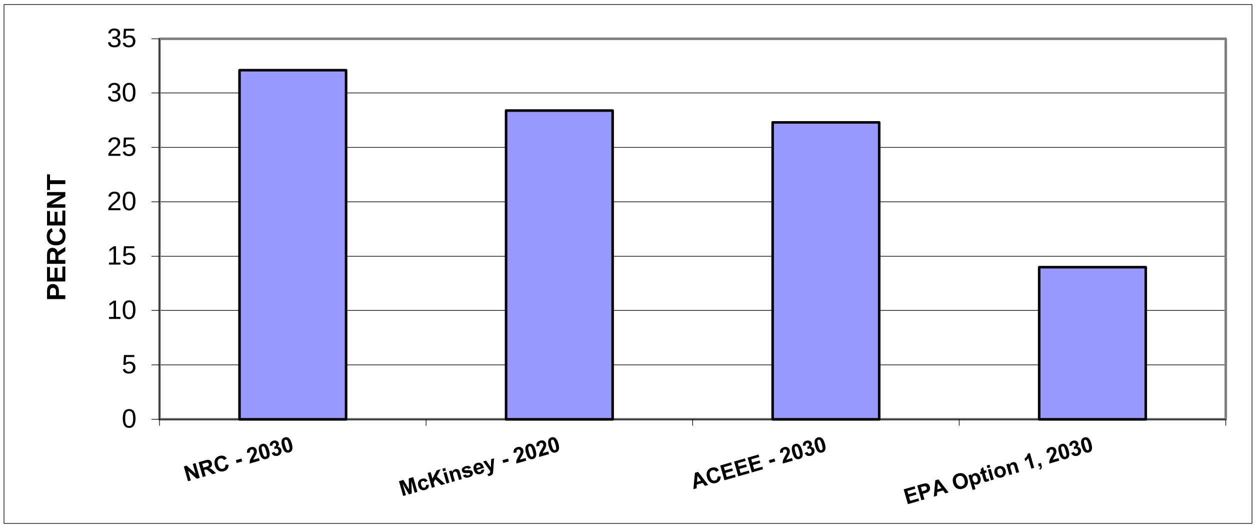
FIGURE VII-9: PROJECTION OF RENEWABLE GROWTH COMPARED TO EPA OPTION 1, ILLINOIS DEPARTMENT OF COMMERCE NUCLEAR REPLACEMENT

GW Nation/Illinois



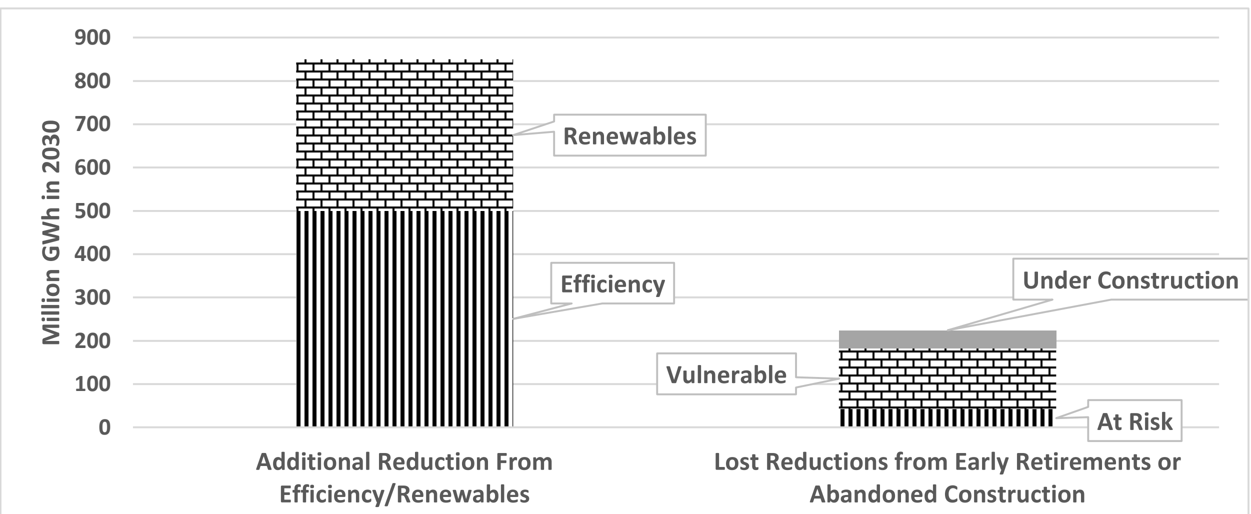
Sources: Dan Eggers, Kevin Cole, Matthew Davis, *The Transformational Impact of Renewables,* Credit Suisse, December 20,2013, p. 18., EPA, *Regulatory Impact Analysis,* 2004, Table 3-11, Illinois Commerce Commission, et al., *Potential Nuclear Power Plant Closings In Illinois: Impacts And Market-Based Solutions, Response To The Illinois General Assembly Concerning House Resolution 1146,* January 5, 2015, p. 139.

FIGURE VII-10: EFFICIENCY POTENTIAL FROM MAJOR NATIONAL STUDIES COMPARED TO EPA OPTION 1



Sources and Notes: See Figure II-1 and EPA, *Regulatory Impact Analysis,* 2004, Table 3-11.

FIGURE VII-12: UNTAPPED CARBON REDUCTION POTENTIAL OF EFFICIENCY & RENEWABLES COMPARED TO "AT-RISK" NUCLEAR REACTORS



Sources and Notes: Figure VIII-3, and EPA, *Regulatory Impact Analysis,* 2004, Table 3-11. At risk reactors and vulnerable reactors are identified in Mark Cooper, *Renaissance in Reverse,* 2013. Quantities are taken from EIA, *Annual Energy Outlook: 2014,* Nuclear Alternative Cases, with 5.7 GW at risk, one-half of the accelerated retirements between 2020 and 2040 assumed by 2030 (19 GW) and 5.5 GW of current construction. An 85% load factor is assumed, since old and new plants tend to have below average load factors.

C. CONCLUSION: GROUND ZERO IN THE WAR AGAINST THE FUTURE

In the introduction I explained why focusing on nuclear power rather than coal provides a better perspective on the conflict between central-station generation and distributed resources. Because nuclear can claim to be low-carbon, the attack nuclear advocates have launched on the alternatives distills the clash of economic interests and institutional conflict between central station power and distributed resources. However, the underlying structural problem that afflicts nuclear power also affects coal. Some utilities have both coal and nuclear resources. The effort of one mixed utility, First Energy, to obtain subsidies from Ohio ratepayers reaffirms earlier observations of Exelon's quest for subsidies in Illinois and adds additional perspective on the ongoing conflict.

In terms of purchase power agreements, First Energy provides predominantly coal (58%) and a substantial amount of nuclear (23%), its second resource by a wide margin (8% hydro, 9% oil and gas, 3% wind and solar). In Ohio, where it is seeking ratepayer subsidies, it has roughly the same 2.5-to-1 ratio of coal to nuclear.[209] The unique thing about First Energy is that in the last decade and a half it acquired coal assets and shed renewable assets when the industry was moving in the opposite direction. This "has not been a winning strategy"[210] because the same factors that have rendered aging nuclear reactors uneconomic have made aging coal generators uneconomic.

> With an aging coal fleet, low natural gas prices driving down power prices, weak electric demand growth, and increasing penetration of energy efficiency and renewable energy… FirstEnergy's merchant power plants, which depend on being able to sell their output for more than their cost of operation, have been hit particularly hard. Indeed, a leading utility analyst has recently estimated that FirstEnergy Solutions, one of FirstEnergy's merchant generation companies, is worth less than $0.[211]

Each of the strategies Exelon has pursued to bail out its nuclear plants has been magnified by First Energy in its efforts to bail out its coal and nuclear facilities. First Energy has taken the war against the future further at the state and regional levels by actively reducing the level of resources available. [212]

- It led the effort to reduce the commitment to renewables and efficiency in Ohio and is actively seeking to implement that reduction on its system.
- It withheld demand resources from the regional power pool by refusing to bid them into the market. This doubled the market clearing price and raised the cost to consumers by hundreds of millions of dollars.
- It is pressing PJM to not allow demand response to be bid into that market even though, as discussed above, it is widely recognized that demand response has played and will play a key role in ensuring reliability and mitigating price increases if markets become tight.

Placing First Energy's strategy over the past couple of decades in the context of the electricity sector further reveals its extremity. First Energy also:

- Sought massive subsidies for its nuclear assets in the transition to a wholesale market.

- Shifted coal generation from the wholesale market to regulated status when it did not like the market price.
- Has requested a direct subsidy from ratepayers.

In essence, First Energy is seeking to create a crisis of reliability by driving resources out of the market so that more centralized resources are needed. Its ability to lure policymakers down this path reflects more than the political muscle of a major utility, which is considerable. Over the past decade, the economics of the electricity sector have been transformed by technological change. Policymakers still have a mindset that is stuck in the past. The economics of aging reactors has been undermined by a

- 40 percent increase in the operating cost of those reactors;
- a 40 percent decrease in the cost of wind;
- 60 percent decrease in the cost of solar;
- low-cost energy efficiency technologies that have taken a bite out of load growth;
- demand response that has become an increasingly valuable and effective resource;
- huge investments in storage technologies that are on the brink of redefining the value of intermittent resources; and
- advanced information and control technologies that transform the approach to reliability.

The strategy pursued by First Energy makes it clear that this is a fight to the finish between the central-station approach and the distributed-resource approach. It provides strong support for Lovins' conclusion (cited above) that an "all of the above" approach simply will not work. It renders null and void the aspiration expressed by the Illinois Department of Commerce and Economic Opportunity that "Illinois has the opportunity to craft effective market-based solutions that can support all forms of low-carbon power generation to be sited in Illinois for the benefit of Illinois' economy and citizens."[213] Above all, if it succeeds, it precludes any real possibility of significantly reducing carbon emissions and responding to the challenge of climate change without the construction of hundreds of new nuclear reactors.

The extremes to which the central-station generation advocates are willing to go to defend their interests in their war against the future suggests that retiring aging reactors in an orderly fashion is an indispensable, early step on the path to building a least-cost, low-carbon future for the electricity sector.

This analysis leads to three interrelated recommendations for policymakers.

- Policy should move to quickly adopt the necessary institutional and physical infrastructure changes needed to transform the electricity system into the 21st century model.
- Policy should not subsidize nuclear reactors, old or new. In the long run, their

large size and inflexible operation make them a burden, not a benefit in the 21st century system.

- Combining their technological characteristics with their political efforts to undermine the development of the 21st century system makes them a part of the problem, not the solution.

ENDNOTES

[1] I use the term political economy in the traditional, positive sense, as suggested by Pearce, 1984, p. 342, which defines political economy as follows: "Until recent times the common name for the study of the economic process. The term has connotations of the interrelationship between the practical aspects of political action and the pure theory of economics. It is sometimes argued that classical political economy was concerned more with this aspect of the economy and that modern economists have tended to be more restricted in the range of their studies."

[2] UBS, 2014, p. 1.

[3] U.S. Environmental Protection Agency, 2014a.

[4] The paper is based on two recent filings in proceedings at federal agencies that will strongly influence the future structure of the electric utility industry in the U.S. – EPA's Clean Power Proposal and the Nuclear Regulatory Commission's (NRC's) consideration of Pacific Gas and Electric Company's (PG&E's) request for a license renewal for its Diablo Canyon reactors. It includes a review of the most detailed state-level analysis to date of the early retirement of aging reactors conducted by the Illinois Commerce Commission in response to Exelon's efforts to secure subsidies for its aging reactors. Exelon triggered the studies by threatening to retire these reactors early because they are losing money in the wholesale markets run by the PJM and MISO regional transmission organizations. Ultimately, the states take responsibility for resource acquisition in the electricity sector, under the direction set by federal policy, which means that this level of analysis will play a vital part in determining the extent to which the electricity system is transformed. There are ongoing regulatory proceedings and legislative action under this threat in Ohio and New York, in addition to Illinois.

[5] Ammer and Ammer, 1984, describe a situation of scarcity that applies well to the peak load problem, noting that "when the supply is exceptionally small – its price will be exceptionally high, and it will be said to have *scarcity value"* (p. 416) and links it to the definition of *quasi-rent,* defined as "a return on capital or labor whose supply is temporarily or permanently fixed, so called to distinguish it from a *real rent,* the return on land (whose supply is always fixed). Pearce, 1984, p. 395, applies the concept of absolute scarcity to fossil fuels.

[6] The Merit Order Effect has been documented in a number of nations in which renewables have shown strong growth in recent years, demonstrating not only that market clearing prices are lowered, but also that they are lowered by an amount that is larger than any subsidies the resources receive. The result is a net benefit to consumers. See for example, United States, Fagan, et al. 2012, Caperton, 2012, Charles River Associates, 2010; Canada, Ben Amora, et al., 2014; Australia, McConnell, et al., 2013, MacGill, 2013, Melbourne Energy Institute, 2013; Ireland, Mahoney and Denny, 2011; Denmark, Munksgaard, and Morthorst, 2008; Germany, Sensfuss, Ragwitz, and Genoese, 2008; Italy: Clò, 2015; Spain, de Miera, et al., 2008; United Kingdom, Green, and Vasilakos, 2011. A separate effect that lowers the market clearing price is the fact that renewables tend to lower the level of concentration of supply, reducing the exercise of market power, Mishra, et al., 2014, Twomey, and Neuhoff, K., 2010; Wirl, 2014, Mountain, 2012,

[7] The Illinois Commerce Commission, 2015, p. 29-30, was not given cost data by Exelon, but relied on EIA estimates.

[8] Cooper 2009a, 2012, reviews the nuclear estimates associated with the "nuclear renaissance." Cooper 2012 and 2013, reviews comprehensive cost estimates.

[9] Chang, et.al. 2014; Jaffee, 2014.

[10] The Hinkley cost ($150/MHWH) is equal to my estimate of costs (Cooper, 2009).

[11] Cooper, 2014.

[12] Eggers, Cole and Davis, 2013. I show 2023, the mid-point of the current period for the EPA Clean Power rule.

[13] Eggers, Cole and Davis, 2013, p. 3.

[14] Zheng, Cheng and Kammen, 2014.

[15] Eggers, Cole and Davis, 2013, p. 3.

[16] Lyons, 2014, "by 2018 the cost of ViZn Energy's 4-hour storage solution in is essentially identical to that of a conventional simple cycle peaker. Given the added benefits of installing storage in distribution, by 2018 storage is a clear winner compared to a typical mid-range cost for a conventional simple cycle CT."

[17] Lazard, 2013, Hoffman, as reported in Fuhs, 2014, Sam, 2014, p. 8.

[18] Walwyn and Brent, 2015.

[19] Cooper, 2014.

[20] Eggers, Cole and Davis, 2013b, p. 1.

[21] Golove and Eto, 1996.

[22] McKinsey, 2009, p. viii,

[23] Schleich and Gruber, 2008, pp. 1-2, emphasis added to identify the three main schools of analysis I ultimately adopt to organize the framework. A similar formulation is offered by Thollander, Palm, and Rohdin, p.3., Why do organizations impose very stringent investment criteria for projects to improve energy efficiency? Why do organizations neglect projects that appear to meet these criteria? Why do organizations neglect energy- efficient and apparently cost-effective alternatives when making broader investment, operational, maintenance, and purchasing decisions? Because of barriers to energy efficiency these seemingly profitable measures are not being adopted… There is a large body of literature on the nature of barriers to energy efficiency at the micro and the macro level, which draws on partly overlapping concepts from neo-classical economics, institutional economics (including principal-agent theory and transaction cost economics), behavioral economics, psychology and sociology. Barriers at the macro level involve price distortions or institutional failures. In comparison, the literature on barriers at the micro level tries to explain why organizations fail to invest in energy efficiency even though it appears to be profitable under current economic conditions determined at the macro level

[24] Cooper 2014b.

[25] Takahasi and Nichols, 2008, p. 8-367.

[26] Junginger, et al., 2008, p. 12; Kiso, 2009, find for Japanese automobiles that "fuel economy improvement accelerated after regulations were introduced, implying induced innovation in fuel economy technology."

[27] Dale, et. al., 2009, p. 1.

[28] Sperling, et al., 2004, p.p. 10-15.

[29] Kok, 2006, The European car industry is highly dynamic and innovative. Its R&D expenditures are well above average in Europe's manufacturing sector. Among the most important drivers of innovation are consumer demand (for comfort, safety and fuel economy), international competition, and environmental objectives and regulations… One element of success of technology forcing is to build on one or more existing technologies that have not yet been proven (commercially) in the area of application. For improvements in the fuel economy of cars, many technological options are potentially available… With respect to innovation, the EU and Japanese policy instruments perform better than the US CAFE [Corporate Average Fuel Economy] program. This is not surprising, given the large gap between the stringency of fuel-efficiency standards in Europe and Japan on the one hand and the US on the other…. One of the reasons for the persistence of this difference is that the US is not a significant exporter of cars to the European and Japanese markets

[30] Hwang, and Peak, 2006.

[31] Harrington, 2006, p. 3; Harrington, 2010.

[32] Whitefoot, et al., 2012, pp. 1…5. We perform counterfactual simulation of firms' pricing and medium-run design responses to the reformed CAFE regulation. Results indicate that compliant firms rely primarily on changes to vehicle design to meet the CAFE standards, with a smaller contribution coming from pricing strategies designed to shift demand toward more fuel-efficient vehicles... Importantly, estimated costs to producers of complying with the regulation are three times larger when we fail to account for tradeoffs between fuel economy and other vehicle attributes.

[33] Nadel and Delaski, 2013; Institute for European Environmental Policy 2013, p. 9.

[34] Hoffman, et al., 2015.

[35] Molina, 2014.

[36] Cooper, 2006.

[37] Cooper, 2014a.

[38] Boccard, 2014; Rangel and Leveque, 2012.

[39] Jansen, Beurskens, and Tiburg, 2006, p. 13 argue for a risk-cost frontier.

[40] Jansen, Beurskens, and Tiburg, 2006, Appendix, p. 59, ""the question of whether a tool could be develop for gauging the impact of incremental technology deployment… the use of a (sort of) Sharpe ratio, showing the tangent of the direction a certain portfolio at (or to the right of) the efficient frontier would move into by incremental use of a certain technology."

[41] Cooper, 2011, 2013b.

[42] Vithayasrichareon, Riesz MacGill, 2015, p. 44, identify portfolio studies of New Zealand, Denmark, Ireland, Macedonia, Portugal, Japan, Brazil, Spain, Taiwan, 44. Cooper, 2011, 2013b, had earlier reviewed studies of the U.S. Scotland, U.K.

[43] Cooper, 2013c.

[44] Cooper, 2012.

[45] In addition to the recent U.S. analysis by U.S. EPA/NHTSA, 2011, see Howland, et al., 2009, and New York State

Energy Research & Development Authority, 2011, for individual states; Homes and Mohanty (2012) and Cambridge Centre for Climate Mitigation Research (2006), and Ryan and Campbell, 2012 for a general global review.

[46] Amann, 2006.

[47] Amann, 2006.

[48] Dombi, 2014; Maxim, 2014.

[49] Pechan and Eisenach, 2014.

[50] Stein, 213, 646… 640.

[51] Johansonn, 2014.

[52] Katarzyna, et al., 2009, 187,

[53] Stein, 2013; Rabl and Rabl, 2013,

[54] Stein, 213, Karakosta, et al., 2013, Verbruggen, Laes and Lemmens, 2014.

[55] U.S. Congressional Office of Technology Assessment, 1994, evaluating Ottinger, Richard et. al., 1990, Chernik, Paul and Emily Caverhill, 1989, Hohmeyer, Olive, 1988 and Shuman, Michael and Ralph Cavanagh, 1982.

[56] Stein, 213, 646… 640.

[57] MIT, 2015, pp. xi… xiii.

[58] U.S. Department of Energy 2015, p. xxvii.

[59] MIT, 2015, p. xiii.

[60] MIT, 2015, pp. xv…xix.

[61] U.S. Department of Energy, 2015, p. xxiii.

[62] U.S. Department of Energy 2015, p. xlii.

[63] See for example, Hoffert, M.I.,2010; Bettencourt, L.M.A., Trancik, J.E., Kaur, J., 2013; Petkovi, Dalibor, 2014; Sueyoshi , Toshiyuki and Mika Goto, 2014; Chmutina, Ksenia and Chris I. Goodier, 2014; Maia, Trieu, et al., 2014; Santiago, de Souza and Bezerra, 2014; Sueyoshia, Toshiyuki, Mika Gotob, 2014; Johnson, Erik Paul, 2014; Zheng, Chengn and Daniel M. Kammen, 201. There are a growing number of scenario analyses at the global level (Jacobson and Delucchi, 2011; Jacobson, et al., 2013; Delucchi and Jacobson, 2011, Budischak, et al., 2013; Delucchi and Jacobson, 2013; Cochran, Mai and Bazilian, 2014).

[64] For academic studies on system integration generally see, for example, Lu, 2013; Veena, P., et al., 2014; Phuangpornpitak, N. and S. Tia, 2013; Jamel, AbdRahman and Shamsuddin, 2013; Chaves-Avila, Hakvoort, and Ramos, 2014. On resource diversity, see for example, Tascikaraoglu, A., and M. Uzunoglu, 2014, Grossmann, Grosssman and Seininger, 2014.

[65] Cooper, 2009b, reviews several of these analyses including, Moody’s, 2009; Moody’s, 2008; Standard & Poor’s, 2009; Standard & Poor’s, 2008; Standard & Poor’s, 2007; Maloney, Stephen, 2008; Maloney, Stephen, 2009; Kee 2009.

[66] Lazard, 2011; Citi Research, 2012; Eggers, Cole and Davis, 2013.

[67] Credit Suisse, 2013; UBS Investment Research, 2013a, 2013b, 2013c; Platts, 2013, Moody’s, 2012

[68] Citi Research, 2012, pp. 54, 55, 56. The academic literature reflects this trend as well. See, for example, Sener, Can and Vasilis Fthenakis, 2014; Martínez-Duart and Hernández-Moro, 2013; Reichelstein, Stefan and Michael Yorston, 2013: Bazilian, Morgan, et al., 2013; Branker, Patha and, Pearce, 2011.

[69] Eggers, Cole and Davis, 2013b, p. 1.

[70] Eggers, Cole and Davis, 2013b, p. 1.

[71] Frankel, Ostrowski, and Pinner, 2014.

[72] Frankel, Ostrowski, and Pinner, 2014.

[73] Parker, 2014, p. 3.

[74] Eggers, Cole and Davis, 2013a, p. 1.

[75] Eggers, Cole and Davis, 2013a, p. 1.

[76] Eggers, Cole and Davis, 2013a, p. 3.

[77] McKinsey, 2009, 2010.

[78] The DOE *Wind Vision* study project almost a one-quarter reduction in base case demand for natural gas.

[79] Eggers, Cole and Davis, 2013b.

[80] Cooper, 2013c.

[81] Navigant, 2015.

[82] UBS, 2013, 2.

[83] Nayyar, 2013.

[84] Navigant, 2014.

[85] Bradley and Leach, Shen, Martinez Aghiri, 2013.

[86] Bradley, Leach and Torriti, 2013, p. 317.
[87] Evans, Kelly , 2015, McMahon, 2015b,
[88] McMahon, 2015a, Did Tesla Just Kill Nuclear Power?, *Forbes* Blog, May 1.
[89] Costello and Hemphill, 2014.
[90] Dumulin-smith, et al., 2014.
[91] Deutsche Bank, 2015, p. 44.
[92] RMI, 2015.
[93] Peare, Atia, Zhao
[94] Chang, et.al, 2014, p. 2
[95] General Electric International, Inc., 2014; Oggioni, Murhpy and Smeers, 2014.
[96] Sahu, Hiloidhari and Baruah, 2013, pp. 349–353.
[97] Imperial College, 2014,
[98] Rasmussen, et al., N.D., 2012, Schaber, Steinke Hamacher, 2013; Rodriguez, 2013; Rasmussen, Andresen, and Greiner, 2012; Greiner, et al., 2013.
[99] On storage and its integration with renewables to achieve reliability see Katarzyna, 2009; Bose, et al., N.D.; National Renewable Energy Laboratory, N.D**.** Boie, et al., 2014; Pleßmann, et al., 2014**;** Komiyamaa, and Fujiib, 2014; Elkind, 2010; Hasan, et al., 2013; Koohi-Kamali, et al., 2013; Díaz-González, et al., 2012; Ippolito, 2014; Lu, 2013; Steinke, 2013. Gao, et al., 2013, Kucsera, and Rammerstorfer, 2014; Cau, 2014.
[100] On demand management, see for example, Falsafi and Jadid, 2014; Arif, Javed and Arshad, 2014; Biegela, et al., 2014; Bergaentzlé, Clastres, and Khalfallah, 2014, O'Connell, et al., 2014.
[101] Heymans, et al. 2014, Reber, et al., 2014, Loisel, Pasaoglu and Thiel, 2014, Parsons, et al., 2014,
[102] The Smart Grid is at the classic turning point in early diffusion and in need of social support to overcome concerns and attitudinal barriers grounded in the real world experience of consumers. Naus, 2012, p. 436, Smart grids generate three key new information flows that affect social relations. Practice theory can reveal the ways in which households handle/govern information. Householders show ambivalence about the workings of the different information flows. Policies should account for the 'bright' as well as the 'dark' sides of information. Park, 2014, p. 211, We examine what factors influence electricity consumers' smart grid acceptance. We test the smart grid technology acceptance model including the perceived risk as a main factor. The importance of consumer education and public relations of the smart grid has been confirmed. Another short cut to ensure the acceptance of the smart grid is to mitigate the anxiety about the risk in the use of the Smart grid. Pepermans, 2014, Guizhou Ma and Cong, 2015.
[103] Both in its interaction with smart grid and directly in transforming production and distribution processes Ravindranath, 2014, Poindexter, 2014, Stephenson, 2014.
[104] Solar as both baseload resources, (e.g. Pfenninger, et al., 2014) and a distributed resource (rooftop PV).
[105] On system integration see, for general policy studies see example, Mills and Wiser, 2014; E3, 2015; U.S. Department of Energy, 2015; and Imperial College, 2014;
[106] Pringles, Olsina and Garcés, 2014; Edenhofer, et al., 2013; Bushnell, J. 2010,
[107] Jim Lazar, 2014. Needless to say, there are many other general analyses of the possibility and benefits to aggressively integrating renewable supply and demand in the long term. The RAP analysis provides a clear, concrete basis for translating these benefits into cost analysis of presently deployed systems.
[108] Lazar, 2014, p. 24.
[109] Mills and Wiser, 2014, p. 17
[110] Id., p. 29.
[111] The LBL study shows the ratio as high as 3-to-1, and cites (p. 14) a similar study for ERCOT, which put the ration at 2.33-to- 1. Other studies have arrive at ratios that favor solar, when that resources is richer.
[112] Mills and Wiser, 2014, p. 19.
[113] Id., p. 24, A portfolio with high geographic diversity leads to a higher value of wind due to a reduction in extremes: fewer hours have significant amounts of wind from all wind sites in the portfolio (reducing overgeneration and curtailment), and more hours have at least a small amount of wind generation from some sites. The benefit of increased geographic diversity is more pronounced with high wind penetration levels since wind is more likely to affect wholesale prices at high penetration levels.
[114] Id. p. 25, The increase in the capacity value of wind with 10% PV is due to PV shifting the timing of the peak prices into the early evening, when wind generation is somewhat stronger. p. 27, as PV penetrations increase, adding 10% wind increases the marginal value of PV substantially relative to the Reference scenario… The increase in the capacity value is tied in part to wind generation occurring in early evening (as described earlier) and thus slowing the shift of high-price hours into the early evening with increasing PV.

[115] Id., p. 33 The increase in the value of PV with low-cost storage is almost entirely due to the increase in the energy value of PV relative to the Reference scenario... The energy value of PV increases in part due to a reduction in PV curtailment from 2.9% with 30% PV in the Reference scenario to less than 0.1% in the Low-cost Storage scenario. The strong negative correlation between PV generation and generation from storage (existing and new) at high PV penetrations indicates storage is consistently charging when PV is generating and discharging otherwise,

[116] Id., pp. 32, 33.

[117] Id., p. 33.

[118] Id., p. 35, since reductions in demand relative to historical levels at time of system need enable a balance between demand and generation rather than relying on new conventional capacity

[119] In the Mills and Wiser, 2014, study the issue enters implicitly through the frequent attention to forecasting error. The other major studies give sub-hourly scheduling prominent, explicit attention.

[120] Id., p. 43,

[121] Id., p. 30, In addition, the impact of more-flexible generation will depend on the degree of flexibility in the existing generation mix. California has significant amounts of CTs, PHS capacity, and hydropower. In comparison, we found in an earlier analysis of highly concentrated wind in the Rocky Mountain Power Area [Mills and Wiser, 2013] that assuming all new CCGTs had quick-start capability increased the value of wind by up to $6/MWh at 30% wind penetration. The Rocky Mountain Power Area has much less flexible incumbent generation relative to California.

[122] Id., p. 39.

[123] Id., pp. 41 (technology diversity), 43 ("quick start" generation, 45 (storage), 45 (demand shaping.

[124] E3, 2015, p. 129.

[125] The four "least regrets" opportunities identified in this study include: 1. Increase regional coordination… 2. Pursue a diverse portfolio of renewable resources…. 3. Implement a long-term, sustainable solution to address overgeneration before the issue becomes more challenging…. 4. Implement distributed generation solutions…. 5. Promising technologies, storage (Solar thermal with energy storage, Pumped storage, Other forms of energy storage including battery storage, Electric vehicle charging, Thermal energy storage)… 6. Flexible loads that can increase energy demand during daylight hours (Advanced demand response and flexible loads)…. 7. Sub-five minute operations…. 8. Size of potential export markets for excess energy from California… 9. Transmission constraints… 10. Changing profile of daily energy demand… 11. Future business model for thermal generation and market design… 12. Optimal thermal generation fleet under high RPS. (pp. 31-35)

[126] E3, 2015, pp. 31-35.

[127] Shrimali, Lynes and, Indvik, 2015, p. 454, "The complementary characteristic of battery (large energy density for long term storage, but low power density, low charge and discharge efficiency) and super-capacitor (low energy density, but high power density, fast charge and discharge rate) has… revealed that, the hybrid of the duo can optimize the battery charge and discharge process, thereby… can extend system lifetime by 62% and reduce the cost of energy storage system by 41%... A suitable energy storage device combined with wind turbines, can firm and shape wind power output, transforming the wind generation into a firm and predictable energy source…However, no single storage technology can meet up with all the criteria. Thus hybrid storage technology is being explored as a potential solution. Bouzid, et al., 2015, p. 753, A micro grid can be defined as a part of the grid consisting of prime energy movers, power electronics converters, distributed energy storage systems, and local loads. This makes the electrical network more flexible and intelligent. Micro grids and virtual power plants (VPPs) are two low voltage distribution network concepts that can participate in active network management of a smart grid. They are becoming an important concept to integrate distributed generation (DG) and energy storage systems.

[128] Id., p. 29

[129] Id., p. 19.

[130] Mill and Wiser, 2014, put costs in the $5-$10/MWh range; Mills and Wiser, 2010, p. 2, We conclude that the costs of managing the short-term variability of PV are dramatically reduced by geographic diversity and are not substantially different from the costs for managing the short-term variability of similarly sited wind in this region. Milligan, et a., p. 93, The incremental balancing costs caused by wind are 10% or less of the wholesale value of the wind power… The experience of countries and regions that already have quite a high wind penetration (from 5% to 20% of gross electric energy demand) has been that there existing reserves are deployed more often after wind power is added to the system, but no additional reserve capacity is required.

[131] Id., pp. 36-37.

[132] Id., p. 31

[133] U.S. Department of Energy, 2015.
[134] U.S. Department of Energy, 2015. p. xv.
[135] Eichman, 2013, Becker 2014a, 2014b.
[136] Becker, et al., 2015.
[137] Navid, 2012, Becker, et al., 2015.
[138] Duthu and Bradley, 2015; Cesna, 2015; General Electric International, Inc., 2014; Oggioni, Murhpy and Smeers, 2014; Sahu, Hiloidhari and Baruah, 2013.
[139] Krozer, 2013; Renewables International, 2012; Imperial College, NERA, DNV-GL, 2014.
[140] Archer, 2007; Kempton, et al., 2010; GTM, 2015; Hernández-Moro. and .Martínez-Duart, 2015.
[141] Holtinent, 2009; Wu, 2015; Rauch, 2014.
[142] Cooper, 2015.
[143] U.S. DOE, 2015, p. xxxvi.
[144] NERC, Potential Reliability Impacts of EPA's Proposed Clean Power Plan: Initial Reliability Review, November 2014.
[145] AEE Institute, NERC's Clean Power Plan 'Phase I' Reliability Assessment: A Critique, May 7, 2015, Jurgen Weiss, 2015, EPA's Clean Power Plan and Reliability: Assessing NERC's Initial Reliability Review, Brattle Group, February; Susan Tierney, Eric Svenson, Brian Parsons, 2015, Ensuring Electric Grid Reliability Under the Clean Power Plan: Addressing Key Themes From The FERC Technical Conferences, April 2015.
[146] Australian Energy Market Operator (AEMO), 2013, *100 Per Cent Renewables Study – Modelling Outcomes,* July; Elliston, B., I. MacGill and M. Diesendorf, 2013, "Least cost 100% renewable electricity scenarios in the Australian National Electricity Market," *Energy Policy*, 59.
[147] AEMO, 2012, p. 14, for 2011 consumption, p. 18 for technical potential, p. 22 for projected economic potential.
[148] AEMO, 2012, p. 34.
[149] AEMO, 2012, p. 9.
[150] Vithayasrichareon, Peerapat, Jenny Riesz and Iain F. MacGill, 2015, "Using renewables to hedge against future electricity industry uncertainties—An Australian case study," *Energy Policy,* 76, p. 43.
[151] Molyneaux, Lynette, et al., 2012, *Australian Power: Can renewable technologies change the dominant industry view?,* Australian Solar Energy Society Conference, Melbourne December, p. 1.
[152] Jacobson, et al., 2015.
[153] The original concept is from Joseph Schumpeter, 1961) and has been greatly expanded and developed in recent widely praised analyses of system change (Perez, 2002, *Technology Revolutions and Financial Capital: The dynamics of Bubbles and Golden Age;* and Acemoglu and Robinson, 2012.
[154] Bischof, 2014.
[155] Murphy 2014. Parker, et al., 2014, p. 3.
[156] Kind, 2013, p. 1.
[157] EEI, 2012.
[158] Bronski, et al., 2015. p. 37.
[159] Pearson and Foxon, 2012, pp. 123–124.
[160] Hildmann, Ulbig and Andersson, 2014, show that if baseload facilities could stop acting like baseload facilities, they would fit into to the emerging electricity system. "Given base load power plants that have sufficient operational flexibility in terms of fast ramping, start/stop times and minimum operation point requirements, energy-only markets seem to work even for high RES penetration scenarios. (p. 13).
[161] Lovins, 2011, p. 216.
[162] U.S. Department of Energy, 2015, pp. 86-87, Most North American power markets now integrate wind power into their security-constrained unit commitment and security-constrained economic dispatch process, allowing the dispatch of wind plants along with conventional power plants based on current grid conditions and economics. This effectively gets wind into the real-time economic optimization process for running the power system, and in turn, encourages the participation of wind plants in the day-ahead markets. Security-constrained economic dispatch also makes wind dispatchable and economical, allowing some degree of wind-plant output control by the system operator. This allows wind forecasts to become more useful and valuable to wind plant operators, market participants, and system operators, because wind is better integrated into systems and markets.
[163] Illinois Commerce Commission, 2015, pp. 71-72,
[164] Id., p. 64,
[165] Id., p. 63, it is also noteworthy that generating facility owners participating in PJM's Reliability Pricing Model base capacity auctions commit to provide generating capacity three years prior to each delivery year; and the

penalties for failing to actually make committed capacity available are steep. In PJM and MISO, generators are required to provide advanced notice of unit deactivations.

[166] Id., p. 64,

[167] Id., p. 64,

[168] Id., p. 64,

[169] Id., p. 64,

[170] Id., pp. 37-38, That is, Exelon's closure of one or more plants can increase market prices and thereby increase the revenues earned by Exelon's other plants. This means Exelon has market power. Thus, even if Exelon's least-profitable plants are at least marginally profitable at the present time and expected to remain so in the future, such market power may provide Exelon with a reason to close one or more of those plants.

[171] Id., p. 76, The reliability modeling in this report focuses on 2018-2019, the first year for which PJM capacity obligations have not been determined. The PJM RPM auction for the 2017-2018 delivery year has cleared at a price lower than the target clearing price, indicating more than the amount of capacity required to meet the reliability standard has cleared the auction. There is most likely time to take other actions prior to a retirement effective in 2019-2020 delivery year. The 2018-2019 horizon was also used for MISO, both for convenience and because MISO itself has not yet issued warnings about future resource adequacy.

[172] Id., p. 73, This analysis contained in this report demonstrates that there is a potential for impacts on reliability and capacity from the premature closure of the at-risk nuclear plants. However, in many of the cases analyzed, reliability impacts remain below industry standard thresholds, and impacts appear to be more significant in other states than in Illinois. Taken alone, there may not be sufficient concern regarding reliability and capacity to warrant the institution of new Illinois specific market-based solutions to prevent premature closure of nuclear plants.

[173] Id., p. 46.

[174] Rowe, 2010, 2011.

[175] Id., p. 73, But combined with the issues raised by the Reports prepared by the ICC, IEPA, and DCEO, the totality of the impacts suggest that the General Assembly may want to consider taking measures that would prevent the premature closure of at-risk nuclear plants. The IPA notes that the impacts found have multi-state implications and policy makers should consider the implications of measures taken by Illinois alone versus regional or even national measures.

[176] Id., p. 166.

[177] License Renewal GEIS, 2013, p. 1-30 – 1-31.

[178] NRC, 1996, p. 8-1.

[179] NRC, 2013, Section 2 is entitled "The Alternatives including the Proposed Action." The first 16 pages define the criteria by which the alternatives will be evaluated. The final teen pages present a tabular summary of the findings and the bibliography. The middle 17 pages evaluate all the alternatives considered.

[180] NRC, 2015, p. 9.

[181] NRC, 2013, p. 1-3. Most utilities are expected to begin preparation for license renewal about 10 to 20 years before expiration of their current operating licenses. Inspection, surveillance, test, and maintenance programs to support continued plant operations during the license renewal term would be integrated gradually over a period of years. Any refurbishment-type activities undertaken for the purposes of license renewal have generally been completed during normal plant refueling or maintenance outages before the original license expires.

[182] PG&E, 2015, p. 7.2-7 – 7.2-14.

[183] PG&E, 2015, p. 7.2-12.

[184] PG&E, 2015, p. 7.2-1

[185] PG&E, 2015, p. 7.2-2.

[186] Gross, et al., 2012, p.18.

[187] Bianconi and Yoshino, 2014, refer to this as the escalation of commitment. See also Bloomberg, 2014; Arbuthnott and Dolter, 2014; Farrar-Rivas and Ferguson, 2014; CERES, 2013.

[188] Acemoglu, et al, 2012, pp. 132.

[189] Gross, et al., 2012.

[190] Gross, et al., 2012, p. 18; Massetti and Nicita, 2010, p. 1

[191] Qui, 2012, Massetti and Nicita, 2010.

[192] Dechezlepetre, et al., 2011.

[193] Grubb Chapuis and Duong, 1995, p. 428,

[194] Zelenika-Zovk, Pearce, 2011

[195] De Cian, Carrara and Tavoni, 2012b, p. 14.
[196] De Cian, Carrara and Tavoni, 2014, p. 1-2.
[197] Goldberg, 2000; Slavin, 2009; Branker and Pearce, J.M., 2010; Badcock and Lenzen, 2010; Pfund and Healey, 2011.
[198] BWE, German Wind energy Association, 2012; Kitson, Wooders, and Moerenhout, 2011*;* Berwick. 2012; U.S. Energy Information Administration, 2011a; Pfund and Healey, 2011; GAO, 2007; Goldberg, 2000.
[199] Badcock, and Lenzen, 2010.
[200] Zelenika-Zovk and Pearce, 2011, p. 2626,
[201] Badcock and Lenzen, 2010. Branker and Pearce, 2010.
[202] Malik, and Polson, 2015; AGREE New York, 2014.
[203] Illinois Commerce Commission, 2015.
[204] Sanzillo and Kunkel, 2014.
[205] Illinois commerce Commission, 2015, p. 150.
[206] Llera, 2013; Santiago, et al., 2014. Islam, Mekhilef and Saidur, 2013; Pleßmann, Guido, et al., 2014, Branker and Pearce, 2010; Black, Geoffrey, et al., 2014, p. 141.
[207] Wei, Patadia and Kammen, 2010.
[208] Illinois Commerce Commission, 2015, pp. 124-125.
[209] Sanzillo and Kunkel, 2014. .
[210] Sanzillon and Kunkel, p. 2.
[211] Sanczillo and Kunkel, p. 2.
[212] Sanczillo and Kunkel.
[213] Illinois Commerce Commission, 2015, p. 125.

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