THE ENDGAME FOR NUCLEAR POWER: A DESPERATE PUSH FOR SUBSIDIES IN THE 2019 TAX EXTENDERS

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EXECUTIVE SUMMARY

- A new proposal to provide a 30% investment tax credit (ITC) for existing nuclear reactors would be harmful to taxpayers, ratepayers, and the climate.
- Even assuming that the new tax credit would phase down slowly as currently proposed, the expenditure over the coming decade comes to almost $23 billion, even using optimistic assumptions for capital expenditures, fuel, and qualifying reactors. Using more realistic assumptions about the cost of aging reactors, the 10-year cost to taxpayers is likely to be over $26 billion.
- As wind, solar, storage, and efficiency are “crowded out” by keeping uneconomical reactors online with tax subsidies, the cost to regular ratepayers over the coming 20 years is $33 billion.
- A recent report from the Rhodium Group analyzes a potential investment tax credit for existing nuclear reactors, but it vastly overstates the number of reactors likely to retire soon, significantly understates the declining cost of renewables, and never analyzes the tax losses from subsidies or the ratepayer impact of reliance on high-cost nuclear reactors.
- If carbon reduction is the ultimate concern, neither new nor existing nuclear reactors can compete with wind and solar, factoring in the cost of carbon abatement.
- Nuclear power is historically one of the largest beneficiaries of federal subsidies, a largesse that has not fundamentally changed its economics or made it competitive with renewables. Today, it is still the beneficiary of numerous advantages built into the tax code, as well as favorable rules adopted by transmission organizations and utility commissions.

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INTRODUCTION

There are valid reasons for the tax code to address our energy system. In a capitalist market economy, tax policy is one of the primary instruments of industrial policy – i.e., policy that is intended to guide the economy by stimulating specific investments and expansions of specific sectors.[1] With the hottest summer on record and growing concern about climate change, 2019 has witnessed a particularly vigorous debate about what tax subsidies should be used to advance the goal of reducing greenhouse gas emissions. Specifically, Congress is preparing to consider a package of energy tax proposals known collectively as the tax extenders.

Under intense lobbying pressure, major policies frequently do not get the full vetting they deserve (numerous hearings and debate among the members of Congress). Private conversations may get half-baked ideas into legislation at the committee stage, and it is difficult to get them out. One topic potentially getting this treatment is the question of large subsidies to keep aging nuclear reactors online because they are low emitters of carbon, the most prominent greenhouse gas.

Under consideration as a possible energy tax extender is a bill circulating in both the House and Senate known as the Nuclear Powers America Act. It would subsidize existing reactors with a new investment tax credit (ITC) worth 30% of annual capital expenditures and fuel costs from the present through 2023. It would phase down to 26% in 2024, 22% in 2025, and 10% permanently thereafter. The cost of this proposal to taxpayers, ratepayers, and the climate is considerable.

Although Congress seems disinclined to consider the implications of this proposal, fortunately, there is a great deal of outside analysis to shed light on this question. Once the light is shined, the policy of massive subsidies for existing reactors shrivels and dies.

A DESPERATE ATTEMPT TO BUY A FUTURE NUCLEAR POWER HAS NOT EARNED AND DOES NOT DESERVE

A good place to start exposing how bad subsidies for nuclear reactors would be is a recent Bloomberg article headlined "Nuclear Called Irrelevant in Climate Fight Without Lower Costs."[2] While this headline may be eye-catching, my economic analysis over the past decade suggests it is far too timid.

In order to address which resources should be used to build the response to climate change, I have argued that policymakers must examine future cost trends and compare them to the history of past cost developments.[3] Looking at nuclear power as the quintessential central station resource, compared to alternatives like efficiency, wind, and solar, that operate in an intensely managed, flexible, and dynamic grid, the conclusion about nuclear power should actually be much stronger. **Nuclear has no place in a least-cost, low-carbon future.**

Subsidizing existing reactors that are uneconomic to prevent them from shutting down steadily over the next few decades, instead of speeding up the transformation of the electricity grid to lower-cost alternatives, not only imposes excess near-term costs on taxpayers and ratepayers but will also delay the transition away from central-station facilities (coal, gas, and nuclear) and, above all, raise the long-term cost of a low-carbon sector.[4]

Ultimately, as a U.N. analyst quoted in the Bloomberg article put it, "The trouble is that about two-thirds of those units are operating in industrial economies and are approaching the end of their lives … Few private investors are willing to go it alone given the large costs."[5] At the current cost of building large central-station reactors, replacing two-thirds of U.S. reactors would impose excess costs – costs above the price of alternatives in the market – of over $750 billion.[6] The economy simply cannot afford to waste that huge sum.

Subsidies for nuclear power violate two fundamental principles of market economics and analysis, each with corollaries.[7]

(1) Sunk costs are irrelevant. It is future, marginal costs that should provide the basis for asset selection.

1(a) Trends from the recent past are the best basis on which to project the near future.

1(b) Over the past two decades, 95% of the low-carbon resources added to the grid have been renewables and efficiency.

(2) If you pay too much for something, you are likely to buy less of it. At present, aging reactors cost twice as much as new renewables and efficiency. New reactors are four to five times as costly. Indeed, renewables are not only competitive with the average nuclear reactor today, they are also competitive with coal and gas. They will gain a larger advantage as their costs fall, as the benefits of a dynamic, integrated 21st-century electricity grid are realized, and as the cost of the aging reactor fleet rises.

2(a) Subsidize the future, not the past – i.e., subsidize technologies that hold the promise of meeting goals (increased consumption, decarbonization, least cost) if you must subsidize something.

2(b) If you are in a hole, stop digging and think about how to climb out.

Since nuclear power has always been subsidized and there is no reason to believe that it will ever be able to compete with the alternatives, the only way to get reactors online and keep them online is nuclear socialism.[8] From the very beginning of the industry, costs that investors refused to bear (liability for accidents, management and storage of waste, overall construction and operating costs), have been subsidized by taxpayers and/or ratepayers. The current push for tax subsidies is nothing new, a search for yet another subsidy led by an uncompetitive and declining industry.

Since that is the history, the only legitimate question is, why stop now, why not increase subsidies to nuclear power instead of allowing uneconomic plants to retire? The answer is straightforward: Nuclear has failed for over 50 years to control its costs, even with help from massive subsidies, and alternatives are available to reduce greenhouse gas emissions at a much lower cost. However, the alternatives need to penetrate the supply side as quickly as possible, while utilities and grid operators build the physical and institutional infrastructure to manage the 21st-century electricity system.

The continued operation of nuclear reactors, with their huge, inflexible quantities of "must-run" generation, gets in the way. Nuclear advocates are pushing subsidies now precisely because they have become so uneconomic, they are beginning to retire, and there is no chance they will ever be able to compete. By keeping reactors online in the near term, the industry crowds out the alternatives, as nuclear power has always done.

Unfortunately, bad economic analysis of nuclear power can enable bad policy outcomes. This paper looks at the push by nuclear utilities for new tax subsidies from three points of view.

First, it considers the consequences of including an ITC for existing reactors as a tax extender. It estimates the cost to ratepayers and taxpayers over the short, medium, and long term.

Second, it considers the analysis offered by others, such as the Rhodium Group, who try to be a bit more evenhanded, laying out a series of options to reduce carbon emissions but without realistically considering the potential contributions of the alternatives or the costs involved.

Third, it examines the historical legacy of nuclear subsidies and critically interrogates the mistaken idea that energy policy should aim for "parity" between different sources.

TWO FUNDAMENTAL TRENDS MUST FRAME THE ANALYSIS

The Current and Future Cost of Resources

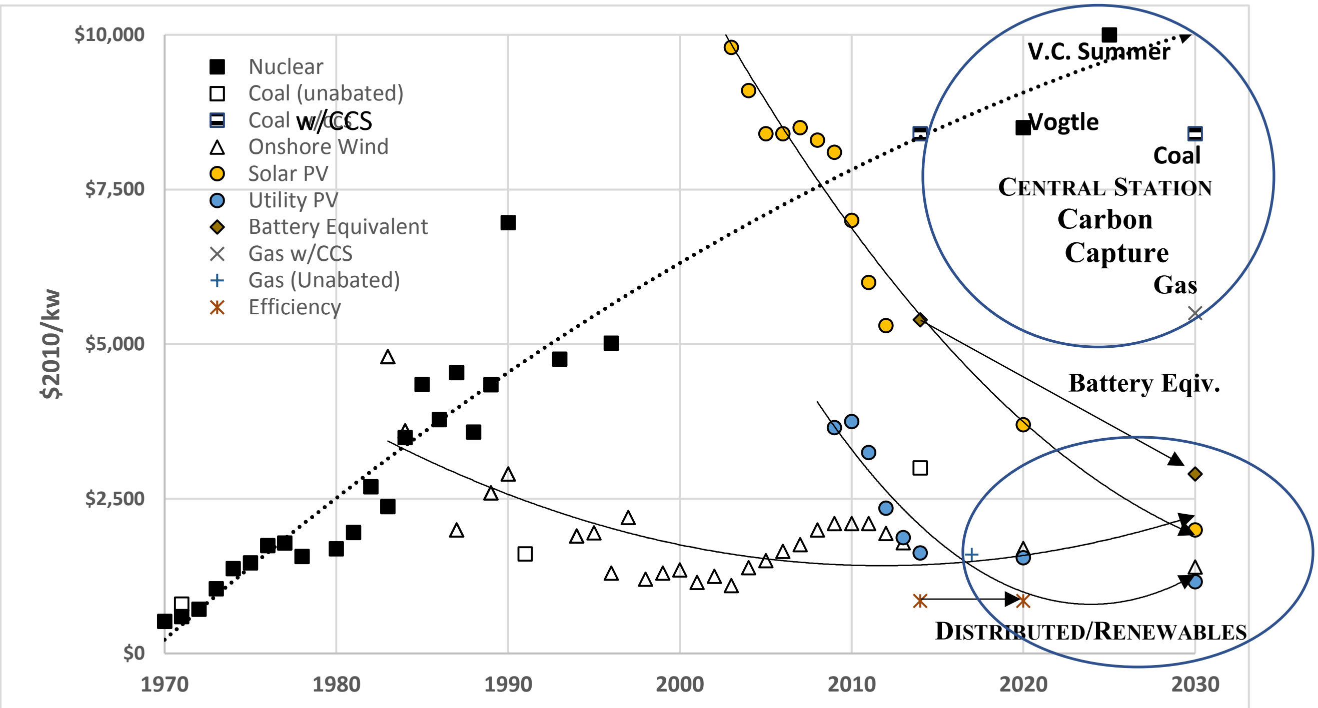
Figure 1 presents the most important economic trend: the cost of resources that can meet the need for electricity in a low-carbon future.

I have long used Lazard's cost estimate as the anchor point for my analysis for a number of reasons: [9]

1. From the outset, Lazard's analysis included efficiency.
2. 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.
3. The analysis always included estimates for coal with carbon capture and storage, and it later added an estimate for the cost of natural gas with carbon capture and storage.
4. The more recent analysis adds two important storage technologies: 1) utility-scale solar with storage and 2) utility-scale battery storage. It also presents a cost trend for storage that is similar to the trends from other renewable and distributed sources.
5. The analysis always 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.

6. The cost of nuclear has been adjusted to reflect the severe cost overruns suffered by the actual construction of reactors in the U.S., although the most recent analysis does not fully reflect the actual costs.
7. The analysis now includes a cost of carbon abatement.
8. Lazard is also useful because it gives both current costs and, in some cases, future trends. Moreover, with annual estimates over a dozen years, one can construct recent cost trends.

FIGURE 1: A RENEWABLE REVOLUTION: ALTERNATIVES VS. CENTRAL-STATION COSTS[10]



Because the electricity systems require the continuous management of resources, resource acquisition in the near term is necessary. The compatibility/conflict between the economics of near-term and long-term resource acquisition is an important consideration. If there is a conflict, choosing resources becomes more difficult. In this instance, that is not the case. Although Lazard estimates current or near-term costs, this data makes an important point for the analysis of decarbonization. Three important resources – efficiency, wind, and utility-scale solar – are cost competitive now with the dominant central-station fossil fuels (natural gas and coal). These three resources account for the vast majority of resources needed to eliminate fossil fuels in the long term. Under an assumption of more-aggressive utilization of efficiency (that our review supports later in this analysis), these three resources reach almost three-quarters of the total need.

They are also less than half the cost of new nuclear reactors or fossil fuels with carbon capture and are widely available. Thus, based on current costs, the renewable resources that are the cornerstone of the 100% renewable scenarios should be the resources chosen today.[11] There is no conflict between the assets that are preferable in the short term and the long term. Any uncertainty about the timing (decades from now) and final high level (80-100%) of reliance on these renewables is far off and should be given little weight in current decision-making, because the course for at least the next several decades is clear. The short- and medium-term view strongly favors the alternatives, and the long-term view is consistent with these choices, particularly when nuclear is the other option.

A second set of important trends to consider is shown in Figure 2. The tax subsidy involves having federal taxpayers underwrite the fuel and operating costs of nuclear reactors. The Nuclear Energy Institute has published data that shows a dramatic decline in operating costs. There are two problems with this data set. First, it is incomplete. Second, the steep decline in costs is associated with the retirement of reactors. Given that these were the most costly to operate, one would have expected the industry average to decline as they were retired. In fact, the purpose of the subsidy is to keep aging, uneconomic reactors online. Therefore, the cost trend tells us nothing about the impact of the tax subsidy.

Since we do not know the specific operating costs of the retired reactors, a secret the utilities guard closely, we have run a regression equation to estimate the impact of the retirements on costs, which is shown in the upper graph of Figure 2. The effect is shown in the middle graph of Figure 2. The upper graph shows that there is a strong, negative correlation between reactor retirements and costs. The middle graph of Figure 2 shows the cost trends when the impact of aging reactor retirements is taken into account. The lower graph of Figure 2 shows the levels of cost used in this analysis. The operating costs for the optimistic cost level of the tax subsidy analysis is set at the most recent level, but a realistic level is approximately one-third higher. The lower graph shows two estimates – one optimistic, one realistic –for the total operating costs of reactors. These will be used below to conduct an analysis of the cost of carbon reductions by various resources.

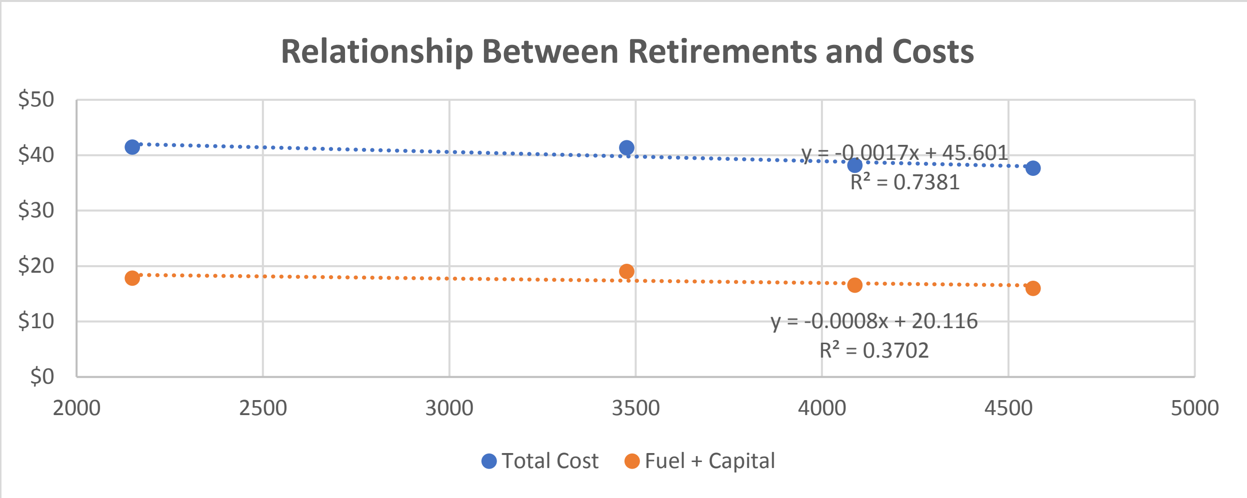
THE COST OF NUCLEAR SUBSIDIES

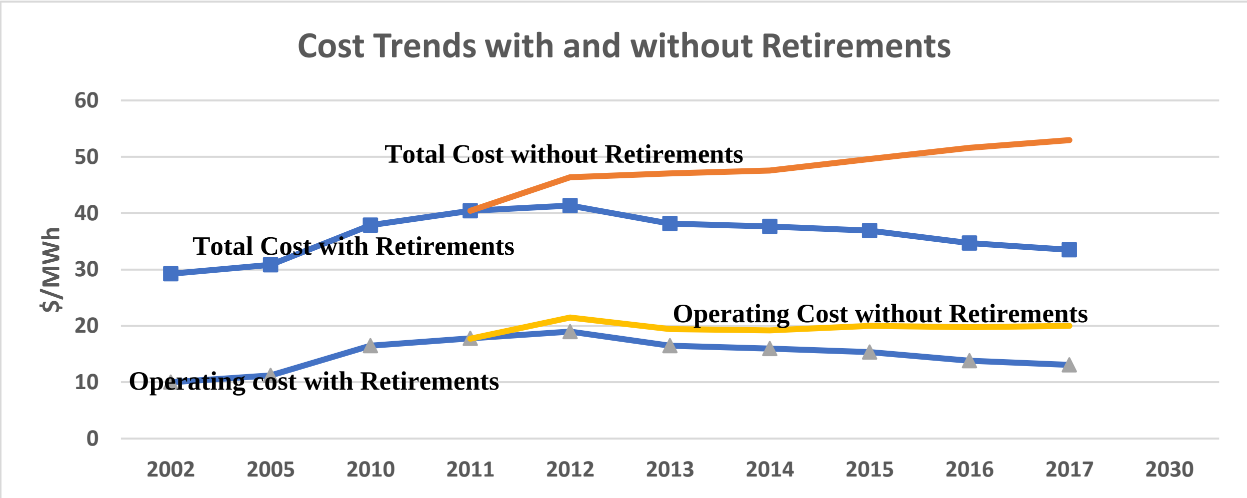
The Taxpayer Cost of Subsidies

First, I estimate the tax loss associated with the proposed creation of a new ITC for existing reactors. I assume 90% of reactors will claim the subsidy, which is feasible and in their economic interest, but it could be higher. I assume no cost escalation and no expenditure acceleration. Both of these are quite conservative, as history has shown escalation, and they would have an economic interest in accelerating capital expenditures to capture the higher rate of subsidy. Tax provisions are usually evaluated over a 10-year time frame, which is shown on the graph.

As shown in Figure 3, using the tax code, the current proposal to subsidize nuclear operating costs will cost taxpayers about $23 billion over the next ten years (the time frame used to score tax losses). However, that is only the tip of the iceberg. As proposed, the tax credit would remain permanent at a lower rate of 10% after 2026, adding billions more to the direct costs. The 20-year tax subsidy would be in the range of $34 billion. But even these estimates reflect the more optimistic cost scenario. Using more-realistic assumptions about the cost of aging reactors, I project the 10-year and 20-year direct costs in tax revenue to be even higher at $26 billion and $39 billion, respectively.

FIGURE 2: IMPACT OF RETIREMENTS ON COSTS[12]





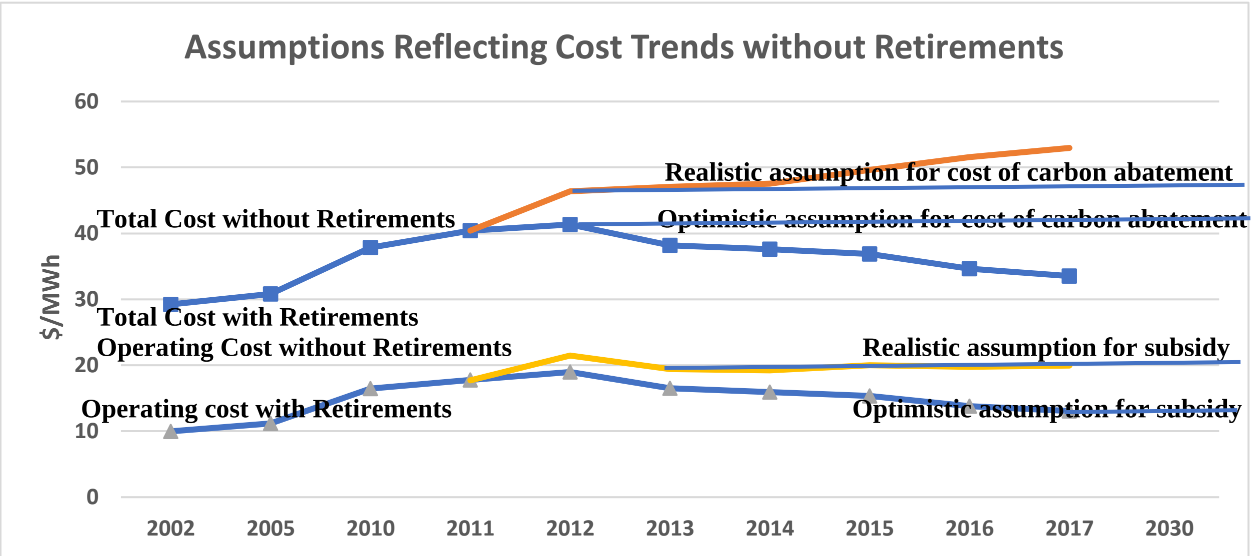
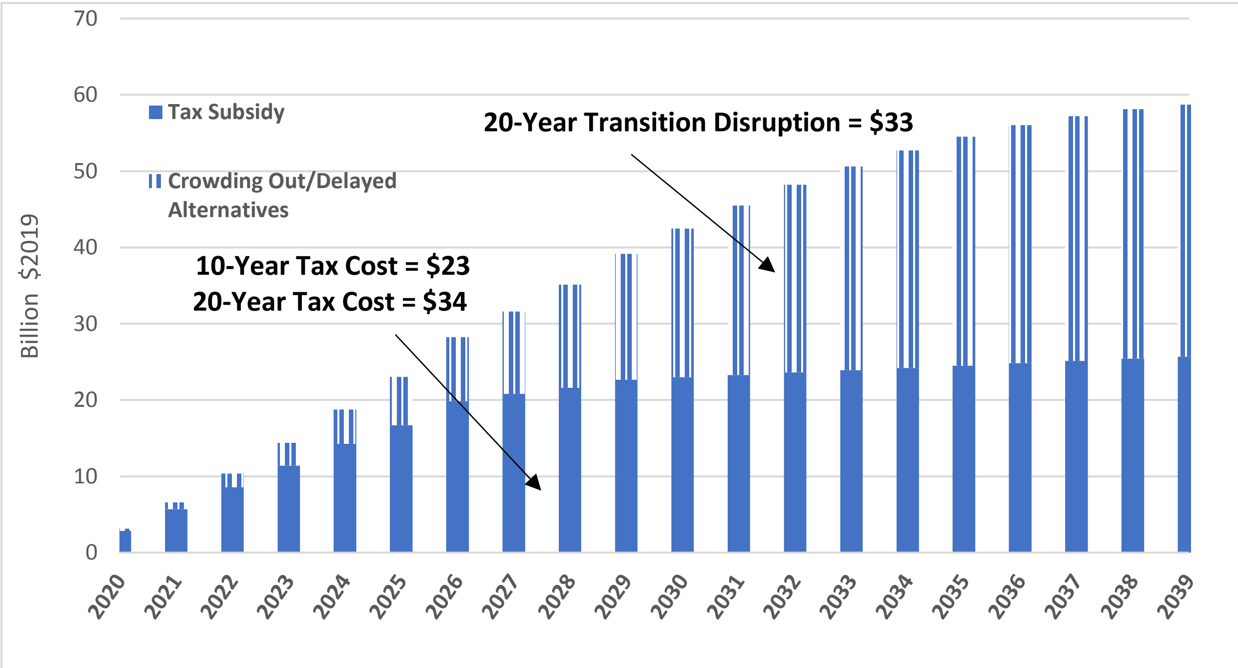
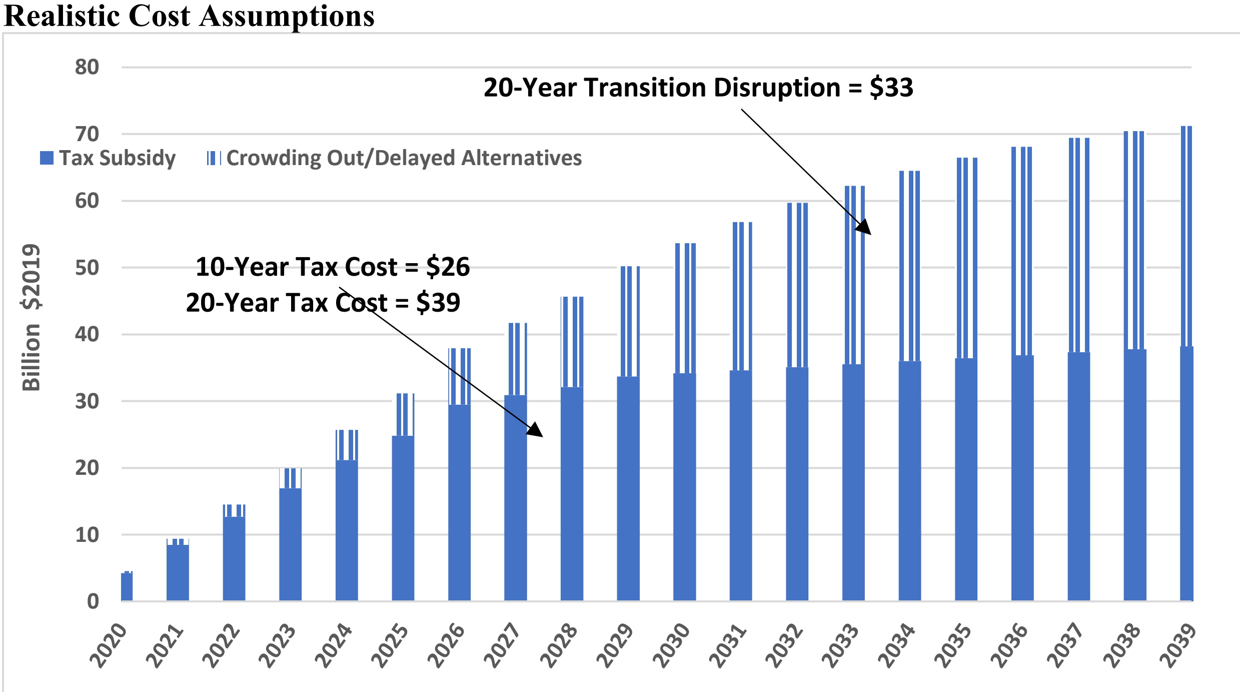


FIGURE 3: CUMULATIVE COST OF SUBSIDIES: TAXPAYER AND RATEPAYER BURDENS[13]

Optimistic Cost Assumptions



Realistic Cost Assumptions



Nuclear advocates frequently argue that existing nuclear reactors account for 60% of current, U.S. low-carbon electricity resources. However, economic analysis should focus on forward-looking costs, not sunk costs. In fact, over the last 20 years, 95% of low-carbon electricity resources have come from alternatives, like wind and solar. In the past 20 years, no nuclear reactors have been brought online in the U.S. The only reactor that might be completed in the next decade has a price tag that is over three times the cost of alternatives.

Taxpayers are not the only ones who bear the burden of subsidizing uneconomic reactors to stay online. The analysis parallels my recent analysis in New York.[14]

The technology of alternatives has progressed to the point where the full cost for the main alternatives – efficiency, wind, and solar (utility-scale PV) – are now below coal and nuclear. Subsidizing nuclear keeps reactors online and crowds out the alternatives. It slows the transition to the electricity grid based on low-carbon distributed resources. In the near term, reactors that should have been retired or whose output should have been reduced keep running. I model this impact assuming one reactor (about 1 GW of capacity) would have been retired but, due to the subsidy, was not. I assume, conservatively, that the cost of these oldest, most-expensive reactors is $3/MWh higher than the average. Keeping these reactors online for 10years costs ratepayers $16.5 billion.

In the New York analysis, I argued that crowding out (i.e., suppressing demand for and delaying the supply of alternatives) would shrink the market for alternatives and slow the transition to a system that they dominate. This has been the historic impact. Nuclear advocates will argue that the electricity sector is not ready to transition and still needs them. To the extent that this argument seems plausible to policymakers, this would not reflect the superior economics of nuclear, it would be a result of the bad policy of subsidizing uneconomic reactors. I assume that it takes 10 years to reverse this impact. Thus, the cost would be another $16.5 billion for a total of $33 billion.

One final note on the issue of disruption of the transition and decarbonization of the electricity sector is in order. As noted, nuclear power needs a 20th-century grid that relies on generation that follows load with huge, must-run reactors. When push came to shove, the nuclear industry supported subsidies for coal plants when the Trump administration proposed them in 2017.[15] Thus, nuclear power demonstrated that, whatever accidental role they had played in reducing carbon emissions was secondary to their desire to preserve the old system, which means undermining the low-carbon alternatives. If you keep a 20th-centurysystem that forces policymakers to choose between coal and nuclear, you must choose nuclear. If you allow a 21st-century system to grow rapidly, you can choose neither coal nor nuclear and build a system based on low-carbon, cleaner, and less-costly alternatives.

If economics decides the fate of nuclear power, as it should, every exiting reactor will be replaced by alternative sources over the course of the 21st century. Simply put, nuclear power has no role to play in the long-term future of a low-carbon electricity sector. Subsidizing nuclear reactors delays their replacement and slows the transition to a low-carbon sector. It is bad policy in the short, medium, and long terms.

Cost of Carbon Abatement and Other Environmental Impacts

A few years ago, Lazard began calculating the value of carbon abatement compared to conventional coal and gas. Figure 4 is based on Lazard's most recent calculations. Positive values indicate that the low-carbon resource costs less than the high-carbon resource being replaced. That is, using these resources is a win-win, lowering costs and reducing carbon emissions. Negative values indicate the low-carbon source is more costly than the resource being replaced, so there is an additional cost incurred to reduce carbon.

This analysis uses a cost of alternatives of $32.5/MWh for onshore wind ($29) and utility solar ($36). Lazard did not include efficiency, but in the past he has shown it in a range of $0-$50, with a midpoint of $25. For the purpose of comparing the cost of carbon abatement, I use $32/MWh for the main alternatives (efficiency, wind, and solar). Given cost trends and the ability to tap significant efficiency, the assumption of a cost of $32/MWh for the alternatives is very cautious.

Figure 4 shows the output of the analysis of the cost of carbon. The obvious conclusion is that new nuclear reactors are an extremely costly way to reduce carbon emissions. Even aging reactors are more costly that the alternatives. In the short term, the advantage of the alternatives is between 25% (optimistic aging reactors) and 50% (realistic aging reactors). Taking cost rends into account (declining cost of supply-side renewables, rising cost of aging reactors), the advantage of the alternatives would grow to the range of 50-75% by the end of the next decade. For the mid- and long term, when policy must confront the problem of replacing the aging reactors, the nuclear cost becomes unbearable. It amounts to excess costs per ton of carbon reduction of between about $100/per ton compared to the alternatives compared to coal and $200/ton compared to gas. This is the sum of the benefit of the alternatives, which are less costly than fossil fuels, and the cost of nuclear, which is more costly than fossil fuels. The comparisons with gas are higher, because gas is less carbon intensive.

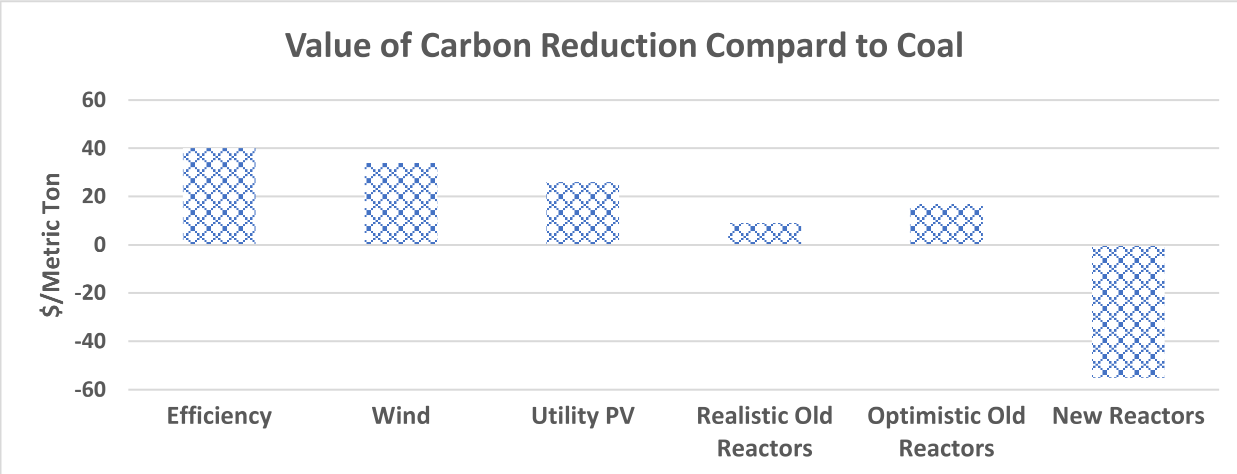
Lazard also assumes that nuclear, wind, and solar are all zero-carbon resources. They are not, as shown in Table 1. Every resource has a carbon footprint, with nuclear being almost six times as great as wind and 25% more than solar. Analysis of building retrofits shows that this is the only resource that is actually close to zero (less than a quarter of wind). This difference is applied to the efficiency cost estimate only. Table 1 makes another important policy point: Nuclear power has much larger impacts that the alternatives in terms of other pollutants, water, and accidents.

All-of-the-Above Strategies Cannot Work and Are Not Necessary

For some analysts, an "all-of-the-above" strategy seems to be evenhanded and balanced. There are three problems with that approach.

First, we did not arrive at the current electricity structure with an "all-of-the-above," evenhanded policy. We got here with a set of policies that were heavily biased in favor of central-station facilities, so shifting to an "all-of the -above" strategy now is heavily biased in favor of the dominant incumbents. I will deal with that issue in the discussion of subsidies below.

FIGURE 4: THE COST OF CARBON ABATEMENT[16]



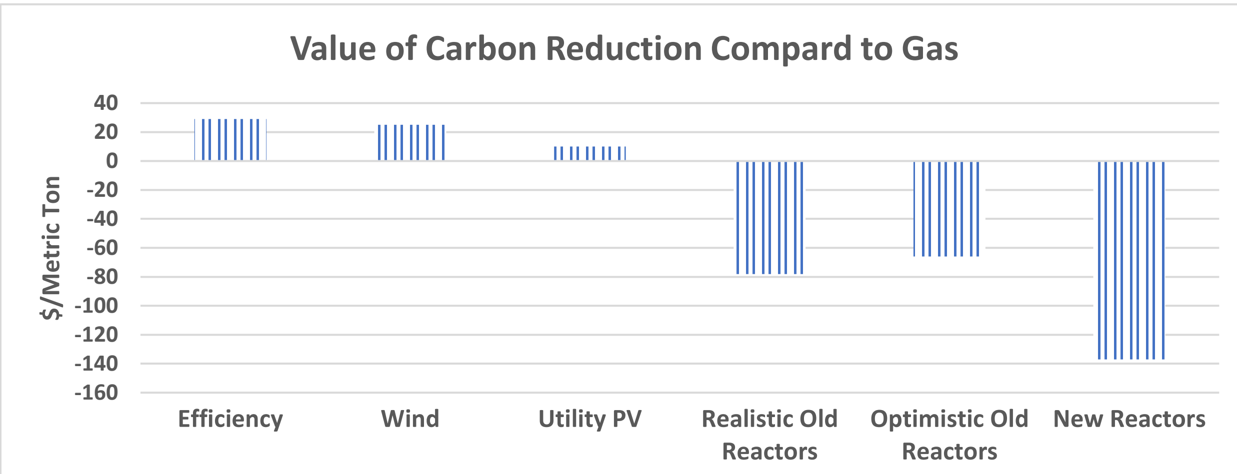


TABLE 1: ENVIRONMENTAL IMPACTS OF ALTERNATIVE RESOURCES[17]

Resource	**Carbon** Life Cycle			Cost of delay In construction		**Other** Pollutants Cents /MWh	Water (m3/MJ)	Land (m2/GWh)	Accidents Fatalities
	Low	Avg.	High	Low	High				
Efficiency		1				~0	0	0	~0
Wind	4	7	10			0.29	0.01	2404	1
PV	19	32	59			0.69	0.042	1232	4
Gas w/CCS		45				5.02	0.1	623	10
Coal w/CCS		90				14.87	0.31	325	20
Nuclear						8.63	0.59	78	7
Old		40	58						
New	9	40	70	59	106				
Hydro	17	25	22	31	49	3.84	22	1803	12
Geothermal	15		55	1	6				

Second, the "all-of-the-above" strategy simply will not work, because it mixes elements of two different approaches that are incompatible. The central-station facilities cannot behave in a manner that is consistent with the distributed-alternative system. When the central-station facilities occupy the space, they squeeze out the alternatives. Amory Lovins had earlier elaborated on the deep-seated sources of conflict between nuclear power and the alternatives, making it clear that a truce that tries to accommodate both sides is neither very likely, nor good policy.

> "All of the above" scenarios are … undesirable for several reasons…. First, central thermal plants are too inflexible to play well with variable renewables, and their market prices and profits drop as renewables gain market share. Second, if resources can compete fairly at all scales, some and perhaps much of the transmission built for a centralized vision of the future grid could quickly become superfluous. Third, big, slow, lumpy costly investments can erode utilities' and other provider's financial stability, while small, fast, granular investments can enhance it. Competition between those two kinds of investments can turn people trying to recover the former investments into foes of the latter – and threaten big-plant owners' financial stability. Fourth, renewable, and especially distributed renewable, futures require very different regulatory structures and business models. Finally, supply costs aren't independent of the scale of deployment, so PV systems installed in Germany in 2010 cost about 56–67% less than comparable U.S. systems, despite access to the same modules and other technologies at the same global prices.[18]

Third, as discussed in the remainder of this section, an "all-of-the-above" strategy is not necessary. The consumer and national interest are much better served by an aggressive embrace of the alternative approach.

Misleading Policy Choices

In its September 2019 analysis entitled "Can Tax Credits Tackle Climate," the Rhodium Group puts policy choices on the table but fails to properly analyze them. Under the proposition that the recent past is the best predictor of the near future, they vastly underestimate what wind and solar can do and vastly overestimate how many nuclear reactors will shut down. The top graph in Figure 5 shows that the Rhodium Group has vastly overestimated the number of reactors that are likely to retire over the decade. The middle graph in Figure 5 shows that wind and solar are capable of a much faster growth rate than reflected in the Rhodium analysis. The bottom graph adds in a big game-changer for alternatives: storage.

The announced retirements for the 2020s fit the nuclear trend line, so there is no doubt that wind and solar can, and almost certainly will, offset those losses, while making a great deal of additional capacity available. Even adjusting for load factors, which are improving dramatically due to better technology and combination with storage, wind and solar can more than offset the loss of nuclear.

At a 30% load factor, wind and solar replace nuclear (at 90% load factor) and add another 50GW of low-carbon resources. Adding in storage, which pushes the renewable load factor to 50%, shows an even greater effect. Renewables with storage bring over 2.5 times as much capacity online as current nuclear. As shown in Figure 6, the contribution of efficiency can be substantial, equal to a large part of the nuclear fleet. This does not include any increase in efficiency or the benefits of reduced need for capacity in a dynamic grid (a benefit that is routinely put at 17%).[19]

FIGURE 5: RECENT AND PROJECTED NUCLEAR, WIND, AND SOLAR CAPACITY[20]

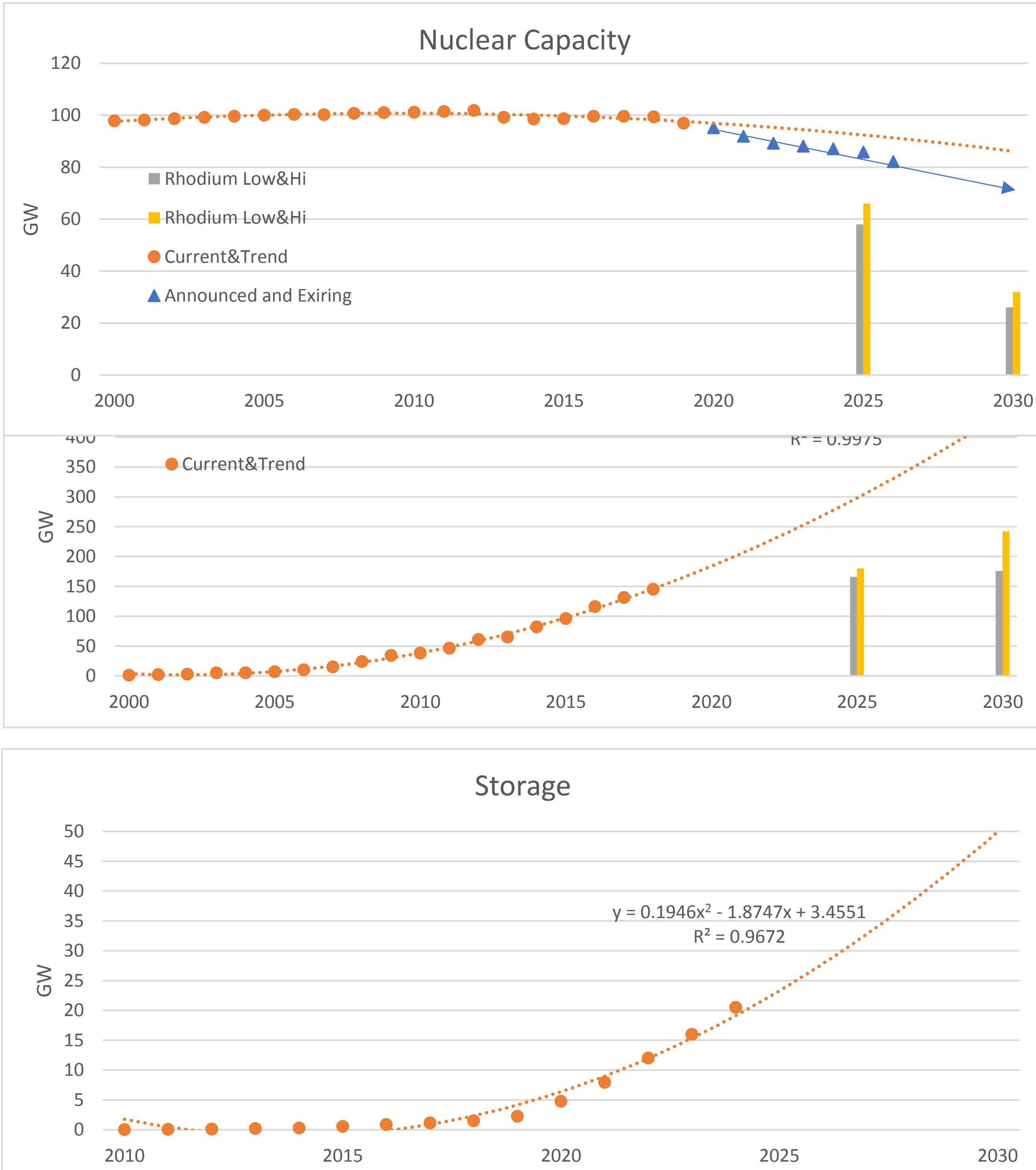
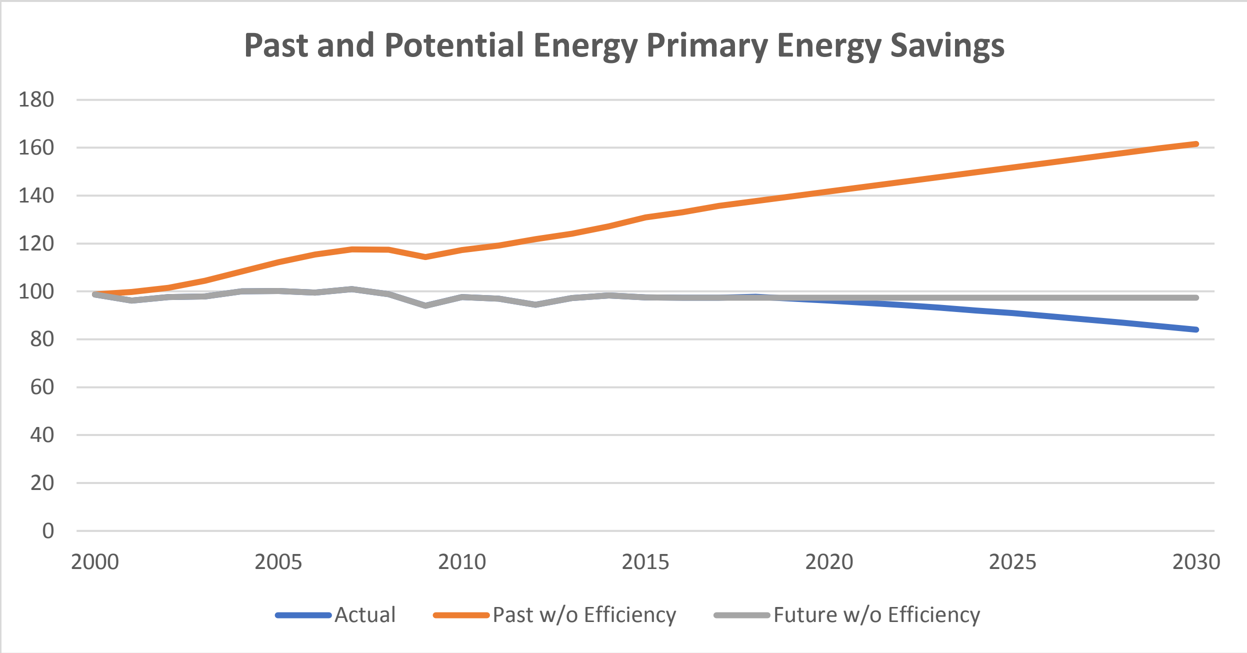


FIGURE 6: PAST AND POTENTIAL FUTURE PRIMARY ENERGY SAVING FROM EFFICIENCY[21]



SUFFICIENCY OF THE ALTERNATIVES

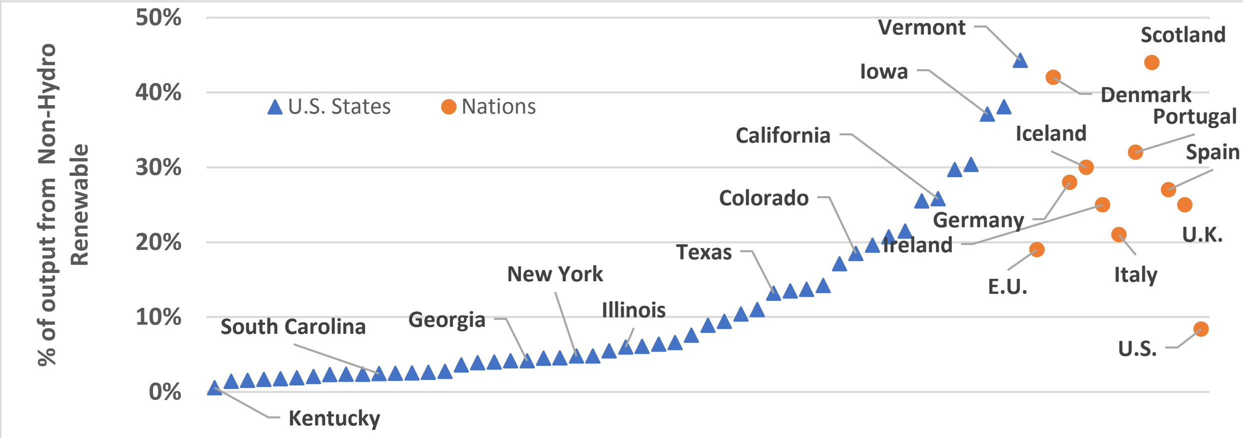
There is an ongoing debate about whether renewables can reach 100% of projected load, but that ignores the immediate question of how to get to the future. To assess the opportunity to meet the need for low-carbon alternatives with renewables, we begin with the present and work to the future. Resources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

Meeting short- and long-term needs

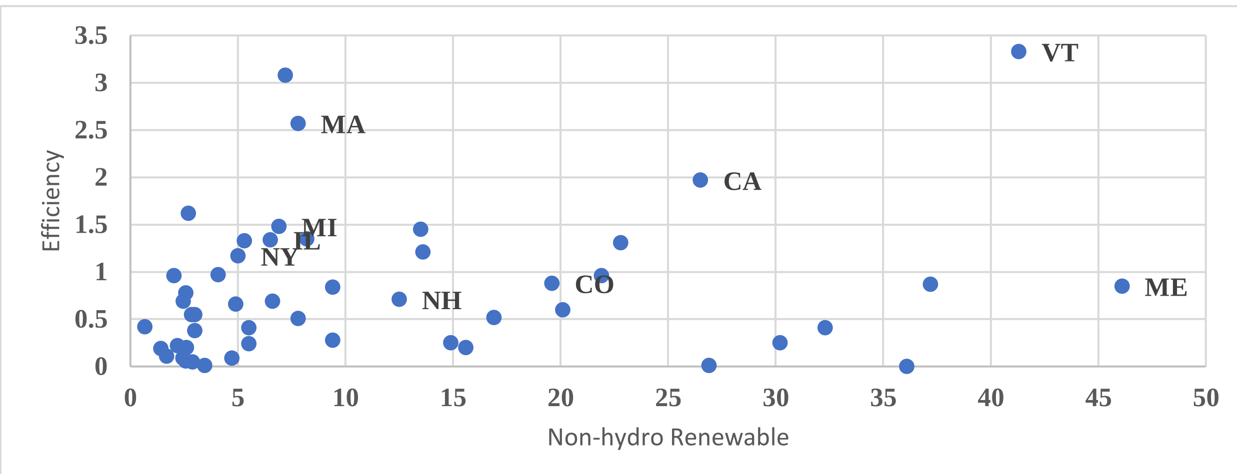
The analysis generally proceeds at two levels. First, as shown in top Figure 7, we see comparisons of how other states and nations are doing in the effort to deploy clean, low carbon alternatives. The upper graph highlights the fact that New York and Illinois, the two states that have offered nuclear bailouts, have had a mediocre performance, at best. At least two large states with large industrial economies have achieved much higher levels of contribution from efficiency and non-hydro renewables. Other advanced industrial nations have achieved even higher levels of contribution from renewables. States and nations have achieved eight times the contribution of non-hydro renewables to their generation needs as New York and Illinois. In New York, combining this level of non-hydro renewables with its large base of hydro would bring the state to its 2030 goal. Relying on the market in the near term should be preferred because it allows for a smoother transition, in addition to reinforcing the overall market framework.

FIGURE 7: AVAILABILITY OF ALTERNATIVE RESOURCES[22]

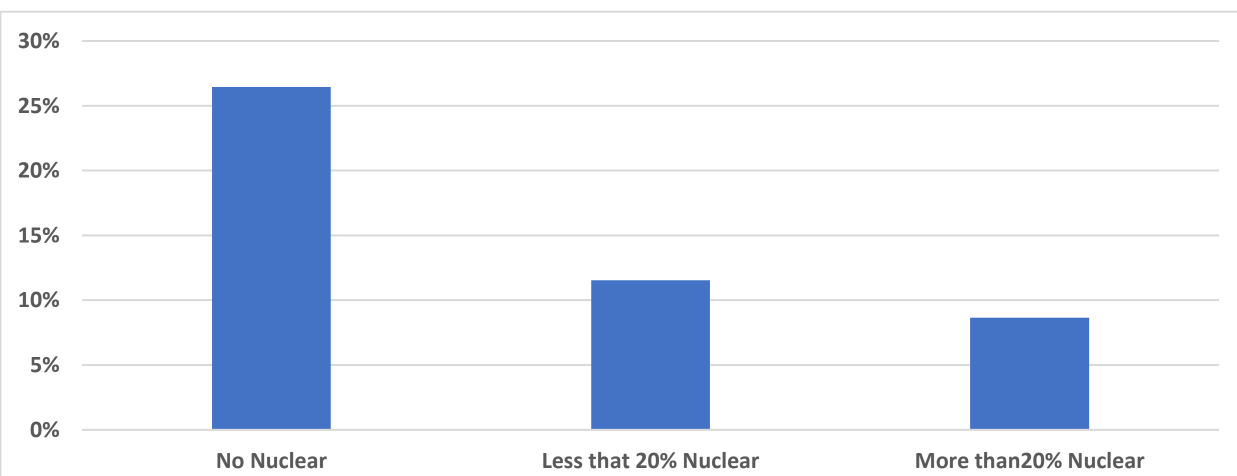
Penetration of non-hydro Renewables



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



Nuclear and Non-Hydro Renewables



The lower graph of Figure 7 addresses the crowding out question. The non-nuclear states have achieved over 2.5 times the level of non-hydro renewables. It also shows that there is little difference between the states with more and less nuclear power. The average nuclear state has 10% renewables and 29% nuclear. The non-nuclear states have 26% non-renewables. If we exclude for coal-dominant states (West Virginia, Kentucky, North Dakota, and Wyoming), the average jump is over 29%. The observation that renewables can replace central-station is consistent with past practice, not to mention future trends. This analysis does not take efficiency into account.

Perspective on the national potential can be gained by examining EPA's Clean Power Plan. It embodied moderate targets laid out by the EPA. While the reduction of carbon emissions that results from the combination of the base case trends and the policy case in the EPA analysis is impressive, it is well below what the literature deems economic and achievable for efficiency and renewables. According to the CITI projection of base-case growth, which includes only existing state RPS programs, at least 60% more could be achieved with renewables. Two-fifths of the states have yet to adopt RPS programs, so it is reasonable to assume that a policy case in which the remaining states sought to increase renewable energy to roughly the same level as the RPS states would nearly double renewables.

Moreover, the contribution of efficiency could also be double the EPA assumption, based on the estimates of the national experts. For both renewables and efficiency, the projected costs are competitive with the current cost of natural gas, so these carbon reductions impose very little increase in the cost of electricity. The aging reactors can be readily offset by the other low-carbon sources.

SUBSIDIZE THE FUTURE, NOT THE PAST

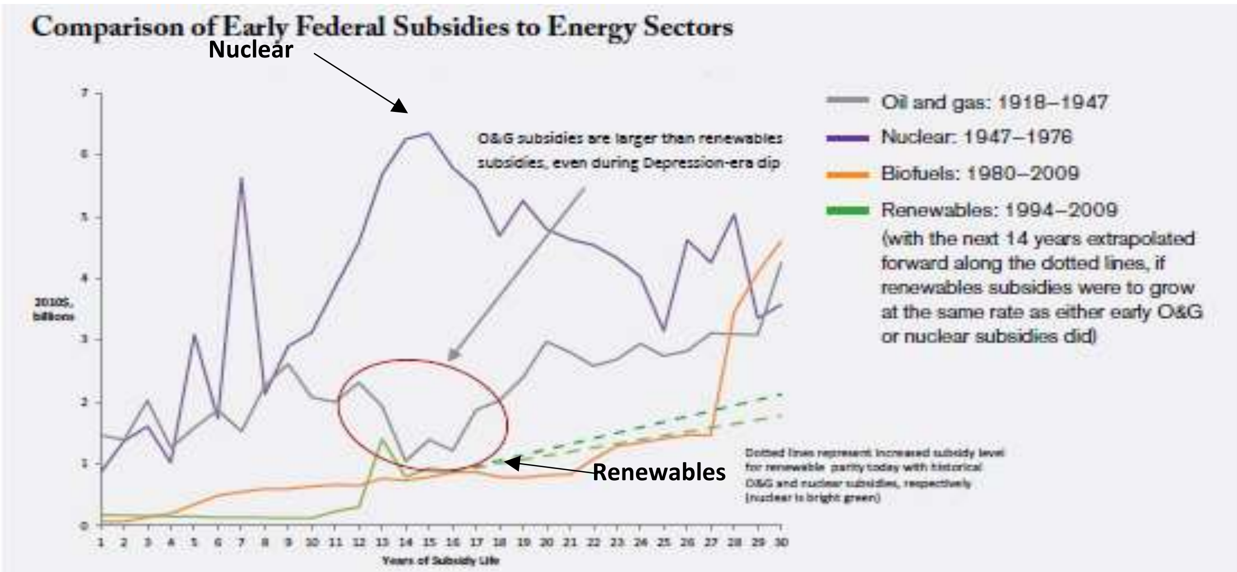
As discussed above, nuclear power comes up short compared to the alternatives on every dimension of economics and environmental impacts and has failed to make the case that an electricity sector based on the alternatives cannot be sufficiently reliable. I have shown at the national and local levels that it also fares poorly in jobs analysis.[23]

The Failure of Nuclear Power to Deliver on its Promises

One last claim the industry makes is that the alternatives are unfairly being subsidized. 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.[24] Renewables are in the early stage of development, as shown in Figure 8. Nuclear received much larger subsidies in its developmental stage and enjoyed truly massive subsidies since its inception, compared to other resources as it grew.

The graph calculates the rate of growth in subsidies that would be necessary to bring renewables into parity with the early rate of growth in subsidies enjoyed by central-station resources. Renewables are more than a dozen years behind the central-station resources, but given the importance of inertia, parity may not be enough to overcome the advantages of incumbency. There can be debate about the current level of subsidies, particularly given the difficulty of valuing the nuclear insurance and waste subsidies which are existential rather than material (i.e., without the socialization of liability and waste disposal, the industry would not exist). However, there is no doubt that the long-term subsidization of nuclear power vastly exceeds the subsidization of renewables and efficiency by an order of magnitude of 10 to 1.[25]

FIGURE 8: FEDERAL SUBSIDIES FOR INFANT ENERGY INDUSTRIES AND BEYOND[26]



The dramatic increase in innovative activity despite relatively low levels of R&D subsidy and much lower cumulative subsidization reflects the decentralized nature of innovation in the renewable space. It leads to the dramatic payoff in terms of declining price. As we have seen, wind had the earlier success, and solar is now catching up.[27] 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 they are deployed on a wide scale. This is the antithesis of past nuclear development. The alternatives are moving rapidly along their learning curves, which can be explained by the fact that these technologies actually possess the characteristics that stimulate innovation and allow for the capture of economies of mass production. They involve the production of large numbers of units under conditions of competition. Nuclear power involves an extremely small number of units from a very small number of firms, with the monopoly model offered as the best approach.

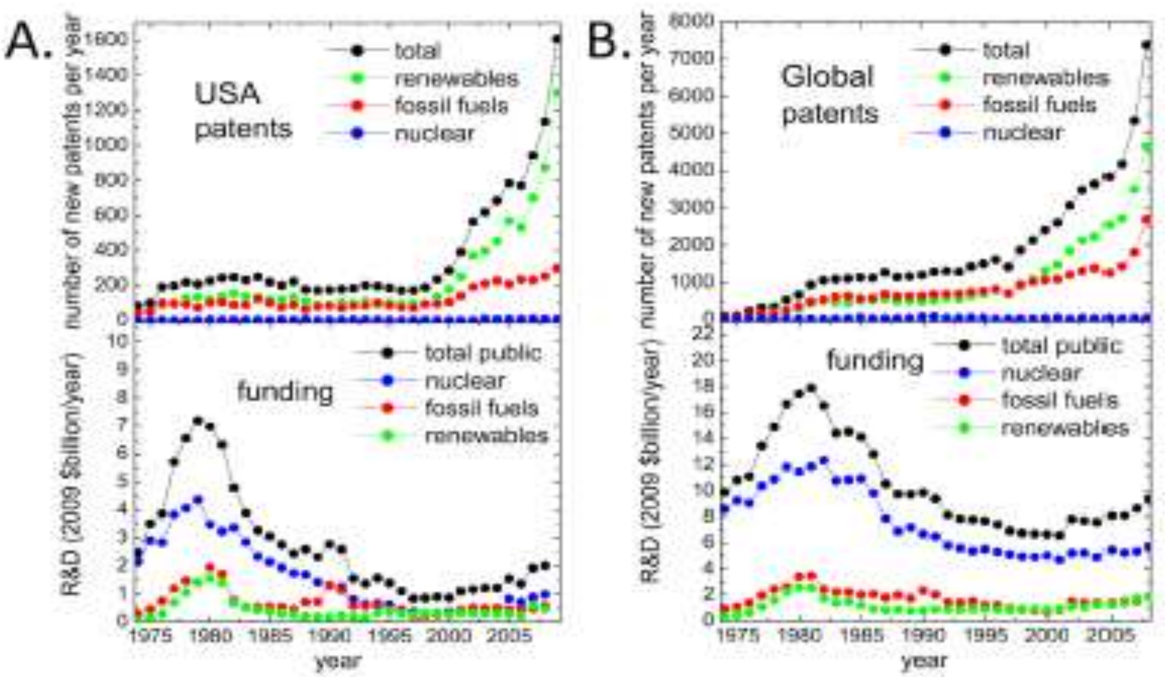
The above discussion of subsidies focuses on long-term patterns of subsidies and underscores the point that much more was invested in nuclear and fossil fuels. This should not be taken to mean that there are no current subsidies enjoyed by nuclear power. In fact, while advocates for nuclear power point to specific subsidies for renewables – production and investment tax credits – there are at least half a dozen policies embedded in current practices that nuclear enjoys.

Continuing Subsidies

Keeping in mind the principle that sunk cost should not matter but future, marginal costs are paramount, one might argue that the past nuclear subsidies should not matter. That suggestion is incorrect for three reasons.

As shown in Figure 1, above, nuclear has failed to deliver on its price promises. The alternatives have performed much better and hold much greater promise. Further, as shown in Figure 8, it is also clear that with a much smaller level of subsidy to drive innovation and economies of scale, the renewables have achieved dramatically declining costs in a little over a decade, which is exactly the economic process that has eluded the nuclear industry for half a century. Figure 9 captures the essence of the subsidy issue by juxtaposing the magnitude and timing of subsidies and the extent of innovation, as measured by patents issued. The ultimate irony is that despite much smaller subsidies to drive innovation and economies of scale, renewables have achieved dramatically declining costs in just over half a decade.

FIGURE 9: INNOVATION AND PUBLIC SUPPORT FOR R&D[28]



The decision to shift subsidies to the alternatives should have nothing to do with fairness; however, it should be based on the likely payoff of the investment. Analyses of past subsidies globally and in the United States make it clear that renewables are a much better bet[29] even though the estimates do not include the very large implicit subsidies nuclear enjoys from the socialization of the cost of risk and waste management.[30]

Current Subsidies

Current subsidies enjoyed by nuclear power are massive. These include the socialization of risk and waste management costs, now under court order to be paid by the Department of Energy to nuclear reactor owners for the failure to provide nuclear waste disposal, because no such safe waste repository exists or may ever exist. Tax treatment of capital expenditures, capacity payments from RTOs/ISO, high system burdens due to the risk of large outages and the inflexibility of nuclear, which requires higher reserve margins, are all subsidies. Nuclear power is favored by the tax code treatment of capital, which is a very large cost.[31]

Nuclear and other centralized resources also get a pass in the treatment of system costs. They have their system costs "socialized" and recovered from ratepayers, while system costs are imposed directly on developers of alternative resources. Lovins describes this bias in detail.

> Specifically, variable renewables' grid balancing costs are generally borne by their developers or owners and are usually <$5/MWh, nearly always <$10. Yet coal and nuclear plants impose analogous costs on the system without being charged for them, at least outside ERCOT. Instead, the grid-balancing costs of managing the intermittence (forced outages) of central thermal plants – reserve margin, spinning reserve, cycling costs, part-load penalties – are traditionally socialized, treated as "inevitable system costs," and hardly ever analyzed.
>
> This asymmetry appears to favor fossil-fueled and nuclear plants, because their balancing costs, emerging evidence suggests, may be severalfold greater than those of a well-designed and −run portfolio of PV and wind resources. Conversely, variable renewables may need less backup (or storage) than utilities have already bought to manage the intermittence of their big thermal plants. (For example: Utilities have found that high wind fractions can be firmed by fueled generators ≤5% of wind capacity – severalfold below classical ∼15-20% reserve margins for thermal-dominated systems. Unbundled ERCOT ancillary services market price data confirm that wind's reserve costs per MWh are about half those of thermal generation. NREL's models confirm for the western U.S. that central thermal plants cost more to integrate than variable renewables.[32]

Conclusion

The nuclear industry is undeserving of another bailout. Creating a new investment tax credit for existing reactors would result is serious direct and indirect consequences for taxpayers, ratepayers, and the climate. Congress should embrace a least-cost vision of our future sustainable energy economy. By definition, that means excluding new subsidies for existing reactors – both from the energy tax extenders and from any future tax legislation.

ENDNOTES

[1] *The Political Economy of Electricity: Progressive Capitalism and the Struggle to Build a Sustainable Power Sector* (Santa Barbara, Praeger, 2017), Chapter 9, notes the role of tax policy in a context that shows the parallel between climate change and other progressive policies.

[2] Johnathan Tirone, October 7, 2019. The key factor was that nuclear power would be "overpowered" by renewables. A similar sentiment was expressed a few months earlier in Australia by a report by the Australia Institute's energy emissions audit for the month of July, as noted by Camron Slessor and Nick Harmsen, "Nuclear power not the answer as renewables continue to boom in Australia, report finds," August 26, 2019 (**https://www.abc.net.au/news/2019-08-27/energy-audit-finds-nuclear-power-is-not-the-answer-for-australia/11450850)**. This argument was made earlier in Australia by Mark Cooper, "Nuclear Power Is an Expensive, Inferior Resource That Has No Place in a Least-Cost, Low-Carbon Portfolio," Submission to the Electricity Generation from Nuclear Fuels, Nuclear Fuel Cycle Royal Commission, August 3, 2015.

[3] This analysis embodies a decade-long cumulative process that examines all aspects of the resource selection process, which includes academic conference papers, journal articles and books, testimony, and research reports.

Articles/Papers: "Governing the Global Climate Commons: The Political Economy of State and Local Action, After the U.S. Flip-Flop on the Paris Agreement," Energy Policy, 2018; *The Political Economy of Electricity: Progressive Capitalism and the Struggle to Build a Sustainable Power Sector* (Santa Barbara, Praeger, 2017); "Nuclear Economics Fatally Flawed," Platts, 2017; "Energy Justice in Theory and Practice, Building a Progressive Road Map," in Thijs Van de Graaf et al. (eds.), *The Palgrave Handbook of the International Political Economy of Energy* (Palgrave, Macmillan, 2016); "Renewable and distributed resources in a post-Paris low carbon future: The key role and political economy of sustainable electricity," *Energy Research & Social Science*, 2016; "Small modular reactors and the future of nuclear power in the United States," *Energy Research & Social Science*, 2014; "Energy Efficiency Performance Standards: Driving Consumer and Energy Savings in California," California Energy Commission's Energy Academy, February 20, 2014; "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; "Nuclear Aging: Not so gracefully," *Bulletin of the Atomic Scientists*, 69, 2013; "Nuclear Safety and Affordable Reactors: Can We Have Both?" *Bulletin of the Atomic Scientists*, 68, 2012; "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*, 67, October 2011; "Prudent Resource Acquisition in a Complex Decision-Making Environment: Multidimensional Analysis Highlights the Superiority of Efficiency," Current Approaches to Integrated Resource Planning, 2011 ACEEE National Conference on Energy Efficiency as a Resource, Denver, September 26, 2011; "The Implications of Fukushima: The US perspective**,"** *Bulletin of the Atomic Scientists*, 67, July/August 2011; "Least Cost Planning for 21st Century Electricity Supply: Meeting the Challenges of Complexity and Ambiguity in Decision-Making," MACRUC Annual Conference, June 5, 2011; "Risk, Uncertainty and Ignorance: Analytic Tools for Least-Cost Strategies to Meet Electricity Needs in a Complex Age," Variable Renewable Energy and Natural Gas: Two Great Things that Go Together, or Best Not to Mix Them, NARUC Winter Committee Meetings, Energy Resources, Environment and Gas Committee, February 15, 2011.

Testimony: "The Economic Feasibility, Impact on Public Welfare and Financial Prospects for New Nuclear Construction, for HEAL Utah," July 2013; "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; "Nuclear Power Is an Expensive, Inferior Resource That Has No Place in a Least-Cost, Low-Carbon Portfolio," Submission to the Electricity Generation from Nuclear Fuels, Nuclear Fuel Cycle Royal Commission, August 3, 2015; Testimony and Surrebuttal Testimony on Behalf of the Sierra Club, 33, Before The South Carolina Public Service Commission, Docket No. 2012-203-E, October 2012; Statement of Mark Cooper, "Nuclear Economics after Fukushima," Before the Standing Committee on Natural Resources, House of Commons, Ottawa, Canada**,** March 24, 2011; "Testimony of Dr. Mark Cooper on House File 9," Minnesota House of Representatives Committee on Commerce and Regulatory Reform, February 9, 2011; Testimony of Dr. Mark Cooper, Senior Fellow for Economic Analysis Institute for

Energy and the Environment, Vermont Law School, on 'Economic Advisability of Increasing Loan Guarantees for the Construction of Nuclear Power Plants," Domestic Policy Subcommittee, Committee on Oversight and Government Reform, U.S. House of Representatives, April 20, 2010; "Testimony of Dr. Mark Cooper on House File 9," Minnesota House of Representatives Committee on Commerce and Regulatory Reform, February 9, 2011; "Direct Testimony of Dr. Mark N Cooper in Re: Nuclear Plant Cost Recovery for the Southern Alliance for Clean Energy," Before the Florida Public Service Commission, FPSC Docket No. 100009-EI, August 2010; "Direct Testimony of Dr. Mark N Cooper in Re: Nuclear Plant Cost Recovery for the Southern Alliance for Clean Energy," Before the Florida Public Service Commission, FPSC Docket No. 090009-EI, July 15, 2009.

Research Reports: **"**The Green New Deal, Nuclear Power and Other Potholes to avoid on the Road to a Progressive, Capitalist, Least-Cost, Low-Carbon, Clean Electricity Sector," Institute for Energy and The Environment, Vermont Law School, April 2019; "A Clean Slate for Vogtle, Clean Energy for Georgia: The Case for Ending Construction at the Vogtle Nuclear Power Plant and Reorienting Policy to Least-Cost, Clean Alternatives," for the Sierra Club of Georgia, February 2018; "Trump's $2 Trillion Mistake, The 'War On Energy Efficiency': The 'command-but-not-control' approach to energy efficiency performance standards for appliances and vehicles corrects market failures and delivers consumer pocketbook savings, macroeconomic and public health benefits," Consumer Federation of America, December 1, 2017; "The Failure of the Nuclear Gamble in South Carolina: Regulators Can Save Consumers Billions by Pulling the Plug on Summer 2 & 3, Already Years Behind Schedule and Billions Over Budget. Things are Likely to Get Much Worse if the Project Continues," for the Sierra Club of South Carolina, July 2017; "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 2015; "Advanced Cost Recovery," Institute for Energy and the Environment, Vermont Law School, September 2013; "Renaissance in Reverse: Competition Pushes Aging U.S. Nuclear Reactors to the Brink of Economic Abandonment," July 2013; "The Economic Feasibility, Impact on Public Welfare and Financial Prospects for New Nuclear Construction," for HEAL Utah, July 2013; "Public Risk, Private Profit, Ratepayer Cost, Utility Imprudence: Advanced Cost Recovery for Reactor Construction Creates another Nuclear Fiasco, not a Renaissance," March 2013; "Fundamental Flaws In SCE&G's Comparative Economic Analysis," October 1, 2012; "Advanced Cost Recovery for Nuclear Reactors," Institute for Energy and the Environment, Vermont Law School, March 2011; "Policy Challenges of Nuclear Reactor Construction: Cost Escalation and Crowding Out Alternatives," Institute for Energy and the Environment, Vermont Law School, September 2010; "All Risk; No Reward," Institute for Energy and the Environment, Vermont Law School, December 2009; "The Economics of Nuclear Reactors: Renaissance or Relapse," Institute for Energy and the Environment, Vermont Law School, June 2009.

[4] My initial analysis of aging reactors provided a broad-brush view of the issue in Cooper, 2013, "Renaissance in Reverse" and "Nuclear Aging." Studies of state-specific reactors followed, including the two major states offering local bailouts (Illinois: Cooper, 2017, "Political Economy," and New York, Cooper, 2018 Affidavit.

[5] Bloomberg, 2019

[6] Using Vogtle's current projected cost of $13 billion per GW compared to $1 billion per GW in Cooper, 2018 Affidavit, based on Lazard ("The Levelized Cost of Electricity, 12.0," November 2019), the difference in capital cost is $12 billion per GW. Using 66 reactors, the total is close to $800 billion.

[7] This is a simplified summary of Chapters 10-11 in Cooper, 2017.

[8] Michael Kanellos, "Time to End Nuclear Socialism, Says New Study," GreenTechMedia.com, September 9, 2010

[9] Cooper, 2017, "The Political Economy," offers detailed discussions of cost estimates.

[10] Most recent update can be found in Mark Cooper, "The Green New Deal and Aging Reactors." A more complete discussion can be found in 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). Underlying data from the following: Lazard, "Lazard's Levelized Cost of Energy Analysis – Version 12.0," November 2018; Mark Cooper, "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; "Small Modular Reactors and the Future of Nuclear Power in the United States," *Energy Research & Social Science*, 3, 2014; Charles Komanoff, *Power Plant Cost Escalation, Nuclear and Coal Capital Costs, Regulation and Economics* (1981); James McNerney, J. Doyne Farmer, and Jessika E. Trancik, "Historical costs of coal-fired electricity and implications for the future," *Energy Policy*, 39 (6), 2011; Lazard, "Lazard's Levelized Cost of Energy Analysis – Version 12.0," November 2018; Galen Barbose, Naïm Darghouth, Samantha Weaver, and Ryan Wiser, "Tracking the Sun VI: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2012," Lawrence Berkeley National

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[11] Cooper, 2017, *The Political Economy of Electricity*, offers detailed discussions of cost estimates. Jacobson et al. (Jacobson, Mark Z., Mark A. Delucchi, Zack A. F. Bauer, Savannah C. Goodman, William E. Chapman, Mary A. Cameron, Cedric Bozonnat, Liat Chobadi, Jenny R. Erwin, Simone N. Fobi, Owen K. Goldstrom, Sophie J. Harrison, Ted M. Kwasnik, Jonathan Lo, Jingyi Liu, Chun J. Yi, Sean B. Morris, Kevin R. Moy, Patrick L. O'Neill, Stephanie Redfern, Robin Schucker, Mike A. Sontag, Jingfan Wang, Eric Weiner, and Alex S. Yachanin) have demonstrated the proposition for nations globally in "100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for 139 Countries," December 13, 2015, and for individual states (Jacobson, Mark Z., Mark A. Delucchi, Guillaume Bazouin, Zack A. F. Bauer, Christa C. Heavey, Emma Fisher, Shean B. Morris, Diniana J. Y. Piekutowski, Taylor A. Vencill, and Tim W. Yeskoo) in "100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for the 50 United States," *Energy and Environmental Science* 8 (2015): 2093-2117.

[12] Retired reactors in this time frame are SONGS 2&3, Kewaunee, Crystal River, Vermont Yankee, and Fort Calhoun.

[13] Assumptions: Output=807,000 MWh (EIA); 90% of output is subsidized; optimistic cost ($13.08)/MWh per NEI; realistic cost ($19.44/MWh), per without retirement regressions; tax subsidies 2020-2023 = 30%, 2024 = 26%, 2025= 22%, 10% is permanent. Transition disruption is calculated as 1,000 MW not replaced each year (no replacements in 1st ten years, the 1,000 MW per year catch-up.

[14] Cooper, 2018 Affidavit and 2019, "The Green New Deal"

[15] As one analyst put it, looking at the Democratic presidential field, "The industry threw its lot in with coal over the past few years in hopes of winning federal subsidies from the Trump administration." Alexander C. Kaufman, "Cory Booker Compares Anti-Nuclear Democrats To Republican Climate Deniers," Huffpost, September 19, 2019. Varun Sivaram and Angela Freeman, "Why is Trump's Energy Initiative Linking Coal and Nuclear Together?" *Foreign Affairs*, November 13, 2017. We see a similar phenomenon at the state level, with the initial push including both nuclear and coal. Andy Balaskovitz: "Ad campaign supporting nuclear, coal bailouts launches in Ohio," Energy Network News, August 27, 2019. Initially, the bill included financial support not only for nuclear plants, but for struggling coal plants. Depending on the fuel mix of the utility, coal subsidies might fade away, but there is no doubt that the utilities will gladly support both central-station approaches, including the mining of the fuel sources. In Illinois, "Initially, the bill included financial support not only for nuclear plants, but for struggling coal plants." www.ncsl.org/research/energy/state-action-in-support-of-nuclear-generation.aspx, October 2019

[16] Lazard, "Lazard's Levelized Cost of Energy Analysis – Version 12.0," November 2018, page 15; Version 9.0, efficiency, p. 2. Old nuclear uses the costs for reactors without retirements. Optimistic cost is $40.4/MWh. Realistic is $47.6, per the retirement analysis.

[17] 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 and Environmental Science*, 2, p. 165, Table 3, 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, April 2015. BEV=battery electric vehicle; CCS=carbon capture and storage. Benjamin K. Sovacool, "Exposing the Paradoxes of Climate Change Governance," *International Studies Review*, 16 (2), 2014; Averages from Benjamin K. Sovacool, "Valuing the greenhouse gas emissions from nuclear power: A critical survey," *Energy Policy*, Volume 36, Issue 8, August 2008, Pages 2950-2963.

[18] Lovins, Amory B., and Rocky Mountain Institute, *Reinventing Fire: Bold Business Solutions for the New Energy Era*, 2011, p. 216

[19] Cooper, 2017, *The Political Economy of Electricity*, discusses this dividend. A similar dividend was evident in New York (Cooper, 2019, p. 34).

[20] To be cautious, the projection of retirements includes 2019 reactors, not included in the base, and others announced or ending their licenses, as well as several (in 2026) that have been the beneficiaries of early bailouts, although the bailouts may expire a little later: in 2019, Three Mile Island; Oyster Creek, and Pilgrim; in 2020, Duane Arnold and Davis Besse; in 2021, Indian Point and Perry; in 2022, Beaver Valley and Palisades; in 2024, Diablo Canyon; in 2025, Diablo Canyon; in 2026, (early bailouts) Quad Cities, Clinton, and Fitzpatrick. Wind and Solar are from the EIA database. Storage is from Wood MacKenzie, "U.S. Energy Storage Monitor."

[21] Energy consumption from EIA database; GDP from BEA.

[22] ACEEE, "The 2018 State Energy Efficiency Scorecard," p. 28; Energy Information Administration, Electric Supply Monthly, generation and non-hydro renewables

[23] Cooper, 2017, *The Political Economy of Electricity;* 2018 Affidavit

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

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[26] Pfund and Healey, "What Would Jefferson Do?" 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., Jessika E. Trancik, and Jasleen Kaur, 2013, "Determinants of the pace of global innovation in energy technologies," *PLOS ONE*, October 8, p. 10.

[27] Badcock and Lenzen, "Subsidies for Electricity-Generating Technologies"; Branker and Pearce, "A Review of Solar Photovoltaic"

[28] Bettencourt, Louis M.A., Jessika E. Trancik, and Jasleen Kaur, 2013, "Determinants of the pace of global innovation in energy technologies," *PLOS ONE*, October 8, p. 10

[29] Badcock, and Lenzen, "Subsidies for Electricity-Generating Technologies"

[30] Zelenika-Zovk and Pearce, "Diverting indirect subsidies from the nuclear industry to the photovoltaic industry: Energy and financial returns," *Energy Policy* 39 (2011), p. 2626

[31] Lovins, Amory B., "Do coal and nuclear generation deserve above-market prices?" *The Electricity Journal*, July 2017

[32] Ibid.