Clear Path to a Clean Energy Future 2022

CLEARPATH

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Executive Summary

In 2022, America reaffirmed its global climate leadership with more aggressive public and private sector action, ranging from the wave of bipartisan landmark federal funding for clean energy research, development, and deployment to more ambitious state, local and utility sector decarbonization commitments. Increased ambition and targeted investments are projected to substantially drive down power sector emissions by the end of this decade and avoid the emissions cul-de-sac observed in our previous report.[1] The emissions reductions demonstrate how significant this break-point in U.S. energy policy is — but a significant gap in carbon emissions remains, necessitating sustained policy support and increasingly ambitious commitments.

This second edition of “Clear Path to a Clean Energy Future” updates the inaugural edition, tracking the power sector, clean technology, and policy trends in America. In our previous report, we identified that utility commitments contribute to significant additional reductions in emissions beyond what was projected in our reference case. Still, underinvestments in new technologies and retirement of the existing nuclear fleet could result in a rebound in emissions out to 2050.[2] The authors again engaged Rhodium Group, a leading research firm that analyzes energy policy and climate risk, to model ClearPath-designed scenarios that incorporate landmark new federal legislation and ambitious utility commitments. Rhodium Group modifies and maintains a version of the National Energy Modeling System (NEMS) created by the Energy Information Administration (EIA), known as RHG-NEMS, to conduct this modeling analysis. This analysis led to three key findings:

1. **Power sector carbon emissions are projected to plummet in the nearterm, but no scenario is on track for net-zero emissions by 2050.** New and updated utility commitments significantly reduce carbon emissions; however, additional policy support will be paramount to sustain decarbonization. Emissions are projected to flatline and backslide after 2030 due to 2022 reconciliation tax incentives phasing out. Additional policy support will be necessary to reach net-zero emissions by mid-century.
2. Retaining the existing nuclear fleet is essential to preventing flatlining and subsequent backsliding on emission reductions after 2030. Recent tax incentives drive unprecedented modeled solar and wind investments, which are projected to achieve immense carbon reductions. However, **our findings revealed that renewables alone have a limited ability to decarbonize the power sector completely, and other recent reports show that this level of deployment is unlikely under current conditions.**[3] Policy support for clean, dispatchable resources – such as nuclear or natural gas with carbon capture and storage – that are affordable and cost-competitive will be critical to fully decarbonize the power sector.
3. **Technology-inclusive decarbonization promotes affordability: all scenarios we assessed achieved much lower electricity prices than in the recent past.** Price declines in natural gas and clean energy technologies will likely drive down national average retail electricity prices for all consumers significantly by 2030. Diversification of the resource mix insulates consumers from price volatility.

Main Takeaways

Utility Commitments Have a Significant Impact on Carbon Reductions With or Without Federal Policy

Nationwide, 83% of customers are serviced by utilities pursuing a carbon-reduction target, while 75% are serviced by utilities pursuing a 100% carbon-reduction target.[4] These commitments are a major driver of power sector decarbonization, as illustrated in Figure 1. Our Utility Commitments scenario, which does not include the 2022 reconciliation law, is projected to reduce emissions 71% below 2005 levels by 2050. This scenario achieves an additional 10% reduction below 2005 levels compared to our Reference case. Cumulatively, this represents more than half a gigaton of additional carbon dioxide (CO_2) reduced between 2025 and 2050. This second edition of the report reflects updated federal and state policies[5] – such as the New Source Review Rules and Connecticut's 100% clean energy by 2040 target – utility commitments, and cost assumptions for fuel and technologies. This progress has led to an additional 15% reduction, using a 2005 baseline, compared to the Utility Commitments scenario from our inaugural report. This represents nearly 2 gigatons of CO_2 between 2025 and 2050, cumulatively, that is projected to no longer be emitted. That's the equivalent of all power sector emissions in 2015.[6]

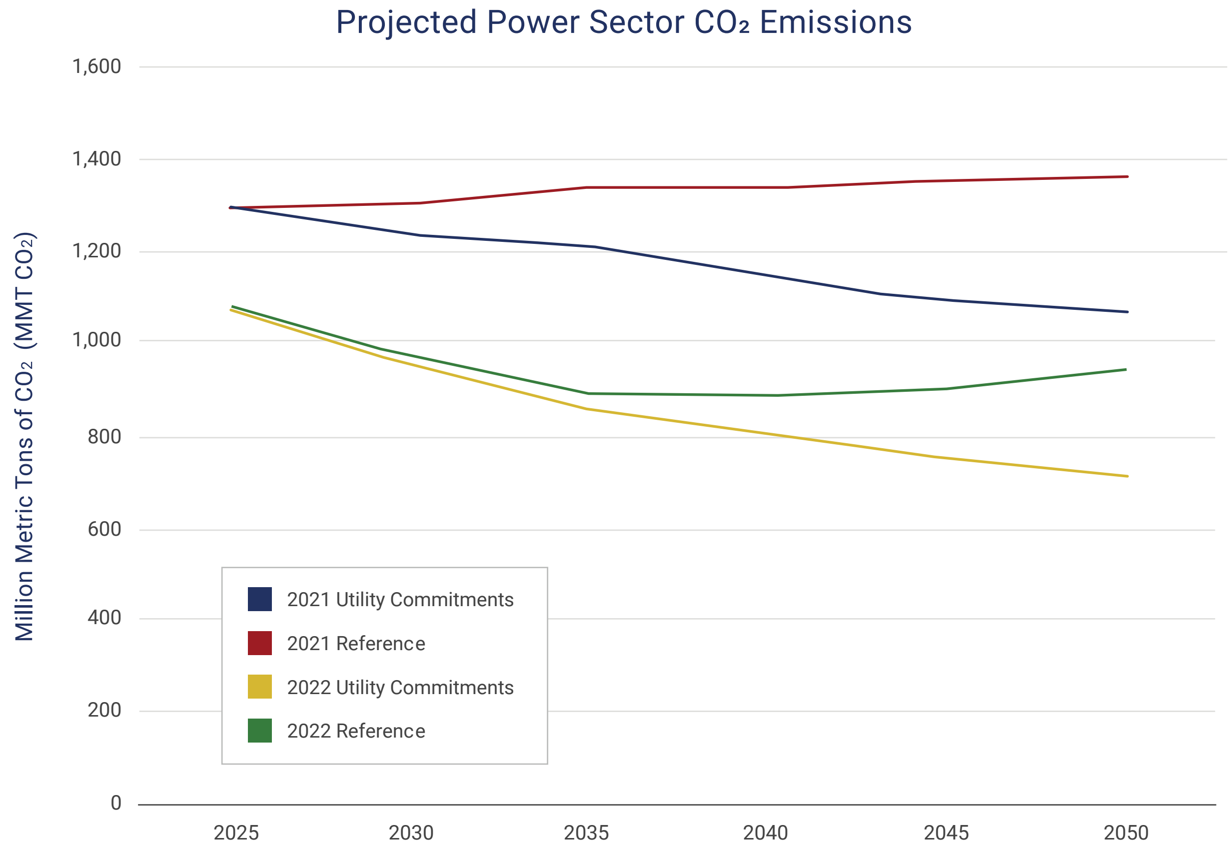

Figure 1. Power sector carbon dioxide emission projections for utility commitments and reference scenarios in 2021 and 2022. Different fuel price and technology cost assumptions in each year contribute to the decline in projected emissions between years in addition to changes in the number and ambition of utility commitments.

Four pivotal pieces of legislation were enacted in the last three years: the Energy Act of 2020, the Infrastructure Investment and Jobs Act, Creating Helpful Incentives to Produce Semiconductors and Science Act, and the Inflation Reduction Act (IRA) – three of which were passed on a bipartisan basis. Together, they modernized the Department of Energy and allocated unprecedented funding for research, development, and deployment programs for clean energy technologies. The Utility Commitments+IRA scenario in Figure 2 illustrates the projected combined impact that these heightened utility commitments and investments will have. It also clearly underscores the emissions gap remaining between our current path and net-zero by mid-century. As further elaborated in this paper, there are numerous limitations on the ability to realize the rapid emissions reductions projected between now and 2030.

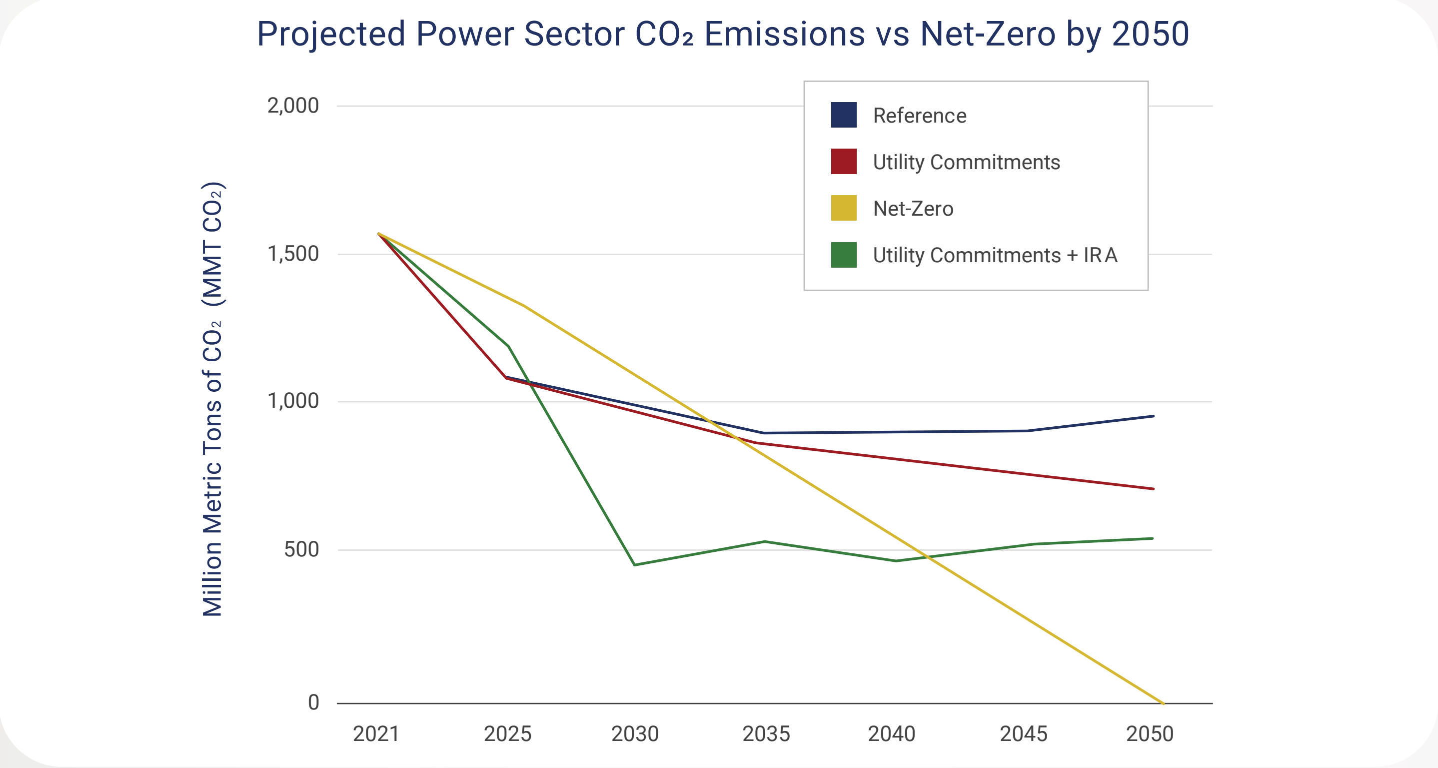

Figure 2. Power sector CO2 emission projections compared to a net-zero by 2050 trajectory.

The IRA Could Accelerate Nuclear Retirements After 2032, With Long-Term Consequences

The 2022 reconciliation package, the Inflation Reduction Act (IRA) of 2022, creates numerous programs and tax credits targeting clean energy deployment, including solar, wind, and nuclear. It also includes a tax credit to preserve existing nuclear reactors through 2032. When combined with utility commitments, these tax incentives are projected to hasten faster and larger coal and nuclear retirements and lead to a dramatic increase of capacity additions between 2025 and 2040, which will consist overwhelmingly of solar, wind, natural gas, and storage. This concentration of deployment of wind, solar, natural gas without carbon capture and storage (CCS), and storage after 2032 results in a reversal of the CO_2 emissions trajectory after 2030. Between 2030 and 2050, annual emissions are projected to increase by roughly 77 million metric tons of CO_2 (MMT CO_2) – equivalent to the total U.S. carbon emissions from cement, iron, and steel production in 2020.[7]

What leads to this reversal? The retirement of existing nuclear plants: the nation's largest source of zero-carbon dispatchable generation (see Figure 3).

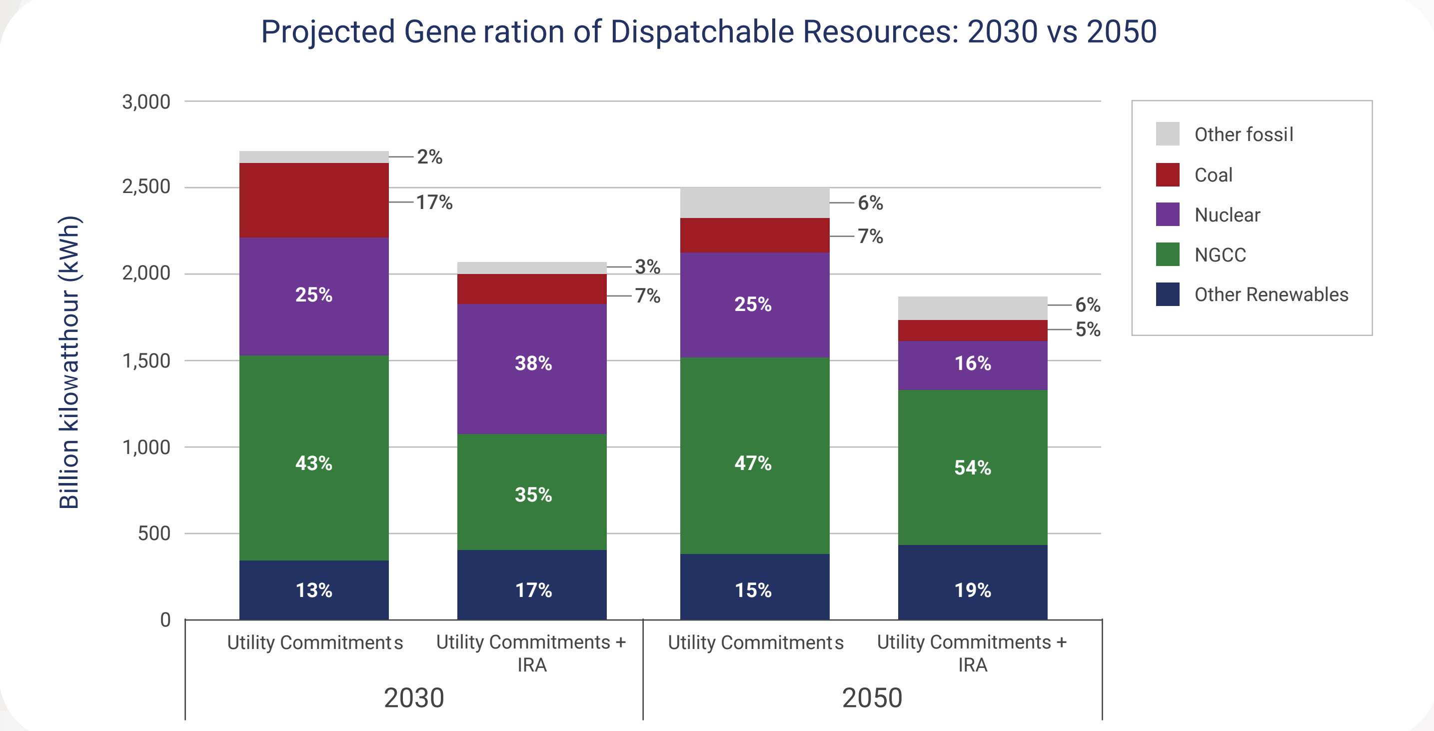

Figure 3. Projected generation of dispatchable resources for 2030 and 2050. Percentages represent each technology's share of total dispatchable generation. Technologies include natural gas combined cycle (NGCC), nuclear light water reactors (LWR) and small modular reactors (SMR), coal, other fossil (non-combined cycle natural gas combustion), and other renewables (hydropower, geothermal, biomass).

The tax credit for existing nuclear plants ends in 2032, while the clean-energy tech-neutral tax credit, which excludes credits for the existing nuclear fleet but includes advanced nuclear technologies, continues well beyond that. In addition to the tax credit phasing out, the Civil Nuclear Credit Program – established in the bipartisan IIJA to invest $6 billion in the existing nuclear fleet – also ends in 2032, contributing to the retirement of existing nuclear facilities. Our analysis shows that as the tax credits and IIJA credit programs end in 2032, the existing nuclear fleet retires and is replaced by natural gas without carbon capture. This analysis ultimately projects nuclear to generate far less under the IRA scenario than a utility-led decarbonization trajectory, despite the 45U tax credit.

Decarbonization and Affordability Go Hand-in-Hand

Retail electricity sales are 2.2% of the U.S. gross domestic product on average, but electricity plays an increasingly important role in our broader economy.[8] Decarbonization should not come at the expense of affordability, and our analysis finds that decarbonization is increasingly affordable (see Figure 4). In each modeled scenario, national retail electricity prices fall below the historical average. Two main factors drive this trend: natural gas prices and technology cost declines. In our Reference, Utility Commitments, and Utility Commitments+IRA scenarios, natural gas prices are expected to decrease going out to 2030 and remain relatively stable out to mid-century. At the same time, technology costs coupled with incentives lead to the rapid deployment of clean technologies whose prices are largely dictated by capital costs.

Russia's invasion of Ukraine in February 2022 led to sanctions on numerous Russian industries and propelled Europe to rapidly reduce its dependence on Russian imports of oil, coal, and natural gas. As a result, energy markets had periods of intense turmoil and volatility that, combined with inflation

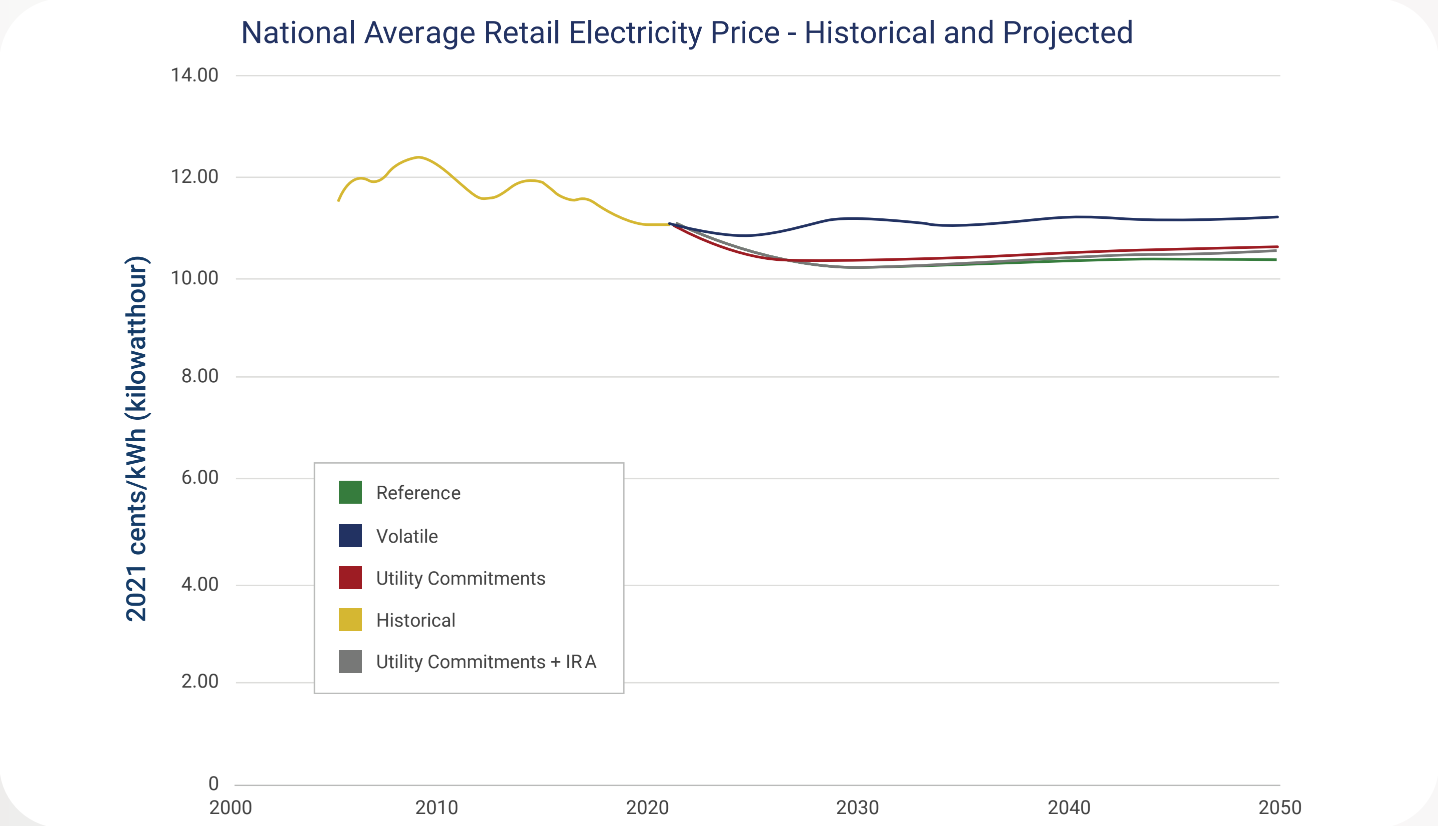

Figure 4. Historical and projected national average retail electricity price in 2021 cents per kWh. EIA provided the historic national average retail electricity nominal prices for all sectors, which the authors adjusted using the consumer price index (1982-84=1) to determine real prices, with 2021 as the base consumer price index.

from the Covid-19 economic recovery, continue to have long-term market effects. To understand how energy market volatility impacts our path to a clean energy system, Rhodium Group designed a separate set of fuel price inputs to assess the same scenarios: Utility Commitments and Utility Commitments+IRA.

This Volatile scenario differs from the Reference only in its natural gas price assumptions; all else remains equal. Figure 4 shows that fuel market turmoil is passed on to electricity consumers but is not expected to raise prices outside the historical range. Over time, the results show the increasing diversification of the resource mix and higher penetration of technologies without variable fuel prices, which will insulate consumers from the impacts of changing fuel prices. The full results of this supplemental analysis will be released in a forthcoming report.

Recommendations

Models, including the one used in this study, deploy energy resources in a techno-economically efficient manner that does not traditionally account for all possible constraints, such as political, social, legal, or supply chains. However, these constraints are important to address to realize the projected deployments of new capacity that result from utility commitments and federal policy.

Realizing the projected emission reductions from existing policies and commitments and closing the half-gigaton emission gap by mid-century requires sustained, targeted policy support over the coming decade. Several key actions can facilitate this effort:

1. **More ambitious utility commitments.** Leveraging federal initiatives will facilitate the achievement of existing targets and enable utilities to set more ambitious targets. Those utilities that already have goals should consider whether their Integrated Resource Plans and targets should incorporate new incentives, such as the expanded 45Q carbon capture credit. Utilities without carbon reduction goals should follow suit by establishing goals and leveraging the influx of public and private sector funds to make them a reality.
2. **Sustain state or federal support to retain the existing nuclear fleet.** Our model results revealed that the phase-out of policy support in the early 2030s led to the retirement of over half of the existing nuclear fleet, resulting in a backsliding of carbon emissions. Retaining this zero-carbon dispatchable resource is a cost-effective means of decarbonizing the grid and supporting longer-term reliability and national security.
3. **Target support toward the development, demonstration, and commercialization of a diverse mix of dispatchable clean energy technologies.** Despite potentially enormous additions of wind and solar to the grid by 2050, carbon reduction flatlined and reversed course due to a lack of affordable dispatchable clean technology. Our analysis found that carbon capture, new nuclear reactors, and dispatchable renewables – hydropower, geothermal, and biomass – are minimally deployed across scenarios. Policies that facilitate cost reductions and the scaling up of resources, such as carbon capture, new nuclear reactors, hydropower, and geothermal, are essential to ensuring a diverse mix of cost-competitive dispatchable clean energy.
4. **Reform interconnection processes to ensure that all types of clean energy are added to the grid in a timely and efficient manner.** An inefficient interconnection process makes deploying all types of technologies on the grid difficult. Policy reforms underway at the Federal Energy Regulatory Commission are paramount to ensure a timely and predictable process for adding new capacity while safeguarding reliability and facilitating net-zero decarbonization goals. Implementing reforms that readily scale with current and expected queue volumes will improve the efficiency and predictability of clean energy deployment.
5. **Maximize the use of existing infrastructure and improve the development timelines of supporting infrastructure, such as pipelines and transmission lines.** Legal challenges, siting opposition, and cost overruns or allocation disputes have increasingly delayed or stopped the development of interstate natural gas and electric transmission lines. Optimizing the existing grid through cost-effective technological solutions should be a focus of future investment, policy, and grid planning. Utilizing existing rights-of-way and disturbed land can minimize the need for greenfield development.

6. **Implement tech-neutral and tech-specific permitting reforms to reduce investor risk and accelerate the deployment of clean energy technologies and supporting infrastructure.** Strengthening and streamlining coordination across agencies and departments can facilitate expeditious reviews. Potential reforms to accelerate clean energy deployment include categorical exclusions for geothermal, updated pore space and well class frameworks for carbon capture and sequestration (CCS), and improved license processes for hydropower and small modular and advanced nuclear reactors.
7. **Develop secure supply chains for all kinds of clean energy technologies.** Actions should be focused on the diversification and expansion of mineral inputs, technology design, and markets to increase the overall number of actors abiding by high environmental and labor standards that can meet the rapidly escalating demand for these clean energy technologies.

Updates on the Path to 2050

The 117th Congress Was Historic for Clean Energy Technologies

Energy Act of 2020

The Energy Act of 2020 was the first comprehensive energy authorization law to be enacted in 13 years. It represents dozens of individual bills that received bipartisan support in both the House and Senate. The Energy Act of 2020 refocuses the Department of Energy's research and development programs on the most pressing energy technology challenges, from carbon capture to advanced nuclear, energy storage, and enhanced geothermal. Significantly, it authorizes the DOE to launch over 20 large clean energy demonstrations over seven years, making the Energy Act of 2020 the most aggressive technological commercialization program in U.S. history. Also included in the package was a two-year extension of the 45Q carbon capture tax credit, two years of the investment tax credit (five years for offshore wind), and a one-year extension of the production tax credit.

Infrastructure Investment and Jobs Act (IIJA)

The energy portions of the bipartisan Infrastructure Investment and Jobs Act (IIJA), enacted in November 2021, include significant funding for programs originally authorized by the Energy Act of 2020, as well as several new energy and climate programs. All told, the programs regarding clean energy demonstrations, orphan well capping, civil nuclear credits, and wildfire prevention policies alone are expected to reduce emissions by up to 190 million metric tons of CO_2 per year[9], greater than all greenhouse gas emissions from aviation in 2019 for the United States.[10] ClearPath previously published a summary of the Key Energy Provisions in the Bipartisan Infrastructure Law[11] and is tracking in real time the implementation and disbursement of these funds with our ClearPath Infrastructure Tracker[12]. Many of the demonstration programs in IIJA will advance and reduce the cost of key technologies needed for reducing emissions affordably.

Creating Helpful Incentives to Produce Semiconductors and Science Act (CHIPS and Science)

The bipartisan CHIPS and Science Act, enacted in August 2022, provides $52 billion in funding for U.S. semiconductor R&D and manufacturing, nanotechnology, artificial intelligence, computing, and clean energy. This includes investing in Fission for the Future, a new effort to promote the licensing and construction of advanced reactors on suitable sites such as brownfields. Notably, CHIPS and Science included the Steel Upgrading Partnerships and Emissions Reduction (SUPER) Act, which established DOE's first R&D program dedicated to low-emissions steel production to strengthen American manufacturing. The law also added significant new DOE technology transfer authorities and comprehensively reauthorized the DOE Office of Science.[13]

Inflation Reduction Act (IRA)

The 2022 reconciliation package, called the Inflation Reduction Act (IRA), creates many new programs and tax credits targeting clean energy deployment, which the Congressional Budget Office estimates will total $369 billion in federal expenditures over the next 10 years. The package's partisan process is disappointing, as many of the individual tax incentive provisions, totaling $270 billion, had been introduced on a bipartisan basis. Among these are the production tax credits available to renewable technologies – geothermal, wind, hydropower, solar, etc. – or investment tax credits for qualifying clean energy properties. Following their phase-out after 2024, qualifying technology developers will have a choice between receiving a production (45Y) or investment (48E) tax credit. Existing nuclear power facilities received a separate production tax credit (45U) for the first time, while the carbon capture and sequestration (CCS) tax credit (45Q) was enhanced in value and scope to accelerate the deployment of carbon capture, carbon sequestration, and direct air capture technologies in the power and industrial sectors. Domestic and new advanced manufacturing of energy technologies and their component parts are also eligible for investment (48C) and production tax credits (45X). Tax credits for several other key innovative energy and climate technologies, such as hydrogen fuel and electric vehicles, and their supply chains were also included.

Emission Trends in the U.S. Economy

In 2021, economy-wide CO_2 emissions in the U.S. were 17.5% below 2005 levels. As anticipated in last year's report, emissions rebounded due to the economic recovery from the global pandemic, representing a 5% increase in emissions from 2020. Preliminary estimates for 2022 indicate that this trend has continued, although to a lesser degree, with a 1.3% year-over-year increase compared to 2021, indicating that economic growth is decoupling from emissions for the first time.[14]

The power and transportation sectors continue to be the largest absolute emitters of CO_2, despite realizing the greatest reductions in CO_2 emission on an annual percentage basis since 2005. In other sectors of the economy, emission trends indicate growing opportunities for increased policy action and investment in decarbonization. The industrial sector, for example, is projected to decarbonize at a slower rate than the power and transportation sectors. This trend will lead to the industrial sector surpassing the power sector to become the second-largest CO_2-emitting sector by volume in 2030 and surpassing the transportation sector by 2050. Meanwhile, emissions from the agriculture and waste; buildings; and oil and gas sectors continue to remain flat.

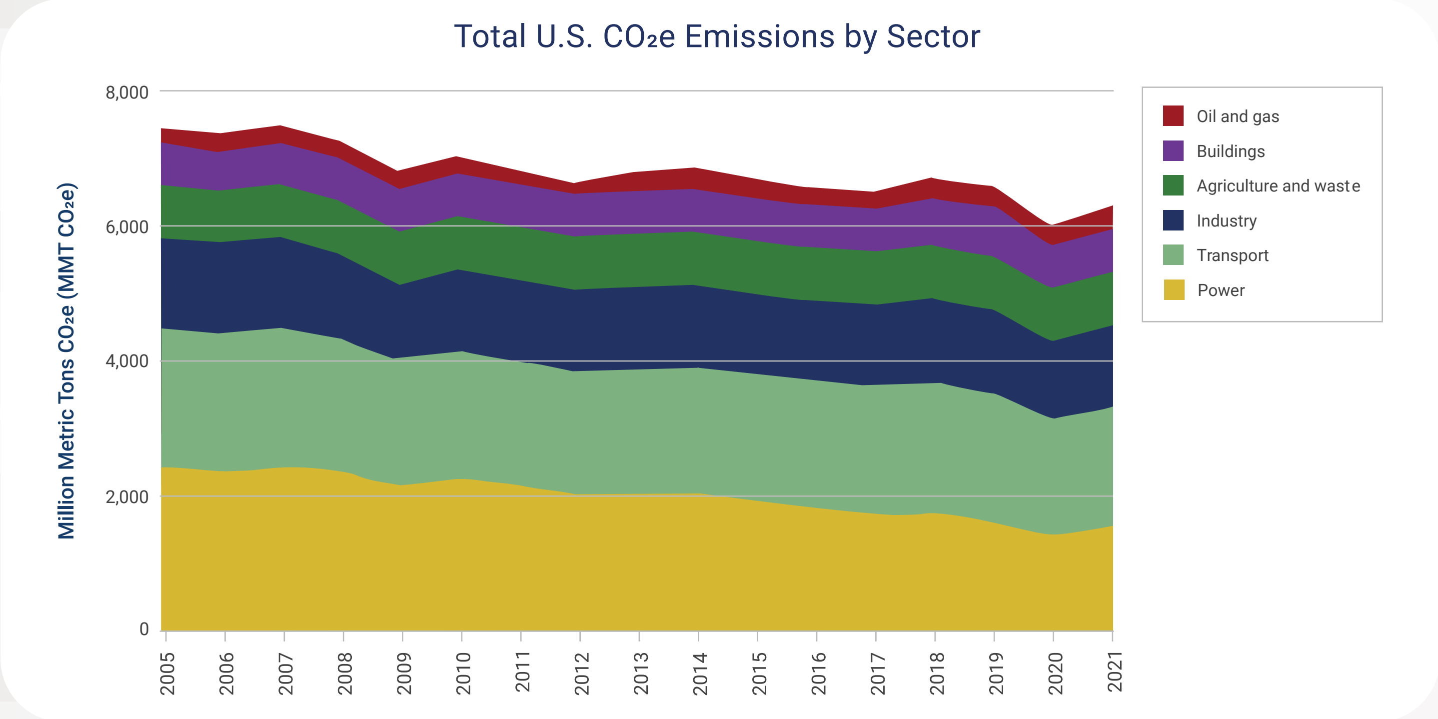

Figure 5. Historical total emissions by sector in the United States from Rhodium Group Climate Deck, accessed December 2022.

Trends in the Power Sector

In 2021 and 2022, the results show continuing growth trends for wind and solar and the retirement of coal units (see Figure 6). Wind, offshore and onshore, and solar photovoltaic (PV) were the majority, 34% each, of new additions by capacity. Notably, wind has a much higher capacity factor[15] than solar PV, which results in wind generating over three times as much electricity compared to solar, despite having roughly twice as much wind capacity on the grid in 2021.[16]

Retirement of conventional steam coal units represented 73% of all retirements, followed by other fossil fuels – inclusive of petroleum and non-combined cycle natural gas – with 13%, and nuclear with 7%. Since 2017, nearly 5 gigawatt (GW) of nuclear capacity has retired, while Georgia's Vogtle Units 3 and 4 – totaling 2,228 MW – are the only planned additions by 2025.[17]

Batteries and natural gas combined cycle (NGCC) are critical resources for balancing the intermittency of wind and solar, so the results show a concurrent growth in the additions of these resources in absolute and percentage terms. Battery storage continues to grow dramatically, eclipsing the growth rate that utility-scale solar has experienced in the past decade.[18]

According to the EIA, battery storage is expected to increase from nearly 5 GW at the end of 2021 to 30 GW by 2025.[19] Twenty-seven states deployed batteries between 2021 and 2022, 57% percent of which were in California, totaling 4.2 GW of capacity. During California's summer 2022 heat wave and related energy emergency, batteries provided more than 3 GW of power during peak demand hours, which helped avoid blackouts.[20] Texas deployed 1.8 GW, followed by Florida with 500 MW deployed;

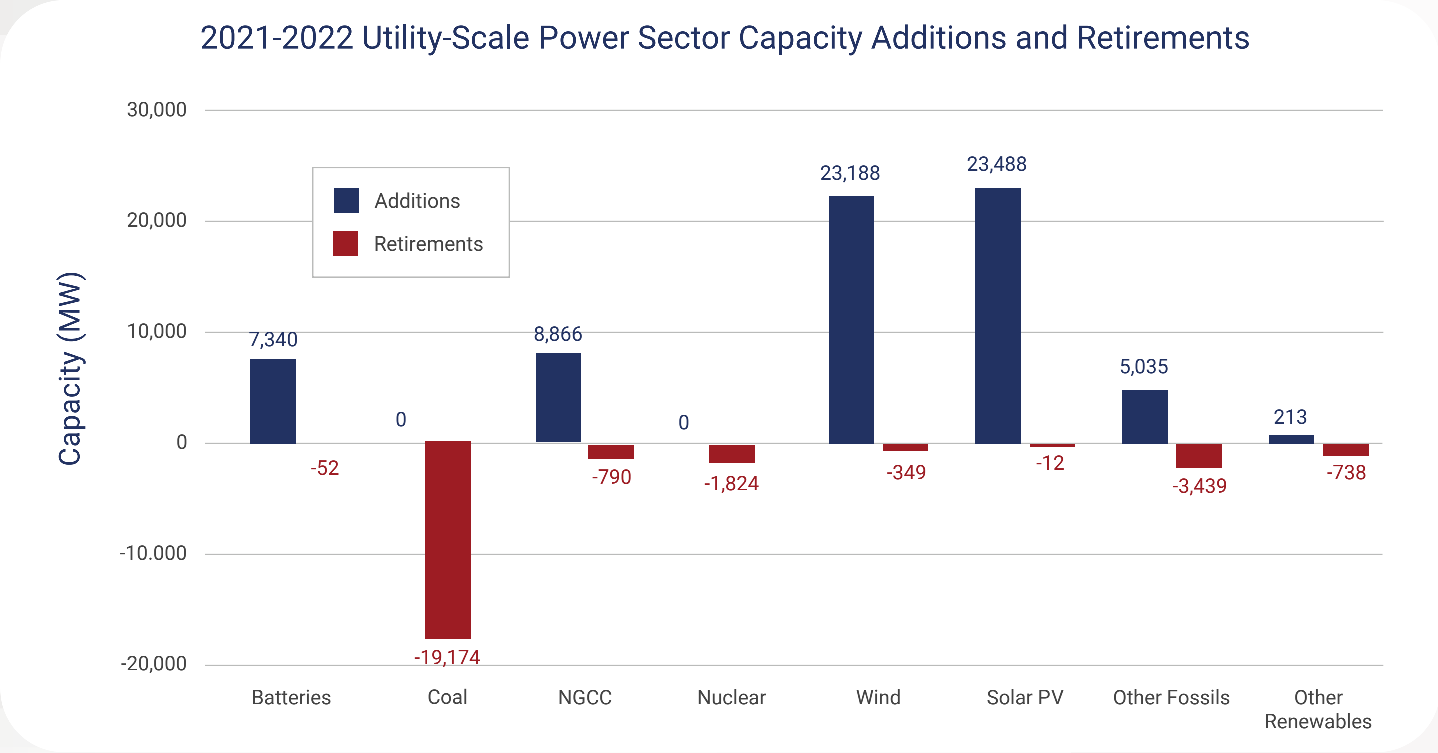

Figure 6. Capacity is reflective of alternating current in megawatts (MW). EIA Form 860 for final 2021 data and Form 860m December 2022 released data. Other renewables include solar thermal, conventional hydropower, pumped storage hydropower, geothermal, landfill gas, biomass, and waste. Other fossil includes non-combined cycle natural gas and petroleum.

combined, they represent 32% of nationwide battery deployment from 2021 to 2022.
In 2022, the price and deployment trajectories for batteries were disrupted by price volatility in the market for minerals, specifically lithium and nickel. For lithium, this was driven by supply deficits, while Russia's invasion of Ukraine and subsequent sanctions applied to their 21% share of global nickel production.[21] Lithium demand is projected to grow 42 times between 2020 and 2040[22] to support Paris Climate Agreement commitments. This portends future supply risks for the mineral, with over 85% of its production occurring in just three countries: Chile, Australia, and China.[23]

The solar photovoltaics (PV) supply chain is concentrated to a greater extent than for batteries. An International Energy Agency report found that China controls 80% of solar panel manufacturing capacity.[24] In 2022, import tariffs were extended for solar products from China, and the Department of Commerce announced an investigation into import tariff evasion.[25] Despite executive action that eased import duties and guaranteed no retroactive application of penalties on solar developers using products under investigation, over half of all installations were delayed.[26]

Utility and State Clean Electricity Commitments

Utility and state commitments continue to demonstrate the impact of sub-federal actions on emission reductions and technology advancements. The Smart Electric Power Alliance tracks utility and state decarbonization commitments through their Utility Carbon-Reduction Tracker. At the end of 2022, 57 individual utilities and utility parent companies had adopted a 100% carbon reduction target, while an additional 71 had adopted carbon reduction targets. At the end of 2022, 14 states had either

100% renewable/clean energy targets or net-zero targets, with binding deadlines before or at mid-century. These state requirements are binding for 320 individual utilities nationwide – a figure that excludes targets adopted voluntarily by utilities or utility parent companies – who must prepare to meet these requirements. A list of current targets is included in the appendix.

How Has 2021-2022 Shaped Our Future Power Sector?

The past two years included the passage of three bipartisan bills and an appropriations package that allocated unprecedented public funding for clean energy technologies, new and strengthened utility decarbonization commitments, and turmoil in global energy markets due to Russia's invasion of Ukraine. In order to ascertain and clarify the magnitude of this past year's impact on the future of the U.S. power sector, the authors engaged Rhodium Group to model several scenarios that capture these developments and their dynamics. Rhodium Group modifies and maintains a version of the National Energy Modeling System (NEMS), developed by the Energy Information Administration (EIA), which can analyze various impacts of policies and technologies on the U.S. energy sector. In the following sections, the authors analyze the ClearPath-designed scenarios modeled by Rhodium Group and their results regarding the U.S. power sector's future operation and capacity expansion.

Modeling Assumptions and Caveats

Unless otherwise noted below, assumptions are aligned with Rhodium Group's Taking Stock 2022 Technical Appendix. This includes existing state and federal policies, enacted by June 2022, and the Inflation Reduction Act. Renewable generation and storage cost estimates across all scenarios reflect mid-cost estimates from the 2022 National Renewable Energy Laboratory's Annual Technology Baseline. Natural gas with carbon capture and storage costs reflect mid-cost Allam cycle technology, which does not become available to deploy until 2026. Natural gas prices for 2022 and 2023 were calibrated to the EIA's June 2022 Short-Term Energy Outlook, while prices out to 2050 are approximated based on their 2022 Annual Energy Outlook.

ClearPath developed three scenarios, which were modeled by Rhodium Group, whose assumptions are outlined in Table 1.

Scenario Assumptions	Description
Reference	Rhodium Taking Stock 2022[27]
Utility Commitments	Rhodium Taking Stock 2022 Updated 2022 utility clean energy commitments
Utility Commitments+IRA	Rhodium Taking Stock 2022 Updated 2022 utility clean energy commitments Programs and incentives passed in the Inflation Reduction Act of 2022

Table 1. Scenario assumptions were developed by ClearPath and modeled by Rhodium Group.

Electricity Trends Through 2050

Projected demand grows 8% from 2021 to 2050, inclusive of electricity-related losses. This represents approximately 7% greater demand in 2050 than was projected in our previous report, reflecting updated state and federal electrification and energy efficiency policies, among other factors.[28] The projected capacity of the grid by 2050 will grow 85%, 101%, and 136% using a 2021 baseline under our Reference, Utility Commitments, and Utility Commitments+IRA scenarios, respectively (see Figure 7). This higher rate of growth for grid capacity compared to demand reflects the lower capacity factors for technologies such as wind, solar, and gas peaking units, which make up the majority of new capacity additions.

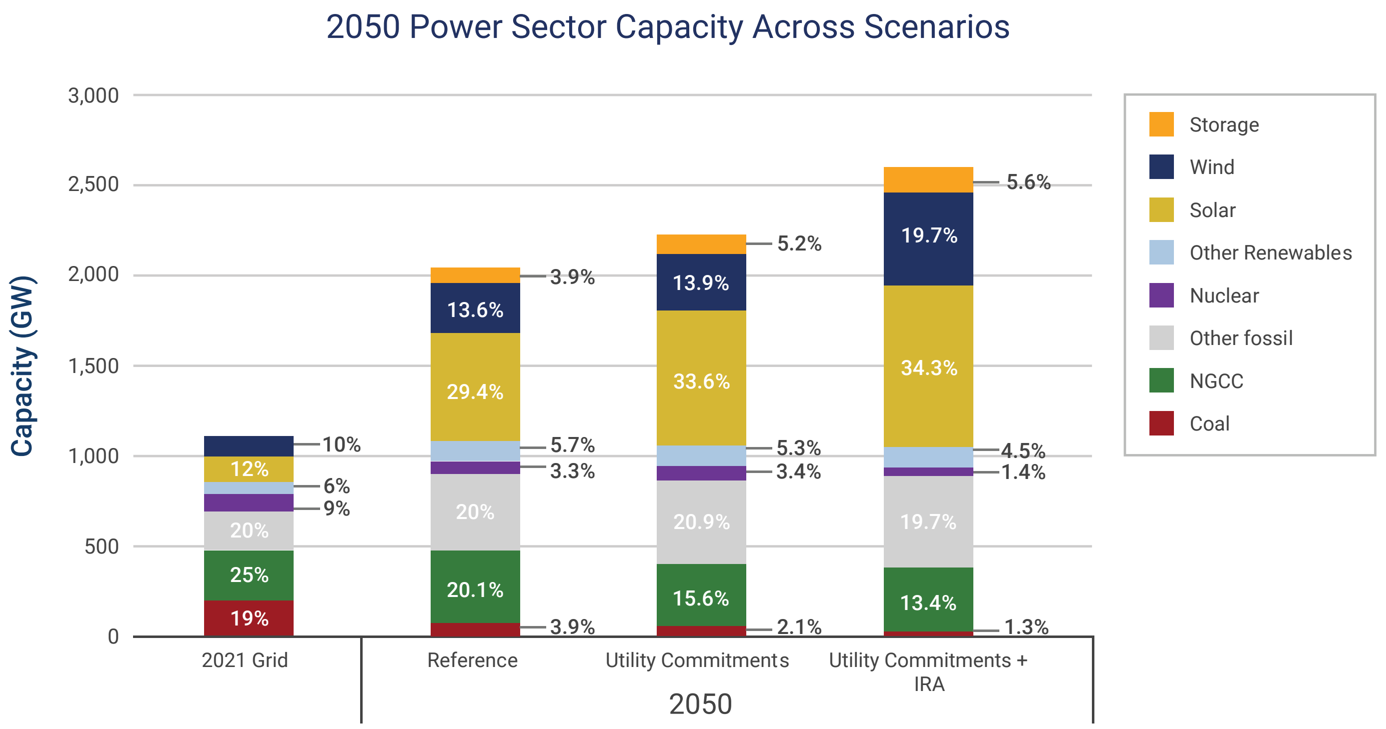

Figure 7. Technologies shown are coal (including new capacity from retrofits), natural gas combined cycle (NGCC), nuclear light water reactors (LWR) and small modular reactors (SMR), other fossil (non-combined cycle natural gas combustion and petroleum), other renewables (hydropower, geothermal, biomass), solar, wind, and storage. Only technologies with a greater than 1% share of total grid capacity are shown.

The results show the continuing trend of the retirement of coal and nuclear power plants, which are increasingly uneconomical, although neither will be removed from the grid completely. Coal and nuclear are at least 1% of grid capacity, respectively, in 2050 across all scenarios. Coal, representing 19% of grid capacity in 2021, is projected to retire between 103 and 130 GW by 2030. The overwhelming majority of nuclear retirements occur between 2030 and 2035, when the Civil Nuclear Credit Program, established in IIJA to preserve the existing nuclear fleet, and the Nuclear Power Production Tax Credit, established in IRA, are set to expire. Only currently planned additions of light water reactors (LWRs) will be added by 2050, while small modular reactors (SMRs) are only deployed in the Utility Commitments+IRA scenario between 2025 and 2029.

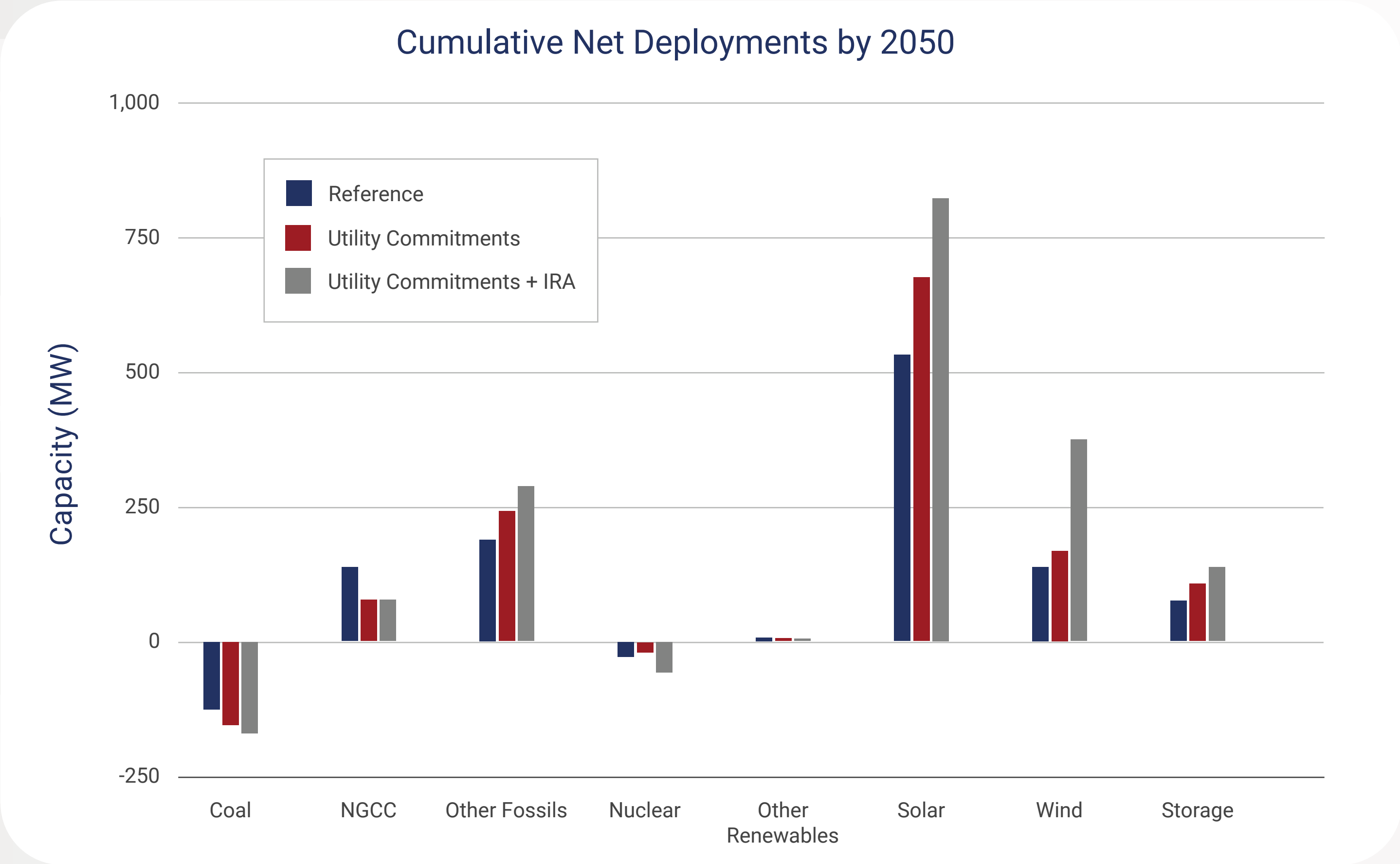

Figure 8. Net deployment – the summation of all capacity additions and retirement – by 2050 for each scenario. Technologies shown are natural gas combined cycle (NGCC), nuclear (LWR and SMR), coal (including new capacity from retrofits), other fossil (non-combined cycle natural gas combustion and petroleum), other renewables (hydropower, geothermal, biomass), solar, wind, and storage.

Natural gas, including combined cycle and all other natural gas/oil combustion pathways encapsulated by "other fossil," is projected to grow in absolute terms but represents a decreasing share of the resource mix going out to 2050. While other renewables – including hydropower and geothermal – remain constant in absolute terms, wind and solar grow by orders of magnitude. In 2021, roughly 64 GW of solar is projected to grow to between 600 and nearly 900 GW by 2050 across scenarios. While not as eye-popping, wind is projected to grow from 136 GW in 2021 to at least 277 GW and over 500 GW by 2050 across scenarios. The predominance of variable capacity on the grid drives the deployment of standalone storage resources that are capable of quickly ramping to balance the grid (see Figure 8). Storage projections range from 4 GW today to between 80 GW and 146 GW in 2050. However, total battery deployment may be underestimated due to hybrid projects – where batteries are co-located with wind and solar – not represented in this model.

Notably, the capacity factor of land-based and offshore wind, about 40%, can be double that of solar PV, typically 20-33%.[29] This leads to wind generation being proportionally greater than solar PV on a capacity basis (see Figure 9). At greater levels of deployment, this phenomenon is exacerbated to the extent that wind generation is higher than solar generation in our Utility Commitments+IRA scenario despite solar capacity being nearly double wind capacity.

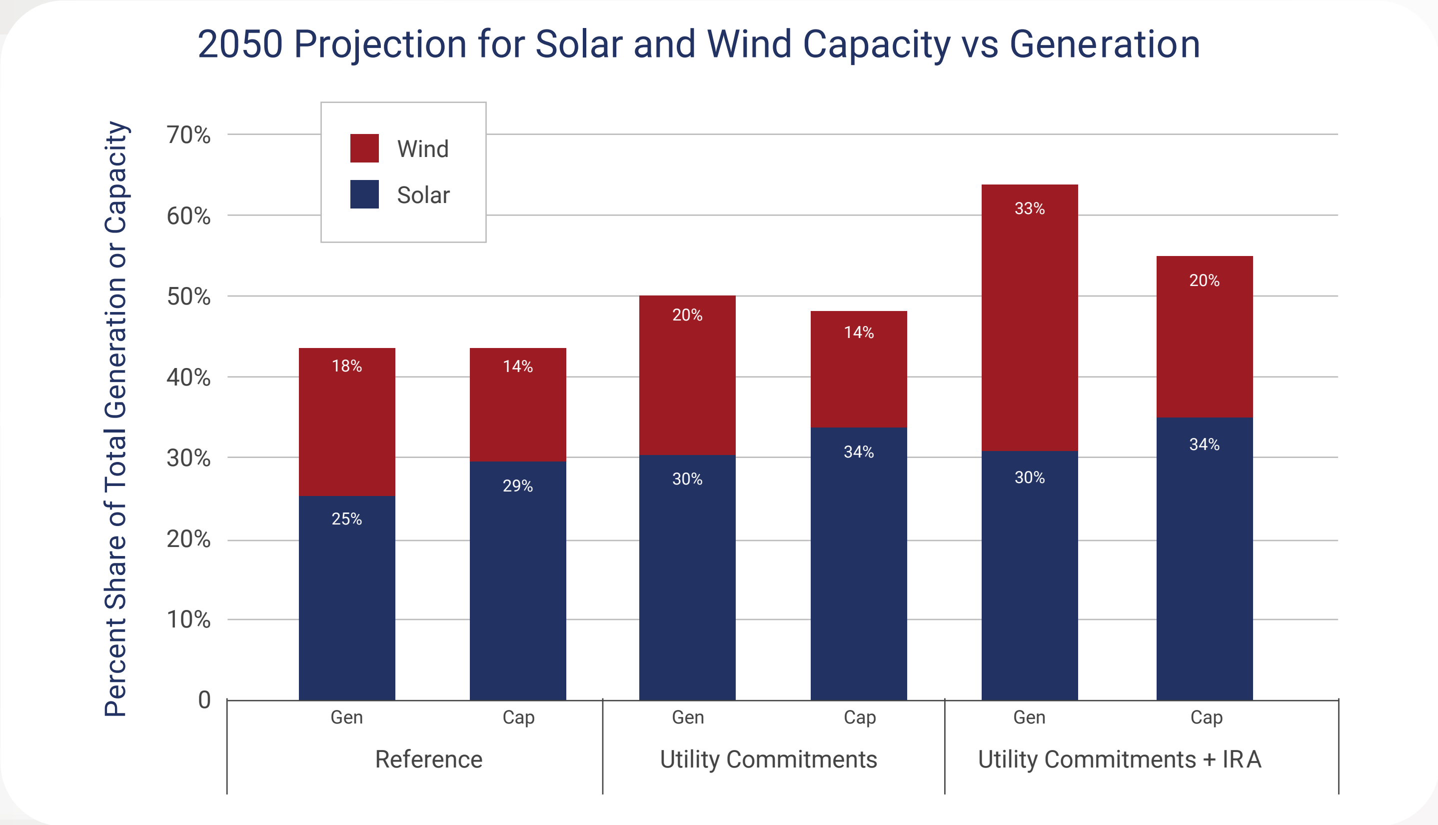

Figure 9. 2050 projection of solar and wind capacity and generation. The percentage represents the share of total generation (Gen) and capacity (Cap), respectively, from wind or solar.

Impacts on Power Sector Emissions

The timing of the capacity additions discussed in the previous section are heavily influenced by the phase-in and phase-out of federal policies and are reflected in projected emission trajectories. For the scenario including the 2022 tax incentives, solar, wind, and battery deployments are heavily concentrated between 2025-2040, with a huge dropoff after 2040. The projected deployments result in rapid emission reductions out to 2030, followed by a flatline and backsliding of emissions (see Figure 10). Between 2030 and 2050, projected annual emissions increase by roughly 77 million metric tons of CO_2. The Utility Commitments scenario, which does not include the IRA, is projected to steadily reduce emissions 71% below 2005 levels by 2050. Comparatively, the Utility Commitments+IRA scenario reduces emissions 81% percent below 2005 levels by 2030, but this increases to 78% below 2005 levels by 2050.

The authors compared the projected power sector CO_2 emissions for the Reference scenario with our Utility Commitments and Utility Commitments+IRA scenarios to quantify the cumulative emissions avoided by these assumptions. As shown in Figure 11, accounting for Utility Commitments results in avoiding half a gigaton of carbon emissions by mid-century, more than the total carbon emissions in 2020 from California and New York combined.[30]

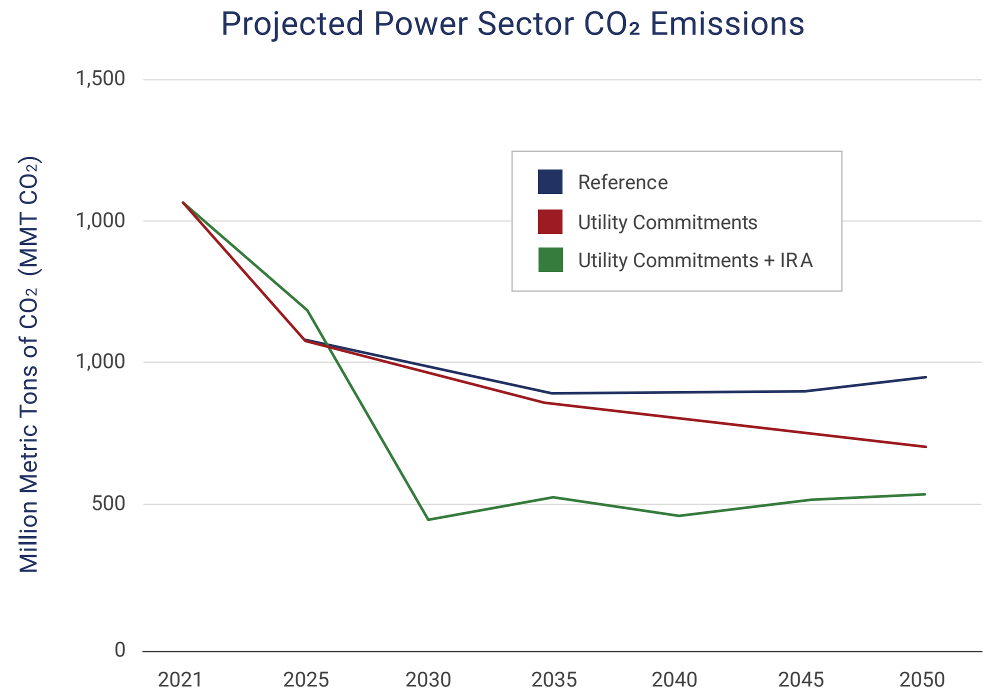

Figure 10. Projections of power sector CO2 emissions for each scenario.

Utility Commitments+IRA drive substantial additional reductions in power sector emissions out to 2050. While near-term emissions are slightly above the Reference scenario, the 2022 tax incentives lead to nearly 2 gigatons of avoided cumulative CO_2 emission by mid-century – equivalent to all power sector emissions in 2015.[31]

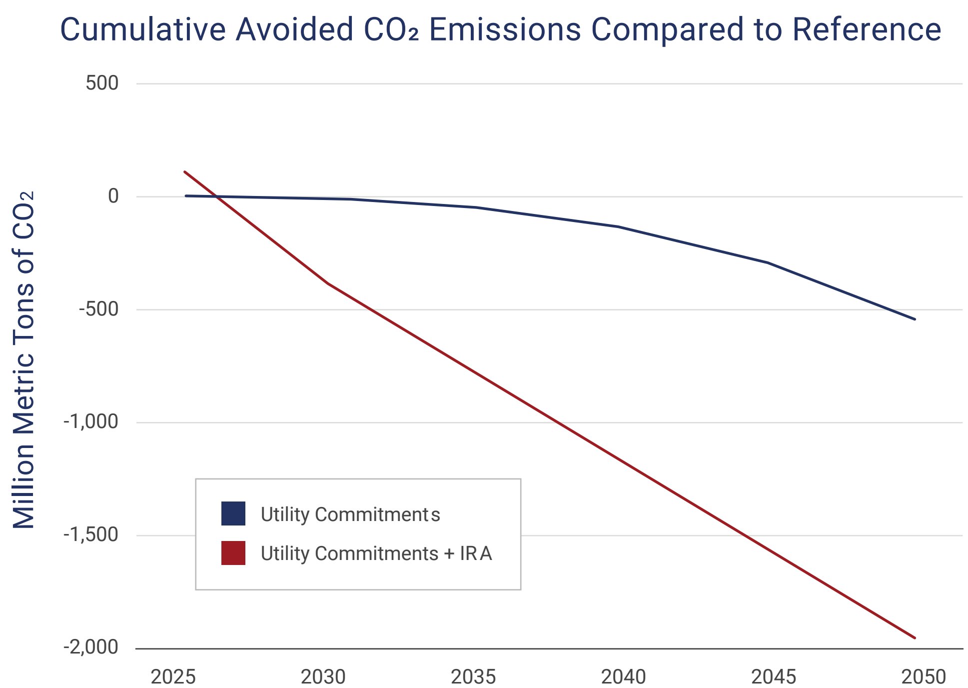

Figure 11. The cumulative avoided CO2 emissions between the Reference scenario and the Utility Commitments and Utility Commitments+IRA scenarios, respectively. Negative values represent years when cumulative power sector emissions were higher for the Reference scenario. Positive values represent years where cumulative power sector emissions were lower for the Reference scenario.

These results reflect the magnitude of utility, state, and federal efforts over the past two years to accelerate carbon reductions, particularly through the 2030 time frame. However, no scenario is on track to achieve net-zero by 2050. Despite projections of emissions plummeting in the Utility Commitments+IRA scenario in the near term, emission reductions backslide after 2030, indicating that sustained policy action is necessary.

Pivotal Role of Dispatchable Clean Energy

What leads to the flatline and subsequent backsliding of annual emission rates when the IRA has incentivized the deployment of magnitudes more gigawatts of wind and solar? The retirement of 64% of the nuclear fleet: the nation's largest source of zero-carbon dispatchable generation.

Dispatchable resources are essential to the fundamental balancing of supply and demand in the power system. While wind and solar output vary based on meteorological conditions, technologies such as natural gas, coal, batteries, hydropower, geothermal, and nuclear have greater – although not absolute – control over when and how much electricity they dispatch to the grid. On a power system operating with a majority of variable resources matching net demand, demand minus wind and solar production, will require dispatchable low- or zero-carbon resources.

Figure 12 illustrates our findings. Nuclear, the largest source of dispatchable zero-carbon electricity on the grid today, and coal are retired en masse and replaced primarily by natural gas. No new nuclear LWRs are added to the grid beyond what is already planned and under construction. Meanwhile, only 3 GW of nuclear SMRs are deployed in the Utility Commitments+IRA scenario. Drilling down further, SMR deployment occurs exclusively in the Tennessee Valley Authority footprint due to their net-zero by 2050 commitment and transmission system constraints, which make a high capacity factor, zero-carbon resource like SMRs economical to deploy.

Next, we find that natural gas will continue to play a crucial role in our power systems, so it is imperative to support the development and adoption of carbon capture and storage (CCS). Despite the expansion of the CCS tax credit (45Q) to enhance its value and scope, this technology's lack of economical deployment in this analysis indicated that additional policy support will be needed to make adopting this technology economically competitive.[32]

Other forms of dispatchable clean energy included in "other renewables" are hydropower and geothermal, but we find that the growth of these resources is minimal across the projection period.

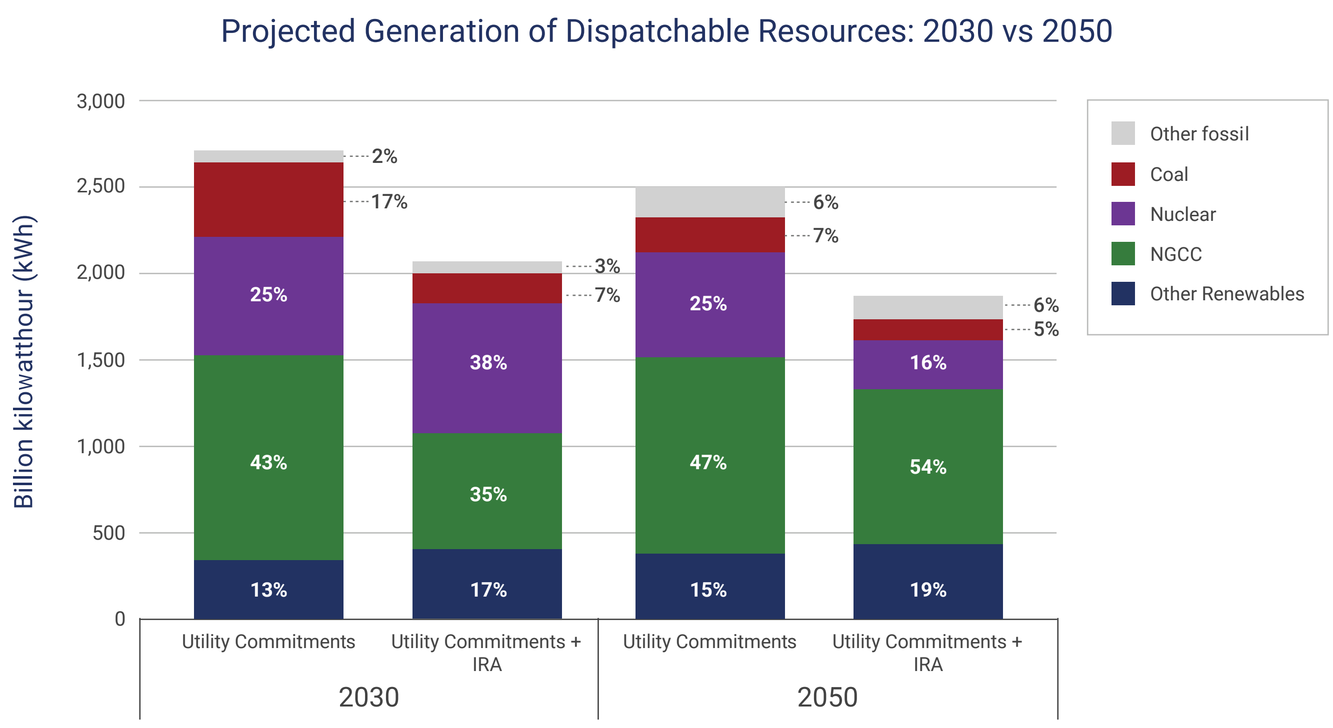

Figure 12. Projected generation of dispatchable resources for 2030 and 2050. Percentages represent each technology's share of total dispatchable generation. Technologies shown are natural gas combined cycle (NGCC), nuclear (LWR and SMR), coal (including new capacity from retrofits), other fossil (non-combined cycle natural gas combustion and petroleum), and other renewables (hydropower, geothermal, biomass).

Debate over Decarbonization and Affordability is a False Choice: We Can Have Both!

Our analysis found that commitments and policy actions to reduce power sector carbon emissions do not sacrifice affordability; rather, they facilitate lower consumer prices and mitigate consumer exposure to potential price shocks.

The projected national average retail electricity prices stay below the historical average real retail price of 11.57 cents/kWh, adjusted to 2021, for each scenario out to 2050. This reveals a continuation of a decade-long trend in real price declines for retail electricity across all consumer classes. These trends were promulgated by cost declines in the domestic production of natural gas and in renewable technologies.

Our findings reveal the increasing cost-competitiveness of a diverse mix of resources and that the higher penetration of technologies without exposure to global fuel markets achieves lower national average retail electricity rates, which are insulated from potential price volatility.

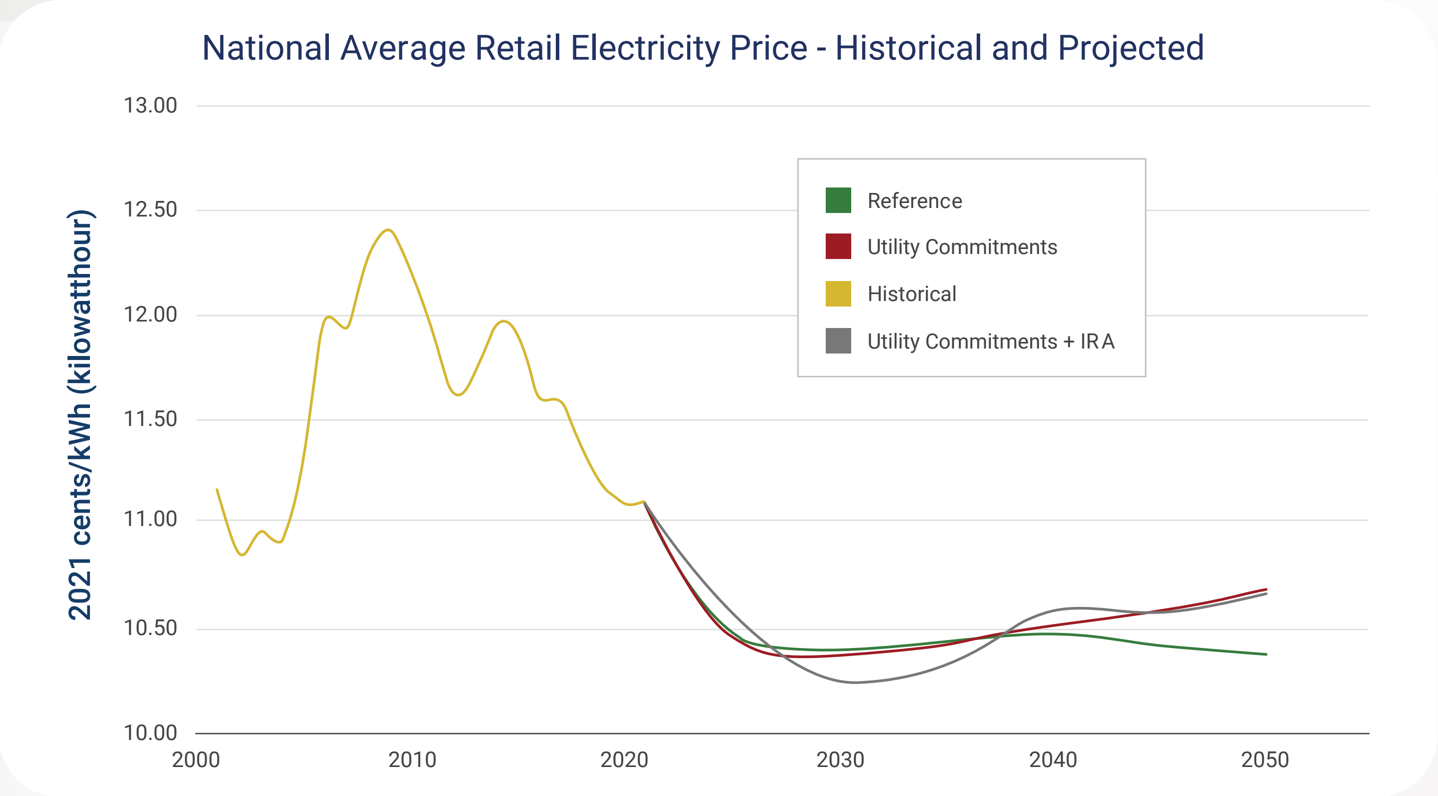

Figure 13. Historical and projected national average retail electricity prices, in 2021 cents per kWh. EIA provided the historic national average retail electricity nominal prices for all sectors. We then adjusted the historical prices using the consumer price index (1982-84=1), to determine real prices with 2021 as the base consumer price index.

Recommendations for Closing the Gap

This report found that the major legislative achievements of the 117th Congress and ambition from utilities across the country have created a break-point in America's energy policy and unlocked carbon reduction potential in the power sector. However, several key actions could close the remaining electricity emissions gap of over half a gigaton of CO_2 by 2050 (see Figure 14).

More Ambitious Utility Commitments Are Needed; Federal Initiatives Can Help

This report demonstrates the significant impact utility commitments, when fulfilled, can make in reducing power sector emissions. The 117th Congress passed multiple bipartisan pieces of legislation that established or enhanced programs for deploying clean energy technologies, which utilities and the states are uniquely positioned to utilize. These resources will be essential in not only achieving existing targets but in enabling more ambitious targets, due to the reduced technology costs these programs are designed to achieve. Utilities that already have goals should consider whether their Integrated Resource Plans and targets should incorporate new incentives, such as the expanded 45Q carbon capture credit. Utilities without carbon reduction goals should follow suit by establishing goals and leveraging the influx of public and private sector funds to make them a reality.

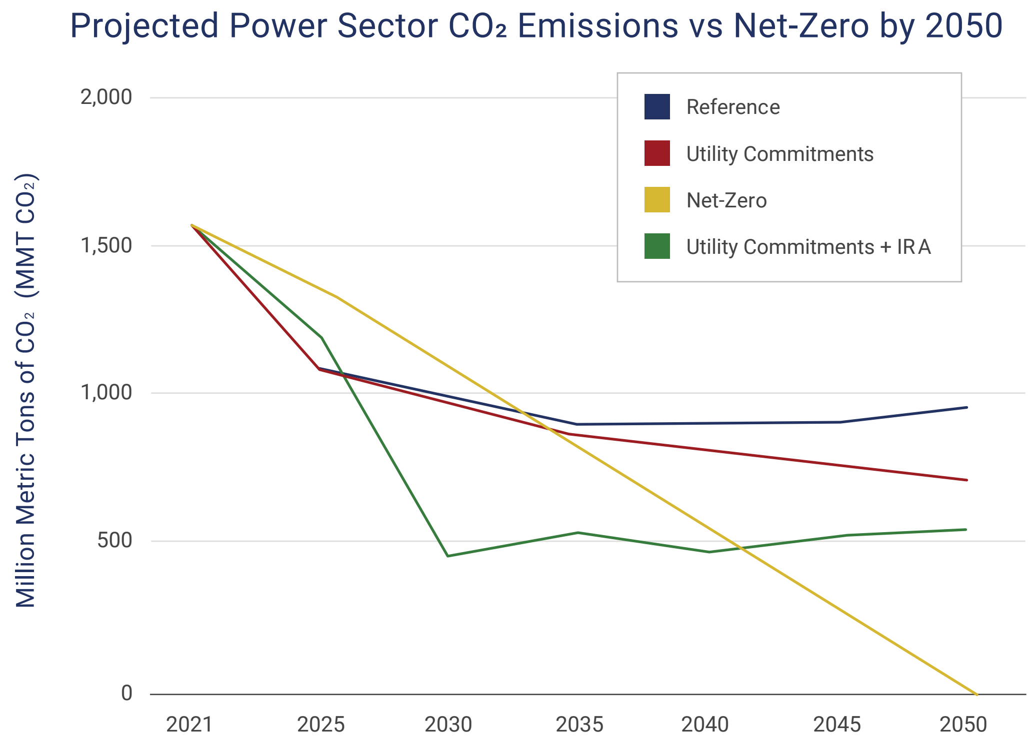

Figure 14. ClearPath-designed scenarios, modeled by Rhodium Group, versus a straight-line trajectory for net-zero by 2050. Existing state and utility commitments, as well as federal policies, are projected to prevent a gigaton of emissions by 2050, but additional action will be needed to close the gap.

Cheaper Dispatchable Clean Energy Is Crucial

Retaining the existing nuclear fleet is a cost-effective means of achieving significant carbon reductions in the power sector. In our Utility Commitments+IRA scenario, 64% of the existing nuclear fleet will retire by 2035. This massive reduction in zero-carbon dispatchable generation leads to an emissions backslide that results in 2050 emissions being greater than 2030 emissions by 77 MMT CO_2. The value of preserving the nation's existing fleet of reactors is only intensified by its contributions to national security and grid reliability, particularly in a decarbonizing system. This value has come into sharp focus with California's reversal of the Diablo Canyon Nuclear closure. The first conditionally selected award recipient of $1.1 billion from the Civil Nuclear Credit Program,[33] Diablo Canyon Power Plant was scheduled to close in 2025 after its licenses expired and following legal challenges from the state and other stakeholders, which ended in a $5.9 billion settlement.[34] However, California's grid operator and numerous other analyses determined that the plant's closure directly contributes to reliability gaps and rising emissions due to the infeasibility of substituting commensurate low-carbon capacity before 2025.[35] Additional state and federal support will be needed to ensure that this dispatchable clean energy resource continues to play a crucial role in decarbonizing the power sector while maintaining security and reliability.

In addition to retaining the existing nuclear fleet, a diverse mix of dispatchable clean energy must be scaled up, while costs must be driven down to enable an affordable path to net-zero. Our analysis found that carbon capture, new nuclear reactors, and dispatchable renewables – hydropower, geothermal, and biomass – are minimally deployed across scenarios. A net-zero power sector by mid-century will require targeted support for the development, demonstration, and commercialization of a diverse mix of dispatchable clean energy technologies.

Near-Term Regulatory and Permitting Reform Is Essential

Building all of the infrastructure and technologies needed to decarbonize the power sector at the scale and pace required for meeting carbon reduction targets will necessitate regulatory reforms. The uncertainty of building nascent clean energy technology and accompanying infrastructure will require clarity and predictability to reduce investment risk and associated high costs.

In order for a new generation of storage resources to connect to the grid, their impacts on the system must be studied, and any risks or constraints they introduce must be addressed through the interconnection process. As discussed in our Fall 2022 report "All Queued Up and Nowhere to Go," this process has broken down and become inefficient across the country as the number of projects seeking to connect has overwhelmed grid operators, and available capacity on the transmission system has shrunk.[36] Currently, projects seeking connection to the grid wait an average of 3.7 years to advance through the queue, and only 23%, on average, eventually reach commercial operation. The projected average annual capacity additions from this analysis show that tax incentives for clean energy result in periods of rapid deployment, which result in 80 to 110 GW added when these incentives phase in. Compared to the historical maximum for annual additions – 67 GW, reached in 2002 – these levels would be record-setting.[37]

An inefficient interconnection process makes deploying all types of technologies on the grid difficult. Policy reforms underway at the Federal Energy Regulatory Commission are paramount to ensure a timely and predictable process for adding capacity that safeguards reliability and facilitates net-zero decarbonization goals. Implementing reforms that readily scale with current and expected queue volumes will improve the efficiency and predictability of clean energy deployment.

Conjointly, the expedient development of supporting infrastructure, such as pipelines and transmission lines, will be as critical as interconnecting generation and storage resources. Legal challenges, siting opposition, and cost overruns or allocation disputes have increasingly delayed or stopped the development of interstate natural gas and electric transmission lines. Maximizing the capabilities of existing infrastructure through cost-effective technological solutions, such as the deployment of grid-enhancing technologies on transmission lines,[38] should be a focus of future investment, policy, and grid planning.

Strengthening and streamlining coordination across agencies and departments – such as the Department of Energy, Department of Interior, Department of Transportation, and the Federal Energy Regulatory Commission – can facilitate expeditious reviews and the construction of infrastructure, particularly in existing rights-of-way and brownfields.

Tech-specific reforms will also be essential to unlocking a diverse suite of decarbonization solutions, including:

- **Carbon capture and storage:** CCS requires capture technology, pipelines, and geological storage to be deployed at an unprecedented scale. While the IIJA funded numerous public-private programs and the IRA expanded the 45Q tax credit, regulatory clarity and established frameworks will be needed to increase developer certainty. Efficient and clear processes for accessing pore space and categorically converting existing wells for geological sequestration will be essential for bringing down the cost of CCS technologies, which will enable low carbon dispatchable generation.
- **Hydropower:** Over the next decade, nearly 300 licenses, representing about 16 GW of hydropower – both conventional and pumped storage – are set to expire.[39] Streamlining review and study processes through improved coordination and expedited licensing and re-licensing for certain low-impact projects can greatly improve the retention of the existing fleet while enabling the development of new resources.[40]
- **Geothermal:** Drilling wells, even exploratory ones, is a process mired in red tape. Analysis from the National Renewable Energy Laboratory found that expanding categorical exclusions for geothermal exploration and centralized federal and state permitting would slash development timelines in half, enabling an additional 7 GW of development by 2050, a 116% increase over business as usual in 2050.[41] Future developments in enhanced geothermal technology could accelerate that growth even further.[42]
- **Small Modular and Advanced Reactors:** Regulatory frameworks at the Nuclear Regulatory Commission (NRC) should be risk-informed and performance-based to appropriately reflect operational differences among multiple novel reactor designs. Performance-based requirements will facilitate demonstration and deployment by focusing NRC and applicant effort on safety rather than navigating an opaque and outdated licensing process developed for a different generation of reactors.[43] Expedient deployment will accelerate the techno-economic learning curve and make low-carbon clean energy available sooner. Additionally, a robust, secure advanced fuel supply chain is critical to bringing these clean energy assets online. Some advanced reactors require a different fuel supply – known as high assay, low enriched uranium (HALEU) – which is currently only available from Russia. Establishing a domestic supply chain is essential to unlocking American innovation and maintaining energy security.[44]

Finally, supply chain security will also feature prominently in realizing carbon reductions in line with targets and facilitating deployments. Battery storage supply chains are controlled by a few countries, in part due to the lack of battery chemistry diversity and under-investment in domestic manufacturing capabilities. There is a push to support alternative battery chemistries in the power sector, but many of these alternative chemistries (such as lithium iron phosphate) have their manufacturing heavily concentrated in China.[45] Solar photovoltaic supply chains are also heavily concentrated in and dominated by China, making the world completely reliant on and vulnerable to a single actor for key components of decarbonization.[46]

Sustaining secure, low-cost supply chains for all kinds of clean energy technologies will require the diversification and expansion of mineral inputs, technology design, and markets to increase the overall number of actors abiding by high environmental and labor standards that can meet the rapidly escalating demand for these technologies.[47]

Conclusion

In 2022, America reaffirmed its global climate leadership with more ambitious state and utility commitments and landmark federal energy and climate legislation. This increased ambition, and funding is projected to substantially drive down power sector emissions by the end of this decade and provide affordable clean energy. Realizing the emission reductions projected in this modeling assessment will require regulatory and permitting reform to facilitate technology deployment and infrastructure development at scale and within the time frame necessary for net-zero by mid-century.

The half-gigaton emissions gap between the path we are on now and net-zero by 2050 necessitates continued support for existing nuclear power plants and other dispatchable low- or zero-carbon resources and technologies – namely, natural gas with carbon capture, small and advanced nuclear reactors, geothermal, and hydropower. The emissions gap also illustrates the importance of sustained policy support to de-risk innovative technologies, and continued public and private sector investments to drive the commercialization and deployment of a diverse suite of technologies to aid in the deep decarbonization of the power sector.

Appendix A. States With Legislated Carbon Reduction Targets Applicable to the Electric Sector

States whose carbon reduction targets originate from executive action or orders are not included. Table is adapted from the Clean Energy States Alliance (CESA) at cesa.org.

State	Emission Reduction Target (%)	Target Year	Year Enacted
California	100% carbon-free electricity	2045	2018
Colorado	100% carbon-free electricity for Xcel Energy	2050	2019
Connecticut	100% carbon-free electricity	2040	2022
District of Columbia	100% renewable energy through the RPS	2032	2018
Hawaii	100% renewable energy through the RPS	2045	2015
Illinois	100% clean energy	2045	2021
Maine	100% clean energy	2050	2019
Maryland	Net-zero greenhouse gas emissions	2045	2022
Massachusetts	Net-zero greenhouse gas emissions	2050	2021
Nevada	100% carbon-free electricity	2050	2019
New Mexico	100% carbon-free electricity	2045	2019
New York	100% carbon-free electricity	2040	2019
North Carolina	Electric generating facilities are carbon neutral	2050	2021
Oregon	Greenhouse gas emissions reduced 100% below baseline emissions	2040	2021
Puerto Rico	100% renewable energy for electricity	2050	2019
Rhode Island	100% renewable energy electricity	2033	2022
Virginia	100% carbon-free electricity for Dominion Energy and Appalachian Power Company	2045; 2050	2020
Washington	100% zero-emissions electricity	2045	2019

Appendix B. Utilities With New or Updated Carbon Reduction Commitments

Utilities that have made new or updated carbon reduction commitments since our last report. This table is exclusive of utilities whose states have adopted legislative carbon reduction targets.

Utility	States	Target	Target Year	Emission Reduction Target
NextEra Energy, Inc.	FL	100%	2045	Zero-carbon emissions
Nebraska Public Power District	NE	100%	2050	Net-zero carbon emissions from generation resources
Northwestern Energy	MT; SD; WY	100%	2050	Net-zero scope 1 and 2 emissions
Otter Tail Power Company	MN; ND; SD	97%	2050	97% reduction in carbon emissions from owned generation resources from 2005 baseline
Trico Electric Cooperative, Inc.	AZ	50%	2032	50% reduction in carbon emissions
WPPI Energy	IA; MI; WI	100%	2050	100% reduction in

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About ClearPath

ClearPath's mission is to develop and advance policies that accelerate breakthrough innovations that reduce emissions in the energy and industrial sectors. To advance that mission, we develop cutting-edge policy solutions on clean energy and industrial innovation. An entrepreneurial, strategic nonprofit, ClearPath 501(c)(3) collaborates with public and private sector stakeholders on innovations in nuclear energy, carbon capture, hydropower, natural gas, geothermal, energy storage, and heavy industry to enable private-sector deployment of critical technologies.

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