

Docket No.: R.23-01-007
Date: June 30, 2023
Commissioner: Douglas
ALJ: Seybert
Witness: Mark Cooper

**BEFORE THE PUBLIC UTILITIES COMMISSION OF
THE STATE OF CALIFORNIA**

Implementing Senate Bill 846 Concerning
Potential Extension of Diablo Canyon Power
Plant Operations

R.23-01-007
(Filed January 14, 2023)

**OPENING TESTIMONY OF MARK COOPER ON BEHALF OF SAN LUIS OBISPO
MOTHERS FOR PEACE ON PHASE 1 TRACK 2 ISSUES**

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VERIFICATION

The statements in the foregoing document are true and correct to the best of my knowledge. The facts presented in the forgoing document are true and correct to the best of my knowledge, and the opinions expressed therein are based on my best professional judgment.

I declare under penalty of perjury under the laws of the state of California that the foregoing is true and correct. Executed on June 30, 2023, in Silver Sp,
md ring.

Mark Cooper

Mark Cooper

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CHAPTER 1: INTRODUCTION

A Statement of Qualifications

Q. Please describe your background.

A. My name is Dr. Mark Cooper, I participated in the 2015 proceeding that dealt with the application for a license extension for Diablo Canyon.¹ Since I testified in opposition to the license extension, I have continually updated the analysis a dozen times in at least one major area on which I testified. These include books and chapters, testimony before various state and federal agencies, and research reports (as shown in Attachment MNC-1.1). This experience is located within over forty years as an expert witness and researcher. I have testified almost 500 times before state and federal regulators on energy, communications and technology issues in virtually every state in the United States. I have also testified in several Canadian provinces. My complete resume appears in Attachment A.

B. Purpose of Testimony

Q. What is the purpose of your testimony?

A. In this testimony, I update the earlier analysis I conducted of the Diablo Canyon reactors, adding a number of additional points that seem particularly relevant under the current circumstances, although they are all related to the earlier issues I addressed. There are eighteen issues covered in total. The outline of the issues I address is contained in attachment MNC-1.2

C. Conclusions

Q. What is your main conclusion?

A. The conclusion of direct relevance to this proceeding, affirmed on an annual basis, is simple.

- Now is not the time to double down on expensive nuclear power with subsidies that will cost ratepayers and taxpayers billions of dollars.

¹ Declaration of Mark Cooper, 2015, in Support of San Luis Obispo Mothers For Peace's Motion to File New Contentions Regarding Adequacy of Environmental Report for Diablo Canyon License Renewal Application, before the Atomic Safety and Licensing Board, in The Matter of Pacific Gas And Electric Company Docket Nos. 50-275-LR Diablo Canyon Nuclear Power Plant 50-323-LR Units 1 And 2, Nuclear Regulatory Commission, April.

- Now is the time to move forward as rapidly as possible with the transformation of the electricity system to one reliant on distributed alternatives (i.e., efficiency, wind and solar), which are much lower in cost and much more reliable.
- This conclusion applies equally to aging nuclear reactors as well as large or small new builds.
- The evidence has gotten stronger over the past decade, particularly with respect to the resource tools and approaches that ensure adequate, reliable supply at lower cost in the 21st century electricity system, which is also very low in carbon.
- Extending the Diablo Canyon license and subsidizing it to stay online is unjustified and a major step backwards.

Q. Doesn't it make sense for the PUC and utilities to buy nuclear in these uncertain times?

A. There is certainly risk in all electricity systems, so buying a little insurance always makes sense. However, that does not mean policy makers should abandon the process of evaluating the risk and buying the most appropriate insurance. The “willing suspension of disbelief” may be fine for poetry, but not for public policy.² Buying nuclear insurance is bad insurance policy – the wrong decision – for several reasons. First, there is no guarantee that the aging nuclear reactors will be there when you need them. They need routine maintenance and may be out of service for “emergency reasons. The transmission grid may not be available to deliver their large output. The alternatives are much smaller and distributed, so the loss of one unit may have a much smaller effect on the grid.

Second, subsidizing aging reactors may send the wrong signal to consumers and the marketplace that nuclear power is essential to the long-term solution. It may divert attention

² *Wikipedia* defines the concept as follows. “**Suspension of disbelief** is the avoidance—often described as willing—of [critical thinking](#) and [logic](#) in understanding something that is unreal or impossible in reality, such as something in a work of [speculative fiction](#), in order to believe it for the sake of enjoying its narrative.” In noting the origin of the phrase, in Coleridge’s writings, Wikipedia summarizes the reason it should not be adopted in a regulatory proceeding; to wit, the semblance of truth should not be the basis for suspending judgement on implausible outcomes... “The phrase first appeared in English poet and [aesthetic](#) philosopher [Samuel Taylor Coleridge](#)’s *Biographia Literaria*, where he suggested that if an author could infuse a “human interest and a semblance of truth” into a story with implausible elements, the reader would willingly suspend judgement concerning the implausibility of the narrative.”

1 from and reduce commitment to the critical task of building the physical and institutional
2 infrastructure to support the 21st century electricity system.

3 Third, no insurance is free. In this case its costs at least \$1.4 billion (the cost may be
4 higher if the utility is convinced to seek federal funds to support operation of the aging reactor).
5 That sum of money would buy a large quantity of alternatives because they are substantially
6 lower in cost. If policy makers are intent on targeting some of the resources at meeting critical
7 needs, they could do so, by focusing on long duration battery storage, geothermal power, of gas
8 combined cycle with carbon capture, which are dispatchable, and more compatible with a 21st
9 century system. They could also diversify resources at specific geographic areas that are deemed
10 to be vulnerable.

11 Fourth, relying on subsidizing nuclear power to keep it online has serious consequences,
12 as discussed below. It restricts the growth of alternatives. It may stimulate the effort to resist the
13 transformation of the electricity system. It may result in further demands for delay of the
14 transformation and crowd out the alternatives.

15 16 **D. The Relevance of My Analysis to the Issues Raised by the Order**

17
18 **Q. How is your testimony responsive to the issues raised by the order in this**
19 **proceeding?**

20 **A.** The order instituting this proceeding recognizes the broad powers of the Commission in
21 evaluating Diablo Canyon and its potential substitutes. My testimony compares the alternatives
22 broadly and with specificity. For example, in the discussion of basic conditions the order states
23 that “In establishing new retirement dates for Diablo Canyon, several of the conditions that must
24 be considered by the Commission are set forth in Public Utilities (Pub. Util.) Code Section
25 712.8(c)(2)(B) through (E).”³ It then cites numerous conditions and seeks comment on issues
26 that my testimony addresses. This section of the order includes addressing issues such as costs of
27 upgrade that “are too high” and “renewables are adequate.” Question posed to the public include
28 adequacy under the loss of load standard, the length of time to ensure an orderly shutdown of

³ Public Utilities Commission of the State of California, Order Implementing Senate Bill 846
Concerning Potential Extension of Diablo Canyon Power Plant Operations in R.23-01-00, p.
2.

1 Diablo Canyon and what measures should be taken to protect ratepayers in the event that Diablo
2 Canyon is authorized to continue operation beyond its shut down date.

3 My testimony in Chapters 2 and 3 reaches the clear conclusion that the costs are “too
4 high”⁴ and that “new renewable energy and zero-carbon resources are adequate to substitute for
5 Diablo Canyon.” To assess the cost conditions, one must consider the short- and long-term costs
6 of all resources, as in Chapter 2 on all resources, Chapter 3 on nuclear. To assess the adequacy
7 of resources one must assess the availability of resources (Chapter 4) and understand how a 21st
8 century electricity system works (Chapter 5). I argue that when examined carefully, the analyses
9 that the order incorporates into the record do not demonstrate the need to extend the operation of
10 Diablo Canyon (Chapter 6). On the contrary the Commission should conclude that “New
11 renewable energy and zero carbon resources are adequate to substitute for Diablo Canyon.” If it
12 does not reach that conclusion, it must take strong measures to protect ratepayers from excessive
13 rates.

14 Attachments MNC-1.3 and MNC-1.4 present a graphic representation of the challenge of
15 how to view prices, as well as the key theme of my testimony. MNC-1.3 presents my estimation
16 of the cost of supply and demand-side resources necessary to meet the growing need for
17 electricity as the economy decarbonizes. This will be discussed in detail in Chapter 2. MNC-1.4
18 presents the inappropriate “suspension of disbelief,” about prices that afflicts some analysis.
19 Nuclear advocates suspend disbelief for self-interested reasons (to argue for a continuing and
20 growing role of nuclear power). This is discussed in Chapter 3.

21 Other analysts simply try to assess the future in an “all of the above” approach that
22 considers all possible outcomes. As explained in Chapters 3 and, especially, Chapter 5, the
23 analytic exercise should not be taken as advocacy for any specific outcome. The message these
24 analyses send is that the worst, and highly unlikely outcome, which is a dependence on
25 extremely expensive nuclear power, should be avoided. The advice is that ability to do so, which
26 has become readily apparent, needs policy to be achieved, is discussed in Chapters 4 and 5.

27 In these comments I build the case for accelerating the transformation of the electricity
28 sector into a 21st century system (see Attachment MNC-1.5. which is one based on distributed
29 and renewable resources (including energy efficiency as the “hidden fuel) integrated into a
30 dynamic and flexible system that uses advanced communications, computing capacity and

⁴ Id., pp. 2 - 8.

1 control technologies to match and manage supply and demand. The 21st century system is very
2 different from the 20th century system, which made perfect sense, given the available
3 technologies and prevalent view of view externalities, but no longer does. In building this
4 positive case, I also show why nuclear power in general, but even as an insurance policy for the
5 near term, is a very wasteful use of public resources.

6 **Q. Please provide an outline of your testimony.**

7 A. The testimony leading up to these conclusions examines each of the steps through which
8 a thorough evaluation should go. The testimony is divided into five chapters, after this
9 introduction, each of which deals with the main steps that policymakers should take.

10 Chapter 2 addresses the issue of the cost of acquiring resources in both the long- and
11 short-terms. It examines other aspects of cost estimation beginning with the “hidden fuel”,
12 energy efficiency, which is a low-cost option that is widely available, but frequently overlooked
13 in “supply-side” analysis. It then examines externalities and certain costs of managing an
14 electricity system dependent on renewable resources and grid integration, including firming
15 costs, avoided costs and values and system costs and values. This analysis shows that the
16 resource costs are a good guide to the relative cost of alternatives. The other cost considerations
17 certainly do not outweigh the conclusions based on the estimation of resource cost; in fact, they
18 reinforce it.

19 Chapter 3 examines high nuclear cost and the failure of innovation in nuclear power. It
20 covers small and large new reactors, as well as aging reactors. It concludes with the problem
21 that nuclear tends to crowd out the alternatives.

22 Chapter 4 examines the potential to deliver reliable resources in a 21st century electricity
23 that is adequate to meet demand. It begins with efficiency and the important contribution it can
24 make to the declining cost of meeting the need for electricity. It then reviews the availability of
25 supply side options, wind, solar, geothermal, and storage. With the supply-side and the demand-
26 side considered, the analysis then shows that the resources that can be developed clearly meet the
27 need for electricity. The chapter concludes with a discussion of the macro-economic benefits of
28 building a low cost, low carbon electricity system by ending the focus on central station
29 facilities.

30 Chapter 5 presents a discussion of the physical and institutional structures that must be
31 built to ensure an effective 21st electricity system that delivers adequate, reliable power the cost

1 to consumers and delivers a large macroeconomic benefit to society. It identifies the “no
2 regrets” policies that constitute the first step, then introduces the many tools that are available to
3 produce an adequate supply of reliable electricity. This involves almost four dozen discrete
4 approaches, which are documented by almost 400 sources from the peer-reviewed and trade
5 literatures. The chapter then turns to a discussion of a 21st century system in the context of
6 numerous analyses that have considered the challenges of building a carbon-free electricity
7 sector that is adequate and reliable, even as it shoulders the increasing burden of the
8 electrification of many of the other parts of the national economy.

9 While there are certainly challenges, the direction in which public policy should head is
10 clear in all these discussions, emphasizing efficiency, renewables, and hybrid projects, woven
11 together in an intelligent, flexible system where supply and demand are integrated. This is the
12 antithesis of the 20th century approach and the one in which nuclear was born and thrived, even
13 though it was always far from the least cost option. To the extent that policy makers conclude
14 that firm, low-carbon power is necessary to complete the process of deep decarbonization, this
15 chapter argues that long duration storage, geothermal and gas with carbon capture are the least
16 cost options.

17 Chapter 6 presents my conclusions in the context of the empirical analysis contained in
18 chapters 2 through 5. First, it offers a number of methodologies the PUC can use to deal with the
19 complexity of the of current price estimation, with the goal of using the complex information
20 available in a logical and responsible manner to ensure that decisions are reasonably made in
21 pursuit of prudence and least cost to ratepayers. It then presents evidence that the information
22 used in chapters 2-5 is consistent with the experience in California. It then shows that various
23 approaches to evaluating options based on the information before the Commission indicates that
24 extending the life of Diablo Canyon is economically and operationally unjustified. Finally, it
25 presents my recommendation for policies the PUC should follow. These are presented as a
26 hierarchy that the PUC believes are within its powers in unique circumstance of this proceeding
27 with the goal of protecting ratepayers from unjustified increases in cost.

28 **E. Recommendations**

29 **Q. How should the PUC handle the proposal to Continue Operation of Diablo Canyon**

30 1. The PUC should not allow PG&E to change its mind and operate the reactor, even though
31 the legislature is throwing money at it.

2. If the PUC cannot follow the first course of action, no matter the reason, it should not allow the utility to collect rates from ratepayers. If the utility wants to operate the reactors for the sums offered by state and federal taxpayers, it can do so, but at no cost to ratepayers.
3. If the PUC cannot follow the second course, no matter the reason, it can impose market discipline. It should require the reactor to accept only the market clearing price for its output, at the relevant time of day. Needless to say, there will be times when that price is zero.
4. If the PUC cannot force the nuclear reactor to bear the burden of curtailments, it should, subject them to a market test by allowing resources to compete for operation at the lowest price,
5. If the PUC finds it necessary to curtail output, the first place it should look is the nuclear reactors, which are higher in cost, unsuited for the operation of the new system and disruptive of the transformation of the system.
6. If the PUC is unable to impose a market test for curtailments, for whatever reason, it should allocate the curtailments in proportion to the share of generation.
7. Regardless of the pricing and operating arrangement, the PUC should insist that the reactor remains online for only the five-year period defined by the subsidy.

CHAPTER 2: THE COST OF ELECTRICITY

A. ASSESSING RESOURCE COSTS

Q. Where should the analysis of costs begin?

A. Evaluating the potential contribution of resources to meeting the need for electricity must take the cost of each resource into account. The first step is to examine long-term costs. Over a 25-year period (roughly to 2050 from the present) most of the existing resources will have to be replaced at least once. This means that the cost of new builds must be taken into account. Of course, over a 50-year period, just about all resources will have to be preplaced.

One way to take the different life spans and other differences between resources (capital intensity, fuel dependence) into account is to express the cost of new generation on a levelized per megawatt hour (MW) basis. There are other costs that must be considered, e.g., externalities, short-term, transmission, system, firming, etc., but the starting point should be the long-term resource costs of generation.

Q. On what data do you base your estimates of long-term costs?

A. For numerous reasons, as shown in Attachment MNC-2.1, over a decade I have used Lazard's estimate as the base: However, I consider two other estimates and projections of costs (EIA⁵ and NREL⁶ that are compared to the Lazard estimates.

Attachment MNC-1.3 above and 2.2 make clear that the terrain of long-term costs of the various resources has been deeply affected by major technological forces, some increasing cost, others holding cost relatively constant, but the majority driving costs down. The arrows reflect the direction of change, not precise estimates of costs, which are dependent upon uncertain estimates of the base case as well as regional differences,

The dominant trend for wind and solar over the past few decades has been the dramatic decline in the cost of renewable resources that are plentiful in supply in the U. S. This technological revolution has been reinforced by the falling cost of storage (primarily lithium-ion batteries) to turn intermittent resources, like solar, into quasi-firm power. Wind, solar and solar

⁵ Energy Information Administration, Energy Information Administration (EIA), 2018 - 2022, Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook.

⁶ National Renewable Energy Laboratory, NREL, Annual Technology BASELINE (ATB), 2020-2022.

1 plus storage are now the least cost resources by far. Other forms of storage may also be
2 attractive, including pumped storage, and other battery materials.

3 A “non” trend that is important is the continued, low cost of efficiency. Efficiency was
4 the least cost resource for a long period and remains competitive with wind and solar today.
5 Efficiency, which is generally not studied in this context, is included here because it can make a
6 major contribution to lowering (and therefore the ability to meet) demand. The cost of efficiency
7 has been relatively constant and is likely to remain so due to technological improvements and
8 economies of scale.

9 At the same time, the cost of nuclear has been rising rapidly. As discussed below, this is
10 true of large and small nuclear facilities. Aging facilities are also relatively costly when capital
11 costs that must be incurred to keep these facilities online are taken into account, in addition to the
12 fact that owners appear to intend to capture a return on their investment in the facilities.
13 Similarly, while coal and natural gas are relatively inexpensive, when the cost of carbon capture
14 is included, they are more costly, but new build gas with carbon capture is one-third less costly
15 than even small nuclear,

16 While the trends are clear and have been analyzed by Lazard in great detail for
17 renewables, there remain differences of opinion about costs. Attachment MNC-2.2 uses the
18 average of the low and high estimates offered by each study (or the average as identified by that
19 study. There are still differences of opinion about the specific costs of individual technologies,
20 as suggested by Attachment MNC-2.2.

21 First, Lazard has a much higher estimate for large nuclear reactors. EIA has consistently
22 had very low estimates for nuclear power that do not reflect developments in the real world. EIA
23 states that no advanced nuclear reactors are being constructed. NREL appears to agree.
24 However, the low cost for nuclear might be for small modular reactors. The figure for the costs
25 of nuclear is almost exactly what the leading vendor is predicting (with a huge subsidy). The
26 projected costs for SMRs are still too low. Even with this assumption SMRs are extremely
27 costly. As shown in Attachment MNC-2.2, we consider the range for SMRs to be \$90 to \$150,
28 per MWH.

29 The second major difference is the very high cost for geothermal given by NREL. While
30 there may be some facilities that cost this much or more, they are not the typical experience.
31 Attachment MNC-2.2 uses the estimate of the average of the other two sources. In both cases we

1 include both the high estimates for nuclear and geothermal. Lazard is also slightly higher than
2 EIA on solar and geothermal, but these differences are small.

3 **Q. Please Describe Your Estimate of Short-Term Costs?**

4 **A.** Short-term costs point in the same direction as long-term costs and support the same
5 conclusion. The renewables are lower in cost. Although the differences are smaller and once
6 again, there are points of debate and important considerations. Nevertheless, Lazard concludes
7 that “certain renewable energy generation technologies have an LCOE [levelized cost of
8 electricity] that is competitive with the marginal cost of existing conventional generation.”⁷ This
9 is based on the fact that the low end of the “all in” costs of renewables is below the lowest
10 marginal cost of traditional resources, as shown in Attachment MNC-2.3

11 There are three assumptions in Lazard’s analysis that underestimate the advantage of
12 renewables.

13 First, there is an assumption implicit in Lazard’s analysis that leads to an underestimation
14 of the cost of traditional central station technologies. As is the case with almost all cost
15 estimates, Lazard uses a high-capacity factor for all three of the traditional technologies, which is
16 well above the actual average observed in the U.S. As a result, costs are underestimated.

17 Second and much more importantly, Lazard compares the full cost of new build wind or
18 solar to the marginal cost of existing conventional generation. This is a very demanding
19 comparison, since it is a comparison of all-in costs for alternatives to marginal costs for central
20 station technologies. It also must be extremely short-term because keeping aging reactors online
21 inevitably involves expenditure of capital. This is particularly true of aging reactors. Thus,
22 Lazard has made an “apples-to-oranges” comparison, albeit for good reason. Since renewables
23 are the “new kid on the block” and new capacity will be necessary to replace existing capacity, it
24 makes sense to show policy makers that even the total costs of new renewables, are competitive
25 with marginal costs of existing resources. However, that is not a reason to underestimate the
26 real-world cost of keeping aging reactors online (i.e., to ignore the capital costs necessary to keep
27 them online.

28 Since the latter assumption can lead policymakers astray, and to give a sense of a
29 comparison that is “apples-to-apples,” we should also look at the marginal cost for all types of

⁷ Id., Lazard, 14.0, p. 7,

resources, and the realistic cost of aging reactors. To do so, I begin with an estimate that includes the estimate of the fixed operating costs provided in the long-run analysis (in MNC-2.4), but not the capital cost for any resources.

Needless to say, renewables are very attractive. The important point is crystal clear, as shown in Attachment MNC-2.5, which include “apples-to-apples” short-term costs and long-term costs. The short-term comparisons are not at odds with the long-term results. Since the alternatives are least cost in the long term and at least competitive in the short term there is no tradeoff necessary. The alternatives are preferable.

Short- and long-term cost estimation is a crucial first step in evaluating resources, but it is only the first step. There are many other considerations that influence the decision to which we now turn, although they do not change the very clear and strong policy conclusion we have reached based on the estimation of costs.

D. OTHER COMPONENTS OF COST: ENERGY EFFICIENCY, THE HIDDEN FUEL

Q. What other elements of costs do you consider?

A. While the cost of acquiring resources is the first step in the analysis, resource cost do not exhaust all of the issues involved in cost estimation. There is another set of costs imposed by resource that inform policymakers, even though they do not override the estimate of resource costs incurred to meet the need for power. This section examines those “other” costs.

First, transmission costs are taken into account in the EIA estimate of resource costs, which have been considered in the averaging of costs for each resource. Therefore, my discussion begins with an examination of the cost of increasing the efficiency of use of electricity because efficiency was not considered a major resource until recently.

Q. Please discuss the cost of efficiency?

A. Efficiency is now seen as a “hidden fuel” that is the equal of the other resources. Moreover, the cost of efficiency is among the lowest of all the resources. As shown in the upper graph of MNC-2.6. the cost of efficiency has remained low for decades and there is every indication that the cost of efficiency is not rising. In fact, vast quantities of energy can be saved at a very low cost, with the economically attractive opportunities expanding as new technologies convert what was known as “technical potential” into “economically attractive.” The forward-

1 looking cost is about \$.03/kWh, well below the backward-looking cost.⁸ There is also a
2 significant reduction in electricity demand that occurs from the effect of shifting to decentralized
3 technologies that better match supply and demand, which I call the transformation dividend.
4 Thus, efficiency is cost competitive with the other alternatives and can make a substantial
5 contribution to meeting need and deep decarbonization.

6 Engineering economic analyses provided the initial evidence for the efficiency gap. *Ex*
7 *ante* analyses indicated that there would be substantial net benefits from promoting and including
8 technologies to reduce energy consumption in consumer durables. As these policies were
9 implemented *ex post* analyses were conducted to ascertain whether the *ex-ante* expectations were
10 borne out. The most intense and detailed studies were conducted by utilities subject to
11 regulation. The lower graph in Attachment MNC-2.6 shows the results of analyses of the cost of
12 efficiency in sixteen states over various periods covering the last twenty years. The data points
13 are the annual average results obtained in various years at various levels of energy savings.

14 The graph demonstrates three points that are important for the current analysis.

15 First, the authors suggest that declining costs for higher levels of efficiency can be
16 explained by economies of scale, learning, and synergies in technologies.⁹ As utilities implement
17 more of the cost-effective measures, costs decline. In addition, when technical potential is higher
18 than achievable savings, then economies of scale, scope, and learning can pull more measures in
19 without raising costs. This analysis supports the assumption that the cost of efficiency will not
20 increase in the mid-term.

21 Second, consistent with these findings and observations, it is important to briefly note the
22 analysis of minimum efficiency performance standards for consumer appliances and vehicles.
23 There is a long (30+ year) and rich (20+ standards) history that affects billions of devices. This is
24 precisely the type of broad and sustained impact that policies to promote and achieve the
25 transformation to a carbon-free economy will have to have.

⁸ Mark Cooper, 2014, CFA-CEC Presentation on Energy Efficiency Seminar, California Energy Commission, February 20; quote is from Mark Cooper, 2013, *Energy Efficiency Performance Standards: Driving Consumer and Energy Savings*, October, pp. 30-31, and the underlying studies.

⁹ Kenji Takahashi and David Nichols, The Sustainability and Cost of Increasing Efficiency Impacts: Evidence from Experience to Date, ACEEE Summer Study on Energy Efficiency in Buildings, 2008.

1 Third, in the lower graph of MNC-2.6, all three major investor-owned utilities are
2 included. San Diego is used to identify the trend line. PG&E is close to that trend line.

3 Moreover, as shown in Attachment MNC-2.7, there was a systematic overestimation by
4 regulators of the cost of efficiency improving regulations in consumer durables. The cost for
5 household appliance regulations was overestimated by over 100% and the costs for automobiles
6 were overestimated by about 50 percent. The estimates of the cost from industry were even
7 father off the mark, running three times higher for auto technologies.¹⁰ Broader studies of the
8 cost of environmental regulation find a similar phenomenon, with overestimates of cost
9 outnumbering underestimates by almost five to one with industry numbers being a “serious
10 overestimate.”¹¹

11 The case-study review suggests that energy efficiency investments have an
12 important effect on learning costs. Required efficiency can provide a significant
13 boost to overall productivity within industry. If this relationship holds, the
14 description of energy-efficient technologies as opportunities for larger
15 productivity improvements has significant implications for conventional
16 economic assessments... ... This examination shows that including productivity
17 benefits explicitly in the modeling parameters would double the cost-effective
18 potential for energy efficiency improvement, compared to an analysis excluding
19 those benefits.¹²

20 These findings of declining cost are not merely descriptive. Several analyses have
21 introduced controls for quality and underlying trends using regression techniques. The findings
22 are affirmed in these more sophisticated analyses.¹³ With such strong evidence of costs far
23 below predictions by regulators who undertake engineering analysis, many authors have sought
24 to identify the processes that account for this systematic phenomenon. For both vehicles and

¹⁰ Hwang, Roland and Matt Peak, 2006, Innovation and Regulation in the Automobiles Sector: Lessons Learned and Implicit on for California CO₂ Standards, April.

¹¹ Harrington, Winston, 2006, Grading Estimates of the Benefits and Costs of Federal Regulation: A Review of Reviews, Resources for the Future, September, p. 3.

¹² Ernst Worrell, et al., 2003, “Productivity Benefits of Industrial Energy Efficiency Measures,” Energy Journal, 11, p. 1081.

¹³ Steven Nadel and Andrew Delaski, Appliance Standards: Comparing Predicted and Observed Prices, American Council for an Energy Efficient Economy and Appliance Standards Awareness Project, July 2013.

1 appliances, a long list of demand-side and supply-side factors that could easily combine to
2 produce the result has been compiled.

3 On the supply-side, a detailed study of dozens of specific energy efficiency
4 improvements pointed to technological innovation.¹⁴ A comprehensive review of *Technology*
5 *Learning in the Energy Sector* found that energy efficiency technologies are particularly sensitive
6 to learning effects and policy.¹⁵ This was attributed to increases in R&D expenditures,
7 information gathering, learning-by-doing and spillover effects. Increases in competition and
8 competitiveness also play a role on the supply side. A comparative study of European, Japanese
9 and American automakers prepared in 2006, before the recent reform and reinvigoration of the
10 U.S. fuel economy program, found that standards had an effect on technological innovation. The
11 U.S. had lagged because of the long period of dormancy of the U.S. standards program and the
12 fact that the U.S. automakers did not compete in the world market for sales, (i.e., they did not
13 export vehicles to Europe or Japan).

14 While the supply-side drivers of declining costs are primarily undertaken by
15 manufacturers, a number of demand side effects are also cited, which are the direct result of
16 policy. Standards create market assurance, reducing the risk that cheap, inefficient products will
17 undercut efforts to raise efficiency. Economies of scale lead to accelerated penetration, which
18 stimulates and accelerates learning-by-doing. The effects of demand stimulus by increasing the
19 growth of the economy (macroeconomic stimulus) also accelerates innovation. Experiencing
20 increasing economies of scale and declining costs in an environment that is more competitive,
21 leads to changes in marketing behaviors.

22 Thus, estimated cost increases resulting from setting higher standards are far too high.
23 There may be a number of factors that produce the result, beyond an upward bias in the original
24 estimate and learning in the implementation, including pricing and marketing strategies.¹⁶

¹⁴ Worrell, 2003, "Productivity Benefits of Industrial Energy Efficiency Measures," *Energy*, 28(11): This examination shows that including productivity benefits explicitly in the modeling parameters would double the cost-effective potential for energy efficiency improvement, compared to an analysis excluding those benefits. (p 1)

¹⁵ Larry Dale, et al., 2009, "Retrospective Evaluation of Appliance Price Trends," *Energy Policy* 37, 2009.

¹⁶ Sperling, Dan et al., 2004, *Analysis of Auto Industry and Consumer Responses to Regulation and Technological Change and Customization of Consumer Response Models in Support of AB 1493 Rulemaking*, Institute of Transportation Studies, UC Davis, June 1, emphasized the

1 **Q. Why do you believe an analysis of appliance efficiency standards is important?**

2 **A.** The track record of efficiency standards for household consumer durables is even more
3 eye catching and important because it is a primary driver of residential electricity consumption.
4 Examining the trends in individual consumer durables suggests several important observations.

- 5 • First, the implementation of standards improved the efficiency of the consumer
6 durables.
- 7 • Second, furnaces have been far less efficient than they should be, since the DOE has
8 set and maintained weak standards.
- 9 • Third, after the initial implementation of a standard, the improvement levels off,
10 suggesting that if engineering-economic analyses indicate that additional
11 improvements in efficiency would benefit consumers, the standards should be
12 strengthened on an ongoing basis.
- 13 • Fourth the analysis of consumer durables also shows that there was no reduction in
14 the quality or traits of the products. The functionalities were preserved while
15 efficiency was enhanced at modest cost. A recent analysis of major appliance
16 standards adopted after the turn of the century shows a similar and even stronger
17 pattern.¹⁷

18 The engineering-economic analysis indicates that although the standards may increase the
19 cost of the consumer durable, the reduction in energy expenditures is larger, resulting in a net
20 benefit to consumers. We have also pointed to evidence that the costs of energy saving
21 technologies tend to be smaller than the *ex-ante* analysis suggests because competition and other
22 factors lower the cost. The experience of the implementation of standards for the household
23 consumer durables is consistent with this interpretation. My analysis of digital (computer)
24 energy efficiency standards in California reaches the same conclusion about the effect of
25 efficiency standards.¹⁸

adaptation of producers in the analysis of auto fuel economy standards.

¹⁷ Steven Nadel and Andrew Delaski, *Appliance Standards: Comparing Predicted and Observed Prices*, American Council for an Energy Efficient Economy and Appliance Standards Awareness Project, July 2013.

¹⁸ Mark Cooper, 2015, “Energy Efficiency Performance Standards: Driving Consumer and Energy Savings in California,” *California Energy Commission Workshop on Computer Standards*, April 15.

Attachment MNC-2.8 shows the results of my econometric analysis of the data.¹⁹ The statistical analysis created (dummy) variables that identify each consumer durable and whether a standard was in place or not. We use the year to estimate the underlying trend. Given that the engineering-economic analysis had justified the adoption of standards and that standards were effective in lowering energy consumption, this means the market trend was not sufficient to drive investment in efficiency to the optimal level. The impact of standards is statistically significant and quantitatively meaningful in all cases. The coefficient in column 6 (All Years, All Variables) indicates that the standard lowers the energy consumption by about 8%. This finding is highly statistically significant, with a probability level less than .0001. There is a very high probability that the effect observed is real. The underlying trend is also statistically significant, suggesting that the efficiency of these consumer durables was improving at the rate of 1.35% per year.

Combining the observations on quantity and price for electricity leads to an extremely important and surprising economic transformation, as shown in Attachment MNC-2.9. The link between electricity consumption and economic growth has been broken. In contrast to the three decades after World War II (1950-1980) where electricity consumption per dollar of per capita GDP grew by almost 3 percent, the figure was flat between 1980 and 1995, and declined by 2 percent per year between 1995 and 2019. Since the pandemic GDP growth has been even stronger, with 2.5 times the growth compared to 1995-2019, while electricity consumption growth has been only about 2/3rd of the earlier period. The period has been short, so it is too early to ballyhoo the results, but the initial direction is consistent with the argument.

Q. In your opinion, why has this approach to standard setting proved so successful?

A. I have long argued that regulation succeeds when it maintains the fundamentals of a competitive market structure in an approach I call “Command-But-Not-Control” Regulation.²⁰

¹⁹ I have built this analysis in the typical way that multivariate regression analysis is conducted. The dependent variable is energy consumption with the base year set equal to 1. Later years had lower values. We introduce a variable to represent the adoption of a standard. This variable (known as a dummy variable) takes the value of 1 in every year when the standard was in place and a value of zero when it was not. A negative number means that the years in which the standard was in force had lower levels of energy consumption. Similarly, the difference between appliances is handled with dummy variables. We include each appliance except furnaces, which shows how the other appliance performed compared to furnaces. Again, a negative number means that the other appliances had lower levels of energy consumption.

²⁰ Mark Cooper, 2017, *Trump’s \$2 Trillion Mistake*, Chapter III.

1 There is the profound implication of this regulatory analysis. All of the appliances were subject
2 to what we call “Command-But-Not-Control” regulation.

3 In this approach, the agency sets a goal, a standard, and producers are allowed to meet
4 that standard however they see fit (see Attachment MNC-2.10). Because they face competition,
5 each producer will choose those technologies and implementation strategies that best reflect their
6 abilities. This has important implications for market and producer performance. The producers,
7 capitalists in a competitive market, will do what they do best, meeting the standards in the least
8 cost manner possible. I have identified six characteristics of a market in which “command-but-
9 not-control” regulation is introduced. When the state decides to pick winners, rather than set
10 goals, as with subsidies for aging reactors, this important process is undermined.

11 **E. EXTERNALITIES AND THE VALUE OF CARBON ABATEMENT**

12 **Q. Please discuss externalities as a component of costs?**

13 A. Although the cost of building or acquiring a resource is the crucial first step, there are
14 other costs that a resource may add to or subtract from the resource costs as it is operated in a
15 system. All the resources considered are generally low carbon, so we do not expect the issue of
16 carbon emissions to have much of an impact on the choice between them. This is certainly the
17 case with existing resources, as shown in the upper graph on the left side of Attachment MNC-
18 2.11, in which the higher the score the better. The differences in emissions, even for aging
19 reactors, is inconsequential compared to the cost estimates we have identified. New builds are
20 larger because of the long period of construction, but again small compared to the very large
21 differences we have identified above. The lower graph of Attachment MNC-2.11 confirms the
22 analysis, where a higher score is better. The main resources considered in this analysis are
23 tightly grouped as generally low carbon emitters. Here I include hydro, although large hydro
24 projects are unlikely to be built. However, pumped storage, a form of hydro, may become
25 important, as well as smaller scale hydro development, so it is useful to have the externalities
26 information.

27 Differences in non-carbon emissions and other environmentally important characteristics
28 show larger difference in conflicting directions. Nuclear is higher on other emission of
29 pollutants, water, and accidents. Natural gas is very high on pollutants and accidents and
30 moderately high on water use. Renewables are high on land use. For the other pollutants
31 nuclear is much higher. On water and waste nuclear is ranked much lower and the aggregate for

1 non-air pollutants and impacts nuclear is between gas and coal. Thus, these differences on
2 externalities do not come close to upsetting the basic conclusions based on resource costs.

3 Attachment MNC-2.12 uses a recent Lazard analysis of the value of carbon reduction for
4 an estimate of the valued of carbon abatement of the main options expressed in a comparison
5 with coal.²¹ The original figure included the low estimate for new builds for wind, solar, gas and
6 nuclear. It recognized the high carbon output of unabated gas, so we focus on the cost compared
7 to coal, avoiding an “apples-to-oranges” problem. The point is that nuclear is very costly and
8 relatively constant. All of the entries are for new builds, since this is a long run analysis.

9 Two important points are underscored by this exhibit. Aging reactors are short term and
10 should not be included, but they are to make a point. First, under the assumption for cost for
11 short to mid-term, they are expensive compared to the other renewables and equal to gas with
12 carbon capture. Gas with carbon capture would be preferable, since it is long term. Second, the
13 growth of competitive, firm (geothermal) and quasi-firm (hybrid systems) as low-cost options
14 has been substantial.

15 **F. LAZARD’S FIRING COSTS**

16 **Q. Does the cost of ensuring adequate supply at crucial moments matter?**

17 **A.** It does and is one of the major challenges that the transition to a carbon free sector must
18 deal with. However, the impact is being handled and does not alter the observation based on
19 short and long-term costs.

20 I begin with an examination of Lazard’s “firming” analysis, which is defined as “the
21 incremental costs to firm intermittent resources (see Attachment MNC-2.13). As discussed in
22 Chapter 4, the challenge can be handled with policies to better integrate and manage the grid.
23 However, here I focus on Lazard’s estimates of resources in the present and near future (5 years).
24 Taken together, they reflect the great complexity of the analysis, but they also make it clear that
25 firming need not be an obstacle to choosing renewables.

26 Attachment MNC-2.13. shows Lazard’s generic estimated in the left column. It includes
27 the details for the CAISO that use a battery as a “target” cost and also includes hybrid facilities
28 (with storage) options. Lazard did not evaluate the traditional “baseload” facilities which, in
29 theory, do not need “firming.” In fact, there is a form of “firming” they do require, reserve

²¹ Lazard, V, 13.0

margin requirements. Very large nuclear facilities require very large reserve margins, so the utility can meet its need without them. We include both the existing reactors (old) and new builds, which is consistent with the underlying assumption of the Lazard analysis. We treat the “alternative” “baseload,” geothermal in the same way, but it involves much smaller plants and therefore demand a much smaller “firming” (reserve requirement) charge. I have assumed \$8/MWH firming costs for coal, SMRs and Geothermal, but \$32/MWH for large nuclear reactors, which are the largest in size by far. I have also included the long duration energy storage alternative that Lazard states are “expected to be competitive with lithium --ion batteries for large-scale 8-hour systems in the second half of the decade (late 2020s), with “anticipated unit costs at longer durations overcoming lower round-trip efficiency.”²²

The firming analysis sends two strong signals. Three options are lower than an aging reactor in cost, efficiency, solar with long duration storage and wind with long duration storage. Three firm resources are competitive with aging reactors, efficiency (which is firm, but not dispatchable) geothermal and new build gas with CCS. Without the sharp decline in cost and hours when the “firm” resource is needed, efficiency and Hybrid systems (PV+storage) are lower in total cost than any of the traditional resources. With long duration storage, solar is much more attractive, while wind with storage become quite competitive.

Attachment MNC-2-14 shows all the regional costs included in the Lazard analysis. The first major difference between the ISOs is the basis for evaluating the cost of new entry (CONE). PJM and CAISO use the cost of a fairly costly stand-alone battery. The other ISOs use gas, peaking or combined cycle. We rule out the latter two, since they are high emitters of CO₂. Therefore, they involve an “apples-to-oranges” comparison. As shown in the table, we adjust this to use gasCC with CCS to evaluate alternatives. Although the basis for the CONE was new builds, I include retrofits to round out the analysis.

The full array of regional ISO analyses conducted by Lazard, which we have grouped by technology first, then the ISO, makes it clear that CAISO is the costliest of the regions. And Solar is the most challenging of the resources. It also shows the value of combining intermittent resources and storage. In the presence of storage, especially long duration storage, firming costs are not a problem. Another approach taken by Lazard is to compare use cases on an ISO-by-ISO

²² Lazard, v, 16.0, p.35.

basis, As shown in Attachment MNC-2.15. The CAISO cases are by far the most attractive to investors with the highest return.

These firming cost evaluations affirm a fundamental fact about firming costs. As solar penetration increases, firming costs go up considerably (see Attachment MNC-2.16). For wind the effect seems to run in the opposite direction. Firming costs of hybrid systems are positively associated with penetration levels, but they increase at less than two thirds the rate of stand-alone solar generators. These simple findings are consistent with much more detailed analyses of system operation. The conclusion is not to “abandon” renewables and distributed resources because they pose a challenge of firming, but to respond to the challenge with policies that better integrate resources and supply and demand, as discussed in Chapters 4 and 5.

G. EIA’S LEVELIZED AVOIDED COST OF ELECTRICITY (LACE)

EIA’s discussion of these issues takes a different approach, but with some of the same elements are at work. It is part of a triumvirate of costs calculated by EIA.

The levelized cost of energy (LCOE) and levelized cost of storage (LCOS) represents the average revenue per unit of electricity generated or discharged that would be required to cost the costs of building and operating a generating plant... during an assumed financial life and duty cycle... Along with LCOE and LCOS, we compare economic competitiveness between generation technologies by considering the value of the plant in serving the electricity grid... We sum this into an annualized value... to develop the levelized avoided cost of electricity (LACE)... LACE accounts for the difference in the grid services that each technology provides, and it recognizes that intermittent resources, such as wind or solar, have substantially different duty cycles than the baseload, intermediate, and peaking duty cycles of conventional generators... When the LACE of a particular technology exceeds its LCOE or LCOS, that technology would generally be attractive to build.²³

Attachment MNC-2.17 presents a rank order of the value ratios for the resources considered in this paper. While most of these are taken directly from EIA, we have used some of the assumptions from the earlier analyses.

²³ Energy Information Administration, 2022 *Levelized Cost of New Generation Resources in the Energy Outlook, 2022*, pp. 4...1.

- First, we set efficiency to be the number one priority, just above geothermal without NREL, another assumption of this paper.
- Second, we refuse to include gas without carbon capture and storage, which keeps the analysis on an apples-to-apples basis.
- Third, we treat the advanced nuclear cost in the EIA analysis as a small reactor, separately from large reactors. We do not provide an estimate for large reactors, which would be the lowest by far.

The rank order should be familiar by now. The most attractive resources are the five main alternatives. Ironically, stand-alone batteries are ranked sixth, ahead of nuclear reactors, gas combined cycle with carbon capture and offshore wind.

H. LBL'S SYSTEM COSTS

The difference between LCOE and LACE can be called “inflexibility waste” to capture the key concept.²⁴ The avoided cost is less than the levelized cost because resources are inflexible, i.e., unable to adapt their output to the needs of the system. The system cost would be lower if technologies that better fit system needs could be used. Inflexibility waste can be lowered in two ways – reducing levelized cost or increasing avoided costs (*i.e.*, a better fit between output and system needs). This is the essence of the system cost approach.

After extensively discussing the EIA system value approach to improving comparisons between alternatives, analysts at two national laboratories (Lawrence Berkeley National Laboratory and Argonne), suggested an alternative approach that rested on system costs. The levelized cost of energy was the starting point and the most important factor, as in the system value approach, but the adjustment made was not by subtracting avoided costs from LCOE, but by adding estimates of the unique system cost of individual technologies to the LCOE. The former is a top-down approach, the latter is a bottom-up approach and the authors caution against double counting by combining the two. This approach was also advocated by a major research

²⁴ Johnson, *et al.*, 2017, “A reduced-form approach for representing the impacts of wind and solar PV deployment on the structure and operation of the electricity system,” *Energy Economics* 64 estimate the system cost of ramping various resources as an “efficiency waste.” The concept of “inflexibility waste” would include that cost plus the cost of larger reserves made necessary by the need to be able to replace the largest unit on the grid...

1 institution in Germany evaluating the aggressive transition to renewables being pursued in that
2 nation.²⁵

3 The authors of MNC-2.18 have recently updated the underlying analysis, looking at the
4 contribution of renewables to system value (see attachment MNC-2.18). The concept is simple.
5 The authors assume the Purchased Power Agreement (PPAs) cover the cost of production
6 (Lazard's "all-in costs"). The system value is calculated as the sum of the hourly full value of
7 the production of these facilities. For 2021, all four of the main renewable alternatives
8 (geothermal, PV, wind and hybrid systems have positive net values. Over the next four years the
9 value of wind and geothermal increase considerably. The value of hybrid systems is the highest
10 by far and these resources maintain their advantage, although they decline very slightly. The
11 decline might be reversed with the consideration of long duration storage, which could increase
12 the value of Hybrid systems by at least 1/8th and as much as 1/3rd.

13 CONCLUSION

14 Throughout this analysis, I rely primarily on the estimates of three national entities for
15 generic costs of each technology, although Lazard is the primary source for the reasons outline at
16 the beginning of the chapter. However, in each chapter, I also rely on California specific
17 estimates where possible, as in Lazard's firming analysis. The reason that the data at the national
18 level and the state level supports similar conclusion is simple; the underlying costs are similar, as
19 shown in Attachment MNC-2.20.

20 There are, of course differences in the cost estimates. Lazard dropped biomass in 2016,
21 so I use NREL for 2023. Lazard did not estimate a cost for gas with carbon capture. I use an
22 estimate from 2018 I made for gas with carbon capture based on Lazard's estimate of the capture
23 technology for coal.²⁶ In 2023 Lazard had an estimate for gas with carbon capture. While Lazard
24 had an estimate for solar thermal with storage in 2018, by 2023 Lazard had switched to PV with
25 storage. The cost of geothermal is Lazard and EIA for 2023. The result is a high correlation for
26 these key technologies ($r=.87$ linear; $r=.97$ logarithmic).

27 Beyond the similarity of current cost estimates, the trends of the past decade and a half
28 are important because they send a strong message about where we are headed. The upper graph

²⁵ Agora, Energiwende, *The Integration Costs of Wind and Solar Power: an Overview of the Debate on the Effects of Adding Wind and Solar Photovoltaic into Power Systems*, 2015.

²⁶ Cooper, Mark, 2021, *Building A 21st Century Electricity Sector With Efficiency, Distributed Resources And Dynamic Management:: The Consumer, Economic, Public Health And Environmental Benefit*, (with Mel Hall-Crawford (Consumer Federation of America) April 22.

1 in Attachment MNC-2.21 shows the experience over a decade and a half of cost experience as
2 captured by the analyses prepared by Lazard. Nuclear became more expensive, while the key
3 renewables, wind and solar (and storage, not shown as a standalone resource) became much less
4 costly. Coal and gas w/o CCS were stable. The lower graph shows a forward-looking projection
5 of instant (overnight) costs from the CEC written in 2010. It predicted exactly what happened.
6 There is no reason to believe that the past decade and a half is not a good guide to the future in
7 the U.S. and California. In this sense, policy makers should not “suspend their disbelief” about
8 the trends.

CHAPTER 3.
THE CONTINUING FAILURE OF FAILURE OF NUCLEAR POWER
TO DELIVER ON ITS PROMISES

A. PAST SUBSIDIES AND CURRENT “SPECIAL TREATMENT” OF NUCLEAR POWER

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.²⁷ Renewables are in the early stage of development, as shown in Attachment MNC 3.1. Nuclear received much larger subsidies in its developmental stage and enjoyed truly massive subsidies since its inception, compared to other resources as it grew. MNC 3.1 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. 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, as shown in Attachment 3.2. It leads to a dramatic payoff in terms of declining cost. As we have seen, wind had the earlier success and solar is now catching up.²⁸ 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 nuclear development. The alternatives are moving rapidly along their learning

²⁷ Marshall, Goldberg, *Federal Energy Subsidies: Not All Technologies Are Created Equal*. Washington, DC: Renewable Energy Policy Project, 2000; Matthew Slavin, “The Federal Energy Subsidy Scorecard: How Renewables Stack Up.” *Renewable Energy World.com*, November 3, 2009.; Kdra, Branker, Michael Pathak, and Joshua M. Pearce. “A Review of Solar Photovoltaic Levelized Cost of Electricity, *Renewable and Sustainable Energy Reviews* 15 (2011) (.” (Branker and Pearce, *Review of Solar*, 4470–4482; Jeremy, Badcock and Manfred Lenzen. “Subsidies for Electricity-Generating Technologies: A Review.” *Energy Policy* 38 (2010): 5038–5047 (hereafter, (Badcock and Lenzen. *Subsidies for Electricity-Generating Technologies*); Pfund, Nancy, and Ben Healey, 2011, *What Would Jefferson Do? The Historical Role of Federal Subsidies in Shaping America’s Energy Future*. San Francisco, CA: DBL Investors, 2011. (Hereafter, Pfund and Healey, *What Would Jefferson do?*)

²⁸ Badcock and Lenzen, 2010, Branker and Pearce, 2011.

1 curves, which can be explained by the fact that these technologies actually possess the
2 characteristics that stimulate innovation and allow for the capture of economies of mass
3 production. They involve the production of large numbers of units under conditions of
4 competition. Nuclear power involves an extremely small number of units from a very small
5 number of firms, with the monopoly model offered as the best approach.

6 **B. CURRENT “SPECIAL TREATMENT”**

7 The above discussion of subsidies focuses on long-term patterns of subsidies and
8 underscores the point that much more was invested in nuclear and fossil fuels. This should not
9 be taken to mean that there are no current subsidies enjoyed by nuclear power. There is no doubt
10 about the advantages that nuclear power enjoys in the current system. In fact, while advocates
11 for nuclear power point to specific subsidies for renewables – production and investment tax
12 credits – there are at least half a dozen policies embedded in current practices that nuclear
13 enjoys. Current special treatments enjoyed by nuclear power are massive. These include:

- 14 • the socialization of risk and waste management costs, now under court order to be
15 paid by the Department of Energy to nuclear reactor owners for the failure to provide
16 nuclear waste disposal because no such safe waste repository exists or may ever exist.
- 17 • Tax treatment of capital expenditures, which are very large for nuclear power.
- 18 • capacity payments from RTOs/ISO,
- 19 • high system burdens due to the risk of large outages. i.e., the inflexibility of nuclear,
20 which requires higher reserve margins.
- 21 • Nuclear and other centralized resources also get a pass in the treatment of system
22 costs. They have their system costs “socialized” and recovered from ratepayers,
23 while system costs are imposed directly on developers of alternative resources.

24 As Lovins put it:

25 “Specifically, variable renewables’ grid balancing costs are generally borne by
26 their developers or owners, and are usually <\$5/MWh, nearly always <\$10. Yet
27 coal and nuclear plants impose analogous costs on the system without being
28 charged for them, at least outside ERCOT. Instead, the grid balancing costs of
29 managing the intermittence (forced outages) of central thermal plants—reserve
30 margin, spinning reserve, cycling costs, part-load penalties—are traditionally
31 socialized, treated as “inevitable system costs,” and hardly ever analyzed.
32 This asymmetry appears to favor fossil-fueled and nuclear plants, because their
33 balancing costs, emerging evidence suggests, may be severalfold greater than
34 those of a well-designed and run portfolio of PV and wind resources. Conversely,

1 variable renewables may need less backup (or storage) than utilities have already
2 bought to manage the intermittence of their big thermal plants.”²⁹

3 As shown in Attachment MNC-2.1, above, nuclear has failed to deliver on its price
4 promises. The alternatives have performed much better and hold much greater promise. It is also
5 clear that with a much smaller level of subsidy to drive innovation and economies of scale, the
6 renewables have achieved dramatically declining costs in a little over a decade, which is exactly
7 the economic-mic process that has eluded the nuclear industry for half a century. Attachment
8 MNC-3.2 captures the essence of the subsidy issue by juxtaposing the magnitude and timing of
9 subsidies and the extent of innovation, as measured by patents issued. The ultimate irony is that
10 despite much smaller subsidies to drive innovation and economies of scale, renewables have
11 achieved dramatically declining costs in just over half a decade.

12 There can be debate about the current level of subsidies, particularly given the difficulty
13 of valuing the nuclear insurance and waste subsidies which are existential rather than material
14 (i.e., without the socialization of liability and waste disposal the industry would not exist).
15 However, there is no doubt that the long-term subsidization of nuclear power vastly exceeds the
16 subsidization of renewables and efficiency by an order of magnitude of 10 to 1.³⁰

17 A decision to shift subsidies to the alternatives should have nothing to do with fairness,
18 however. It should be based on the likely payoff of the investment. Analyses of past subsidies
19 globally and in the United States make it clear that renewables are a much better bet,³¹ even
20 though the estimates do not include the very large implicit subsidies nuclear enjoys from the
21 socialization of the cost of risk and waste management.³²

²⁹ Lovins, Amory, B., 2017, Do coal and nuclear deserve above market prices?,” The Electricity Journal, 30 (6), July, p. 2.

³⁰ BWE, German Wind Energy Association. The Full Costs of Power Generation: A Comparison of Subsidies and Societal Cost of Renewable and Conventional Energy Sources. BWE, Berlin, August 2012.; Lucy Kitson, Peter Wooders, and Tom Moerenhout. *Subsidies and External Costs in Electric Power Generation: A Comparative Review of Estimates*. Geneva, Switzerland, 2011; Ann G. Berwick, *Comparing Federal Subsidies for Renewables and Other Sources of Electric Generation*. Massachusetts Department of Public Utilities Massachusetts Solar Summit, June 13, 2012; U.S. GAO. Federal Electricity Subsidies: Information on Research Funding, Tax Expenditures, and Other Activities That Support Electricity Production, GAO-08-102. Washington, DC: U.S. Government Printing Office, 2007.; Goldberg, *Federal Energy Subsidies*, Pfund and Healey, *What Would Jefferson do?*.

³¹ Badcock, and Lenzen, 2010.

³² Zelenika-Zovk and Pearce, *Diverting Indirect Subsidies*, p. 2626,

1 C. THE CONTINUING NUCLEAR COST PROBLEM

2 The current terrain of resource costs is consistent with the earlier analysis, as shown in
3 Attachment MNC-2.1. New nuclear reactors are between five (large) and three (small) times as
4 costly as the alternatives. The large reactors have been under construction for over a decade, and
5 they are still experiencing delays and cost increases. Small reactors do not yet have full
6 regulatory approval (even though it has been accelerated on their behalf), have not entered
7 construction, and are struggling to find takers for their power. As discussed in an earlier paper³³
8 and shown in Attachment MNC-3.3. SMRs need very large production runs to achieve any cost
9 reduction due to scale and their projected costs have been challenged from the outset.

10 Attachment MNC-3.4 shows the recent trends of large and small reactor costs and the
11 range used in this study to balance the extremely low estimates that have been assumed for small
12 modular reactors (which are below even the hopes of the current SMR advocates). When
13 combined with the deviations, SMRs is put at \$120/per MWH. This is over 20% higher than a
14 new build GasCC w/CS and 5% higher than a retrofit. It is 20% below large reactors. Given the
15 recent projected cost increase and subsidy, I use \$120/MWH for SMRs. I put the cost of large
16 construction at \$150/MWH, given the history of the failure of the nuclear renaissance.

17 Small modular reactors are the latest in a long line of technologies that the advocates of
18 nuclear power hope will be provide answers to the many problems that have afflicted their
19 industry. Hyped as the dream solution, they turn into a nightmare. Small modular reactors that
20 have been on the drawing board for at least a decade exhibit all of the characteristics of failure.
21 Like the “nuclear renaissance” before it, the initial estimates of cost have doubled before they go
22 into construction and cost overruns really only begin when construction does. While they can
23 find companies to back them and governments to support them, and academics to explain the
24 theory of why they should work, the one thing they cannot do is deliver low-cost power. While
25 SMR advocates also claim it is safer than large units, they achieve that goal not by simply
26 solving safety problems, but by being excused from safety rules (like exclusion zones).

³³ Mark Cooper, “Small modular reactors and the future of nuclear power in the United States,”
Energy Research & Social Science 3 (2014) 161; “Comments of Dr. Mark Cooper.” In the
Matter of Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric
Utility Generating Units, Environmental Protection Agency, RIN 2060-AR33, November 24,
2015

1 The estimated costs of the NuScale reactor design have been consistently going
2 up.... Because the NuScale design might have to be modified to resolve the problems
3 flagged by the Nuclear Regulatory Commission, there could be further cost increases
4 even before construction starts. There is a long history of dramatic cost increases when
5 paper designs are first constructed.³⁴

6 Attachments MNC-3.3 and MNC-3.4 above describes the SMR cost problem. It
7 updates my 2014 analysis by including two recent estimates. I have included the current
8 estimate for the only active small modular reactors project. The high cost of nuclear
9 power is apparent and there is nothing in the small modular reactor technology that
10 suggests it will result in a cost revolution for nuclear. Using the math of the vendor, the
11 first cost estimate was put at \$0.055/kWh, so the current estimate is about twice that
12 before subsidies and construction cost overruns.

13 On the other hand, as shown in MNC-3.5 renewables are entering the market at very low
14 prices. Put on this “apples-to-apples” comparison basis, they are less than one third the cost of
15 small reactors. A technology that has no future, in terms of high costs, should not be encouraged
16 in the present and aging reactors have additional problems.

17 In other words, SMRs are at least 3 times as costly as the bundle of alternatives
18 (efficiency, wind and solar) and likely to be even more if construction takes place. The economic
19 failure of SMR technology should be the end of nuclear power, since a low-cost, low-carbon,
20 low-pollution electricity system, in which it can play no role, should be in place before any of
21 these reactors are constructed.

22 **D. THE COST OF AGING REACTORS**

23 Attachment MNC-3.6 provides detail on the cost of aging nuclear reactors. Utilities have
24 threatened to shut down aging reactors that are “losing money” but they never make public what
25 their costs are and what it means to “lose money,” i.e., they want all reactors to earn enough to
26 make a contribution to capital cost recovery. In public statements, utilities have claimed they
27 want a full return on investment for these plants – 10% to 18. The obvious point is that with
28 costs in the range of \$70/MWh used in this analysis, the cost of alternatives is well below the

³⁴M. V. Ramana, 2020, Eyes Wide Shut: Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors, Oregon Physicians for Social Responsibility, September.

1 cost of aging reactors. The Lazard estimates for new and young nuclear, would be well above
2 efficiency and solar and competitive with wind.

3 A Synapse analysis of the costs of subsidizing aging reactors in Illinois is instructive on
4 this point. Although heavily redacted, it does provide insight into the subsidy question. Based on
5 market clearing prices for energy and capacity, it appears that \$0.03/KWH is available in the
6 market. Synapse estimates that Dresden covers its out-of-pocket costs at a subsidy of
7 \$ \$0.02/KWH. To hit the target rate of return (discount rate) the reactor needs another \$0.015/
8 KWH. Thus, the cost with capital recovery and the target discount rate is \$0.065/KWH. This is
9 consistent with my earlier analysis of Illinois, New York and aging reactors in general (as
10 described in Attachment MNC-3.6).

11 The Synapse analysis tells a very different story than the utility does. Without the
12 subsidy, Byron and Dresden generate about \$400 million in revenues above costs. The other two
13 reactors that Synapse analyzed exceed the target discount rate for the utility, generating revenues
14 above costs of about \$1.3 billion. In the short term, the four reactors are cash flow positive,
15 although Dresden is negative for the first five years and Byron is slightly positive. Over 10
16 years, they are all positive, generating almost \$1.7 billion in cash above operating expenses. The
17 Synapse estimates for subsidies in Illinois make clear it that it may not be in the interest of the
18 state to give any subsidy at all.

19 **Q. Does the testimony of Pacific Gas and Electric in the Rulemaking to Implement**
20 **Senate Bill 846 Concerning Potential Extension of Diablo Canyon Power Plant Operations**
21 **refute or Rebut Your Analysis of Industry Costs and Cost Trends?**

22 **A.** No, not at all. On the contrary, it reinforces and supports that analysis in several ways.

23 **Q. Please describe how it supports your testimony.**

24 **A.** First, I must point out the tentative nature of the analysis. It is laced with redactions that
25 make it difficult to estimate costs that the public deserves to know, wrapped in caveats about the
26 uncertainty of near-term costs, but showing clear trends before the decision not to extend the
27 license.

28 Second, it describes how it would use the billions offered in subsidies, but never
29 examines any of the alternatives available. PG&E does not have to take the money and the PUC
30 does not have to allow it, if the continued use of Diablo Canyon is not in the interest of rate

1 payer, or federal and state taxpayers. If it sustains the reliance on power that is not least cost,
2 which I have demonstrated and the utility has failed to rebut, the PUC should reject it.

3 Third, the CAISO specific costs we have analyzed strongly support the value of
4 alternatives compared to aging reactors.

5 Fourth, the fiction that nuclear power from aging reactors is low cost because it does not
6 entail the recovery of capital costs, which I have criticized, is demonstrated to be false in the
7 PG& E statement. There were hundreds of millions of capital costs incurred to keep Diablo
8 Canyon online before the decision to retire the reactors and hundreds of millions of dollars in
9 capitals costs projected to be incurred if its life is extended.

10 Fifth, operating costs are substantial and likely to rise. Attachment MNC-3.6, show that a
11 regression across time indicates a substantial increase.

12 Sixth, it appears that Diablo Canyon was earning about \$50/MWH before the decision to
13 retire it and will be earning at least that much if its life is extended, plus the subsidy. Thus,
14 Diablo Canyon is likely to be receiving more than \$70/MWH, if its life is extended. I have used
15 \$70/MWh for aging reactors.

16 **Q. Are Your Cost Estimates Consistent with Other Analyses of California Costs?**

17 **A.** Yes, they are. That consistency is demonstrated in my use of CAISO estimates, e.g.,
18 wind, storage and solar in the firming analysis, California specific values in the net value
19 analysis above, as well as showing that my estimate of the cost of aging reactors is right on target
20 with California. I recognize that using the average of a number of estimates introduces some
21 differences with the California data. However, as shown in Attachment MNC-2.20, above, there
22 is a very strong correlation ($r > .9$) between my estimates and the California evidence.

23 **E. FUNDAMENTAL CONFLICT BETWEEN TECHNOLOGIES: NUCLEAR CROWDS OTHERS OUT**

24 This analysis also lays the groundwork for the broader consideration of technology
25 choice. In the long-term, nuclear new builds are extremely uneconomic, yet the subsidy proposal
26 makes no provision for what will happen at the end of the short-term subsidy period. The grid is
27 stuck with a larger nuclear footprint than economically justified. With power still coming from a
28 large, inflexible source, the challenge remains to replace it. Based on economics, the replacement
29 cannot be nuclear. Therefore, the economically rational approach is to not insulate nuclear from
30 near-term competition, but let it cope with its economic fate, which means retirements should
31 take place sooner, rather than latter over the next several decades. This is not only the preferable

1 approach from an economic point of view, but also the preferable approach from the point of
2 view of the transformation to a 21st century electrical system.

3 The economic conflict of interest between nuclear power and the lower-cost, low-carbon
4 alternatives is not limited to the cost of nuclear power. It is reinforced by fundamental
5 differences between central station power and distributed resources, both in terms of
6 technological competence and institutional requirements. Lovins elaborated earlier on these
7 deep-seated sources of conflict, making it clear that a truce that tries to accommodate both sides
8 is neither very likely, nor good policy.³⁵

9 If nuclear were subject to current market discipline, its load factor would decline, as
10 would its income. The result would be a much higher cost. In short, this clash is inevitable and
11 has given rise to a frontal assault by nuclear advocates on alternative resources and the
12 institutions that support them.³⁶ Policymakers should reject the “all of the above” argument
13 because the severely restricted market created by the forced presence of nuclear power will
14 strangle the ability of non-hydro renewables to expand, which is likely to drive the market
15 clearing price down. These low-cost resources compete for a smaller market. If there had been
16 no nuclear carve out, renewables could have competed for and won this load in an orderly

³⁵ Amory B. Lovins and Rocky Mountain Institute, *Reinventing Fire: Bold Business Solutions for the New Energy Era* (Boulder, CO: Rocky Mountain Institute, 2011), 216, “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 percent less than comparable U.S. systems, despite access to the same modules and other technologies at the same global prices.

³⁶ Mark Cooper, 2015, Power Shift, The Nuclear War Against the Future: How Nuclear Advocates Are Thwarting the Deployment of a 21st Century Electricity Sector, Institute for Energy and the Environment, Vermont Law School, May,

fashion, avoiding another “crisis” at the termination of the current subsidy, a “crisis” that the industry will inevitably invoke to demand another round of subsidies.³⁷

F DISTORTING WHOLESALE MARKETS

Efforts to defend short term subsidies for aging reactors are based on a fundamental diaphanization of the market and its clearing price/process in deregulated states. The wholesale market does what markets are expected to do, find the lowest possible price to clear the market. Central station facility owners claim, without any evidence that this price fails to put a proper value on key attributes of energy resources – attributes that their facilities happen to possess. Evidence of a market failure – i.e., disruption of supply – is lacking. While there has been a “cannibalization” of renewable revenues, they have not been as severe as claimed (curtailments as quite small) and solutions have been offered. Regulators have recognized the challenge and taken steps to address the issue of capacity, but whenever they stick to market principles of least cost competitive supply, nuclear fails, seeking subsidies and doubting the ability of regulators to design adequate programs.

The one example that is frequently cited is not a situation of deficit but one of surplus. There are moments when supply is so plentiful that it is necessary to curtail some output or pay people not to produce to keep the system in balance. Those very rare instances would be reduced, if not eliminated if a fully integrated system were deployed. Ironically, the behavior of the 20th century electricity system, based on central station generation has its “odd” moments and characteristics too. Above all, the system deploys resources that are rarely used (peakers), only at moments when the price escalates dramatically because there is a shortage of available supplies (peak load hockey-stick prices). The plants are curtailed 85-90% of the time. This evidence is dismissed as part of the system, which the grid operators labor to reduce and control. All systems have moments of stress and their existence of one does not provide evidence of market failure or mean that one system is better than the other.

Here I argue that the manner in which the aging reactors subsidies shrink the market available to non-hydro renewables and keeps aging reactors online, creating a serious distortion in the short term (see Attachment MNC-3.7). By doing so it creates the conditions for another crisis in the future, since nuclear advocates will, once again, argue that the system is not ready to

³⁷ Lovins, 2017.

1 give up nuclear power because of the “underdevelopment” of renewables and demand another
2 round of subsidies. This is linked directly to the broader pattern of crowding out that we observe
3 in the electricity sector (as shown in Attachment MNC-3.8). Reliance on central station facilities
4 crowds out alternatives in the long run, which is also the short run effect of the subsidy program.
5 The short-term problem aging reactors face is that operating costs are quite high, and total costs
6 are higher still—well above recent market clearing prices.

7 The flashpoint of the conflict over the transformation of the electricity sector (captured is
8 captured in Attachment MNC-3.7, above), which centers on the market clearing price of
9 electricity in those areas where markets (as opposed to regulators) set that price. The downward
10 pressure on the market clearing price, initially driven by gas, but increasingly driven by
11 renewables that are cost competitive with gas, means not only that aging reactors cannot cover
12 their costs, but are not likely to in the future.

13 As shown in Attachment MNC- 3.8, central station generation has a tendency to crowd
14 out alternatives. The smaller the share of central station facilities, the larger the share of
15 renewables. One can look at this graph and say, it is just arithmetic. When a state has so much
16 nuclear, there is no need for renewables, but that is the point in three respects.

- 17 • The math is favored by policy choices and those policy choices have
18 consequences. Resources are denied to alternatives if nuclear output
19 increased by the subsidy.
- 20 • For nuclear facilities in particular, especially during the construction
21 phase, utility management resources are devoured by nuclear reactors.
- 22 • Since it is a policy choice, it can be reversed, and the share of renewables
23 expanded.

24 Attachment MNC-3.8 highlights the real world crowding out effect. The graph tells a
25 very clear story. The logarithmic regression explains 44% of the variance in renewable
26 penetration ($r=.67$), while using a liner fit it account for about 31% ($r=.55$). Each of the central
27 station resources had about the same independent impact and they are uncorrelated, so the
28 combined effect is pronounced. To grasp the impact, the 23 low nuclear states have 26% non-
29 hydro renewables in the generation for 2017. The high nuclear states have 9%. The 8 low coal
30 states have a non-hydro renewable share of 27%, compared to 12% for the high coal states.

CHAPTER 4:
ADEQUACY THROUGH EFFICIENCY, DEMAND MANAGEMENT,
AND. RENEWABLE SUPPLY WITH STORAGE

A. The Hidden Fuel: Energy Efficiency

While the cost of key generation resources (wind, solar) is important, there are also two key technological revolutions that have also taken place on the demand side. First and foremost is the large role that energy efficiency can play in the transformation of the electricity system. The second is what I call the transformation dividend, which is a result of the development and application of intelligent technologies to the management of the grid. This is a mixture of supply-side and demand-side developments. Because demand management plays an important role here, I discuss the dividend in the conclusion to this chapter. However, the chapter begins with the much larger and “pure” benefits of energy efficiency.

A recent comment³⁸ on the International Energy Agency³⁹ report on energy efficiency note that energy efficiency can be called the “hidden fuel.”

What is the World’s most important fuel? (Hint: it is also the energy resource that all countries have in abundance). The answer to this riddle is energy efficiency, which is sometimes referred to as the “hidden fuel.” That is the powerful message of the *Energy Efficiency Market Report 2016* published by the International Energy Agency.

A strong energy efficiency policy is vital to achieving the central policy goals of improving energy security and reducing CO2 emissions as well as air pollution in the most cost-effective way. More and More countries are discovering that the safest and cleaned power plant is the one you don’t have to build thanks to higher efficiency.

Whereas energy policy has traditionally been dominated by a supply-side bias (i.e.: how do we produce more oil, gas, electricity?), policy makers increasingly understand we need to focus more on the demand side of the equation (i.e.: how

³⁸ Noel van Hulst. Hydrogen Envoy at the Ministry of Economic Affairs & Climate Policy of the Netherlands, *The Untapped Potential of Energy Efficiency*, 11 May, 2017.

³⁹ *Energy Efficiency Market Report 2016*, October 2016.

do we consume less energy)⁴⁰

The report cited supports this observation by estimating that about 30% of projected demand could be met with efficiency.

B. U. S. EFFICIENCY POTENTIAL

Current estimates for the near-term ability to reduce energy consumptions without reducing energy services are in the range of 15% for 2030 and 30% for 2050 respectively as shown in Attachment MNC-4.1. It includes some that are 20 years old, as well are more recent estimates, all from leading research institutions in the field. Needless to say, the 30% figure is a good, mid-term estimate. Since deep decarbonization requires electrification of transportation, these fuels are important to consider. The potential long-term reduction in consumption of diesel fuel, which is used by heavy duty trucks is considerably larger, primarily because the first fuel economy standards were only recently adopted, almost forty years after the first fuel economy standards for light duty vehicles were adopted.

In an earlier paper, I summarized the analytic consensus, shown in Attachment MNC-4.1 as follows:

In the past year, four major national research institutions have released reports that document the huge potential for investments in energy efficiency to lower consumers' bills and greenhouse gas emissions, creating a win-win for consumers and the environment. The National Research Council of the National Academy of Sciences has estimated the potential reduction in electricity, natural gas and gasoline at approximately 30 percent, similar to the estimates of NHTSA/EPA. McKinsey and Company and the American Council for Energy Efficient Economy have reached a similar conclusion on electricity and natural gas. Across these three sectors, saving energy costs about one third of the price of producing it. With the publication of these studies, the question is no longer "Can efficiency make a major contribution to meeting the need for electricity in a carbon constrained environment?"

These studies demonstrate that it can.⁴¹

⁴⁰ Van Hulst, 2017, p. 1.

⁴¹ "Prudent Resource Acquisition in a Complex Decision-Making Environment: Multidimensional Analysis Highlights the Superiority of Efficiency," *Current Approaches to*

1 The figure includes potential efficiency gains in all forms of fossil fuels, in addition to
2 electricity, for several reasons.

3 First, the existence of the “efficiency gap” across all the uses and the form of energy is
4 testimony to the pervasive market failure that afflicts energy markets. These market
5 imperfections are not the subject of this paper, but they are important to note, as measured by the
6 gap.⁴²

7 Second, the effort to eliminate carbon emissions would inevitably include a significant
8 electrification of the end uses for natural gas, gasoline and diesel, in addition to the
9 decarbonization of the electricity sector. That is, more efficient use of these fossil fuels, would
10 still leave each with a substantial carbon footprint. Electrification with zero carbon resources
11 would eliminate that footprint.

12 Third, although much of the efficiency gap that could be filled involves technologies
13 applied to the use of fossil fuels, i.e., improving the combustion characteristics of internal
14 combustion engines – some of the improvement comes from the design and operating
15 characteristics of the durable good. Those gains are available to improve performance, even with
16 the shift to electrification.

17 Ironically, although significant progress has been made in capturing energy efficiency
18 gains, the potential contribution of energy efficiency has been quite constant for several decades,
19 since it first attracted attention. The fact that the potential has not been diminished can be
20 explained by factors of technological and economic progress.

21 **C. Availability of Resources for Decarbonization While Meeting Short- and Long-term** 22 **needs**

23 To assess the opportunity to meet the need for low carbon alternatives with renewables,
24 we begin with the present and work to the future. There is an ongoing debate about whether
25 renewables can reach 100% of projected load, but that ignores the immediate question of how to
26 get to the future. Resources have to be added in the present to replace aging facilities and retire
27 polluting sources. I have argued that the key principle for making decision under this type of
28 uncertainty is to move in the right direction.

Integrated Resource Planning, 2011 ACEEE National Conference on Energy Efficiency as a Resource, Denver, September 26, 2011, p. 7.

⁴² See Cooper, 2017, pp. 98, 101, 152-179.

1 The analysis generally proceeds at two levels. First, as shown in Attachments MNC-4.2,
2 we see comparisons of how other states and nations are doing in the effort to deploy clean, low
3 carbon alternatives. At least two large states (California and Massachusetts) with large industrial
4 economies have achieved higher levels of contribution from efficiency and non-hydro
5 renewables. The states that have subsidized aging reactors (Illinois and New York) have much
6 lower levels. Other advanced industrial nations have achieved even higher levels of contribution
7 from renewables. States and nations have achieved much larger contributions of non-hydro
8 renewables to their generation needs with California the closest but still far behind.

9 As the graph in Attachment MNC-4.3 shows, the vast majority of states have an
10 abundance of potential supplies of renewable resources. Only a handful have potential that is
11 less than five times demand. California is in the middle of the states. The renewables are local
12 resources, and they present a new opportunity to diversify supply. Moreover, not only does
13 California have abundant supply, but it is located in a region with a great deal of supply,

14 **D. General Studies of Employment and Macro Economic Impacts**

15 Having shown the current and future economic superiority of the alternatives, I next
16 evaluate the impact that alternatives would have on the other policy goals – decarbonization,
17 macroeconomic growth and job creation. Although I find that economic and growth impacts are
18 the paramount benefit, I begin with a discussion of decarbonization, since that affects and is
19 affected by the economics of resource selection.

20 Above I showed that if policy makers conclude that subsidies are necessary to accelerate
21 and ensure the transition to a low carbon sector, they should target those subsidies at the
22 alternatives. I reach the same conclusion with respect to employment and macroeconomic
23 impacts. If policy makers conclude that the transformation of the electricity sector requires
24 support for local labor and the local economy, they should focus on moving toward the
25 alternative electricity system, not move toward a dead end by extending the life of existing
26 reactors.

27 As alternatives replace nuclear and back out transitory gas, there is a macroeconomic
28 impact. Construction for the alternatives is much more labor intensive than operating nuclear
29 reactors. Because the cost of the alternatives is lower, they have a larger long-term impact on
30 indirect economic activity because they leave more money in the consumer's pocketbook to buy
31 other things. The literature overwhelmingly supports the proposition that the economy is better

1 off relying on the alternatives. The macroeconomic impact of energy policy has taken on great
2 significance in the current round of decision making. Every policy is evaluated for its ability to
3 stimulate growth and create jobs. Assessing the macroeconomic impact of policy choice
4 generally relies on complex models of the economy. Cost savings on energy and economically
5 beneficial energy efficiency investments yield net savings; the reduction in energy costs exceeds
6 the increase in technology costs. Thus, such investments have three effects from the point of
7 view of the economy.

- 8 • The increase in economic activity resulting from spending to develop new technology
9 (indirect).
- 10 • The economic activity round deploying that technology (direct).
- 11 • Finally, there is the induced economic activity that results from an increase in
12 consumer disposable income that flows through the economy, raising the income of
13 the producers of the additional products that are purchased and increasing
14 employment. In short, the decrease in energy expenditures is substantially larger than
15 the increase in technology costs, resulting in an increase in the disposable income of
16 individuals to spend on other things.

17 These large increases in economic activity led to increases in employment. The effect is
18 magnified by the fact that the non-energy sectors of the economy are substantially more labor
19 intensive than energy production. The energy sector is less than half as labor intensive as the rest
20 of the economy, so the ratio of job creation for efficiency, compared to other production option
21 in electricity is also two to one.⁴³ As consumers substitute away from energy, the goods and
22 services they purchase stimulate economic and, disproportionately large, job growth.

23 **E. MACROECONOMIC MULTIPLIERS IN U.S. IN DEMAND-SIDE ENERGY POLICY**

24 Econometric models that use general flows of resources between economic activities
25 have been used to assess these economic impacts. In a sense, the coefficients in the macro

⁴³ Max Wie, Shana Patadia and Daniel Kammen, 2010, “Putting Renewables and Energy Efficiency to work: How Many Jobs Can the Clean energy Industry Generate in the US?”, *Energy Policy*, 38, 2010 (hereafter Wie, *Putting Renewables*); Rachel Gold, et al., *Appliance and Equipment Efficiency Standards: A Money Maker and Job Creator*, American Council for an Energy Efficient Economy, January 2011; James Heintz, Robert Pollin, Heidi Garrett-Peltier, *How Infrastructure Investments Support the U.S. Economy: Employment, Productivity and Growth*, , Political Economy Research Institute, January 2009.

1 models are representations of the relationships in the economy through which the micro level
2 effects flow. No matter the level or approach, the evidence strongly supports the conclusion that
3 there is a positive impact from both the demand⁴⁴ and the supply points of view.⁴⁵ Although the
4 uptake on macroeconomic impacts in the U.S. has been slow, Attachment MNC-4.4 shows four
5 examples of the impact on the U.S. economy using two different models for four different
6 locations.

7 The results differ across studies because the models are different, the impact varies
8 according to the size of the geographic unit studied and because the assumptions about the level
9 and cost of energy savings differ. These differences are not an indication that the approach is
10 wrong. On the contrary, all the analyses conclude that there will be increases in economic
11 activity and employment. Given that there are different regions and different policies being
12 evaluated, we should expect different results.

13 The rule of thumb – an approximate doubling of the economic impact – that emerges in
14 the literature reflects the observation on jobs.⁴⁶ Similarly, in a study of 52 examples of increases
15 in industrial productivity, where benefit was monetized, the productivity savings were 1.25 times
16 as large as the energy savings.⁴⁷ Macroeconomic models measuring the outcome in change in
17 GDP yield a “responding” effect that clusters around 90%. These efforts to model the economic
18 impact of have proliferated with different models⁴⁸ being applied to different geographic units,

⁴⁴ Lisa Ryan, and Nina Campbell, *Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements*. (Hereafter, Ryan and Campbell, *Spreading the Net*), 2012, Insight Series. Paris, France: International Energy Agency, pp. 1...2 ...3. For the consuming sectors, it is relatively straightforward to observe how investment in energy efficiency and energy savings can lead to increased spending and economic activity with second round effects such as employment, government revenue, and price effects (if other investment and spending is not crowded out). There are likely to be positive income effects, unless household wage demand increases as the labor supply becomes more competitive.

⁴⁵ U.S. EPA, Memorandum To: Docket EPA-HQ-OAR-2009-0472, Subject: Economy-Wide Impacts of Greenhouse Gas Tailpipe Standards, March 4, 2010 (hereafter, *Memorandum*).

⁴⁶ Gold, et al., *Appliance and Efficiency*, “In our experience modeling efficiency investments, we find that re-spending the energy savings typically creates an equivalent number of jobs as implementing the investment.” (p. 2)

⁴⁷ Worrel, Earnest, et al., 2003, “Productivity Benefits of Industrial Energy Efficiency Measures.” *Energy* 28 (2003) (hereafter, Worrel, *Productivity Benefits*), p. 5.

⁴⁸ For example, EPA, *Memorandum*, IGEM; Rachel Gold, et al., *Appliance and Equipment Efficiency Standards: A Money Maker and Job Creator*, American Council for an Energy Efficient Economy, January 2011, (hereafter, Gold, *Appliance and Efficiency*), p. 9, based on

1 including states⁴⁹ and nations.⁵⁰ MNC-4.4 shows examples of the multiplier, with the GDP
2 impact expressed as a multiplier of the value of net pocketbook savings. That is, we subtract
3 costs from the estimated value of energy savings. This ensures we do not double count benefits.

4 Ironically, the EPA reviewed the literature on the macroeconomic impact of reduced
5 energy consumption.⁵¹ These impacts, as discussed in EPA analysis are an indirect effect of the
6 rule, a genuine externality. The U.S. regulatory agencies have not recognized this macro-
7 economic benefit in rulemakings to set minimum efficiency standards. The EPA came close in
8 setting the “national plan” for light duty vehicles, commissioning a study of the effect of
9 lowering the cost of driving. Very substantial benefits were identified, but EPA failed to
10 mention them in the final rule, adopting a much lower standard than could have been justified.
11 This approach has become quite common with detailed analyses of energy efficiency across a

the IMPLAN Model, 2009. Howland, Jamie, Derek Murrow, Lisa Petraglie, and Tyler Comings. *Energy Efficiency: Engine of Economic Growth*. Rockport, ME: Environment Northeast, 2009(hereafter Howland and Murrow, *Energy Efficiency*) and New York State Energy Research & Development Authority. *Macro-Economic Impact Analysis of New York’s Energy Efficiency Programs: Using REMI Software*. Albany NY: NYSERDA, August 4, 2011 (hereafter, NYSERDA, *Macroeconomic*), REMI).

⁴⁹ For example, New York (NYSERDA, *Macroeconomic*), New England (Howland and Murrow, *Energy Efficiency*), California (David, Roland-Holst, Revised Standardized Regulatory Impact Assessment: Computers, Computer Monitors, and Signage Displays, prepared for the California Energy Commission, June. 2016) David, Roland-Holst, Samuel Evans, Samuel Heft-Neal, Drew Behnke, Cecilia Han Springer (2016). “Berkeley Energy and Resources (BEAR) Model: SRIA Baseline Forecast for the California Economy.” Report prepared for the California Energy Commission) and (Samuel, Evans, and David Roland Holst, *Model Comparison for SRIA Macroeconomic Assessment*, BEAR, June, 2017) for a comparison of models.

⁵⁰ For example, U.S. has been studied repeatedly, see notes 61 and 62, as have many other countries like the UK, e.g. (Benjamin S. Warr, Robert U. Ayres, and Eric Williams. *Increase Supplies, Increase Efficiency: Evidence of Causality Between the Quantity and Quality of Energy Consumption*, Warr, Ayres and Williams, 2009) The Cambridge Centre for Climate Change Mitigation Research. *The Macro-Economic Rebound Effect and the UK Economy*. Cambridge, U.K.: Cambridge Econometrics and Policy Studies Institute, May 2006. notes recent studies on Asian economies, Korea, Canada and Spain,

⁵¹ Id., pp. 3-4. “Lower prices allow for additional purchase of investment goods, which, in turn, lead to a larger capital stock. These price reductions also allow higher levels of government spending while improving U.S. competitiveness thus promoting increased exports relative to the growth driven increase in imports. As a result, GDP is expected to increase because of this rule.

1 range of activities (autos, appliances, buildings, industries),⁵² sectors (e.g., energy,
2 manufacturing, service, particularly as it impacts use of labor)⁵³ and with a variety of analytic
3 approaches (qualitative, econometric).⁵⁴

4 For the purposes of this analysis, I assume that the approach that relies on alternatives has
5 a multiplier that is twice that of nuclear. MNC-4.5 summarizes the basis for this assumption. It
6 combines the results of three studies that apply a very common approach. Using macroeconomic
7 models, the study estimates the direct and indirect effect of investing in a technology to produce
8 or conserve energy. Some activities have larger multipliers because the results (savings or
9 spending) circulated faster through the economy. This is true both across sectors, as shown in
10 the right-side graph of Attachment MNC-4.5 and within the electricity sector, as shown in the
11 left side graph of the Attachment.

12 I have rendered the results of these studies comparable by indexing energy across studies
13 and expressing the outcome as a ratio. The Political Economy Research Institute (PERI) study
14 gives estimates for the impact of investment in nuclear and oil and gas. I equate the energy
15 category from American Council for an Energy Efficient Economy (ACEEE) to the oil and gas
16 category from PERI. Setting nuclear equal to one as the base, I can then calculate the relative
17 job intensive of broad economic sectors (to the right) and electricity resources (to the left). Wei
18 et al., calculated the number of jobs for each of the resources directly. While the correlation is
19 not perfect, it is substantial, and the directionality is clear. The nuclear multiplier is the smallest
20 of all sources of electricity and economics sectors. In light of this data, my assumption that the
21 alternatives would have a multiplier twice the size of nuclear is extremely cautious.

22 **F. International Recognition of Macroeconomic Benefits**

23 Ironically, almost a quarter of a century ago, the literature on climate change began
24 recognizing these potential benefits and they have consistently done so since then. A review of

⁵² Worrel, et al. 2003, identified 70 industrial case studies, with 52 that monetized the benefits.

⁵³ Wei, and Kammen, 2010.

⁵⁴ Ryan and Campbell, *Spreading the Net*, identify a dozen partial equilibrium models that have been applied to regions within nations, individual nations, groups of nations and the global economy. The effects analyze include GDP, employment by sector, public budgets, trade, distribution, and investment.

1 the literature by Smith,⁵⁵ identifies numerous studies, all conducted in the first decade of the 21st
2 century by leading energy, environmental and economic analysts, which identified various
3 aspects of the “co-benefits” of efficient low carbon generation. Although, the authors identified
4 13 such studies in a text box, a review of the footnotes shows at least two dozen more studies of
5 major emitting economies (U.S., Australia, China) and the general economic benefits of
6 efficiency and reduced pollution and resource use. The total is well over three dozen. The basic
7 observation about the failure of simplistic economic analysis is the same as the domestic U.S.
8 critique which the author summarized simply, “Most economic modelling to date has failed to
9 include or quantify productivity co-benefits from action on climate change.”⁵⁶

10 I have organized the climate mitigation strategies into five broad categories in
11 Attachment MNC-4.6. First comes renewables. Then we find two efficiency categories,
12 business and residential. These are the transformation categories we have emphasized throughout
13 this analysis. Next comes transportation efficiency, but recently (after the publication of the
14 underlying paper) electrification of the vehicle fleet has become a central policy point. Thus,
15 between 3/4 and 7/8 of the climate change mitigation measures are deeply entwined with the
16 transformation of the electricity sector.

17 However, the primary purpose of the work is not to examine the implications of policy
18 for climate change, it is to examine the implication for productivity in the context of doubling the
19 energy efficiency of the economy. Climate change benefits, measured in MNC-6.4 as a
20 reduction in the emissions of carbon, are a welcome co-benefit of improved energy efficiency
21 and partially responsible for improved efficiency. Therefore, we include estimates of the
22 economic gains that result from improved energy efficiency. These estimates of benefits are
23 contained in the text, along with numerous examples and case studies of how they could be
24 achieved. In order to achieve the goal, the author argues for a doubling (100%) increase in
25 energy productivity. The total savings listed in MNC-6.4 far exceeds that level for two reasons.
26 The levels for each individual item may not be achieved, and there is overlap between the
27 categories.

⁵⁵ Smith, Dr. Michael H., 2015, Doubling Energy & Resource Productivity by 2030 –
Transitioning to a Low Carbon Future through Sustainable Energy and Resource
Management, ANU discussion Paper.

⁵⁶ Id., p. 13.

1 One study on China, cited by the author put it, described the effect of failing to take the
2 economic impacts of energy efficiency into account:

3 Positive effects of emissions reduction policies on productivity are typically not
4 fully captured in conventional economic modelling studies. Partial equilibrium
5 modelling of climate change does not take changes in productivity into account.
6 Unless combined with specific estimates of beneficial impacts from mitigation,
7 these analyses by their very nature present only costs not benefits... [L]ack[ing]
8 detailed information about differential productivity between sectors of activities,
9 [they] typically assume that in the baseline and economies follow an efficient
10 pattern of investment and structural change. Thus, by default, a deviation from a
11 model's base case (the hypothetical future scenario against which scenarios with
12 emissions reductions are compared) will show up as a reduction in productivity
13 and economic growth.”⁵⁷

14 Although Smith's focus is on the economic effect of clean energy policies, he also notes
15 that there is a convergence between climate policy and economic policy, as shown in Attachment
16 MNC-4.6. The upper part of the exhibit shows the individual effects across the economy and
17 climate goals. The lower part shows that there is a high correlation ($r = .95$ linear, $.91$
18 logarithmic) between carbon reduction and macroeconomic benefits, which I have extracted
19 from his textual discussions. Efficiency and renewables are the top two sources of
20 environmental and economic benefits.

21 The author then enumerates the co-benefits which have been ignored, including, “energy
22 and resource efficiency, co-generation, renewables, reducing methane leakage, energy efficiency
23 sustainable transport, reducing waste and achieving a transition to a circular economy, reduced
24 energy consumption and waste and deforestation are significant because most of the significant
25 smart climate change mitigation strategies are productivity enhancing.”⁵⁸ In this analysis I do not
26 try to quantify the indirect benefits associated with environmental damage of pollution and
27 public health, but we focus on the macroeconomic benefits created by lower cost for alternatives.

57 Teng, F. and F. Jotoz, 2014, “Reaping the Benefits of Decarbonization, for China,” *CEP, Working paper, 1413, August*.

58 Smith 2015, p. 18.

1 In general, however, business and residential efficiency are the largest contributors, followed by
2 renewables and energy efficiency.

3 **G. State Level Analysis of Employment and the Local Economy**

4 Given that subsidies for aging reactors make no sense on the basis costs, in the two states
5 that have subsidized aging reactors the utilities have tried to claim that there is a net benefit from
6 the ability of aging reactors to keep jobs in the area. The arguments are incorrect. More jobs are
7 added by the alternatives, as suggested by MNC-4.6, above, and Attachment MNC-4.7.

8 Utility funded studies of the impact of retirement of aging reactors, are riddled with
9 erroneous assumptions. Ultimately the Illinois Department of Commerce analysis presents a
10 more balanced view and raises the question of the impact on the local and state economy. The
11 loss of nuclear reactor-related jobs (direct and indirect) is offset in the early years by
12 construction of alternatives. When the construction jobs expire, the loss of nuclear jobs exceeds
13 the ongoing number of jobs added by the “operation” of replacement resources. However, this
14 calculation does not include decommission activities at the reactors. Ironically, while the
15 Department of Commerce does not include decommissioning jobs, it then criticizes the Nuclear
16 Energy Institute analysis that failed to do so.⁵⁹ The oversight is substantial. In the long term, the
17 lower cost of the alternatives and high multipliers far outweigh the small difference in direct
18 jobs, yielding much higher levels of employment and economic activity. There is no reason to
19 delay capturing these benefits or put them at risk by extending the life of reactors.⁶⁰

20 Similarly, a 2015 Brattle Group Report, entitled “New York ‘s Upstate Nuclear Power
21 Plants’ Contribution to the State Economy Brattle Group” (“Brattle Report”)⁶¹ assumes that
22 every kilowatt hour of electricity produced by a retired reactor is replaced with a kilowatt hour
23 generated by natural gas, and there will be no increase in production by wind, solar or efficiency,

⁵⁹ Illinois Commerce Commission, Illinois Power Agency, Illinois Environmental Protection Agency, and Illinois Department of Commerce and Economic Opportunity. *Response To The Illinois General Assembly Concerning House Resolution 1146*. January 5, 2015, p. 150.

⁶⁰ Lovins, *Do coal and nuclear*, argues that the jobs claims are little more than climate change blackmail (unsupported by empirical evidence, pp. 23, 28) and that the number decommissioning jobs are unaffected by the timing of plant retirement (p. 24).

⁶¹ Mark Berkman and Dean Murphy, Brattle Group, *New York’s Upstate Nuclear Power Plants’ Contribution to the State Economy*, prepared for New York State IBEW Utility Labor Council Rochester Building and Construction Trades Council Central and Northern New York Building and Construction, December 2015.

1 at the end of the subsidy period, the elasticity of price with respect to supply implicit in the
2 analysis is just under one, while the elasticity of demand with respect to price is zero. The
3 macroeconomic multiplier on the use of natural gas to generate electricity is assumed to be equal
4 to that of nuclear, so the reduction of direct and indirect jobs and economic activity resulting
5 from the price increase is a total loss. All of these assumptions are incorrect.

6 Above all, the “dash to gas” is not an unavoidable or inevitable outcome. If the PSC does
7 not put its thumb on the scale of competition; but allows all low carbon resources to compete to
8 meet increasing levels of carbon reduction set by mandates on utilities, the lower cost
9 alternatives would expand rapidly. Initially there is reliance on gas, but that is eliminated over
10 time. Based on the Brattle Report’s assumption at the end of the period of aging reactor
11 subsidies, New York will find itself in exactly the same position it is in today, having less
12 electricity produced from new renewable technologies and more electricity still being produced
13 by aged, 60+ year, outdated nuclear reactor technology.

14 Attachment MNC-4.8 plots the macroeconomic impacts of this alternative scenario.
15 Since “indirect” jobs represent over 90% of total jobs, the multiplier is far and away the most
16 important factor. In this analysis I do not include decommissioning jobs, since those will be
17 captured whenever the reactors close.⁶² In this orderly transition, there is no net loss of jobs
18 even from the beginning.

19 This does not mean that the transformation of the electricity system will not require
20 adjustments, but direct efforts to manage the transition are less costly than the ill-considered
21 subsidization of aging, uneconomic facilities. The Commission, the Governor, or the legislature
22 could implement a community and worker protection program to ensure a responsible and
23 effective economic transition for communities and workers impacted by power plant closures.
24 Multiple pieces of state energy policy are designed to supplant the state’s current dirty energy
25 resources with new, renewable, and/or distributed resources. The state should recognize this fact
26 and approach it proactively and with a commitment to ensure that workers and communities land
27 on their feet.

28 The above discussion of the benefits of lower utility bills reflecting low-cost efficiency,
29 wind, solar and hybrid systems, show that there is a huge macro-economic benefit, but even

⁶² Lovins, 2017, p. 24, notes that decommissioning jobs will be the same whenever the reactors are shut down and do not affect the employment picture in the long-term.

1 those underestimate the value of the transformation of the electricity system. There is an added
2 benefit that I call the “transformation dividend.” The alternative system not only reduces
3 demand, but it also shifts it (see Attachment MNC-4.9). Some of the shift is a function of the
4 underlying technology. Efficiency tends to work at all hours of the day, although it has its
5 largest effect when people are awake and using appliances. Some of the shift is part of the effort
6 to increase the value of renewables (i.e., batteries coupled with solar) and some of it is part of the
7 effort to keep the system in balance (i.e., regulatory decisions that provide incentives to build
8 capacity to keep the system in balance). Either way, the dividend is large, has an impact of the
9 viability of the system, and delivers a macroeconomic benefit.

10 In examining this effect on peak demand, it is important to keep in mind that the
11 magnitude of the effect and the “benefit” must be measured or conceptualized in comparison to
12 where demand could have been, not where it is. It might be growing, but more slowly than
13 would have been the case. The comparison should be with the wildly expensive and
14 overwhelmingly curtailed, peak load generators. Thus, this aspect of the transformation dividend
15 might be underestimated by a comparison to average prices.

16 The transformation dividend is built into a variety of analyses. Above we noted that
17 assumption on the low-demand scenario of 10-20 percent. The Regulatory Analysis Project puts
18 the figure at 17%. The NYSERDA analysis in New York put the figure at xx -yy. In CAISO,
19 the impact by 2030 is 10-15%. Thus, there is close agreement on the mid-teens as the magnitude
20 of the “transformation dividend.”

21 The upper graph in Attachment MNC-4.8 shows the basis of this dividend at the
22 conceptual level. Efficiency, demand management, renewables and storage lower the overall
23 demand and shift the peak. The smaller system with a lower peak reduces the cost of electricity.
24 It is important to keep the overall process in mind to recognize the benefit of demand reduction
25 and shifting. As shown in the lower graph of Attachment MNC-4.8. Over the course of a
26 decade and a half there has been a lowering of demand and a shifting, which lowers the total
27 cost, below what it otherwise would have been. While it may be attractive to make the mistake
28 of claiming that the current allocation of costs could be different, with more costs recovered from
29 the users of solar power, one would also have to assume that, in the face of higher costs, the
30 benefits of reduced and shifted demand would be smaller, or perhaps eliminated. The
31 environmental and macroeconomic gains would also be foregone. Thus, the transformation is

socially and economically beneficial and it is extremely important to take a long-term, holistic view of the process of building as 21st century system.

CHAPTER 5:

BUILDING A LOW CARBON, LOW COST 21ST CENTURY ELECTRICITY SYSTEM

Low cost and adequate resources are two important ingredients to support the alternative system, as is the commitment to build one, but operating the system remains a challenge. This chapter addresses this issue by making it clear that the tools to successfully operate a 21ST century system are developing rapidly. Delaying or distorting that process by keeping uneconomic, inflexible central station facilities, like aging reactors, online is the opposite of what is needed. Subsidizing existing nuclear reactors is a very bad idea from the point of view of promoting a successful transformation.

In a sense, the resources for a 21st century system have existed for a long time. The sun does not shine anymore and the wind does not blow any more than historically. Technological change has made exploiting these resources less costly and has made energy efficiency much more attractive. Physical technologies – rapid communications and computation abilities – have also made it possible to manage and integrate demand with supply feasible. Building the institutional infrastructure to accomplish this goal, while ensuring adequate, reliable supply is the imminent task. Yet, with so much technological change creating the possibility of an alternative approach, there is strong public interest in an effort to do so.

Thus, it is important to recognize that the 20th century system made perfect sense, in the 20th century. Large, load following central station facilities were inexpensive to develop (except for nuclear) as long as they were excused from the cost of their externalities (including of course, waste and risk of accidents or proliferation, embodied in the Price Anderson Act). That has changed. The system that they built was tailored to their needs, load following with reliance on very high cost, sparsely used peaking facilities. The socialization of system cost and shifting them to ratepayers was attractive, given the low costs resources. That system no longer makes sense on all counts.

High-cost nuclear generation is still more costly than high-cost fossil fuels that must bear their external costs. It is now possible to switch to lower cost alternatives combined that seek to modify and match demand with supply, instead of simply following it. The most difficult challenge is transforming the physical and institutional infrastructure that favor the incumbent facilities to the detriment of the alternatives. That is the topic of this chapter.

TOOLS TO ACHIEVE LOW COST, RELIABLE POWER

1 The upper graph of Attachment MNC-5.1 shows the many tools available to achieve low
2 cost and reliable supply. The lower graph shows the differences between the 20th century system
3 approach and the 21st (repeated from MNC-1.5). In the original analysis of these tools, I
4 identified 41 tool and 260 citations supporting them. In updating this analysis, I have added over
5 100 citations, but I keep them separate by identifying additions to the list (sub-issues in some
6 cases) for most of the original 41 (as shown in Attachment MNC-5.2). The citations are
7 presented in lieu of a bibliography in the Attachment C.⁶³

8 A decade ago, a California proceeding examined the issue of operating the emerging
9 system. It challenged parties to think about how high levels of renewables could be integrated
10 into the grid. Utilities offered a host of approaches and my summary concluded there were
11 numerous general ways to handle the challenge.⁶⁴

12 The LBNL analysis⁶⁵ of that period shows that the technical and economic processes by
13 which policies work to mitigate the impact of variability are straight forward.⁶⁶

- 14 • Geographic diversity, particularly for wind, reduces extremes of generation,
15 Technological diversity fosters a better fit with load.
- 16 • Storage allows more energy to be captured and used when needed, by
17 reducing curtailment, increasing and shifting supply, and by increasing
18 demand (and therefore prices) during slack periods.
- 19 • Demand shaping allows a better balance between supply and demand.
- 20 • Flexibility is a key attribute, achieved by
 - 21 ○ sub-hourly scheduling to reduce the magnitude and impact of forecasting
 - 22 error,
 - 23 ○ “quick start” generation, or
 - 24 ○ a portfolio approach that uses a mix of generation assets that can reduce the
 - 25 need for flexibility of individual assets.

⁶³ Because I give full citations to evidence in the text, I do not include a bibliography. However, most of the sources cited in text also are cited in the list of tools. I list the citations in alphabetical order and I show the number of the citation which can be linked to the tool.

⁶⁴ Cooper, 2017.

⁶⁵ Mills, Andrew, and Ryan Wiser, 2014, *Strategies for Mitigating the Reduction in Economic Value of Variable Generation with Increasing Penetration Levels*. Environmental Energy Technologies Division, Lawrence Berkely National Laboratory.

⁶⁶ *Ibid.*, p. 25, 27,

- Exploiting the best sites for renewable resources yields much larger economic value—three times the average.

Although the utilities in California⁶⁷ put together an analysis that takes a very different approach than the LBNL analysis and seems much more ominous, close examination shows that when the utility analysis introduces mitigation measures, it reaches a similar end point. Consistent with the LBNL analysis. Introduction of mitigating policies immediately solves the problem. 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. However, adding in three blocks of “flexibility solutions” reduces the curtailment of PV generation to the level of the 33 percent penetration, which was virtually zero. The transformation dividend is present in the utility analysis. Pursuing downward “flexibility solutions” yield 15000MW of reduced demand, which 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 on the transformation dividend.⁶⁸

This level of “flexibility solutions” is in the range of the planning reserves. As the penetration of relatively small-scale distributed technologies increases, the need for planning reserves may decline because, 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 LBNL analysis. The utility study finds significant challenges, but also opportunities. The “least regrets” opportunities identified in the study reflect the discussion offered herein, including.

- pursuing a diverse portfolio of renewable resources.

⁶⁷ E3, Higher Renewables Portfolio Standard, E3. Investigating a Higher Renewables Portfolio Standard in California. Energy and Environmental Economics, Inc., January, 2015.

⁶⁸ Lazar, Jim. *Teaching the “Duck” to Fly*, Regulatory Assistance Project, January 2014, shows various aspect of the transformation reducing load by 10-20%.

- implementing a long-term, sustainable solution to address over-generation before the issue becomes more challenging.
- implementing distributed generation solutions.
- expanding research and development for technologies to address over-generation 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 market for excess energy,
 - changing the profile of daily energy demand, and
 - optimizing the thermal generation fleet under high RPS.⁶⁹

A. THE POLICY RECOMMENDATIONS FOR A PATH TO DEEP DECARBONIZATION

Q. Does your earlier discussion of NRELs’ nuclear and geothermal cost resolve the differences and reflect the importance of these erroneous assumptions?

A. No, it does not. It moves in the right direction, but NREL’s discussion of 100% clean energy scenarios raises other issues and is important because the errors point in a different direction.⁷⁰ As shown in Attachments MNC-1.3 and 2.2 above, NREL assumed a low cost for nuclear. In fact, its assumption was even farther off the mark. As shown in Attachment MNC-5.3, NREL not only assumed an unrealistically low cost for nuclear, but it also assumed, contrary to reality, that the cost would decline. The cost scenarios shown in the Attachment MNC-5.3 have no “high-side, for nuclear, only a low side. The decline is substantial, about 40%. In reality estimate for the U.S. SMR project that has been the target of greatest attention has announced a

⁶⁹ E3, *Higher Renewables Portfolio Standard, E3. Investigating a Higher Renewables Portfolio Standard in California*. Energy and Environmental Economics, Inc., January, 2015, pp. 31–35.

⁷⁰ Denholm, P., et al., 2022, “Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035, NREL/TP-6440-81644.

1 major increase in projected cost. Adding in a huge federal subsidy, the cost is almost three times
2 the NREL low estimate. The only active large reactor project which is a new build is higher still.

3 For geothermal, NREL's cost estimates are technology specific, but even the lowest cost
4 technology is higher than the current estimates from Lazard and EIA. Even NREL's low
5 geothermal projections are higher than the current projections from others. In any scenario where
6 new build, "baseload" capacity is needed, reality suggests much less nuclear and much more
7 geothermal.

8 The only scenario in which NREL envisions nuclear increasing its share of output (to
9 27%)⁷¹ is the "constrained" scenario,⁷² which it defines as follows: "**Constrained** is a scenario
10 where additional constraints to deployment of new generation capacity and transmission both
11 limits the amount that can be deployed and increases costs to deploy certain technologies."⁷³
12 The high-cost technologies are the renewables, while nuclear is low cost. The constraints and
13 cost assumptions drive this result. However, the "constraints" do not appear to operate on
14 nuclear, even though its share of capacity is double the current share. Nuclear additions are
15 between 40 and 50 times as much as geothermal in this scenario.

16 NREL notes that the "build rate of nuclear would have to be 4 times as large as the
17 highest ever achieved in the U.S. It fails to note that the high rate was achieved 50 years ago.
18 Compared to the last ten years, the nuclear "build" rate would have to be at least 40 times as high
19 as the current level. In the "unconstrained" scenarios, the build rates of wind and solar would
20 have to be 4 times what had been achieved, certainly a formidable task, but one that is much
21 closer to the reality of recent build rates.⁷⁴ The necessary nuclear build out is implausible to say
22 the least.

23 **Q. Are there useful observations that can be drawn from the basic NREL supply cost**
24 **estimates?**

25 **A.** Yes, there are, but first one must see through (get past) the unrealistic nature of the
26 assumed nuclear costs and builds and the high cost of geothermal. These studies assume a
27 complete failure of the 21st century system, efficiency, demand management, renewables,

⁷¹ Id., p. xi.

⁷² Id., p. 24.

⁷³ Id., p. vii.

⁷⁴ Id., p. xi.

1 storage, and geothermal. There are a series of studies that assume contrary to current reality and
2 history, that the cost of nuclear will fall by 60%, or that costs don't matter,⁷⁵ the load factor of
3 nuclear will be 33% higher than it could be in a system based on efficiency and renewables.
4 Attachment MNC-5.4, repeated from MNC 1.4, above, after the specific evidence has been
5 introduced, places the suspension of disbelief by policy makers that is necessary to accept the
6 nuclear scenario in the context of the history of cost trends. The complete reversal of past trends
7 is highly unlikely and not the assumption that policymakers should make.

8 **Q. Putting the suspension of disbelief aside on nuclear and geothermal, what is the**
9 **message in the NREL study?**

10 **A.** NREL is polite and calls it the "Constrained" scenario, as shown in Attachment MNC-
11 5.5. The useful advice for policy makers that can be extracted from the NREL study is
12 consistent with my discussion of costs, and demand-side contributions. Policymakers should
13 take existing trends and craft policies to reinforce them. In a sense, public policy can only
14 succeed by striving to prevent the constrained scenario.

15 First, the costs of wind and solar are quite low and there is little uncertainty in these cost
16 estimates.

17 Second, the same is true of hybrid systems (solar with storage), once one takes the choice
18 of the battery size into account. More hybrid systems and larger batteries are clearly the direction
19 of resource choice.

20 Third, even with large batteries, hybrid systems are lower in cost than nuclear and
21 geothermal (even with NREL's low-cost assumptions).

22 Fourth, gas with carbon capture and storage (especially in new builds) is lower in cost
23 than nuclear and geothermal, but higher in cost than solar wind, and hybrid systems.

⁷⁵ Some, like the Breakthrough Institute abandon cost altogether, Hausfather, Zeke, 2021, *Quantifying Solar Value Deflation in California*, Breakthrough Institute, Jul 14, arguing that "The bottom line is that it doesn't matter what a technology costs; it matters what the electricity system needs... What matters isn't their cost, it's their value." Although I have shown that on value, the current leading application has plenty of value, whereas the high cost of nuclear undermines its potential value. Others, Like Aborn, et al., 2021, *An assessment of the Diablo Canyon Plant for Zero-Carbon Electricity, Desalinization and Hydroproduction*, MIT/Stanford, November, make a series of assumptions all of which are favorable to Diablo Canyon, and which are refuted in this testimony, current and future low cost for the aging reactor, a dash to gas, (ignoring renewables as substitutes),

1 Fifth, depending on the quality of the resource, even offshore wind is lower in cost than
2 nuclear and geothermal, and competitive with solar and onshore wind in the more attractive
3 locations.

4 **Q. Are these other observations one can make from the NREL study?**

5 **A.** Yes, there are. Many of the scenarios involve contingencies around interactions with the
6 supply-side core. Although this touches on many of the issues discussed below, it is worth
7 noting that key messages, which reinforce my later observations.

8 As shown in Attachment MNC-5.5, the first key message is to get as much as possible
9 from the demand side. This holds down costs dramatically. Thus, the NREL paper considers a
10 set of scenarios that includes the long-term demand reduction, which it describes as follows:

11 We also evaluated all scenarios with a sensitivity case using electricity demand
12 from the *Long-Term Strategy of the United States* (LTS) (White House 2021a) to
13 reflect an alternative demand-side pathway to reaching a net-zero emissions
14 economy by 2050. The LTS reflects higher levels of energy efficiency and
15 demand-side flexibility, resulting in slower annual load growth of 1.8%/year
16 (compared to 3.4%/year under ADE) and, importantly, lower demand peaks that
17 occur predominantly in summer as compared to the sharp winter peaks assumed
18 for our primary ADE scenarios. In addition to direct electricity demand, both ADE
19 and LTS assumptions include demand for clean hydrogen production for
20 transportation and industrial applications, which may be produced from
21 electrolysis or from natural gas with CCS depending on scenario....

22 The need for new generation capacity would be even higher without the energy
23 efficiency and demand-side flexibility measures assumed in the ADE trajectory.
24 Results from the LTS sensitivity cases result in a 16%–20% reduction in the need
25 for new installed capacity compared to the ADE cases due, in part, to the higher
26 levels of energy efficiency assumed in LTS.⁷⁶

27 The role of demand-side policy is clear. Moreover, the “transformation dividend” that I
28 discuss above is 17%, in the middle of the impact observed by NREL.

⁷⁶ Denholm, et al., 2022, p. ix... xi.

1 A second observation is the importance of strengthening the infrastructure, which here
2 means transmission. As NREL put it, “**Infrastructure Renaissance** assumes improved
3 transmission technologies as well as new permitting and siting approaches that allow greater
4 levels of transmission deployment with higher capacity.”⁷⁷

5 The third message, similar to the earlier NREL analysis, is that low-cost renewable
6 supply is important.

7 Fourth, high-cost supply or no carbon capture drive up the cost dramatically; gas with
8 carbon capture is the least cost disputable low carbon resource.

9 Trying to achieve 100% clean energy under the constrained scenario is extremely
10 expensive and, in its reliance on a huge decrease in nuclear cost and increase in the nuclear fleet,
11 very unlikely.

12 Thus, the policy strategies that can keep the transformation affordable are reduced
13 demand, an infrastructural renaissance, low-cost renewables and carbon capture.

14 **B. EXTRACTING ADVICE FROM OTHER EVALUATIONS OF DEEP DECARBONIZATION** 15 **SCENARIOS**

16 **Q. Are there other studies that take this “positive” view of how to develop a zero-carbon** 17 **future?**

18 **A.** There are many such studies that identify the challenges, but lay out scenarios that move
19 toward a low-cost, low carbon future based on the elements I have discussed. The technologies
20 are visible, if not in hand, efficiency, renewables, storage. The challenge is scaling up the
21 distributed technologies, building the physical (transmission) and institutional (regulation and
22 other structures) that support the low-cost technology and ensure the appropriate behaviors by
23 companies and the public.

24 The results of the National Academy of Sciences workshop, which put over half a dozen
25 studies into the record, summarized much of the research. The interesting thing is the policy
26 recommendations that the committee offered. Attachment MNC-5.6, lists the issues that the
27 Committee felt were urgent. The attachment includes only the measures that are of the “highest
28 priority and indispensable” to achieve the objective policies. It puts them in two categories,

⁷⁷ Id., p. vii.

technology development and socioeconomic. The description of the policies is particularly revealing:

Technological Goals:

Invest in energy efficiency and productivity. Examples include **accelerating the rate of increase of industrial energy productivity (dollars of economic output per energy consumed) from the historic 1% per year to 3% per year.** **Electrify energy services in transportation, buildings, and industry.** Examples include, by 2030, moving half of vehicle sales (all classes combined) to EVs, and deploying heat pumps in one-quarter of residences. Produce carbon-free electricity. **Roughly double the share of electricity generated by carbon-free sources from 37% to 75%.** Plan, permit, and build critical infrastructure. **Build critical infrastructure needed for the transition to net zero, including new transmission lines, an EV charging station network, and a CO₂ pipeline network.** Expand the innovation toolkit. Triple federal support for net-zero RD&D.

Socioeconomic Goals:

Strengthen the U.S. economy. Use the energy transition to accelerate U.S. innovation, reestablish U.S. manufacturing, increase the nation's global economic competitiveness, and increase the availability of high-quality jobs. Promote equity and inclusion. **Ensure equitable distribution of benefits, risks, and costs of the transition to net zero.** Integrate historically marginalized groups into decision making by ensuring adherence to best-practice public participation laws. Require that entities receiving public funds report on leadership diversity to ensure nondiscrimination. **Support communities, businesses, and workers.** Ensure **support for those directly and adversely affected by the transition. Maximize the cost-effectiveness of the transition to net zero.**⁷⁸

Arguably, the things the NAS identifies as policy goals in need of urgent attention covers the same terrain as the NREL study, efficiency, infrastructure (transmission, EV charging stations, pipelines for CO₂, capture, federal RD&D in support of a dramatic increase in low carbon electricity, and macroeconomic benefits. The one issue that the NAS includes that has not been noted heretofore is the equity concerns. These include in general non-discrimination and the incorporation of “historically marginalized groups” and support for the communities, businesses and workers adversely affected by the affected by the transition. The equity concerns

⁷⁸ National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press, pp. 7-10.

1 weigh heavily on the NAS recommendations. They recommend a carbon tax that is well below
2 what it deemed necessary for equity reasons.⁷⁹

3 Attachment MNC-5.7 identifies these concerns in policy statements and studies of the
4 groups representing these interests. These concerns are generally met with a call for greater
5 transparency, consultation with affected communities and participation in decision making.

6 However, throughout the analysis, whenever strategies are laid out, the NAS falls into the
7 “all of the above” camp. They identify low-cost renewables but then say “firm” low carbon
8 resources should also be relied on (or at least researched) from a list that includes, “hydropower,
9 energy storage, bioenergy, geothermal, nuclear energy, and carbon capture and sequestration are
10 available to compensate for the intermittency of wind and solar electricity.”⁸⁰ Accompanying
11 this text is a graph from Lazard’s version 14.0 of levelized costs (2020). The costs included in
12 this graph involves only the major sources and it contradicts a policy that endeavors to
13 “Maximize the cost-effectiveness of the transition to net zero” because the cost of nuclear is an
14 order of magnitude higher than the alternatives. In an analysis a year earlier, nuclear was over
15 \$90 per ton of carbon more costly than wind or solar PV.⁸¹

16 As shown in Attachment MNC-5.8, based on various Lazard estimates across time, the
17 weakness of the “all of the above” approach is even more evident, not because nuclear is more
18 expensive but because so many options have become more attractive. Aging reactor were 4th of
19 7 in the 2020 list, with my addition of aging reactors. New reactors were 6th of 7. Today, using
20 the midpoint of the high and low estimate on Lazard’s 2022 list plus my addition of aging
21 reactors and my treatment of small and large reactors, the aging reactors are 8th of 18. For the

⁷⁹ Id., p. 12, Also, because the direct impacts of an economy-wide price on carbon would fall disproportionately on people with the lowest incomes and the fewest choices, it should be augmented by rebates and by funding programs that promote a fair and just transition. The proposed carbon price is deliberately set at a level that would not by itself cause a 30-year transition to net zero because of concerns about equity, fairness, and competitiveness. For example, the committee was not confident that it could design a package of policies that would address competitiveness and mitigate unfair impacts of a carbon price that starts at or climbs rapidly to \$100/tCO₂. In addition, the committee calls for the establishment of entities within the federal government to bring equitable access to economic opportunities and wealth creation during the energy transition. These policies are designed to help achieve diversity and fairness goals and to support workers, families, and communities through the transition.

⁸⁰ Id., p. 41.

⁸¹ Lazard, v. 13.0.

1 new builds, which is the long-term view, new reactors were 13th or 14th among 18, depending on
2 whether they are large or small. The expansion of the options in the middle – quasi-firm power
3 from hybrid systems, geothermal, biomass, as well as efficiency, and even gas with carbon
4 capture, which are competitive with aging reactors, and certainly SMRs – is the key
5 technological change that must be recognized by policymakers.

6 That is exactly the point. The “constrained” scenario of NREL and the “all of the above”
7 approach of the NAS, must assume that everything else fails, efficiency, wind, solar, hybrids,
8 storage, and carbon capture. That is highly unlikely. More importantly for feasibility evaluation
9 of low carbon resources, some of the things that nuclear needs, like must run status, inflexible
10 demand, macro, rather than micro- and nano-grid transmission, are antithetical to the
11 alternatives.

12 Interestingly, the NAS time frame for the “all of the above” approach is quite short
13 (roughly a decade), ending in 2030, a period in which very little nuclear capacity has been or will
14 be added. Thus, given the history, the most likely “fail” is not the alternatives, but nuclear
15 power.

16 **Q. Are there other approaches that reinforce your conclusions?**

17 **A.** Yes, a particularly interesting approach claims that studies which look at potential
18 scenarios miss the issue of what is feasible to accomplish. Brutshin, et al.⁸² examines four
19 dimensions of feasibility, technological, economic, sociocultural and institutional (see
20 Attachment MNC-5.9).

21 Long-term mitigation scenarios developed by integrated assessment models
22 underpin major aspects of recent IPCC reports and have been critical to identify
23 the system transformations that are required to meet stringent climate goals.
24 However, they have been criticized for proposing pathways that may prove
25 challenging to implement in the real world and for failing to capture the social and
26 institutional challenges of the transition. There is a growing interest to assess the
27 feasibility of these scenarios, but past research has mostly focused on theoretical
28 considerations. This paper proposes a novel and versatile multidimensional
29 framework that allows evaluating and comparing decarbonization pathways by
30 systematically quantifying feasibility concerns across geophysical, technological,

⁸² Brutshin, Elina, et al., 2021, “A multidimensional feasibility evaluation of low- carbon scenarios,” Environmental Research Letter, June,

1 economic, socio-cultural and institutional dimensions. This framework enables to
2 assess the timing, disruptiveness and scale of feasibility concerns, and to identify
3 trade-offs across different feasibility dimensions.⁸³

4 As shown in MNC-5.9, in the upper graph the largest concern is the institutional
5 structure, which is defined by the Governance structure. The middle graph lists the elements of
6 the framework. The lower graph shows the constituent parts of each element and the “cut points
7 used to define the feasibility score.

8 The authors build a summary governance index based on the average of the 6 World
9 Bank Worldwide Governance Indicators, which are estimations of how effective the government
10 will be in enforcing decarbonization policies. “[W]e find a strong positive correlation between
11 governance levels and environmental performance, with countries with higher governance
12 capacity being among the top environmental performers.⁸⁴ The governance score is cross
13 tabulated by an environmental performance score.

14 The second most important source of concern is the economic impact of deep
15 decarbonization policy. GDP is the first indicator, followed by a price on carbon, the investment
16 ratio and the stranding of coal assets (and jobs). These are similar to the issues I raised in
17 Chapter 4, with one exception. I have not mentioned a cost on carbon, although I have noted the
18 analysis of the value of carbon reduction, which was given a monetary value.

19 I do not consider a price on carbon because I have long argued that the most important
20 policy measures are those that will further the alternatives, in a direct way.⁸⁵ While this has been
21 a great debate in the decarbonization literature I have taken the view that “complementary”
22 policies to further the construction of a 21st century system take precedence. I quote at length
23 from authors who take the view of “transitions theory” in economics⁸⁶ because the authors raise
24 all of the issues and concerns, I have raised.

25 Our work, and the work of a growing number of other energy system scholars,
26 suggests that carbon prices do not directly address the critical challenges of a
27 transition to an energy system completely free of fossil fuels and their associated
28 CO2 emissions. The policy instruments that are more likely to be effective are

⁸³ Id., p. 1.

⁸⁴ Id., Supplemental Materials, p.

⁸⁵ Patt, Anthony and Johan Lilliestam, 2018, “The Case against Carbon Prices,” 2018, *Joule* 2, December,

⁸⁶ Id., p, 2095.

1 those that directly support the diffusion of a limited set of technologies needed to
2 replace fossil fuels, in some cases through initial financial support, and
3 increasingly through institutional and infrastructural changes...
4

5 The first barrier, for still immature technologies, is typically cost. This is the same
6 barrier that carbon prices address... The reason lies in industry dynamics. It takes
7 time to scale up supply chains for new technologies, typically involving new
8 market entrants with limited financial reserves, meaning that the deployment of
9 capital stock starts slowly and then grows. Meanwhile the price differential
10 between old high-carbon technologies and new low-carbon ones starts large and
11 then shrinks.
12

13 The second barrier is a mismatch between the new technology and the existing
14 infrastructure. For example, it has been possible to generate small amounts of
15 fluctuating PV and wind power without threatening the stability of power
16 transmission and distribution grids... it is becoming apparent that major elements
17 of the grid, from [transformer stations](#) to long-distance transmission lines, will
18 need to be upgraded or replaced. We will also need new infrastructures, such as
19 large-scale electricity storage. Unless we adapt the infrastructure, the problems
20 will only grow. Infrastructure development takes coordinated planning and
21 development based on long-term strategic priorities, and this is not something that
22 carbon prices directly address.
23

24 The third barrier is institutional. One example is to be found in the rules
25 determining wholesale power prices... Under current power market designs,
26 growing shares of wind power and PV have pushed down wholesale power prices,
27 in some cases well below zero, precisely during their times of peak production.
28 This reduces profits for fossil generation, but even more so for wind and solar
29 themselves. Carbon prices do not directly address this problem, whereas market
30 reforms can...
31

32 Simply put, carbon prices are outdated. They made sense as our primary
33 tool against climate change when our climate policy ambitions were limited, and
34 the greatest barrier was cost. Today our ambition is to eliminate CO₂ emissions
35 entirely, and the greatest barriers are associated with infrastructure and
36 institutions. The barrier to technological change that carbon prices address, the
37 higher cost of renewable energy, is ceasing to be relevant. Where such costs are
38 still relevant, technology support instruments are more effective. We do have a
39 window of opportunity to stop climate change within a range of safety, and
40 therefore need to use that time to develop and implement policies that actually
41 make a difference.⁸⁷
42

⁸⁷ Id., pp. 2495... 2496... 2497... 2498.

1 In short, as I have shown, we have had the technological cost revolution. We now need
2 the physical (infrastructural) and institutional (regulation) to achieve the goal.

3 **Q. Does feasibility study also consider scenarios?**

4 **A.** Yes, the paper applies the feasibility methodology to a small number from the
5 IPCC assessment (see Attachment MNC-5.10).⁸⁸ It yields important insight consistent with my
6 policy recommendations. As shown in Attachment MNC-5.10, governance matters most when it
7 can deliver low demand. Governance that delivers high energy intensity is a much greater
8 concern. Demand reduction is the key, but concern depends on institutional arrangements.

9 **Q. Are there also studies of many scenarios?**

10 **A.** Yes, Jenkins has reviewed 40 such studies.⁸⁹ While I draw important insights from his
11 very general conclusions, I show below that his recommendations for policy makers leave a lot
12 to be desired.

13 Renewable resources, supported by storage, demand flexibility and expanded
14 transmission are the obvious first step. These will need policy to expand storage, transmission,
15 and demand flexibility.⁹⁰ The initial approach is likely to fall short of the 100% decarbonization
16 scenario so a second set of low carbon resources may be needed, which requires decarbonization
17 with firm resources. These include carbon capture geothermal, biomass, and nuclear,⁹¹ but one
18 important objective is to keep costs down. This is a major concern of the authors with “outsized”
19 importance:

20 At the same time, costly routes to decarbonization that substantially increase the
21 price of electricity would make low-carbon electricity a less attractive substitute

⁸⁸ Bruthsin, Elina, et al., 2021., and Supplemental Materials.

⁸⁹ Jenkins, Jesse, D., Et al., 2018, “Getting to Zero Carbon Emissions,” *Joule* 2, December 2.

⁹⁰ Id., pp. 2498-2499, The studies collectively outline two overall paths to decarbonize electricity. [One path] that relies primarily (or even entirely) on variable renewable energy sources (chiefly wind and solar power) renewable energy sources, chiefly wind and solar power supported by energy storage, greater flexibility from electricity demand, and continent-scale expansion of transmission grids; and a second path that relies on a wider range of low-carbon resources including wind and solar as well as “firm” resources such as nuclear, geothermal, biomass, and fossil fuels with carbon capture and storage.

⁹¹ Id., p.2506. [W]e find strong agreement in the literature that reaching near-zero emissions is much more challenging—and requires a different set of low-carbon resources... This is chiefly because more modest goals can readily employ natural gas-fired power plants as firm resources.

1 for oil, natural gas, and coal in transportation, heating, and industry. Finding
2 feasible and affordable routes to decarbonize the power sector thus takes on
3 outsized importance in global climate mitigation efforts.⁹²

4 Given historic trends and current estimates, I view nuclear power as the primary culprit in
5 increasing the price of electricity. Attachment MNC-5.11 is derived from the article by Jenkins'
6 that lists 40 studies that evaluate models of a zero-carbon system. His big table identifies three
7 key policies that support the alternatives, long duration storage, transmission and flexible
8 demand. The partial references (between 0 & 1, between 1 & 2 and between 2 & 3) represent
9 instances in which some consideration, but not full, was given to one or more factors. There is a
10 high correlation ($r = \sim .8$) between inclusion of these three policies and the absence of nuclear
11 power. Nuclear drops from 100% inclusion in the 30% of studies that included none of the
12 factors to 20% in the 50% of studies that included more than two of the factors.

13 In a sense, the studies of the U.S. are even more extreme. Although the correlation
14 coefficient is of roughly the same magnitude, any study that does not include all of the three
15 policies that support the alternatives, includes consideration of nuclear. The specific magnitude
16 and make-up of the supply mix is not given, but the overall message is the same. Including all
17 the necessary policies to support alternatives makes it much more likely that expensive nuclear
18 power can be avoided. Ignoring these alternatives, nuclear becomes “necessary.”

19 Jenkins argues strongly for an “all of the above” strategy, but his discussion highlights
20 the weakness of a simplistic “probability” approach. He states it is only a hypothetical and he is
21 careful to point out the challenges facing all of the alternatives. He divides them into two
22 groups. One group is composed of low-carbon intermittent resources – “grid expansion, flexible
23 demand, very low [renewables] wind and solar, and seasonal storage.”⁹³ The other group is
24 composed of low carbon “firm” resources – “nuclear power, Carbon Capture and Storage,
25 bioenergy and enhanced geothermal, each have the ability to fill the role in a low-cost, low-
26 carbon portfolio. As shown in Attachment 5.12, Jenkins, et al., provide a detailed road map to
27 the challenges facing deep-decarbonization in these early studies.

28 His use of information about the current environment is to assume a 1-in-6 chance that
29 the technologies in the first group will fail, while there is a 1-in-2 chance that the technologies in

⁹² Id., p. 2506.

⁹³ Id., p. 2509.

1 the second group will succeed.⁹⁴ He then calculates the joint probability of reaching the goal,
2 given the rate of failure. The probability that all of the first group will succeed is described as
3 like “rolling a dice and not coming up with 1.” The likelihood of success is just over 50% [$1 -$
4 $(.833)^4 = 1 - .48 = .52$]. He flips the betting around for the second group calculating “the odds
5 that at least one succeeds is 94% [$1 - (.5)^4 = .94$]. Pursuing both groups “would raise the chance
6 of success of at least one affordable pathway to decarbonize electricity to 97% [$.52 + (.94 * .48) =$
7 $.97$]

8 Jenkins is aware of the importance of price and prudence. “Obstacles remain along any
9 path to zero-carbon... It is therefore vitally important the decision makers identify and pursue
10 prudent strategies to improve the odds of feasible and cost effective decarbonization.” In
11 advocating for keeping the second groups on the table since it “may fill the critical niche for
12 firm, low-carbon power should other technologies falter.” He stresses however, that it must be
13 “low-carbon, affordable and scalable, within the next two decades.” The advantages of the low
14 capital cost, high variable cost approach, even among the firm low-carbon resources, is
15 acknowledge in the context of high reliance on variable source from the first groups. These are
16 “economically better suited to pair with high wind and solar shares.”

17 Aside from creating the two baskets of technologies to apply different probabilities,
18 which indirectly reflects the amount and structure of costs, little use is made of information about
19 current costs, variability and cost projections. These are primary concerns in determining
20 prudence and least cost that are the focal point of regulatory review. What happens to the
21 probabilities if we exclude one technology from the second group (i.e., nuclear)? There is good
22 reason to do so.

23 To summarize the concept, we accept the popular proposition – “Don’t put all your eggs
24 in one basket” –which is certainly good advice, which we follow, by having three eggs in the
25 second basket, not four. The reason to exclude nuclear is also summed up in a popular
26 proposition – “One bad apple spoils the bunch” – which is also good advice. The science is that a
27 bad apple emits gases that spread the decay to good apples. In the case of energy policy, one
28 technology may crowd out other technologies, especially when they have a century of advantage
29 built into their existence, when they require rules (must run status) that are antithetical to the

⁹⁴ Id., p. 2509.

logic of the core resources), and they are extremely expensive to boot (violating the prudence/least cost) standard.

What happens to the probability of success if we exclude nuclear. The probability of success declines, but only slightly ($1 - (.5^3) = .875$). The probability of overall success also declines, but very slightly. Instead of 97% chance of success, we find a 94% ($.52 + (.875 \times .48) = .94$).

What is the “benefit” of accepting this small increase in overall risk. One way to estimate it is the costs of each technology. Ironically, EIA did not estimate future costs of two of the second group (advanced nuclear, and biomass) because no examples of construction existed (ignoring Vogtle and the struggles of Nuscale). The estimates of costs we have used for the other two (gasw/CCS and geothermal) average about \$85/MWH. In contrast, we have estimated the costs nuclear at \$120/MWH for SMRs and \$150/MWH for large reactors.

In attachment MNC-5.12, I consider different levels for the group 1 technologies, which is then used to adjust the bill impact of relying on group 2. In the 60% scenario, I assume group 2 accounts for 40% of the market. In the 80% scenario, I assume group 2 accounts for 20% of the market. The two levels are mentioned in the analysis as the “highest” level that the group 1 technologies could achieve without sharp increases in cost. The assumed cost of group 1 in the base case is cautious and I assume a higher cost for the higher penetration of group 1. Under these assumptions there are substantial cost savings by following the estimated cost. There is a significant cost advantage enjoyed by a group 2 low-cost approaches (CCS and geothermal) and additional advantages to reliance on group one, the core renewables and the supporting technologies. Given the base case costs, the savings are at least 10% of the final bill and as much as 20%, in the low-penetration scenario for group 1.

More importantly, the message for policymakers who are concerned about prudent, least cost achievement of deep decarbonization is clear in light of the analysis in this section. They should seek to ensure maximum contribution of the core renewables (wind, solar and storage) and efficiency. To do so, they should address institutional arrangements, above all, followed by economic issues. The objective of reduced and controlled demand is paramount.

1 Efficiency is not only an extremely valuable resource, but it also lowers overall volatility
2 and risk,⁹⁵ and its potential is very large. This potential spills over into the benefit of demand
3 response to meet challenges to reliability.

4 Moreover, by improving the reliability of the power system and, in the long term,
5 lowering peak demand, DR reduces overall plant and capital cost investments and
6 postpones the need for network upgrades. In this paper a survey of DR potentials
7 and benefits in smart grids is presented. Innovative enabling technologies and
8 systems, such as smart meters, energy controllers, communication systems,
9 decisive to facilitate the coordination of efficiency and DR in a smart grid.⁹⁶

10
11 At the same time, it is important to recognize the future role of storage. While wind and
12 solar technologies have gone through a long period (at least a decade) of declining costs that
13 have reached very low levels, the cost of storage is much earlier in that process and promises to
14 deliver ongoing decreases in the cost of and increases in the value of hybrid systems of a similar
15 process. New technologies hold great promise, and some, like pumped storage may support
16 substitution of renewables for solar, as shown in Attachment MNC-5-14.

17 If the ability to reach the ultimate goal with these resources is doubtful, based on
18 unfolding experience, they should devote their attention to the lower cost options in group two.
19 The worst outcome would be if they are forced to rely on high-cost group 2 resources. Thus, the
20 early days should be devoted to ensuring that policy get the most out of (is most supportive of)
21 the group 1 resources. Given that the development of resources takes time, a critical question
22 becomes how and when to declare that policy must resort to high-cost resources. Given that the
23 current supply-demand mix is far short of the suggested limit and the system is far from fully
24 transformed, these core resources should command policy attention. The ultimate problem is
25 very much a problem with “new builds,” in the long term. Therefore, current, aging reactors
26 should not be the target of public policy and nuclear power should be the last resource
27 considered, commanding the smallest share of public resources, only if all else fails.

28 C. CONCLUSION

⁹⁵ Brendon Baatz, James Barrett, and Brian Stickles, 2018, *Estimating the Value of Energy Efficiency to Reduce Wholesale Energy Price Volatility*, ACEEE, April, Report U1803, PP. 20-21, In long-term resource planning, utilities and others must consider the risks associated both with normal price fluctuations and with occasional extreme events like the polar vortex.... Having a correct perception of these risks is critical to effective planning. In the creation of a plan that manages these risks and the costs of hedging against them, energy efficiency can play a role that has largely gone unrecognized so far. By offering electricity services at fixed and low prices, efficiency can reduce the amount of electricity that needs to be purchased when electricity prices are high, thus lowering overall system risk. To the extent that utilities, regulators, and other planners recognize this characteristic of efficiency, its overall value should increase in planning processes, and more efficiency resources should be deployed.

⁹⁶ Siano, Pierluigi, 2014, “Demand Response and Smart Grids —A survey,” *Renewable and Sustainable Energy Reviews* 30.

1 As with the earlier chapters, although the earlier discussion and Attachments have shown
2 the relevance of the analysis to California, we conclude with observations that link the discussion
3 directly to California.

4 First, we note a study by the University of California which identified a path to deep
5 decarbonization.⁹⁷ Bending the curve, which is a California policy analysis never mentions
6 nuclear power. In contrast, four of its “10 Scalable Solutions” mention the primary resources I
7 have emphasized – solar, wind, battery, and efficiency (solutions 6, 7, 8, 9). Three of the
8 solutions involve institutional goals (culture 2, 3) and governance models (4). Two involve
9 economic structures (markets 5, regulation 6), along the lines I have discussed. One involves
10 natural systems (e.g. deforestation, 10). Arguably, one might argue that nuclear power could fit
11 under one solution, (maximize use of available technologies, 9), but the example given is a small
12 scale technology, not a primary concern for California, “access to clean cooking for the poorest 3
13 billion people who spend hours each day collecting solid biomass fuels and burning them indoor
14 for cooking.”

15 The full list of technologies mentioned for encouragement and innovation that apply to
16 California never mentions nuclear, but 14 other technologies, including those listed in
17 Attachment MNC-5.15. These technologies and supporting policies are the core of my
18 recommendation for the development of a 21st century electricity system.

19 Second, the dramatic change in storage costs, which we have seen chapters 3 and 4, can
20 also be seen in California data, as shown in Attachment MNC-5.16. The upper graph is from the
21 Lazard analysis and it examines both in-front-of-the-meter and behind-the-meter cases. In all
22 cases, CAISO is very attractive in terms of the return to investors. In the upper graph, the behind
23 the meter cases, for commercial and industrial storage are much lower in cost, In the hybrid case,
24 the California case is extremely attractive. This is confirmed in the lower graph which looks at
25 the incremental value of community rooftop solar. The value stack for PG&E is about
26 \$58/MWH. This confirms two of my earlier observations. First, since other forms of renewables
27 with storage have lower costs, they are likely to have much higher values. Second, it is

⁹⁷ University of California, 2015, *Bending the Curve Executive Summary: Ten scalable solutions for carbon neutrality and climate stability*, October 27.

important to not jump to conclusion about behind-the-meter costs; all of the potential system costs and benefits should be considered.

1 **6. ASSESSING AND (MIS)REPRESENTING RELIABILITY**

2 **A. THE INDEPENDENT SYSTEM OPERATOR**

3 **Q. Is there other evidence that these approaches can work?**

4 **A.** Yes, the performance of the Independent System Operators recently confronted with very
5 demanding supply-demand events is encouraging. They recognize the challenge but have
6 applied recent experience to navigate through them and they identify additional steps to support
7 effective performance.

8 The most relevant is the CAISO report on what worked and needs to be improved in the
9 management of the grid. Attachment MNC-6.1 shows the adaptation based on past challenges
10 and the areas for continued improvement. These are exactly what the PUC proceeding,
11 discussed in Chapter 4, identified several years ago – increasing supply, storage, demand
12 response under the control of the ISO and voluntary, coordination with utility and other levels of
13 government, etc. There was similar performance under stress in other ISOs, like MISO.
14 Moreover, while CAISO is a summer peaking area, MISO suffered a winter peak. The
15 challenge was the summer of 2022 in CAISO and the Winter of 2022 in MISO.

16 The CEC “Diablo Canyon Power Plant: Final Draft analysis of Need to support
17 Reliability” is a perfect example of speculative analysis done for the purpose of convincing its
18 target, in this case the California Public Utility Commission (CPUC) to buy ill-advised,
19 expensive insurance, even though it fails to note the cost of the insurance and the analysis is, in a
20 sense, disavowed:

21 **DISCLAIMER**

22 Staff members of the California Energy Commission (CEC) prepared this report.
23 As such, it does not necessarily represent the views of the CEC, its employees, or
24 the state of California. The CEC, the State of California, its employees,
25 contractors, and subcontractors make no warrant, express or implied, and assume
26 no legal liability for the information in this report; nor does any party represent
27 that the uses of this information will not infringe upon privately owned rights.
28 This report has not been approved or disapproved by the CEC nor have they
29 passed upon the accuracy or adequacy of the information in this report.⁹⁸

⁹⁸ Implementing Senate Bill 846 Concerning Potential Extension of Diablo Canyon Power Plant Operations, Rulemaking 23-01-007, April 20.

1 There is good reason for this disclaimer. The policy recommended is like trying to kill a
2 gnat with a baseball bat. The analysis does not consider the cost of the policy. It takes no notice
3 of the damage it would do trying to kill the gnat (putting holes in the wall), or even if it
4 successfully killed it.

5 Given that it accepts the proposition that there is not likely to be a resource shortfall
6 during the period of the subsidy,⁹⁹ but it warns that two years later there could be a shortfall,
7 one cannot help but suspect that the hidden agenda is to keep PG&E's nuclear power online
8 until after the subsidy expires. Under the assumptions used in the analysis, one cannot help but
9 suspect that the CEC will come back and claim that more bad insurance is needed, *ad infinitum*.
10 The hidden agenda may well be to keep nuclear power in the mix for a much longer period of
11 time.

12 The CEC report notes that based on a 20-year record the confluence of events represents
13 a 1-in-14 chance. While it is not as great as the planning probability of a 1-in-10-year chance,
14 the CEC report argues that the probability of the confluence of events in the thirty-year period
15 was only 1-in-27, so 1-in-10 may be too close for comfort, even though it was sufficient. It
16 never says what the alternative should be, but a little arithmetic says the planning horizon should
17 be prepared for 1-in-5 contingencies [$((14)/(27))*10=5.2$]. Whether or not that is the right
18 number, is unclear, but underlying analysis fails to recognize the steps taken by the CAISO to
19 deal with the challenge.

20 In the analysis, the CEC notes that "On February 23,2023, the CPUC ordered load
21 serving entities to procure an additional 4,000 MW of net qualifying capacity, 2,00 MW in 2026
22 and additional 2,000 in 2027." However, "this additional procurement was not included in the
23 analysis."¹⁰⁰ Including these two additions eliminate any shortfall in the analysis until 2032,
24 which is well beyond the detailed discussion offered in the report.¹⁰¹ The CEC also delays 2000
25 mw of 8-hr storage or geothermal by 2 years.

⁹⁹ Id., Attachment E: Diablo Canyon Power Plant Extension Final Draft CEC Analysis of Need to Support Reliability SB 846 only requires consideration of 2024 through 2030, the CEC included the analysis developed for the Joint Agency Reliability Planning Assessment, which covered 2023 through 2032. The analysis shows that under the current resource adequacy planning standard, the CPUC's procurement orders, Decision (D) 19-11-016 and D.21-06-035, are sufficient to eliminate shortfalls through 2030, (p.3).

¹⁰⁰ Id., p. 24.

¹⁰¹ Id., p. 23.

1 These are not the only ways in which the CEC analysis underestimates resources. It
2 assumes that the deployment of alternatives hits the wall in 2024. It explains this as a function of
3 the challenges that the alternatives face.

4 Development is being impacted by [1] supply chain issues, particularly for solar
5 and storage, and [2] interconnection and [3] permitting delays resulting from the
6 large number of projects coming on-line that require safety and environmental
7 reviews. [4] Climate change is impacting grid reliability by causing more frequent
8 extreme events beyond what current planning standards account for, such as
9 record-setting heat, droughts, and wildfires that can impact transmission.¹⁰²

10 These issues are mentioned at least two dozen times in just 31 pages. Ironically, two of
11 the four challenges are within the power of the PUC and CAISO to address to some extent.
12 Regulatory integration and approval of projects can be accelerated, something on which
13 regulators are working. The climate change issue is beyond their control, but it is driving their
14 responsive actions. The supply chain problems triggered by the COVID pandemic may be fading
15 like the pandemic. Although it is difficult to predict how successful the regulators will be, or
16 how big the supply chain problem will continue to be, 2022 stands as an example of how tight
17 conditions can be dealt with.

18 As shown in MNC-6.2, even assuming a flat DR performance, there is no shortfall if the
19 historic pattern of growth holds. DR fills the gap in 2024 and supply growth fills it in 2025.
20 Moreover, as described in the CAISO report of 2022, there are several other sources of power
21 available that would more than fill the gap. Attachment MNC-6.2 also shows, cumulatively,
22 77% of the Diablo Canyon capacity is excess. Even looking at individual years it is surplus. In
23 three of the five years for which we have analysis, there is no shortfall. Looking at year-to-year
24 shortfalls, about 70% of the capacity is surplus. Put another way, The excess capacity of Diablo
25 Canyon is 3.5 time the capacity that is needed under these assumptions. Looking at what the
26 CEC has assumed about the performance of the system without efforts by the CAISO to do its
27 job, one can argue that the strategy of subsidizing Diablo Canyon is, in fact, to crowd out
28 alternatives for half a decade. This analysis looks very much like nuclear blackmail, intended to
29 convince policymakers to buy bad insurance.

¹⁰² Id., p. 4.

1 In the next section I examine the regulatory response to a clear case of such blackmails,
2 Exelon Illinois.

3 **B. BASELOAD BIAS, UTILITY SCALE FETISH, & SHORT-RUN MYOPIA IN NUCLEAR LICENSE**
4 **RENEWAL:**

5 The flashpoint of the conflict over the transformation of the electricity sector was
6 discussed in chapter 4, as the “merit order effect: in which¹⁰³—wind backs inefficient natural gas

¹⁰³ 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: Bob Fagan et al. The Potential Rate Effects of Wind Energy and Transmission in the Midwest ISO Region, Synapse Energy Economics, Inc., May 22, 2012; Richard W. Caperton, Wind Power Helps to Lower Electricity Prices, Center for American Progress, October 10, 2012; Charles River Associates, Analysis of the Impact of Cape Wind on New England Energy Prices, Charles River Associates, February 8, 2010; Canada: Mourad Ben Amor et al., “Influence of Wind Power on Hourly Electricity Prices and GHG (greenhouse gas) Emissions: Evidence that Congestion Matters from Ontario Zonal Data,” Energy 66 (2014); Australia: Dylan McConnell et al., “Retrospective Modeling of the Merit-Order Effect on Wholesale Electricity Prices from Distributed Photovoltaic Generation in the Australian National Electricity Market,” Energy Policy 58 (2013); Iain MacGill, The Impact of Wind on Electricity Prices in the Australian National Electricity Market, Centre for Energy and Environmental Markets, June 2013; Melbourne Energy Institute, The Impact of Distributed Solar Generation on the Wholesale Electricity Market, June 2013; Ireland: Amy Mahoney and Eleanor Denny, The Merit Order Effect of Wind Generation in The Irish Electricity Market, Department of Economics, Trinity College, Dublin, 2011; Denmark: Jesper Munksgaard and Poul Erik Morthorst, “Wind Power in the Danish Liberalized Power Market—Policy Measures, Price Impact and Investor Incentives,” Energy Policy 36 (2008): 3940–3947; Germany: Frank Sensfuss, Mario Ragwitz, and Massimo Genoese, “The Merit-Order Effect: A Detailed Analysis of the Price Effect of Renewable Electricity Generation on Spot Market Prices in Germany,” Energy Policy 36 (2008): 3086–3094; Italy: Stefano Clò, Alessandra Cataldi, and Pietro Zoppoli, “The Merit-Order Effect in the Italian Power Market: The Impact of Solar and Wind Generation on National Wholesale Electricity Prices,” Energy Policy 77 (2015); Spain: Gonzalo Sáenz de Miera, Pablo del Río González, and Ignacio Vizcaíno, “Analysing the Impact of Renewable Electricity Support Schemes on Power Prices: The Case of Wind Electricity in Spain,” Energy Policy 36 (2008); United Kingdom: Richard Green and Nicholas Vasilakos, “The Economics of Offshore Wind,” Energy Policy 39 (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., “Mitigating Climate Change”; Paul Twomey and Karsten Neuhoff, “Wind Power and Market Power in Competitive Markets,” Energy Policy 38 (2010); Franz Wirl, “Taxes Versus Permits as Incentive for the Intertemporal Supply of a Clean Technology by a Monopoly,” Resource and Energy Economics 36 (2014); Bruce Mountain, Market Power and Generation from

1 (and some coal) plants out of the supply needed to clear the market at the peak. This lowers the
2 market clearing price, which results in substantial consumer savings. The downward pressure on
3 market clearing prices has led to a several years of losses for the aging nuclear reactors.

4 Operating costs alone are almost twice the current market clearing price of electricity and things
5 are likely to get worse over time. These reactors cost more to run than the alternatives, so they
6 cannot cover their operating costs or make any contribution to ongoing capital costs that are
7 necessary to keep them online. In the near term, numerous aging reactors are predicted to lose
8 millions of dollars per year, although the amount of the losses will vary from market to market.

9 Thus, coal, natural gas, and subsidies are not the ones giving aging nuclear reactors
10 heartburn, but rather it is the superior economics of wind (solar in California) and efficiency
11 combined with the increasing operating costs of aging nuclear reactors themselves. It is
12 important to recall that both the Lazard and Jacobson cost projections were estimated as subsidy-
13 free costs. The “merit order” predicament in which nuclear power finds itself is deeply ironic.
14 Historically, nuclear power presented itself as a low-cost option by emphasizing its low
15 operating costs, downplaying its very high initial fixed capital costs, and glossing over ongoing
16 capital costs to keep them online. Two decades of technological innovation in renewables, and
17 the aging of extremely complex nuclear facilities, has put an end to that sleight of hand.

18 Utilities in New York,¹⁰⁴ Illinois,¹⁰⁵ and Ohio¹⁰⁶ asked for above-market prices for six
19 reactors. These reactors have lost hundreds of millions of dollars over the last couple of years,
20 but the utilities claim that the low price of gas is the cause of the problem. This is incorrect in
21 three respects. First, the rising cost of operating reactors accounts for about a third of the
22 problem. Second, the addition of wind, which backs inefficient gas out of the market clearing
23 price, contributes to the shift. Third, demand has declined due to increased efficiency. The price
24 of gas matters as well, but less than the other three factors. Two-thirds of the revenue shortfall

Renewables: The Case of Wind in the South Australian Electricity Market Australian
Economic Report: No. 2, Centre for Strategic Economic Studies Victoria University,
Melbourne, June 2012.

¹⁰⁴ Malik and Polson, “New York Reactors”; William Opalka,” New York Adopts Clean Energy
Standard, Nuclear Subsidy,” *RTOinsider*, August 1, 2016; William Opalka,” CES Under
Attack on Multiple Fronts in Rehearing Requests,” *RTOinside*, September 5, 2016

¹⁰⁵ Illinois Commerce Commission et al., *Response*.

¹⁰⁶ Tom Sanzillo and Cathy Kunkel, *First Energy: A Major Utility Seeks a Subsidized
Turnaround*, Institute for Energy Economics and Financial Analysis, October 2014.

1 experienced by aging reactors is caused by the rising cost of keeping nuclear reactors online, the
2 superior economics of renewables, and the attractiveness of efficiency.

3 Against this background, a Rocky Mountain Institute’s (RMI) study concludes that solar
4 with battery storage will trigger a large wave of “grid defection” in five to ten years.¹⁰⁷ It shows
5 that refusing to offer payment that reflects their value to the consumers who install this
6 equipment could delay the impact by about a decade, but it will arrive in any event. The
7 message, aimed at utilities, is that their interests would be better served if they use the transition
8 to build a system that accommodates and manages the transition, rather than being overwhelmed
9 when it comes. However, one could take the opposite lesson from this analysis. If this one
10 policy (impeding net energy metering) can delay the transition significantly for a decade, utilities
11 might see this as an opportunity to protect their short-term interests and secure an alternative
12 long-term structure. By layering a number of attacks on the alternatives while simultaneously
13 securing policies that advance their economic interests, utilities can significantly delay and alter
14 the shape of the future. This interpretation is more consistent with their behavior, and it suggests
15 that the current battle over fundamental policies—subsidies, rate structures, deployment of
16 physical facilities, and so on—are strategic, and could profoundly affect the future structure of
17 the industry.

18 RMI is certainly not the only one to suggest that there is a direct link between policy
19 choices and industry structure. The baseload-dominated electricity system was created by policy
20 support and subsidies for physical and institutional infrastructure that favored a specific type of
21 technology. The dominant incumbents will seek to slow or stop the spread of alternatives by
22 denying their access to a similar process that they understand well. The proposition that
23 industries or technologies whose ascendancy is threatened by new competition tend to respond,
24 carries some weight. It also suggests that actors, such as large energy companies, with substantial
25 investments in the current system and its technologies, and relatively strong political influence,
26 are likely to act to frustrate the implementation of institutional changes that would support the
27 implementation of low carbon technologies.

¹⁰⁷ Peter Bronski, et al., 2015, “The Economics of Load Defection How Grid-Connected Solar-Plus-Battery Systems Will Compete with Traditional Electric Service, Why It Matters, and Possible Paths Forward,” Rocky Mountain Institute, April.

1 Their diffusion can be slowed by effects of path dependence and lock-in of earlier
2 technology systems. . . . High carbon technologies and supporting institutional
3 rule systems have co-evolved, leading to the current state of “carbon lock-in.” For
4 example, reductions in cost and the spread of infrastructure supporting coal- and
5 gas-fired electricity generation enabled the diffusion of electricity-using devices
6 and the creation of institutions, such as cost-plus regulation, which encouraged
7 further investment in high carbon generation and networks. This created systemic
8 barriers to investment in low carbon energy technologies.¹⁰⁸

9 In short, this clash is inevitable and has given rise to a frontal assault by nuclear
10 advocates on alternative resources and the institutions that support them.¹⁰⁹

11 **C. The False Reliability Crisis: Exelon’s Nuclear Retirement Blackmail**

12 Exelon is the largest nuclear utility in the United States (with a total of 14 reactors), and
13 Illinois (with 6 reactors), where it is headquartered, has more nuclear reactors than any other
14 state. The two regional transmission organizations (RTOs) into which Exelon sells power—
15 MISO and PJM—have the largest number of nuclear reactors by far. Exelon claimed that it
16 would have to close many of its reactors if it did not get financial relief. This was part of an
17 aggressive campaign to get more favorable treatment for its reactors from state, regional, and
18 federal policymakers, with Illinois being the focal point.

19 State policymakers resisted, deflecting the initial demand for new laws to favor nuclear.
20 They called for state agencies to study the impact of the early retirement of aging nuclear
21 reactors, and the outcome was exactly the opposite of what Exelon had hoped for. The State of
22 Illinois agencies’ analyses concluded that there would be no crisis that merits subsidies of
23 billions of dollars over the next decade.

¹⁰⁸ Peter J. G. Pearson and Timothy J. Foxon, “A Low-Carbon Industrial Revolution? Insights and Challenges from Past Technological and Economic Transformations,” *Energy Policy* 50 (2012), 123–124.

¹⁰⁹ Marcus Hildmann, Andreas Ulbig, and Goran Andersson, *Revisiting the Merit-Order Effect of Renewable Energy Sources*, Working Paper, February 11, 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).

1 First, from both the reliability and carbon-reduction points of view, the amount of at-risk
2 nuclear power is not large enough to warrant immediate subsidization without an evaluation of
3 the cost of the available alternatives. There are a host of approaches to managing the grid that
4 can ensure reliability even as the share of variable renewable resources rises substantially.¹¹⁰
5 Therefore, it takes a set of worst-case assumptions devoid of foresight, planning, and preparation
6 to yield a hint of concern about reliability in the near term.

7 Resources in both RTOs are adequate in the “base case,” and continue to be adequate
8 when the at-risk nuclear plants are retired in the “nuclear retirement case.” In MISO resources
9 remain adequate if the nuclear plants are retired even if there is a “polar vortex” event, but not in
10 the “high load and coal retirement” case. On the other hand, resource adequacy is substandard in
11 PJM in both stress cases; but demand response mitigates the problem in the “high load and coal
12 retirement” case. . . . The IPA attributes the superior resource adequacy in Illinois, even given the
13 premature closures of the nuclear plants, to its initial capacity surplus and to its robust
14 transmission system that enables Illinois to call on out of state capacity support.¹¹¹

15 RTOs have rules that require notice about decisions to abandon generation, which affords
16 the operator and market participants time to adjust, and also imposes penalties for failing to
17 deliver on existing commitments.¹¹² Usually, nuclear plant closures are not sudden unheralded
18 events. Rather they are planned and anticipated months or even years in advance. This would be

¹¹⁰ U.S. Department of Energy, *Wind Vision*, 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.”

¹¹¹ Illinois Commerce Commission, *Response*, 71–72,

¹¹² *Id.*, 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.”

1 particularly true of a closure prompted by low power prices rather than a serious accident or the
2 unexpected failure of plant equipment.¹¹³

3 To the extent that the early retirement of several reactors might put pressure on the
4 electricity system, the Illinois analysis found that responses are available, and that it would not
5 be an Illinois-specific problem but a regional problem. In some senses, such an event
6 immediately triggers mitigating responses. “Thus, the eventual closure of a generating facility
7 could be accompanied by a variety of actions by the affected RTO to alleviate reliability
8 concerns.”¹¹⁴ To the extent that a problem might be caused by the closure of multiple reactors, it
9 would elicit responses from other market participants to mitigate the impact. “Such actions
10 would also have the effect of increasing the supply or availability of other generating resources
11 or the supply of demand response resources... [and] moderate what might otherwise have been a
12 sudden increase in energy market prices.”¹¹⁵ At the same time, the analysis notes that the
13 transmission system has built-in mechanisms that respond to the challenge. The list of immediate
14 potential short-term responses is quite long, including obligations of the utility to assist in
15 preserving system reliability, redispatch and reconfiguration of resources, management of
16 planned outages, and expansion of transmission facilities.¹¹⁶ These are exactly the responses of
17 CAISO to the recent summer challenge and MISO to a similar winter challenge.

18 **D. PG&E’S DIABLO CANYON EARLY EXTENSION FORAY**

19 **Nuclear Regulatory Commission Guidelines**

20 The PG&E application for a license renewal for its Diablo Canyon reactors represents a
21 different point in the reliability debate—a mid-term, general claim about reliability. It also

¹¹³ Id., 64.

¹¹⁴ Id.

¹¹⁵ Id.

¹¹⁶ Id. “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.”

1 reminds us that institutional inertia in the public/regulatory sector is a critical factor in the
2 transition between modes of production. Indeed, as noted, social institutions (government being
3 the most prominent) are slower to change than economic forces and institutions.¹¹⁷

4 The Nuclear Regulatory Commission’s (NRC) Generic Environmental Impact Statement
5 for License Renewal¹¹⁸ gives guidance to utilities on the general criteria the NRC will apply in
6 license renewal. In its updated GEIS in 2013, the NRC recognized that the energy field is
7 evolving very rapidly, and therefore requires a case-by-case analysis of energy alternatives in
8 license renewal proceedings, using “state-of-the-science” information.¹¹⁹ However, a close look
9 at the GEIS in the context of the contemporary industry shows quite clearly that two decades of
10 rapid and dramatic economic and technological change have rendered obsolete even the modified
11 standard that the NRC uses to evaluate request for license renewal.

12 Under the 1996 Guidelines, the NRC framework for evaluating license renewal requests
13 focused on nuclear reactors as baseload generation facilities.¹²⁰ The first page of the section of
14 “Alternatives to License Renewal” concluded by stating that “therefore, NRC has determined
15 that a reasonable set of alternatives should be limited to analysis of single, discrete electric
16 generation sources and only electric generation sources that are technically feasible and
17 commercially viable.”¹²¹ In the evaluation of the sources, the NRC invoked the concept of
18 baseload over 30 times. The majority were references to the failure of renewables to meet the
19 baseload criteria.

20 In the 2013 revision, that standard was revised somewhat. Utility scale replaces baseload
21 as the central concept, while a reliable quantity of replacement capacity equal to the baseload
22 capacity is the target. “The amount of replacement power generated must equal the baseload

¹¹⁷ Perez, Carlota, *Technological Revolutions and Financial Capital: The dynamics of Bubbles and Golden Ages*, (Elgar, Northampton, MA) pp. 155-156.

¹¹⁸ NRC, *2013 Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437)* (Washington, DC: Nuclear Regulatory Commission, 2013).

¹¹⁹ NRC, *2013 GEIS*, 1-30–1-31.

¹²⁰ NRC, *2013 GEIS*.

¹²¹ NRC, *1996 Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437)* (Washington, DC: Nuclear Regulatory Commission, 1996), 8-1.

1 capacity previously supplied by the nuclear plant and reliably operate at or near the nuclear
2 plant's demonstrated capacity factor.”¹²² The change is cosmetic, at best.

3 The NRC continues to exhibit an extremely narrow focus on utility-scale and baseload. In
4 the current technological and economic environment, this focus is tantamount to an irrational
5 baseload bias and a utility-scale fetish that is out of touch with reality. Section 2 of the revised
6 relicensing regulation invokes baseload and utility-scale 25 times in the 16 pages where
7 alternatives are evaluated. The assessment of the alternatives is defined by these two antiquated
8 concepts. Moreover, the identification of alternatives does not include building new generation
9 facilities, efficiency, or integrated management of supply and demand.

10 Ironically, the NRC suggests that the fact that PG&E is asking for the license renewal ten
11 years in advance is a matter of necessity and routine.¹²³ This suggests that it takes as long to
12 implement the steps necessary to extend the life of a nuclear reactor as it does to build a new one.
13 Thus, aging reactors suffer from the same drawback that was demonstrated for new reactors in
14 the earlier discussion. They are a very bad investment in a dynamic environment. An erroneous
15 decision to approve the license extension under these circumstances imposes direct and
16 immediate harm on consumers. It reinforces the utility's incentive and ability to resist the
17 superior economic options that have become available, frustrating the transformation of the
18 utility sector.

19 **E. The Diablo Canyon Application**

20 The harm of failing to give proper guidance to utilities can be seen clearly in the PG&E
21 application for a license renewal for Diablo Canyon. PG&E continued to apply the standard from

¹²² NRC, *2013 GEIS*, 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 ten pages present a tabular summary of the findings and the bibliography. The middle 17 pages evaluate all the alternatives considered.

¹²³ NRC, *2013 GEIS*, 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.

1 the 1996 GEIS. PG&E repeatedly citing the old standard to “disqualify” alternatives.¹²⁴ PG&E’s
2 focus on “standalone” energy sources reflects two unsupported biases—one toward reliance on
3 “baseload” generation by a single source, and another toward “utility-scale” generation.

4 To appreciate why these developments, deserve much more consideration than PG&E
5 gave them, one need only compare PG&E’s Amended Environmental Report with the California
6 Energy Commission’s documents. PG&E rejects the option of geothermal energy based on the
7 assumption that a single new geothermal plant would have to be built in PG&E’s service
8 territory.¹²⁵ Conservatively assuming that the PG&E service territory includes half the
9 geothermal resources in the state, geothermal resources are twice as large as Diablo Canyon
10 capacity. Efficiency, renewables, and distributed generation potential are also about twice the
11 size of Diablo Canyon.¹²⁶

¹²⁴ PG&E, 2015, 7.2-7–7.2-14. This section identifies *standalone* alternatives that PG&E deemed unreasonable, and the bases for these determinations. PG&E accounted for the fact that DCPD provides baseload generation and that any feasible alternative to DCPD would also need to be able to provide baseload power. In performing this evaluation, PG&E relied heavily upon NRC's GEIS. 7-2.7, *There may be insufficient operational flexibilities to both meet those renewable power requirements and replace DCPD 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 DCPD 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 DCPD 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 DCPD 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 DCPD*. 7-2.11, Geothermal plants offer base load capacity similar to DCPD, but it is unlikely to be available *within PG&E's service area* on the scale required to replace the capacity of DCPD. 7-2.12

¹²⁵ PG&E, Diablo Canyon Environmental Report, PG&E, 2015, 7.2-12.

¹²⁶ PG&E, Diablo Canyon Amended Environmental Report, PG&E, 2014, 7.2-6, 7.2-11, 7.2-12.

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

9 Because PG&E is so focused on disqualifying alternatives based on the erroneous
10 standard of “sufficient, single resource baseload power,” it fails to conduct a responsible analysis
11 of its own data. For example, in updating the Environmental Report from 2010 to 2015, PG&E
12 provides data to show that a dramatic transformation of the sector is well under way. This trend
13 includes reduced energy demand, greater capacity for managing demand, and greater reserve
14 margins than existed even ten years ago.¹²⁷ The dramatic decrease in demand and sharp increase
15 in reserve margins between 2008 and 2014 suggests that there is a lot more leeway to retire large,
16 costly, inflexible reactors like those at Diablo Canyon. The reduction in projected peak demand
17 in a mere six years equals almost twice the total output of Diablo Canyon.

18 PG&E’s analysis of the supply-side of the California electricity sector also obscures a
19 simple fact: non-hydro renewables (i.e., wind and solar) have increased dramatically and are
20 poised to surpass nuclear generation (which has been in decline) in the state. PG&E’s analysis is
21 also fundamentally weakened because it fails to recognize the dramatic development in battery
22 technology that has been occurring over the past several years. Instead, PG&E focuses on
23 pumped storage and compressed air. PG&E’s failure to address battery technology is particularly
24 egregious in light of the fact that many analysts conclude that batteries will play a key role in the
25 transformation of the electricity system. Declining costs of batteries are a key driver, as
26 discussed, but so too is the increasing array of new technologies and applications, not to mention
27 the additional critical and valuable functions they provide with increasing renewable penetration.

¹²⁷ PG&E, Diablo Canyon Environmental Report, 7.2-1.

1 Finally, PG&E makes the argument that Diablo Canyon is needed to reduce carbon
2 emissions.¹²⁸ But PG&E relies on the results of a dated, 2009 EPRI analysis and makes no effort
3 to consider its relevance to the current market situation. When change takes place as rapidly as it
4 has in the present electricity sector, half a decade is a long time. In 2009, EPRI may well have
5 still been under the spell of the “nuclear renaissance.” The challenge of building 45 nuclear
6 reactors in less than three decades in a nation that has brought one online in the past two decades
7 at an astronomical cost, suggests the utter impossibility of this scenario. More importantly, that
8 scenario is not the only approach to reaching climate change goals. Since 2008, the wind and
9 solar capacity brought online in the United States has increased its total sat more than twice that
10 rate, storage dramatically increased the duty cycle of solar and demand grew well below the
11 historical rate, all of which dramatically cut the need for nuclear power.

12 The recent analysis from the Department of Energy suggested that a simple projection of
13 recent wind deployments would not only cover the shortfall but retire a substantial part of the
14 aging nuclear fleet. PG&E was wrong then and they are even more wrong today. There is less
15 reason to extend the life of Diablo Canyon today than there was when they agreed to shut it
16 down. Given the ability of CAISO to cope with demanding conditions in the past and the
17 likelihood that that capacity will increase if nuclear power does not get in the way, there is no
18 reason to subsidize the continued existence of Diablo Canyon.

19 **F. CONCLUSION AND RECOMMENDATIONS**

20 **Using Information to Improve Decision Making**

21 **Risk-Aware Cost Estimates:**

22 As I suggested in Chapter 1, policy makers cannot afford to “suspend disbelief” and hope
23 for cost trends that are not supported (even contradicted) by the historical record. When it comes
24 to price projections, they must deal with uncertainty. A systematic approach that I have
25 advocated has been available in the electricity space for quite some time. It involves calculating
26 “risk-aware” prices that reflects the uncertainty of estimates. Earlier I showed that the near-term

¹²⁸ PG&E, Diablo Canyon Environmental Report, 7.2-2, 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.

1 uncertainty and price estimates did not contradict the long-term estimate. Because the discussion
2 is clearly long-term and there is no conflict between the short- and long-term conclusions,
3 Attachment MNC-6.3 presents a “risk-aware” estimate of long-term costs.

4 Risk is measured by the standard deviation of the estimates and the risk aware value is
5 calculated as the Euclidian distance from the origin.¹²⁹ The higher the number the higher the
6 risk-aware estimate of cost. I continue to use the estimate for geothermal without NREL, as
7 discussed in chapter 2. However, I included an estimate for Biomass, which Lazard dropped after
8 2013. The others continued to conclude biomass and nuclear even though there is no ongoing
9 construction of these facilities (according to EIA, which ignore Vogtle and Nuscale). I also
10 include Lazard’s estimate of the cost of gas combined cycle with carbon capture as discussed in
11 Chapter 2. Aging reactors do not enter into the long-term analysis, which is based on new
12 builds.

13 The message from the calculation of risk-aware cost estimates is that there is a set of
14 resources (renewables, i.e., wind, solar and hybrid (solar +batteries) and efficiency) that is much
15 lower. As shown in MNC-6.1, efficiency could be considered part of the low-cost technology in
16 group 2, since it definitely a firm resource. Geothermal with the lower cost estimate is on the
17 border between low-cost group 2 and group 1. The estimates for nuclear, large or small, are
18 much higher. In the long term, even small modular reactors are 2-3 times more costly, while
19 large reactors are 3-4 times more costly. The long-term cost sends a clear message on where the
20 cost to society will be lowest.

21 **Ranking on Multiple Criteria**

22 Another way to view the results in the earlier chapters is to consider the relative ranking
23 of the alternatives. The measures of cost are used to rank the options (see Attachment MNC-6.4).
24 While I have not ranked all the options on each of the dimensions, we do have a ranking for at
25 least three of the four criteria. Since we have not calculated the cost for all options, we compute
26 the average on the basis of those we have estimated. The results follow the earlier discussion.
27 Efficiency and the renewables stand out as the preferable way to meet the need for electricity.

¹²⁹ The methodology is described in Cooper, Mark, 2013, “Multi-Criteria Portfolio Analysis of Electricity Resources: An Empirical Framework For Valuing Resource In An Increasingly Complex Decision-Making Environment”, *Expert Workshop: System Approach to Assessing the Value of Wind Energy to Society*, European Commission Joint Research Centre, Institute for Energy and Transport, Petten, The Netherlands, November 13-14.

1 They are, in essence, a low marginal cost “baseload” resource. have low marginal cost and very
2 low firming costs. Wind onshore and solar are both low compared to the traditional alternatives.

3 **Spending the money on other things**

4 Another simple way to assess the situation would be to ask what else (other than a
5 subsidy for old nuclear reactors could we buy for the money being offered nuclear (in this case
6 \$1.4 billion from the state, but additional tax benefits from the federal income taxes could raise
7 the total to \$2,5 billion). We could weatherize about a quarter of a million homes. The foregone
8 benefit depends on how the money is spread out (see Attachment MNC-6.5). In the attachment,
9 I have used two scenarios (reliance on the pure subsidy, i.e., no contribution to capital, or one-
10 half capital contributed by the owner. I use three approaches which are near term (less than 3
11 years) and appear to be available and attractive, technologically and economically, based upon
12 the Lazard’s firming analysis without long duration storage. Since the CEC does not project a
13 shortfall in that period, the build-up of resources from these three strategies appears to be good
14 insurance against a future problem. The important point is that these alternative investments are
15 long-term and the quicker they are built the better.

16 **G. RECOMMENDATIONS**

- 17 1. The PUC should not allow PG&E to change its mind and operate the reactor, even though
18 the legislature is throwing money at it.
- 19 2. If the PUC cannot follow the first course of action, no matter the reason, it should not
20 allow the utility to collect rates from ratepayers. If the utility wants to operate the reactors for
21 the sums offered by state and federal taxpayers, it can do so, but at no cost to ratepayers.
- 22 3. If the PUC cannot follow the second course, no matter the reason, it can impose market
23 discipline. It should require the reactor to accept only the market clearing price for its output, at
24 the relevant time of day. Needless to say, there will be times when that price is zero.
- 25 4. If the PUC finds it necessary to curtail output, the first place it should look is the nuclear
26 reactors, which are higher in cost, unsuited for the operation of the new system and disruptive of
27 the transformation of the system.
- 28 5. If the PUC cannot force the nuclear reactor to bear the burden of curtailments, it should,
29 subject them to a market test by allowing resources to compete for operation at the lowest price,
- 30 6. If the PUC is unable to impose a market test for curtailments, for whatever reason, it
31 should allocate the curtailments in proportion to the share of generation.

1 7. Regardless of the pricing and operating arrangement, the PUC should insist that the
2 reactor remains online for only the five-year period defined by the subsidy.

3 The conditions imposed on the operation of the aging reactors may seem “onerous”, but
4 they are not vindictive. They represent the fundamental principles of the PUC, prudent and least
5 costs at the core of the PUC’s mission and are driven by the policy of promoting the transition to
6 a 21st century electricity system.

7 **Q. Does this conclude your opening testimony**

8 **A. Yes.**

ATTACHMENT A

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EDUCATION:

Yale University, Ph.D., 1979, Sociology
University of Maryland, M.A., 1973, Sociology
City College of New York, B.A., 1968, English

PROFESSIONAL EXPERIENCE:

President, Citizens Research, 1983 - present
Research Director, Consumer Federation of America, 1983-present
Senior Fellow for Economic Analysis, Institute for Energy and the Environment, Vermont Law School 2009-present
Associated Fellow, Columbia Institute on Tele-Information, 2003-2016
Fellow, Donald McGannon Communications Research Center, Fordham University, 2005-2015
Fellow, Silicon Flatirons, University of Colorado, 2009-2014
Fellow, Stanford Center on Internet and Society, 2000-2010
Principle Investigator, Consumer Energy Council of America, Electricity Forum, 1985-1994
Director of Energy, Consumer Federation of America, 1984-1986
Director of Research, Consumer Energy Council of America, 1980-1983
Consultant, Office of Policy Planning and Evaluation, Food and Nutrition Service, United States Department of Agriculture, 1981-1984
Consultant, Advanced Technology, Inc., 1981
Technical Manager, Economic Analysis and Social Experimentation Division, Applied Management Sciences, 1979
Research Associate, American Research Center in Egypt, 1976-1977
Research Fellow, American University in Cairo, 1976
Staff Associate, Checchi and Company, Washington, D.C., 1974-1976
Consultant, Division of Architectural Research, National Bureau of Standards, 1974
Consultant, Voice of America, 1974
Research Assistant, University of Maryland, 1972-1974

TEACHING EXPERIENCE:

Lecturer, Washington College of Law, American University, Spring, 1984 - 1986, Seminar in Public Utility Regulation
Guest Lecturer, University of Maryland, 1981-82, Energy and the Consumer, American University, 1982, Energy Policy Analysis
Assistant Professor, Northeastern University, Department of Sociology, 1978-1979, Sociology of Business and Industry, Political Economy of Underdevelopment, Introductory Sociology, Contemporary Sociological Theory; College of Business Administration, 1979, Business and Society
Assistant Instructor, Yale University, Department of Sociology, 1977, Class, Status and Power
Teaching Assistant, Yale University, Department of Sociology, 1975-1976, Methods of Sociological Research, The Individual and Society
Instructor, University of Maryland, Department of Sociology, 1974, Social Change and Modernization, Ethnic Minorities

Instructor, U.S. Army Interrogator/Linguist Training School, Fort Hood, Texas, 1970-1971

PROFESSIONAL ACTIVITIES:

Member, Advisory Committee on Appliance Efficiency Standards, U.S. Department of Energy, 1996 - 1998
Member, Energy Conservation Advisory Panel, Office of Technology Assessment, 1990-1991
Fellow, Council on Economic Regulation, 1989-1990
Member, Increased Competition in the Electric Power Industry Advisory Panel, Office of Technology Assessment, 1989
Participant, National Regulatory Conference, The Duty to Serve in a Changing Regulatory Environment, William and Mary, May 26, 1988
Member, Subcommittee on Finance, Tennessee Valley Authority Advisory Panel of the Southern States Energy Board, 1986-1987
Member, Electric Utility Generation Technology Advisory Panel, Office of Technology Assessment, 1984 - 1985
Member, Natural Gas Availability Advisor Panel, Office of Technology Assessment, 1983-1984
Participant, Workshop on Energy and the Consumer, University of Virginia, November 1983
Participant, Workshop on Unconventional Natural Gas, Office of Technology Assessment, July 1983
Participant, Seminar on Alaskan Oil Exports, Congressional Research Service, June 1983
Member, Thermal Insulation Subcommittee, National Institute of Building Sciences, 1981-1982
Round Table Discussion Leader, The Energy Situation: An Open Field For Sociological Analysis, 51st Annual Meeting of the Eastern Sociological Society, New York, March, 1981
Member, Building Energy Performance Standards Project Committee, Implementation Regulations Subcommittee, National Institute of Building Sciences, 1980-1981
Participant, Summer Study on Energy Efficient Buildings, American Council for an Energy Efficient Economy, August 1980
Member, University Committee on International Student Policy, Northeastern University, 1978-1979
Chairman, Session on Dissent and Societal Reaction, 45th Annual Meeting of the Eastern Sociological Society, April, 1975
Member, Papers Committee, 45th Annual Meeting of the Eastern Sociological Society, 1975
Student Representative, Programs, Curricula and Courses Committee, Division of Behavioral and Social Sciences, University of Maryland, 1973-1974
President, Graduate Student Organization, Department of Sociology, University of Maryland, 1973-1974

HONORS AND AWARDS:

Ester Peterson Award for Consumer Service, 2010
American Sociological Association, Travel Grant, Uppsala, Sweden, 1978
Fulbright-Hayes Doctoral Research Abroad Fellowship, Egypt, 1976-1977
Council on West European Studies Fellowship, University of Grenoble, France, 1975
Yale University Fellowship, 1974-1978
Alpha Kappa Delta, Sociological Honorary Society, 1973
Phi Delta Kappa, International Honorary Society, 1973
Graduate Student Paper Award, District of Columbia Sociological Society, 1973
Science Fiction Short Story Award, University of Maryland, 1973
Maxwell D. Taylor Award for Academic Excellence, Arabic, United States Defense Language Institute, 1971
Theodore Goodman Memorial Award for Creative Writing, City College of New York, 1968
New York State Regents Scholarship, 1963-1968
National Merit Scholarship, Honorable Mention, 1963

PUBLICATIONS:

ENERGY

Books and Chapters

The Political Economy of Electricity: Progressive Capitalism and the Struggle to Build a Sustainable Power Sector (Praeger, 2017)

"Energy Justice in Theory and Practice: Building a Pragmatic, Progressive Road Map," in Thijs de Graf, Benjamin K. Sovacool, Arunabha Gosh, Florian Kern, and Michael T. Klare (Eds.) *The Palgrave Handbook of the International Political Economy of Energy*, (PALGRAVE, Macmillan, 2016)

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"Nuclear Safety and Nuclear Economics, Fukushima Reignites the Never-ending Debate: Is Nuclear Power not worth the risk at any price?," *Symposium on the Future of Nuclear Power*, University of Pittsburgh, March 27-28, 2012

"Nuclear liability: the post-Fukushima case for ending Price-Anderson," *Bulletin of the Atomic Scientists*, October, 67, 2011.

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- "Economics of Power: Heading for the Exits, Deregulated Electricity Markets Not Working Well," *Natural Gas*, 19:5, December 2002
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- "Conceptualizing and Measuring the Burden of High Energy Prices," in Hans Landsberg (Ed.), *High Energy Costs: Assessing the Burden* (Washington, D.C.: Resources For the Future, 1982)
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- "Policy Packaging for Energy Conservation: Creating and Assessing Policy Packages," in Jeffrey Harris and Jack Hollander (Eds.), *Improving Energy Efficiency in Buildings: Progress and Problems* (American Council for An Energy Efficient Economy, 1982)
- "The Role of Consumer Assurance in the Adoption of Solar Technologies," *International Conference on Consumer Behavior and Energy Policy*, August, 1982
- "Energy and the Poor," *Third International Forum on the Human Side of Energy*, August, 1982
- "Energy Price Policy and the Elderly," *Annual Conference, National Council on the Aging*, April, 1982
- "Energy and Jobs: The Conservation Path to Fuller Employment," *Conference on Energy and Jobs conducted by the Industrial Union Department of the AFL-CIO*, May 1980

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U.S. Capitalism and the Public Interest: Restoring the Balance in Electricity and Telecommunications Markets (Consumer Federation of America, August 2002)

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Electricity Restructuring and the Price Spikes of 1998 (Consumer Federation of America and Consumers Union, June 1999)

The Residential Ratepayer Economics of Electric Utility Restructuring (Consumer Federation of America, July 1998)

Consumer Issues in Electric Utility Restructuring (Consumer Federation of America, February 12, 1998)

A Consumer Issue Paper on Electric Utility Restructuring (American Association of Retired Persons and the Consumer Federation of America, January, 1997)

Transportation, Energy, and the Environment: Balancing Goals and Identifying Policies, August 1995

A Residential Consumer View of Bypass of Natural Gas Local Distribution Companies, February 1988

The National Energy Security Policy Debate After the Collapse of Cartel Pricing: A Consumer Perspective, January 1987

The Energy, Economic and Tax Effects of Oil Import Fees, October 25, 1985

The Bigger the Better: The Public Interest in Building a Larger Strategic Petroleum Reserve, June 12, 1984

The Consumer Economics of CWIP: A Short Circuit for American Pocketbooks, April, 1984

Public Preference in Hydro Power Relicensing: The Consumer Interest in Competition, April 1984

Concept Paper for a Non-profit, Community-based, Energy Services Company, November 1983

The Consumer and Energy Impacts of Oil Exports, April 1983

Up Against the Consumption Wall: The Impact of Rising Energy Prices on Lower Income Consumers, March 1983

A Decade of Despair: Rising Energy Prices and the Living Standards of Lower Income Americans, September 1982

The Impact of Rising Energy Prices on the Delivery of Public Service by Local Governments, August 1982

The Impact of Rising Energy Prices on the Low-Income Population of the Nation, the South, and the Gulf Coast Region, July, 1982

A Comprehensive Analysis of the Impact of a Crude Oil Import Fee: Dismantling a Trojan Horse, April 1982

The Past as Prologue II: The Macroeconomic Impacts of Rising Energy prices, A Comparison of Crude Oil Decontrol and Natural Gas Deregulation, March, 1982

The Past as Prologue I: The Underestimation of Price Increases in the Decontrol Debate, A Comparison of Oil and Natural Gas, February 1982

Oil Price Decontrol and the Poor: A Social Policy Failure, February 1982

Natural Gas Decontrol: A Case of Trickle-Up Economics, January 1982

A Comprehensive Analysis of the Costs and Benefits of Low-Income Weatherization and Its Potential Relationship to Low Income Energy Assistance, June 1981

Summary of Market Inhibitors, February 1981

Program Models and Program Management Procedures for the Department of Energy's Solar Consumer Assurance Network Project: A Rapid Feedback Evaluation, February 1981

An Analysis of the Economics of Fuel Switching Versus Conservation for the Residential Heating Oil Consumer, October 1980

Energy Conservation in New Buildings: A Critique and Alternative Approach to the Department of Energy's Building Energy Performance Standards, April, 1980

The Basics of BEPS: A Descriptive Summary of the Major Elements of the Department of Energy's Building Energy Performance Standards, February, 1980

COMMUNICATIONS AND MEDIA

Books and Chapters

“The Future of Journalism: Addressing Pervasive Market Failure with Public Policy,” in R.W. McChesney and Victor Picard (eds.), *Will the Last Reporter Turn out the Lights* (New York: New Press, 2011)

“Broadband in America: A Policy of Neglect is not Benign,” in Enrico Ferro, Yogesh K. Dwivedi, J. Ramon Gil-Garcia, and Michael D. Williams, Eds., *Overcoming Digital Divides: Constructing an Equitable and Competitive Information Society*, IGI Global Press, 2009.

“Political Action and Internet Organization: An Internet-Based Engagement Model,” in Todd Davies and Seeta Pena Gangaharian, Eds., *Online Deliberation: Design, Research and Practice*, CSLI press.

“When Counting Counts: Marrying Advocacy and Academics in the Media Ownership Research Wars at the FCC,” forthcoming in Lynn M. Harter, Mohan J. Dutta, and Courtney Cole, Eds., *Communicating for Social Impact: Engaging Communication Theory, Research, and Pedagogy*, Hampton Press.

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Open Architecture as Communications Policy (Stanford Law School, Center for Internet and Society: 2004)

Media Ownership and Democracy in the Digital Information Age: Promoting Diversity with First Amendment Principles and Rigorous Market Structure Analysis (Stanford Law School, Center for Internet and Society: 2003)

Cable Mergers and Monopolies: Market Power In Digital Media and Communications Networks (Washington, D.C.: Economic Policy Institute, 2002)

“When Law and Social Science Go Hand in Glove: Usage and Importance of Local and National News Sources, Critical Questions and Answers for Media Market Analysis,” forthcoming in, Philip Napoli, Ed. *Media Diversity and Localism: Meaning and Metrics*, (Lawrence Erlbaum, 2007)

“The Importance of Open Networks in Sustaining the Digital Revolution,” in Thomas M. Lenard and Randolph J. May (Eds.) *Net Neutrality or Net Neutering* (New York, Springer, 2006)

“Reclaiming The First Amendment: Legal, Factual And Analytic Support For Limits On Media Ownership,” Robert McChesney and Benn Scott (Eds.), *The Future of Media* (Seven Stories Press, 2005)

“Building A Progressive Media And Communications Sector,” Elliot Cohen (Ed.), *News Incorporated: Corporate Media Ownership And Its Threat To Democracy* (Prometheus Books, 2005)

“Hyper-Commercialism In The Media: The Threat To Journalism And Democratic Discourse,” Snyder-Gasher-Compton-(Eds), *Converging Media, Diverging Politics: A Political Economy Of News In The United States And Canada* (Lexington Books, 2005)

“The Digital Divide Confronts the Telecommunications Act of 1996: Economic Reality versus Public Policy,” in Benjamin M. Compaine (Ed.), *The Digital Divide: Facing a Crisis or Creating a Myth?* (Cambridge: MIT Press, 2001)

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“Business Data Services after the 1996 Act: Structure, Conduct, Performance in the Core of the Digital Communications Network The Failure of Potential Competition to Prevent Abuse of Market Power,” Telecommunications Policy Research Conference, September, 2016.

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- "Testimony of Dr. Mark N. Cooper on Behalf of the Arkansas Attorney General," before the Arkansas Public Service Commission, In the Matter of an Earnings Review of Southwestern Bell Telephone Company, Docket NO. 92-260-U, April 21, 1995
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- "Statement of Dr. Mark N. Cooper," DPUC Exploration of Universal Service Policy Options, Docket No. 94-07-08, November 30, 1994
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- "On Behalf of Manitoba Anti-poverty Organization and the Manitoba Society of Seniors," before the Public Utilities Board in the Matter of the Request of Manitoba Telephone System for a General Rate Review, March 16, 1987
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- "On Behalf of North Carolina Legal Services, in the Matter of Application of Continental Telephone Company of North Carolina for an Adjustment of its Rates and Charges, Before the North Carolina Utilities Commission, Docket No. P-128, Sub 7, February 20, 1985
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"The Impact of Rising Energy Prices on the Low Income Population of the Nation, the South and the Gulf Coast Region," before the Mississippi Public Service Commission, Docket No. U-4190, August 1982

ATTACHMENT B

Books and Chapters

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Building A Least Cost, Low-Carbon, Electricity System With Efficiency, Wind, Solar & Intelligent Grid Management: Why Nuclear Subsidies Are An Unnecessary Threat To The Transformation (Friends of the Earth, July 15, 2021

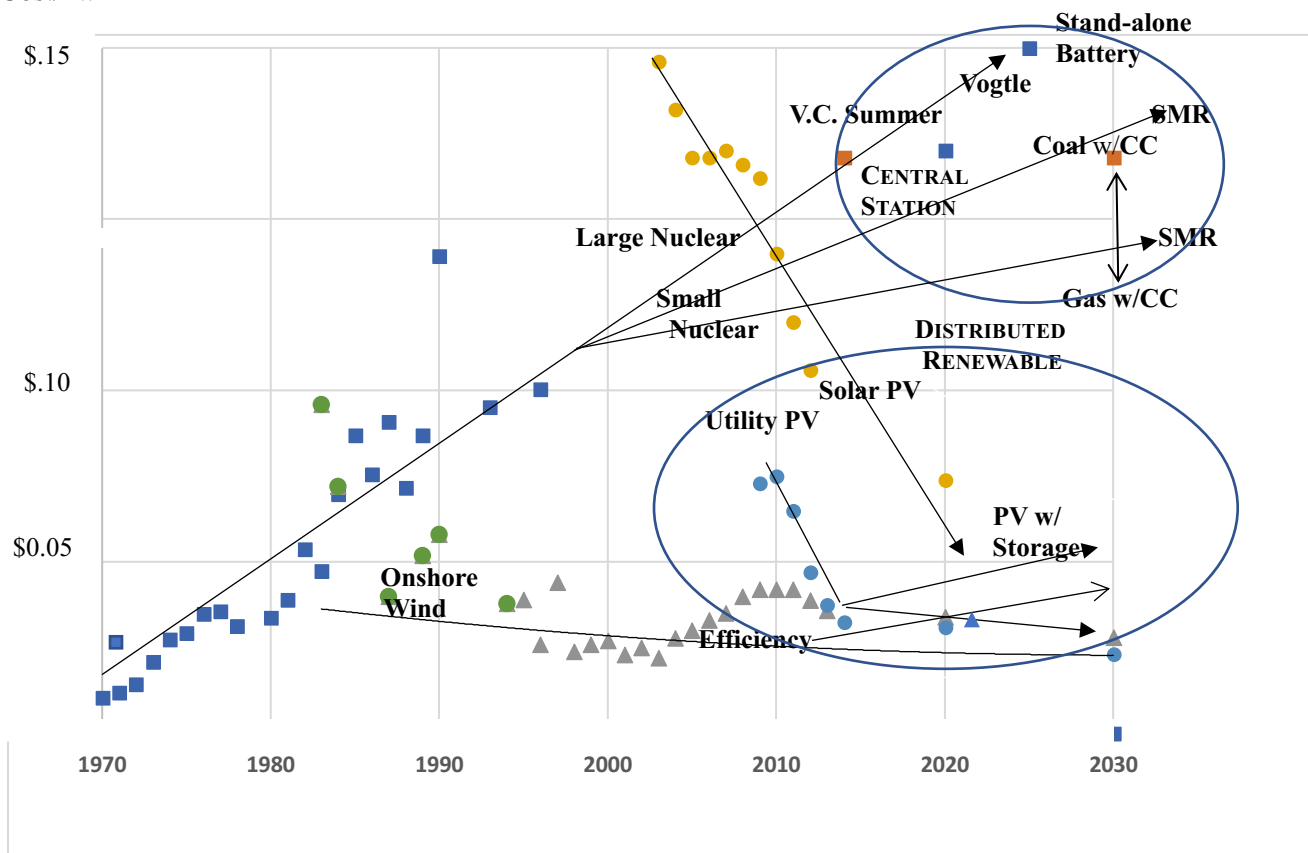
AREAS OF ANALYSIS

Analysis areas	Nuclear		Distributed Alternatives
Cost			<u>(New or expanded)</u>
Long-Term	All ,	High	Low
Short-Term	Aging,	Escalating, Capital Cost	Low “all in”, <u>very low marginal</u>
Projections	All	Escalating to flat	Declining to flat
System	Large	High operating reserve	<u>equal to low</u>
Transformation	All	Crowding Out	<u>Need to refocus on distributed</u>
Reliability	All	Load following	<u>Load shaping, Diversity</u>
	All	Risk of Outage	<u>Increasing tools of integration</u>
Transmission	All	Need creating	<u>Local independence</u>
Resource Adequacy	All	Old Transmission dependent	<u>Declining Demand</u>
Macroeconomic	All	Negative	Positive
Climate	All	Low	Low
Health	All	Mixed	Mixed
Clean Energy Scenarios			
Probability	All	Highly unlikely	<u>Likely but Challenging</u>
Cost	All	High	Moderate to low

Sources: The Original Analysis was primarily articulated in Mark Cooper, 2015, “Declaration of Mark Cooper in Support Of San Luis Obispo Mothers For Peace’s Motion to File New Contentions Regarding Adequacy of Environmental Report for Diablo Canyon License Renewal Application, before the Atomic Safety and Licensing Board, in The Matter Of Pacific Gas And Electric Company Docket Nos. 50-275-LR Diablo Canyon Nuclear Power Plant 50-323-LR Units 1 And 2, Nuclear Regulatory Commission, April. The Updates Can Be Found in Mark Cooper, *The Political Economy of Electricity: Progressive Capitalism and the Struggle to Build a Sustainable Power Sector* (Praeger, 2017); *Trump’s \$2 Trillion Mistake, The War on Energy Efficiency*, November 2017 (Consumer Federation of America); *The Green New Deal Can Build a Progressive, Capitalist, Low Cost, Low Carbon, Electricity Sector, If it Avoids the Nuclear Power and Fossil Fuel Potholes Along the Way*, April 2019. *Institute for Energy and the Environment*, Vt Law School; *Building A 21st Century Electricity Sector With Efficiency, Distributed Resources And Dynamic Management:: The Consumer, Economic, Public Health And Environmental Benefit*, (with Mel Hall-Crawford (Consumer Federation of America) April 22, 2021; *Building A Least Cost, Low-Carbon, Electricity System With Efficiency, Wind, Solar & Intelligent Grid Management: Why Nuclear Subsidies Are An Unnecessary Threat To The Transformation* (Friends of the Earth, July 15, 2021

BROAD, LONG-TERM RESOURCE COST TRENDS

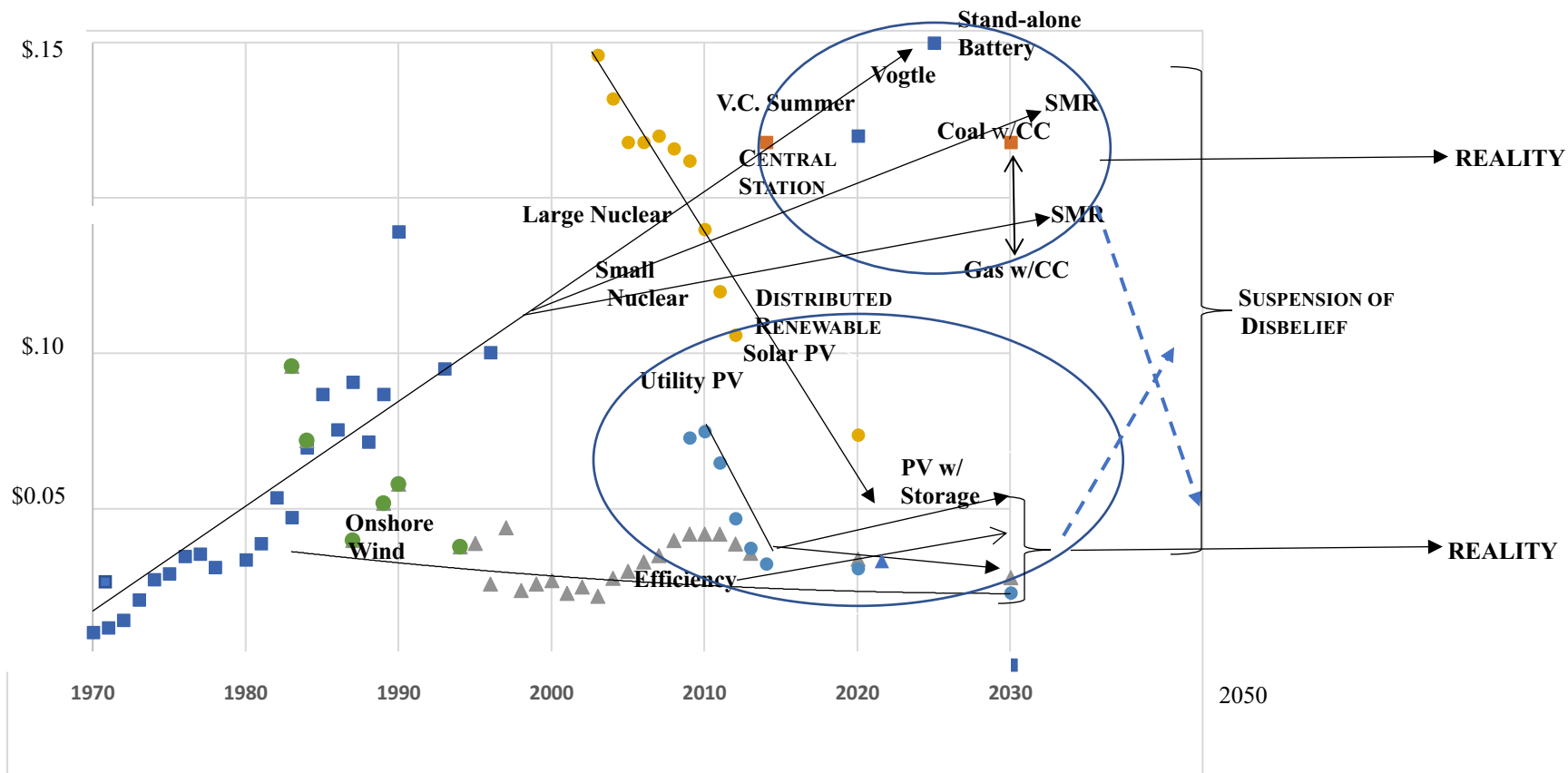
Cost/kwh



Source: Updated and adapted from Mark Cooper, *The Political Economy of Electricity: Progressive Capitalism and the Struggle to Build a Sustainable Sector* (Santa Barbara, Praeger, 2017), Figure 2.1 and accompanying text. (overnight cost for capital-intensive technologies, fuel-intensive technologies based on relative cost per kWh).

THE SUSPENSION OF DISBELIEF ABOUT LONG-TERM RESOURCE COST TRENDS

Cost/kwh



Source: Attachment MNC-1.3, as updated in text.

FUNDAMENTAL DIFFERENCES BETWEEN CENTURIES AND SYSTEMS

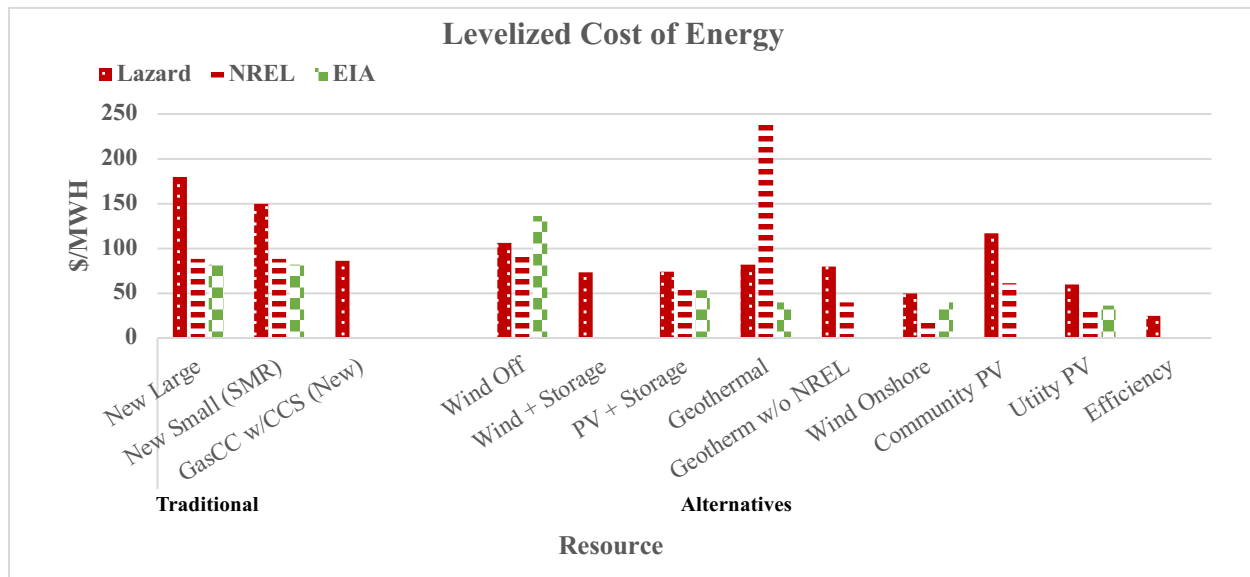
<u>Characteristic</u>	<u>20th Century</u>	<u>21st Century</u>
Goal	Redundancy (as resilience)	Flexibility (resilience as a result)
Operational objective	Increase capacity to follow load	Integrate & match supply and demand
Configuration, size	Island set by economies of generations	Interconnection set by value
Supply-Demand	Segregation	Integration
Demand driver	Dumb load	Smart Retailer
System cost recovery	High, lumpy and fixed	Variable targeted and local
Organization	Centralized	Distributed
Challenges	Increase capacity to follow load	Integrate & match supply and demand
Flash point	50 most expensive hours (>\$10,000)	50 least expensive hours (< \$0)
Market power	High	Low
Optimization Target	Meet peaks	Shave peaks, Fill valleys (shed & shift)
End users role	Passive	Active & Prosumer
Flow:		
Output	Hub & Spoke, linear	Networked, Dynamic & Transparent
Information	Aggregate	Transparent, local
Resources:		
Physical	Fuel, Cement and Boiling Water	Steel, Silicon and Intelligence
Intellectual	Engineering judgement	Communications, Advanced Control
Capital	High for base, low for peak	Moderate for both
Energy intensity	High, concentrated	Low, diffuse

Source: Adapted from Carlotta Perez, 2009, *Technological Revolutions and Techno-economic Paradigms*, Working Papers in Technology Governance and Economic Dynamics, 18, January.

10 REASONS WHY LAZARD IS A GOOD BASIS FOR COST ESTIMATION

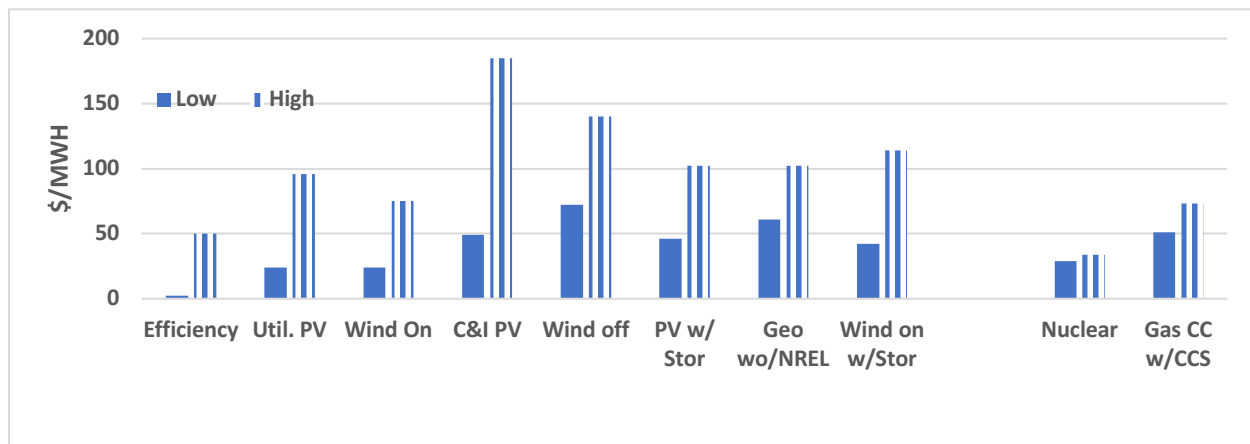
1. First and foremost, Lazard's projections have tracked the actual development of costs over the past decade and a half much more closely than others. Lazard's estimates reflect the behaviors of those building the resources in the marketplace,
2. From the outset, Lazard's analysis included efficiency.
3. 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 for peak power in some major markets.
4. The analysis included estimates for coal with carbon capture and storage, and later added the cost of natural gas with carbon capture and storage.
5. The analysis includes regional estimates for resources whose economics vary by location.
6. The more 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 renewable and distributed sources.
7. The annual reports included natural gas peaking capacity costs and, in a recent analysis, added a cross-national comparison of peaking technologies that might displace gas as the peaker resource.
8. The analysis has also added comparisons of carbon abatement costs, as the determination to deal with climate change has grown.
9. Lazard also recognized the importance of combining generation (especially solar) with battery storage (hybrid systems) and has now published six such evaluations. After significant deployment of renewables with storage, the report examined the cost of these installations.
10. Most recently, the unique costs associated with "firming" intermittent resources has been estimated.

LONG-TERM COSTS



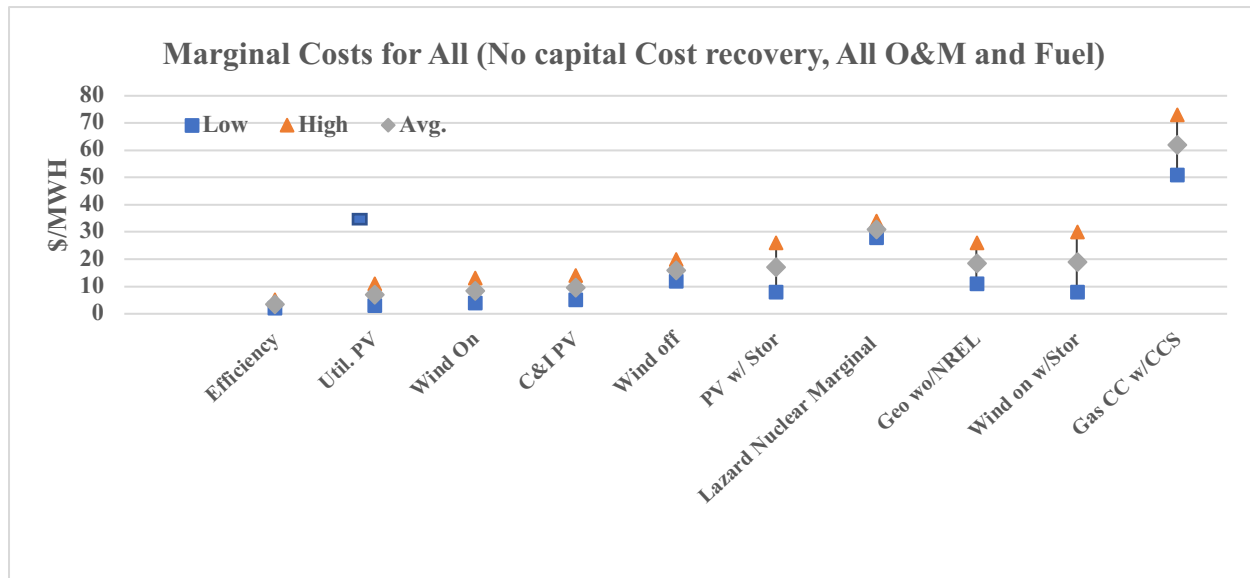
Sources: Lazard, *Levelized Cost of Energy*, v. 16.0, 2023; NREL, *Annual Technology BASELINE (ATB)*, 2020-2022, Energy Information Administration (EIA), 2018 - 2022, *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook*.

ALL-IN RENEWABLES V. MARGINAL TRADITIONAL: COMPARING APPLES-TO-ORANGES

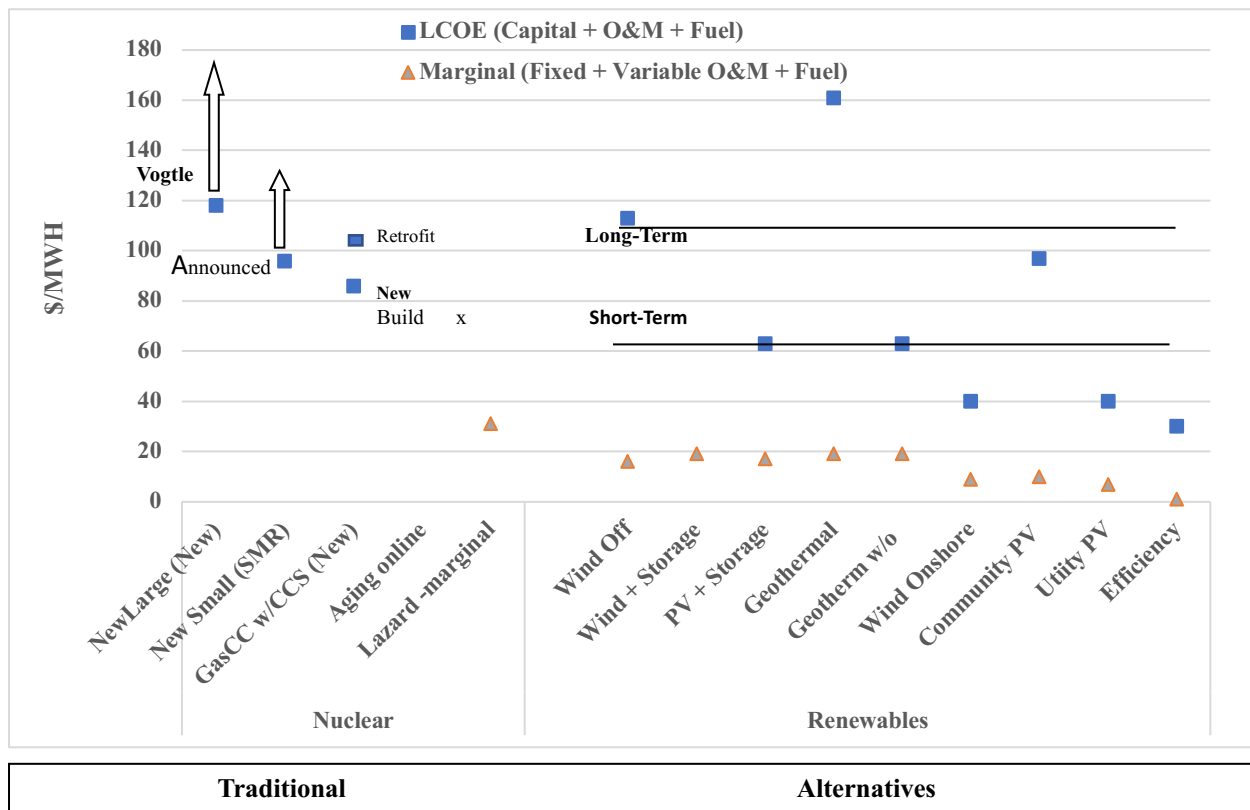


Sources: See Attachment MNC-2.2 and Lazard, *Levelized Cost of Energy*, v. 16.0, p. 7

MARGINAL ANALYSIS - COMPARING APPLES-TO-APPLES

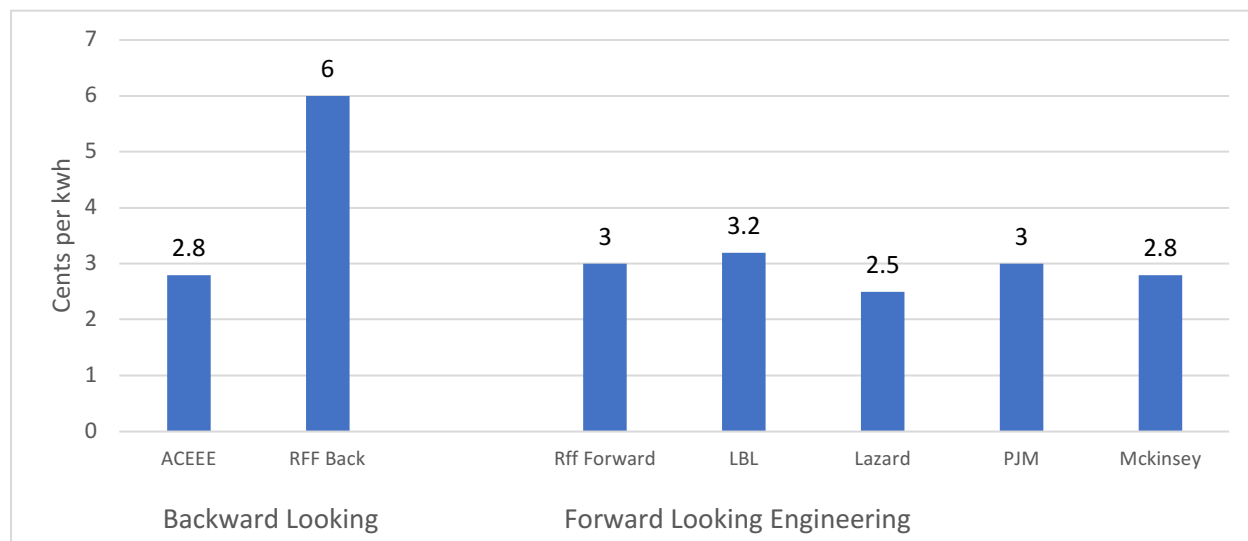


SHORT-TERM REINFORCES CONCLUSIONS BASED ON THE LONG-TERM



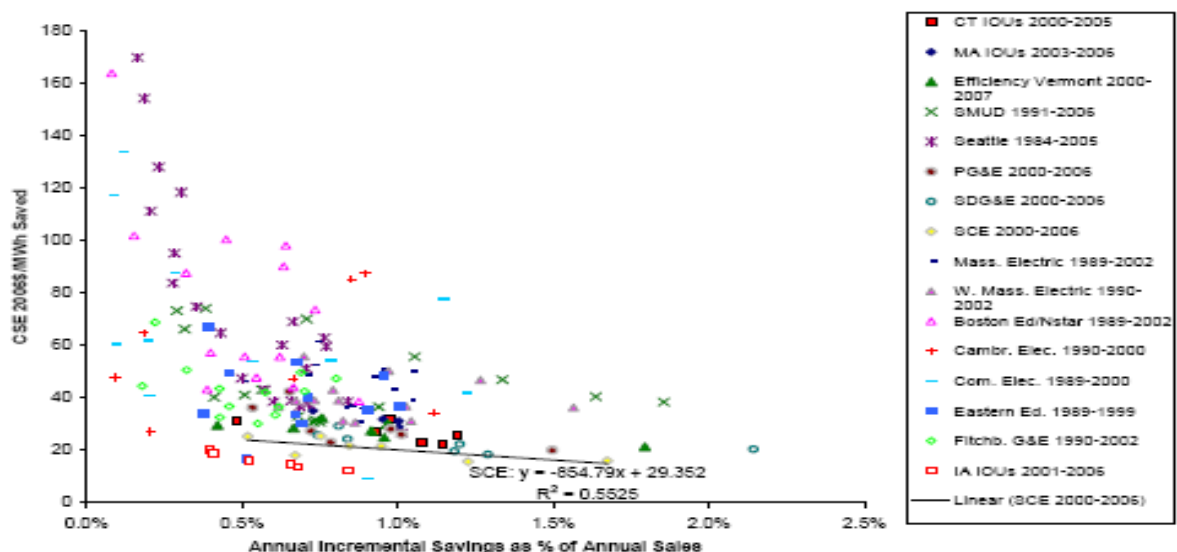
Sources: See Attachment MNC-2.2 and Lazard, *Levelized Cost of Energy*, v. 16.0, p. 7

THE COST OF SAVED ELECTRICITY



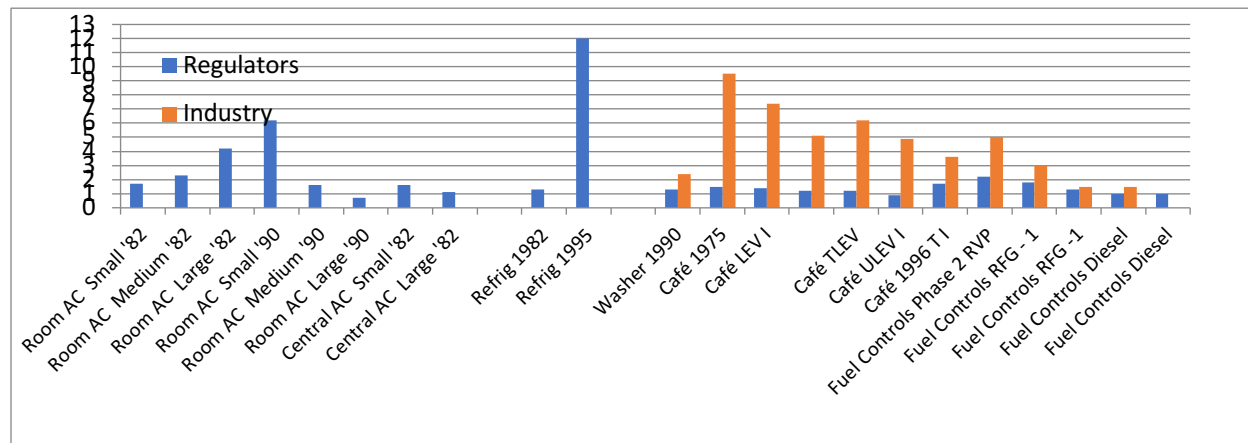
Source: Kenji Takahasi and David Nichols, “Sustainability and Costs of Increasing Efficiency Impact: Evidence from Experience to Date,” *ACEEE Summer Study on Energy Efficient Buildings* (Washington, D.C., 2008), p. 8-363, McKinsey Global Energy and Material, *Unlocking Energy Efficiency in the U.S. 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).

UTILITY COST OF SAVED ENERGY VS. INCREMENTAL ANNUAL SAVINGS AS A % 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), p. 8-363.

THE PROJECTED COSTS OF REGULATION EXCEED THE ACTUAL COSTS: RATIO OF ESTIMATED COST TO ACTUAL COST BY END-USE AND 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 CO₂ Standard*, Natural Resources Defense Council, 2.7pril 2006; Larry Dale, et al., "Retrospective Evaluation of Appliance Price Trends," *Energy Policy* 37, 2009.

MULTIVARIATE ANALYSIS OF APPLIANCE STANDARDS IMPACT ON ENERGY USE

Variable	Statistic	5-years before/after			All Years			
		1	2	3	4	5	6	
Standard	β	-.1637	-.1386	-.1086	-.2260	-.1079	-.0803	-
	Std. Err.	(.0485)	(.0587)	(.0382)	(.0366)	(.0414)	(.0227)	
	p <	.000	.023	.007	.000	.010	.001	
Trend	β	NA	-.0053	-.0111	NA	-.0107	-.0135	
	Std. Err.		(.0081)	(.008)		(.0026)	(.0019)	
	p <		.51	.176		.000	.000	
Refrig	β	NA	NA	-.2775	NA	NA	-.2242	
	Std. Err.			(.0382)		(.0289)		
	p <			.000			.000	
Washer	β	NA	NA	-.2889	NA	NA	-.2144	
	Std. Err.			(.0561)		(.0391)		
	p <			.000			.000	
RoomAC β	β	NA	NA	.0478	NA	NA	-.0895	
	Std. Err.			(.0642)		(.0321)		
	p <			.383			.009	
CAC	β	NA	NA	-.0050	NA	NA	.0383	
	Std. Err.			(.0292)		(.0260)		
	p <			.864			.143	
R ²		.20	.21	.85	.29	.36	.75	

Statistics are Beta coefficient and robust standard errors.

Source: Mark Cooper, *Trump's \$2 Trillion Mistake, The War on Energy Efficiency*, November 2017 (Consumer Federation of America); *Energy Efficiency Performance Standards: Driving Consumer and Energy Savings in California*. Presentation at the California Energy Commission's Energy Academy, February 20, 2014.

ANNUAL CHANGE IN U.S ELECTRICITY GENERATION PER DOLLAR OF GDP/PER CAPITA

Period	Annual % Change Electricity	GDP/capita	Electricity/ GDP/capita
1950-1980	+6.4	+3.5	+2.89
1980-1995	+1.9	+2.2	-0.000
1995-2019	+1.3	+3.3	-2.0

Source: U.S. Energy Information Administration, *Monthly Energy Review*, various, and; [US Real GDP by Year](#).

ELEMENTS OF “COMMAND-BUT-NOT-CONTROL” REGULATION

Long-Term: Setting a high standard for the next fifteen years is intended to foster and support a long-term perspective for automakers and the public, by reducing the marketplace risk of investing in new technologies. The long-term view gives the automakers time to re-orient their thinking, retool their plants and help re-educate the consumer. The industry spends massive amounts on advertising and expends prodigious efforts to influence consumers when they walk into the show room. By adopting a high standard, auto makers will have to expend those efforts toward explaining why higher fuel economy is in the consumer interests. Consumers need time to become comfortable with the new technologies.

Product Neutral: The new approach to standards accommodates consumer preferences; it does not try to negate them. The new approach to standards is based on the footprint (size) of the vehicles and recognizes that SUVs cannot get the same mileage as compacts. Standards for larger vehicles will be more lenient, but every vehicle class will be required to improve at a fast pace. This levels the playing field between auto makers and removes any pressure to push consumers into smaller vehicles.

Technology-neutral: Taking a technology neutral approach to the long-term standard unleashes competition around the standard that ensures that consumers get a wide range of choice at the lowest cost possible, given the level of the standard. There will soon be hundreds of models of electric and hybrid vehicles using four different approaches to electric powertrains (hybrid, plug-in, hybrid plug-in, and extended range EVs), offered across the full range of vehicles driven by American consumers (compact, mid-size family sedans, large cars, SUVs, pickups), by half a dozen mass market oriented automakers. At the same time, the fuel economy of petroleum powered engines can be dramatically improved at consumer-friendly costs and it will continue to be the primary power source in the light duty fleet for decades.

Responsive to industry needs: Establishing a long-term performance standard recognizes the need to keep the standards in touch with reality. The standards can be set at a moderately aggressive level that is clearly beneficial and achievable. With thoughtful cost estimates, consistent with the results of independent analyses of technology costs, a long-term performance standard will contribute to a significant reduction of cost.

Responsive to consumer needs: The approach to standards should be consumer-friendly and facilitate compliance. An attribute-based approach ensures that the standards do not require radical changes in the available products or the product features that will be available to consumers. We include the principle that standards should be attributed based as the key to this

criterion. Consumers purchase and use durables for specific purposes. The attributes of the durables are extremely important. To the extent that agencies design standards to ensure consumers get the functionalities they need, the standards will be more effective. The setting of a coordinated national standard that lays out a steady rate of increase over a long-time period gives the market and the industry certainty and time to adapt to change.

Procompetitive: All of the above characteristics make the standards pro-competitive. Producers have strong incentives to compete around the standard to achieve them in the least cost manner, while targeting the market segments they prefer to serve. Well-designed performance standards that follow these principles command but they do not control. They ensure consumer needs are met while delivering energy savings and increasing consumer and total social welfare.

Source: Mark Cooper, xx, *Trump's \$2 Trillion Mistake*, Consumer Federation America, Chapter IV.

EXTERNALITIES

**Lifecycle Carbon Emissions with Lost Opportunity of Delay
(Grams of CO₂/ kwh)**

	LIFE CYCLE			COST OF CONSTRUCTION DELAY			TOTAL
	LOW	AVG.	HIGH	LOW	AVG.	HIGH	
EFFICIENCY		1					
WIND	4	10	7	1			
CSP	9	10	11	10			
SOLAR	19	32	59	1			
GEOTHERMAL	15	35	55	6	38	44	
NEW GAS W/CCS	44			44			
NUCLEAR: OLD		58					
NEW	9	40	70	59	106	120	

Non-Carbon Environmental Impacts

Resource	Pollutants Cents/MWh	Water (m3/MJ)	Land (m2/GWh)	Accidents Fatalities
Efficiency	~0	0	0	~0
Wind	0.29	0.01	2404	1
PV	0.69	0.042	1232	4
Gas w/CCS 14.87	0.31	325	20	
Nuclear	8.63	0.59	78	7

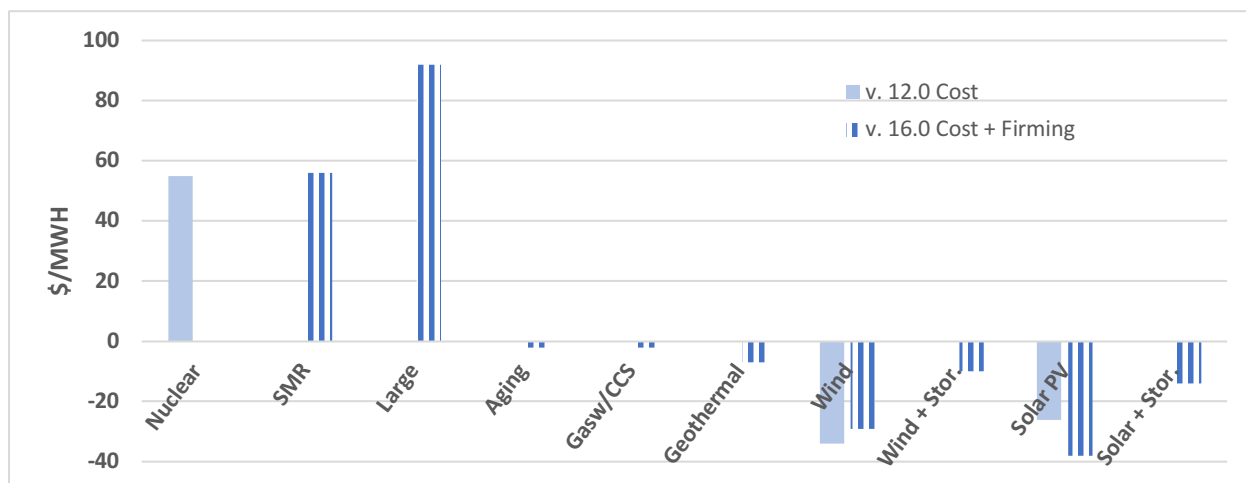
Source: Mark Cooper, *The Political Economy of Electricity*, Table 5.8 and 5.9 and accompanying text. Underlying data is from Benjamin K. Sovacool and Michael Dworkin, *Global Energy Justice*, Cambridge University Press, 2014 (Non-GHG, p. 149; GHG, p. 108); Benjamin K. Sovacool, "Exposing the Paradoxes of Climate Change Governance," *International Studies Review*, 16 (2), 2014; Mark Z. Jacobson, "Review of solutions to global warming, air pollution and energy security," *Energy Environ. Sci.*, 2, p. 165, 2009; Saeed Hadian and Kaveh Madani, "A system of systems approach to energy sustainability assessment: Are all renewables really green?" *Ecological Indicators* 52, 2015. Sharon J. Klein and Stephanie Whalley, "Comparing the sustainability of U.S. electricity Options through multi-criteria decision analysis," *Energy Policy*, 79 (2015). BEV=battery electric vehicle; CCS = carbon capture and storage.

RANK ORDER OF EXTERNAL IMPACTS

Pollutant^{a/}	CO2	NOX/ SOX	Land	Water	Water Use	Solid Dischg.	Bio Waste	Avg. NON- CO2	Rank on ^{b/} non-air impacts Original Scale Converted to 3.0 scale	
Resource										
Efficiency	3	3	3	3	3	3	3	3	9.98	2.99
Hydro	3	1.89	3	1	1.5	2	2	1.98	2.65	.80
Geothermal	2.92	2.3	2	2.8	2	3	2	3	2.05	7.96
Wind	2.87	3	2.85	1	3	3	2	2.47	7.30	2.19
Solar	2.8	2.86	2.83	1	2.5	1	3	2.37	6.98	2.09
Nuclear	2.61	2.13	2.76	1	0	0	0	1.13	0.98	0.29
Gas	0.78	1.42	1.62	1	2	1.5	2	1.54	5.62	1.69
Coal	0	0.74	0.15	0	0	0.5	1	0.3	0.98	0.29

Source: ^{a/} Acar, Canan and Ibrahim Dincer, 2017, "Environmental impact assessment of renewables and conventional fuels for different end use purposes," *Int. J. of Global Warming*, 13. ^{b/} Dincer, Ibrahim, 2018, "Energetic and Environmental Dimensions," *Exergetic*, Table 7.

VALUE OF CARBON ABATEMENT



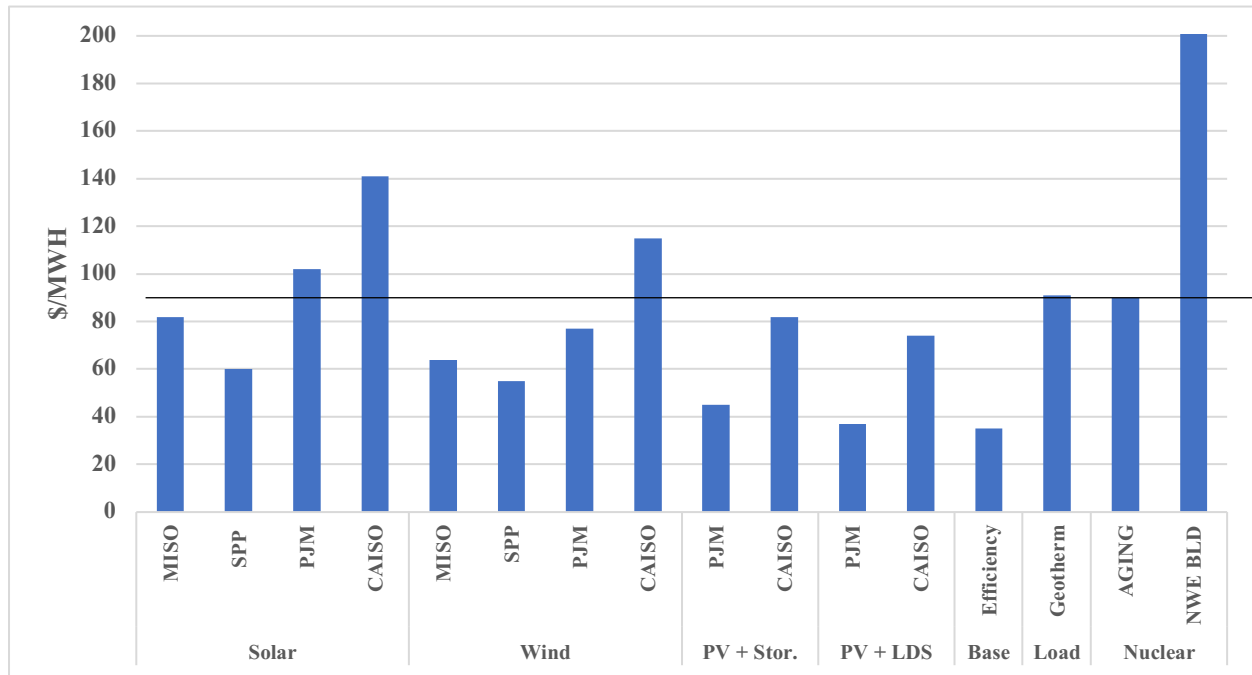
Source: Based on Lazard, which uses low Levelized Cost, v. 14.0. Updated with Lazard v. 16.0 costs adding aging reactors, hybrid (storage systems, and firming costs.

LAZARD'S FIRING ANALYSIS

Alternative Resource	Generic Avg.	CAISO/ PJM	Res- ource	Firm- ing	Total	Total w/ LDES	Key assumptions
<u>Cost of Firm New Entry</u>							
Stand Alone Battery	229	229					
Gas Peaking	115-221						Ruled out. high carbon
GasCC	39-101						" "
GasCC w/ CS retro	103		103	8 - 16	111-124		Low is 90%, High is 30% Capacity Factor
GasCC w/ CS New	86		86	8 - 16	94-123		" "
LDS at Scale, avg.	192						Average
Low cost	180						Electrochem., Mechanical
<u>Intermittent Alternatives</u>							
Solar	141		43	98	141		
Solar + Storage	150		32	50	82		100% resource, 50% firming due to capacity
Solar + Long Dur. Stor. (low)			32			41-62	" "
Wind on			60	72	132		" "
Wind on + Storage	286		60	52	113		" "
Wind + Long Dur. Stor.			60			374-9	
<u>Alternative "Baseload"</u>							
Efficiency	35			0	35		No firming or 0 reserve margin
Geo w/o NREL w/reserve rqt.	82		82	9	90		Geothermal plants are 1/4 of one Diablo unit
<u>Traditional "Baseload"</u>							
Aging Reactors w/reserve	70		70	8 - 32	78 -102		Low is 1 unit at 90%, High is 2 New at 80%, with firming
New Small Reactor w/reserve			120	8	128		" "
New Reactor w/reserve	141-221	141-221	8-32	148-253			

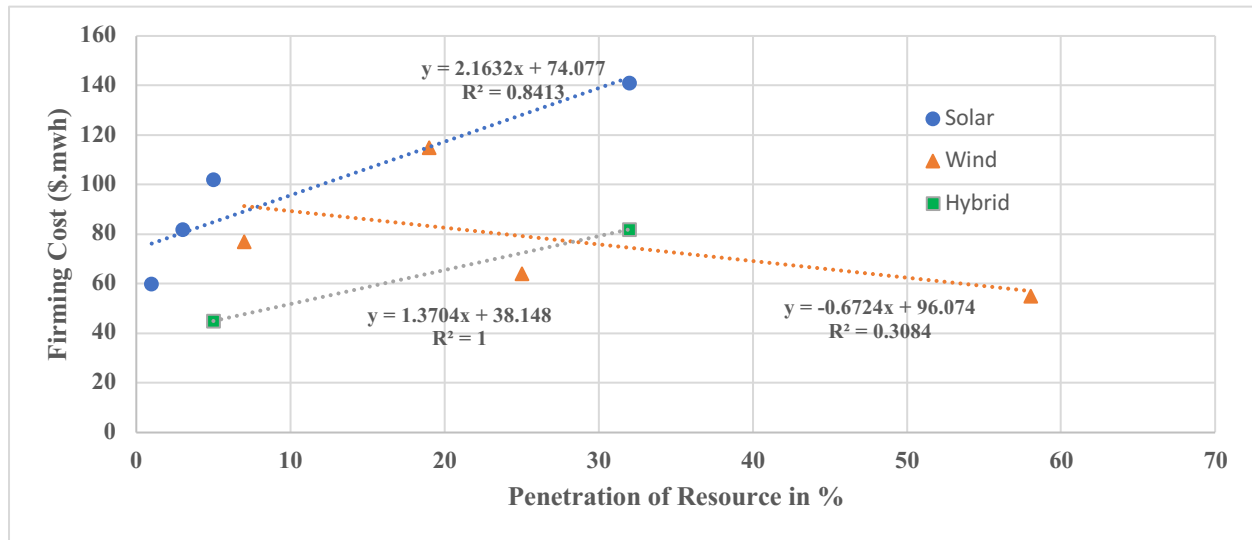
Source: Lazard, *Levelized Cost of Energy, V. 16.0*, pp. xx.

REGIONAL FIRING ANALYSIS



Penetration 3% 1% 5% 32% 25% 58% 7% 19% 5% 32%

RESOURCE PENETRATION AND FIRING COSTS



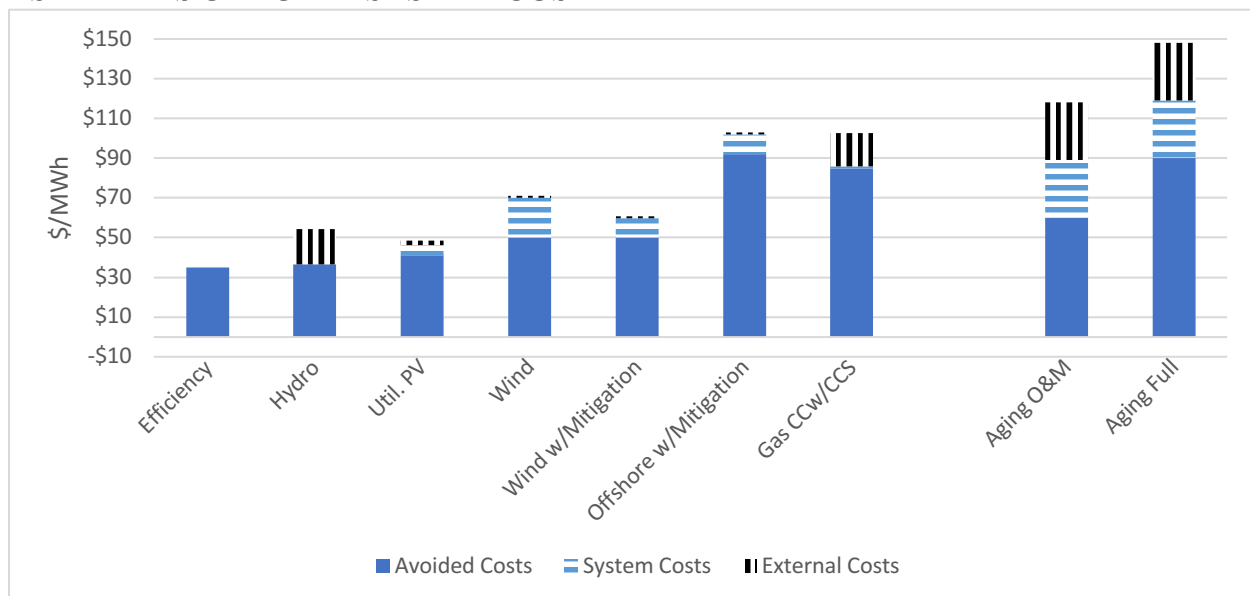
Source: Lazard, *Levelized Cost of Energy*, V. 16.0, pp. 7, 8, 31, 35, 37-40

VALUE COST RATIO

Resource	Value Ratio
Efficiency	1.26
Geo w/o NREL	1.25
Solar	1.02
Solar + Storage	0.94
Wind on	0.92
Stand Alone Battery	0.79
Small Nuclear	0.55
Aging Reactors	0.55
GasCC w/ CS New	0.43
GasCC w/ CS retro	0.36
Wind Off	0.35

Source: Energy Information Administration (EIA), 2022, *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook*, pp. 12-13

ESTIMATES OF TOTAL SYSTEM COST



Source: EIA, 2018, *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2018*, February Tables 2 and 3, for the adjustment to levelized costs to account for the value of output, using capacity weighted averages where available and unsubsidized costs. Wisner, Ryan, Andrew Mills and Joachim Seel, 2015. Argonne and Lawrence Berkeley National Laboratories, Chapter 5. Lazard, 2018. Lazard's Levelized Cost of Energy Analysis – Version 12.0 for LCOE, 10. For carbon costs, NRC, 2010, *The Hidden Cost of Electricity*, for non-carbon pollution costs of gas, with other resources expressed as a multiple of gas.

PPA PRICES AND NET VALUE FOR MAIN RENEWABLE RESOURCE

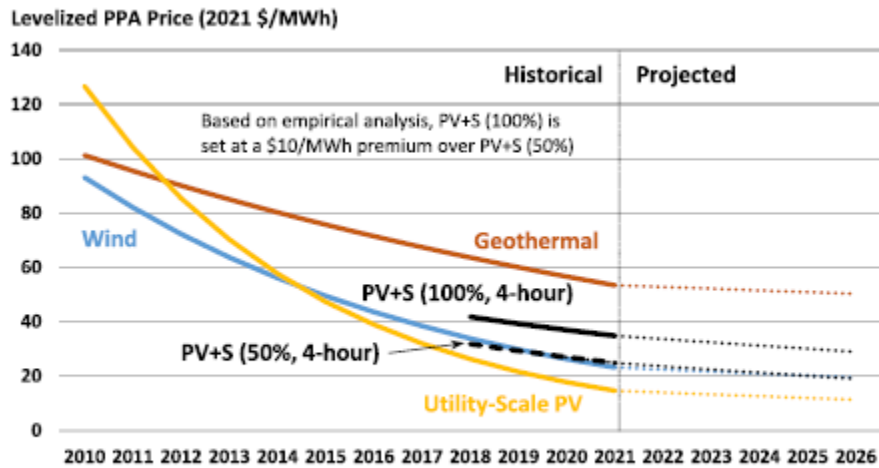


Fig. 4. PPA price trends and extrapolation based on 2022 ATB.

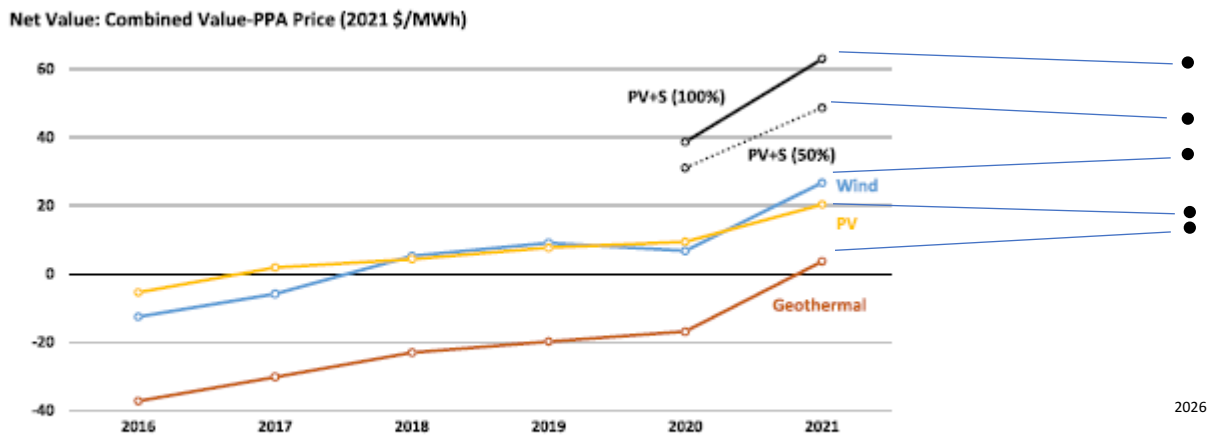
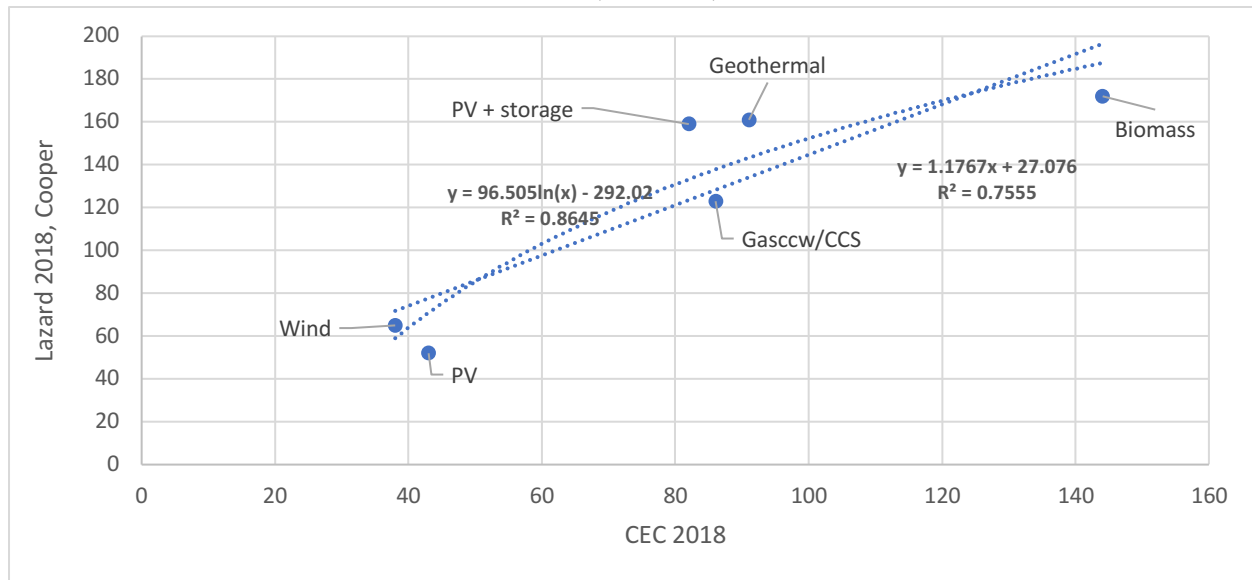


Fig. 7. Net value of PV, wind, geothermal, and PV + S in the West.

Source: Bolinger, Mark, et al., 2023, "Mind the Gap: Comparing the Net Value of Geothermal, Wind, Solar, and Solar+Storage in the Western United States," *Science Direct*.

COMPARISON OF LEVELIZED COSTS (\$/MWH)



Sources, Staff Report, 2019, "Estimated Cost of New Utility-Scale Generation in California: 2018 Update," California Energy Commission, May, Lazard, 2018, 2022, MNC-2.1, NREL, ATB, 2022, for Biomass.

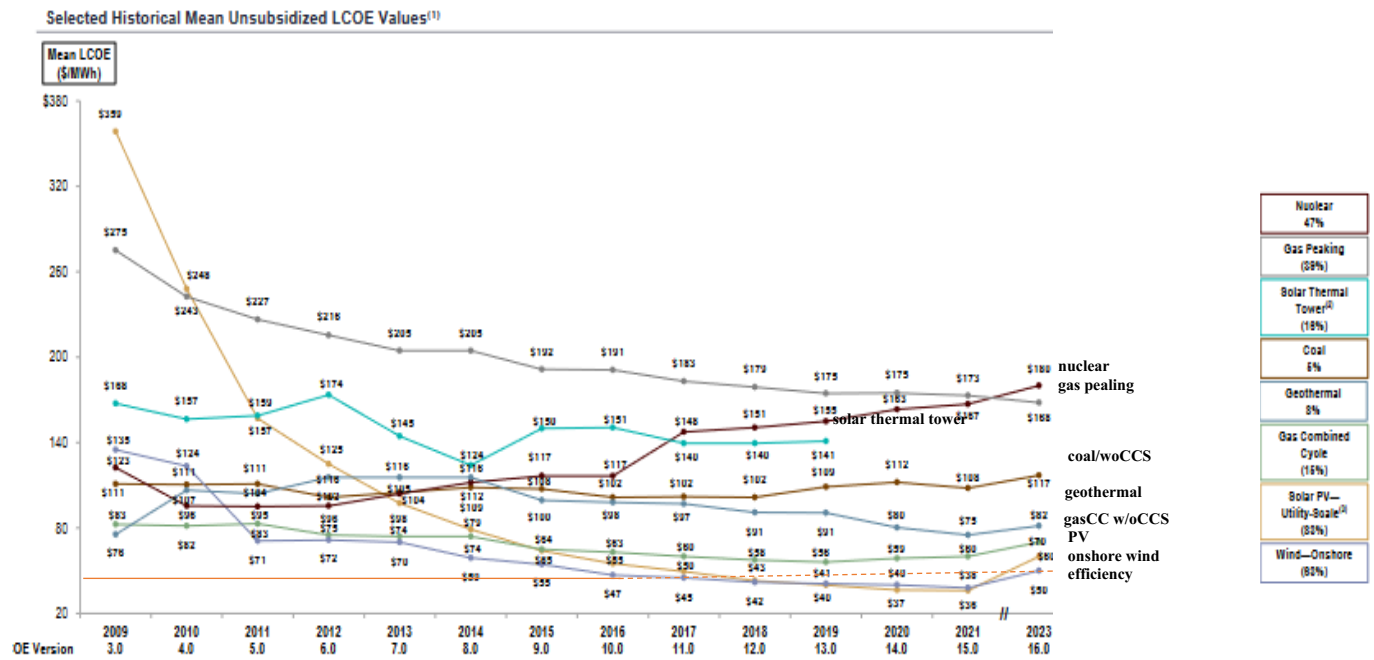
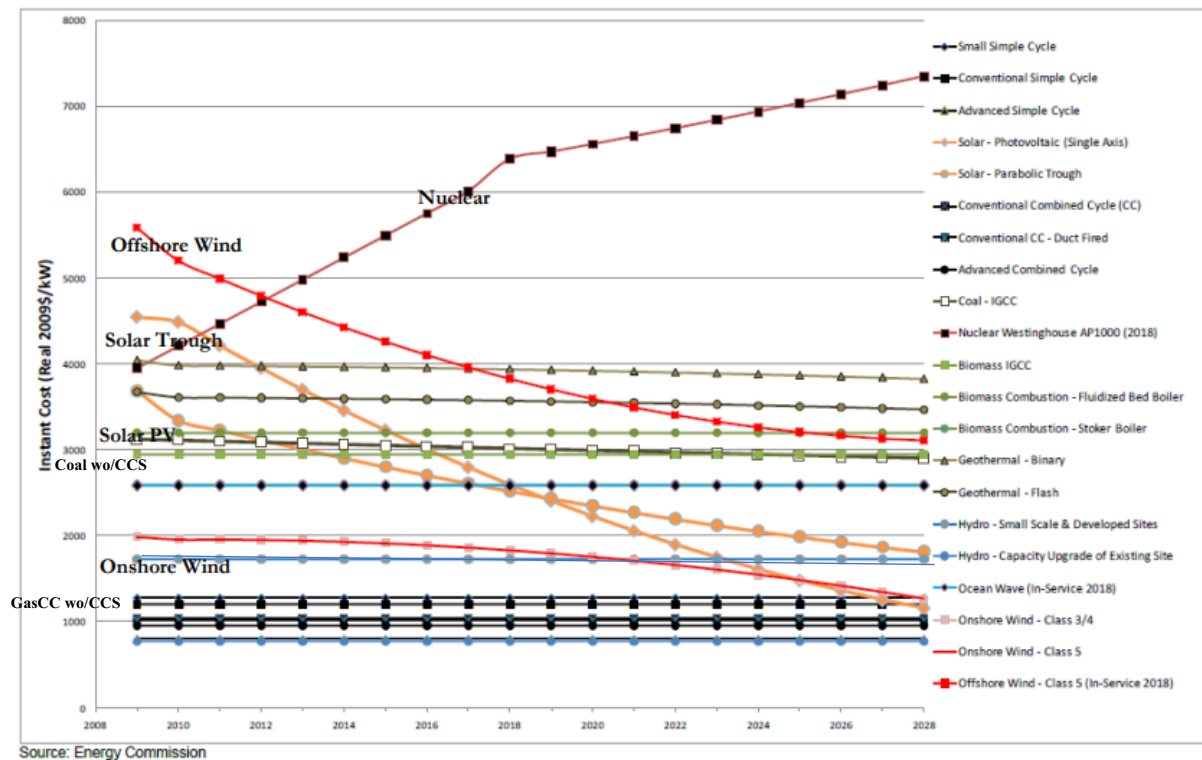


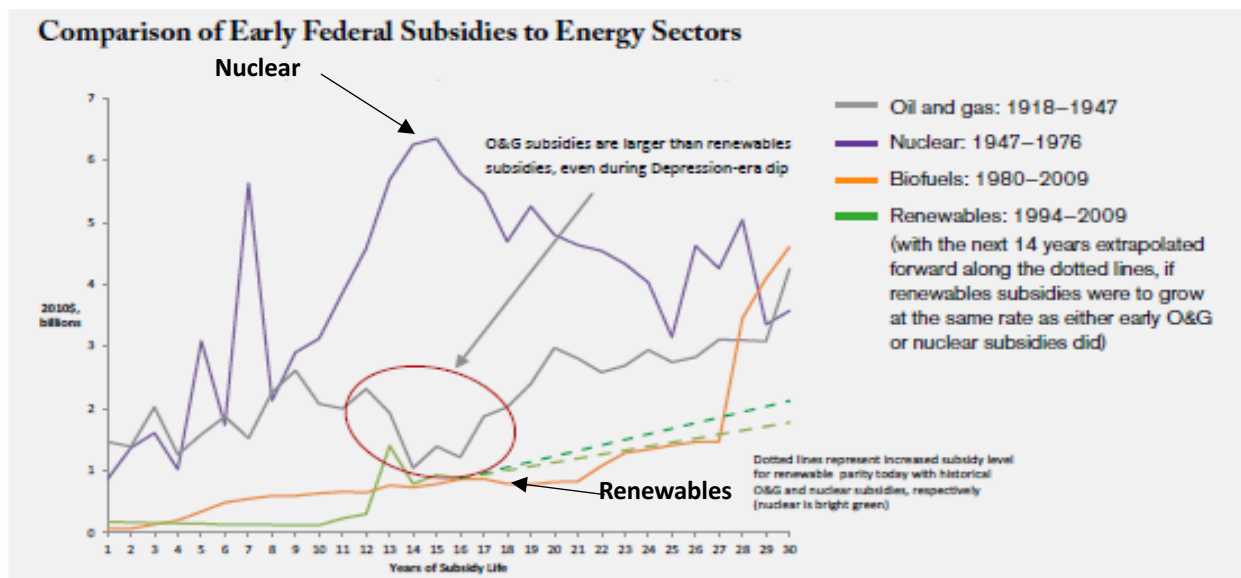
EXHIBIT VI-7: CALIFORNIA ENERGY COMMISSION OVERNIGHT COST TRENDS (JANUARY 2010)

Figure 3: Average Instant Cost Trend (Real 2009 \$/kW)



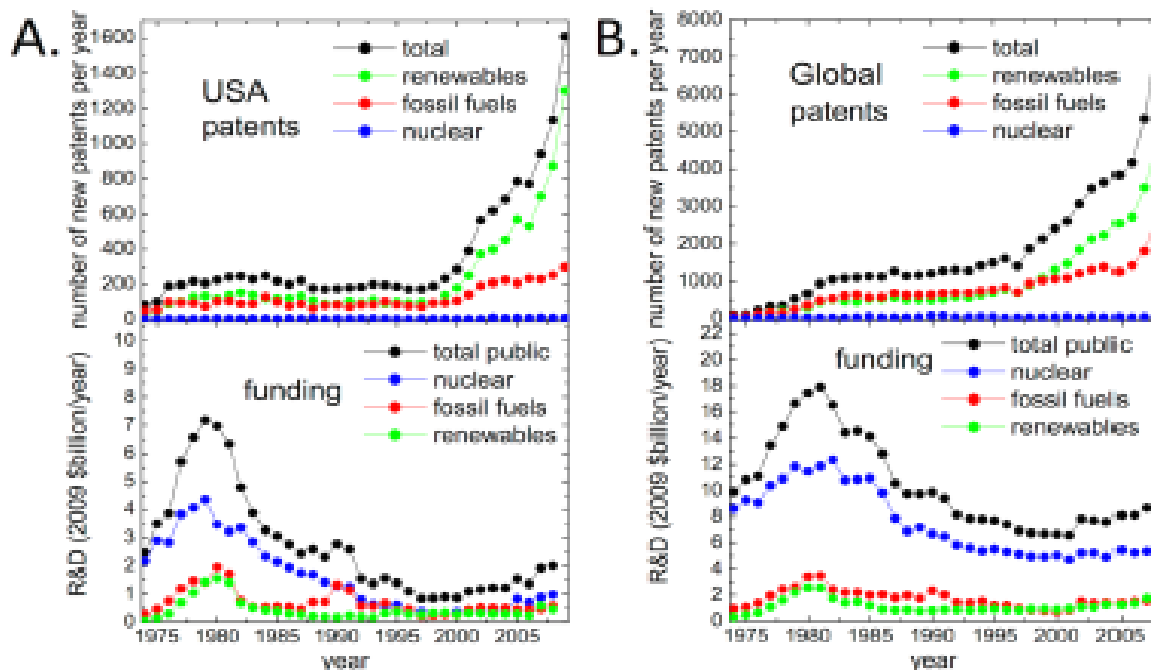
Source: Mark Cooper, 2012, Nuclear Safety and Nuclear Economics, Fukushima Reignites the Never-Ending Debate: Nuclear Safety at an Affordable Cost, Can We Have Both? Is Nuclear Power Not Worth the Risk at Any Price? Symposium on the Future of Nuclear Power University of Pittsburgh March 27-28.

FEDERAL SUBSIDIES FOR INFANT ENERGY INDUSTRIES AND BEYOND



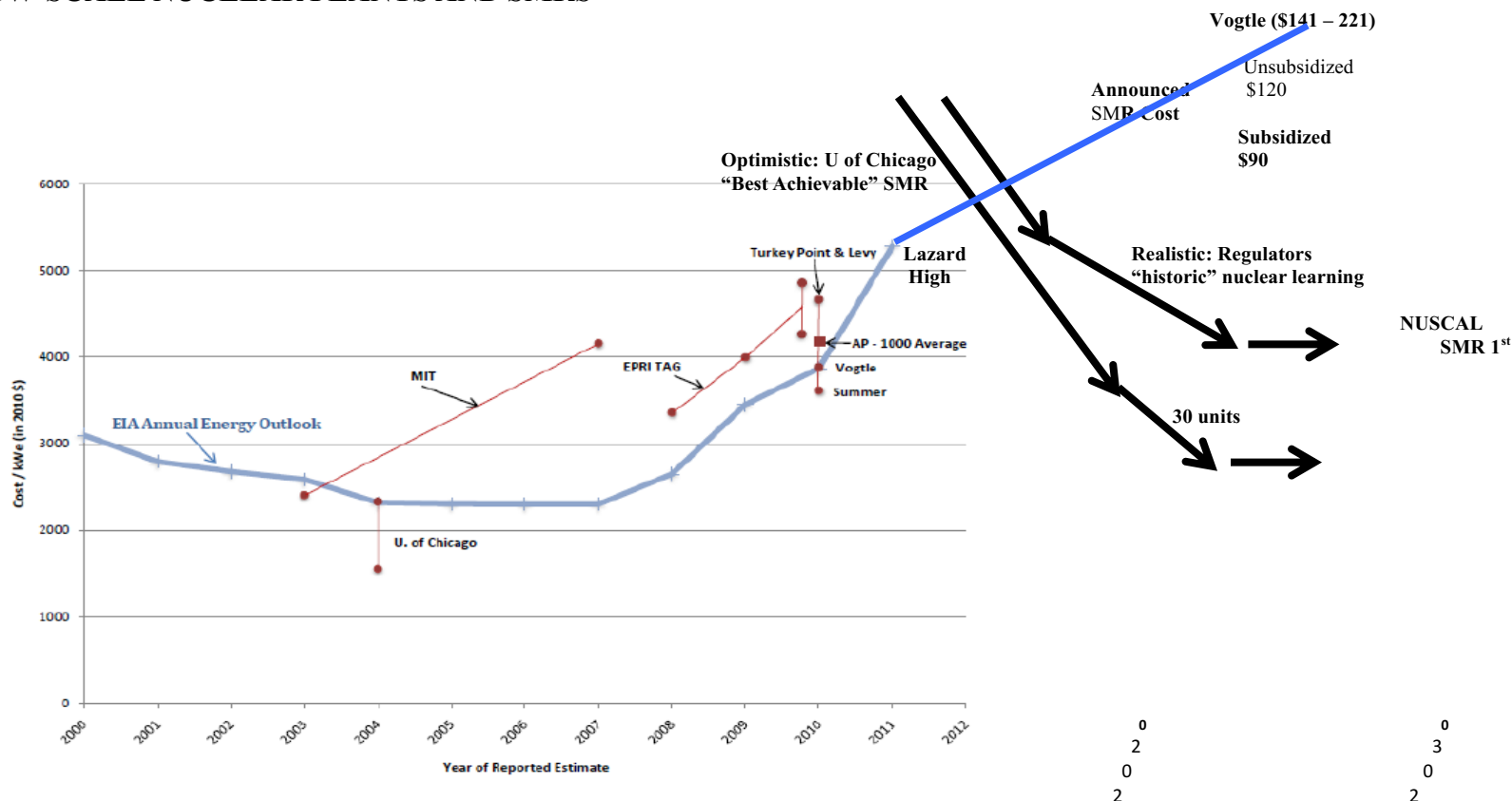
Source: Nancy Pfund and Ben Healey, What Would Jefferson Do? The Historical Role of Federal Subsidies in Shaping America's Energy Future, Double Bottom Line Investors, September 2011, pp. 29–30. A similar conclusion, from the point of view of the effectiveness of subsidies in innovation can be found in Bettencourt, Louis M.A., Jessica E. Trancik, and Jasleen Kaur, 2013, "Determinants of the pace of global innovation in energy technologies," *PLoS ONE*, October 8, p. 10.

INNOVATION AND PUBLIC SUPPORT FOR R&D



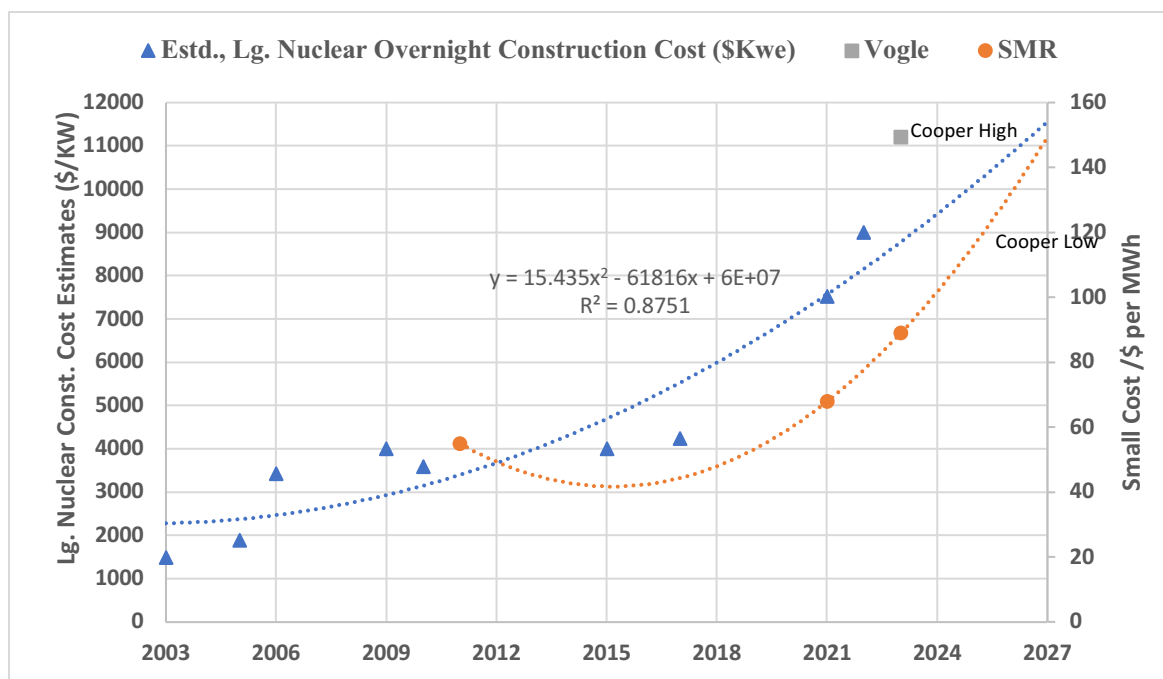
Source: Bettencourt, Louis M.A., Jessica E. Trancik, and Jasleen Kaur, 2013, "Determinants of the pace of global innovation in energy technologies," *PLoS ONE*, October 8, p. 10.

UNIVERSITY OF CHICAGO RECAP OF ENTHUSIAST/UTILITY ESTIMATES OF OVERNIGHT COST FOR NEW GW-SCALE NUCLEAR PLANTS AND SMRS



Sources: Mark Cooper, "Small modular reactors and the future of nuclear power in the United States," *Energy Research & Social Science* 3 (2014) 161; Rosner, Robert and Stephen Goldberg, 2011, *Small Modular Reactors – Potentially Key Contributors to Future Nuclear Power Generation in the U.S.*, Center for Strategic and International Studies, December 1; Rosner, Robert, et al., *Analysis of GW-Scale Overnight Capital Costs*, EPIC, University of Chicago, Technical Paper Nov. 2011. For the cost and other problems with the only active U.S. small modular Reactor see, h. V. Ramana, 2020, *Eyes Wide Shut: Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors*, Oregon Physicians for Social Responsibility.

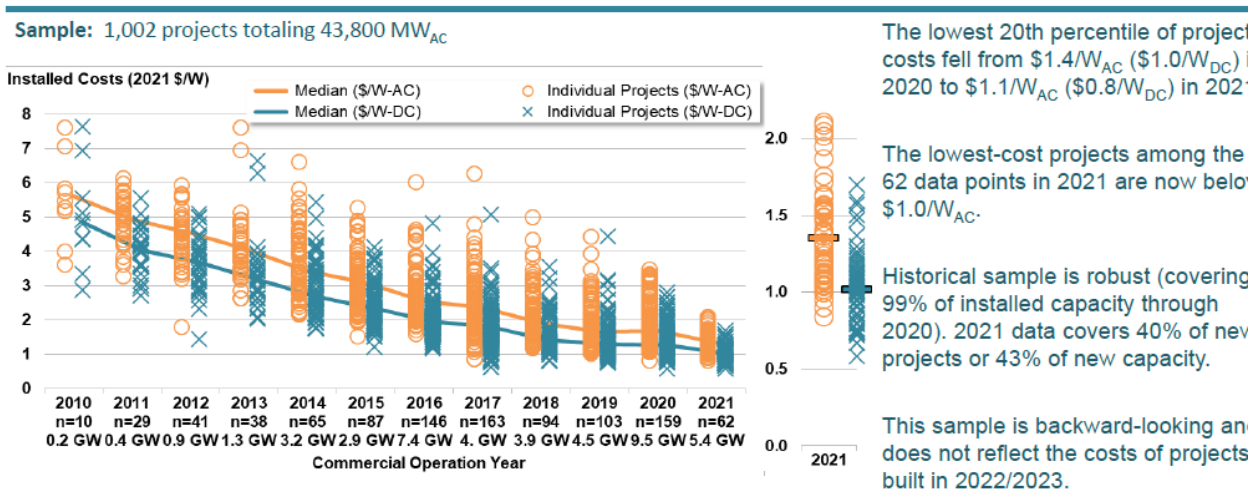
RECENT ESTIMATES AND TRENDS OF NUCLEAR NEW BUILD COSTS



Sources: David Schlissel, 2023, *Eye-popping new cost estimates released for NuScale small modular reactor*, IEEA, January 11, [David Kemp](#) and [Peter Van Doren](#), 2023, “Cost Escalation and Delays for Small Modular Reactors Suggest Caution about Nuclear Power Renaissance,” *CATO*, March 23, David Kemp and Peter Van Doren, 2022, “Nuclear Power in the Context of Climate Change, Comparing the Cost of Nuclear and Fossil Fuel Power Plants with a Carbon Tax,” *CATO*, July 26

SHARPLY DECLINING PRICES OF RENEWABLES IN THE 2ND DECADE OF THE 21ST CENTURY

Solar

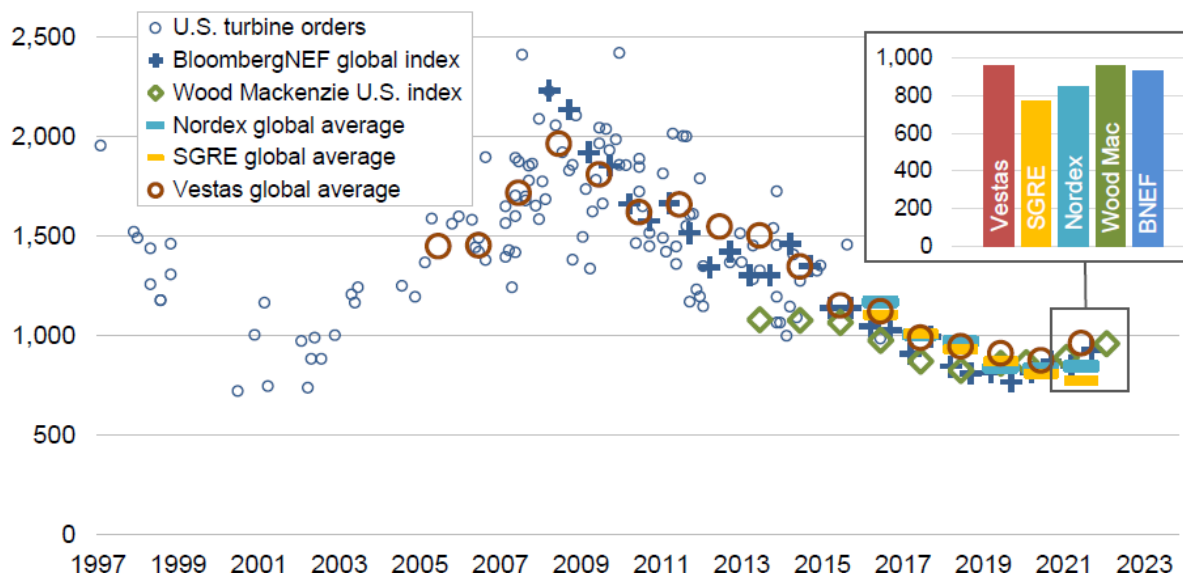


Utility-Scale Solar, 2022 Edition
<http://utilityscalesolar.lbl.gov>

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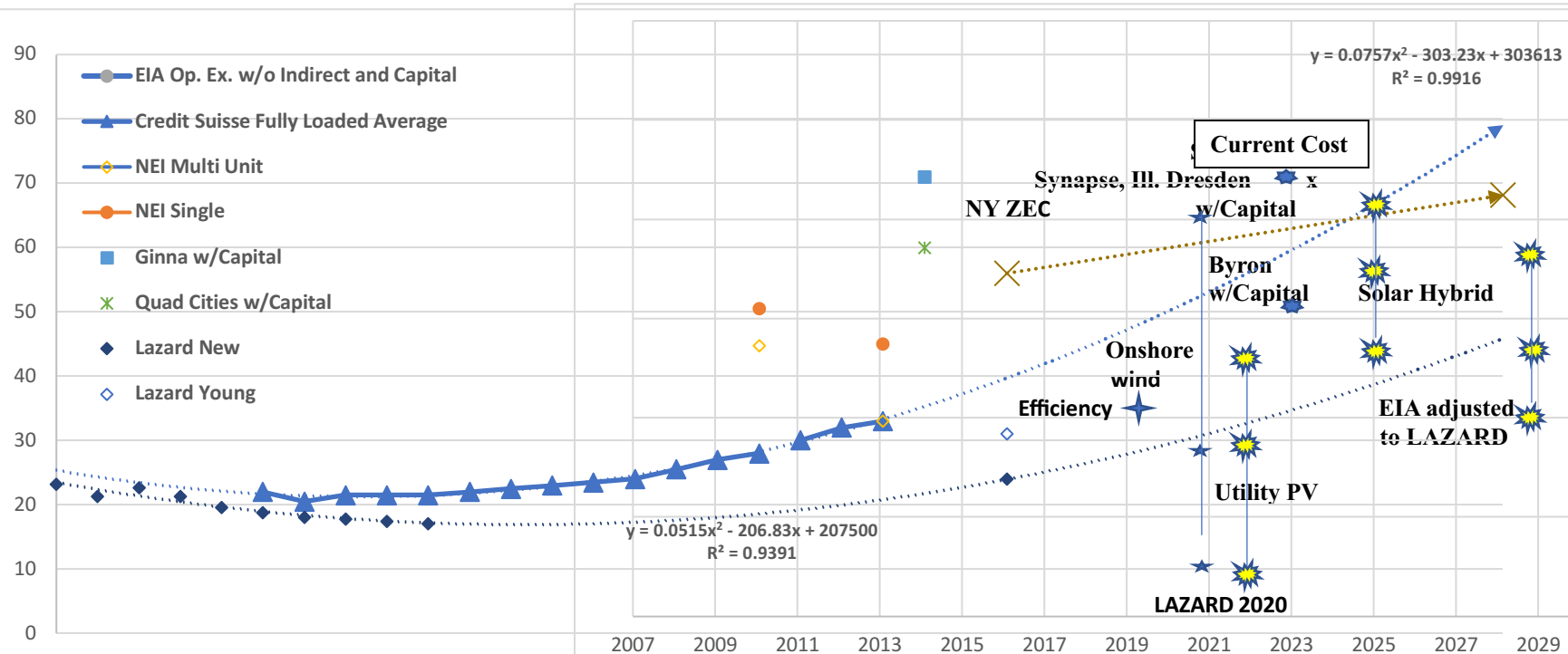
Wind

Turbine Price (2021 \$/kW)



Sources: Berkeley Lab, annual financial reports, forecast providers

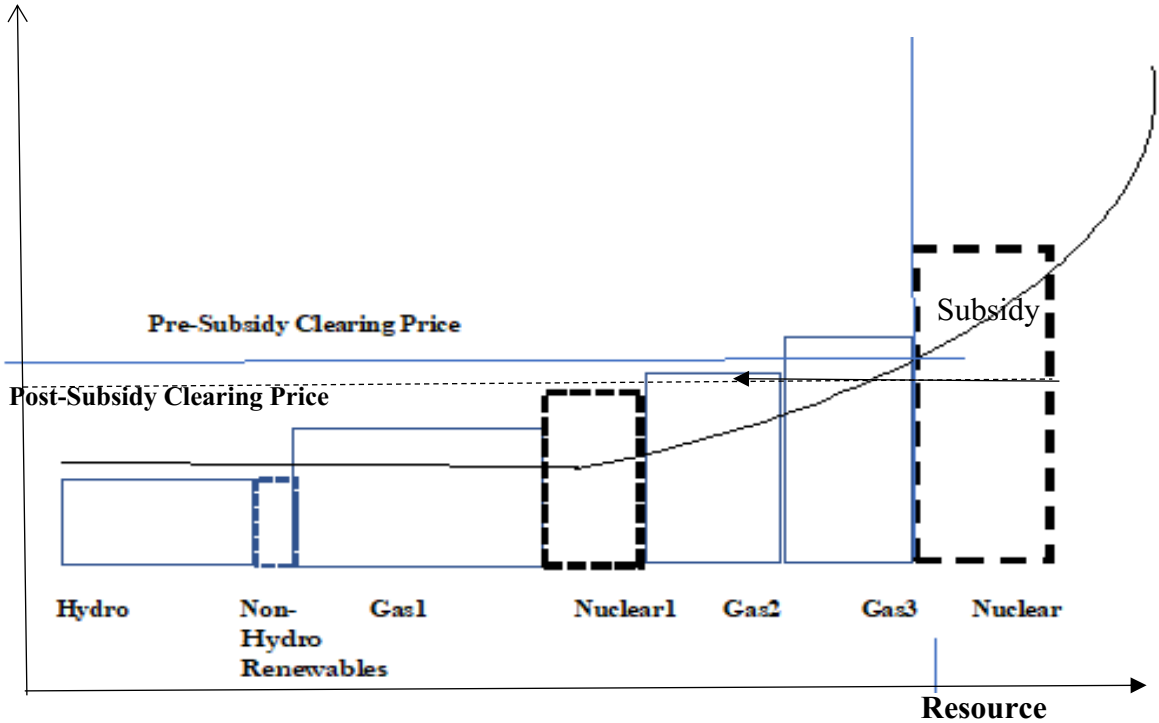
COST OF AGING REACTORS COMPARED TO ALTERNATIVES



Sources: Eggers, Dan, Kevin Cole, and Matthew Davis. Nuclear . . . The Middle Age Dilemma? Facing Declining Performance, Higher Costs, Inevitable Mortality. Credit Suisse, 2013; Lazard. Lazard's Levelized Cost of Energy Analysis 12.0, November 2018, Nuclear Energy Institute, Nuclear Costs in Context, October, 2018; 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>); 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. "Comments of Dr. Mark Cooper." In the Matter of Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, Environmental Protection Agency, RIN 2060-AR33, November 24, 2015. Comments by Alliance For A Green Economy and Nuclear Information and Resource Service, Proceeding on Motion of the Commission to Implement a Large-Scale Renewable Program and a Clean Energy Standard, Case 15-E-0302, April 22, 2016; RE: Case 15-E-0302- In the Matter of the Implementation of a Large-Scale Renewable Program and a Clean Energy Standard Re: Case 16-E-0270: Petition of Constellation Energy Nuclear Group, LLC; R.E. Ginna Nuclear Power Plant, LLC; and Nine Mile Point Nuclear Station, LLC to Initiate a Proceeding to Establish the Facility Costs for the R.E. Ginna and Nine Mile Point Nuclear Power Plants, July 22, 2016. Energy Information Administration, Electricity Annual, 2015, Table 8.3. Lazard, *Levelized cost of Energy Analysis*, 14.0; Bhandari, Divita, et al., *Exelon Nuclear Fleet Audit, Findings and Recommendations*, Synapse, April 14, 2021,

MARKET DISTORTION CAUSED BY THE AGING NUCLEAR REACTOR SUBSIDY, CROWDING OUT NON-HYDRO-RENEWABLES

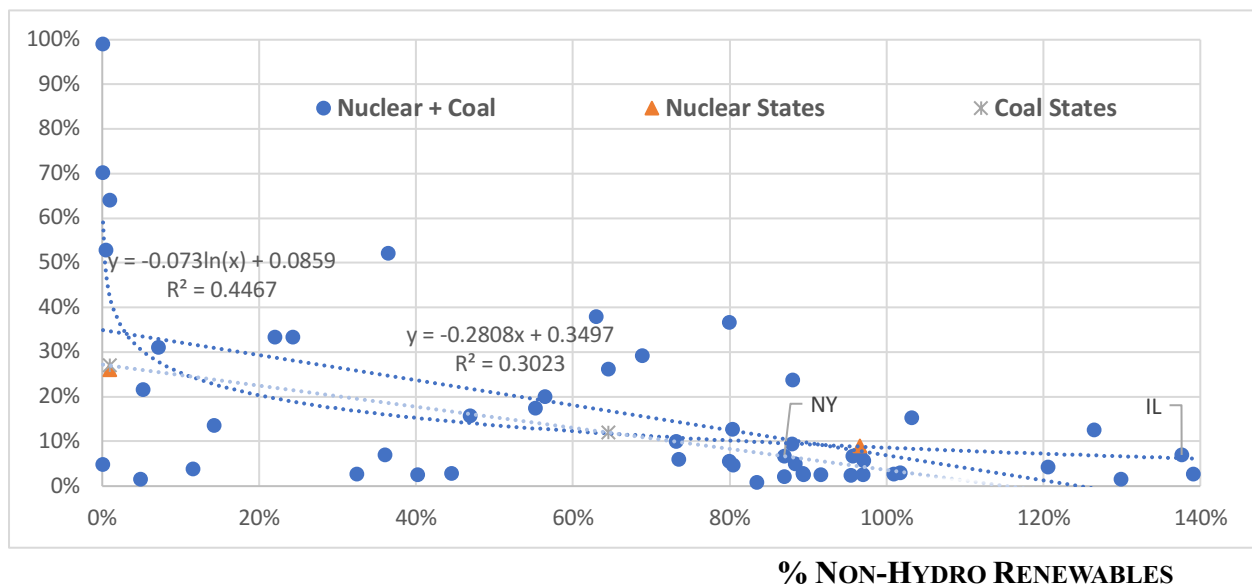
Quantity



Source: Based on Mark Cooper, 2017a, *The Political Economy of Electricity, Progressive Capitalism and the Struggle to Build a Sustainable Power Sector*, p. 184 presents the conceptual figure, p. 194 present the real world situation in Illinois.

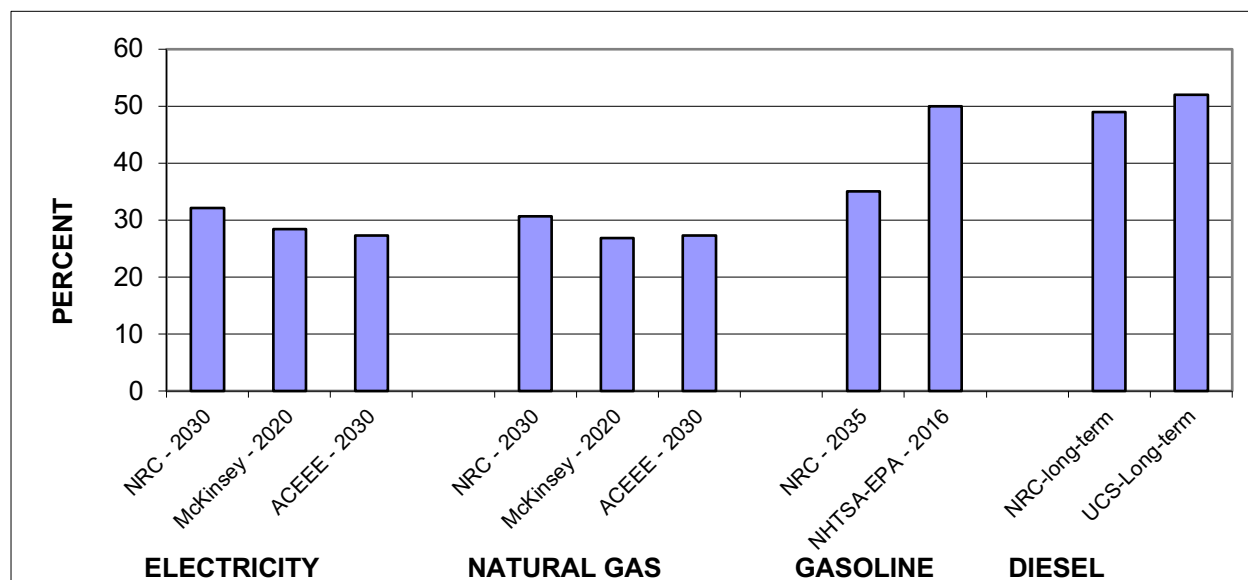
NUCLEAR V. NON-NUCLEAR STATES

% NUCLEAR



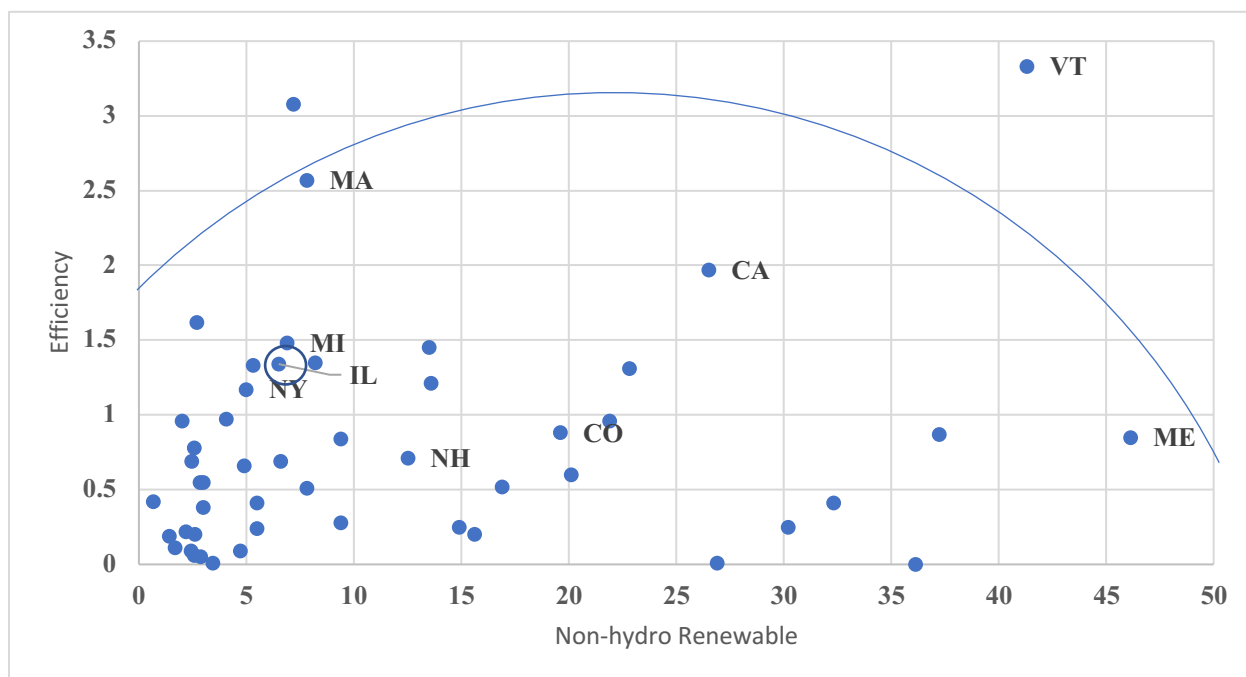
Source: U.S. Energy Information Administration, *Electricity Generation, database*, 2018

EFFICIENCY GAP ACROSS U.S. ENERGY MARKETS: TECHNICALLY FEASIBLE, ECONOMICALLY PRACTICABLE POTENTIAL ENERGY SAVINGS



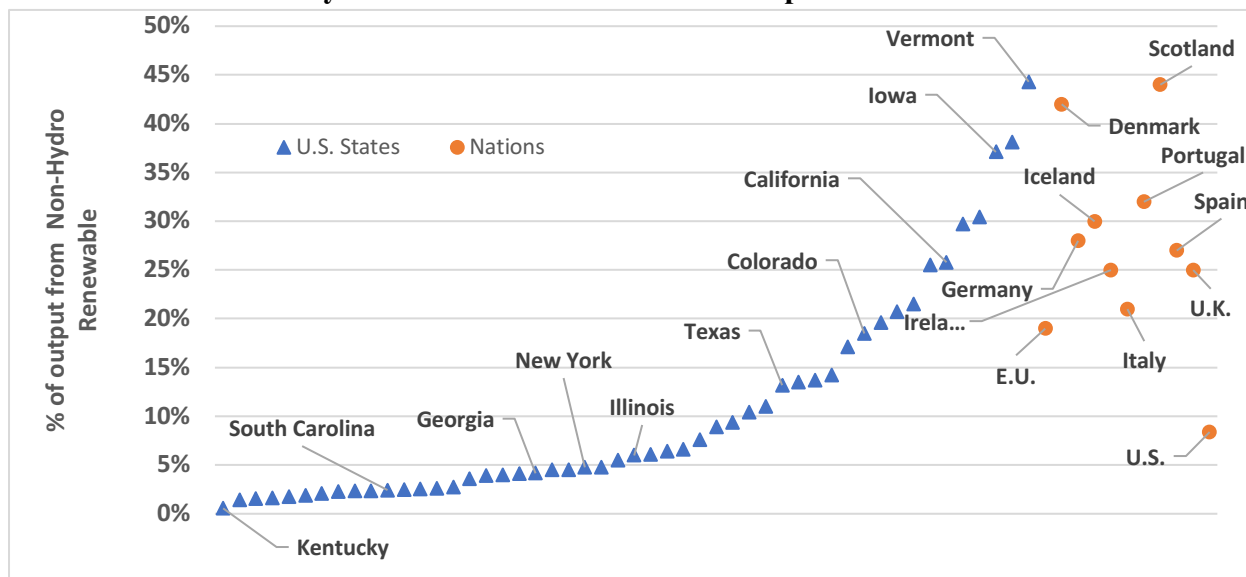
Sources: Cooper, Mark, 2013, *Energy Efficiency Performance Standards: The Cornerstone of Consumer-Friendly Energy Policy*, Comments of the Consumer Federation of America, October. Electricity and natural gas savings based on Gold, Rachel, Laura, et. al., *Energy Efficiency in the American Clean Energy 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 Brow, Sam Borgeson, Jon Koomey and Peter Biermayer, *U.S. Building-Sector Energy Efficiency Potential* (Lawrence Berkeley National Laboratory, September 2008). Gasoline based on: National Highway Traffic Safety Administration, *Corporate Average Fuel Economy for MY2012-MY 2016 Passenger Cars and Light Trucks, Preliminary Regulatory Impact Analysis*, Tables 1b, and 10. The 7 percent discount rate scenario is used for the total benefit = total cost scenario; NAS -2010, National Research Council of the National Academy of Science, *America's Energy Future* (Washington, D.C.: 2009), Tables 4.3, 4.4; MIT, 2008, Laboratory of Energy and the Environment, *On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions* Cambridge: July, 2008), Tables 7 and 8; EPA-NHTSA - 2010, Environmental Protection Agency Department of Transportation In the Matter of Notice of Upcoming Joint Rulemaking to Establish 2017 and Later Model Year Light Duty Vehicle GHG Emissions and CAFE Standards, Docket ID No. EPA-HQ-OAR-0799 Docket ID No. NHTSA-2010-0131, Table 2, CAR – 2011. Diesel based on: Northeast States Center for a Clear Air Future, International Council on Clean Transportation and Southwest Research Institute, *Reducing Heavy Duty Long Haul Combination Truck Fuel Consumption and CO₂ Emissions*, October 2009; Don Air, *Delivering Jobs: The Economic Costs and Benefits of Improving the Fuel Economy of Heavy-Duty Vehicles*, Union of Concerned Scientists, May 2010; Committee to Assess Fuel Economy for Medium and Heavy Duty Vehicles, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, National Research Council, 2010.

CONTRIBUTION OF EFFICIENCY AND NON-HYDRO RENEWABLES (% OF DEMAND)



Source: ACEEE, *The 2018 State Energy Efficiency Scorecard*, 2018, p. 28; Energy Information Administration, *Electric Supply Monthly*, generation and non-hydro renewables.

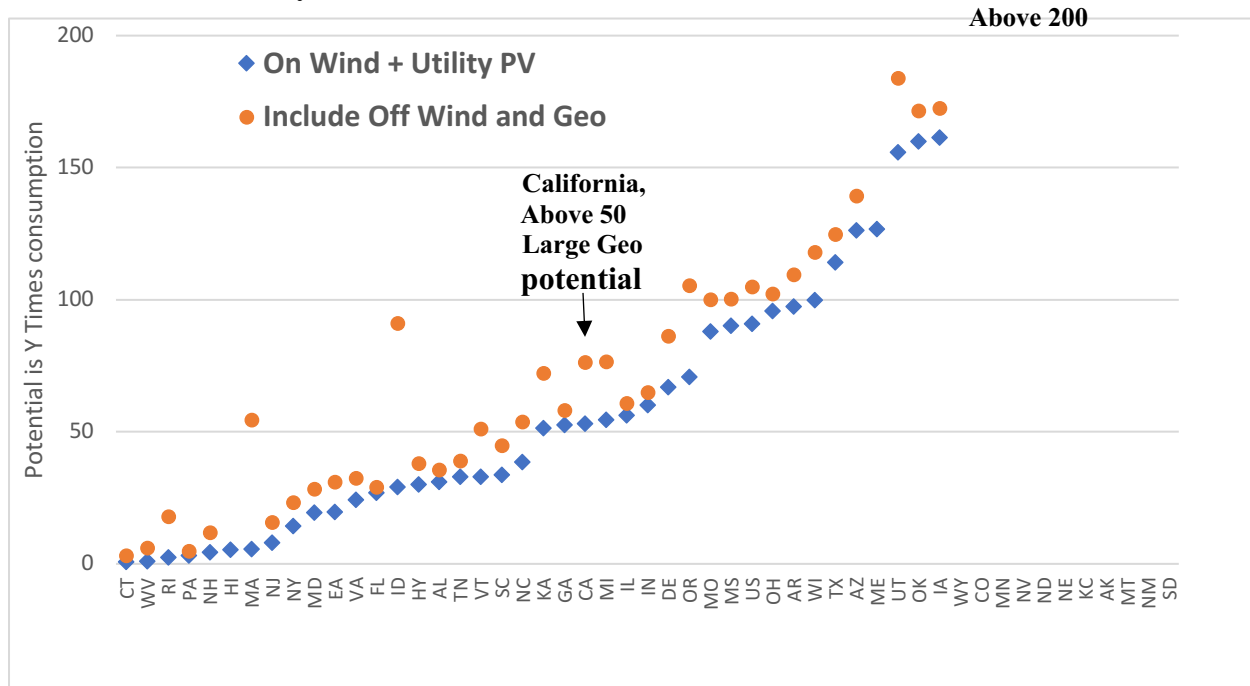
Contribution of Non-Hydro Renewables in a Global Perspective



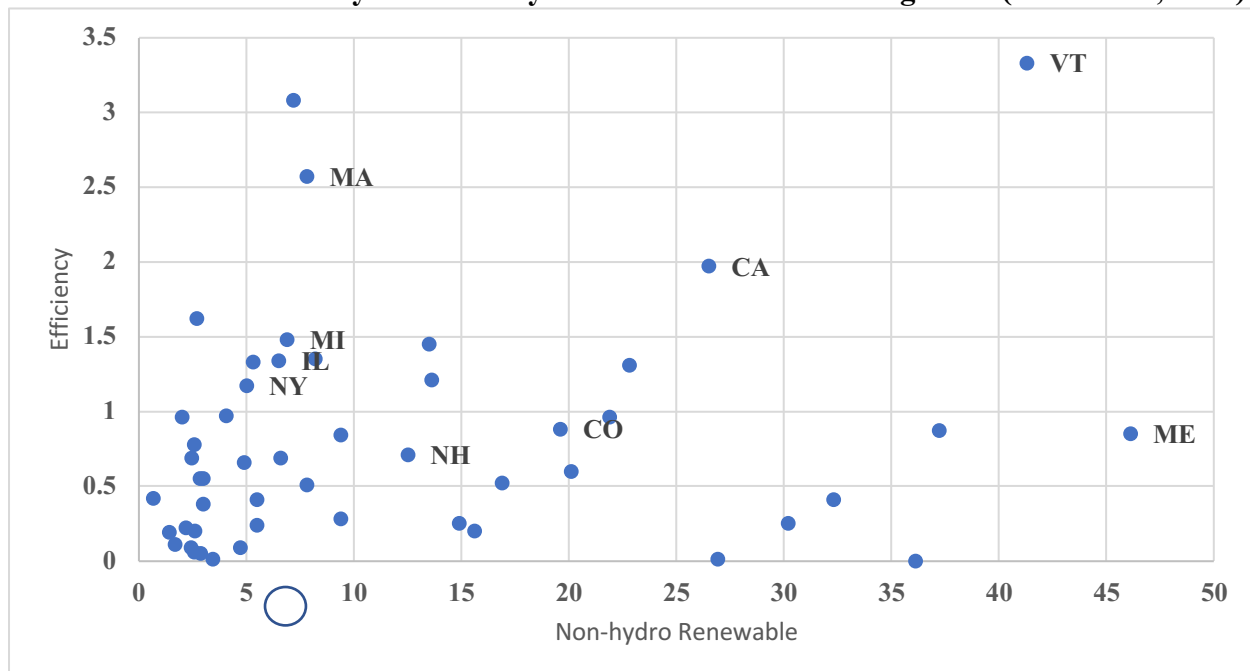
Source: Lovins, Amory B. 2017. "Reliably integrating variable renewables: Moving grid flexibility resources from models to results." *The Electricity Journal*, 30(10)

ASSESSING THE ADEQUACY OF SUPPLY, POTENTIAL SUPPLY COMPARED TO DEMAND

Onshore Wind, Utility PV, Off Wind and Geothermal



Contribution of Efficiency and Non-Hydro Renewables to Meeting Need (% of Total, 2017)

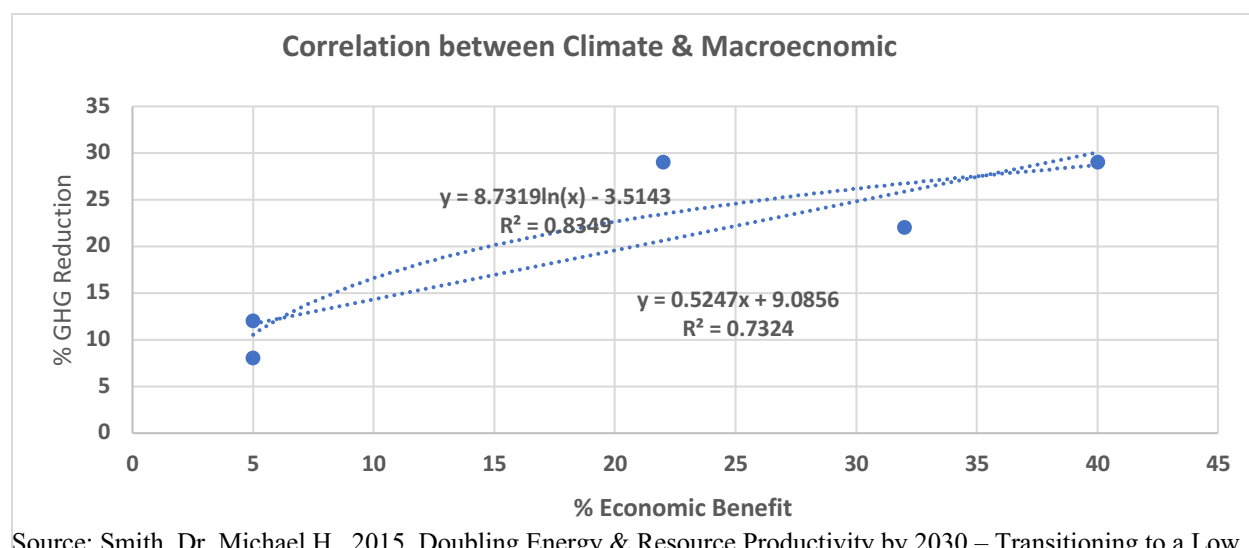


Source: ACEEE, *The 2018 State Energy Efficiency Scorecard*, 2018, p. 28; Energy Information Administration, Electric Supply Monthly, generation and non-hydro renewables.

STRATEGIES FOR LIMITING CLIMATE CHANGE & INCREASING ENERGY PRODUCTIVITY

Strategies	Greenhouse Gas Reductions		Improved Energy Productivity	
	GtC	% of Total	% Incr. in GDP	% of Total
Mitigation				
Energy	5 ^{7/8}	33		
Renewables				
Solar	4 ^{1/4}		Low cost supply	40
Wind	1		Peak Load reduction	5
Geothermal	^{1/8}			
Conventional fuel efficiency	^{1/2}			
Efficiency Primarily Business	4	22	Industrial Savings	60
Building Const.	1 ^{1/2}		Materials	30
Waste & recycling	1		Automation	10
Motors	^{1/2}		Buildings	20
Processes	1			
Efficiency Primarily Residential*	3 ^{7/8}	22	Ambient Quality (also labor)	61
Transportation	3 ^{1/4}	18	Ventilation	11
Cars (fewer miles (more efficiency))	2		Lighting	23
Trucks* (efficiency)	^{3/4}		Temperature	18
Air	^{1/2}		Hospital stay length	9
Cropping & Grazing	1	6	Agriculture	25
Deforestation Halt	1	6	Forestry	17
Total	18	100	(with overlap)	208

* Includes ^{1/2} black carbon.



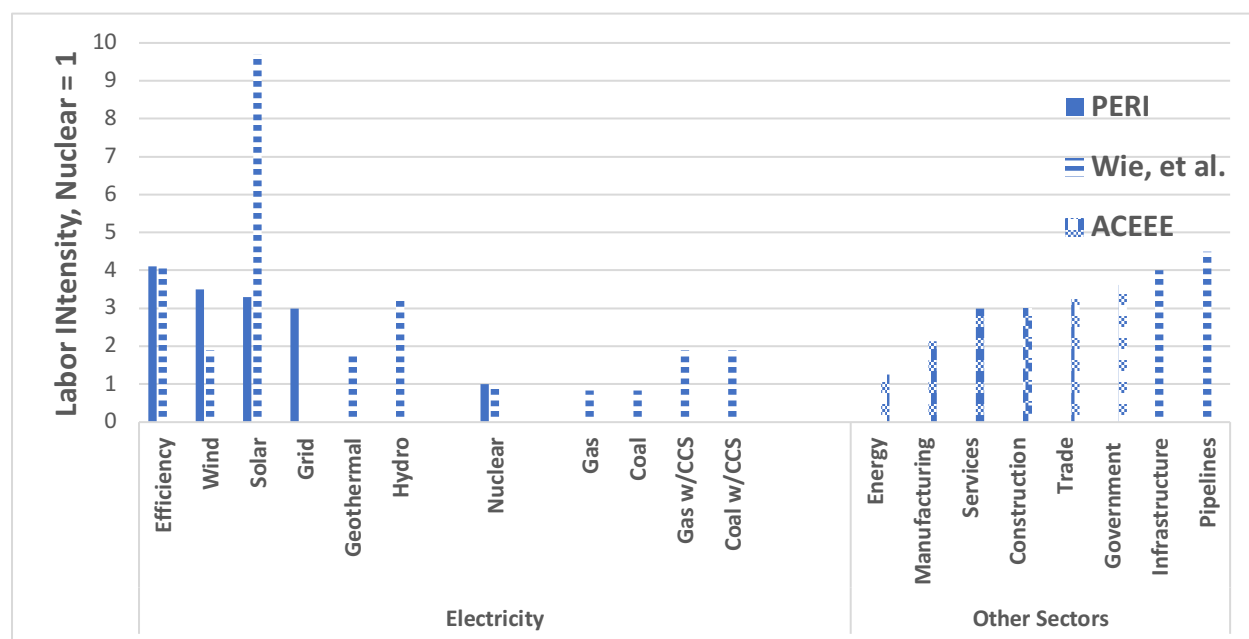
Source: Smith, Dr. Michael H., 2015, Doubling Energy & Resource Productivity by 2030 – Transitioning to a Low Carbon Future through Sustainable Energy and Resource Management, ANU discussion Paper.

MACROECONOMIC MULTIPLIERS AS A MULTIPLE OF NET POCKETBOOK SAVINGS

Modeler	Model Date	Policy Assessed	Region	GDP/\$ of Net Savings	
				Base Case Adjustment	Rebound
Roland-Holst	DEAR	Computer Standard	California	1.8	2.0
ENE	REMI	Utility Efficiency	Northeast	2.2	2.4
Cadmus	REMI	Utility Efficiency	Wisconsin	2.5	2.8
Arcadia	REMI	Utility Efficiency	Canada	2.7	3.0

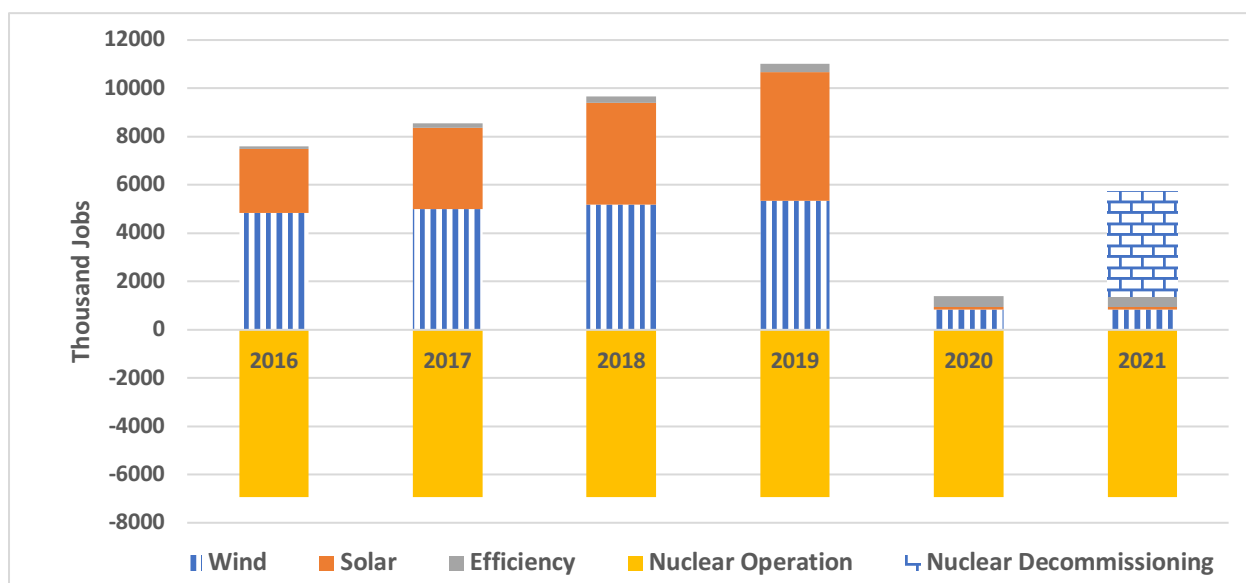
Sources: David Roland-Holst, 2016, *Revised Standardized Regulatory Impact Assessment: Computers, Computer Monitors, and Signage Displays*, prepared for the California Energy Commission, June. ENE, *Energy Efficiency: Engine of Economic Growth: A Macroeconomic Modeling Assessment*, October 2008. Cadmus, 2015, *Focus on Energy, Economic Impacts 2011–2014*, December. Arcadia Center, 2014, *Energy Efficiency: Engine of Economic Growth in Canada: A Macroeconomic Modeling & Tax Revenue Impact Assessment*, October 30,

MACROECONOMIC MULTIPLIERS FOR ELECTRICITY RESOURCES & ECONOMIC SECTORS



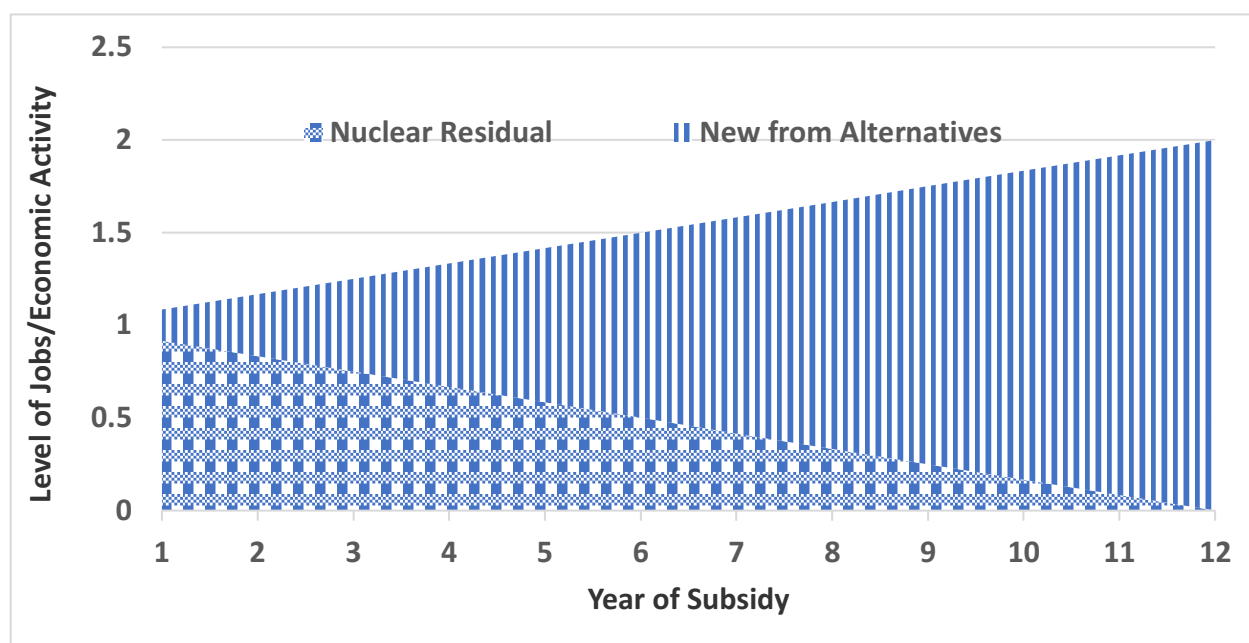
Sources: Wie, Max Shana Patadia and Daniel Kammen, 2010, “Putting Renewables and Energy Efficiency to work: How Many Jobs Can the Clean energy Industry Generate in the US?”, *Energy Policy*, 38. Rachel Gold, et al., *Appliance and Equipment Efficiency Standards: A Money Maker and Job Creator*, American Council for an Energy Efficient Economy, January 2011, p. 9, based on the IMPLAN Model, 2009., *How Infrastructure Investments Support the U.S. Economy: Employment, Productivity and Growth*, James Heintz, Robert Pollin, Heidi Garrett-Peltier, Political Economy Research Institute, January 2009.

JOBS IMPACT OF EARLY RETIREMENT AND REPLACEMENT, INCLUDING DECOMMISSIONING



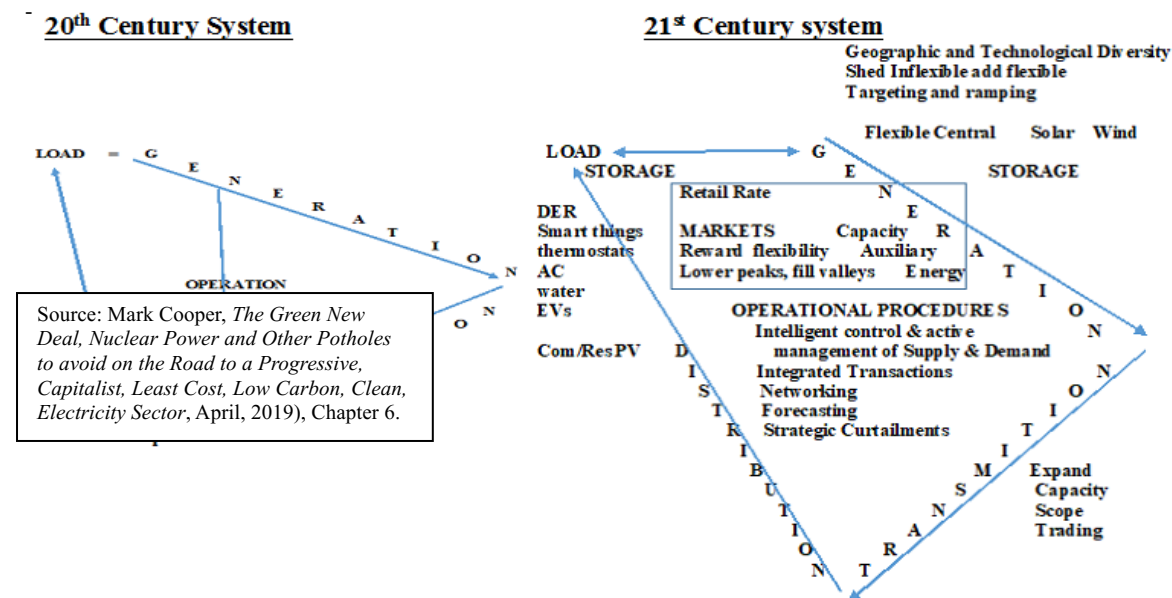
Sources: Illinois Commerce Commission, Illinois Power Agency, Illinois Environmental Protection Agency, Illinois Department of Commerce and Economic Opportunity, *Potential Nuclear Power Plant Closings in Illinois: Impacts and Market-Based Solutions, Response to The Illinois General Assembly Concerning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

IMPACT OF RETIRING UPSTATE REACTORS: JOBS/MACROECONOMIC IMPACT



Source: Adapted from Mark Berkman and Dean Murphy, *New York's Upstate Nuclear Power Plants' Contribution to the State Economy prepared for New York State IBEW Utility Labor Council, Rochester Building and Construction Trades Council, Central and Northern New York Building and Construction Trades Council, Brattle Group*, December 2015

CREATING THE 21ST CENTURY ELECTRICITY SYSTEM:



FUNDAMENTAL DIFFERENCES BETWEEN CENTURIES AND SYSTEMS

<u>Characteristic</u>	<u>20th Century</u>	<u>21st Century</u>
Goal	Redundancy (as resilience)	Flexibility (resilience as a result)
Operational objective	Increase capacity to follow load	Integrate & match supply and demand
Configuration, size	Island set by economies of generations	Interconnection set by value
Supply-Demand	Segregation	Integration
Demand driver	Dumb load	Smart Retailer
System cost recovery	High, lumpy and fixed	Variable targeted and local
Organization	Centralized	Distributed
Challenges	Increase capacity to follow load	Integrate & match supply and demand
Flash point	50 most expensive hours (>\$10,000)	50 least expensive hours (<\$0)
Market power	High	Low
Optimization Target	Meet peaks	Shave peaks, Fill valleys (shed & shift)
End users role	Passive	Active & Prosumer
Flow:		
Output	Hub & Spoke, linear	Networked, Dynamic & Transparent
Information	Aggregate	Transparent, local
Resources:		
Physical	Fuel, Cement and Boiling Water	Steel, Silicon and Intelligence
Intellectual	Engineering judgement	Communications, Advanced Control
Capital	High for base, low for peak	Moderate for both
Energy intensity	High, concentrated	Low, diffuse

Source: The most recent version, with the contrast between the 20th and 21st century systems is available in Mark Cooper and Mel Hall Crawford, 2021, *Building*, Chapter 4.

PERFORMANCE MEASURES & TOOLS TO MANAGE A 21ST CENTURY ELECTRICITY SYSTEM

1.	Penetration: States	1, 2, 23, 47, 51, 52
2	Nations	1, 32, 36, 53, 54, 55, 56, 57, 58, 59 60, 66, 154
	a. Recent	269, 278, 289, 341, 352, 374, 377, 380, 381
3	Cost: General Components	1, 5, 9, 10, 16, 18, 29, 36, 46, 47, 63, 69, 71, 75, 76, 77, 98, 116, 130, 137, 147, 150, 183, 184, 246
	a. Recent estimates	261, 262, 263, 368, 369
4	System cost/value	5, 75, 155, 184, 217, 243, 244, 260
	a. Recent Estimates	267, 325-327, 386
5	Challenges: With solutions	5, 8, 9, 10, 12, 93, 94, 215, 232
	a. Recent, Deep Decarbonization	276, 376, 269, 274, 280-283, 286, 289, 300, 301, 322, 336, 337, 339, 342-345, 347-351, 353-355, 357, 358-368, 371-373 378, 379, 382, 383, 385, 389, 393, 399,
6	Pure negatives	83, 87, 95, 96, 214, 230
	a. Recent	357, 388, 391, 400
7	Generation (100% Scenarios)	257, 258, 259, 278, 279
7	a. Wind and Solar	261-263, 269, 293, 294, 299, 306-308, 312, 314, 317-319, 324, 325, 330, 332, 333, 341, 346, 396, 397
8	Geographic diversity	5, 7, 8, 12, 36, 151, 152, 153 , 237
9	Technological diversity	7, 8, 10, 15, 36, 38, 44, 102, 151, 237, 240, 246, 247
	a. Recent	289, 302, 304, 341, 377
10	Peak targeted solar	7, 155, 156, 246, 247
11	Quick start/rapid ramp	1, 7, 10, 23, 151, 246
12	Shed inflexible baseload	7, 27, 151, 230, 232, 247
13	Shift to flexible	5, 7, 160, 161, 162, 163, 164, 165, 166, 167, 232
14	Flexible central	1, 2, 26, 60, 84, 85, 183
15	Firm renewables	1, 2, 10, 19, 22, 24, 26, 88
	a. Geothermal	264, 266, 284, 285, 290, 291, 298, 365, 377
16	Value ancillary services;	1, 2, 5, 8, 12, 48, 52, 59, 60, 138, 139, 140, 182, 183, 185
17	Avoid lumpy investment	7, 155
18	Load	1, 3, 26, 70, 105, 106, 107, 108, 109, 110, 111, 112, 113
	a. Recent	368-370
19	Supply-side	7, 169,
20	Target peaks	7, 27, 151, 240
21	Use more in slack, less scarcity	1, 7, 105, 160
22	Demand-side	7, 12, 13, 27, 36, 172, 173, 174, 175, 176, 177, 178, 179, 85
	a. Recent	368, 369
23	Aggressive demand response	7, 27, 151, 175, 177, 178, 179, 181
24	Smart controllers manage use	7, 8, 27, 186, 187
25	Transmission	1, 2, 3, 5, 7, 22, 24, 25, 26, 28, 31, 34, 40, 41, 57, 65, 67, 68, 103, 126, 127, 128, 129, 181, 183, 185, 188, 189, 190, 191, 192
	a. Recent	287, 311, 356
26	Expand balance areas	5, 7, 27, 151, 160, 181
27	Storage	1, 5, 7, 8, 12, 19, 20, 21, 22, 23, 41, 43, 49, 100, 101, 102, 151, 157, 185, 194, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 230
	a. Including Hybrid systems, Long Duration	261, 270, 271, 302, 309, 310, 314, 316, 333, 342, 384
28	Dispatchable, traditional	1, 36, 111, 183, 232
29	Distributed (virtual powerplant)	1, 2, 11, 13, 27, 36, 39, 45, 56, 115, 116, 117, 118, 119, 194, 233, 254
	a. including Virtual Power Plants	368, 369
	Alternative Grid (micro, etc.)	
30	Electric vehicles	1, 11, 13, 35, 104, 113, 114, 233

	a. Recent	340, 348, 375
31	Operational Procedures	1, 7, 12, 25, 26, 136, 212, 213, 231, 250, 252
32	Flexibility/integration	1, 5, 8, 9, 10, 13, 17, 18, 24, 26, 30, 31, 32, 34, 36, 72, 73, 78, 82, 97, 99, 127, 147, 173, 171, 180, 183, 185, 194, 230, 231, 245, 253
	a. Recent (Firming load)	261, 269, 320
33	Integrated Transactions	8, 9, 18, 241, 242
	a. Recent	320, 368, 387
34	Strategic Curtailment	1, 8, 23, 61, 120, 121, 122, 123, 124, 125, 248, 249
35	Improve forecasting	1, 7, 12, 36, 37, 53, 143, 144, 145, 151,, 215, 216, 217, 218, 219
36	Market Design	1, 2, 8, 12, 13, 18, 23, 26, 32, 33, 40, 41, 56, 57, 58, 59, 60, 62, 94, 146, 147, 148, 181, 183, 184, 248, 250, 252
	a. Recent	278, 276, 315, 373, 322, 376-378, 394
37	Positive and Negative prices	1, 5, 8, 10, 17, 57, 148, 181, 235, 238, 253
	a. Recent	269
38	Target fixed cost recovery;	9, 14, 181, 183, 184
	a. Recent	373
39	TOU (cut peaks, fill valleys)	7, 8, 9, 27, 64, 105, 106, 107, 108, 109, 110, 111, 112, 93, 193, 220, 221, 222, 223, 234, 235, 239
40	Smart Grid	1, 3, 7, 8, 11, 12, 22, 42, 79, 80, 81 ,82, 119, 131, 132, 133, 134, 135, 224, 225, 226, 227, 228, 229
	a. Recent	272, 328, 329, 371, 399
41.	CHP	2, 26, 50, 54, 89, 90

Source: Originally presented in Mark Cooper,

NREL CAPITAL COST PROJECTIONS V. REALITY

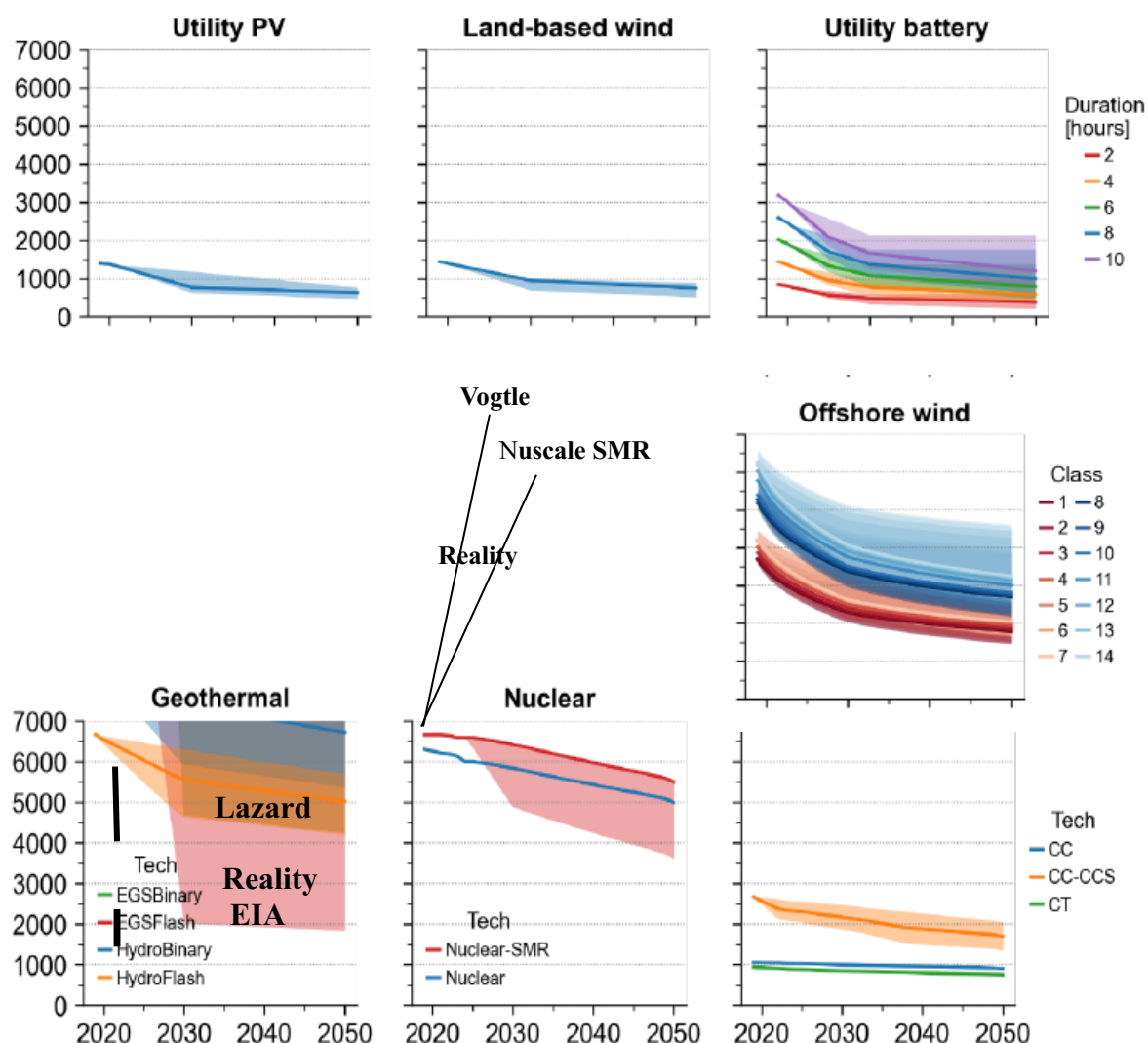


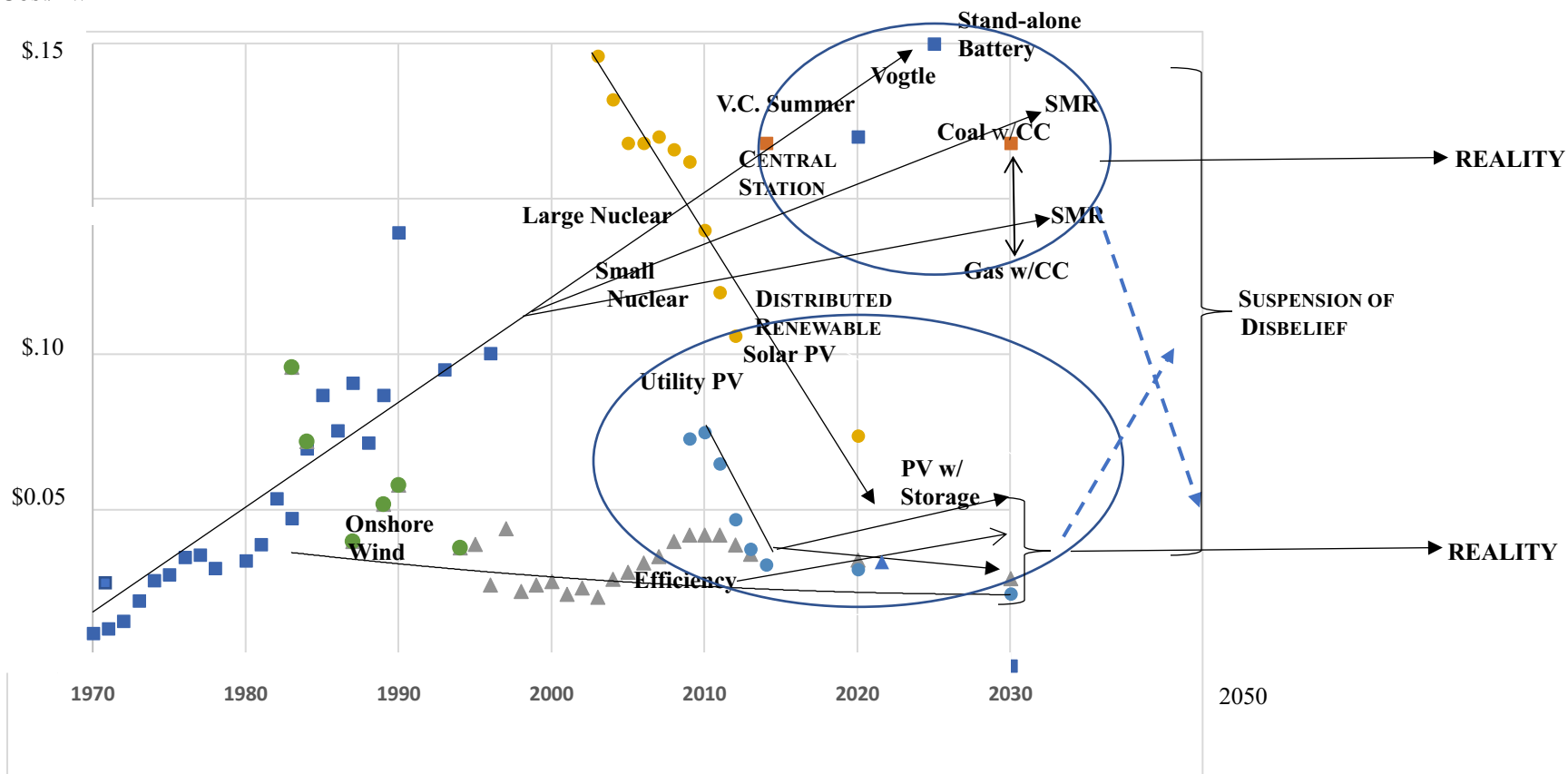
Figure B3. Overnight capital cost inputs for utility-scale solar PV, land-based wind, utility-scale battery energy storage, concentrated solar power (CSP), biopower, offshore wind, geothermal, nuclear, and natural gas under moderate (center line), advanced (bottom of shaded area), and conservative (top of shaded area) cost assumptions

All costs except nuclear and geothermal "advanced" costs are from the 2021 ATB. The advanced cost case for nuclear is based on a trajectory that achieves capital cost targets of \$4,500/kW in 2035 and \$3,600/kW by 2050. The advanced geothermal cases were generated for this report and will be documented in the 2022 ATB. Additional cost details and other input costs are documented in the 2021 ATB (NREL 2021).

Source: Denholm, P., et al., 2022, "Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035, NREL/TP-6440-81644, p. 108.

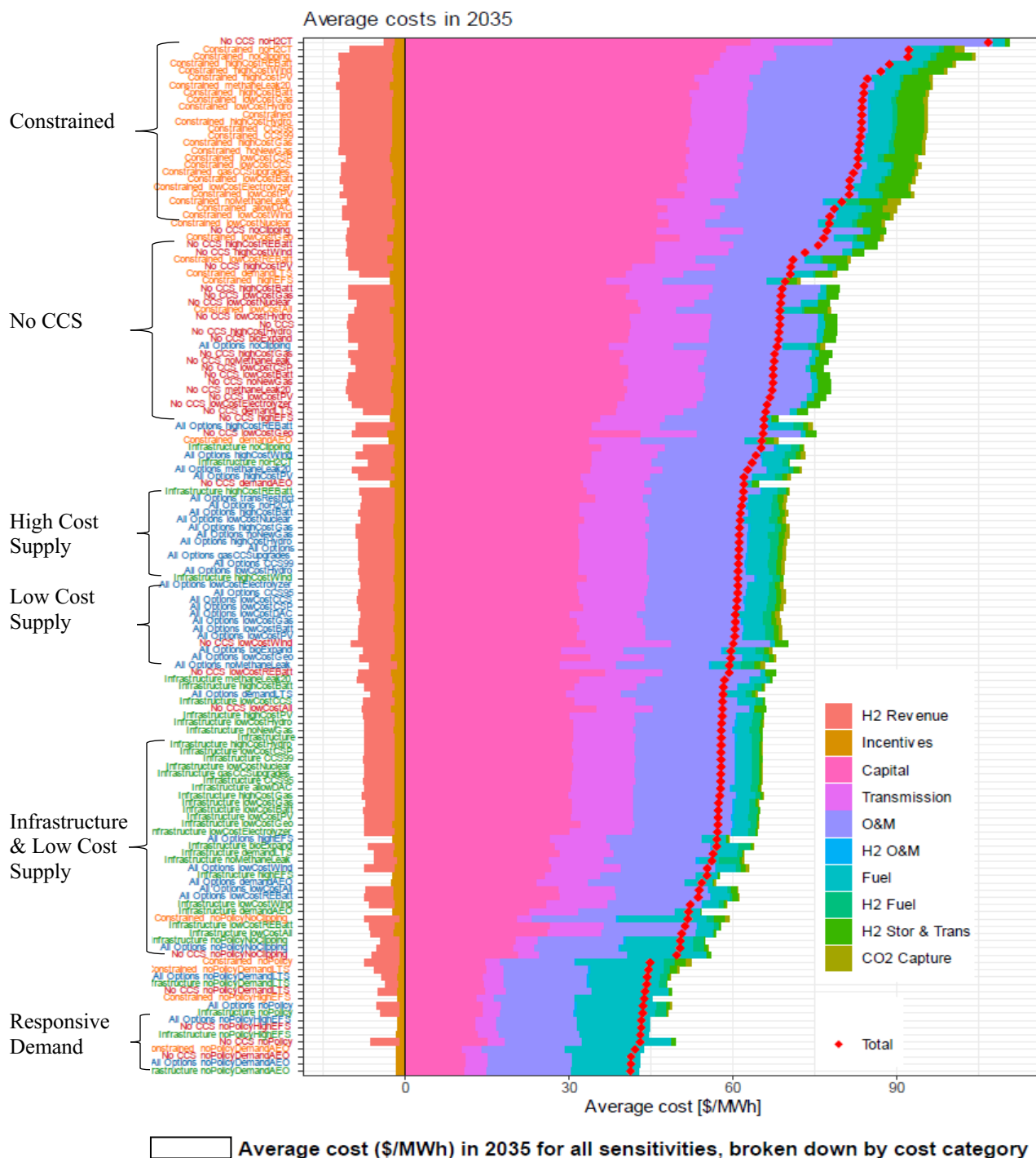
THE SUSPENSION OF DISBELIEF ABOUT LONG-TERM RESOURCE COST TRENDS

Cost/kwh



Source: Attachment MNC-1.3, as updated in text.

NREL COST RESULTS FOR ALL SENSITIVITY CASES



Source: Denholm, P., et al., 2022, "Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035, NREL/TP-6440-81644, p. 91.

SUMMARY OF POLICIES DESIGNED TO MEET NET-ZERO CARBON EMISSIONS GOALS WITH HIGHEST PRIORITY AND INDISPENSABLE TO ACHIEVE THE OBJECTIVE: THE NATIONAL ACADEMY OF SCIENCES, ACCELERATING DECARBONIZATION OF THE U.S. ENERGY SYSTEM.

Technological Policies deemed urgent:

Set national standards for light-, medium-, and heavy-duty zero-emissions vehicles, and extend and strengthen stringency of Corporate Average Fuel Economy (CAFE) standards. Light-duty zero-emission vehicle (ZEV) standard ramps to 50% of sales in 2030; medium- and heavy-duty to 30% of sales.

Set manufacturing standards for zero-emissions appliances, including hot water, cooking, and space heating. Department of Energy (DOE) continues to establish appliance minimum efficiency standards. Standard ramps down to achieve close to 100% all-electric in 2050;

Establish educational and training programs to train the net-zero workforce, with reporting on diversity of participants and job placement success.

Increase clean energy and net-zero transition research, development, and demonstration (RD&D) that integrates equity indicators.

Amend the Federal Power Act and Energy Policy Act by making changes to facilitate needed new transmission infrastructure.

Increase clean energy and net-zero transition RD&D that integrates equity indicators.

Socioeconomic Policies deemed urgent:

Economy-wide price on carbon. Carbon price level not designed to directly achieve net-zero emissions. Additional programs will be necessary to protect the competitiveness of import/export exposed businesses.

Establish White House Office of Equitable Energy Transitions; Establish criteria to ensure equitable and effective, energy transition funding; Sponsor external research, to support development and evaluation of equity indicators and public engagement; Report annually on energy equity indicators and triennially on transition impacts and opportunities.

Recipients of federal funds and their contractors must meet labor standards, including Davis-Bacon Act prevailing wage requirements; sign Project Labor Agreements (PLAs) where relevant; and negotiate Community Benefits (or Workforce) Agreements (CBAs) where relevant.

Ensure that Buy America and Buy American provisions are applied and enforced for key materials and products in federally funded projects.

Establish an environmental product declaration library to create the accounting and reporting infrastructure to support the development of a comprehensive Buy Clean policy.

Establish a federal Green Bank to finance low- or zero-carbon technology, business creation, and infrastructure.

Establish educational and training programs to train the net-zero workforce, with reporting on diversity of participants and job placement success.

Increase funds for low-income households for energy expenses, home electrification, and weatherization.

Increase electrification of tribal lands.

Establish National Laboratory support to subnational entities for planning and implementation of net-zero transition.

Establish 10 regional centers to manage socioeconomic dimensions of the net-zero transition.

Establish local community block grants for planning and to help identify especially at-risk communities. Greatly improve environmental justice (EJ) mapping and screening tool and reporting to guide investments

Source: National Academies, 2021, *Accelerating Decarbonization of the U.S. Energy System*, Table S.1.

EQUITY ISSUES IN DEEP DECARBONIZATION POLICY ANALYSIS

Energy Justice Issues # of Studies	Principles of Energy Justice # of Mentions	
	Unduplicated	Duplicated
Climate	27	Place-based 26
Green jobs & economic	13	Root causes, inequality 31
Energy transition	9	Balance of power 29
Sustainable Development	7	New systems of governance 25
Economic democracy	7	Rights-based approach 20
Transportation	5	Rejecting false solutions 34

Source:

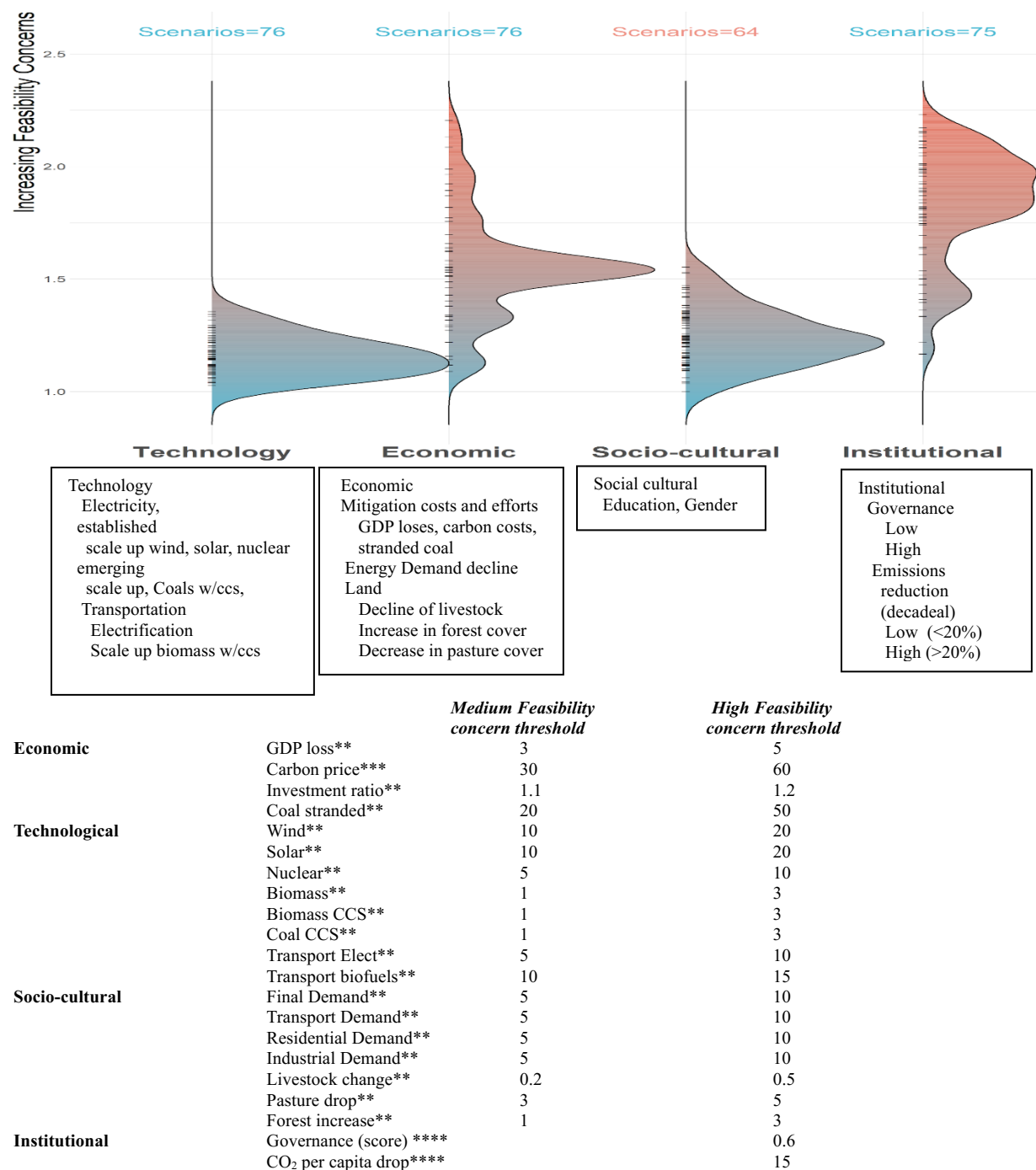
COST OF POWER (\$/MWH)

Resource	Type of power	Lazard	
		2014	2022
Efficiency*	Firm	35	35
Wind on	Int.	41	60
Solar PV	Int.	37	43
Wind Off	Int.		106
Com. & Ind. PV	Int.	115	117
Rooftop PV	Int.	187	148-253
Solar Hybrid	Quasi-Firm		53-82
Wind Hybrid	Quasi-Firm		84-113
Geothermal	Firm		91
Aging Reactors	Firm	78-102	78-102
Biomass**	Firm		85
Gasw/CCs New	Firm		90-142
Gasw/CCs Retro	Firm		111-161
Long Duration Storage			
Electrochem.	Firm		114
Mechanical	Firm		187
Thermal	Firm		216
Nuclear, Large	Firm	155	181
SMR	Firm		128

*Last entered in v. 9.0; **Last entered in v. 8.0

Source: National Academy of Science, 2014, p. 41, adapted from Lazard, v. 14.0, 16.0

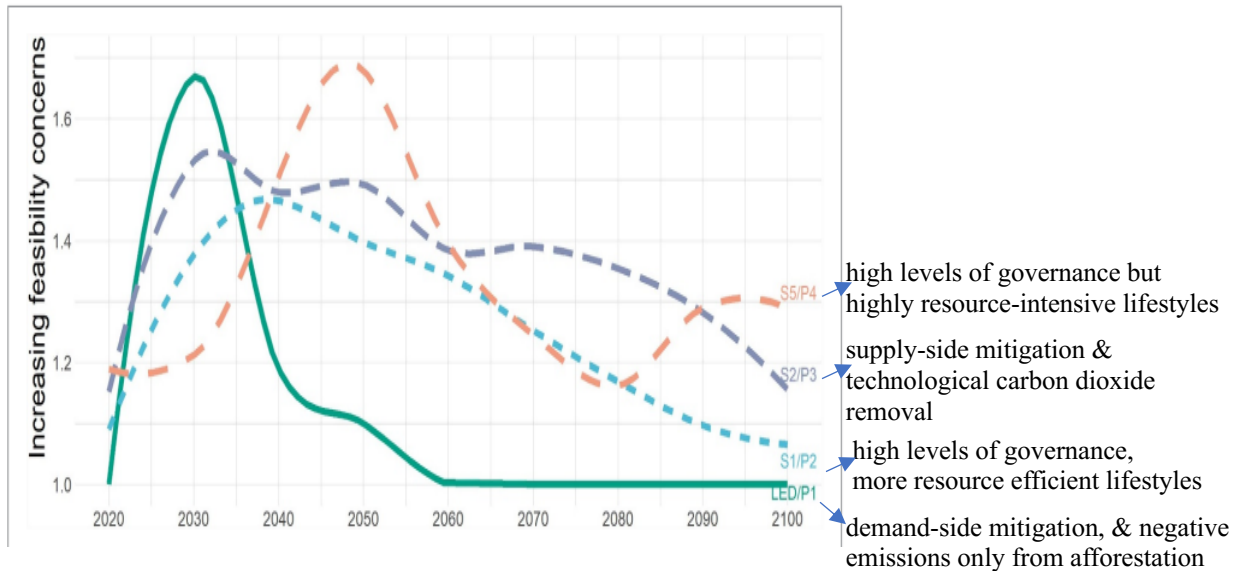
FEASIBILITY CONCERNS (2020-2100)



Legend, Each variable is generally expressed as one of three Categories: * levels, 1= low, 2= moderate, 3= high. In many cases, the categories have “meanings”, i.e., ** = %, or *** = \$/ton, In some cases, the categories are **** = indices.

Source: Brutschin, Elina, et al., 2021, “A multidimensional feasibility evaluation of low- carbon scenarios,” *Environmental Research Letter*, June, Figure 2 and Supplemental Materials.

ILLUSTRATION OF FEASIBILITY CONCERNS AGGREGATED OVER ALL DIMENSIONS FOR THE PERIOD 2020–2100 FOR FOUR ILLUSTRATIVE PATHWAYS FROM THE 1.5 °C SCENARIO ENSEMBLE.



Scenarios compare the evolution over time of overall feasibility concerns of four illustrative pathways from the 2018 IPCC Special Report that reach the 1.5°C goal

S2/P3: which relies on supply-side mitigation and technological carbon dioxide removal;

LED/P1: the low energy demand scenario which relies on demand-side mitigation and negative emissions only from afforestation

S1/P2: sustainable development pathway with high levels of governance and more resource-efficient lifestyles

S5/P4: high levels of governance but highly resource-intensive lifestyles

Source: Brutschin, Elina, et al., 2021, “A multidimensional feasibility evaluation of low- carbon scenarios,” *Environmental Research Letter*, June, Figure 5.

THE TERRAIN OF CHALLENGES FOR DEEP DECARBONIZATION

Continent-Scale Transmission Expansion: First, in order to smooth renewable energy variation across wider regions, high-VRE scenarios routinely entail a continent-scale expansion of long-distance transmission capacity.

Flexible Demand: Most scenarios highly reliant on wind and solar assume that sources of electricity consumption will become much more flexible and responsive to power system needs in the future. ... These scenarios envision reshaping demand to match variable supply, rather than shaping supply to match variable demand, as is commonplace in all power systems today. Electrification of transportation, heating, and industry will increase demand for electricity, as discussed above, but some of these new sources of demand could also become flexible resources.

Inefficient Utilization Requires Very-Low-Cost Wind and Solar to Make Overcapacity Economical
 Either “Firm” Generation or “Seasonal” Storage Is Needed to Ensure Reliability in Wind- and Solar-Dominated Scenarios

This means that resources with low capital costs and high variable costs (e.g., bioenergy, hydrogen, or natural gas fueled power plants) are economically better suited to pair with high wind and solar shares. Considerable uncertainty remains about the real-world cost, timing, and scalability of these storage options.

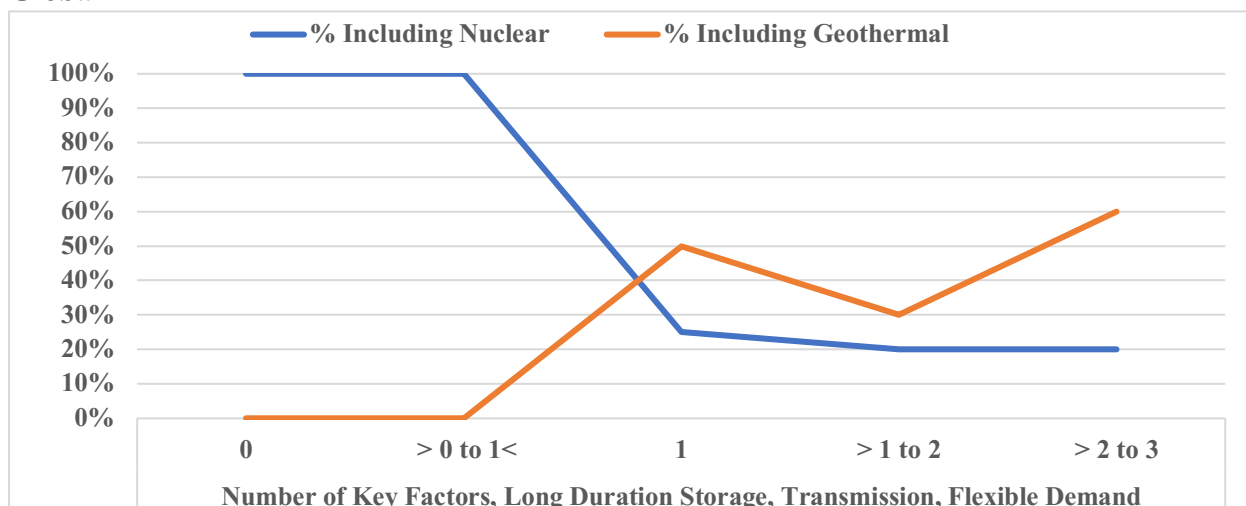
Firm Low-Carbon Resources Can Lower Decarbonization Costs: Most of the challenges associated with very high shares of wind or solar energy can be avoided by adopting a more balanced portfolio of resources. Across decarbonization scenarios that harness variable renewables alongside firm low-carbon generation resources—including nuclear power, coal or natural gas plants with CCS, and greater shares of firm renewable resources such as bioenergy or geothermal power plants—total installed capacity is more closely sized to peak demand, all resources enjoy higher asset utilization, and substantial curtailment of renewable energy output is avoided.

However, all currently available firm low-carbon energy sources face challenges that may impede adoption at the scale or pace desired for climate stabilization. Worldwide, deployment of new nuclear power is barely keeping pace with retirement of aging reactors, while high-profile cost overruns and bankruptcies have plagued nuclear construction in the United States and Europe. Carbon-capture technologies continue to make progress at the demonstration scale, but commercial deployment remains nearly nonexistent. Furthermore, while solid biomass use is rapidly increasing, driven particularly by renewable energy policies in Europe, researchers have raised serious questions about the net life-cycle greenhouse gas benefits of biomass from both managed forests and dedicated energy crops. Reservoir hydropower systems are mature, but new construction is geographically limited and entails substantial environmental impact, including the release of methane. Conventional geothermal energy technologies are constrained to locations with ideal geological conditions, while enhanced or engineered geothermal systems, which could unlock widespread resource potential, are pre-commercial.

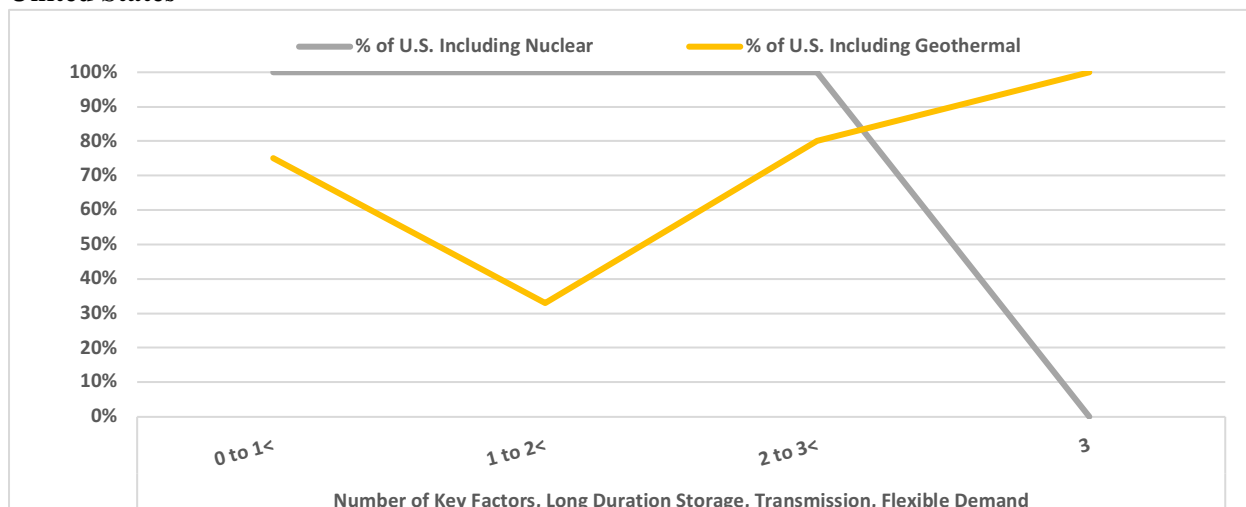
Source: Jenkins, Jesse D., et al., 2018, “Getting to Zero Carbon Emissions in the Electric Power Sector,” *Joule* 2, December.

KEY ASSUMPTIONS ABOUT POLICIES AFFECTING ALTERNATIVE RESOURCES & RELIANCE ON NUCLEAR POWER, 40 DEEP DECARBONIZATION STUDIES

Global



United States



Source: Jenkins, Jesse D., et al., 2018, "Getting to Zero Carbon Emissions in the Electric Power Sector," *Joule* 2, December.

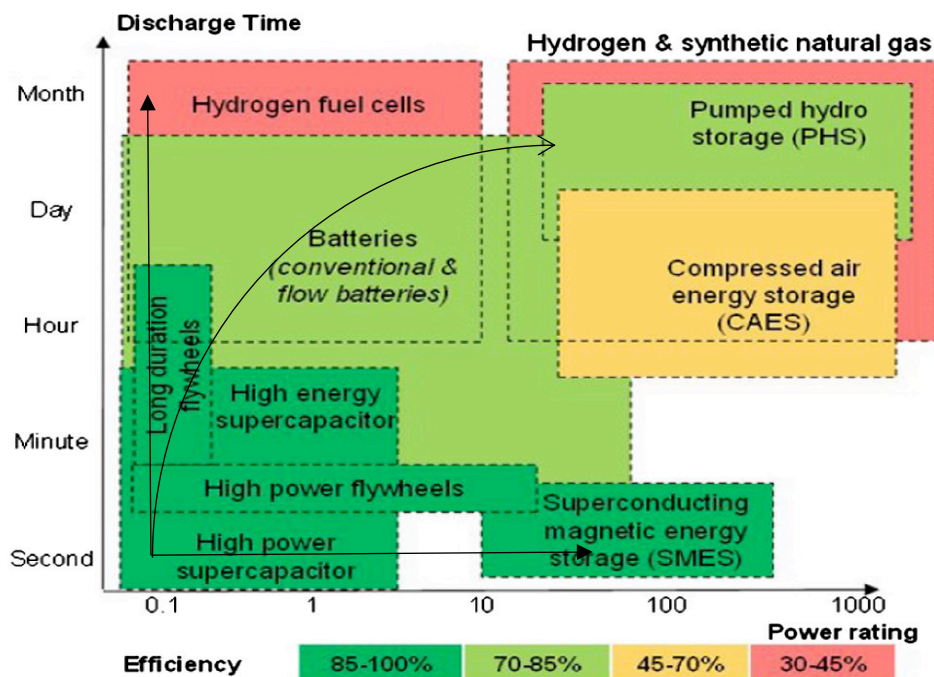
IMPACT ON COST OF DIFFERENT PATHS TO DEEP DECARBONIZATION

Cost Advantage (\$/MWH) Adjusted for Market Share of Group 1 (i.e. bill impact)

	Lo v Hi Cost Group 2		Group 1 v. Lo. Group 2		Group 1 v. Hi Group 2	
Group 1, Share/Cost	60%/\$60	80%/\$70	60%/\$60	80%/\$70	60%/\$60	80%/\$70
Hi-Cost Group 2						
SMR (\$120)	14	7	10	6	24	10
Large (\$150)	26	13	36	16	36	16

Source: Author as described in text,

POTENTIAL STORAGE EXPANSION PATHS



Source: Véronique Dias 1, et al. 2017, Position paper on Energy Transition Energy Transition Workshop, Université Libre de Bruxelles, Belgium, March 9.

BENDING THE CURVE: EXECUTIVE SUMMARY, 10 SCALABLE SOLUTIONS FOR CARBON NEUTRALITY AND CLIMATE STABILITY

General structure

1. Replacing fossil fuels with carbon neutral technologies
2. Foster a global culture of climate action through coordinated public communications and education at the global and local scale
3. Deepen the global culture of climate collaboration
4. Scale up subnational models of governance and collaboration.
5. adopt market-based instruments to create efficient incentives
6. Narrowly target direct regulatory measures at high emission sectors no covered by market-based policies

7-9 Technologies for increasing clean supply and decreasing demand

- a. photovoltaics,
- b. wind turbines,
- c. battery and development of lower-cost storage for applications in transportation including:
 - batteries,
 - hydrogen fuel cells for vehicles,
- d. Storage generally including
 - super-capacitors,
 - compressed air,
 - hydrogen and thermal storage,
- e. efficient end use devices
 - lighting,
 - air conditioning,
 - appliances,
 - advances in heat pumps,
- f. smart buildings,
- g. industrial processes,
- h. system integration
- i “access to clean cooking for the poorest 3 billion people

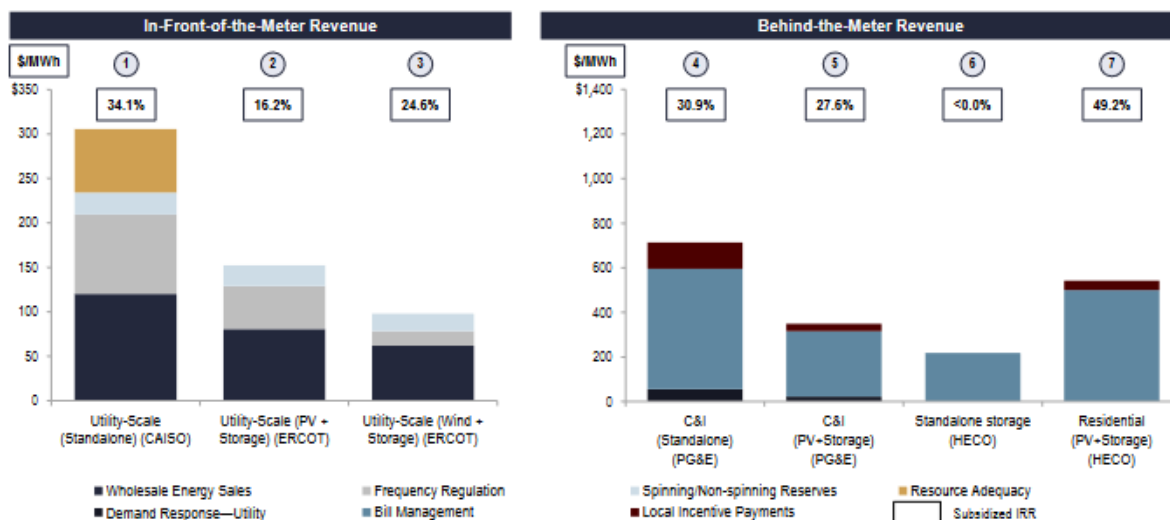
10. Regenerate damaged natural ecosystems and restore soil organic carbon to improve natural sinks

Source: University of California, 2015, *Bending the Curve Executive Summary: Ten scalable solutions for carbon neutrality and climate stability*, October 27.

THE ECONOMICS OF STORAGE AT THE CASE STUDY LEVEL

Value Snapshot Case Studies—Summary Results

Project economics evaluated in the Value Snapshot analysis continue to evolve year-over-year as costs change and the value of revenue streams adjust to reflect underlying market conditions, utility rate structures and policy developments



Source: Lazard and Roland Berger estimates, Provention Analytics and publicly available information.
 Note: Levelized costs presented for each Value Snapshot reflect local market and operating conditions (including installed costs, market prices, charging costs and incentives) and are different in certain cases from the LCOS results for the equivalent use case on the pages titled "Levelized Cost of Storage Comparison—Energy (\$/MWh)", which are more broadly representative of U.S. storage market conditions versus location-specific. Levelized revenues in all cases show gross revenues (not including charging costs) to be comparable with the levelized cost, which incorporates charging costs. Subsidized levelized cost for each Value Snapshot reflects: (1) average cost structure for storage, solar and wind capital costs, (2) charging costs based on local wholesale prices or utility tariff rates and (3) all applicable state and federal tax incentives, including 30% federal ITC for solar, 30% federal ITC for storage, 28% federal PTC for wind and 30% federal ITC for solar and storage systems. Value Snapshots do not include cash payments from state or utility incentive programs. Revenues for Value Snapshots (1)–(3) are based on hourly wholesale prices from the 365 days prior to Dec. 15, 2022. Revenues for Value Snapshots (4)–(8) are based on the most recent tariff, programs and incentives available as of December 2022.

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Incremental Value Stack Results – by Utility and Case

Incremental Value Stack of Rooftop CSS

25-Year Levelized €/kWh

	Low Case			High Case		
	SCE	SDG&E	PG&E	SCE	SDG&E	PG&E
Energy	1.22	1.58	1.02	1.22	1.58	1.02
Capacity	3.27	3.11	3.26	4.61	4.39	4.66
Transmission	-0.12	-1.19	-0.33	-0.12	-1.19	-0.33
Distribution	1.86	0.77	0.75	3.24	1.37	1.30
Environmental	0.10	0.11	0.11	0.10	0.11	0.11
Total	6.33	4.39	4.80	9.05	6.26	6.76

Chapman, Tom, et al., 2023, *Analysis of the Incremental Value of Rooftop Community Solar + Storage in California*, Brattle, June 6.

CALIFORNIA INDEPENDENT SYSTEM OPERATOR (CAISO) REPORT ON SUMMER, 2022

Despite the sustained heat wave and unprecedented load levels, the California Independent System Operator (ISO) did not order rotating outages and maintained reliable system operations at all times.¹ As we continue to integrate new resources... our experience and lessons learned during the September 2022 heat wave will help us navigate the next climate-driven challenge.² This would not have been possible without,³

1. Increased capacity through resource adequacy procurement since summer 2020, the significant mobilization of new generating resources
 - pricing
 - grid battery storage, integration of new capacity, including the highly effective use of recently added lithium-ion batteries; and conservation, including more than 3,500 MW of lithium-ion battery storage
 - ISO visible demand response
2. Enhanced, unprecedented levels of communication and coordination between the ISO, state and federal agencies, and industry that have occurred over the past two years; coordination; awareness, and communications internally, and with neighboring balancing authority areas, including those participating in the WEIM, external stakeholders
 - robust advance planning;
 - utilization of both market and non-market resources;
3. Market enhancements developed and implemented over the past two years, including
 - clarification of scheduling priorities,
 - enhancements to resource sufficiency evaluations and
 - electricity market pricing designed to incentivize generation during periods of high demand.
4. The use of new state programs to provide non-market resources to address extreme events, voluntary load reduction
5. Close coordination with load-serving entities during the ISO's highest emergency alert level,
6. Geographic diversity of extreme heat across the West,;
7. The ISO both received emergency assistance energy and provided it to other balancing authority areas experiencing stressed system conditions.
 - imports

At the same time, the ISO's analysis of the event reveals several issues that led to unintended consequences that impacted specific components of the market.⁴

- additional software improvements that are needed,
- especially for the clearing of exports and the resource sufficiency test used in the Western Energy Imbalance Market (WEIM)

1. Ensuring storage resources are appropriately charged and accounted for in ISO systems to avoid manual corrective action.
2. Ensuring exports are awarded based on their intended priorities
3. Over and under-counting of capacity available to the ISO in the WEIM resource sufficiency evaluation.

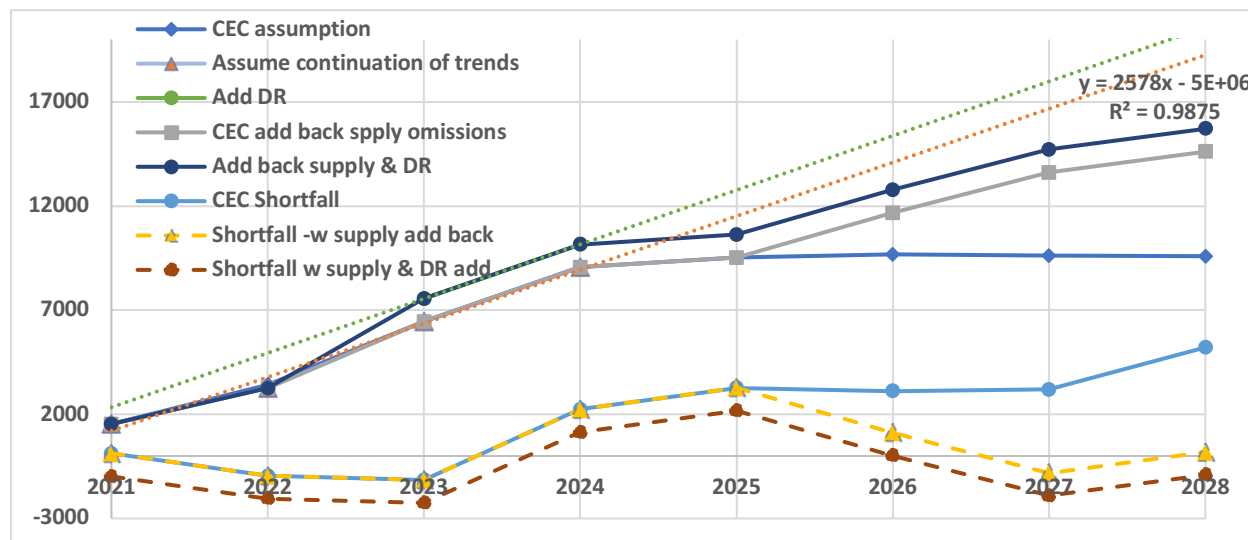
¹ California ISO, *Summer Market Performance Report, Sept. 2022*, November, 2 (hereafter, CAIOS Report) p.12

² CAIOS Report., p. 16

³ CAIOS Report, pp. 12, 13-15

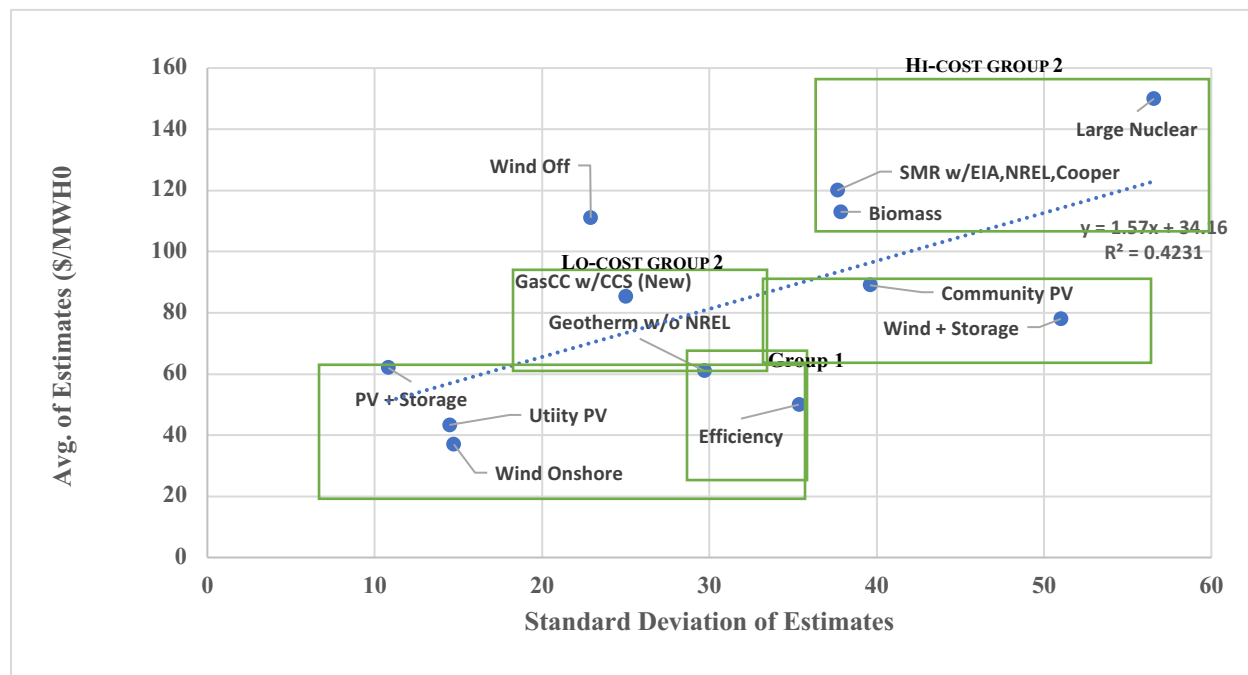
⁴ CAIOS Report, pp. 12, 15-16.

CEC'S MISCHARACTERIZATION OF THE PG&E NET LOAD CONDITION



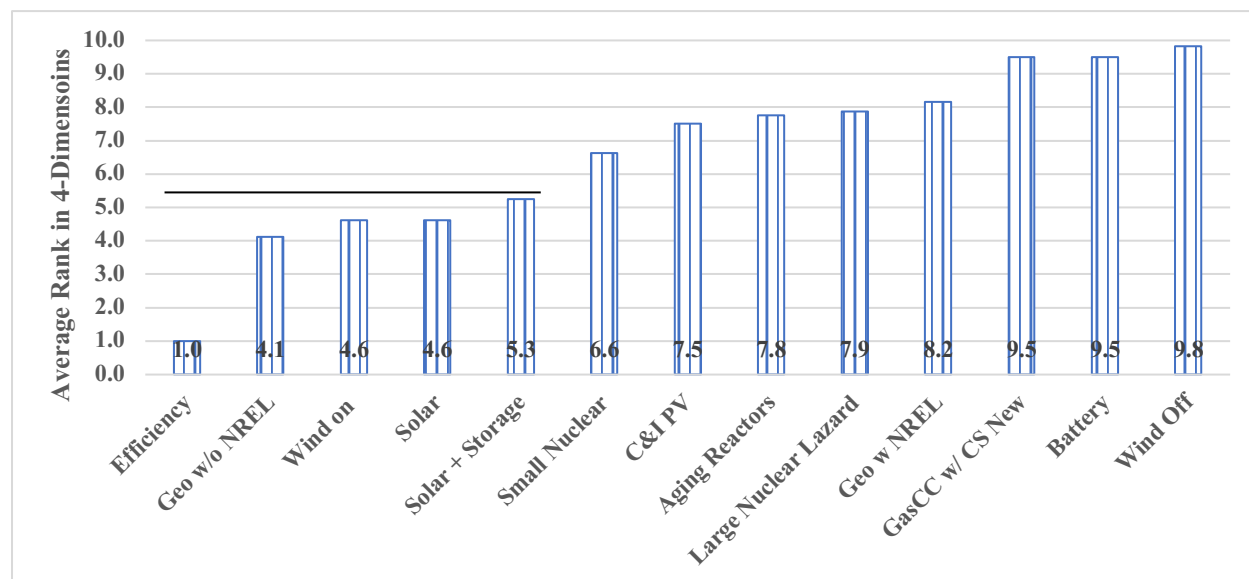
Source: Public Utilities Commission of the State of California, Implementing Senate Bill 846 Concerning Potential Extension of Diablo Canyon Power Plant Operations, Rulemaking 23-01-00, Attachment E: Diablo Canyon Power Plant Extension, Final Draft CEC Analysis of Need to Support Reliability, modified as described in text.

RISK-AWARE LONG-TERM COST ESTIMATION



Source: LCOE, Energy Costs, Lazard, 16.0, 2023; Energy Information Administration (EIA), 2023, *Levelized Cost of Energy*; National Renewable Energy Laboratory (NREL), 2022, *Annual Technology Baseline (ATB)*, 2022 *Electricity*, and discussion in chapter 2. Risk-Aware is calculated as the Euclidian distance from the origin. Using standard deviation and Average cost. The Method is described in Mark Cooper, "Multi-Criteria Portfolio Analysis of Electricity Resources: An Empirical Framework For Valuing Resource In An Increasingly Complex Decision-Making Environment", *Expert Workshop: System Approach to Assessing the Value of Wind Energy to Society*, European Commission Joint Research Centre, Institute for Energy and Transport, Petten, The Netherlands, November 13-14, 2013.

AVERAGE RANK ACROSS 4-DIMENSIONS
(Risk-Aware Price: long & short, Firming, Value-Ratio)



WHAT MONEY CAN BUY: A LOT, BUT IT DEPENDS ON ASSUMPTIONS

	Subsidy Facilities	1-Cycle Life-time capacity (MW)	Owners Cover 50% Facilities capacity (MW)	Load Factor	Effective Load Carry Capacity (MW) (CAISO)
		Annual	Annual		1-Cycle Owners 50%
Geothermal	2	500	4	85%	425 850
Solar Hybrid	54	5400	108	51%	2754 5508
Efficiency (30% savings) (over 5 years growth is .9% per year, rather than 1.4%)				90%	184

Source: uses average Lazard.16.0 capital, for the case used in the firming analysis for solar and the geothermal general analysis. Assumes \$2.5 billion in Federal and state subsidies; rounded to the nearest “whole” plant.

ATTACHMENT C

ATTACHMENT C: Citations Supporting Building a 21st Century Systems

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