



An Innovation + Regulation Policy Approach to Decarbonizing the U.S. Electric Power Sector: Modeling and Analysis

**Prepared for
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PREFACE

Purpose of Study

Over the past several years, the Energy Innovation Reform Project (EIRP) has developed and promoted an Innovation + Regulation Policy Framework (I+R) for decarbonizing the U.S. electric power sector that calls for government investment in innovation followed by a Clean Electricity Standard to achieve significant reductions in power sector emissions. This framework provided the basis for the initial bipartisan McKinley-Schrader Clean Energy Future Through Innovation Act (CEFTIA) of 2020, first introduced in the House of Representatives in December 2020 by Congressmen David McKinley (R-WV) and Kurt Schrader (D-OR) and reintroduced in June 2021. In support of the I+R framework development effort, EIRP retained OnLocation, Inc., in 2018 to provide comprehensive modeling and analysis to explore the impact of the innovation and regulation components of the framework as well as the benefits of the combined I+R approach.

In 2021-22, EIRP again retained OnLocation to build upon the prior analysis by updating the integrated modeling assessment to reflect updates to the I+R policies as reflected in the McKinley-Schrader CEFTIA 2021, and to compare this policy approach with another clean energy policy proposal, the CLEAN Future Act (CFA) introduced in the House of Representatives in March 2021 by Congressman Frank Pallone, Jr. (D-NJ). For this analysis, OnLocation created the EIRP21-NEMS model that reflects current trends in energy markets and technology as well as model enhancements to allow representation of specific policy incentives and low-carbon technologies. The analysis of the I+R framework as well as the comparison with the CFA policy is designed to illustrate the relative environmental and economic costs and benefits of the two policies. After enactment of the November 2021 Infrastructure Investment and Jobs Act (IIJA), OnLocation assessed the potential impact of the Act's prescribed new investments in the electric power sector as a comparison point to the I+R core scenario.

About OnLocation, Inc.

OnLocation, Inc., a KeyLogic Company, is a leading energy consulting firm providing objective quantitative analysis to a diverse set of energy policy stakeholders. Since 1984, OnLocation has served a broad range of government and industry clients with a common interest in energy and the environment. OnLocation's experienced professionals rely on thorough research and analysis to achieve practical and customized solutions for our clients. To help our clients understand the implications of the challenges facing our energy system, we develop, modify, and apply a variety of computer models to examine potential energy trends, impacts of proposed government policies, and the associated financial and economic impacts of energy-related investment decisions.

The staff of OnLocation has extensive working experience with integrated energy models including the National Energy Modeling System (NEMS), EIA's widely recognized energy model. While NEMS was developed and is maintained by EIA, OnLocation has provided technical support to EIA in the design, development, and application of the NEMS model since its creation, as well as created customized versions to analyze specific issues and policies for our clients. For more information about OnLocation and its parent company KeyLogic, visit <https://www.onlocationinc.com> and <https://www.keylogic.com/>.

EXECUTIVE SUMMARY

Overview of the Analysis

Using the customized EIRP21-NEMS model,¹ OnLocation analyzed several scenarios for the Energy Innovation Reform Project (EIRP) to examine how innovation policies that lower the cost of a broad suite of zero- and low-carbon energy technologies, combined with CO₂ mitigation regulations, can achieve substantial CO₂ reductions in the electric power sector by 2050. The objective of these scenarios is to provide insights of what could happen if the scenario assumptions reflect future technology evolution and market conditions.

Referred to here as the Innovation + Regulation (I+R) Policy, this core scenario combines innovation policies with a Clean Electricity Standard (CES) to reduce power sector CO₂ emissions 80 percent below 2022 levels by 2050. More specifically, the innovation policies would promote the use of advanced power sector technologies, by lowering the cost and improving performance of technologies such as carbon capture and storage, advanced nuclear power, renewable energy, and energy storage. Innovation policies would provide federal funding for research, development, and deployment of these technologies, expand existing tax credits, provide targeted investment to reduce first-of-a-kind costs, and fund matching grants and other policies designed to spur further private-sector investment.

OnLocation modeled several scenarios as part of this analysis, including the I+R policy scenario and a CLEAN Future Act (CFA) CES scenario which are the focus of this paper. The CFA CES is a regulatory policy that aims to achieve net zero CO₂ emissions in the power sector by 2035. We compare the cost and effectiveness of these two policies to each other, as well as to a business-as-usual (reference) case. Comparisons are also made with a revised reference case that reflects select power sector provisions of the recently enacted Infrastructure Investment and Jobs Act (IIJA).

Key Findings

Four key findings from the EIRP21-NEMS analysis are summarized as follows:

1) Innovation alone can achieve significant CO₂ mitigation, but long-term goals are unlikely to be met after policy incentives expire

The combination of significant innovation technology policies and incentives as implemented in EIRP21-NEMS is very effective in reducing CO₂ emissions from current levels. In our analysis, the measures achieve the policy goal of 80 percent reduction from current levels 10 years earlier than the I+R target year of 2050, as shown in Figure 1.

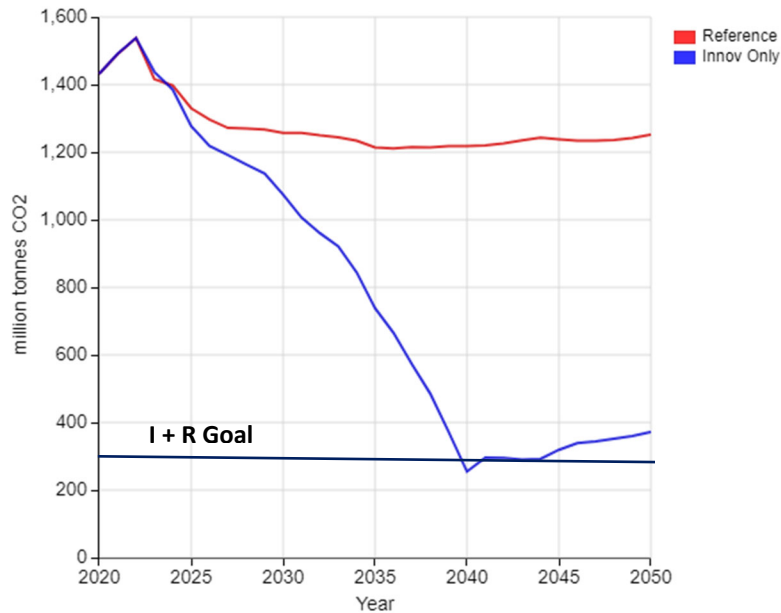
While the innovation measures alone achieve the policy goal early, the I+R policy assumes that most of the policy incentives phase out by 2040 (several years after the CES takes effect), and without these incentives and a carbon policy in place, CO₂ emissions in the Innovation Only scenario begin to rise by

¹ EIRP21-NEMS is a version of the U.S. Energy Information Administration (EIA) National Energy Modeling System (NEMS) developed by OnLocation for use in this analysis. The model is based on the EIA Annual Energy Outlook 2021 version of the NEMS and does not represent the views of EIA. For more information about the NEMS model, visit <https://www.eia.gov/outlooks/aeo/>.

2045. For example, without the continued support of the expanded Zero Emission Credit program, many nuclear plants are projected to retire and be replaced by CO₂-emitting natural gas generation.

The regulation component of the policy is needed to ensure that the emissions goal continues to be met through 2050 and beyond by providing continued policy support for carbon-free technologies such as nuclear power and carbon capture technologies. The regulation policy also serves to provide a consistent target for future emission reductions that must be achieved.

Figure 1. EIRP21-NEMS Power Sector CO₂ Emissions, Innovation Only Scenario

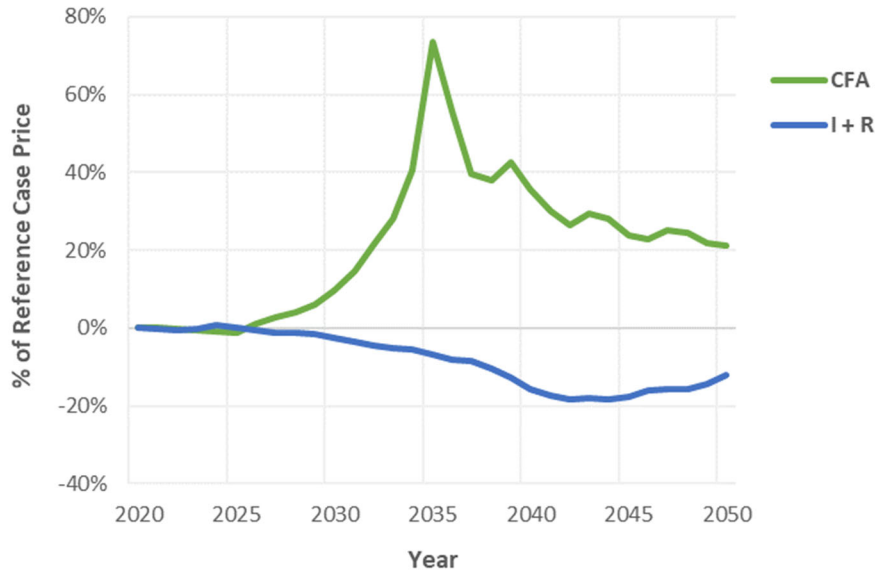


2) Both innovation and regulation are needed to meet emission reduction targets cost-effectively

The CLEAN Future Act (CFA) Clean Electricity Standard scenario reduces CO₂ emissions more rapidly and results in lower emissions than the Innovation + Regulation (I+R) scenario. However, because the CFA does not include Federal policies and incentives designed to accelerate innovation prior to imposing regulatory standards, compliance costs of power suppliers rise significantly leading to higher energy prices for consumers and overall electric power system costs compared to the I+R scenario.

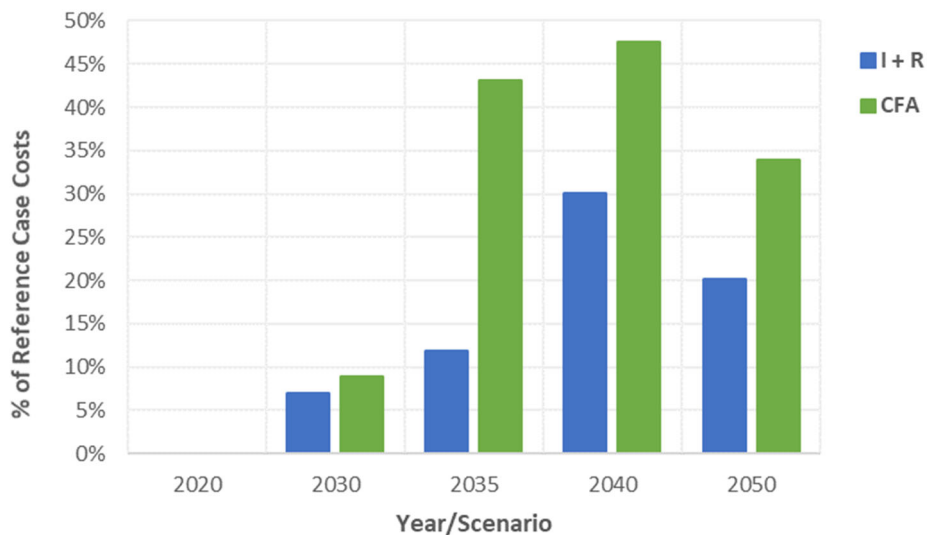
- **Electricity prices.** The innovation policies and technologies in the I+R scenario lead to lower average retail electricity prices than the Reference case, while CFA prices rise as high as 73 percent (7.5 cents per kilowatt-hour) above Reference case prices, as shown in Figure 2. Higher electricity prices increase energy bills to consumers and reduce growth in consumer demand for electricity.

Figure 2. EIRP21-NEMS Average Electricity Retail Price as Percent from Reference, CFA vs. I+R Scenarios



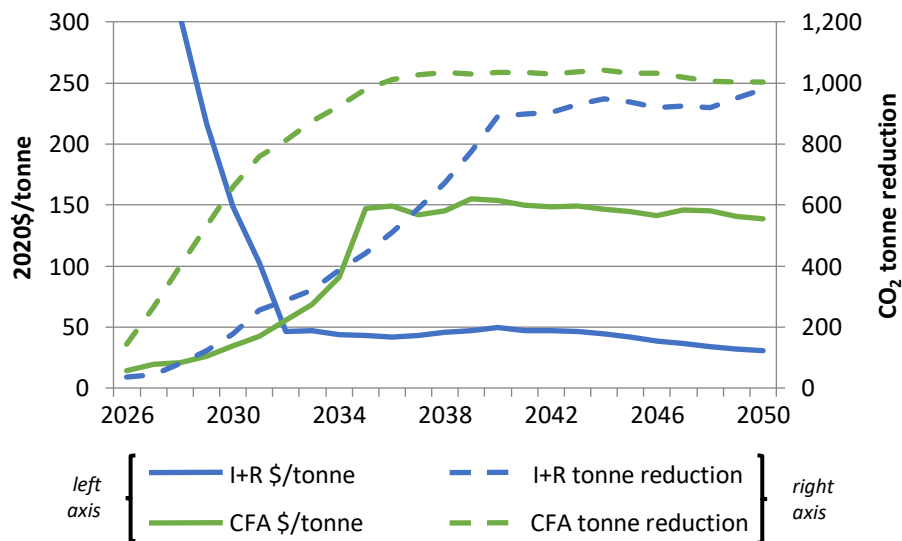
- **Electric power system costs.** Power system costs that represent the costs of power supply (excluding tax credit payments and subsidies) are about 14 percent higher in the CFA scenario than in the I+R scenario by 2040, and almost 50 percent higher than the Reference case, as shown in Figure 3. Costs are higher in the CFA scenario primarily due to higher capital investments in new low-emitting power plants necessary to meet the CFA CES goal without the cost benefit of expanded R&D investments as in the I+R scenario. The CFA scenario costs are also higher despite lower consumer electricity demand than in the I+R scenario.

Figure 3. EIRP21-NEMS Electric Power System Costs as Percent from Reference, CFA vs. I+R Scenarios



- **CO₂ mitigation cost.** In the I+R scenario, investments in innovation technologies and policies quickly pay off, and the mitigation cost² per metric tonne CO₂ declines as low carbon emitting technologies become less expensive over time, as shown in Figure 4. The mitigation cost can be used to measure the average cost of meeting each policy’s requirements. Note that the I+R pre-2030 CO₂ reductions are relatively small leading to a high cost per tonne though small impact on total cost.

Figure 4. EIRP21-NEMS Mitigation Cost per Tonne CO₂, CFA vs. I+R Scenarios



3) The I+R policy incentivizes a more diverse portfolio of carbon-free generation

EIRP’s innovation approach promotes the development of a variety of advanced energy technologies capable of significantly reducing CO₂ emissions including advanced nuclear energy, carbon capture (CCS)³ from fossil fueled technologies, renewable energy such as wind and solar, and electricity storage technologies. The I+R scenario results illustrate the benefits of a diverse portfolio.

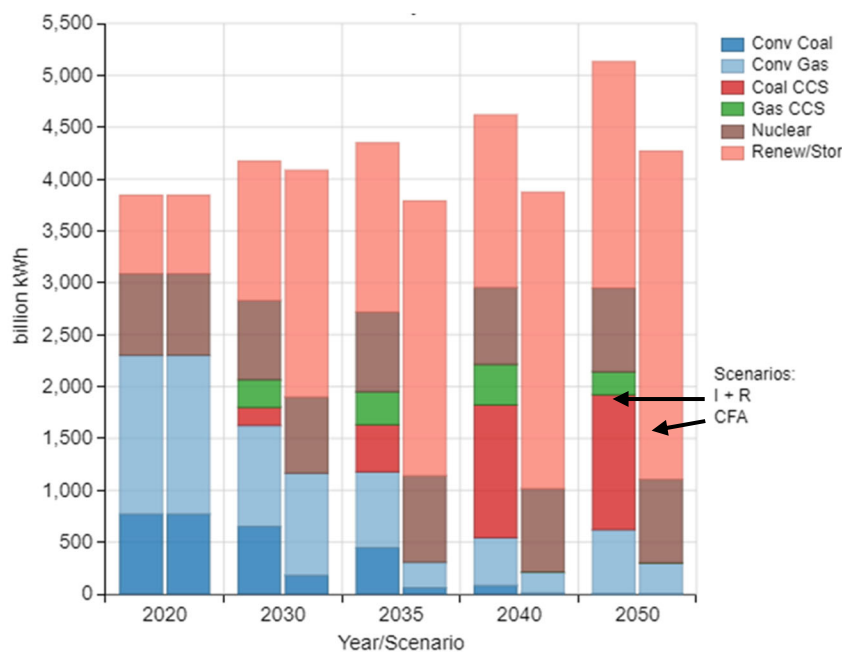
- **Shifting generation portfolio.** The generation mix of conventional fossil fuels (coal and natural gas), nuclear, and renewable power shifts over time to less carbon intensive technologies in each policy scenario, as shown in Figure 5, but the I+R scenario results in a more diverse mix of generation options than the CFA scenario. With technology cost reductions for carbon capture and storage, decarbonized fossil fuels can be a significant element of the generation mix, replacing conventional fossil capacity.

² Mitigation costs are derived from power system costs plus R&D spending and the policy’s economy-wide emissions reductions each year. See Appendix F for more information.

³ Throughout the paper, the terms “carbon capture,” “CCS,” and “CCUS” refer to carbon capture, transport, utilization, and sequestration, and are used interchangeably.

- **Technology neutral approach enhances portfolio diversity.** Renewable technologies and electricity storage play an important role in meeting clean electricity goals, but with a combination of technology policy incentives and investments in innovation, emerging technologies such as Allam-cycle carbon capture may provide cost-effective alternatives for meeting these goals. The CFA policy provides very little incentive for fossil fuel technologies with carbon capture; virtually all the CES credits for fossil technologies phase out after 2035. The result is greater reliance on variable renewable generation such as wind and solar that may reduce system reliability over time. The I+R approach uses more technology-neutral incentives in recognition of the need for a diverse portfolio including firm and dispatchable clean power to meet CO₂ mitigation goals.

Figure 5. EIRP21-NEMS Electricity Generation Mix, CFA vs. I+R Scenarios



The first stacked bar (on the left) in each year is the I+R scenario; the second (or right-hand stacked) bar is the CFA scenario.

4) The Infrastructure Investment and Jobs Act (IIJA) will reduce emissions slightly, but falls far short of meeting CO₂ mitigation goals

While some Federal spending in the Infrastructure Act aligns with I+R goals, the resulting impacts in the revised reference case with IIJA provisions,⁴ including CO₂ reductions and infrastructure improvements, are very limited and do not continue beyond 2030. As shown in Figure 6, the IIJA nuclear subsidies are successful in preventing a few at-risk plants from retiring, but the subsidies are short-lived resulting in nearly the same number of retirements by 2030 as the original reference case and many more retirements than in the I+R scenario that includes longer-term nuclear subsidies and a CES policy to

⁴ As described in Appendix E, the primary provisions of the Infrastructure Investment and Jobs Act (IIJA) that were modeled in the Reference IIJA case are subsidies to preserve existing nuclear plants and for new carbon capture, utilization, and storage (CCUS) infrastructure including demonstration plants and CO₂ pipelines.

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incentivize low-carbon generation. IIJA subsidies for CCUS infrastructure reduce the cost of deployment for a few coal and natural gas CCUS power plants prior to 2030 and induce modest capital cost reductions, but additional I+R policies are needed to achieve significant CCUS deployment levels and an improved power infrastructure for meeting long-term CO₂ reduction goals.

Figure 6. EIRP21-NEMS Capacity Retirements and CCUS, IIJA vs. I+R Scenarios

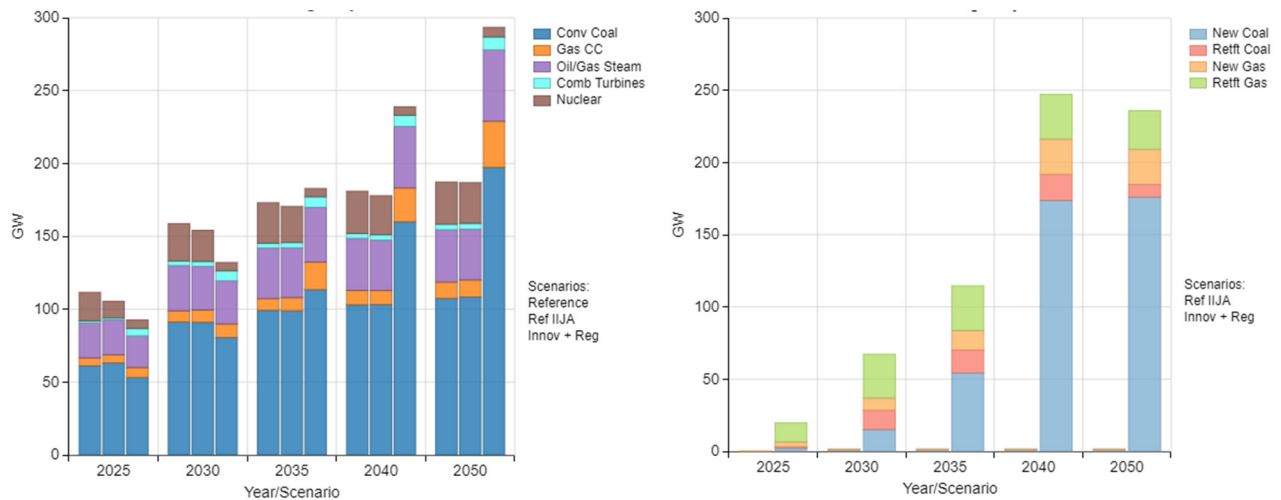
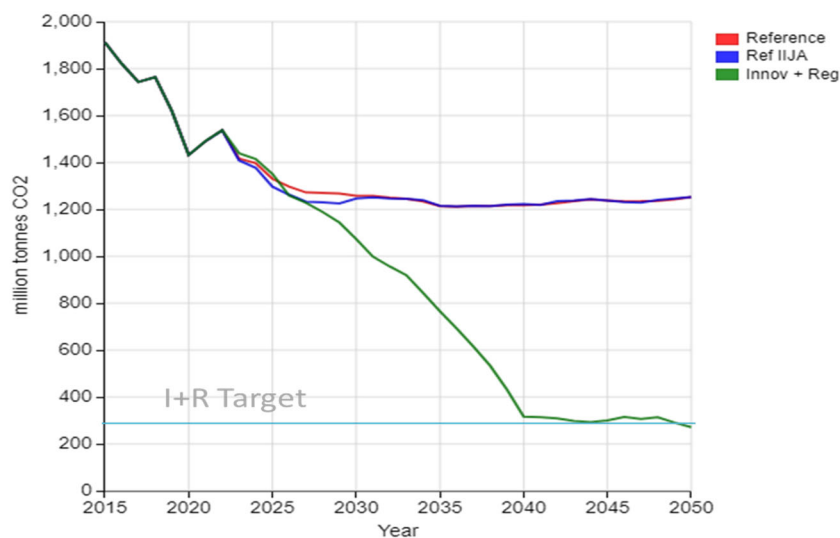


Figure 7 illustrates the projected CO₂ emission reductions from the original Reference case (with no IIJA investments), the Reference with IIJA provisions, and the I+R policy scenario. For comparison, the 2050 I+R target is also noted here. As shown, the IIJA Reference achieves some CO₂ reductions in the short term, but those gains disappear by 2030 without additional investment and fall far short of meeting the I+R long-term target. I+R policies will ensure that goals are met through 2050 and beyond.

Figure 7. EIRP21-NEMS CO₂ Emissions from Power Sector, IIJA vs. I+R Scenarios



INTRODUCTION

The U.S. energy system has evolved rapidly over the past decade as electricity markets have responded to new technologies and resources. Costs for wind and solar photovoltaic (PV) technologies have fallen substantially, while natural gas prices have declined with increased supplies from shale gas production (despite recent short-term price increases). These advancements were spurred by federal, state, and private sector investments in energy research, development & deployment (RD&D) in new technologies, a federal tax credit for what was then considered unconventional gas exploration (i.e., fracking), and policies and incentives to deploy clean energy technologies, especially renewable energy. In addition, environmental policies such as the Mercury and Air Toxics Standards⁵ along with low electricity prices, primarily due to lower natural gas prices, have increased the retirement of many conventional coal-fired power plants in recent years.

This evolution has resulted in a shift in the electric generation mix from mostly coal generation to more gas-fired generation and renewable technologies, especially wind and solar photovoltaics, while reducing annual carbon dioxide (CO₂) emissions. However, there has been little deployment of other zero- and low-carbon technologies such as carbon capture and advanced nuclear power that provide firm dispatchable power. Further technology innovation and additional policies are needed to fully decarbonize the electricity system while maintaining a diversified generation mix that will likely be necessary to achieve emission reductions in a cost-effective way.

To address this need, the Energy Innovation Reform Project (EIRP) developed the Innovation + Regulation (I+R) Policy Framework, which combines public investment in technology innovation and deployment incentives with a Clean Electricity Standard (CES) to reduce power sector CO₂ emissions 80 percent below 2022 levels by 2050. This framework provided the basis for the bipartisan Clean Energy Future Through Innovation Act (CEFTIA) of 2020,⁶ first introduced in the House of Representatives in December 2020 by Congressmen David McKinley (R-WV) and Kurt Schrader (D-OR) and reintroduced in June 2021.⁷ The I+R Policy focuses initially on energy innovation to lower the cost and improve the performance of several power generation technologies that are most likely to make significant contributions to reducing CO₂ emissions, including carbon capture, advanced nuclear power, renewable energy, and electricity storage. As the cost of these technologies fall and deployment increases over time, the CES enters into force to ensure that the power sector meets the 2050 CO₂ emission target.

EIRP retained OnLocation to perform an integrated modeling assessment of the I+R policy and compare this policy approach with another clean electricity policy proposal, the CLEAN Future Act (CFA) introduced in the House of Representatives in March 2021 by Congressman Frank Pallone, Jr. (D-NJ).⁸ The CFA Clean Electricity Standard is a policy that aims to achieve net zero CO₂ emissions in the power sector by 2035 without the benefit of new innovation investment. Using the customized EIRP21-NEMS model, OnLocation modeled several scenarios as part of this analysis, including the I+R and CFA CES scenarios which are the focus of this paper. We compare the cost and effectiveness of these two policies to each other as well as to a business-as-usual (reference) case, with some additional comparisons to a

⁵ For more information, visit <https://www.epa.gov/mats/regulatory-actions-final-mercury-and-air-toxics-standards-mats-power-plants>

⁶ For more information, see <https://www.congress.gov/bill/116th-congress/house-bill/9054>

⁷ For more information, see <https://www.congress.gov/bill/117th-congress/house-bill/4153>

⁸ For more information, see <https://www.congress.gov/bill/117th-congress/house-bill/1512>

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revised reference case that incorporates select power sector provisions of the recently enacted Infrastructure Investment and Jobs Act (IIJA).⁹

⁹ For more information, see <https://www.congress.gov/bill/117th-congress/house-bill/3684>

OVERVIEW OF CLEAN ELECTRICITY POLICIES

The overall goal of clean electricity policies (also referred to as clean energy policies) is to reduce or eliminate CO₂ emissions in the electric power sector at either a state or national level. “Clean electricity” is commonly defined as electricity that is produced with net-zero greenhouse gas emissions or lower emissions than a designated benchmark technology.

One popular approach—pioneered at the state level and now the focus of federal policy deliberations—is to implement a clean electricity standard (CES). Renewable portfolio standards (RPS) that incentivize the deployment and use of renewable generation have been implemented by many states in recent years; a CES is similar to an RPS but more broadly covers all sources designated as “clean” that emit fewer greenhouse gases than conventional sources.

A CES is a market-based policy that uses a carbon intensity benchmark to calculate the “percentage clean” for each electricity generation source and sets an annual target amount of clean electricity that must be generated or sold by electricity suppliers in the program. This target share of clean electricity then rises over time leading to greater emissions reductions. CES policies typically create clean electricity credits (CECs) that are tradable among generators. These credits allow “clean” electricity generators to earn and sell excess credits to others for whom compliance would otherwise be more costly.

A CES policy’s technology benchmark is often tied to the average carbon intensity of either conventional coal or natural gas fired generators. If the carbon intensity of coal generation is used as the benchmark, then natural gas generators receive partial CES credits¹⁰ under the policy; however, if natural gas provides the basis for the benchmark, then these generators get zero credits which results in a more restrictive policy. Fossil technologies with carbon capture often receive partial credits based on their capture rate. Carbon free electricity generated by renewable energy or nuclear power receives a full credit.

In order to sell electricity, generation sources must have the required number of clean electricity credits per MWh sold based on each year’s standard. If the generator does not have the credits required in a given year, then it must purchase credits from other eligible sources that have excess credits. In some cases, there is an “alternative compliance payment” (ACP) option for obtaining additional credits at a specified price that effectively caps the market price for CECs bought and sold between generators. Some programs will also allow generators to bank excess credits earned in one year for use in meeting requirements in a future year, although the ability to bank excess credits is often limited.

The two policies included in this analysis, the Innovation + Regulation policy and the CLEAN Future Act’s power sector policy, both employ versions of a national clean electricity standard that are defined in different ways. The I+R approach combines this standard with complementary innovation policies.

¹⁰ For example, an advanced natural gas combined cycle plant has 60 percent lower emissions on average compared to a conventional coal plant and receives 0.6 credits for each megawatt-hour (MWh) sold.

INNOVATION + REGULATION POLICY ASSESSMENT

Overview of I+R Policy Framework

In the Innovation + Regulation (I+R) policy framework, technology innovation and policy incentives are combined with a Clean Electricity Standard (CES) to advance clean power technology development and to reduce annual power sector CO₂ emissions to 80 percent below 2022 levels by 2050. This framework provides the basis for the McKinley-Schrader Clean Energy Future Through Innovation Act of 2021 legislation, introduced to Congress in June 2021.

Innovation. The first step in this approach is for the Federal government to provide innovation policies and incentives to promote the use of advanced power sector technologies, particularly during the first decade after enactment, before the regulation takes effect. The energy innovation policies are intended to lower the cost and improve the performance of power generation technologies that are most likely to make significant contributions to CO₂ mitigation. These technologies include carbon capture for fossil fuel generation, advanced nuclear power, renewable energy such as solar and wind, and battery storage technologies. Innovation policies provide federal funding for research, development, and deployment of these technologies, extend and expand existing technology tax credits, provide targeted investment to reduce first-of-a-kind costs for promising new technologies, and fund matching grants and other policies designed to spur further private-sector investment. The goal of the policies is to drive down technology costs through innovation and increased deployment.

Regulation. The next step is to implement a federal technology-neutral regulation in the form of a Clean Electricity Standard.¹¹ The standard, defined as the percentage of “clean” electricity sales, would take effect no later than 10 years after the innovation investments and policies are implemented¹² and would increase over time to ensure that 2050 emission reduction targets are met. The goal of the standard is to reduce power sector CO₂ emissions by 80 percent below current (2022) emission levels by 2050. The delayed start of the regulation allows the innovation measures time to reduce the cost of CO₂ mitigation while ensuring that 2050 goals are met.

The primary benefit of the I+R approach is to use innovation policies and technology incentives to reduce costs and increase deployment of carbon-free generation sources before implementing the CES regulation, thereby lowering the cost of the regulation for electricity producers and limiting its price impact on electricity consumers.

¹¹ The CEFTIA legislation directs the Department of Energy, in consultation with the Environmental Protection Agency, to establish a program to determine the appropriate annual clean electricity targets necessary to meet CO₂ emissions targets, and to annually review and monitor progress toward meeting these targets.

¹² For purposes of this analysis, we assume the CES takes effect 10 years after enactment. The legislation establishes that the CES could be brought into effect sooner if certain metrics for cost-effective deployment of eligible technologies are met. The CES would take effect 2 years after that “trigger” date, or no later than 10 years after the date of enactment.

EIRP21-NEMS Modeling Approach

For this analysis, OnLocation created a customized version of the U.S. Energy Information Administration's National Energy Modeling System (NEMS) used to produce the Annual Energy Outlook (AEO) 2021,¹³ referred to here as EIRP21-NEMS.¹⁴

EIRP21-NEMS is an integrated energy-economic modeling system of U.S. energy markets. NEMS projects energy supply, demand, imports, conversion, and prices to the year 2050. Energy supply and demand sectors are represented in separate modules with an integration function that passes energy prices and quantities between the sectors. This analysis focuses primarily on the electricity sector module which is one of the most detailed and data rich within NEMS. The electricity module projects investment in new electric generating technologies, utilization of both new and existing electricity sources to meet electricity demand, and electricity prices to consumers annually over the forecast period. The module includes a detailed database with key economic and technical performance characteristics of existing power plants in the U.S. as well as costs and characteristics for a variety of new and retrofit technology options available for investment. This model is well suited to perform the EIRP integrated modeling analysis.

Innovation. OnLocation represented the EIRP proposed technology policy incentives within EIRP21-NEMS for the Innovation scenarios. These policies are reflected in the McKinley-Schrader legislation, CEFTIA 2021. The innovation policies are primarily intended to improve the cost and performance of power generation technologies that are most likely to make significant contributions in reducing CO₂ emissions. The target technologies that were modified in the Innovation scenarios include the following.¹⁵

- Fossil fuel technologies with carbon capture, modified to represent a Petra Nova-style carbon capture retrofit technology for existing coal-fired plants (described below) and Allam Cycle-based coal and gas technologies with 100 percent carbon capture for greenfield plants;
- Advanced non-light water nuclear power;
- Lithium-ion battery storage with 4-hour storage capability; and
- Renewable power, especially wind and solar photovoltaics (PV).

While end-use energy efficiency is also an important tool for reducing energy consumption and CO₂ emissions (and CEFTIA 2021 does have provisions to incentivize efficiency), this analysis focused on electric generation technologies only.

Two separate approaches were combined to reflect the innovation policies. In the first approach, OnLocation modeled an approximation of the proposed technology policy incentives that could be represented directly in the model:

¹³ For more information about the Annual Energy Outlook, go to <https://www.eia.gov/outlooks/aeo/>.

¹⁴ EIRP21-NEMS is based on the National Energy Modeling System (NEMS), a model developed by the U.S. Energy Information Administration at the Department of Energy. The model has been modified by OnLocation for this analysis and does not represent the views of EIA.

¹⁵ Note, these technologies are also represented in the Business-as-Usual reference case but with the same cost and performance characteristics as EIA's AEO 2021 Reference case.

- For carbon capture technologies, extended and expanded the FUTURE ACT 45Q Tax Credits, provided bonus tax credits for natural gas technologies with carbon capture, and provided federal subsidies for building new CO₂ pipeline infrastructure;
- For nuclear technologies, implemented a national Zero Emission Credit program for existing nuclear plants and expanded the production tax credit for new nuclear power plants; and
- For renewable and electricity storage technologies, extended the production and investment tax credits.

For more information about the assumptions used in modeling these policy incentives, see Appendix A.

In the second approach, electric technology costs and characteristics were modified in the model to reflect the estimated outcome of additional federal research, development, and demonstration (RD&D) investment in advanced technologies, loan guarantees, and other federal support programs that could not be represented directly in the modeling framework. A set of advanced technology costs and characteristics was selected from a number of sources. As noted in the preface, the modeling approach used to analyze the I+R policies in EIRP21-NEMS builds upon an assessment of a prior version of the I+R framework performed in 2018. In particular, the technology costs and characteristics used in this study were developed in the prior assessment, with minor adjustments made to reflect the passage of time. Detailed descriptions of the updated technology costs and characteristics and how they were implemented in the model can be found in Appendix B.

In support of the innovation policies for carbon capture technologies, OnLocation modified EIRP21-NEMS to represent an Allam Cycle-based technology option¹⁶ for new natural gas and coal plants with 100 percent carbon capture, and a Petra Nova-style¹⁷ carbon capture retrofit technology for existing coal plants. The retrofit technology relies on an auxiliary natural gas boiler to provide steam for the capture unit rather than the traditional design of using steam from the coal boiler. More information about modeling these carbon capture technologies can be found in Appendix B.

Regulation. The Clean Electricity Standard, the regulation portion of the I+R policy, was assumed to begin 10 years after the date of enactment or in 2032. As noted above, the goal of the standard is to reduce power sector CO₂ emissions by 80 percent below current (2022) emission levels by 2050 or about 300 million metric tonnes CO₂. This was implemented in the model with a CES target that achieves approximately 95 percent¹⁸ clean electricity sales by 2050. CES credits per unit of generation are assigned to each technology based on the effective CO₂ percent reduction achievable relative to a benchmark conventional coal-fired power plant. In this approach, carbon-free generators receive a full credit for each MWh of generation, and generators that emit CO₂ are eligible for partial clean electricity credits if their average emissions intensity is below the benchmark. An alternative compliance payment

¹⁶ The Allam Cycle is an oxy-combustion process in which fossil fuel is burned with pure oxygen and captures 100 percent of CO₂ emissions. For more information, visit <https://netpower.com/technology/>.

¹⁷ Petra Nova refers to a three-year carbon capture demonstration project at the Petra Nova coal plant near Houston, Texas. For more information, visit <https://www.nrg.com/case-studies/petra-nova.html>.

¹⁸ The equivalent percent of clean electricity sales can vary due to the remaining mix of generation that is not considered “clean” using the policy’s benchmark carbon intensity and therefore is approximated here based on the EIRP21-NEMS modeling and analysis.

(ACP) option is set to \$30 per MWh, rising 5 percent annually plus inflation. For more information about the modeling approach and assumptions for the I+R CES policy, see Appendix C.

Scenario Descriptions and Results

A reference case and two policy scenarios were implemented in EIRP21-NEMS to analyze the impact of the EIRP Innovation and Regulation (I+R) proposed policies:

- The **Reference** case assumes the AEO 2021 technology and policy assumptions updated with the renewable and 45Q sequestration tax credit extensions passed in the FY2021 Omnibus Spending Bill;¹⁹
- The **Innovation Only** scenario assumes advanced technology characteristics and policy incentives to spur technology innovation and deployment;
- The **Innovation plus Regulation** scenario combines the innovation only scenario technologies and policies with a national Clean Electricity Standard (CES) that achieves 80 percent reduction in CO₂ emissions from 2022 levels by 2050. The CES is implemented in 2032 (10 years after the 2022 policy enactment).

For comparison purposes, an additional scenario was implemented:

- A **Revised Reference** case includes Reference case technology and policy assumptions combined with select provisions from the Infrastructure Investment and Jobs Act (IIJA) related to the power sector. Select results are compared to the original reference case.

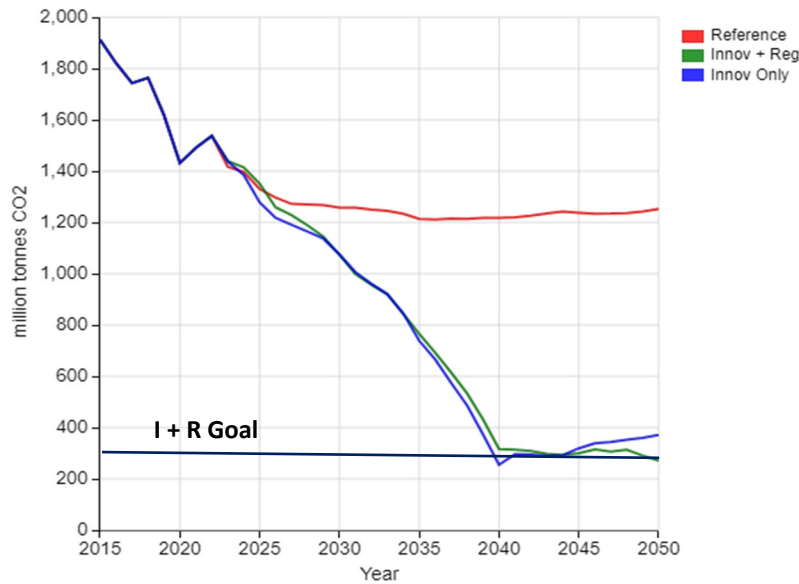
For more information about the modeling assumptions for these cases, see the Appendices.

The I+R policies aim to reduce annual power sector CO₂ emissions to 80 percent below 2022 levels by 2050 or about 300 million metric tonnes CO₂. Due to a combination of aggressive policies and technology assumptions, the Innovation Only scenario achieves this target by 2040 without the need for the CES policy, but by 2045, emissions begin to rise, as shown in Figure 8. CO₂ emissions in the I+R scenario are the same as the Innovation Only scenario through 2045, but after 2045 the CES policy is needed to maintain this level of emissions through 2050.

If the innovation policies alone are as effective at meeting CO₂ mitigation goals as we found in our analysis, then the cost to electricity producers and consumers of adding the regulation should be minimal. After the innovation policies sunset, the CES policy will act as an insurance policy that will ensure that the targeted level of emissions is achieved through 2050 and beyond.

¹⁹ Also known as the Consolidated Appropriations Act of 2021. See <https://www.congress.gov/bill/116th-congress/house-bill/133>

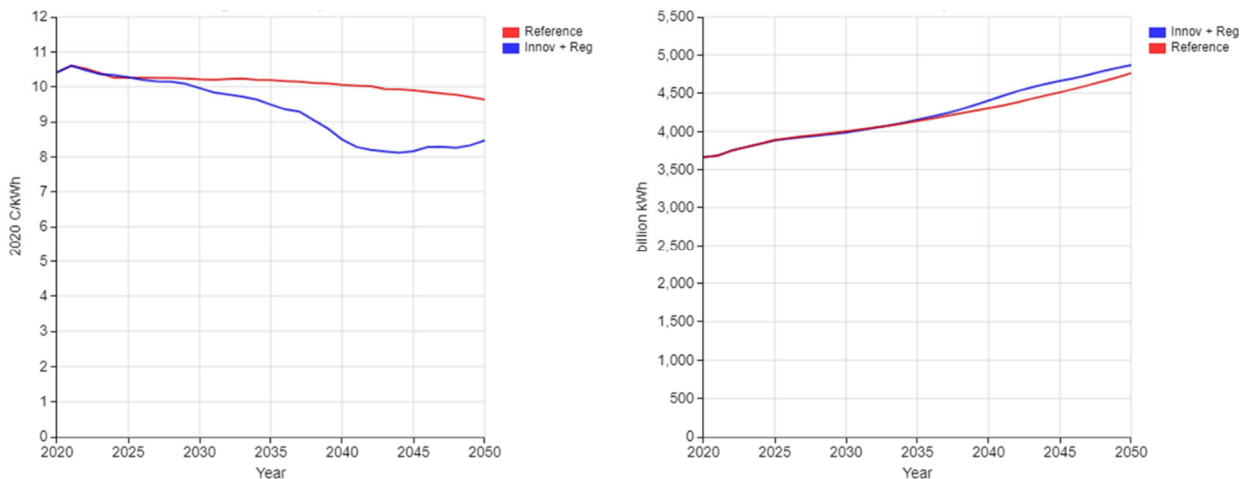
Figure 8. EIRP21-NEMS Power Sector CO₂ Emissions, Innovation and I+R Scenarios



Most of the model results between the Innovation Only and I+R scenarios are very similar so the remaining scenario results will focus primarily on the I+R scenario, and its comparison with the Reference case and CFA scenario, unless otherwise noted.

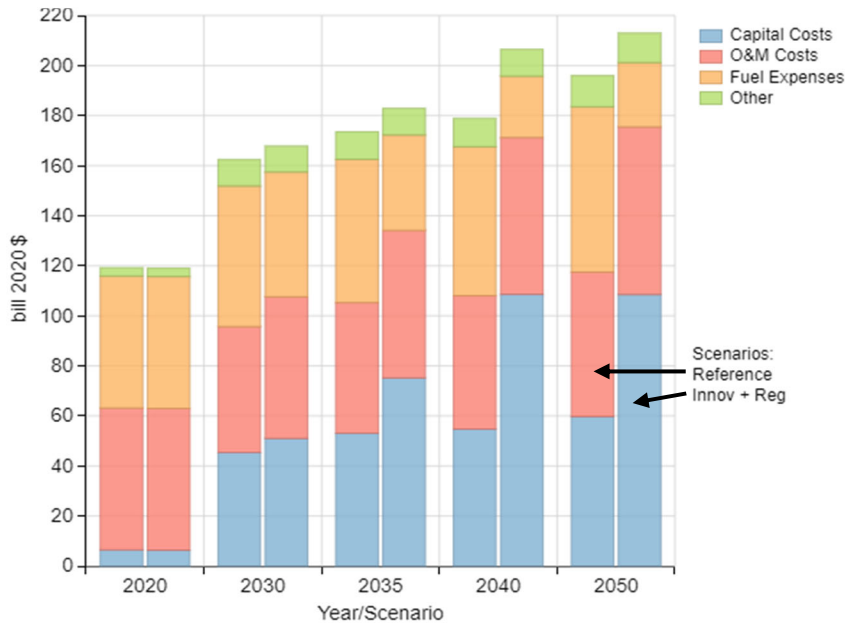
Lower advanced technology costs in the I+R scenario, coupled with expanded tax credits and other subsidies, lead to lower average electricity prices than the Reference case, as shown in Figure 9. In response to the change in prices, electricity sales are somewhat higher in the I+R scenario.

Figure 9. EIRP21-NEMS Electricity Prices and Sales, I+R Scenario



In contrast to electricity prices, power system costs,²⁰ which represent the actual costs of power supply before federal tax credit payments and subsidies, are higher in the I+R scenario than in the Reference case, as shown in Figure 10. The difference in costs is more than would result from simply an increase in generation to meet higher electricity sales. The tax credits and subsidies included in the Innovation policies reduce the costs of private investment and generation and hence reduce electricity prices to consumers, but these federal expenditures for tax credits and subsidies are included in the total system costs.

Figure 10. EIRP21-NEMS Power System Costs, I+R Scenario



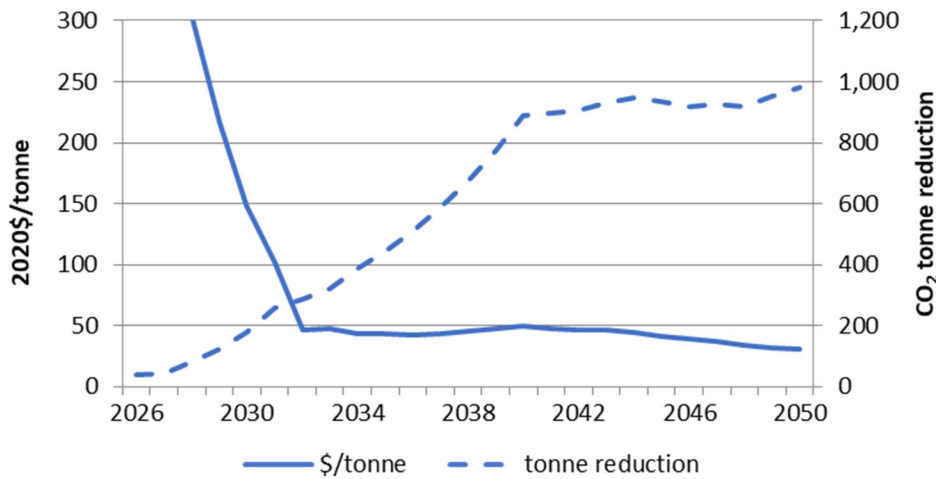
Investments in innovation quickly pay off in the I+R scenario, with the CO₂ reductions rising and the mitigation cost per metric tonne CO₂ declining sharply in the short term, as shown in Figure 11. Costs remain low in the long term as low carbon emitting technologies become less expensive.

The mitigation cost is primarily computed as the incremental power system costs that include private and government paid costs divided by economy-wide CO₂ reductions compared to the Reference case with an adjustment for differing levels of electricity demand. The average mitigation cost across all years is about \$54 per tonne CO₂.²¹ Note that the I+R pre-2030 CO₂ reductions are relatively small leading to a high cost per tonne though small impact on total cost. For more information about the methodology for calculating mitigation costs, see Appendix F.

²⁰ Power system costs in EIRP21-NEMS include power plant investments, transmission hook-up costs for new power plants, and inter-regional transmission costs, but do not include the cost of intra-regional transmission costs, annual costs of maintaining the grid, or distribution costs. Costs include private sector expenditures plus federal tax credits and subsidies.

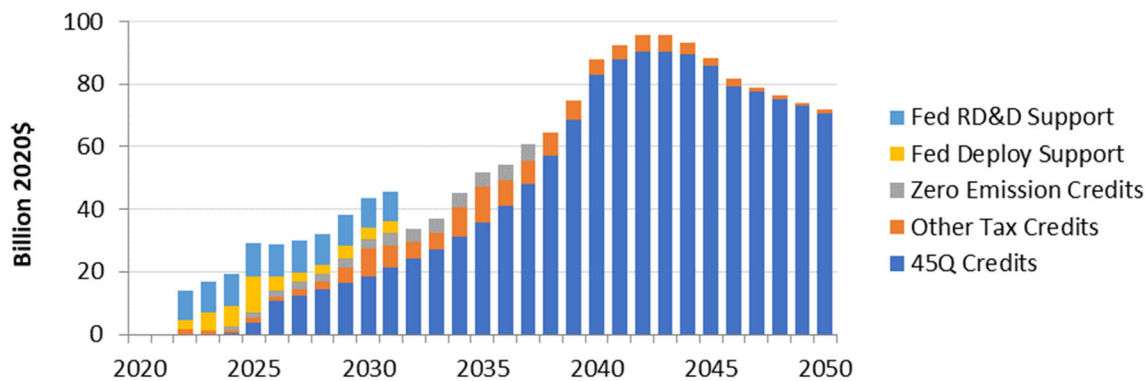
²¹ The average mitigation cost is computed as the undiscounted sum of costs for all years divided by the sum of all economy-wide emission reductions, in other words, equivalent to a weighted average cost.

Figure 11. EIRP21-NEMS CO₂ Reductions and Mitigation Cost per Tonne CO₂, I+R Scenario



Federal expenditures for all the Innovation tax credits and subsidies are shown in Figure 12. Annual expenditures peak at about \$95 billion (in 2020\$). The 45Q sequestration credits account for the largest share of annual federal expenditures, especially after 2030. The 45Q credit payments continue past 2041, when the credits are no longer available for new construction, as facilities receive 20 years of credits from commencement of operations, then payments start to decline as facilities reach the end of the 20-year credit period. All tax credits, including production tax credits (PTC) and investment tax credits (ITC) for renewable energy, 45Q sequestration credits, and the Zero Emission Credits (ZEC) payments for existing nuclear plants are based on EIRP21-NEMS scenario results, as are the subsidies for carbon capture (CCS) deployment and CO₂ pipelines up to the specified limit on spending in the policy. All other expenditures are external assumptions based on appropriations specified in the proposed CEFTIA 2021 legislation. In the I+R policy framework, these expenditures spur innovation and reduce the long-term cost of CO₂ mitigation. Note that these government expenditures are included in the total mitigation costs shown in Figure 11.

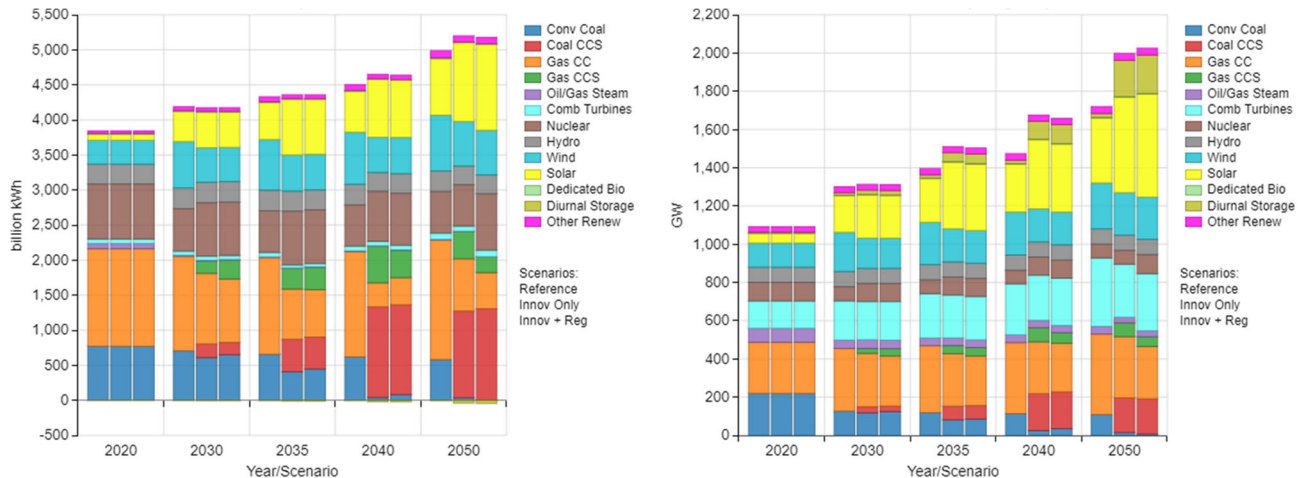
Figure 12. EIRP21-NEMS Annual Federal Expenditures for Innovation, I+R Scenario (Difference from Reference)



By 2040, the mix of electricity generation in both Innovation scenarios (with and without the CES) has shifted to mostly carbon-free sources including solar, wind, nuclear, battery storage,²² and Allam Cycle coal and natural gas with carbon capture, as shown in Figure 13. A small amount of conventional gas generation without capture remains through 2050 in both policy scenarios; however, no conventional coal generation remains. The mix is essentially the same between the innovation scenarios until after 2040 when many of the Innovation policies expire. The result is more nuclear retirements and more conventional gas generation in the Innovation-Only scenario after 2040, whereas the CES in the I+R scenario preserves more nuclear plants and continues the shift away from conventional gas generation through 2050.

As with generation, the mix of electric capacity in the Innovation scenarios shifts to mostly carbon-free sources by 2050, including gas and coal with carbon capture. The total amount of capacity in the policy scenarios is proportionally higher than generation relative to the Reference case due to the lower capacity utilization for variable generation renewables and their low contribution to system reserve requirements.

Figure 13. EIRP21-NEMS Electric Generation and Capacity Mix, Innovation and I+R Scenarios



Capacity additions in the Innovation scenarios are more than 50 percent higher than the Reference case by 2050. Additions are dominated by solar, wind, diurnal (battery) storage, and coal and gas CCS capacity, but also include a small amount of new conventional gas turbines and combined cycle plants to maintain grid reliability.

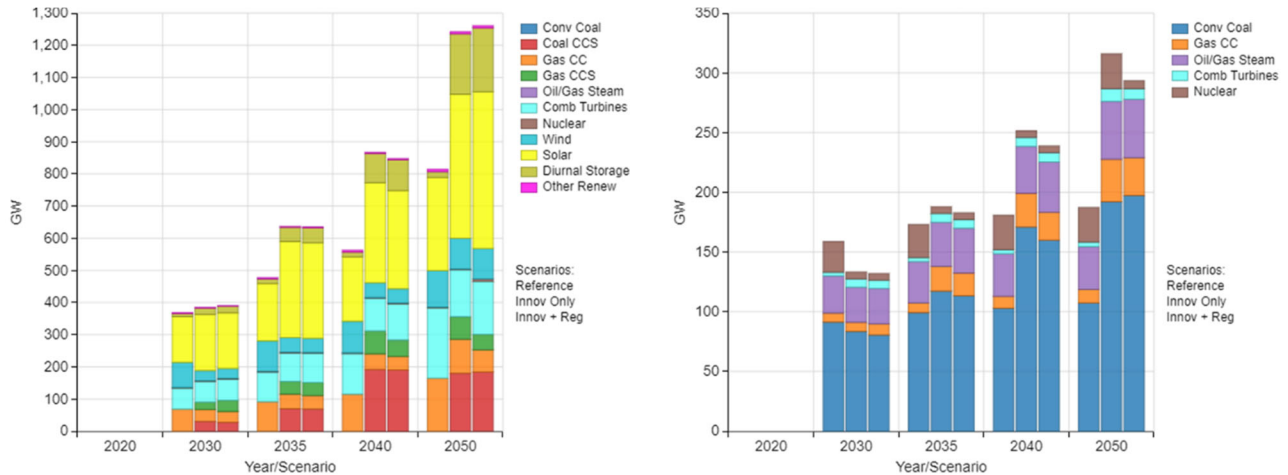
Most existing fossil generators retire by 2050 in both scenarios, especially coal plants, as they can no longer sell electricity cost-effectively due to the large number of CES credits they would need to purchase. But new fossil with carbon capture is eligible for CES credits which can permit fossil generation to retain its share of the generation mix.

There are fewer nuclear plant retirements in the Innovation scenarios compared to the Reference case due to their improved financial prospects under the Innovation policies, although by 2050, nuclear

²² Note: Diurnal (battery) storage produces net negative generation due to electricity losses.

retirements increase in the Innovation-Only scenario in the absence of policies such as the CES. Capacity additions and retirements are shown in Figure 14.

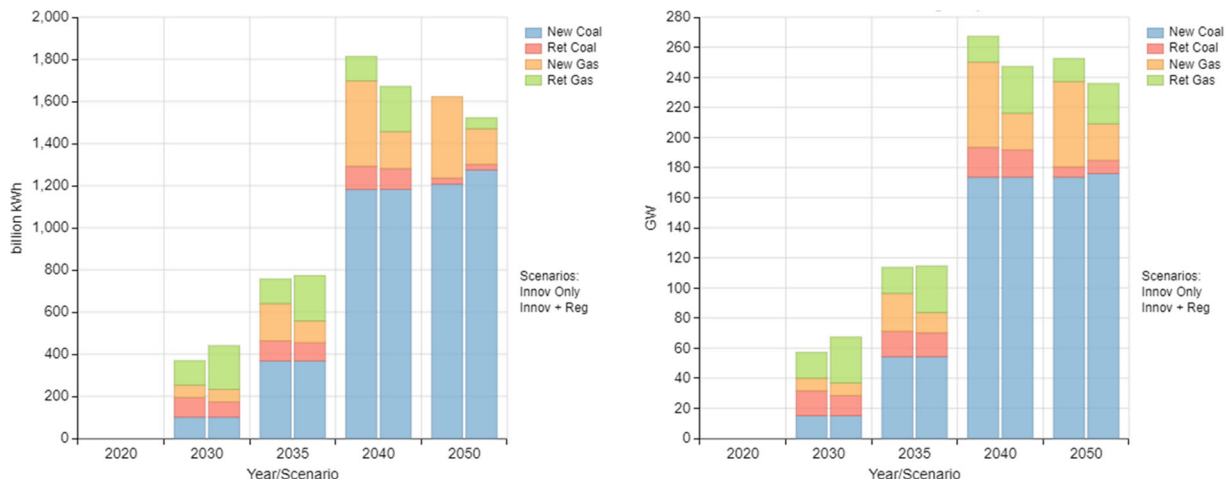
Figure 14. EIRP21-NEMS Electric Capacity Changes, Innovation Only and I+R Scenarios



(note the difference in scales between the two figures)

New Allam Cycle technologies with 100 percent carbon capture make up the majority of capacity and generation with carbon capture (CCUS) built in the Innovation scenarios, as shown in Figure 15. Allam Cycle coal dominates by 2040²³ but some Allam Cycle natural gas and a small amount of retrofit (Petra Nova-like) coal and retrofit gas capacity is also built in both scenarios. CCUS generation declines slightly after 2040 as early entrants complete their 20 years of 45Q tax credits.

Figure 15. EIRP21-NEMS Electric Generation and Capacity with Carbon Capture, Innovation and I+R Scenarios



²³ The 45Q sequestration tax credit for new coal CCUS is worth roughly \$50 to \$60 per MWh (depending on storage type), while the credit for new gas CCUS and PTC equivalents are only about \$24 to \$30 per MWh. The coal credit is enough to pay the full capture cost for new coal plants as the costs decline due to innovation.

CLEAN FUTURE ACT CLEAN ELECTRICITY STANDARD

Overview of CFA CES Policy

The Climate Leadership and Environmental Action for our Nation's (CLEAN) Future Act (CFA) was introduced in the House of Representatives by Energy & Commerce Committee Chairman Frank Pallone, (D-NJ) in March 2021. The CFA is a comprehensive bill designed to achieve net zero greenhouse gas emissions across the entire energy system no later than 2050. A key provision of the bill establishes a federal Clean Electricity Standard with a goal of achieving 100 percent clean electricity sales by 2035. The CFA CES provision is the focus of the comparative analysis with the I+R policies.

The CFA CES requires all retail electricity suppliers to reach 80 percent clean electricity by 2030 and 100 percent clean by 2035. The policy awards CES credits to electricity generators based on a carbon intensity benchmark that declines over time. Full clean electricity credits are provided to renewable and nuclear generators while partial credits are provided to generators using fossil fuels if their emission rates are below the declining carbon intensity benchmarks outlined in the CFA. CES credits are tradable between electricity suppliers.

An important distinction between the I+R CES and this policy is that the CFA CES phases out the ability of fossil fuel power plants to earn partial credits by lowering the carbon intensity benchmark between 2030 and 2035 from a value initially derived from the average emissions of a conventional coal plant to a lower value derived from the emissions of a natural gas combined cycle plant. This approach makes this policy more restrictive than the I+R and more difficult to achieve the standard because by 2035 the only fossil fuel generators that can receive any credits are natural gas-fired generators with carbon capture.

Another significant feature of the CFA's crediting scheme that adds to the stringency of the policy is that fossil fuel generators are scored based on carbon intensity values that include both the direct carbon dioxide emissions of the generating unit plus the carbon dioxide and methane emissions that are estimated to occur upstream during extraction, flaring, processing, transmission, and transportation of the fuel. Carbon capture technologies produce more upstream emissions than conventional fossil fuel technologies with no carbon capture due to the additional energy needed to capture and compress CO₂ for transport and storage. For example, these upstream emissions represent roughly one-third of total greenhouse gas emissions for natural gas technologies without carbon capture, and about 80 percent for natural gas technologies with carbon capture. When these carbon intensity values are compared to the crediting benchmarks, natural gas generators with carbon capture are eligible for far fewer credits than they are under direct emissions-based benchmarks used in most CES crediting schemes including the I+R approach. Note that the CFA CES crediting incorporates greenhouse gas emissions from upstream fossil fuel production and transportation but does not consider other indirect emissions resulting from processes such as the mining and production of materials used in the construction of fossil and other power plants. For more information about the crediting scheme for the CFA CES, see Appendix D.

The CFA CES policy design imposes two key provisions in a short 5-year period (2030-2035): a rapidly increasing CES target of 80 percent clean electricity sales by 2030 and 100 percent clean by 2035; and a phasing out of partial clean electricity credits for fossil fuel generators by lowering the benchmark used

for crediting. Each of these provisions alone creates a challenge for generators and retail suppliers, and the combination of the two means the policy's goals are likely to be very difficult and costly to achieve.

Scenario Descriptions and Results

The Reference and I+R scenarios described above are compared to the CFA CES as implemented in EIRP21-NEMS:

- The **CFA CES** scenario includes a national CES standard that starts in 2023 and is defined as the percent of clean electricity sales (applied to retail electricity suppliers²⁴) that reaches 80 percent clean by 2030 and close to 100 percent by 2035, remaining at the same level through 2050. Partial clean electricity credits for fossil generators phase out by 2035 except for natural gas with carbon capture. All other assumptions are the same as the Reference case.

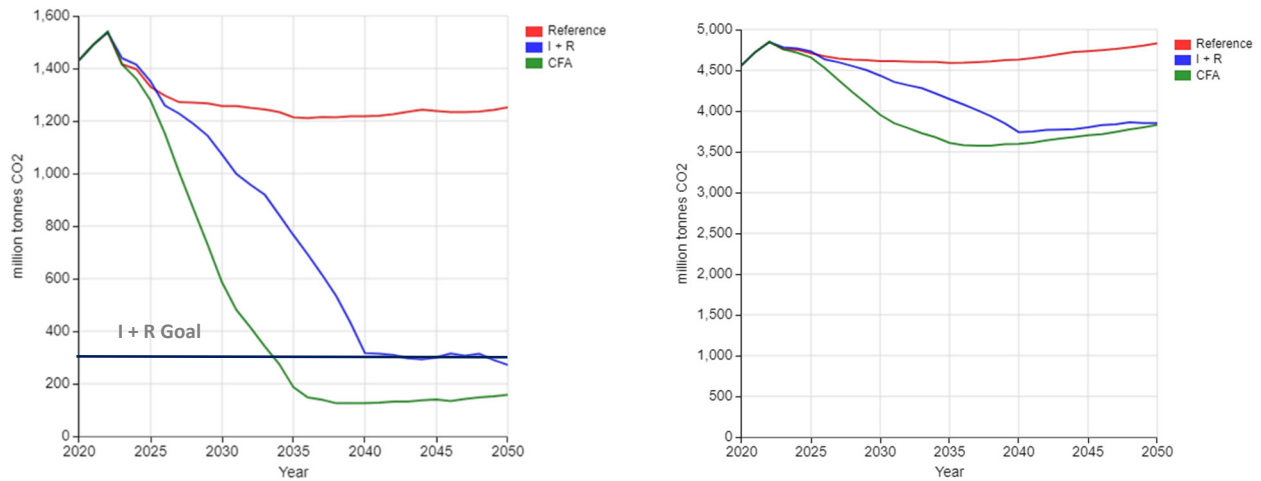
For more information about the CFA CES scenario assumptions, see Appendix D.

Both the I+R and CFA policy scenarios achieve significant CO₂ reductions compared to Reference case emissions. The CFA CES goal is to achieve 100 percent clean electricity sales by 2035 or close to net zero CO₂ emissions in the power sector. In our modeling, the CFA CES scenario falls just short of the 100 percent goal, reaching about 98 percent clean electricity sales, so some CO₂ emissions remain after 2035 (see Modeling Challenges and Caveats below for an explanation of this). The I+R CES policy aims to reduce annual power sector CO₂ emissions to 80 percent below 2022 levels or about 300 million metric tonnes (MMT) CO₂ by 2050, but effectively achieves this level of reductions 10 years earlier, as shown in Figure 16. Economy-wide CO₂ emissions are also reduced significantly in both scenarios, primarily due to the reductions in the power sector. However, in the CFA scenario, there is some emissions "leakage" in the industrial sector as manufacturers switch to producing their own electricity using gas-fired generators such as combined heat-and-power (CHP) to avoid the higher electricity prices resulting from the policy (see Figure 17 below). These gas-fired generators emit CO₂ so industrial emissions increase about 90 MMT by 2050 compared to the Reference case, causing the total economy-wide emissions reductions from the I+R and CFA cases to be nearly identical in 2050.

While the CFA scenario reduces emissions even more rapidly than the I+R scenario, it does so without the benefit of additional federal funding for innovation technologies and policies. As shown in the charts below, the CFA scenario requires greater investment and produces higher power system costs while generating less electricity at higher electricity prices.

²⁴ We interpret the definition of the standard to be percent of electricity sales, which allows a small amount of generation to emit CO₂ due to transmission losses (generation minus losses = sales).

Figure 16. EIRP21-NEMS Power Sector and Economy-Wide CO₂ Emissions, I+R vs CFA Scenarios

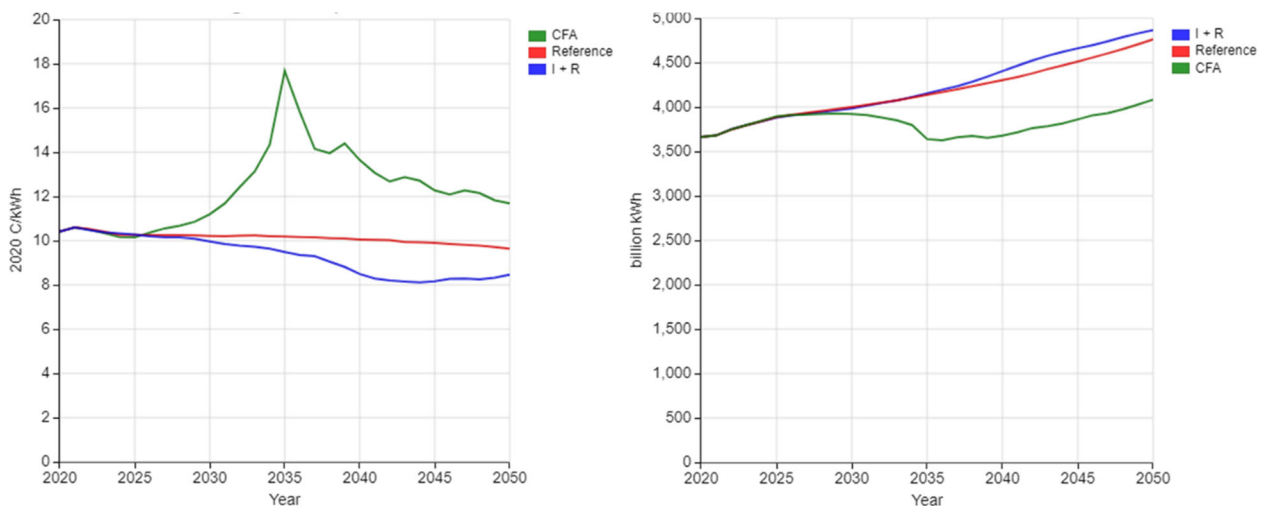


(note the difference in scales between the two figures)

The CFA CES scenario results in significantly higher average retail electricity prices than the I+R scenario and Reference case, as shown in Figure 17. CFA prices reach almost 18 cents per kilowatt-hour (KWh) in 2035 or 73 percent (7.5 cents per KWh) above Reference case prices. CFA prices then decline after 2035 but remain higher than the Reference case through 2050. In contrast, lower advanced technology costs coupled with tax credits and other subsidies in the I+R scenario lead to lower average electricity prices than the CFA scenario and even lower than the Reference case. Prices decline to about 8 cents per KWh or 18 percent below Reference case values by 2040 and remain at this level through 2050.

In response to changes in electricity prices, electricity sales are somewhat higher in the I+R scenario but decline in the CFA scenario, especially in 2035 when electricity prices peak and thereafter. Sales decline in response to higher electricity prices primarily due to behavioral responses (such as adjusting thermostats) as well as a shift to onsite generation such as rooftop solar and industrial combined heat and power.

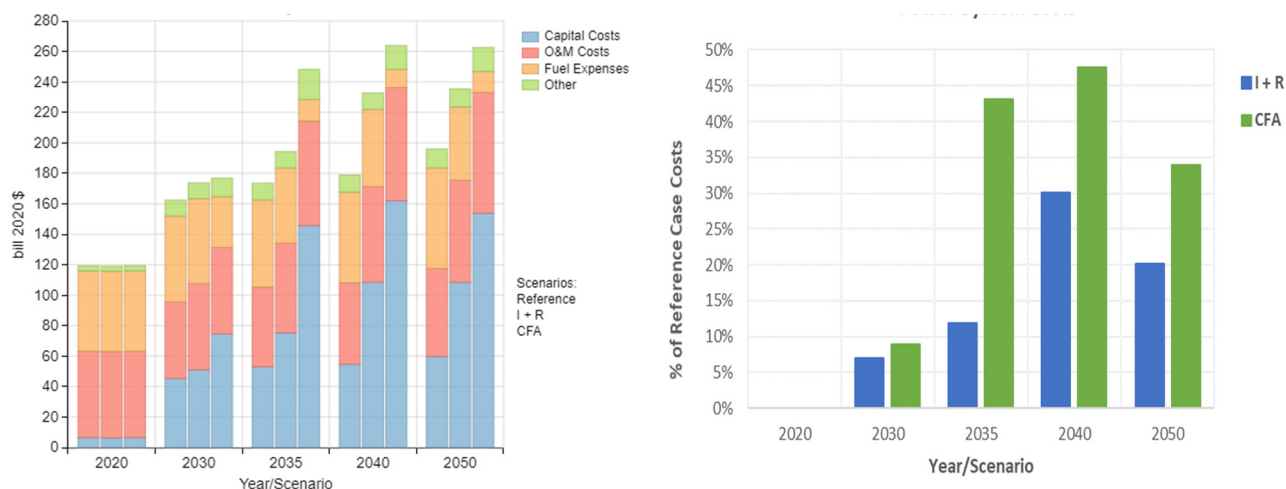
Figure 17. EIRP21-NEMS Electricity Prices and Sales, I+R vs CFA Scenarios



Power system costs²⁵ that represent the costs of power supply (excluding tax credit payments and subsidies) are about 14 percent higher in the CFA scenario than in the I+R scenario by 2040, and almost 50 percent higher than Reference case costs, as shown in Figure 18. Capital investments in the CFA scenario increase significantly in the short run as the industry quickly pivots from a reliance on mostly fossil fuels to zero emitting technologies in a short period of time. After 2035, fuel expenses decline, but capital expenses remain high in order to maintain near 100 percent clean electricity sales.

In contrast to electricity prices, power system costs in the I+R scenario are higher than in the Reference case but much lower than the CFA scenario, \$46/MWh in I+R vs. \$61/MWh in CFA in 2050. Note that the I+R scenario also has higher generation due to higher electricity sales, but the CFA scenario has lower sales resulting in much higher costs per unit of electricity sold.

Figure 18. EIRP21-NEMS Power System Costs and Costs vs. Generation as Percent Change from Reference, I+R vs CFA Scenarios



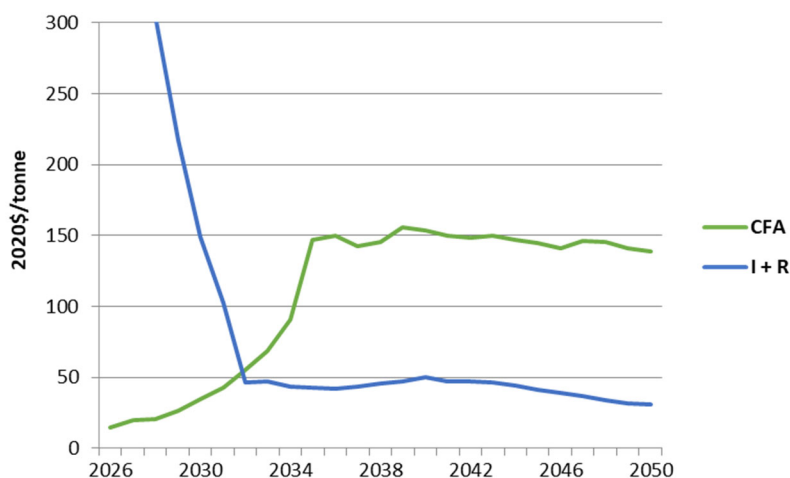
As seen previously, investments in innovation technologies and policies quickly pay off in the I+R scenario, and the mitigation cost per tonne declines sharply as low carbon emitting technologies become less expensive over time. In the CFA scenario, the cost per tonne rises significantly by 2035 with the increasing stringency of the policy, as shown in Figure 19. The average mitigation cost across all years is about \$54 per tonne CO₂ with Innovation + Regulation, compared to \$116 per tonne in the CFA scenario.²⁶ Note that the pre-2030 CO₂ reductions are relatively small in the I+R scenario, so the higher cost per tonne in these years has a relatively small effect.

²⁵ Power system costs include power plant investments, transmission hook-up costs, and inter-regional transmission costs, but do not include the cost of intra-regional transmission costs, annual costs of maintaining the grid, or distribution costs.

²⁶ The average mitigation cost is computed as the undiscounted sum of costs for all years divided by the sum of all emission reductions, in other words, equivalent to a weighted average cost.

Power system costs used to calculate the mitigation costs shown here have been adjusted to account for different levels of electricity sales between scenarios. For more information on the mitigation cost calculation, see Appendix F.

Figure 19. EIRP21-NEMS Mitigation Cost per Tonne CO₂, I+R vs CFA Scenarios



By 2035, the mix of generation in both CES scenarios has shifted to mostly carbon-free sources, although the mix between the scenarios is quite different, as shown in Figure 20. The CFA generation shifts primarily to solar, wind, nuclear, and some battery storage.²⁷ The CFA CES crediting scheme gives few credits to carbon capture technologies, so none were deployed in the CFA scenario.

The I+R scenario has a more diverse mix that includes renewables, nuclear, and battery storage, but also includes Allam Cycle coal and natural gas with 100 percent carbon capture. A small amount of gas generation without capture remains through 2050 in both policy scenarios to maintain grid reliability. No conventional coal generation remains by 2050.

As with generation, the mix of capacity in the CES scenarios shifts to mostly carbon-free sources in order to meet the policy goals. In the CFA scenario, there is greater reliance on renewable generation: 68 percent of generation by 2050 in the CFA case vs 43 percent in the I+R case. Variable renewable generators, especially solar, are not available during all hours of the day and their availability is not always predictable, requiring other technologies to increased generation and spinning reserves to maintain grid reliability. In addition, all of the low carbon technologies in the CFA scenario are more expensive without federal innovation policies than in the I+R case, especially newer technologies such as carbon capture technologies that are more dependent on innovation policies to reduce first costs.²⁸

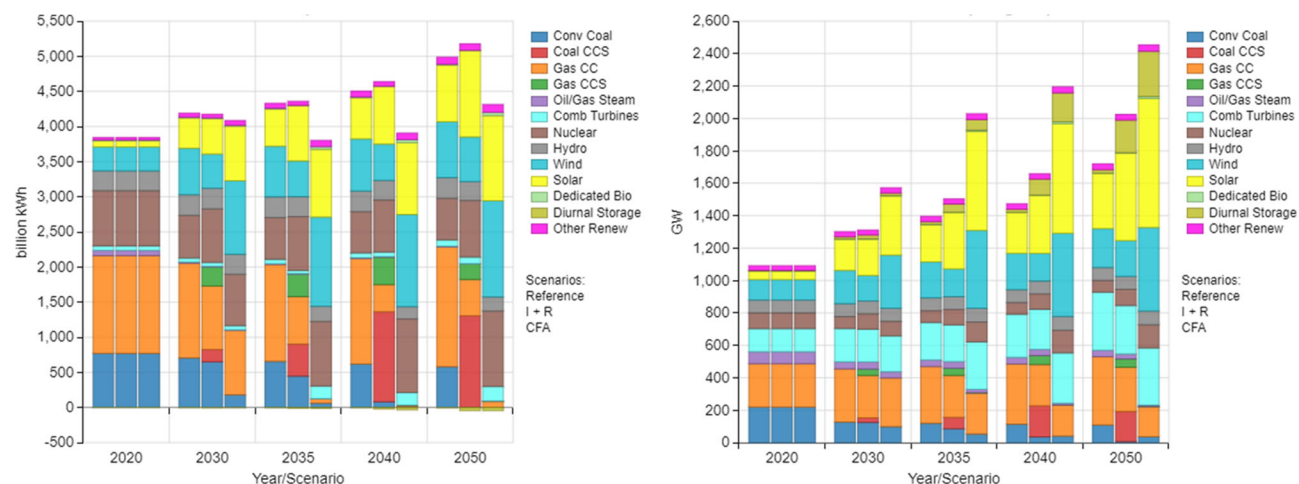
Total generation is lower in the CFA scenario as consumers reduce their electricity use due to higher electricity prices, whereas the total amount of capacity in the policy scenarios, especially in the CFA

²⁷ Note: Diurnal (battery) storage produces net negative generation due to electricity losses.

²⁸ The CFA case includes endogenous learning for power technologies based on “learning-by-doing” whereby capital costs decline with additional deployment based on their relative maturity, as well as from a minimum learning rate. Thus technologies that deploy at a higher rate in the CFA case relative to reference will experience greater cost decreases, although no large reductions due to breakthroughs nor performance improvements beyond those in the reference case are represented.

scenario, is higher than the Reference case due to the lower capacity utilization for variable generation renewables and their low contribution to reserve requirements.

Figure 20. EIRP21-NEMS Electric Generation and Capacity Mix, I+R vs CFA Scenarios



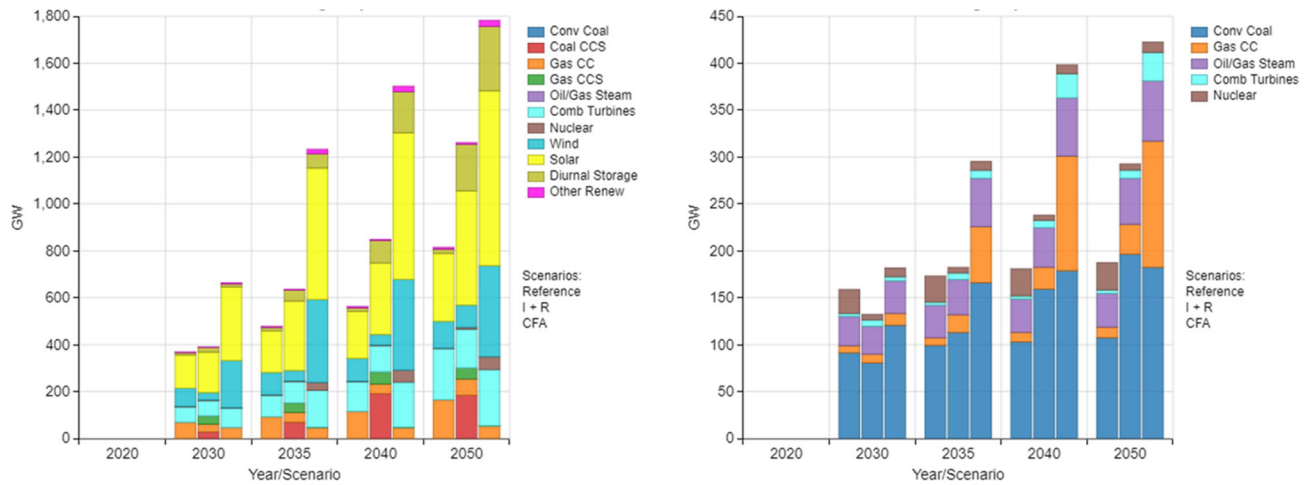
Capacity additions in the policy scenarios are higher than the Reference case, especially in the CFA scenario where total additions in 2050 are more than double Reference case additions, as shown in Figure 21. The need for higher levels of capacity additions is due to increased retirements of technologies that receive no CES credit, as well as a large share of renewable capacity with lower capacity utilization and low contribution to reserve requirements. Additions are dominated by solar, wind, diurnal (battery) storage, coal and gas CCS—only in the I+R scenario—and some new nuclear, but also include a few conventional gas turbines to maintain grid reliability.

Most existing fossil generators retire by 2050, especially coal, in the CES scenarios; 85 to 90 percent of coal capacity is retired by 2050. Gas combined cycle plants fare much better in the I+R scenario due to receiving partial CES credits that are not provided in the CFA CES policy: only 12 percent of existing combined cycle capacity is retired by 2050 vs. 50 percent in the CFA scenario.

Only about 10 percent of existing nuclear plants retire in the policy scenarios due to their improved financial prospects with CES crediting.²⁹ In contrast, the Reference case retires 30 percent of existing nuclear capacity by 2050.

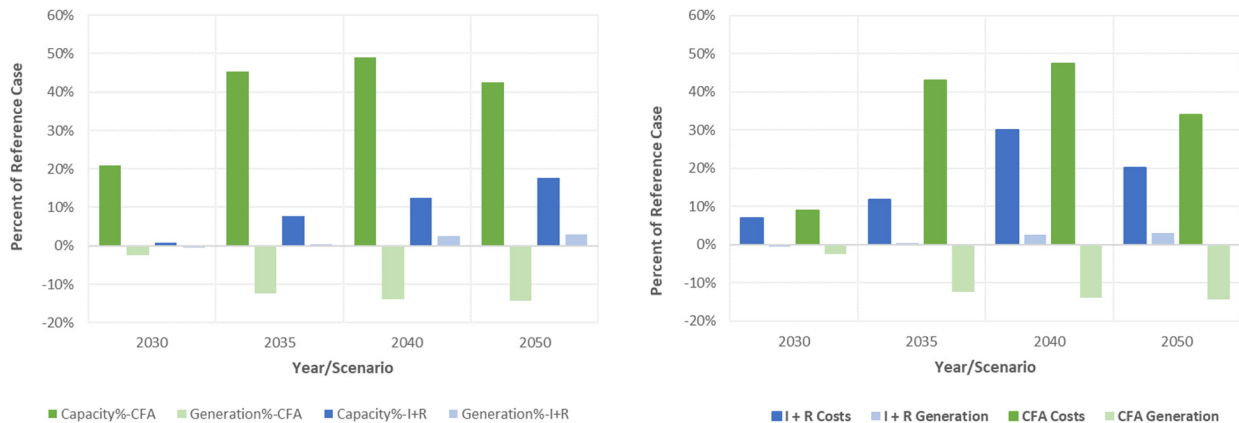
²⁹ Nuclear plants that have not already announced retirement dates are assumed to retire on an economic basis and are not limited to a 40- or 60-year lifetime.

Figure 21. EIRP21-NEMS Electric Capacity Additions and Retirements, I+R vs CFA Scenarios



A side-by-side comparison of electric capacity and generation as a percent change from Reference case values illustrates more clearly how capacity increases significantly in the CFA despite lower generation, as shown in Figure 22 (note that the solid bars in the left-hand chart are capacity change while lighter bars are generation). Greater capacity additions require greater capital investment which contributes to higher power system costs in the CFA scenario as shown in the right-hand chart (solid bars are cost change while lighter bars are generation).

Figure 22. EIRP21-NEMS Capacity and System Costs vs Generation, I+R vs CFA Scenarios

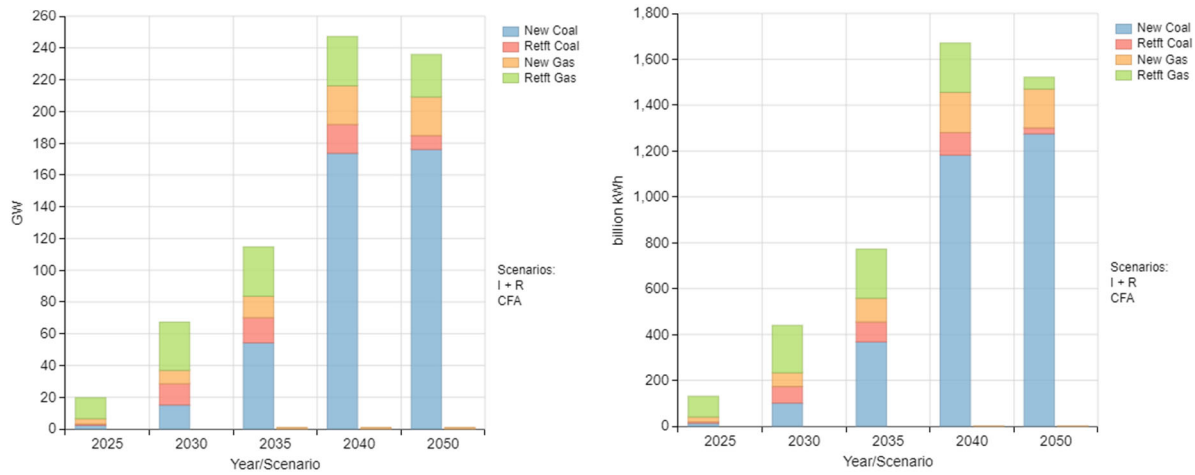


New Allam Cycle coal makes up the majority of CCUS capacity and generation in the I+R scenario, as shown in Figure 23. New Allam Cycle natural gas and a small amount of retrofit coal and gas capacity is also built. No significant CCUS capacity is built in the CFA scenario due to minimal CES crediting for these technologies.

CCUS generation declines slightly after 2040 in the I+R scenario as early entrants complete their 20 years of 45Q tax credits. The I+R expanded 45Q tax credit for new coal CCUS is worth roughly \$50 to \$60/MWh (depending on storage type), while the credit for new gas CCUS and PTC equivalents are only worth \$24 to \$30/MWh. The coal credit is enough to pay the full capture cost for new coal plants as the

costs decline due to innovation policies, allowing this emerging technology to contribute in a significant way toward meeting the I+R CO₂ mitigation goals.

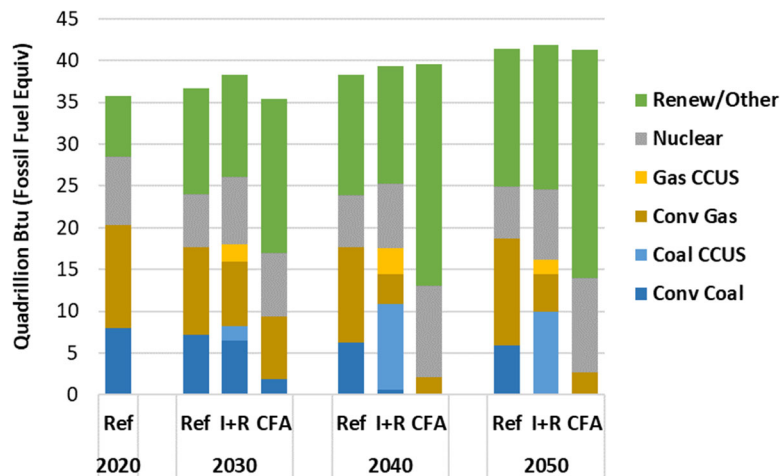
Figure 23. EIRP21-NEMS CCUS Generation and Capacity, I+R vs CFA Scenarios



Coal consumption with carbon capture in the power sector in the I+R scenario more than makes up for the decline in conventional coal by 2030 and beyond, as shown in Figure 24. Total coal consumption is higher in the I+R scenario than both the Reference and CFA scenarios after 2030, and fossil energy consumption (coal + gas) is nearly the same as the Reference case through 2050. This is mainly due to the favorable incentives for carbon capture technologies provided in the I+R framework.

In contrast, the CFA scenario achieves nearly all CO₂ reductions by switching to nuclear and renewable energy due to the CFA policy’s restrictive crediting scheme for fossil fuels.

Figure 24. EIRP21-NEMS Power Sector Energy Consumption, I+R vs, CFA Scenarios³⁰



³⁰ Solar and wind energy consumption are reported on a fossil equivalent basis.

MODELING CHALLENGES AND CAVEATS

As with all modeling studies, care must be taken in the interpretation and use of the EIRP21-NEMS scenario results. The projections shown here are not predictions of what will happen if the I+R or CFA CES policies are adopted, but rather provide insights of what could happen if the scenario assumptions reflect future technology evolution and market conditions. Additional sensitivity cases where key modeling assumptions are altered could help provide more certainty in understanding the role these assumptions play in the modeling outcomes.

All scenario assumptions used in this analysis reflect policies and market conditions that existed at the time of this study. Major world events, such as the continued global pandemic and wars disrupting energy supplies can have a significant impact on future energy prices and other market conditions in the U.S. and are not reflected in this analysis. The analysis and its conclusions primarily focus on the difference in results between scenarios that is likely to be less sensitive to these uncertainties than is the baseline projection.

Following is a discussion of the challenges in modeling the I+R and CFA CES policies as well as caveats related to the capabilities and limitations of the EIRP21-NEMS modeling framework.

Innovation + Regulation Scenarios

In order to model the effects of the proposed I+R innovation policies and incentives, many modeling assumptions were made. This is especially true for policies that are not directly tied to the costs or deployment levels of specific technologies such as research, development, and demonstration (RD&D) funding, and for costs for emerging technologies such as many advanced reactors and carbon capture technologies that are not yet fully commercially available or have had very limited deployment to date. OnLocation, with guidance from EIRP, assumed that these policies would result in substantial improvements in technology costs and performance as reflected in industry predictions and engineering estimates of technological progress for each emerging technology. See Appendix B for more information about these technology assumptions and sources.

CLEAN Future Act CES Scenario

In our modeling abstraction of the CFA CES, we experimented with how close to 100 percent clean electricity can be achieved by 2035. We were able to achieve 80 percent clean by 2030 and about 98 percent clean by 2035. The model's power system did not achieve zero CO₂ emissions for two reasons:

- The CFA CES target as modeled was less than 100 percent clean in order to reach a feasible solution due to limitations in the EIRP21-NEMS modeling framework;
- Even if 100 percent clean were achieved, the definition we used for the standard (i.e., percent of electricity sales) allows a small amount of generation to emit CO₂ due to transmission losses (generation minus losses = sales).

The CFA policy design combines two distinct provisions, a rapidly increasing CES target and a phasing out of partial credits for fossil fuel generators, imposing both provisions in a short 5-year period (2030-2035). Each of these provisions alone creates a challenge for generators and retail suppliers, and the combination of the two causes the policy's goals to be extremely difficult to achieve.

Modeling Challenges and Caveats

The CFA CES crediting scheme provides partial credits to natural gas technologies with carbon capture even after the partial credit phase out in 2035. However, these technologies did not deploy in our analysis because the small amount of credits provided per MWh requires these generators to buy numerous credits from other eligible generators at very high prices in order to continue generating, making these technologies cost prohibitive.

Finally, the CFA CES crediting incorporates CO₂ and methane emissions from upstream fossil fuel production and transportation which disadvantages carbon capture technologies. Without this option, the policy relies heavily on non-firm renewable generation and electricity storage to meet the policy requirements.

EIRP21-NEMS Modeling Approach

The electricity model of EIRP21-NEMS is designed to represent the current and evolving power grid. However, the significant transformation of power technologies and the grid by 2050 is pushing the boundaries of the model's normal solution range, and the model does not fully address the resulting challenges including, among others:

- Variable generation and curtailment impacts on grid reliability are represented as a simplified abstraction and therefore subject to considerable uncertainty in costs and grid performance;
- The operational flexibility of emerging technologies such as the Allam Cycle with carbon capture, advanced nuclear reactors, and other baseload technologies is uncertain;
- Additional technologies may be needed to reach net zero emissions that are not reflected in the current version of the model such as long duration electricity storage technologies or carbon free fuels that can be used in combustion turbines for peaking purposes.

These issues are more pronounced in the CFA CES scenario that relies more heavily on variable renewable generation and requires greater emissions reductions.

APPENDIX A: I+R INNOVATION: TECHNOLOGY POLICY INCENTIVES

OnLocation modeled an approximation of the proposed Innovation Technology Policy Incentives that could be represented directly in the EIRP21-NEMS model. The design of the incentives is based on specifications provided by EIRP. A 2022 enactment date was assumed for these policies.

Policy incentives cover these technologies:

- Carbon capture and storage
- Nuclear power
- Renewable energy and electricity storage
- Energy efficiency (*note, these incentives are not covered in this analysis*)

Following is a description of the policies that we implemented in the EIRP21-NEMS Innovation scenarios.

Carbon Capture Technologies

The FUTURE ACT Tax Credits (45Q):

- Extended the commence-construction eligibility window to be online by end of 2041 (equivalent to a start construction date by 1/1/2036) assuming the current 6-year construction window.³¹
- Extended the credit duration period from the current 12 years to 20 years for eligible plants.
- Increased the credit from \$35 to \$70 per tonne for CO₂ to Enhanced Oil Recovery (EOR) and from \$50 to \$85 for geologic storage.

Gas CCS Bonus Credits:

- Provided natural gas CCS plants with bonus credits (implemented as a Production Tax Credit) that represent an incremental value above the 45Q credits. The combined 45Q and PTC credits is worth roughly \$30/MWh for CO₂ saline storage or \$24 per MWh for CO₂ to EOR, and the credit duration period is 20 years (consistent with the 45Q credit duration).

Support for CO₂ Storage Infrastructure:

- Provided a \$2 billion subsidy per year for 10 years for a total of \$20 billion subsidy to support pipeline infrastructure. The subsidy reduces the cost of the CO₂ pipeline network through 2031.

Support for Deployment of Carbon Capture Facilities:

- The policies provide Federal support for 11 GW of deployment (up to \$10 billion) with at least 5.5 GW on-line and the rest under construction by 2030.

Nuclear Power

Zero Emission Credits for existing nuclear plants:

- Expanded the model's state-level Zero Emission Credit (ZEC) program representation to include all states with nuclear generation starting in 2024 (2 years after enactment). The generation

³¹ Per IRS guidance issued in December 2020. See <https://www.irs.gov/pub/irs-drop/n-20-12.pdf>

subsidy is the amount sufficient to prevent nuclear plants from retiring and was capped at \$13.25/MWh annually, adjusted for inflation. The ZEC program expiration date was extended to 2037 which is 5 years after the compliance date of the CES.

- Prevented some nuclear plants from retiring. The AEO 2021 includes planned nuclear retirements that represent announced retirements of 8.7 GW in the next 5 years. Of these, 3 GW are scheduled to retire starting in 2022, so we assumed that these units would continue to operate under the expanded ZEC policy. The model can choose to retire nuclear plants and other technologies based on whether a plant's projected revenues are sufficient to cover its going forward operating costs.

Expansion and Extension of the Production Tax Credit (PTC) for Nuclear Power:

- Raised the existing nuclear PTC 8-year payments from 1.8 cents/kWh to 2.7 cents/kWh. The maximum nuclear capacity eligible for the credit was also increased from 6 GW to 15 GW.

Renewable Energy and Electricity Storage

Production Tax Credit (PTC) for Solar and On-Shore Wind Projects

- For wind projects, we extended the requirement to begin construction before 1/1/2031, entering service by end of 2034. Additionally, the phase-out of the credit value was also delayed until January 1, 2031, so the credit value remains at the 60 percent level of 1.5 cents/kWh through the commence-construction year of 2030, then phases out over the next 3 years.
- For solar projects, we re-instated the PTC with the same commence-construction year and credit value as the on-shore wind PTC extension described above.

Investment Tax Credit (ITC)

- Extended the ITC for offshore wind projects at the full value of 30 percent for 5 years if construction begins before January 1, 2026, as specified in the FY2021 Omnibus bill extension. The ITC is assumed to drop to 10 percent after the 5-year extension and remain at 10 percent in perpetuity similar to the existing Solar ITC.
- For the ITC applied to electricity storage technologies, we assumed the same commence-construction year and credit values as the offshore wind ITC extension described above.

APPENDIX B: I+R INNOVATION: TECHNOLOGY COSTS AND CHARACTERISTICS

The EIRP21-NEMS model represents technology costs, including overnight capital costs and fixed and variable O&M costs, as well as heat rates for fossil technologies, all of which can change over time. Overnight capital costs for generating technologies generally decline over time due to endogenous learning functions in which increased capacity deployments lead to lower costs. Alternatively, costs as well as heat rates can be user-specified over time to reflect both R&D and expected deployment effects.

Capital costs for all technologies are also adjusted by a cost-adjustment factor used to approximate the declining cost of steel and other construction materials relative to general inflation (i.e., declining in real terms) assumed in the underlying Annual Energy Outlook 2021 that was the starting point for the EIRP21-NEMS Reference case. This factor is applied to each technology's base cost and reduces the capital costs by about 20 percent by 2050. If recent trends of higher material costs relative to general inflation were to persist, investment costs of all power technologies would rise which would have a greater impact on more capital-intensive technologies. Because many low carbon-emitting generation technologies are relatively capital intensive, it is not clear the degree to which their relative competitiveness would be altered.

For this analysis, we built upon the technology research conducted for the 2018 I+R study for the costs of key technologies. All technology assumptions are exogenously specified in each year, including capital costs, O&M costs, and heat rates, thereby reflecting external views of technology advancements instead of using the model's endogenous learning functions.

The technology costs and characteristics are represented in the Innovation scenarios as follows:

- For coal and natural gas with carbon capture (both new and retrofit) and advanced nuclear technologies, we used the technology costs and characteristics provided in the prior analysis with minor adjustments to these costs related to the timing of commercialization years.
- For lithium-Ion battery storage, solar photovoltaics, and wind technologies (both onshore and offshore), we updated the costs to reflect the cost projections published in the National Renewable Energy Lab Annual Technology Baseline 2020³² (NREL ATB 2020).

The following charts illustrate the sources and derivation of our Innovation case technology costs in which the costs from the external sources were adjusted by applying the AEO 2021 construction cost inflation multipliers to the costs provided in the sources in order to be consistent with costs for the rest of the EIRP-NEMS technologies that were not adjusted for innovation, as was done in the prior analysis. In each chart, the initial unadjusted costs are labeled as 'Innovation Base' (in yellow) and the final adjusted costs with the construction cost multipliers are labeled as 'Innovation Total' (in green). The base and total costs are compared with those used in the EIRP Reference case.

³² For more information, visit <https://atb.nrel.gov/>

New Coal Generation with Carbon Capture

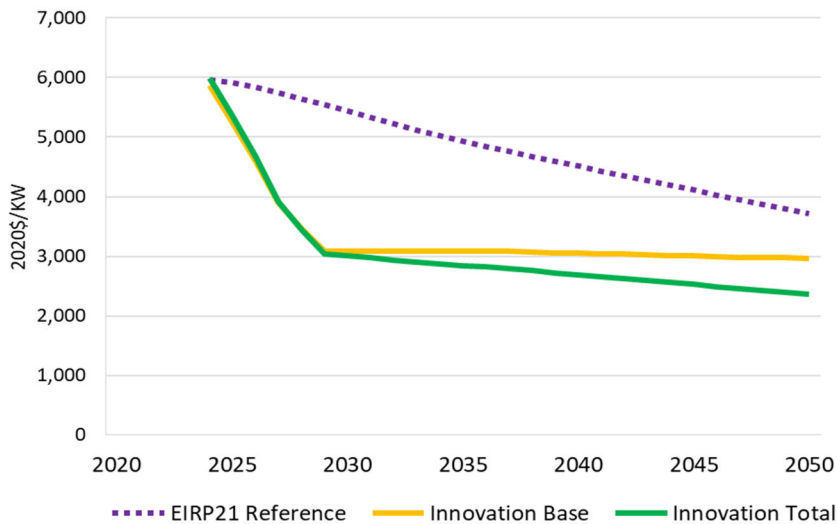
A NET Power style coal gasification technology with 100 percent CO₂ capture is assumed for the new coal with carbon capture technology. Allam Cycle technology uses captured supercritical CO₂ to drive a combustion turbine, then CO₂ is sent to storage.

Key assumptions include overnight capital cost, fixed and variable O&M costs, heat rate, carbon capture rate, and commercial availability year. The Innovation scenarios assume an initial cost similar to the AEO 2021 initial cost in 2025 that declines to about \$4,000 by 2027, with further declines to the Nth cost (or mature cost) by 2029. Base costs are assumed to remain constant after 2030. Figure 25 illustrates the resulting costs.

First year of commercial availability	2025
Overnight capital cost (\$ / KW)	2,896
Fixed O&M cost (\$/kW/yr)	147.9
Variable O&M cost (\$/MWh)	1.8
Heat rate for fossil technologies (Btu/KWh)	7,506

Source: EIRP

Figure 25. EIRP21-NEMS Innovation Capital Cost, New Coal with Carbon Capture



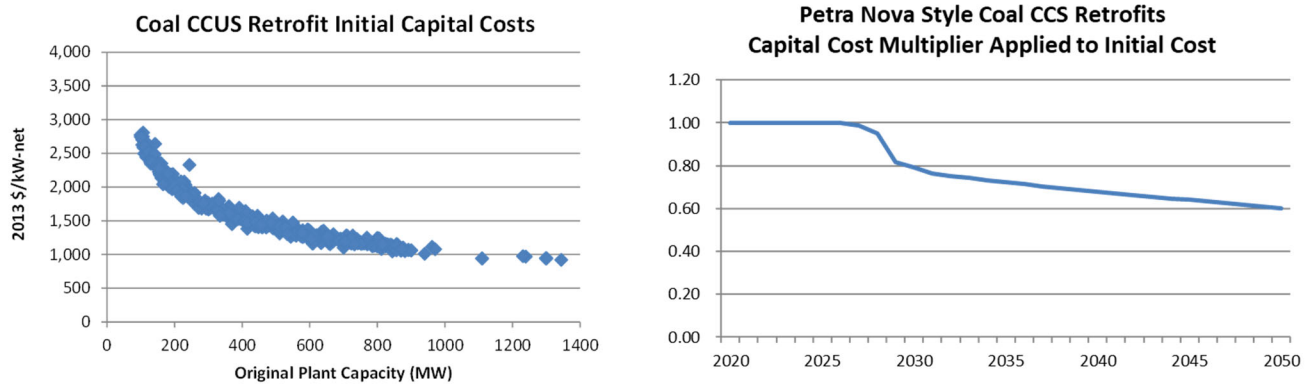
Petra Nova Style Coal Retrofit Technology with Carbon Capture

The model was modified to represent a carbon capture retrofit technology for coal plants that relies on an auxiliary natural gas boiler to provide steam for the capture unit rather than using steam from the coal boiler. This reduces the capacity de-rating but introduces an additional gas boiler and associated fuel cost.

Appendix B

Initial cost and efficiency assumptions were provided by the Clean Air Task Force (CATF) and applied to the model’s existing coal plants. A multiplier is applied to the initial costs to represent a cost decline over time that results in a 40 percent reduction in costs by 2050. See Figure 26 for a plot of the initial capital costs for each existing plant and the cost multiplier applied to these initial costs over time.

Figure 26. EIRP21-NEMS Initial Capital Cost and Multiplier, Coal Retrofit with Carbon Capture



New Natural Gas Generation with Carbon Capture

Technology characteristics for natural gas with carbon capture are based on a NET Power style technology with 100 percent CO₂ capture. Allam Cycle technology uses captured supercritical CO₂ to drive a combustion turbine, then CO₂ is sent to storage. Also, Allam Cycle technology uses oxygen (for combustion) mixed with a large amount of CO₂ (for mass to drive the turbine), making separation and capture of CO₂ much simpler than traditional turbines using air for these purposes.

Key assumptions including overnight capital cost, fixed and variable O&M costs, heat rates, carbon capture rate, and commercial availability year were provided by EIRP and are shown in the table below. The first-of-a-kind (FOAK) capital cost is assumed to be reduced by Federal deployment support down to the 5th-of-a-kind cost (SN5); further advances then bring down the cost to the Nth or mature cost (SN30). Overnight capital costs are assumed to drop from the first-of-a-kind (FOAK) to the “prior to Nth” and then to the Nth of a kind by 2030. The commercial availability year was pushed out two years to 2023 to be consistent with the construction lead time and updated technology start years for the AEO 2021 technology. Figure 27 illustrates the reference case capital costs as well as the base cost reflected in the table and the adjustment made for the construction index. Base costs are assumed to remain constant after 2030.

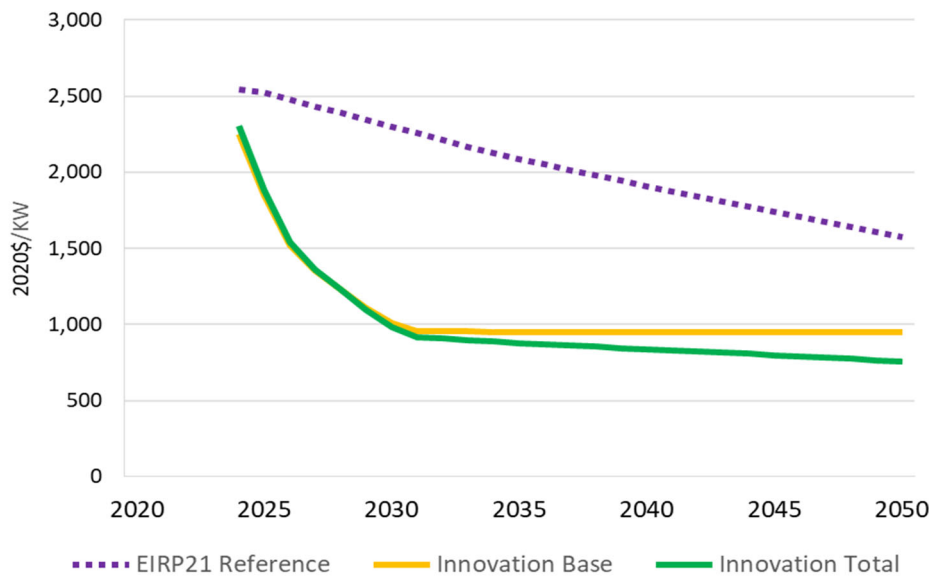
Appendix B

Original assumptions prior to two-year shift in time:

Vintage	SN1	SN5	SN30
First year of commercial availability	2021	2023	2025-2030
Overnight capital cost (\$/KW)	2,128	1,415	884
Fixed O&M cost (\$/kW/yr)	28.4	28.4	28.4
Variable O&M cost (\$/MWh)	1.32	1.32	1.32
Heat rate for fossil technologies (Btu/KWh)	6874	6313	6313

Source: EIRP

Figure 27. EIRP21-NEMS Innovation Capital Cost, Natural Gas with Carbon Capture



Advanced Nuclear Generation

Technology characteristics for the Advanced Nuclear technology were based on CATF/EON estimates for Advanced Non-Light Water Nuclear Fission Power (non-LWR) with a modular and standardized plant design. The first-of-a-kind FOAK plant is assumed to be available in 2026, and the Nth-of-a-kind (NOAK) plant is available by 2030. These costs are shown in the table below expressed in 2018\$.

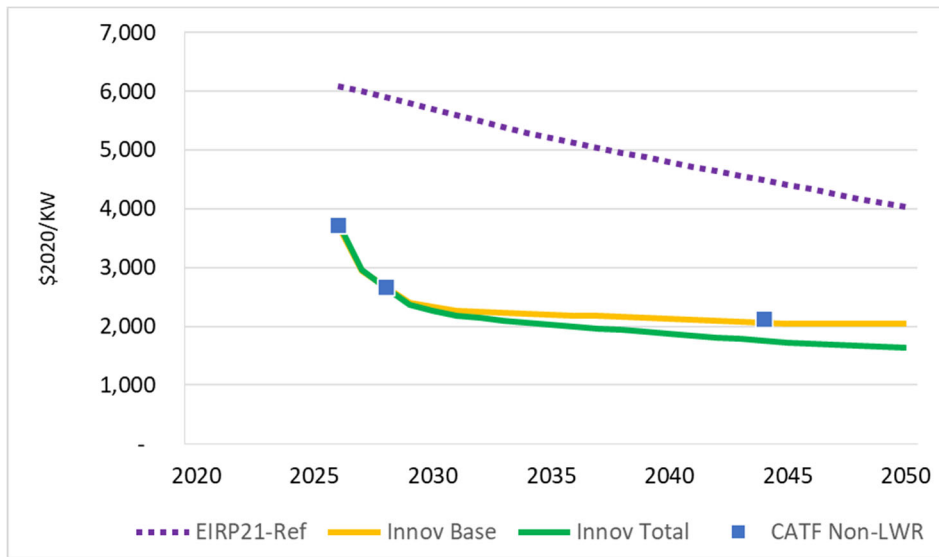
Key assumptions include

overnight capital cost, O&M costs, and commercial availability year. The base capital cost is assumed to be about \$3,700 (in 2020\$) in 2026, and the cost declines to about \$2,300 (2020\$) by 2030 as shown in Figure 28. This cost is then adjusted for the construction index for the total cost.

	Today or First Plant	Prior to Nth Plant	Nth Plant or modular systems capability	Climate Scale
Overnight capital cost (\$/KW)	\$3,500	\$2,500	\$2,000	\$1,500 - \$2,000
Variable O&M cost (\$/MWh)	\$18	\$15	\$15	\$10-12

Source: EIRP

Figure 28. EIRP21-NEMS Innovation Capital Cost, Advanced Nuclear

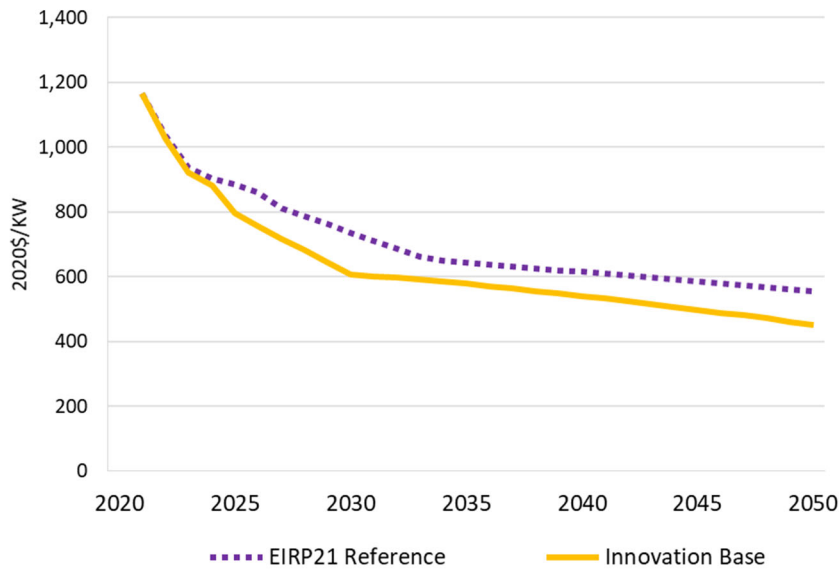


Grid-Scale Battery Storage

A large-scale (100 MW) diurnal lithium-ion battery storage technology with a duration of four hours is assumed to provide both energy services (e.g., energy arbitrage and load following) and capacity services (e.g., planning reserves) to the grid.

Key assumptions include overnight capital cost, fixed and variable O&M costs, system size, number of hours available for discharge/recharge (duration), efficiency, lifetime of battery, and commercial availability. We used the NREL ATB 2020 Advanced cost scenario the capital cost. The cost is exogenously specified over time without the construction index represented (“Innovation Base”) as illustrated in Figure 29.

Figure 29. EIRP21-NEMS Innovation Capital Cost, Grid-Scale 4-Hour Battery Storage

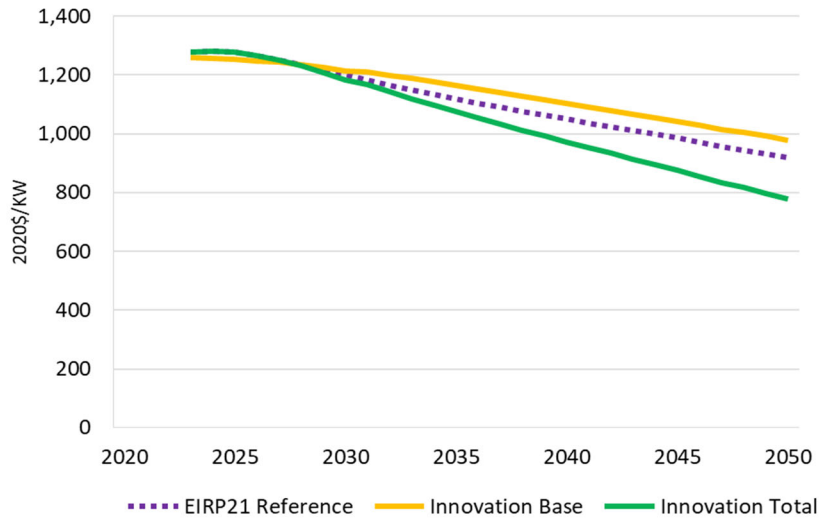


Onshore Wind

Onshore wind is a mature technology relative to other clean technologies. Future cost reductions will be driven primarily by the increasing height of the turbine and other design improvements. The technology’s variable generation profile can introduce challenges related to grid stability which the model addresses by building additional backup capacity (natural gas or battery storage).

Key assumptions include overnight capital cost, fixed O&M costs, diurnal and seasonal generation profile, and the location of the best wind resources. Capital costs are assumed to begin at the AEO 2021 cost and transition to the NREL ATB20 Moderate costs by 2030. With the construction cost multiplier applied, the final costs fall below that of the AEO 2021. Capital costs vary by wind class with best wind class shown in Figure 30.

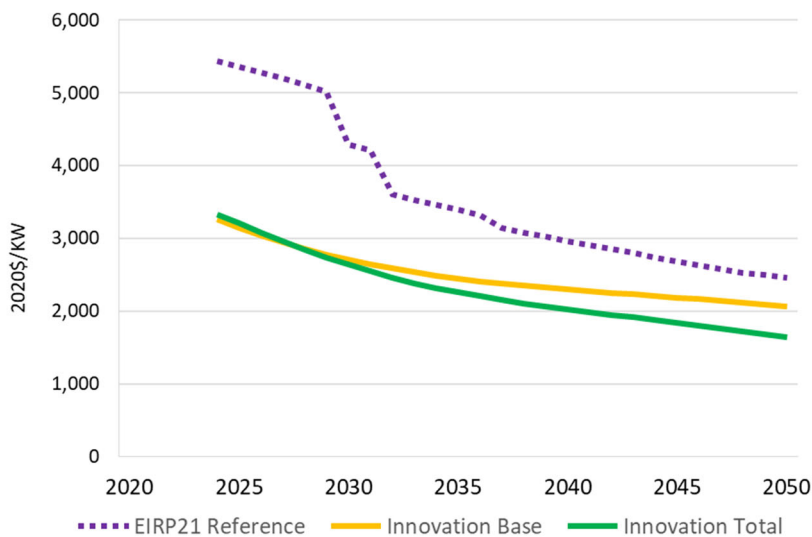
Figure 30. EIRP21-NEMS Innovation Capital Cost, Onshore Wind



Offshore Wind

Industry views on offshore wind costs differ significantly between the AEO 2021 and the NREL ATB 2020, especially in the near term. Costs start much higher in the AEO 2021 but decline more rapidly than the ATB costs though remain higher through 2050. We have assumed the NREL ATB moderate case assumptions for the Innovation scenarios as shown in Figure 31.

Figure 31. EIRP21-NEMS Innovation Capital Cost, Offshore Wind

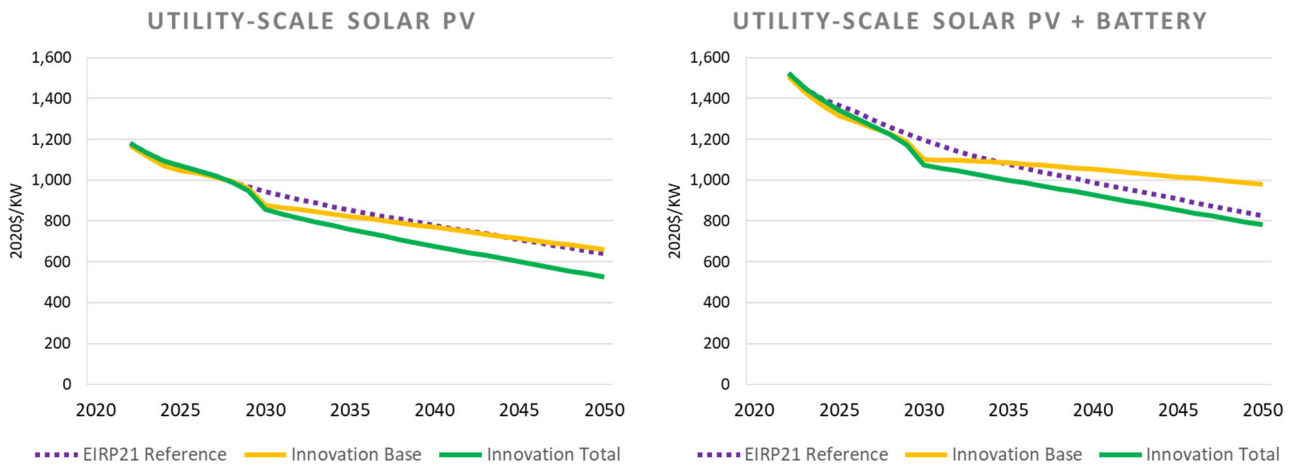


Utility-Scale Solar Photovoltaic

The cost of utility-scale solar PV has declined significantly in the AEO 2021 compared to previous Annual Energy Outlooks and is now below the costs of the NREL ATB20 Moderate cost scenario. Therefore, we used the AEO 2021 costs through 2028 and then transitioned to the NREL Advanced cost scenario, as shown in Figure 32.

The hybrid PV technology (PV + battery) costs were also adjusted to be consistent with reductions for solar PV and for batteries. Rooftop solar PV costs were also adjusted to reflect the NREL ATB20 assumptions.

Figure 32. EIRP21-NEMS Innovation Capital Cost, Utility-Scale Solar PV and Hybrid PV+Battery



APPENDIX C: I+R REGULATION: CLEAN ELECTRICITY STANDARD

For the I+R scenario we implemented a federal Clean Electricity Standard (CES) designed to achieve 80 percent CO₂ emissions reduction from 2022 levels (the proposed enactment year) by 2050 in the power sector, as described in the EIRP specifications. The first CES compliance period for the I+R scenario is 10 years after enactment (2032 for the purposes of this modeling). Note, we did not implement the policy's cost-effective market mechanism that includes a trigger date for the CES regulation to begin up to, but no later than, 10 years after enactment if specified technology deployment goals are met.

Technology-specific CES credit factors represent the effective CO₂ percent reduction achievable relative to an emissions intensity benchmark of 0.82 metric tons CO₂ equivalent per MWh (equivalent to the emissions intensity of a coal plant with no carbon capture). Based on this benchmark, carbon free technologies (e.g., renewables and nuclear) receive a full CES credit per MWh, and fossil technologies including conventional natural gas and carbon capture technologies are eligible for partial credits if their average emissions intensity (based on the year of enactment) is below the benchmark. Generation from both existing and new generation technologies may be eligible for credits.

The credits per MWh for each fossil technology are based on an estimated heat rate in the policy start year (2032) and remains fixed for all years. Eligible credits for each technology are calculated as 1 minus the ratio of the average carbon intensity of the technology and the benchmark. The following table provides an example of this calculation for an advanced natural gas generator without carbon capture and the resulting credits per MWh

NGCC (No Capture)	CO ₂ e Intensity per MWh	Benchmark Intensity	Intensity Ratio to Benchmark	CES Credits per MWh
I+R CES (all years)	0.338	0.82	.338 / .82 = .41	1 - .41 = .59

The CES credits for each technology used in the I+R scenario are shown in Figure 33.

Figure 33. EIRP21-NEMS CES Credits By Technology, I+R Scenario

Innovation Technologies	CES Credits per MWh*	Notes
Emissions Benchmark (CO₂/MWh)**	0.82	
Nuclear and Renewables	Full Credit	
Fossil Fuels with CO₂ Capture:		
New Coal with CO ₂ Capture	Full Credit	Allam Cycle
Retrofit Coal with CO ₂ Capture	75%	Petra Nova-like
New Natural Gas with CO ₂ Capture	Full Credit	Allam Cycle
Retrofit Natural Gas with CO ₂ Capture	94%	
Conventional Fossil Fuels:		
Advanced Natural Gas Combined Cycle	59%	
Existing Natural Gas Combined Cycle	51%	
Advanced Gas Turbine	36%	
Natural Gas Steam/Existing Turbines	23%	
Conventional Coal	No Credit	

* Credit values are based on average heat rates assumed in CES start year 2032.

** Benchmark factors are expressed as metric tons CO₂ equivalent per MWh of generation.

We assumed that generators must meet the standard in each year of the compliance period (i.e., no banking of credits), and CES credits are tradable among generators nationwide. The regulation allows generators the option of purchase credits by paying an Alternative Compliance Payment (ACP) of \$30 per MWh, rising 5 percent annually plus inflation. The ACP effectively caps the price of credits and therefore can reduce the cost of the policy if compliance costs for all generators are higher than anticipated.

APPENDIX D: CLEAN FUTURE ACT CLEAN ELECTRICITY STANDARD

To reduce emissions in the power sector, the CLEAN Future Act establishes a nationwide Clean Electricity Standard (CES) policy that starts in 2023 and requires all retail electricity suppliers to reach 80 percent clean electricity by 2030 and 100 percent clean by 2035. “Clean electricity” is defined as electricity that is produced with net-zero greenhouse gas emissions.

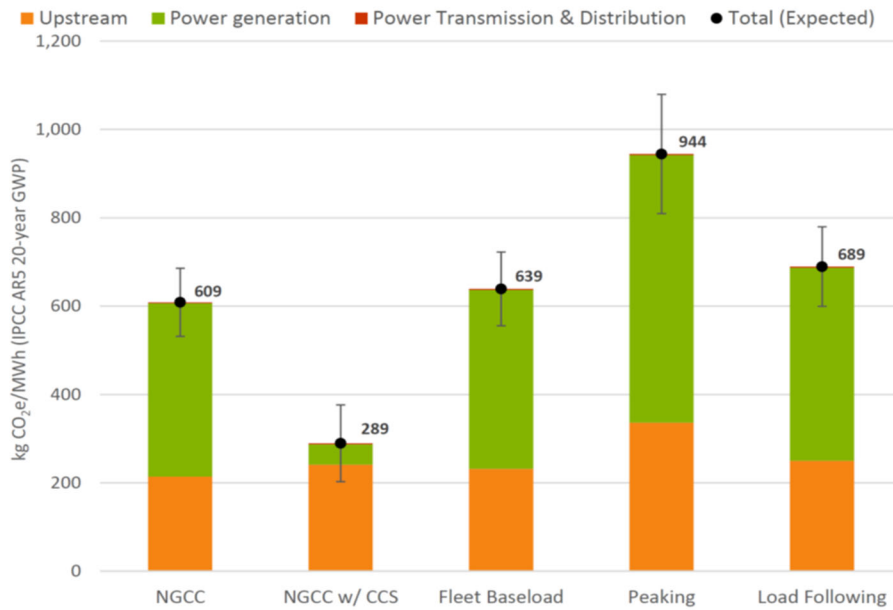
CFA CES credits are awarded to electricity generators based on the amount of net-zero emitting generation (MWh) produced each year. Full credits are provided to renewable and nuclear generators while partial credits are provided to generators using fossil fuels to the extent that their emissions are below the carbon intensity benchmarks outlined in the CFA. CES credits are tradable between suppliers.

A key component of the CFA CES is that the policy phases out the ability of fossil fuel power plants to earn partial CES credits by lowering the carbon intensity benchmark between 2030 and 2035 linearly from 0.82 metric tons CO₂ equivalent per MWh (equivalent to the direct emissions of a coal plant with no carbon capture) to 0.40 metric tons per MWh (equivalent to direct emissions from a natural gas combined cycle plant). Before 2030, conventional gas technologies are eligible for partial credits, but after 2035, the only fossil technology eligible for credits is natural gas with carbon capture.

Unlike most CES policies, the CFA CES carbon intensity values for fossil fuel generators are based on estimated greenhouse gas emissions which include the direct carbon dioxide emissions of the generating unit *plus* the carbon dioxide and methane emissions that occur upstream during extraction, flaring, processing, transmission, and transportation of the fuel. These intensity values are calculated using a 20-year CO₂-equivalent global warming potential (GWP) as specified in the CFA bill, which means that methane emissions have 87 times the GWP value of carbon dioxide. The following figures compare these upstream emissions across technologies and provide the basis for the credit values used in the CFA CES scenario.

- Figure 34 compares total greenhouse gas emissions across natural gas technologies and indicates the carbon intensity benchmarks for 2030 (0.82) and 2035 (0.40). The figure, which is taken from a 2019 report published by the Department of Energy’s National Energy Technology Lab (NETL), clearly illustrates why the only technology that is eligible for credits after 2035 is the natural gas combined cycle (NGCC) with CCS. Upstream emissions represent roughly one-third of total GHG emissions from gas technologies without carbon capture as defined here, and about 80 percent of emissions from NGCC with carbon capture.

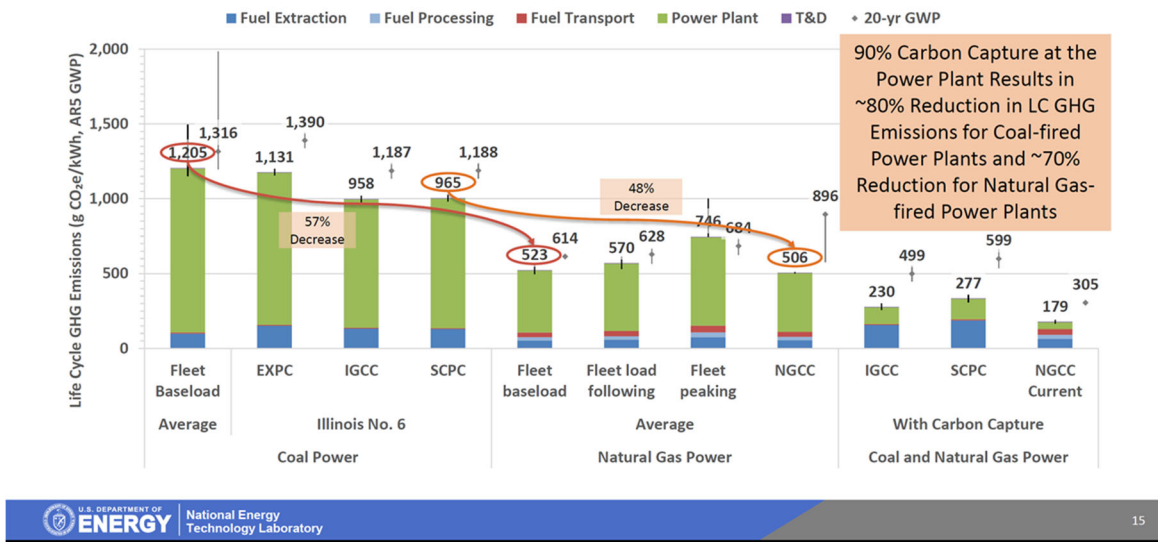
Figure 34. DOE/NETL GHG Emissions, Gas Technologies, 20-year GWP



Source: Littlefield, James, et. al., "Life Cycle Analysis of Natural Gas Extraction and Power Generation," DOE/NETL-2019/2039, April 19, 2019.

- Figure 35 compares total GHG emissions across coal and natural gas technologies and is taken from a NETL presentation from 2015. Emissions from a new (IGCC) coal with carbon capture plant are a bit lower than for a retrofit (SCPC) coal with CCS, but higher than for NGCC with CCS. Upstream emissions represent a large percentage of total GHG emissions for the CCS technologies due to the additional energy needed to capture and compress CO₂ for storage.

Figure 35. DOE/NETL GHG Emissions, Fossil Technologies, 20-year GWP



Source: Skone, Timothy, "Life Cycle Greenhouse Gas Emissions: Natural Gas and Power Production," presented at the 2015 EIA Energy Conference, Washington, D.C., June 15, 2015.

Eligible credits for each technology are calculated as 1 minus the ratio of the average carbon intensity of the technology and the benchmark. The following table provides an example of the difference between the two crediting schemes in their treatment of an advanced natural gas generator without carbon capture and the resulting credits per MWh. The resulting credits in 2030 are much lower in the CFA CES due to both the direct plus upstream greenhouse gas emissions method of determining the emissions intensity, and this technology is no longer eligible for credits by 2035 due to the lower benchmark.

NGCC (No Capture)	CO ₂ e Intensity per MWh	Benchmark Intensity	Intensity Ratio to Benchmark	CES Credits per MWh
I+R CES (all years)	0.338	0.82	.338 / .82 = .41	1 - .41 = .59
CFA CES (2030)	0.609	0.82	.609 / .82 = .74	1 - .74 = .26
CFA CES (2035)	0.609	0.40	.609 > .40	No Credit

Figure 36 compares the eligible credits for NGCC and other technologies between the I+R CES policy and the CFA CES in each time period.

Figure 36. EIRP21-NEMS CES Credits By Technology, I+R Scenario vs CFA CES

Generation Technologies	I+R CES Credits	CFA CES Credits	
	2032 - 2050	2023 - 2030	2035 - 2050
Emissions Benchmark (CO₂/MWh)*	0.82	0.82	0.40
Nuclear and Renewables	Full Credit	Full Credit	Full Credit
Fossil Fuels with CO₂ Capture:	100% Capture	90% Capture	90% Capture
New Coal with CO ₂ Capture	Full Credit	0.39	No Credit
Retrofit Coal with CO ₂ Capture	0.75	0.27	No Credit
New Natural Gas with CO ₂ Capture	Full Credit	0.65	0.28
Retrofit Natural Gas with CO ₂ Capture	0.94	0.57	0.11
Conventional Fossil Fuels:			
Advanced Natural Gas Combined Cycle	0.59	0.26	No Credit
Existing Natural Gas Combined Cycle	0.51	0.16	No Credit
Natural Gas Steam/Turbines (peaking)	0.23	No Credit	No Credit
Conventional Coal	No Credit	No Credit	No Credit

* Benchmark factors are expressed as metric tons CO₂ equivalent per MWh of generation.

Other provisions of the CFA CES that were not modeled include limited alternative compliance payment and credit banking options, crediting of behind-the-meter clean energy sources, emissions standards at new waste-to-energy facilities, and funding for clean energy microgrids, among others.

APPENDIX E: INFRASTRUCTURE INVESTMENT AND JOBS ACT SCENARIO

A Revised Reference case was modeled with EIRP21-NEMS Reference case technology and policy assumptions combined with select provisions from the Infrastructure Investment and Jobs Act (IIJA) related to the power sector only.

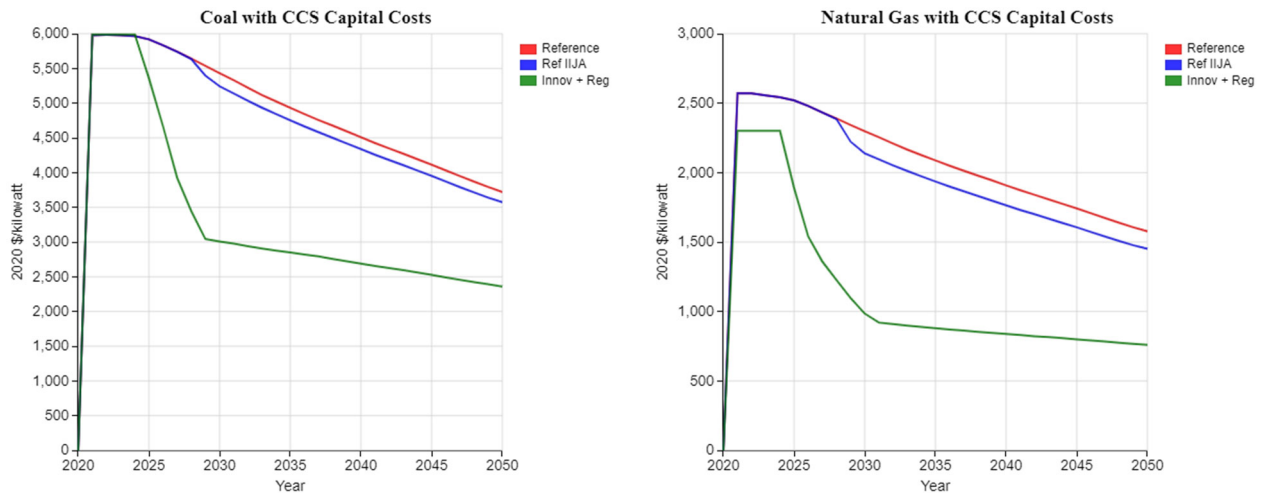
IIJA provisions that were modeled focused on funding for carbon capture, transport, and storage infrastructure and for a national nuclear crediting program for existing at-risk nuclear facilities located in competitive electricity regions.

IIJA Carbon Capture, Transport and Storage provisions modeled include three components:

- Carbon capture demonstration and pilot projects: We modeled a representation of cost-sharing for carbon capture demonstration and pilot projects, based on the allocation of \$3.5B in FY 2022-2025 (assuming 50/50 cost sharing). Funding was used to model planned new construction of 810 MW of new coal-fired carbon capture power plant capacity and 810 MW of new gas-fired carbon capture capacity by 2028. The capacity was assumed to be built in five states: Texas, Florida, Ohio, Wyoming, and California.
- Carbon transport infrastructure: We incorporated the provisions for the federal credit instruments and grants mechanism to design and build new carbon transport infrastructure. This provision allocates \$2.1B+ towards building out this infrastructure and allows for delayed loan repayments 5 years after the date of substantial completion of the project. Funding and delayed loan repayments were used to reduce the cost of building new CO₂ pipelines.
- Carbon storage infrastructure: We also incorporated the provisions for grants for feasibility studies, permitting and construction of carbon sequestration storage sites and associated Class VI wells. This provision allocates \$2.5B+ of spending over the years 2022-2026 for this purpose. Funding was used to reduce the cost of building new carbon storage sites.

As noted in Appendix B, capital costs for generating technologies in the original and IIJA Reference cases decline over time due to endogenous learning functions whereas costs in the I+R scenario are exogenously specified based on a literature review. Due to this endogenous learning effect, the IIJA funding for deployment of 1.6 GW of CCUS demonstration and pilot plants results in lower capital costs over time for both coal and natural gas CCUS technologies. However, costs remain higher than the assumed Innovation costs in all years as shown in Figure 37.

Figure 37. EIRP21-NEMS Carbon Capture Technology Costs, I+R Scenario vs Ref IIJA



(note the difference in scales between the two figures)

The IIJA authorizes DOE to establish a Nuclear Credit Program that targets nuclear facilities that operate in competitive electricity markets and are at risk of plant closure due to economic factors. Facilities receiving state subsidies such as zero emission credits (ZECs) are eligible to apply for the Federal credits under this program. Credits are allocated to eligible facilities based on their projected annual operating loss. The Act authorizes \$6B for the period of fiscal years FY22-26.

This provision was modeled by providing funds in each year of the funding period to nuclear plants that are projected to retire in the original Reference case, operate in a competitive region, and are projected to have net negative revenues. About 16 GW of nuclear plants in 10 states were assumed eligible for credits. As in the I+R Zero Emission Credit Program, the 3 GW of planned nuclear retirements scheduled to retire in 2022 in the AEO 2021 were allowed to continue operating in the IIJA Reference case due to the credit program. Economic retirements for nuclear plants and other technologies are allowed in all scenarios.

IIJA power sector provisions that were not modeled primarily focused on technologies that are not represented in EIRP21-NEMS (such as Direct Air Capture), or targeted geographic areas that cannot adequately be represented due to the model's defined regionality (such as clean energy projects on reclaimed mine land).

APPENDIX F: MITIGATION COST METHODOLOGY

Mitigation or compliance costs for regulation scenarios can be measured in a variety of different ways. For our analysis, we computed mitigation costs per metric tonne CO₂ as the difference in costs between the CES scenario and the reference case as performed in EIRP21-NEMS. The annual compliance cost is primarily a function of the change in power system costs divided by the economy-wide CO₂ reduction in each year. Cost components include:

- Power system costs including generation and transmission capital investments, non-fuel operating and maintenance costs, and generation fuel costs.
 - Capital investments reflect the full technology costs not including the effect of tax credits and are expressed as annuities of the investments (i.e., financed over their economic lifetime of the investment). In other words, investments include expenditures by the private sector plus the value of investment tax credits and subsidies.
 - Non-fuel operating costs reflect variable and fixed power generator expenditures plus any annual payments from the Federal government through tax credits or subsidies, net of any revenues for sales of CO₂ for EOR production.
 - Transmission investments include hook-up costs for new power plants and inter-regional transmission costs, but do not include the cost of intra-regional transmission costs, annual costs of maintaining the grid, or distribution costs.
- Federal R&D expenditures called for by the I+R policy are also added to the power system costs to derive total costs.
- Costs have been adjusted to reflect the change in estimated consumer willingness-to-pay (WTP) due to changes in electricity sales between cases. The change in WTP is estimated as the product of the change in electricity sales and the average electricity price between the reference and policy case.³³
- The mitigation cost analysis is based on the policy provisions modeled in each scenario and does not include the costs or emission reductions associated with provisions outside of the power industry such as end-use energy efficiency and electrification..

³³ See Mignone, et al, *Cost-effectiveness and Economic Incidence of a Clean Energy Standard, Economics of Energy & Environmental Policy, Vol. 1, No. 3. 2012.*