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The Value of Advanced Energy Funding

Projected Effects of Proposed US Funding for Advanced Energy Technologies

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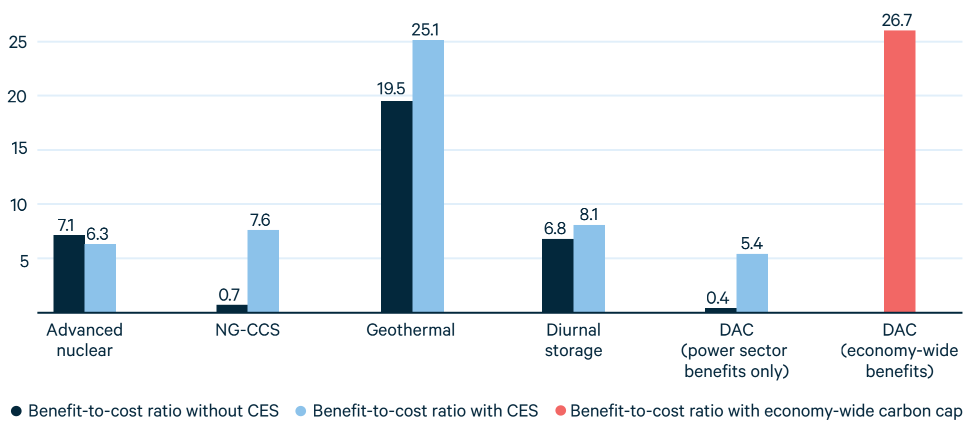
Executive Summary

This study estimates some effects of proposed additional US government funding for research, development, and demonstration (RD&D) of five advanced clean energy technologies: advanced nuclear, generation from natural gas with carbon capture and sequestration (NG-CCS), advanced geothermal, diurnal energy storage, and direct-from-air capture of CO_2 (DAC). Specifically, we estimate the effects of the additional funding on the costs of these technologies and some of the societal benefits that would result from these cost reductions.

The Energy Act of 2020, which became US law in December 2020, authorizes additional funding for those five advanced energy technologies (AETs). Although work on this study began before the law passed, the funding levels we evaluate in the study were based on a remarkably close prediction of the final bill's programs and authorized funding amounts for the AETs. It is uncertain how much funding each of the technologies will receive—they could receive less than authorized in the act, or more, perhaps as part of stimulus, infrastructure, or energy legislation.

In a rigorous expert elicitation process, we asked 26 experts in these five technologies to estimate the effect of additional funding on the levelized costs of new facilities using these technologies, in 2035. We asked the experts to assume that the added funding would be provided for 10 years, from 2022 to 2031. Their answers indicate that additional funding would result in average cost reductions of approximately 29 percent for advanced geothermal, 29 percent for DAC, 25 percent for nuclear, 16 percent for diurnal storage, and 9 percent for NG-CCS in 2035. These percentages reflect estimates of how much lower the cost of each technology would be with the added RD&D funding than without it.

Figure ES1. Estimated Benefit-to-Cost Ratios from 10 Years of Higher RD&D Funding



To estimate some of the benefits of these cost reductions for society, we used detailed power sector simulations of the year 2050 with and without a national clean electricity standard (CES) that requires 94 percent clean power by 2050. We make the conservative assumption that the experts' cost projections for 2035 would still apply in 2050, even though costs tend to decline over time, deployment accelerates the cost reductions, and lower costs significantly increase the benefit from further cost reductions. Our simulations indicate that without a national CES, the benefits from the additional funding would be a mix of electricity bill savings, reduced health damages, and reduced climate damages. With a national CES, on the other hand, the benefits would come mainly from electricity bill savings. These electricity user savings amount to an average of approximately $14 per household per year for each technology without a CES and $56 per household per year for each technology with a CES.

Figure ES1 shows the estimated benefit-to-cost ratios of additional funding for each technology. The costs are the added US public and private RD&D spending, based on the experts' responses. We assume the benefits estimated by the simulation last 20 years (mid-2040 to mid-2060). The ratios are present value of benefits over present value of costs, using a 3 percent real discount rate. Overall, we estimate that the additional funding would produce an average benefit-to-cost ratio for each technology of 6.9 without the CES and 10.5 with it. Without the CES, three of the five technologies have benefit-cost ratios above 1 (in fact, above 6). With the CES, all five technologies have benefit-cost ratios above 4. These benefit-to-cost ratios do not count benefits outside the years 2040 to 2060, US RD&D expenditure changes outside the 10-year period from 2022 to 2031, US export revenues, US benefits from reduced foreign emissions, or net benefits abroad.

Further, these benefit-to-cost ratios count only the benefits inside the electricity sector, whereas in reality, benefits in other sectors, such as industry, transportation, and consumer products, are likely for all five of the technologies.

A DAC study by Hafstead **(2020)** allows us to also estimate the US economy-wide benefit-to-cost ratio for the added DAC RD&D funding in the presence of a policy that cost-effectively reduces economy-wide emissions to approximately 50 percent below 2005 levels by 2050. In this situation, we estimate that benefits of additional DAC funding would be 27 times as great as the costs, as shown in the right-most portion of Figure ES1.

Our results also indicate that the benefits of each $1 reduction in expected levelized cost per MWh grow substantially larger as expected cost falls. This implies that the expected benefits per dollar of additional RD&D funding for each technology could actually grow larger per dollar spent on that technology.

Contents

1. Introduction

Many US states and utility companies are pursuing ambitious clean energy policies to curb greenhouse gas emissions from electricity generation. Achieving these goals requires substantial investment in zero-carbon and carbon-negative technologies within the electricity sector. Generation from wind and solar energy has become inexpensive, but because of the variability of these resources, achieving ambitious targets is likely to require other, nonvariable, nonemitting technologies. Making these other technologies less costly could increase their use and produce substantial benefits for society by enabling the power sector to meet existing and future climate targets at a lower cost.

Innovation policy, which includes funding for research, development, and demonstration (RD&D), is intended to help technologies develop, lower their costs, and ultimately achieve commercial operation at scale.

The Energy Act of 2020 proposes funding for RD&D to advance several clean energy technologies, including geothermal energy, diurnal storage, direct air capture (DAC) of carbon dioxide, natural gas with carbon capture and sequestration (NG-CCS), and advanced nuclear. These advanced energy technologies, which we will call “the AETs,” can contribute to the energy system by reducing the cost of the electricity supply, especially in the presence of clean energy goals.

Shawhan, Funke, and Witkin (2020) find that reducing the costs of the AETs would have significant benefits under scenarios both with and without a national clean electricity standard (CES), in the form of reduced compliance costs, lower costs for electricity users, and reduced emissions from the electricity sector. Their study indicates that cost reductions of these technologies targeted by the Energy Act of 2020 could produce billions of dollars per year of benefits even if there is no new national clean energy policy to further increase the demand for such technologies. Without a CES, the benefits are a mix of lower electricity bills, health benefits, and climate benefits. With a CES, the main benefit is lower electricity bills.

The legislation authorizes significant increases in funding to the AETs. Each year, the US Congress must decide how much funding to actually provide. One outstanding question is how much the innovation funding authorized in the legislation is likely to contribute to achieving cost reductions for these energy technologies. Estimating this effect requires comparing future costs of the technologies with and without the funding—and both costs are difficult to predict. A common method for estimating the effect of innovation policy on technology costs is to survey experts who are very knowledgeable about the technologies through a careful expert elicitation. Like other available options, this method is far from perfect, as we discuss more in the Methods and Discussion sections below; however, it can still be informative. This study estimates the effects of additional funding, very similar to that authorized in the Energy Act of 2020, on the costs of the energy technologies through an expert elicitation. Additionally, this study makes use of simulations reported in Shawhan, Funke, and Witkin (2020) and Hafstead (2020) that estimate the societal value of cost reductions for the same five technologies.

Notably, this study began prior to the passage of the Energy Act of 2020 in December 2020, so the programs and funding levels that we asked the experts to assume in projecting the costs of the technologies do not exactly match the authorized funding levels passed into law. However, thanks to a knowledgeable and prescient legislative staffer, our expert elicitation and this report are based on legislation, programs, and authorized funding levels very similar to what passed. Specific research programs in the act are structurally nearly identical to what we asked the experts to assume, and the funding amount for each technology is also very similar to what we asked the experts to assume.

2. Methods for Conducting the Expert Elicitation

To design and conduct the expert elicitation, we drew on lessons from prior experience and literature, including Baker et al. (2009), Diaz et al. (2013, 2016), Few et al. (2018), Klaassen et al. (2005), Morgan (2014), National Research Council (2005, 2007), Nemet et al. (2015), Verdolini et al. (2018), and Wiser et al. (2016). We sought out a diverse set of experts in academia, industry, and nongovernmental institutions for each of the five technologies. In the expert elicitation portion of this study, we also include a sixth technology, multiday energy storage, which was not analyzed in Shawhan, Funke, and Witkin's (2020) simulation modeling. We found experts primarily through searches of recent literature on the technologies and through recommendations from other experts and contacted nearly 190 experts, 29 of whom fully participated in the study. Because of overlapping expertise, three of the experts in diurnal storage also provided answers for multiday storage. We ultimately had five participants for each technology except for DAC, for which we had four because of the limited number of experts able to participate. We asked the experts for their unbiased projections and agreed not to individually attribute their responses. Each expert was paid $1,000 for participating.

Experts were asked to complete a detailed questionnaire specific to their technology that required them to provide numerous estimates, including the levelized cost of their technology in the year 2035 with and without the legislation. We asked them to assume that the facility is designed in the year 2035 and built shortly thereafter.[1] Levelized cost can be an ambiguous metric, but in this study we asked for the details that go into it, so it is not ambiguous and we can apply uniform background assumptions.

In addition to the questionnaire itself, experts were given detailed instructions and a list of assumptions for answering the questions, a detailed summary of the legislation written by RFF researchers, and a copy of the text from the bill. After completing the questionnaire, the experts completed an hour-long phone interview with the principal investigator (Shawhan), after which they typically revised one or more answers in response to reminders about details of the instructions (most commonly, changing their projected costs of capital from nominal to real). Copies of all questionnaires, instructions, bill summaries, and the bill excerpts are available in the online appendix.

A summary of the pieces of legislation given to the experts and their projected effects on RD&D funding for these technologies is provided in Table 1, and detailed summaries of the legislation by technology are in the online appendix. The funding projections below are for fiscal year (FY) 2022 through FY 2031. The funding projections without the legislation are based on continuation of FY 2020 funding levels in real terms. (Nominal annual values increase at an assumed annual inflation rate of 1.4 percent). The funding projections with the legislation are based on the funding authorizations,

1 The AETs require different time periods to be built. Diurnal storage units may be buildable within one year, whereas nuclear power plants may take 10 years to come online after being designed.

which were for five years, but for the purpose of this study we assume a total of 10 years, since it is common for authorized funding increases to continue beyond the term mentioned in the authorizing legislation. We asked the experts to assume that after the 10 years of increased funding for the technologies, the US government funding would return to the level it would have been if the legislation had not passed. The funding authorized in the legislation is almost entirely US Department of Energy funding and does not necessarily include all US government funding for the technologies. The dollars used differ from technology to technology because the annualized funding streams have different anchor years.

The questionnaire was composed of three parts. The first part asked experts which specific technology subtypes (e.g., which types of energy storage) they expected to be the most competitive and second-most competitive in 2035, and to estimate total private and public R&D spending, both in the United States and abroad, for the technology if the legislation were enacted and if it were not. The second part was a checklist to help the experts confirm that their answers correctly reflected the questions being asked.

The third part asked experts to provide the 90th, 50th, and 10th percentiles of the levelized cost of energy (LCOE) of the technology in 2035 (or in the case of DAC, the levelized cost of capture), as well as the corresponding most likely or representative values of the cost components that make up that technology's LCOE calculation. The cost components included capital expenditures, fixed costs, energy input costs, other variable costs, weighted average cost of capital, co-product profits, operating lifetime, and total outage rates. We asked experts to provide separate cost estimates for two scenarios, one in which the legislation was enacted and fully funded and one in which it was not enacted. We asked about costs in the year 2035 because we judged, with input from the literature and two other researchers, that asking about costs further in the future would involve too much speculation and uncertainty about what might happen in the intervening years and how it would affect costs.

We note several challenges associated with conducting an expert elicitation of this type. Some (and possibly most) of the participants are likely not experts with respect to all the cost and performance features, their probability distributions, and how a given policy is likely to affect those probability distributions. The ideal expert response would involve a joint probability distribution for all nine or more cost components of the technology with and without the added funding; however, this would be extremely difficult even to communicate, and even more difficult to estimate.

The method chosen for this expert elicitation questionnaire strikes a balance between obtaining detailed answers and being cognitively achievable, albeit still demanding for the experts. We asked for the probability distribution only of levelized cost (10th, 50th, and 90th percentile values), and not for the probability distributions of individual cost components. We did, however, ask experts to provide the "most likely or representative combination of component values" consistent with each levelized cost estimate.

Table 1. Summary of Funding Assumptions, by Technology

Technology	Summary of Legislation*
Advanced nuclear (from Clean Energy Jobs and Innovation Act)	Would increase nuclear program funding from $9.35 billion to $17.9 billion ($8.55 billion increase) (2020 dollars) over 10 years with additional funds dedicated to RD&D programs for advanced nuclear reactors, nuclear hybrid energy, used nuclear fuel, and light water reactors, plus workforce development.
Natural gas carbon capture and sequestration (NG-CCS) (from American Energy Innovation Act)	Would increase funding for gas and coal CCS from $4.9 billion to $11.2 billion ($6.3 billion increase) (2020 dollars) over 10 years for demonstration of carbon capture for coal and natural gas plants, carbon storage validation and testing, and carbon utilization research and demonstration. These values include funding for CCS for both NG and coal plants. Three experts specified expected proportion for NG-CCS; average was 60%.
Direct air capture (DAC) (from American Energy Innovation Act)	Would increase funding from $164 million to $727 million ($563 million increase) (nominal dollars) over 10 years for RD&D of DAC technologies, including sorbent-based DAC as well as bioenergy, enhanced geological weathering, forest management, and other carbon sinks.
Geothermal energy (from American Energy Innovation Act)	Would increase funding from $1.2 billion to $1.75 billion ($550 million increase) (nominal dollars) over 10 years for geothermal RD&D programs for geothermal energy systems, including enhanced geothermal, geothermal heat pumps, and direct use.
Diurnal energy storage (from AEIA)	Would increase funding from $592 million to $2.3 billion ($1.7 billion increase) (2024 dollars) over 10 years for electricity storage to improve reliability, supply energy during peak periods, and improve feasibility of microgrids, among others, and for expanded research on battery material disposal, vehicle-to-grid integration, distributed storage, pumped hydroelectric systems, and others. Some funding would be for longer-duration and shorter-duration storage.
Multiday energy storage (from American Energy Innovation Act)	Would authorize $500 million (2024 dollars) over 10 years for demonstration program for long-duration storage projects. This is in addition to funding for energy storage (preceding row), which also supports long-duration storage.

*Legislative funding as summarized in table 1 is from the Clean Energy Jobs and Innovation Act for advanced nuclear and from the American Energy Innovation Act for the other AETs. Both pieces of legislation were introduced in the 116th Congress and ultimately passed as modified versions as part of the Energy Act of 2020, with slightly different authorized funding amounts.

We use the cost component values to harmonize answers between different experts. Some components, such as capital costs, measure differences in technological advancement. Other components, such as fuel costs, storage duration, and capacity factors, do not. To allow for an apples-to-apples comparison of experts' answers, we modify component values in the latter category so that they are consistent among all expert responses for a given technology. Furthermore, we adjust each expert's weighted average cost of capital (WACC) values based on a calibration question (in which we asked for the WACC of onshore wind), to adjust for the fact that some experts expect higher costs of capital for all generation technologies. For a detailed list of cost adjustments and the technologies to which they were applied, see Appendix A.

Since the experts' answers for each technology are highly variable, we devised a method of aggregating expert responses into a single cost distribution. To develop probability distributions for each technology's harmonized levelized cost both with and without the legislation, we used a least squares optimizer to fit a cumulative probability distribution function to the experts' harmonized levelized cost answers. We used a nonlinear weighted least squares setup where the weights are determined by the variance of the estimated 10th, 50th, and 90th percentiles relative to the experts' responses. We opted for weights to minimize standard errors in the tails of the distribution, given the wide distribution of cost predictions. The optimizer helps minimize the sum of squared residuals between the true percentile cost estimates of the experts and the predicted costs based on the probability distribution. We used the skew-normal distribution because it can represent the often highly skewed nature of the cost distributions. Also, the distribution need not start from zero, which is a primary reason we preferred the skew-normal distribution over the gamma distribution. The three parameters that we optimized over are the location, scale, and shape parameters for the distribution.

3. Results

This section summarizes the experts' projections of the AET costs and combines them with the results of energy sector modeling to estimate the benefits of providing the funding authorized in the Energy Act of 2020. Section 3.1 reports the estimated effects of the additional public RD&D funding, as summarized in Table 1, on total public and private spending for each technology in the United States and abroad. Section 3.2 provides experts' estimates of the effect of the additional RD&D funding on future technology costs. Section 3.3 estimates the societal benefits of these cost reductions in the year 2050, based on simulations done in Shawhan, Funke, and Witkin (2020). Section 3.4 compares the estimated benefits from Section 3.3 with the average annual public and private costs to show a benefit-cost ratio of the legislation for each technology.

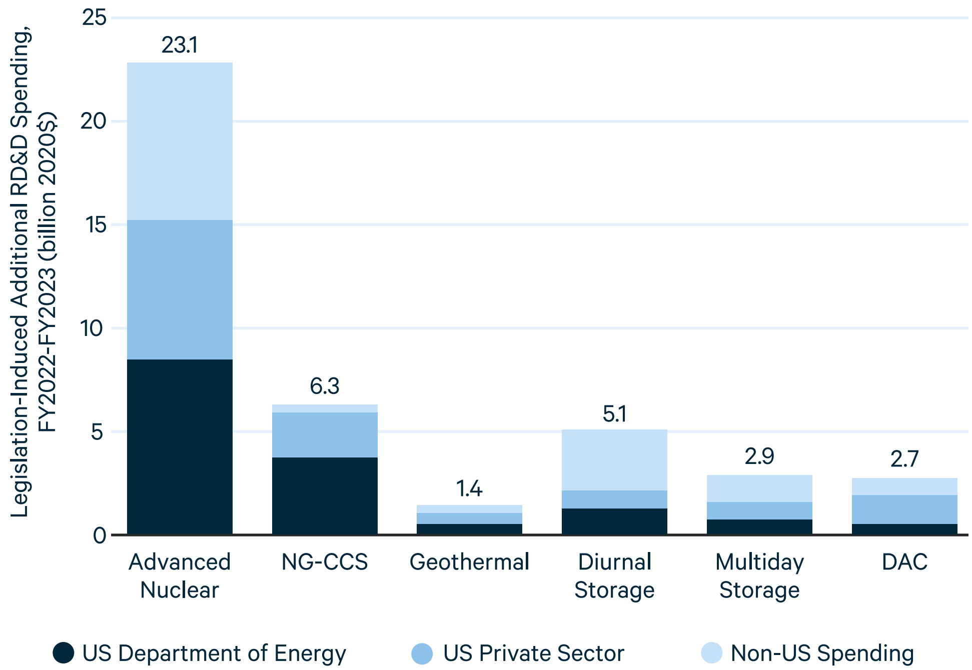
3.1. Effects of the Funding on Public and Private RD&D Spending

An increase in public spending on a technology is typically expected to increase private spending on that technology because of lower costs or increased public support in development. Public funding of technologies in the United States can also have spillover effects in other countries.

The questionnaire asked the expert participants to estimate total public and private R&D spending from FY 2022 through FY 2031 in and outside the United States both with and without the legislation. This section was intended to provide estimates of (1) the effect of the additional funding from the legislation on total public and private RD&D funding in the United States for the technology; and (2) the spillover effect of the legislation on total RD&D spending outside the United States.

Figure 1 displays the average incremental public and private R&D spending in and outside the United States that the experts expect to occur from FY 2022 through FY 2031 as a result of full enactment and 10-year funding of the legislation, as described in the detailed legislation summaries that we provided. The dark blue portions come directly from the legislation. For NG-CCS, we assumed, based on estimates from three experts, that 60 percent of the CCS funding would be for NG-CCS only (as specified in Table 1, the authorized funding was for both coal and NG). We assumed, based on the legislative language, that 60 percent of the storage total would be for diurnal storage, one-third would be for multiday storage, and the remaining 6.7 percent would be for storage of other durations. The US government funding increases differ substantially among the technologies.

Figure 1. Projected Additional RD&D Spending in United States and Abroad Resulting From the Legislation If It Is Fully Funded for 10 Years



For every technology, the experts predicted that the legislation would increase private US RD&D spending and foreign RD&D funding relative to a scenario without the legislation. Their responses varied, however, on the extent of this effect. The experts estimated that the legislation, if fully funded, would increase FY 2022–FY 2031 total private RD&D spending in the United States by more than $6.8 billion for nuclear but by about $0.5 billion for geothermal. These responses roughly reflect differences in funding authorizations in the legislation, since of the technologies, advanced nuclear receives the highest amount of additional US government RD&D funding and geothermal receives one of the lowest amounts.

Most experts projected that total public and private RD&D spending outside the United States would be boosted by the legislation, though to a lesser degree than within the United States. The exception was for diurnal storage, where experts predicted that the increase in foreign R&D spending as a result of the legislation would be higher than the increase within the United States, perhaps because of very high battery RD&D spending outside the United States by multiple companies and governments.

The estimates of the spillover effects of the legislation on private and public spending differed by technology and by the scale of the funding. The experts estimated that domestic private spending would increase between $0.59 and $1.91 for every dollar of US government funding increase. They estimated that outside the United States, RD&D spending would increase between $0.17 and $2.98 for every dollar increase in US government funding.

3.2. Effects of the Funding on Future Technology Costs

This section summarizes and analyzes the experts' estimates for future levelized costs of the AETs in 2035 with and without the legislation, as presented to them in the detailed legislation summaries. All cost values presented here were harmonized to a standard set of assumptions, as described in the Methods section.

The technology experts predicted that the additional funding authorized by the legislation would have the largest percentage effect on the levelized costs of DAC and geothermal (for both, an expected reduction of 29 percent), followed by advanced nuclear (a 25 percent reduction) and energy storage (a 16 percent reduction). NG-CCS and multiday storage show the lowest expected reductions in costs from the legislation, at 9 percent and 7 percent, respectively.[2]

On average, the expert responses indicate that in 2035, the carbon capture rate of NG-CCS units will be 92 percent at the 90th percentile cost and 96 percent at the 10th percentile cost. Similarly, the experts estimate that the mean diurnal storage duration in 2035 will be 8.9 hours and the mean multiday storage duration will be 6.7 days. All subsequent cost estimates for diurnal storage and multiday storage reported in this section are thus cost estimates for storage units with 8.9-hour and 6.7-day durations, respectively.

Figures 2 through 7 show the individual experts' estimates for the 90th, 50th, and 10th percentiles of harmonized levelized cost for each technology, both without and with the legislation. Individual experts' estimates are shown by the horizontal bars. The two endpoints represent the 10th and 90th percentiles, respectively, and the circled point in the middle indicates the 50th percentile. The red bars show the projections without the legislation, and the blue bars show the projections with the legislation. For each technology, the first red bar is from the same expert as the first blue bar, the second red bar is from the same expert as the second blue bar, and so on. Note that five graphs show levelized cost per MWh of electricity delivered to the grid; the DAC graph shows levelized cost per short ton of CO_2 captured.

Superimposed on the plots is the least-squares fitted probability distribution of levelized cost, determined as described in Section 2. The red curve is the estimated probability density without the legislation, and the blue curve is the estimated probability density with the legislation. The curves show the probability distributions of levelized cost for each technology in 2035, based on the experts' responses.

2 These percentage difference estimates are based on weighted averages of the experts' estimates with and without the legislation, with weights of 30, 40, and 30 percent for the 90th, 50th, and 10th percentile cost estimates of each technology, respectively.

Figure 2. Expert Levelized Cost Projections for Advanced Nuclear in 2035, in Cases with and without the Additional Funding

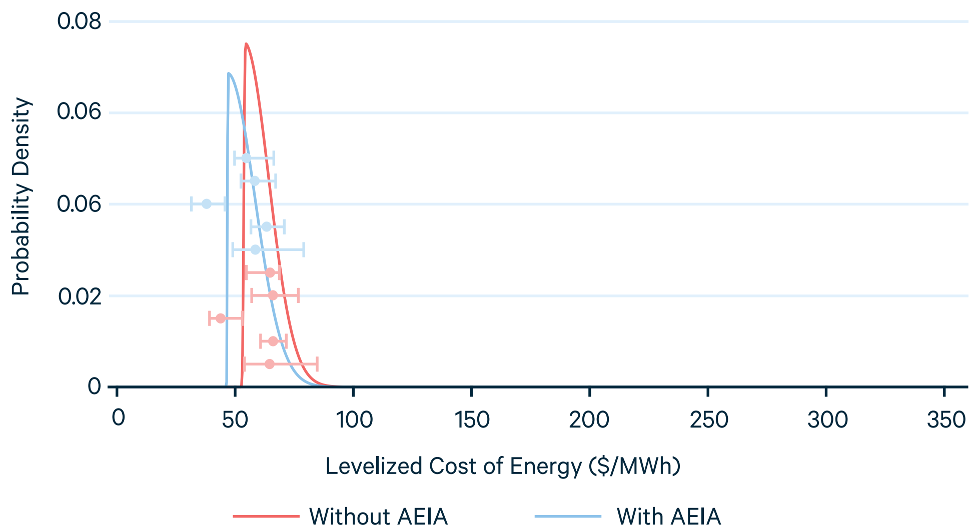


Figure 3. Expert Levelized Cost Projections for NG-CCS in 2035, in Cases with and without the Additional Funding

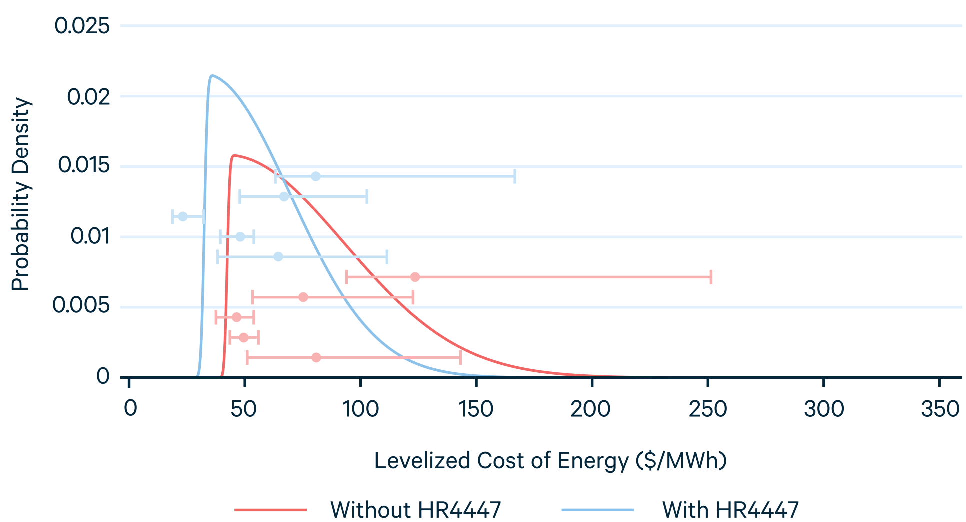


Figure 4. Expert Levelized Cost Projections for Advanced Geothermal in 2035, in Cases with and without the Additional Funding

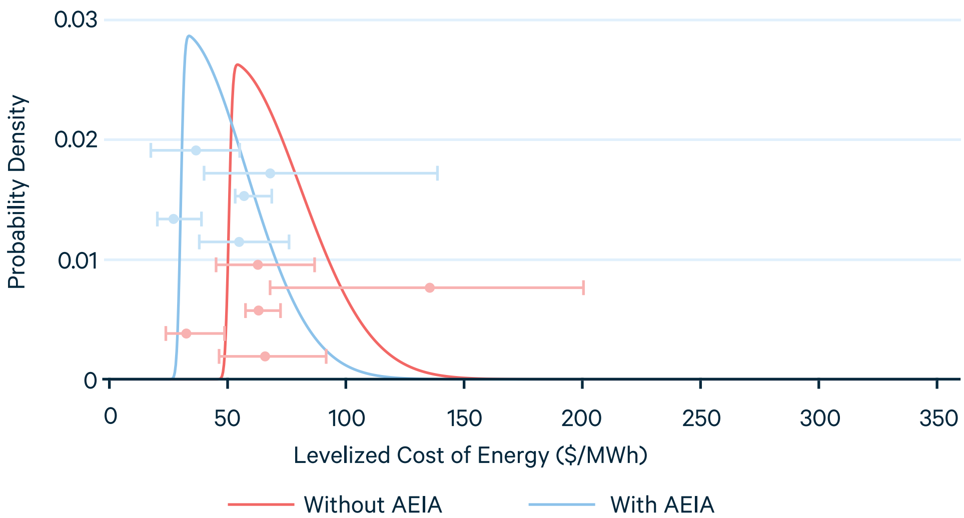
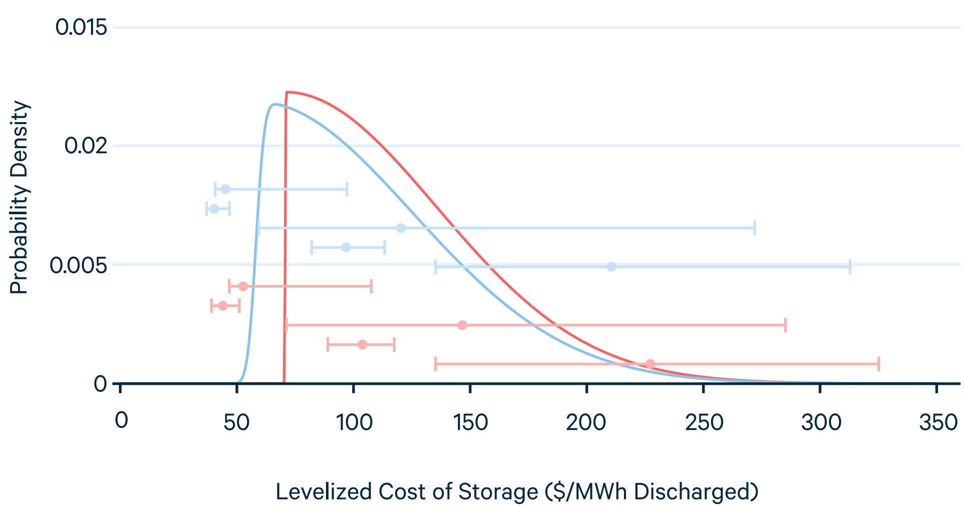
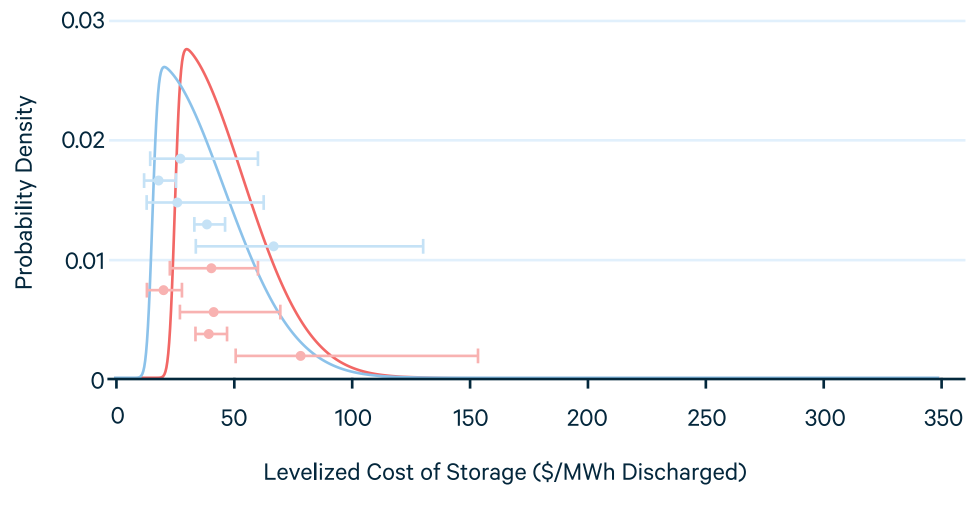


Figure 5. Expert Levelized Cost Projections for Diurnal Storage in 2035, in Cases with and without the Additional Funding



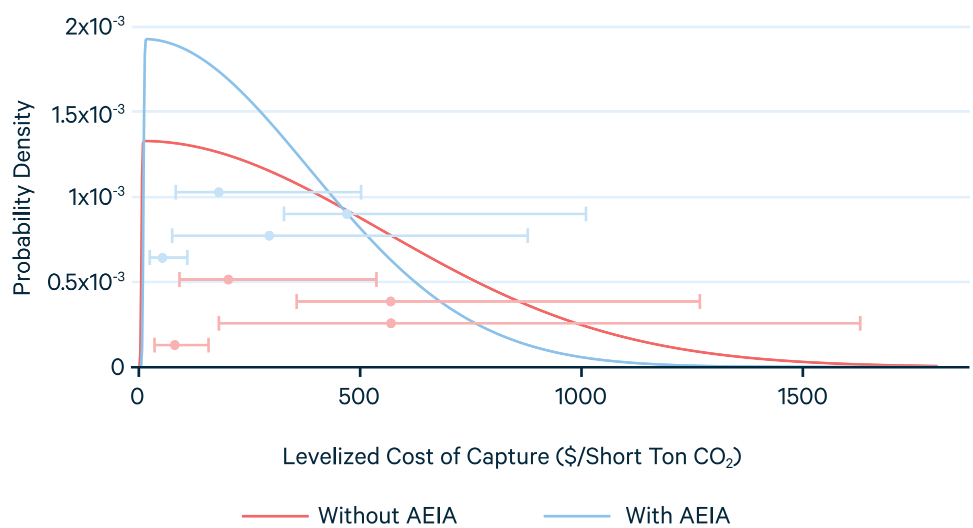
Note: Cost projections are for units 8.9 hour storage duration.

Figure 6. Expert Levelized Cost Projections for Multiday Storage in 2035, in Cases with and without the Additional Funding



Note: Cost projections are for units 6.7 day storage duration.

Figure 7. Expert Levelized Cost Projections for DAC in 2035, In Cases with and without the Additional Funding



Those plots display the wide distribution of projected costs for the technologies with and without the added funding authorized in the legislation. These wide distributions highlight the uncertainty associated with innovation policy and the value of advancing multiple technologies, since it is impossible to know which will become the most cost-effective.

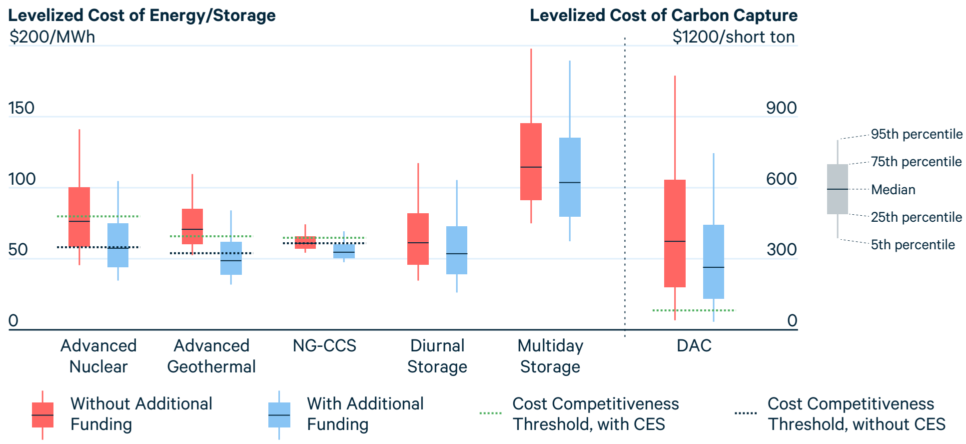
To allow for easy comparison of the cost distributions in the above figures, Figure 8 shows side-by-side cost distributions of all technologies. The values shown in this box-and-whisker plot are percentiles based on the least-squares fitted cost distributions shown in Figures 2–7, above. The line across each box shows the estimated 50th percentile for each technology. The boxes extend to the 25th and 75th percentiles of the distribution, spanning the interquartile range, and the whiskers extend to the 5th and 95th percentiles of the distribution, such that the plots represent the middle 90 percent of each technology's estimated levelized cost distribution both without and with the additional RD&D funding assumed to result from the legislation.

To provide context for these cost reduction estimates, we have included estimates of cost-competitiveness thresholds from Shawhan, Funke, and Witkin (2020), where possible. That report simulated various policy scenarios with and without a national CES to estimate the costs that would make each AET cost-competitive in the year 2050, defined as accounting for at least 1 percent of US power generation. The cost needed for competitiveness may be a tipping point. Once a technology becomes cost-competitive, its cost may continue to decline because of large-scale use and learning-by-doing. These 2050 cost-competitiveness threshold values are overlaid on the box plot, represented by dashed horizontal lines. The horizontal green line (higher, lighter dashed line) shows the cost needed for cost-competitiveness in the 2050 simulations with the CES; the horizontal brown line (lower, darker dashed line) shows the cost needed for cost-competitiveness in 2050 without the CES.[3] Shawhan, Funke, and Witkin (2020) did not include simulations for multiday storage and assumed a different duration for diurnal storage than the one assumed here, so we do not have cost-competitiveness estimates for those two technologies. DAC shows a line only for the case with the CES because DAC was not implemented at large scale without a stringent emissions policy, at any of the costs simulated.

The thresholds for competitiveness vary because the technologies differ in terms of the value of their generation and where they can cost-effectively be built. With the national CES, NG-CCS differs from the other technologies in that it does not receive a full CES credit per MWh because it has some emissions. In addition, the scale for DAC is different from the scale for the other technologies.

3 Ingersoll et al. (2020) and Bistline et al. (2019) are prior studies that have also estimated the cost and/or performance requirements for a technology to be competitive. Both studies do so for advanced nuclear power.

Figure 8. Probability Distributions of Levelized Cost, Without and With Added RD&D Funding



Notes: Costs for diurnal storage are for 8.9-hour storage units, and costs for multiday storage are for 6.7-day storage units. The figure also shows estimated cost-competitiveness thresholds in 2050 with and without a national CES.

The box-and-whisker plot (Figure 8) offers several takeaways. First, the experts expect the additional funding from the legislation to reduce the levelized costs of these technologies across the board. Second, the plot shows differences in expectations for the effect of this additional funding on future costs across technologies. The expected cost reductions are 25 percent for advanced nuclear, 9 percent for NG-CCS, 29 percent for advanced geothermal, 16 percent for diurnal storage, 7 percent for multiday storage, and 29 percent for DAC.[4] Third, the plot reveals which technologies have higher uncertainty with respect to costs, with NG-CCS showing the smallest cost uncertainty among the technologies and DAC showing the largest.

As mentioned above, the horizontal dashed lines, which indicate cost-competitive thresholds in 2050 for each technology in the CES and no-CES policy cases, provide context for these estimates of cost reductions. For example, without the national CES (brown dashed line), new nuclear plants are approximately 25 percent likely to be cost-competitive in 2050 without the additional RD&D funding and approximately 50 percent likely to be cost-competitive in 2050 with the additional RD&D funding. With the national CES, the probabilities increase to a little over 50 percent and a little over 75 percent, without and with the added funding. For NG-CCS, the probabilities

4 These percentage difference estimates are based on weighted averages with and without the proposed additional funding. We used weights of 30, 40, and 30 percent for the 90th, 50th, and 10th percentile cost estimates of each technology, respectively.

are higher than those for nuclear.[5] For DAC, they are lower than those for nuclear. For geothermal, they are lower without the added funding but higher with the added funding.

The experts provided some insights about why the funding could be more effective for some technologies than others. For example, a geothermal expert explained that geothermal technologies do not receive much private R&D funding, and thus additional public funding could potentially have a large effect on costs while encouraging private sector R&D funding. In contrast, some storage experts projected that the private sector globally would fund much R&D for diurnal storage even without any US government spending, particularly for lithium-ion batteries. Additional federal funding could have a larger effect on the costs of technologies that have received less total public and private RD&D funding to date. How the funding is allocated for each technology could also be an important factor, with some funding uses being more effective in reducing costs than others.

3.3. Benefits of Additional RD&D Funding

The experts' responses indicate that the additional public funding from the legislation is expected to reduce technology costs, either directly or indirectly, by triggering additional private sector investment. However, reductions in technology costs alone do not necessarily produce societal benefits; the additional funding must reduce costs enough to affect the deployment and use of the technology for electricity generation. Such benefits can be estimated using an electricity sector model that considers technology costs for determining generator dispatch and investment. Baker et al. (2009), Clarke et al. (2006), Ingersoll et al. (2020), Murphy et al. (2017), Palmer et al. (2018), and Shawhan (2018) are prior studies that have used energy system models to estimate the effects when an energy technology becomes less costly.

To estimate the annual benefits of the additional funding for these technologies in 2050, we expand on work of Shawhan, Funke, and Witkin (2020), who used a detailed model of the US electricity sector—the Engineering, Economic, and Environmental Electricity Simulation Tool (E4ST)—to estimate societal benefits in 2050 as a function of AET technology costs. E4ST predicts the future hourly operation of each generator, along with generator retirements and construction, using a detailed engineering model of the electric power grid. It solves a large optimization problem that represents the decision criteria of both generation investor-owners and electricity users. Shawhan, Funke, and Witkin (2020) provide benefit functions (as a function of technology cost) for all AETs except multiday storage, which will therefore be omitted from the subsequent analysis. The benefit functions show how societal benefits vary as a

5 For diurnal storage as well, the probabilities would be higher than those for nuclear. In fact, with the national CES, diurnal storage would be competitive even at its current cost. However, we do not have precise calculations of the diurnal storage levelized costs necessary for competitiveness because Shawhan, Funke, and Witkin (2020) assumed diurnal storage with a duration (ability to discharge without recharging) of 4 hours, whereas this plot assumes the average duration projected by the experts, which is 8.9 hours.

function of technology costs, assuming that all other AET costs remain constant. Shawhan, Funke, and Witkin (2020) define benefits as the sum of five components: (1) electricity users' savings; (2) producers' profits; (3) reductions in health damages from sulfur dioxide and nitrogen oxide emissions; (4) reductions in estimated damages from emissions of CO_2 and methane; and (5) increases in government net revenue. We adopt their definition of benefits in this analysis.

The benefit functions can be used to estimate only the benefits from reduced cost of an individual technology, not the benefits from simultaneous cost reductions for all technologies. Since the AET technologies compete against one another, the total benefit from simultaneous cost reductions for all technologies will be less than the sum of the benefits from individual cost reductions.

Shawhan, Funke, and Witkin (2020) estimated the total benefits to society of the AETs under two policy scenarios: (1) the no clean electricity standard (without CES) case assumes that no new clean energy or environmental policies are made by the US government (other than potentially the added RD&D funding); and (2) the CES scenario assumes that a federal clean electricity standard requires 100 percent of retail sales of electricity (94 percent of electricity generated) to come from clean sources by 2050. In the CES scenario, generation sources receive full or partial credits toward meeting the requirement in proportion to how far their CO_2-equivalent emissions rates are below 0.82 metric tons per MWh,[6] and a ton of methane is counted as equivalent to 32 tons of CO_2. Direct air capture receives one credit for each 0.82 metric ton captured. In the subsequent sections, we report benefit-cost ratios under the two policy scenarios.

We use benefit curves from Shawhan, Funke, and Witkin (2020) to estimate the societal benefits of the experts' cost estimate reductions. For example, we estimate the benefits of the additional funding at the 10th percentile cost using the following two-step method. First, we use the benefit curves in Shawhan, Funke, and Witkin (2020) to estimate the benefits when the technology's cost is at the 10th percentile of its distribution both with and without the added RD&D funding. Second, we subtract the latter from the former to estimate the benefit of the added funding.

The experts' cost projections are for the year 2035, and the benefit functions are based on costs in 2050. By using the experts' costs in the benefit functions, we implicitly assume no further technological advancement between 2035 and 2050. This is quite a conservative assumption, since in reality we would expect costs to fall further during this time period. As our results will show, reductions in expected cost tend to produce larger benefits if the starting cost is lower. A small challenge in this approach was that some of the experts' cost projections were outside the domain of the benefit curves. This was true for low nuclear and geothermal costs, and for the high nuclear, NG-CCS, and diurnal storage costs. In these cases, we extrapolated the benefit curves using the same estimated function that was used in the original paper to plot the curves.

6 0.82 metric ton per megawatt-hour (MWh) is the same benchmark emissions rate used in the Clean Energy Innovation and Deployment Act of 2020 (HR 7516). That bill also would have given DAC one credit for each 0.82 metric ton captured.

We also had to make minor adjustments to fuel costs and storage duration to harmonize the experts' costs with those used in Shawhan, Funke, and Witkin (2020). First, we adjusted the fuel costs from their original values to account for differences between 2050 and 2035. Second, we adjusted the experts' costs for diurnal storage for 4-hour storage duration, to match the storage parameters used in Shawhan, Funke, and Witkin (2020). This adjustment was possible because the experts gave us cost components that allowed us to adjust their estimates to diurnal storage systems of any duration.

To calculate benefit-cost ratios, we conservatively assume that the benefits begin in 2040 and end in 2060, and we assume that our estimated benefits in 2050 are representative of the annual benefits in that 20-year period. Assuming a 3 percent real discount rate, we calculate the net present value of benefits and the net present value of the increased RD&D spending from 2022 through 2031 (the costs). Both are net present values from the perspective of 2021. Figures 9 and 10 shows the resulting benefit-cost ratios for the technologies. These benefit-cost ratios illustrate the value of the additional funding authorized in the legislation.

Figure 9. Benefit-Cost Ratios for Added RD&D Spending without National Clean Electricity Standard

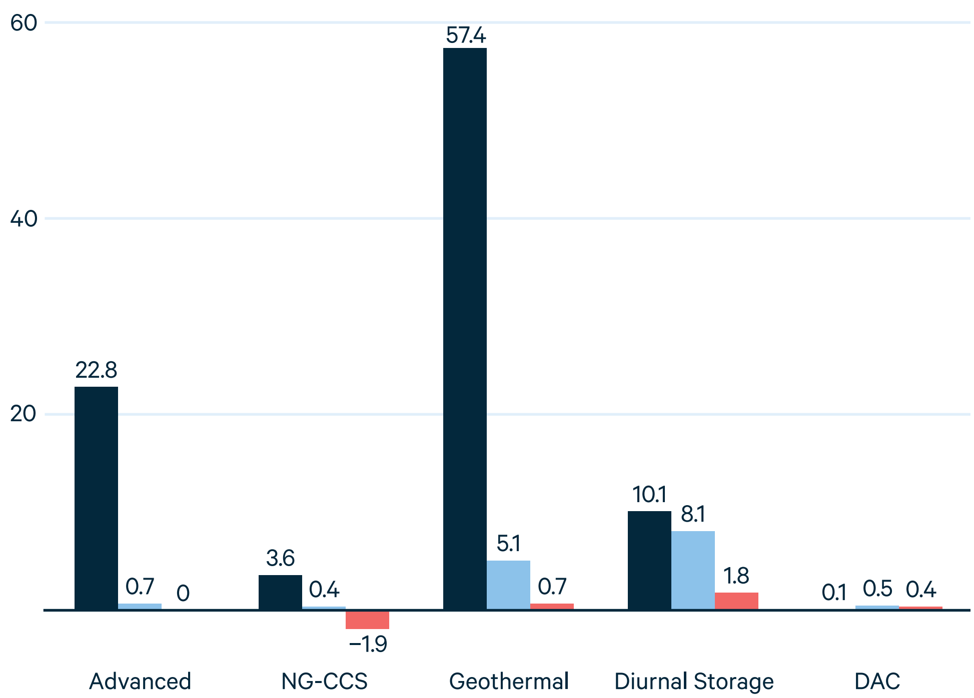
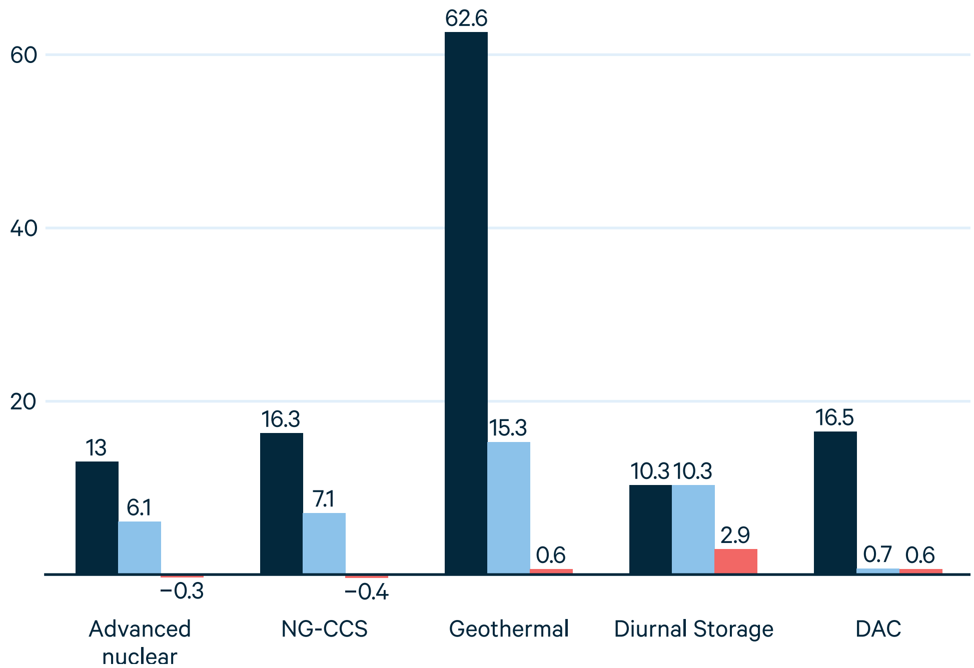


Figure 10. Benefit-Cost Ratios for Added RD&D Spending with National Clean Electricity Standard



Across nine of the 10 trios of benefits, the 10th percentile bar is larger than the 50th percentile bar, which is larger than the 90th percentile bar. That indicates that the benefits of cost reduction for a technology tend to be larger if the reduction begins from a lower starting cost. This implies that the benefits per dollar of additional RD&D funding do not necessarily decline with increased funding. This has implications for higher funding of clean energy RD&D in general and funding above the levels in the Energy Act of 2020 in particular.

The figures also illustrate how a market-based national clean electricity policy can increase the societal benefits of the additional funding authorized by the legislation. The societal benefits in 2050 that result from the added RD&D funding are higher with the CES than without. There are just two exceptions: for advanced nuclear at the 10th percentiles of its cost and advanced geothermal at the 90th percentiles of its cost, benefits are higher without a new national policy because then the technologies displace more coal-fired generation and its associated harmful emissions.

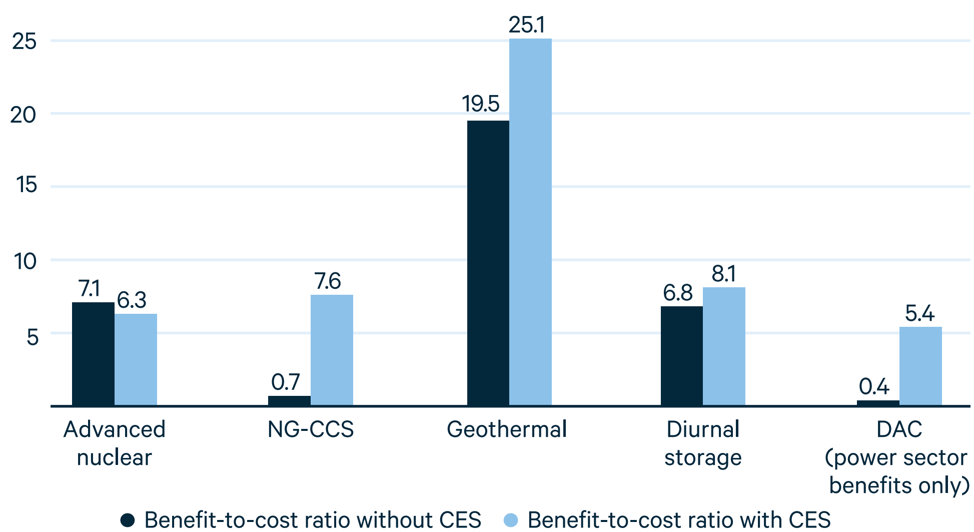
Nuclear at its 90th percentile costs has a small negative benefit because less costly nuclear reduces the CES credit price. Reducing the credit price raises wholesale electricity prices, which increases coal-fired generation, with its high sulfur dioxide and nitrogen oxide emissions. The small cost savings in the nuclear 90th percentile cost case are not large enough to offset the additional coal-related health damage. Any nonemitting technology could have this effect, under a narrow range of circumstances.

The negative benefits from less costly NG-CCS at its 90th percentile costs result from the assumption in Shawhan, Funke, and Witkin (2020) that this technology earns full credit in some state and utility policies even though it produces some emissions. If it received credit only in proportion to its emissions advantage relative to conventional generation, it would not produce negative net benefits, or they would be smaller, like those of nuclear.

In the no-national-CES scenarios and to a lesser extent in the scenarios with a national CES, the benefits of the additional AET RD&D depend in part on state and utility policies, since those policies increase the value of the AETs. This is particularly true for DAC. In the simulation assumptions, one medium-sized state has a net zero power sector emissions requirement, and that is the main use of DAC in the absence of a national CES. In reality, by 2050, more states or utilities could have similarly stringent policies.

We can combine each trio of bars in Figures 9 and 10 into an approximate expected value by calculating a weighted average of the three values, as in Figure 11. We use weights of 30 percent on the 10th percentile and 90th percentile values and 40 percent on the 50th percentile value.

Figure 11. Estimated Benefit-Cost Ratios from 10 Years of RD&D Funding, Using Weighted Average Benefits over 20 Years



Without the national CES, the benefit-to-cost ratio for the 20-year benefits period of 2040 to 2060 is greater than 5 for geothermal, advanced nuclear, and diurnal storage. For NG-CCS it is 0.7, and for DAC it is 0.4. With the national CES, the benefit-to-cost ratio is greater than 5 for all five technologies. The simple averages across the five technologies are 6.9 without the national CES and 10.5 with it. On average, the estimated benefits of the additional funding from the legislation are $30 billion under the without-CES scenario and $39 billion under the with-CES scenario, per technology, assuming a 20-year benefit stream. These are net present values, from the perspective of 2021, calculated using a 3 percent real discount rate.

Advanced geothermal has the highest estimated benefit-cost ratio of all technologies with or without the national CES. Advanced geothermal thus has the highest estimated benefits per dollar of additional RD&D spending.

The above benefit-cost ratios assume conservatively that the benefits of the added RD&D funding last from mid-2040 to mid-2060. As sensitivities, we also calculate the benefit-cost ratios if the benefits last for 30 years (2035 to 2065) and 10 years (2045 to 2055), as shown in Table 2.

Table 2 also shows benefits separate from costs. Again, these costs are total US public and private RD&D spending on each technology from FY 2022 through FY 2031, as estimated by the experts. In this table, the benefits and costs are net present values from the perspective of 2021 and are expressed in 2020 dollars. Of all the technologies, nuclear has both the largest estimated cost and the largest estimated benefits.

Table 2. Benefit-Cost Ratios for 10-, 20-, and 30-Year Benefits, by Technology

Technology	**Benefits lifetime (years)**	**Total costs (billion 2020$)**	**Without CES**		**With CES**	
			Total benefits (billion 2020$)	Benefit-cost ratio	Total benefits (billion 2020$)	Benefit-cost ratio
Advanced nuclear	10	13.1	46.3	3.5	40.7	3.1
	20	13.1	93.7	7.1	82.2	6.3
	30	13.1	143.1	10.9	125.6	9.6
NG-CCS	10	5.1	1.7	0.3	19.2	3.8
	20	5.1	3.4	0.7	38.7	7.6
	30	5.1	5.2	1.0	59.2	11.6
Geothermal	10	2.3	21.9	9.6	28.1	12.4
	20	2.3	44.2	19.5	56.9	25.1
	30	2.3	67.5	29.8	86.9	38.3
Diurnal storage	10	1.3	4.5	3.4	5.4	4.0
	20	1.3	9.1	6.8	10.9	8.1
	30	1.3	14.0	10.4	16.6	12.3
Direct air capture	10	1.3	0.2	0.2	3.4	2.7
	20	1.3	0.5	0.4	6.9	5.4
	30	1.3	0.7	0.6	10.6	8.3

Finally, using results from Shawhan, Funke and Witkin (2020), we can decompose the above benefits into their components. In the without-CES case, the benefits are 74 percent from reduced climate and health damages, 49 percent from electricity bill reductions, –20 percent from changes in producer profit, and –3 percent from changes in government revenue. With a CES, the benefits come 151 percent from electricity bill reductions, 4 percent from climate and health benefits, and –56 percent from changes in producer profit. Negative percentages indicate negative benefits, such as a reduction in the profits of producers of electricity. In summary, without a CES, the benefits of the AET cost reductions are a mix of emissions reductions and electricity bill reductions, whereas with a CES, the benefits are primarily from electricity bill reductions. This pattern would not necessarily hold if the CES had a price cap. If the CES were at its price cap instead of reaching its clean energy target, emissions reductions would likely account for a larger share of benefits relative to electricity bill reductions because the AET cost reductions would likely enable more clean energy production at the same CES credit price, reducing emissions more and not reducing electricity prices as much.

From the benefit components, we compute the expected total electricity bill savings per household that result from the added RD&D funding. The values in Table 3 were calculated by dividing the expected total national electricity bill savings in 2050 by the total number of US households. Therefore, values include not just savings on residential electricity bills but also electricity savings for businesses and other organizations, which are eventually passed to households in the form of lower product prices and higher profits and wages. The estimated effect on residential electricity bills alone would be roughly one-third of the savings in Table 3, since residential electricity consumption constitutes approximately one-third of total US electricity consumption. As seen in the table, the additional funding of AETs could potentially lead to large pocketbook benefits for households, especially in the event of a new national CES.

Table 3. Expected Savings for Households in 2050 Resulting From Additional Funding For Each Technology (2020$/Household), by Policy Scenario

Technology	Savings per household (without CES)	Savings per household (with CES)
Nuclear	28	102
NG-CCS	2	82
Advanced geothermal	31	77
Diurnal storage	8	11
Direct air capture	2	6

3.4. Economy-Wide Benefits of Increased RD&D Funding for DAC

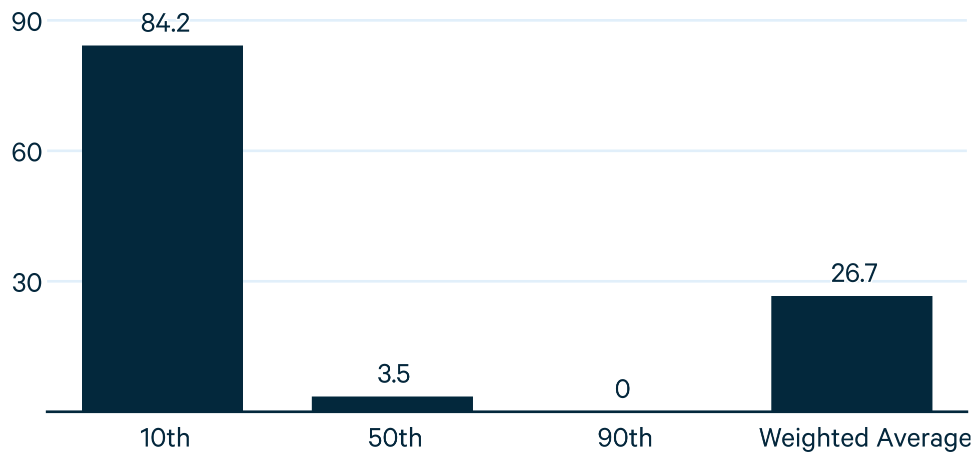
Our analysis thus far includes only those benefits that result from uses of the AETs in the electricity sector, but cost reductions for the AETs can also produce benefits outside that sector. For example, electricity storage can support decarbonization of transportation and improvement of various consumer products, DAC can be used to offset emissions that would be very costly to eliminate, CCS can be used to decarbonize industrial processes, and geothermal, CCS, and nuclear can provide heat for various direct uses in industry and buildings.

For DAC, Hafstead (2020) estimated benefit curves that we can use to estimate the economy-wide benefits of the cost reductions from the additional RD&D spending. Hafstead uses the Dynamic Regional Computable General Equilibrium (RFF-DR) model to estimate the economy-wide benefits of DAC in 2049. The RFF-DR model is a dynamic multiregion and multi-industry intertemporal model of the US economy with international trade. Like most computable general equilibrium models, it does not separately represent every generation type, so it does not separately represent the other AETs. It does, however, separately represent DAC, which makes it an excellent model for representing the whole-economy effects of less costly DAC. The model assumes multiple technologies are available for reducing emissions, but DAC is the only available technology for removing CO_2 from the air. Like Shawhan, Funke, and Witkin (2020), Hafstead provides the benefits of DAC for various cost levels of the technology. We therefore apply methods identical to the ones in the previous section.

Figure 12 shows the updated benefit-to-cost ratios for DAC using benefit estimates from Hafstead (2020) that take into account economy-wide benefits of DAC deployment. The results assume a policy or set of policies that cause a cost-effective CO_2 emissions reduction of approximately 50 percent by 2050, relative to 2005 levels. Under a more stringent policy or set of policies, we would expect the benefits of DAC to be even higher than the ones presented here.

At the 90th percentile costs, DAC is not competitive for use in the economy, regardless of whether it received additional funding. On the other hand, if DAC is already widely cost-competitive, decreases in the costs of DAC have large benefits to society. As seen in the figure, the additional DAC funding produces zero benefit if the cost of DAC remains high (a benefit-to-cost ratio of 3.5 at the 50th percentile costs) but benefits more than 80 times as large as the added RD&D spending if DAC becomes widely cost-competitive. We estimate that the expected value of the benefit-cost ratio is 27 (using a weighted average, with 30, 40, and 30 percent weights on ratios at the 10th, 50th, and 90th percentiles, respectively).

Figure 12. Economy-Wide Benefit-to-Cost Ratios for DAC Assuming Policy That Reduces CO_2 Emissions Approximately 50 Percent by 2050, Relative to 2005 Levels



As in the power-sector-only benefit and cost estimates, the results in Figure 12 assume that the annual 2049 benefits are received for a 20-year period centered on 2050, discounted to present values at a 3 percent discount rate. To test the sensitivity of the results to the 20-year benefits period, Table 4 shows how the weighted average benefit-cost ratio changes with the benefits period. In all cases, the expected benefit-cost ratio of the additional funding for DAC exceeds 10, indicating exceptionally large potential societal returns to the greater DAC RD&D envisioned in the Energy Act of 2020.

Table 4. Economy-Wide Benefits and Costs for DAC under Three Benefits Scenarios

Technology	Benefits lifetime (years)	Total costs (billion 2020$)	Total benefits (billion 2020$)	Benefit-cost ratio
Direct air capture (economy-wide benefits)	10	1.3	16.9	13.2
	20	1.3	34.1	26.7
	30	1.3	52.1	40.7

Note: All benefit values are weighted averages of benefits in the 10th, 50th, and 90th percentile cases.

4. Discussion

There are several caveats associated with our results and methodology. First, the results omit benefits from the use of the less costly AETs outside the power sector (except in the supplementary DAC analysis), benefits outside a 20-year (or 10- or 30-year) period, US RD&D expenditure changes outside the 10-year period from 2022 to 2031, benefits abroad from use of the less costly AETs there, US benefits from the resulting emissions reductions abroad, and US benefits from higher export profits. The amount of electricity generated outside the United States is currently approximately four times the amount generated domestically.

Second, even for the benefits and costs that we do estimate, the benefit estimates are subject to a large amount of unavoidable uncertainty around the central estimates that we provide. A substantial part of this comes from the cost projections; projecting the probability distributions of the levelized cost of a technology with and without a given set of additional RD&D legislation and funding is difficult.

Third, as can be the case with any expert elicitation, the results have a potential for bias. Often, professionals who have expertise in these technologies may benefit from increased government funding for the technologies. Although we asked for unbiased estimates, the experts' answers could still reflect some bias in favor of the legislation. However, it is also possible that experts underestimate technological change, which could result in cost projections that are too high. Wiser et al. (2016) observe that that has been the case with expert elicitations on solar energy, where prior studies, such as Curtright et al. (2008), have underpredicted cost reductions under various policy scenarios. Underprediction of cost reductions has also been the case for other technologies even when the experts surveyed had a vested interest in giving answers that encourage more government RD&D funding; even most experts may not be able to see all the opportunities for cost reductions.[7] Also, the experts' cost projections were for projects designed in 2035 and built shortly thereafter, but we assume that they are representative of the costs of building and operating new AET facilities in 2050. As a result, if the experts were overoptimistic about the pace of cost reductions by approximately a decade, their answers would still not be too low for the way we use them.

Fourth, as discussed in the Results section, we conservatively assume that the experts' cost projections for 2035 still apply in 2050. Costs tend to decrease over time, especially with use, and our results show that cost reductions tend to significantly increase the expected benefits of further cost reductions.

Finally, the set of experts we ultimately interviewed was not random because of the limited number of experts in each field and the limited number who were willing and able to participate in the study. Many of our respondents were recommended by experts whom we had already interviewed, so their answers could have been similarly biased.

7 Gregory Nemet, University of Wisconsin–Madison, personal communication, December 18, 2020.

5. Conclusion

This study provides insights from experts and from simulation modeling about the effects of additional RD&D funding on future technology costs of five advanced energy technologies—advanced nuclear, advanced geothermal, diurnal energy storage, carbon capture and sequestration, and direct air capture. Experts were asked to predict the levelized costs of these technologies in the year 2035 under scenarios with and without additional federal RD&D funding very similar to that authorized in the recently enacted Energy Act of 2020. The actual funding amounts are decided annually, so estimates of the benefit-cost ratios of the funding have an ongoing potential to be helpful to members of the US Congress and presidential administration.

We note salient points from the results. First, we report the average of experts' predictions for total public and private RD&D spending in and outside the United States in the coming 10 years, from 2022 through 2031, both with and without the legislation. We observe that the experts expect increased US government funding as authorized in the legislation to have positive spillover effects for both US private and foreign RD&D for the same technologies. Second, the general consensus of the experts was that the legislation would reduce costs for all five advanced energy technologies, and additionally for multiday energy storage (which was included in the legislation but not in the simulation modeling). The extent of the projected reductions varied by expert and by technology.

To estimate the benefits to society of these technology cost reductions, we interpolated the results of simulations from Shawhan, Funke, and Witkin (2020). We conservatively assumed that the benefits would last for just 20 years, from 2040 through 2060. With a national clean energy standard, the estimated benefit-cost ratios for all technologies are greater than 1—in fact, greater than 5. Even without a national clean energy standard, the benefit-cost ratios are greater than 1—in fact, greater than 5—for three technologies: advanced geothermal, advanced nuclear, and diurnal storage. The results suggest that the value of fulfilling the spending authorizations in the 2020 legislation would be high. They also suggest that there are likely to be further opportunities for beneficial additional funding increases, above those authorized in the Energy Act of 2020.

In a future paper, we will expand our reporting of the experts' answers and add to the benefit-cost analysis provided in this manuscript.

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Note: For readers' convenience, references cited together in the text are organized by topic, as indicated by the three topic headings below.

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Appendix A. Cost Assumptions for Harmonizing Experts' Answers

The following assumptions and cost adjustments were made to harmonize the experts' answers:

- Since advanced nuclear, geothermal, and DAC technologies tend to run all or almost all the time except when an outage occurs, we assumed the capacity factor for these technologies to be 1 – total outage rate.
- NG-CCS was assumed to have a capacity factor of 80 percent.
- The capacity factor for multiday storage was assumed to be 33.333 percent. This is equivalent to discharging (generating) one-third of the time, at full output. Assuming a lower capacity factor would have resulted in a higher levelized cost.
- Diurnal storage was assumed to charge and discharge its full energy capacity once per day. For example, a diurnal storage system with a duration (energy capacity divided by power capacity) of 8.9 hours (the average duration projected by the experts) was assumed to have a capacity factor of 8.9/24 = 36%.
- Storage durations for diurnal and multiday storage technologies were assumed to be the averages of all expert responses. This assumption made the durations uniform for diurnal storage and uniform for multiday storage.
- For both storage technologies, we adjusted the input price of electricity. For diurnal storage, we set the input electricity price to $0/MWh so that our levelized cost estimate is levelized cost of storage, not counting the cost of input energy. For multiday storage, however, we assumed an input electricity price of $22.69/MWh. This figure is between the levelized cost of energy from solar and wind in 2038, as reported in the 2020 Annual Technology Baseline from the National Renewable Energy Laboratory, after adjusting for inflation. This is consistent with the multiday storage representing 100 percent "green" storage, charged with incremental nonemitting generation.
- For DAC, we set the electricity input price to the average price across all expert responses.
- The natural gas fuel cost per MMBtu for NG-CCS and DAC is the same price we use in simulation modeling for 2038: $3.8/MMBtu for DAC, and $3.764/MMBtu for NG-CCS.
- The weighted average cost of capital (WACC) we requested was postconstruction real WACC. The postconstruction real WACC answers provided by the experts reflect (1) the expert's judgment about the riskiness of investing in the technology and also (2) the expert's assumptions about the type of investor-owner and the real WACC across all investments. To remove the effect of (2), we also asked the experts for projected WACC for an established technology,

arrays of land-based wind turbine generators (wind farms).[8] We replace each postconstruction real WACC answer with the difference between that answer and the same expert's corresponding wind farm postconstruction real WACC answer, plus 2.96 percent real, which is a projection of the postconstruction real WACC of wind farms in 2035, from the National Renewable Energy Laboratory's 2020 Annual Technology Baseline. In this way, we use a standard WACC assumption for wind farms plus the expert's estimated difference between the WACC for the technology in question and the WACC for wind.

8 We did this for each of the six scenarios, where a scenario is a combination absence or presence of the additional RD&D funding and percentile of levelized cost of the technology in question (for example, 90th percentile of levelized cost of energy from enhanced geothermal without additional RD&D funding).

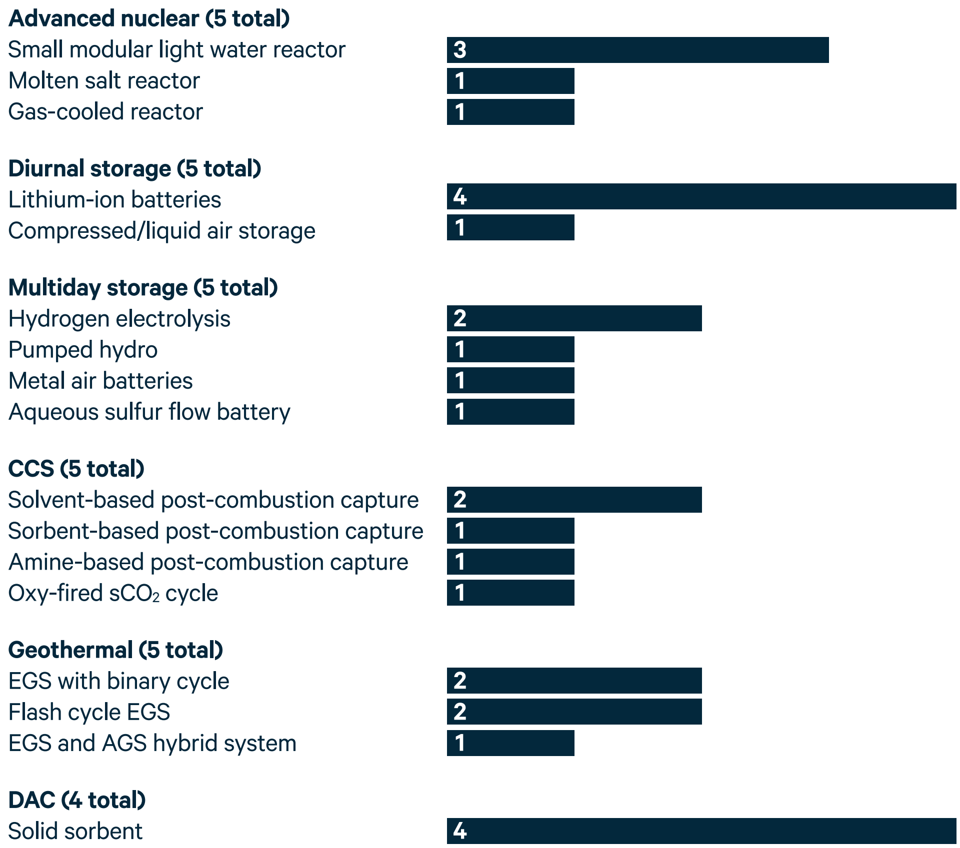
Appendix B. Projected Competitiveness of Technology Types

The questionnaire asked experts to predict most cost-competitive and second-most cost-competitive technology subtypes for their technology in 2035, both with and without the legislation. Respondents' answers varied, but notably, most respondents (90 percent) estimated that the legislation would not affect which technology was the most competitive in 2035. These results suggest that the legislation may not be highly likely to change the relative competitiveness of technology types but would instead give an added push to reduce the costs of the subtechnologies that were already likely to be the most competitive.

Experts had varied predictions for the most competitive and second-most competitive technologies across the categories, with some consensus on certain technologies. For example, for advanced nuclear, three of the five experts predicted that small light-water reactors would be the most cost-competitive in 2035 with or without the legislation. Experts in diurnal storage were largely in agreement that the most competitive technology in 2035 with the legislation would be lithium-ion batteries. The NG-CCS experts provided a larger range of responses.

Figure B1 displays the tallies of experts' answers about the most competitive technology subtypes in 2035 with the legislation. As noted above, the responses given for the scenario without the legislation were very similar.

Figure B1. Tally of Expert Answers: Most Competitive Technology Subtypes in 2035, With Legislation



When asked to predict the second-most competitive technology in 2035, most experts (72 percent) gave the same response under both scenarios, which suggests, as in the responses to the first question, that the legislation may not influence which technology subtypes are most likely to be successful. However, some experts who believed that the legislation would not change which technology was the most competitive chose different technologies as the second-most competitive under each scenario. These responses suggest that some subtypes may be sufficiently advanced to be the clear winners today, but that the second-place technology could be more readily influenced by RD&D funding.