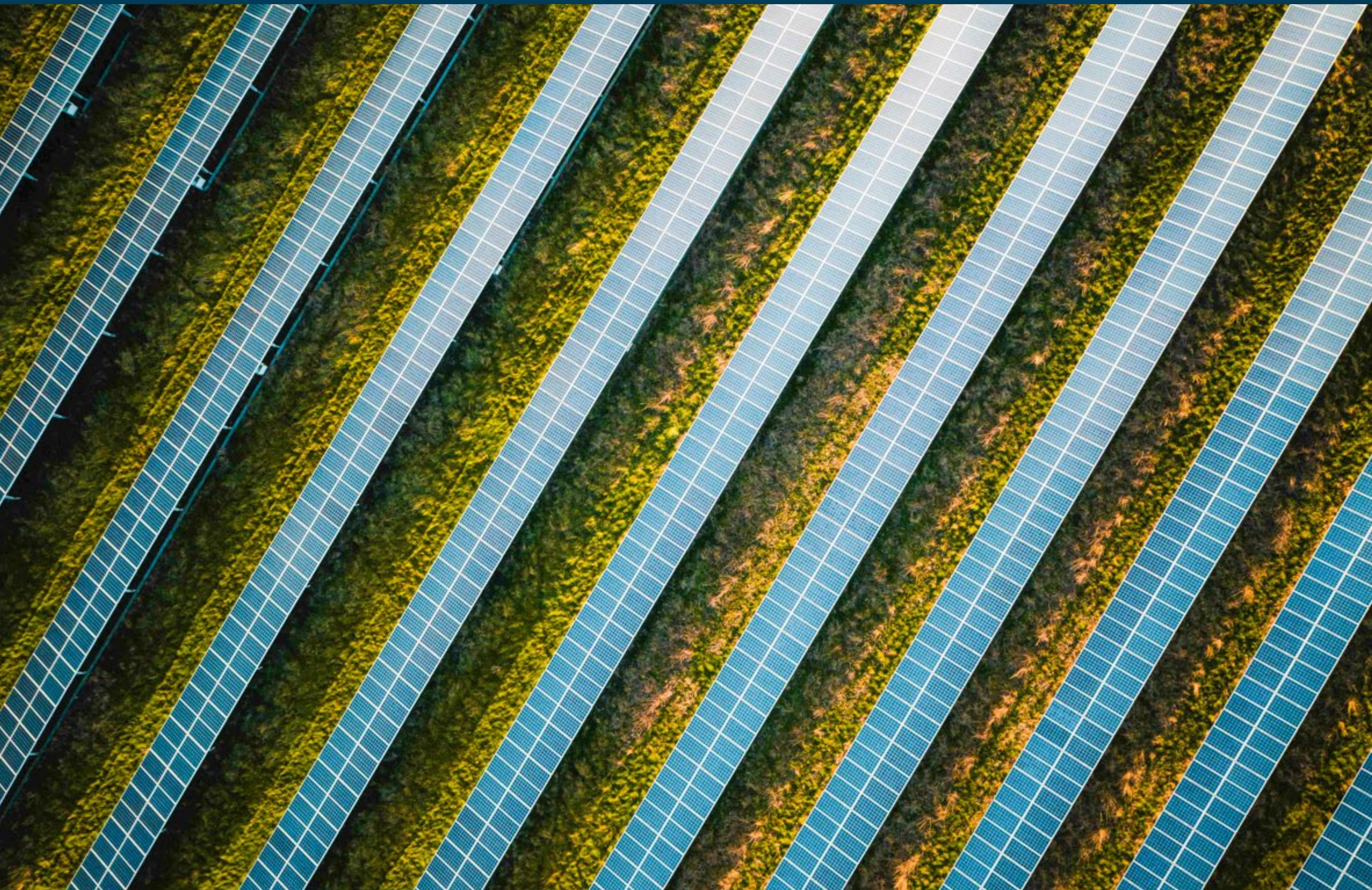
Rhodium Group

Taking Stock 2023

US Emissions Projections after the Inflation Reduction Act

July 20, 2023



Rhodium Group

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Ben King, Hannah Kolus, Naveen Dasari, Michael Gaffney, Anna van Brummen, Whitney Herndon, Galen Hiltbrand, Nathan Pastorek, Alfredo Rivera, Kate Larsen and John Larsen

Table of Contents

Executive Summary

Every year, Rhodium Group provides an independent projection of future US greenhouse gas (GHG) emissions, under current policy and expectations for economic growth, future fossil fuel prices, and clean energy cost and performance trends. This year, the ninth edition of our annual Taking Stock report, the current policy baseline we model includes something different than the last eight reports: meaningful congressional action on climate change in the form of the Inflation Reduction Act (IRA). We've quantified the effect of the IRA in previous work, but this is the first time major federal climate legislation is incorporated into Taking Stock.

The full suite of current policies on the books as of June 2023 drives US emissions to 32-51% below 2005 levels in 2035. Along the way, the US will achieve a 29-42% reduction in GHGs in 2030—a meaningful departure from previous years' expectations for the US emissions trajectory but not enough for the US to meet its pledge under the Paris Agreement to reduce emissions by 50-52% below 2005 levels by 2030. The difference between our estimate's low and high ends is primarily driven by faster economic growth, cheaper fossil fuels, and more expensive clean energy technologies.

Today, nearly one year after Congress passed and President Biden signed the IRA, its effects on the US's path to decarbonization are coming into clearer focus. We have more signals on how federal agencies plan to implement key aspects of the law, including tax credit provisions for clean electricity and clean vehicles—two major sources of emissions abatement. We've also seen markets and supply chains begin to respond to the incentives the law puts in place, and we incorporate the latest cost and performance projections for wind, solar, electric vehicle batteries, and a range of other clean energy technologies to reflect these responses.

With the IRA in place, the power and transportation sectors continue to see the largest declines in GHG emissions relative to today, as detailed in Chapter 3 of this report. The power sector in particular looks quite different in 2035 compared to today, with zero- and low-emitting power plants making up 63-87% of all generation that year, up from around 40% in 2022. Electric vehicles also continue their rapid growth, and, taken together, this progress on decarbonization also reduces household energy bills by an average of $2,200-$2,400 per year in 2035 from 2022 levels.

But challenges remain in achieving these outcomes, especially a massive build-out of new infrastructure. In the power sector, for example, the US needs to add 32-92 gigawatts (GW) of wind and solar on average every year from now until 2035 to achieve these ambitious results. For comparison, adding 32 GW of renewables is roughly equivalent to the best year of renewable installations on record, and adding 92 GW is triple the best year on record. This level of deployment faces headwinds in nearly every direction, meaning more work is likely needed to address supply chain constraints, transmission, interconnection, and siting issues, and a growing need for a qualified workforce—to name a few hurdles.

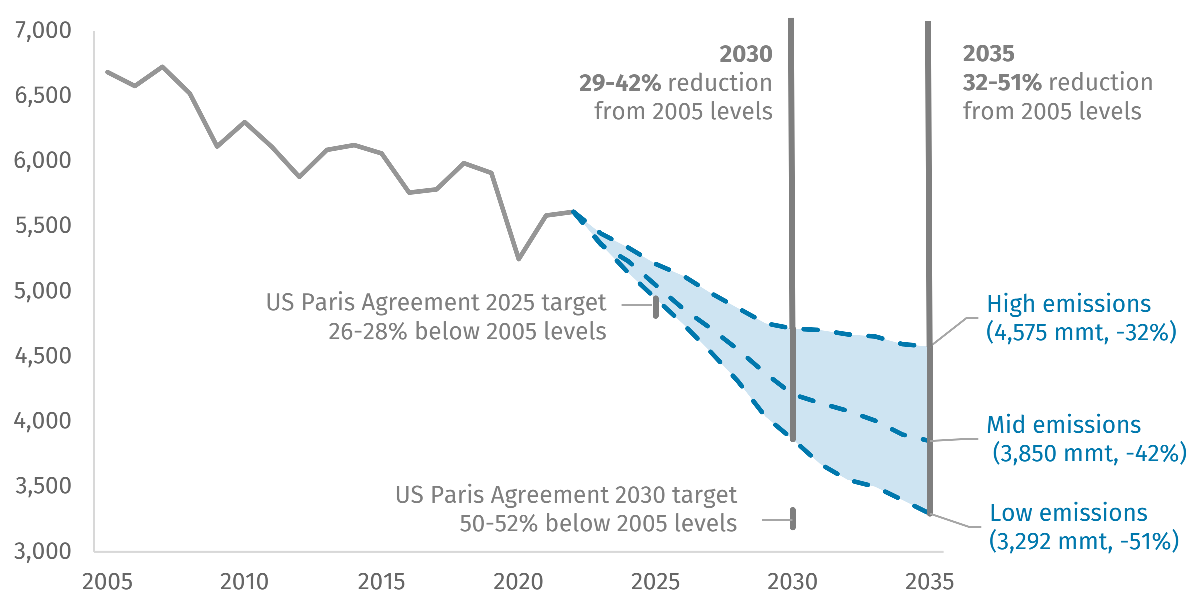
In the vein of additional policy action, in this year's Taking Stock, we also update our look at what other policies are required for the US to achieve its 2030 target under the Paris Agreement. Our previous Pathways to Paris reports quantified the impacts of a set of additional steps that all levels of government need to take to push US emissions to 50% below 2005 levels in 2030. In this report, we update key components of some of those policies to reflect the latest proposals from the federal government, and we find that reductions of 41-52% below 2005 levels are still possible—putting the 2030 Paris target within reach—but getting there won't be easy. Federal actions that the Biden administration can take unilaterally and that can be achieved in the president's first term only yield GHG reductions of 37-49% below 2005 levels, leaving the 2030 target out of reach. While critical, these federal regulatory policies will need to be paired with ambitious state actions. The IRA is the most substantial federal action the US has ever taken to combat climate change, but it was not intended to solve every decarbonization challenge in one bill. A sustained stream of federal and state actions is the only way to close the US emissions gap. While there is more activity at all levels of government than ever, the ramp-up of policy action required in the years ahead will be a substantial lift above and beyond the unprecedented actions of late.

In the first two chapters of this report, we account for changes in policy and energy market & economic conditions since last year's edition. Chapter 3 shares our new projections under current policy, including key trends by sector, and in Chapter 4 we assess the path to the 2030 Paris Agreement target. As in years past, we provide our emissions projections at the 50-state level in all emitting sectors of the economy for all greenhouse gases for the three main emissions scenarios. This detailed data is available on the ClimateDeck, a partnership between Rhodium Group and Breakthrough Energy.

FIGURE ES1

US greenhouse gas emissions under current policy

Net million metric tons (mmt) of CO_2-equivalent (CO_2e)



Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

CHAPTER 1

The Inflation Reduction Act and Other Policy Progress

Rhodium Group releases Taking Stock every year, our baseline projections for future emissions pathways for the United States under current policy (as of June 2023), and expectations for future energy and technology prices. These projections give a sense of where the US is headed on its path to decarbonization, and they also provide an important baseline from which to assess the impacts of potential future policy and technology developments.

This is our ninth year producing Taking Stock and our first baseline update since the landmark Inflation Reduction Act (IRA) was passed in August 2022. We previously assessed the impacts of the IRA and found that it could reduce US greenhouse gas (GHG) emissions by 32-42% below 2005 levels in 2030, given the Taking Stock 2022 baseline. Rhodium Group also participated in a multi-model comparison of the effects of the IRA, recently published in *Science*, that examined the law's expected impacts as quantified by nine different modeling teams. In that paper, the expected GHG reductions from the IRA drive US emissions to 33-40% below 2005 levels in 2030 across the nine models and various scenarios considered.

A lot has changed since we produced our estimates of the impacts of the IRA last year, though nothing as seismic as enacting the most significant climate legislation in US history. We update economic growth projections, energy market expectations, and technology cost and performance data as part of Taking Stock each year, and we discuss the changes we've made in Taking Stock 2023 in Chapter 2. In addition to those modeling fundamentals, we also now have greater clarity on how key aspects of the IRA will be implemented. And though the IRA marks the most significant policy contribution to advance US decarbonization, it's far from the only concrete step taken in the last year. The federal government has continued to make progress on key regulations, and states have also advanced important policies. We discuss these developments later in this chapter. Finally, we consider the implications of this progress for the US meeting its 2030 target of reducing emissions by 50-52% below 2005 levels as part of the Paris Agreement.

Updates to modeling the IRA

Our modeling this year lets us consider whether we're still on the same emissions pathway as we've previously estimated for the US after passage of the IRA, in light of changes to economic forecasts, energy markets, and future technology cost and performance. In addition to these key factors, we have greater clarity on how the federal government—especially the Department of Treasury and the Internal Revenue Service (IRS)—will implement important parts of the IRA. Though questions remain about some provisions, IRS has proposed regulations or otherwise provided increased specificity on essential questions, including:

- Personal and commercial clean vehicle tax credits
- The definition of energy communities eligible for certain bonus credits
- Transferability and direct pay provisions for tax credits
- Prevailing wage and apprenticeship requirements

Many of these rules are proposed or only finalized for the near term. Still, where appropriate, we've updated our representation of these policies, at least directionally, to reflect the specifics coming out of the IRS.

Federal and state policy progress beyond the IRA

Congress has been relatively quiet on the climate front since last year. Despite multiple stops and starts, the House and Senate largely failed to enact meaningful permitting reform. The Fiscal Responsibility Act of 2023, the bill that increased the debt ceiling, included some changes to the administration of the National Environmental Policy Act (NEPA) and approved construction of the Mountain Valley Pipeline by legislative fiat rather than subjecting it to full executive branch review. But the bill did not include language that would actually address the permitting and non-cost barriers that could hold back progress on deployment of clean energy technologies, most notably reforms to the way transmission lines are approved and paid for. There may still be an opportunity to enact such policies in this Congress, but the window is closing. We examine the impacts of permitting challenges and a host of other non-cost barriers to decarbonization later in this chapter.

If Congress has been relatively ineffectual since the IRA, federal agencies have been hard at work. In addition to the raft of guidance mentioned above coming from the IRS, the Environmental Protection Agency (EPA) has also been fairly prolific, most notably proposing greenhouse gas standards on new and existing electrical generating units (EGUs) as well as for light-, medium-, and heavy-duty vehicles for model year 2027 and beyond. EPA has also proposed new limits on effluent discharge as well as mercury and other hazardous air pollutant emissions from steam EGUs. Since these policies haven't yet been finalized, we don't include them in our current policy baseline, but we discuss them in greater detail in Chapter 4. EPA also finalized regulations phasing down hydrofluorocarbons (HFCs), which we include in this year's policy baseline.

At the state level, Washington started its cap-and-invest program in January 2023, and we reflect emissions reductions attributable to that policy in this year's baseline. Another key state carbon program, the Regional Greenhouse Gas Initiative (RGGI), has also seen increased focus, with Virginia taking steps to leave the program and Pennsylvania's participation on legal hold. Given legal uncertainty, we continue to include Virginia and exclude Pennsylvania from RGGI. Several states have also advanced their clean electricity targets.

In the transportation sector, California formally adopted its Advanced Clean Cars II regulations, targeting 100% zero-emitting vehicle and plug-in hybrid vehicle sales by 2035, and six states have followed California's lead and adopted the regulations as well. We provide a complete list of all state policies we include in the current policy baseline in the Technical Appendix.[1]

A pathway to Paris?

It's a near-constant refrain, but it bears repeating: although the IRA leads to a step change in US GHG emissions, that legislation alone does not put the US on a path to meeting its 2030 climate goal under the Paris Agreement. Aggressive policy action from all levels of government is required if the US stands a chance of reducing its GHG emissions by 50-52% below 2005 levels in 2030.

In October 2021, we released Pathways to Paris: A Policy Assessment of the 2030 US Climate Target, in which we quantified the effects of a "joint action" scenario in which policymakers take such aggressive action at all levels. Our original report found that the policies we quantified resulted in a 45-51% reduction by 2030, putting the Paris target in reach. Earlier this year, we updated our projections for that policy package in light of passage of the IRA, finding a 41-51% reduction in the joint action scenario.

In Chapter 4, we again update our quantification of the effects of that policy package in order to incorporate

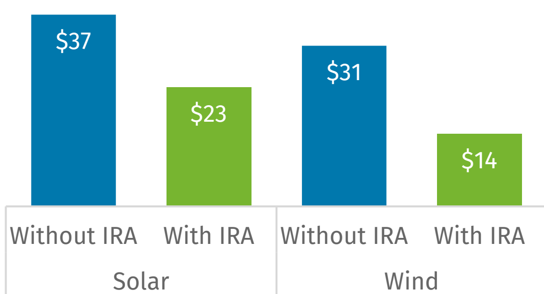
[1] To capture state-level action in our Taking Stock 2023 estimates, we include all state and sub-national polices that are codified with specific targets and timelines to measure progress. We do not include emission reduction targets or goals that are not enforceable or not actionable.

our new baseline emission projections under Taking Stock 2023. We also modify the specifics of some of the policies included in that package to be better aligned with equivalent policies that have been proposed since our original publication—most notably the proposed EPA power plant and LDV GHG standards. We provide this updated modeling as a benchmark against which to assess US progress toward the Paris goal in the limited time remaining to meet it.

Clean energy transition headwinds

Without the IRA, cost competitiveness would be one of the primary barriers to clean energy deployment. For example, new wind and solar facilities have been increasingly competitive with new natural gas generation facilities. However, these generators must also compete with existing, partially or fully depreciated fossil-generating assets to gain substantial market share. But cost competitiveness is not the only barrier to clean technology deployment. An array of headwinds, including onerous permitting processes, siting challenges, workforce constraints, supply chain scale-up difficulties, principal/agent issues, limited consumer information, and other factors also stand in the way.

FIGURE 1
Comparison of representative levelized costs of electricity for facilities built in 2022
2022 US dollars per megawatt-hour



Source: Rhodium Group, NREL Annual Technology Baseline 2022. Note: these costs are based on ATB's resource definition for a representative facility. Without IRA represents unsubsidized LCOE.

Passage of the IRA has largely addressed the cost competitiveness issue for many clean technologies in the power sector, accelerating an existing price trend for renewables and substantially reducing the levelized cost of generation at these facilities (Figure 1) relative to unsubsidized LCOEs—and are increasingly edging out the price of generation at existing fossil facilities as well. Outside the power sector, tax credits in the IRA also help reduce the green premium for electric vehicles, efficient heat pumps, hydrogen electrolyzers, carbon capture, and a host of other technologies. At least while the IRA tax credits are in place, adopting new, lower-emitting technologies is economically attractive.

But if cost is less of a barrier, all the other headwinds remain. Until now, relatively less attention has been paid to these other challenges because cost was front and center. That means policy solutions for overcoming these barriers are less developed and have less political momentum. The recent back and forth in Congress on permitting reform is a case in point.

Without addressing non-cost barriers, it will be harder to achieve ambitious decarbonization outcomes both in this decade and in the long run. Our estimates in this report assume economically rational deployment of clean energy with an implicit representation of many of these non-cost headwinds. Though we take them into account to some degree, the full spectrum of potential outcomes is not explicitly accounted for. We intend to explore and quantify the implications of these headwinds on US emissions in future research.

CHAPTER 2

Bounding Uncertainty in Emissions Projections

We project the energy system and emissions effects of the suite of current policies under a range of future energy markets, technology, and economic futures. Critically, we do not produce probabilistic forecasts but rather determine a range of possible outcomes using a combination of testing and modeler judgment. As such, the ranges we report shouldn't be taken as confidence intervals on a central estimate, instead representing three distinct emissions pathways.

We provide future trajectories under three main pathways:

- Our **low emissions pathway** represents a reasonable low bound on US emissions through 2035, combining our most aggressive cost declines and performance improvements for a range of clean energy technologies (including clean power, industrial decarbonization technologies, electric vehicle prices, direct air capture costs, and beyond) with our highest projected prices for fossil fuels in the future and economic growth consistent with current Congressional Budget Office (CBO) projections through the early 2030s.
- Our **high emissions pathway** represents a reasonable high bound on emissions through 2035 and is effectively the opposite scenario of low emissions: more expensive clean technologies, cheapest fossil fuel prices, and faster-than-expected economic growth.
- Finally, our **mid emissions pathway** takes more moderate projections for many of these factors, with continued cost declines for clean technologies, but not as aggressive as in the low emissions scenario; fossil fuel prices roughly consistent with recent historical averages; and continued use of CBO's baseline economic growth.

We provide more details on the constituent inputs of these scenarios and our modeling environment in the rest of this chapter, and we go into much greater detail in the Technical Appendix to this report.

Economic projections

We compared a range of macroeconomic forecasts from government institutions, non-governmental organizations, and the financial sector, considering key metrics, including inflation and federal funds rates. Ultimately, we opted for two economic forecasts that effectively bracket official expectations from the Congressional Budget Office (CBO). Under baseline economic conditions, which we use in our low and mid emissions pathways, GDP is slow to grow in the near term, averaging 1.1% annual growth through 2025—essentially a soft landing on the back of aggressive interest rate hikes but avoiding a recession. Growth returns to a steadier 1.9% per year through the rest of the 2020s before settling at its average since 2008 of about 1.8% through the early 2030s. CBO projects a slightly faster return to growth after a slow 2023, averaging 1.6% annual growth through 2025, then settling in just under 2% a year through 2033 (the end of their current forecast).

Under high growth, used in our high emissions pathway, annual GDP increases exceed the CBO forecast, reaching 2% a year through 2025, 2.2% a year from 2026-2030, and 2.1% a year from 2031-2035.

Economic growth alone is a major factor in future emissions pathways, and in our testing, we found that a shift from baseline to high economic growth while holding all other inputs constant yields an emissions increase of at least 200 million metric tons in 2030. Conversely, any surprise shocks that push GDP down can also decrease emissions (see, for instance, the impact of the COVID-19 recession on emissions in 2020), and such shocks are not captured in this framework. Overall, GDP drives emissions growth through a number of factors, including availability of household disposable income, which in turn drives factors like electricity consumption, vehicle miles traveled, and vehicle purchasing decisions. Industrial output, a key component of GDP, is also positively correlated with emissions.

Energy markets

We use three energy market projections for future fossil fuel prices alongside the two economic growth forecasts discussed above. In the lowest price projection, natural gas prices at Henry Hub average $3.60/MMBtu through 2025 and hover around $2.60/MMBtu in the late 2020s, declining to match some of the lowest annual average prices in recent history. Prices rebound to $2.90/MMBtu in the early 2030s. Brent crude prices likewise remain slightly elevated through 2025, averaging $88/barrel, before settling just above historical averages at $78/barrel in the late 2020s and $80/barrel in the early 2030s. These prices represent continued strong US production of gas and oil and flattening demand for domestic consumption, especially for natural gas.

The mid and high fossil price projections represent higher prices than in recent history, which aligns with many external projections for these prices. In the mid price scenario, natural gas averages $4.20/MMBtu for the next few years, $3/MMBtu in the late 2020s, and $3.40/MMBtu in the early 2030s. In the high price scenario, gas prices take even longer to return from recent peaks, averaging $5.70/MMBtu through 2025, before settling to $4.90/MMBtu in the late 2020s and $5.30/MMBtu in the early 2030s.

In oil markets, Brent crude likewise remains elevated, averaging $90 and $94/barrel in the mid and high price scenarios through 2025, then $88 and $97/barrel in the late 2020s, and finally $92 and $98/barrel through 2035.

Clean technology cost and performance

We rely on the latest technology cost projections from the National Renewable Energy Laboratory's 2023 Annual Technology Baseline for most of our utility-scale and distributed renewable energy costs. Where appropriate, we adjust costs to reflect important differences between the technologies that ATB assumes and the technology included in our model, but we remain well-aligned with the overall cost trajectories. For both onshore wind and utility-scale PV, this year's ATB projects higher expected capital costs through our study window than last year's vintage of the ATB.

We use low, reference, and high battery storage costs from Annual Energy Outlook (AEO) 2023 in the power sector. We use Rhodium Group's estimates for central, low, and high costs for carbon capture technologies in the power sector. We generally rely on AEO2023 reference case projections for unabated fossil and nuclear costs.

In the transportation sector, our lowest electric vehicle (EV) battery cost projections are based on forecasts from BloombergNEF, while our mid and high battery costs are modified versions of the AEO2023 reference case. In industry, we recently completed a substantial update to our Industrial Carbon Abatement Platform (ICAP), including updated carbon capture retrofits costs and replacing existing steam methane reformers with electrolyzers.

Using RHG-NEMS

We use RHG-NEMS to quantify the energy sector and emissions outcomes. RHG-NEMS is a modified version of the National Energy Modeling System (NEMS), a model developed by the US Energy Information Administration (EIA) to produce their Annual Energy Outlooks. Rhodium Group maintains a version of NEMS that we modify from the EIA base version. In addition to changing a number of key inputs (as described above) and bringing the current policy representation up to date as of June 2023, we also vary key assumptions and algorithms in the model based on research and real-world observations.

We expand this version of NEMS to include all sectors of the US economy and coverage for all six greenhouse gases targeted for reduction under the Kyoto Protocol. This year, we update to the latest land use, land use change, and forestry (LULUCF) projections from the US Fifth Biennial Report. Consistent with EPA's annual Inventory of Greenhouse Gas Emissions and Sinks and United Nations Framework Convention on Climate Change (UNFCCC) requirements, we also update to use 100-year global warming potential (GWP) values from the IPCC Fifth Assessment Report (AR5). We integrate this version of NEMS and RHG-ICAP to produce deployment of decarbonization technologies in the industrial sector. Finally, we downscale this data to provide state-level results for key metrics.

CHAPTER 3

Emissions Outlook and Key Trends by Sector

Based on the scenarios described in Chapter 2, we estimate that total net greenhouse gas emissions will decline to 3.3 to 4.6 gigatons (Gt) of CO_2-equivalent (CO_2e) in 2035, representing a 32-51% reduction below 2005 levels that year (Figure 2). In all scenarios, emissions decline the most rapidly in the 2020s, while the bulk of IRA provisions remain in place. Then abatement slows as some IRA provisions expire in the early 2030s. The US meets its 2025 Paris climate target of a 26-28% reduction below 2005 levels in the low emissions case but doesn't do so in the other cases. Without additional policy action, the US reaches its 2030 Paris climate target under our low emissions scenario—but five years too late.

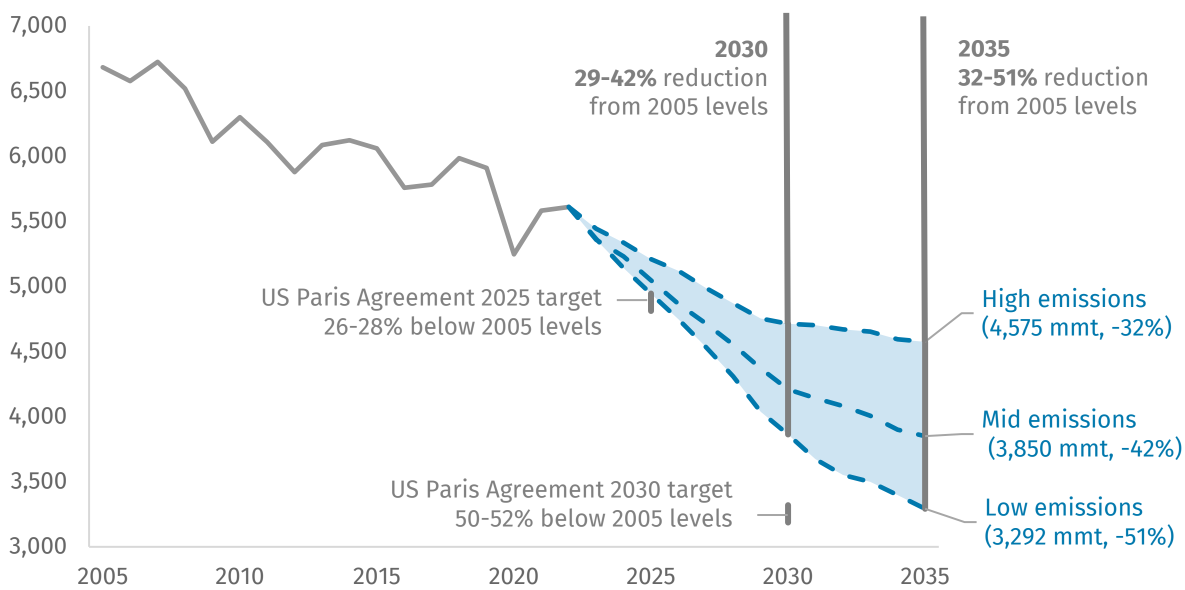
In 2030, we estimate GHG emissions decline to 3.9 to 4.7 Gt or 29-42% below 2005 levels. These estimates comprise a slightly wider range of emissions outcomes from our previous estimates of the impacts of the IRA, in which we found emissions could reach 32-42% below 2005 levels in 2030.[2] Several factors account for this difference, including a bit less abatement in the power sector, revised estimates of the carbon sink associated with natural and working lands, and generally higher levels of domestic natural gas production.

A few key sectoral trends are underpinning these economy-wide results, which we unpack in the remainder of this chapter.

FIGURE 2

US greenhouse gas emissions under current policy

Net million metric tons (mmt) of CO_2e



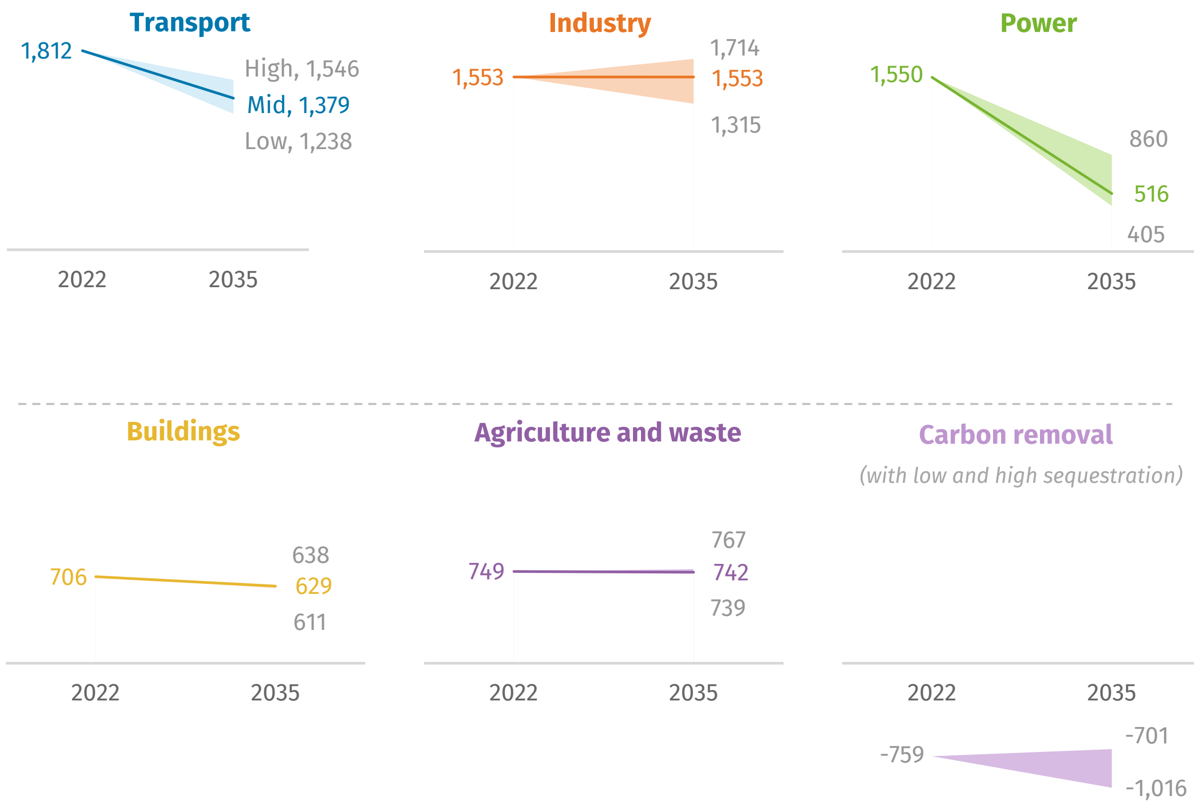
Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

[2] Absolute emissions levels are not directly comparable between Taking Stock 2022 and 2023 due to our use of updated global warming potentials (GWP), consistent with EPA's approach in their annual Inventory of U.S. Greenhouse Gas Emissions and Sinks.

FIGURE 3

US greenhouse gas emissions under current policy

Net million metric tons (mmt) of CO_2e



Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

GHG emissions abatement is primarily concentrated in the power and transportation sectors.

Emissions decline by 45-74% from today's levels in 2035 in the power sector and by 15-32% from today's levels in 2035 in the transportation sector (Figure 3). Deployment of direct air capture (DAC) and bioenergy with CCS (BECCS) technologies for fuel production, alongside a modestly increasing carbon sink in natural and working lands, also drive abatement in the carbon removal sector.

On the other hand, emissions decline more modestly in the buildings sector, reducing by 10-14% over today's levels in 2035, and are effectively flat in agriculture and waste. As expected, the industrial emissions trajectory heavily depends on the underlying emissions pathway assumptions, but in all cases industry becomes the largest emitting sector in 2035. Higher output and cheap natural gas drive industrial emissions up in the high emissions case, while the opposite is true in the low emissions case.

Economic growth and gas and renewable prices drive the biggest differences between emissions cases.

We estimate that a shift to the faster GDP growth pathway between the mid and high cases is responsible for about 250 MMT, or about four percentage points, of the emissions differences between those cases in 2035. Higher natural gas prices drive lower industrial output and lower industrial emissions between the low and mid cases. The wide spread in industrial emissions is also partly a function of domestic gas production, which we discuss in more detail later in this chapter.

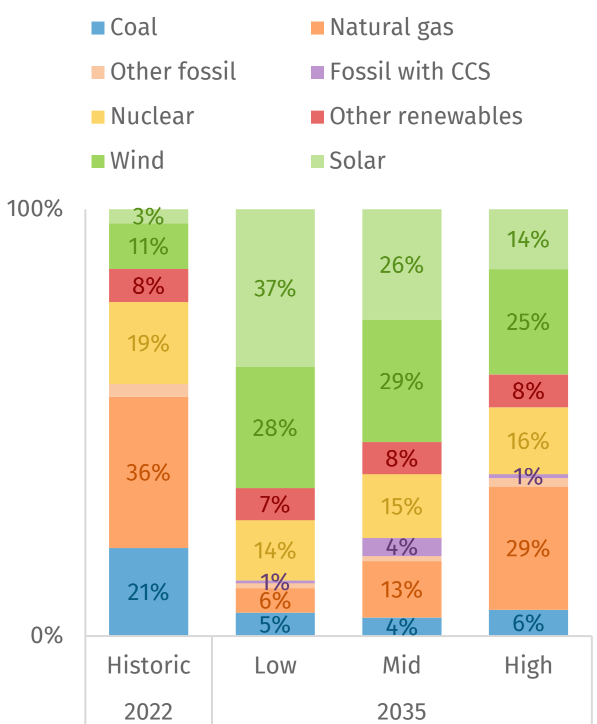
In power, renewables and natural gas vie to backfill retiring coal (and, to a lesser extent, nuclear) capacity, with the relative economics of those resources determining deployment and power sector emissions reductions. The difference in uptake of EVs between the cases in both the light-duty and freight fleets is the major determinant of transportation sector emissions.

The power sector looks very different in 2035 than it does today.

In 2022, unabated fossil-fired power plants represented just under 60% of total electricity generation, with the remaining 40% made up of nuclear, wind, solar, and other renewables. Coal remained a major contributor to the grid, providing around 21% of total generation, and remained a major source of GHG emissions as well.

Even in the high emissions scenario in 2035, this breakout flips, with zero-emitting generating sources powering 63% of the grid, including 39% of power coming from wind and solar alone (Figure 4).

FIGURE 4
Power sector generation by technology
Percent of total generation



Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

As clean generating sources get cheaper and fossil fuels get more expensive in our mid and low-emissions cases, clean generators make up an increasing share of total generation: 81% and 87% of all generation, respectively.

Half to two-thirds of generation comes from wind and solar in these scenarios. Clean generators are also able to meet increasing demand for electricity, which expands by 12-14% in 2035 from 2022 levels.

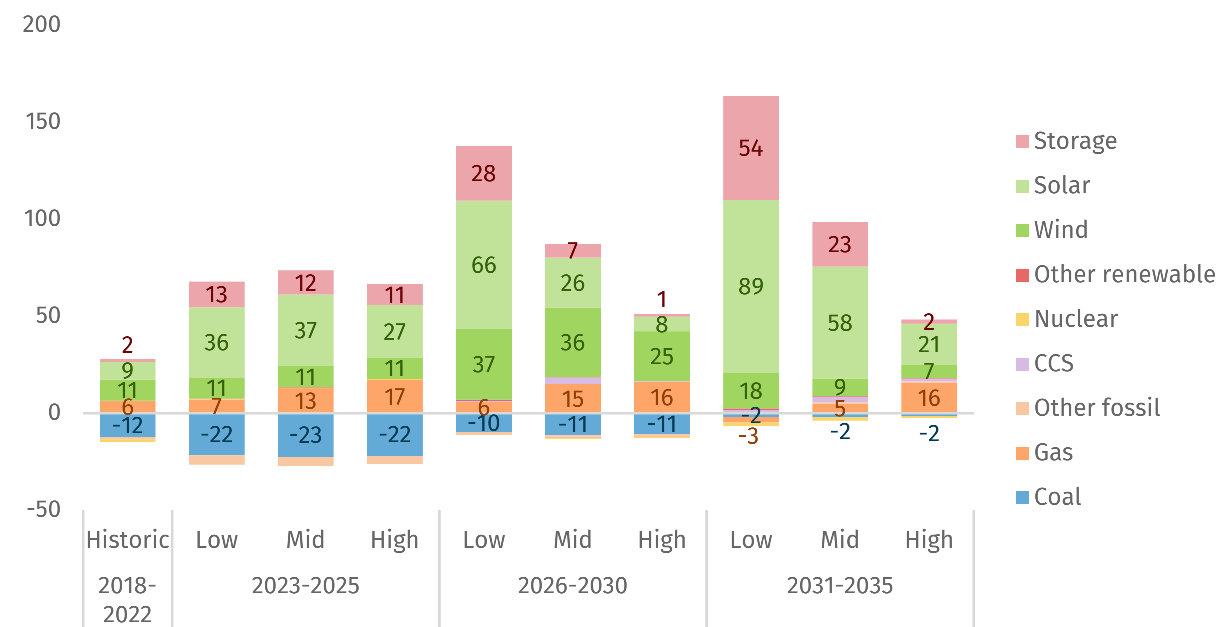
These impressive clean energy shares are achieved through a massive buildout of new generators and changes to the fossil fleet.

Wind and solar add an average of 32-92 GW of capacity to the grid *every year* from 2023-2035, with solar in particular shattering historical records and adding as much as 89 GW alone per year in the early 2030s (Figure 5). On the low end of this range, this level of growth means matching our best historical year of deployment every year from now until 2035, while on the high end of this range it means tripling our best year on record. Energy storage also expands substantially to help integrate these increases in variable renewable generating capacity, averaging 4-35 GW of new capacity annually through 2035.

As we discuss above, achieving this level of growth is likely to face non-economic headwinds, including limitations on transmission build-out, the potential for local opposition and other siting and permitting issues, and supply chain constraints. Finding ways to mitigate these headwinds will be critical to realizing the potential emissions-reducing benefits of installing this much capacity.

The other factor driving emission outcomes in the power sector is changes to the fossil generator fleet. Based on both announced retirements as well as economic decision-making by plant owners, we project the existing trend of coal plant retirements to accelerate in the near term, averaging 22-23 GW of coal retirements each year from 2023-2025, up from 12 GW over the past five years. Retirements return to historical levels in the late 2020s and then trail off in the early 2030s given a much smaller coal fleet.

FIGURE 5
Average annual net capacity change (additions less retirements)
GW



Source: Rhodium Group

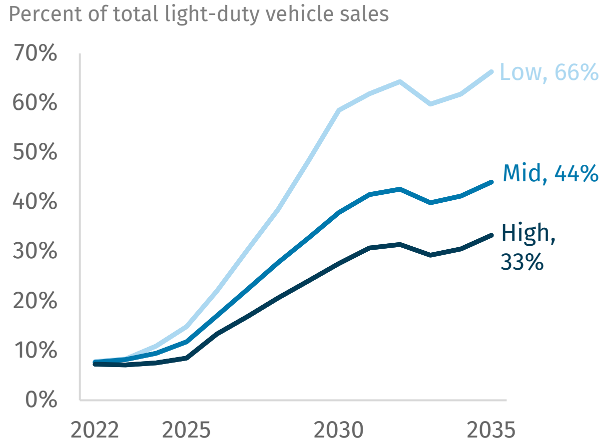
Additions of combined-cycle and peaker gas plants also accelerate into the 2030s in the mid and high emissions cases. But gas capacity growth is effectively flat through 2030 in the low emissions case and then starts to decline in the early 2030s.

Electric vehicles generally see significant growth through 2035

We estimate that EVs could make up 33-66% all light-duty vehicle (LDV) sales in 2035, up from around 6% in 2022 (Figure 6). In the near term, we assume a relatively small share of electric LDVs qualify for the consumer clean vehicle tax credit. Most of the increase in sales by 2025—to 9-15% of total LDV sales—is a function of declining battery prices. In the late 2020s and early 2030s, we assume increasing numbers of vehicles meet the sourcing requirements for battery components and critical materials and meet the retail price requirements, driving large increases in EV sales through that period. Once the consumer and commercial vehicle credits expire in 2032, we see modest declines for a few years before battery price reductions again yield upticks in EV adoption.

Beyond the LDV fleet, zero-emitting vehicle (ZEV) sales also accelerate for freight trucks, with medium- and heavy-duty trucks reaching 16-48% ZEV sales in 2035. The difference in EV uptake in the LDV fleet is responsible for the majority of transportation emissions differences between cases, but this ZEV uptake for trucks also drives emissions outcomes.

FIGURE 6
Light-duty vehicle electric sales shares
Percent of total light-duty vehicle sales



Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

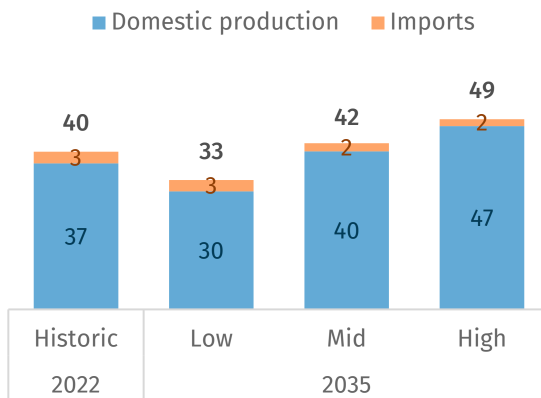
Domestic gas production and consumption show increasing signs of decoupling.

Compared to 2005, before the shale revolution fundamentally altered natural gas production in this country, domestic gas production has effectively doubled while domestic consumption has increased by about 50%. Though consumption has grown more slowly than production, thanks in part to decreased gas imports, these two figures have historically moved in the same direction.

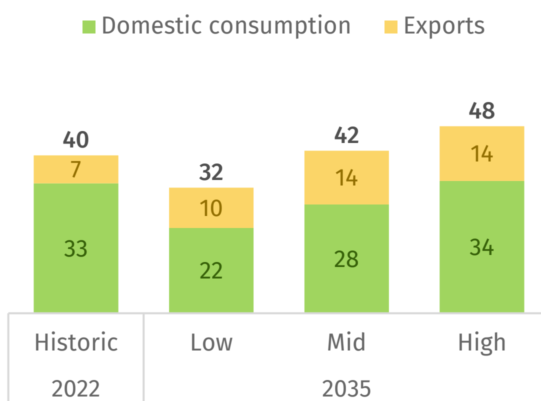
We see a weakening of this trend through 2035. In our mid and high-emissions cases, domestic gas production increases by 8% and 26% from 2022 levels, while production drops by 19% from 2022 levels in the low-emissions case (Figure 7). Meanwhile, domestic consumption drops in both the low and mid emissions case, by 34% and 16%, respectively, in 2035 and increases by a modest 2% in the high emissions case. This increasing divergence between supply and demand is partly driven by increased natural gas exports, predominantly via liquified natural gas (LNG) terminals. Exports increase in all cases, comprising around a third of total gas use in 2035.

The Energy Information Administration released an informative Issues in Focus in conjunction with this year's Annual Energy Outlook, considering the effect of global LNG prices on the US natural gas market. EIA finds that higher global LNG prices lead to higher US LNG export levels and exported LNG comprising an increasing share of domestic gas production. Our modeling suggests that the economic dynamics they identify also exist even absent higher global prices with slack US gas demand keeping gas prices lower than they otherwise would have been and improving the economics of LNG exports.

FIGURE 7
Natural gas supply in 2035
Quadrillion BTU



Natural gas use in 2035
Quadrillion BTU

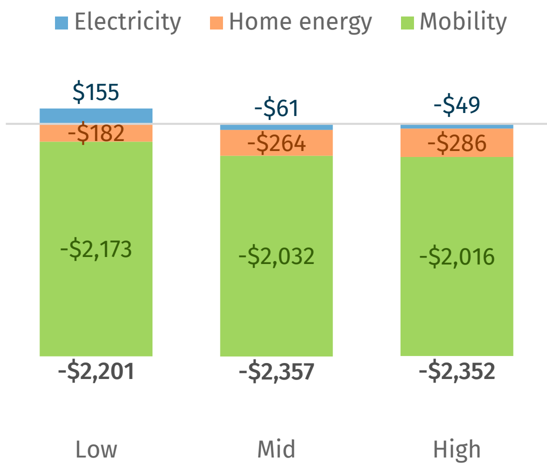


Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

Household energy bills see meaningful declines.

In 2035, total average annual household energy bills are $2,200-$2,400 (34-36%) lower compared to 2022 levels. The most substantial change comes in spending on gasoline and diesel for motor vehicles, helped by higher levels of EV deployment, fuel economy standards, and overall lower fuel demand leading to lower prices for all consumers. Electricity bills see declines or, in the case of the low case, a modest increase, in part owing to this new electricity demand from EV charging. Lower economy-wide gas demand also reduces the price of natural gas for home heating, reducing home energy bills.

FIGURE 8
Change in household energy costs from 2022 to 2035
2022 US dollars



Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

CHAPTER 4

Closing the Gap to the Paris Target

In October 2021, Rhodium Group released Pathways to Paris: A Policy Assessment of the 2030 US Climate Target, a report that proposed one set of policy actions that could put the US on course to meet its 2030 Paris climate target of a 50-52% reduction in GHG emissions from 2005 levels. We projected the US would achieve a 17-25% reduction by 2030 under current policy at the time, so there was a substantial gap to close—and meaningful congressional action on climate was anything but certain. Nonetheless, we found in our joint action scenario that with an aggressive set of policy actions across congressional, federal executive, and subnational actors, the US could expect a 45-51% reduction in GHG levels by 2030.

Then the unexpected happened: Congress passed the Inflation Reduction Act, the single largest investment in addressing climate change the federal government has ever made. In so doing, they also largely satisfied the congressional component in our joint action scenario—but a host of other actions are still required. To set the stage for these additional actions, in March 2023 we updated our estimates of the emissions impacts of the remaining federal executive and subnational policies accounting for the IRA's passage, finding that a 41-51% decline below 2005 levels was still possible in 2030 in our joint action scenario. We also modeled a federal action-only scenario that isolated the emissions impacts of policies that could be enacted by federal executive branch agencies, and we estimated a 38-48% decline in 2030 emissions from these policies alone.

A few key things have changed since we released those updated estimates earlier this year. First, we have updated current policy baselines accounting for the latest developments in technology costs, fossil fuel prices, and policy action, which we unpacked in Chapter 3. Second, federal agencies have been busy, proposing new regulations tackling GHG emissions in several sectors.

In the remainder of this chapter, we discuss changes we've made to the policies we model in our future policy scenarios in light of the proposals we've seen from federal agencies. Then we provide updated emissions estimates, starting from our new baseline and incorporating these policy changes.

Updates to federal regulatory policy

We include updated representation of key elements of several federal executive agency policies in our joint action and federal action-only scenarios.

One of the most hotly anticipated rules in the federal regulatory agenda is EPA's proposal for regulating GHG emissions from new and existing power plants. Since the Supreme Court's decision last year in *West Virginia v. EPA* eliminated generation shifting as a method of setting the best system of emissions reduction (BSER), energy analysts and Clean Air Act attorneys have been eagerly waiting to see how EPA would draft rules that they hope will pass muster with the Court but still move the needle on power sector emissions. EPA responded with requirements for a mix of carbon capture retrofits, hydrogen blending, natural gas cofiring, federally enforceable retirement decisions, and capacity factor limitations.

Though EPA's proposed rule fills in many of the unknown details, there are some open questions on which EPA is soliciting comment. Moreover, the rule is likely to change between now and its anticipated finalization next summer. In our update to GHG regulations for power plants, we generally adopt EPA's proposed phase-in schedule and the stringency of emissions reductions, but we offer a high degree of flexibility for states to create and submit plans for achieving equivalent levels of emissions reductions. As such, our estimates of the impacts of the 111 rules should be understood as an initial cut, and we plan to dig more into the details of a number of design elements in future work.

Beyond power plant rules, EPA has also proposed the first-ever GHG standards for light-, medium-, and heavy-duty vehicles for model years 2027 and beyond. EPA estimates these rules could drive EV sales to 60% of all LDVs in 2030 and 67% in 2032. In our joint action and federal action-only scenarios, we reflect a roughly equivalent grams-per-mile pathway for the light-duty fleet. EPA has also issued a supplemental proposal for their oil and gas methane rule, which we update in this version of the two action scenarios as well.

Aggressive joint action keeps the US 2030 climate target in reach

The complete list of policies we model as part of our joint action scenario is included in the Technical Appendix and includes the federal regulatory policies we discuss above, additional rules for the power sector, minimum equipment performance standards, and repurposing discretionary funding at the Commodities Conservation Corporation for climate-smart agriculture and forestry practices. In addition, climate leader states ramp up to best-in-class clean energy standards, ZEV mandates, adopt low-carbon fuel standards, and implement other decarbonization policies.

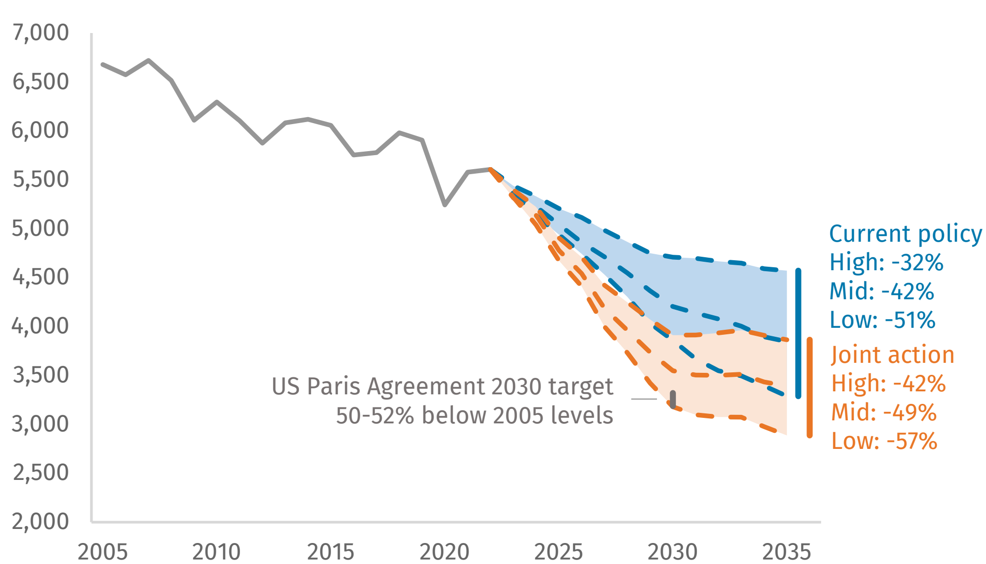
Together, these actions can reduce economy-wide GHG emissions to 3.2-3.9 gigatons in 2030, or a 41-52% reduction below 2005 levels (Figure 9). The US achieves its 2030 climate target under the Paris Agreement in the low emissions case. Abatement continues beyond 2030 except in the high case, and by 2035 emissions are 42-57% below 2005 levels.

The sectoral sources of this abatement vary somewhat from emissions pathway to emissions pathway in 2030, but the biggest gains occur in power, transport, industry, and carbon removal (Figure 10).

FIGURE 9

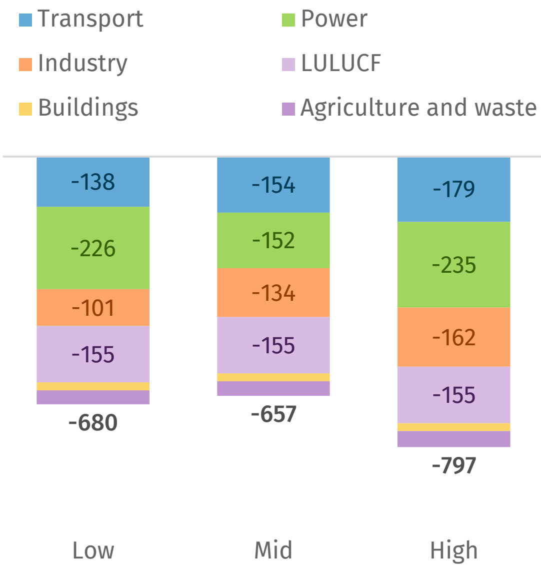
US greenhouse gas emissions with joint action

Net million metric tons (mmt) of CO_2e



Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

FIGURE 10
Emissions abatement by sector in 2030
Million metric tons of CO_2e



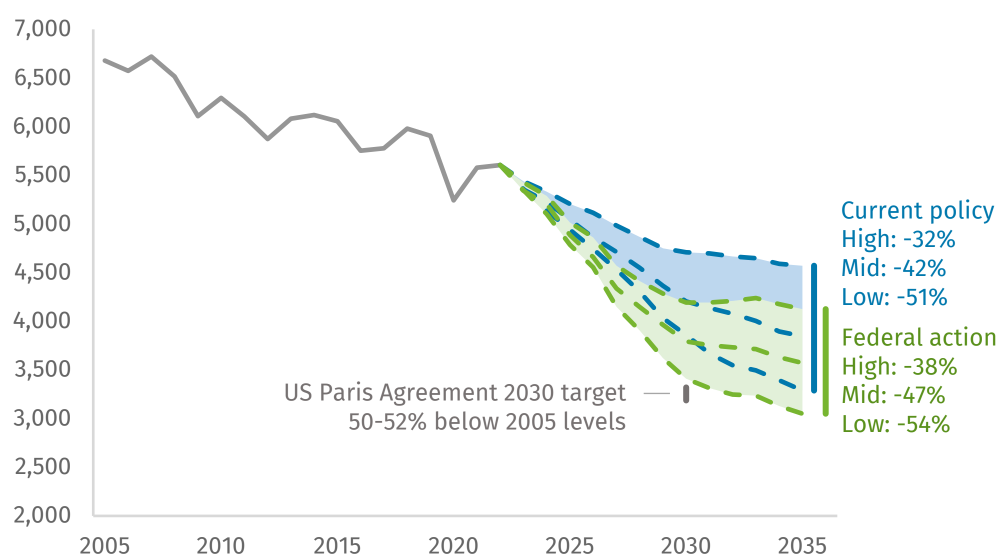
Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

In the low and high emissions pathways, the power sector sees the single largest abatement increase, spurred on by the EPA power plant rules as well as state clean electricity standard targets. The abatement is nearly evenly spread across these four sectors in the mid-emissions pathway. Transportation sector emissions are driven down across the board by higher uptake of zero-emitting vehicles in the light-duty fleet and among freight trucks owing to EPA standards and state policy. Industrial abatement primarily results from EPA finalizing its oil and gas methane regulations. In addition, important if small progress is made in buildings and agriculture and waste—two sectors where we see less impact from the IRA.

Federal action is a critical component of meeting emissions goals

When we look at the impacts of just the federal components from our joint action scenario, setting aside any potential policy progress at the state level, we find that federal policies make a meaningful difference but are not enough on their own to achieve the 2030 Paris climate target (Figure 11). As with the joint action scenario, the bulk of abatement occurs by 2030, at which point emissions are 37-49% below 2005 levels. The rate of emissions abatement slows in the following half-decade, and emissions wind up at 38-54% below 2005 levels in 2035. Though not enough to get the US to the Paris finish line, these actions are critical to an all-of-government approach to doing so.

FIGURE 11
US greenhouse gas emissions with federal action only
Net million metric tons (mmt) of CO_2e



Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around future fossil fuel prices, economic growth, and clean energy technology costs.

CHAPTER 5

A Look Ahead

As we've identified throughout this report, there are some important issues to watch between now and the release of Taking Stock 2024 next year.

We will be digging more deeply into non-cost barriers to clean technology deployment. The extent to which these headwinds can be abated will significantly impact just how many wind turbines, solar panels, EV batteries, and a host of other clean technologies we will see in use in the real world.

We also anticipate that the Biden administration will rush to finalize many important regulations before the end of this presidential term. We plan to unpack the power plant GHG regulations in more detail in the coming months to better understand how those complex proposed rules will affect the power system and US emissions. We'll also monitor EPA's proposed vehicle emissions standards and watch for finalization of the proposed oil and gas methane rules.

Access the data

We've provided a national look at trends in this report, but RHG-NEMS also produces state-level estimates for GHG emissions and key energy sector outcomes. Direct access to those results for our three main emissions scenarios is available via the ClimateDeck, a partnership between Rhodium Group and Breakthrough Energy. The ClimateDeck can equip users with comprehensive datasets, unique and responsive insights, and a robust set of tools for tracking pathways to climate targets and understanding the emissions and economic implications of major international, national, and state developments. All of this is available for exploration and download from our interactive data visualization platform. For access, contact climatedeck@rhg.com.

TABLE 1

US GHG emissions under emissions scenarios

Million metric tons of CO_2e

Gas	2005	2022	2025	2030	2035
Carbon dioxide	6,120	5,099	4,547 to 4,763	3,691 to 4,405	3,240 to 4,295
Methane	790	654	658 to 712	616 to 726	594 to 739
Nitrous oxide	415	427	384 to 389	374 to 386	371 to 387
HFCs	116	179	154	116	92
Other F-Gases	22	11	12	11	11
Gross GHG emissions	7,466	6,369	5,754 to 6,030	4,809 to 5,644	4,308 to 5,525
Carbon removal*	-781	-759	-809 to -820	-931 to -946	-950 to -1,016
Net GHG emissions	6,682	5,610	4,944 to 5,210	3,863 to 4,713	3,292 to 4,575
Change from 2005	0%	-16%	-22% to -26%	-29% to -42%	-32% to -51%

Source: Rhodium Group. Columns represent the minimum and maximum annual net US emissions given likely energy market, policy, and carbon removal outcomes. *Includes Land Use, Land Use Change, and Forestry (LULUCF) from the high sequestration scenario and carbon capture and sequestration.

Technical Appendix

This Technical Appendix provides additional detail on the methods and data sources used in Rhodium Group's Taking Stock 2023 report, as well as those in the update to the Pathways to Paris report. Direct access to all energy and emissions results from our Taking Stock 2023 baselines—including results broken down by gas and sector for all 50 US states through 2035—is available via the ClimateDeck. ClimateDeck also includes dashboards with results from our updated joint action and federal action only scenarios.

All historical greenhouse gas (GHG) emissions and removal estimates (1990-2021) come directly from the Environmental Protection Agency (EPA) Greenhouse Gas Inventory. Like the EPA inventory, all gases are reported in carbon dioxide (CO_2)-equivalent emissions based on the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) 100-year global warming potential (GWP) values. To model potential future emissions and policy scenarios, we use RHG-NEMS, a modified version of the detailed National Energy Modeling System used by the Energy Information Administration (EIA) to produce the Annual Energy Outlook 2023 (AEO2023) and maintained by Rhodium Group. We expand on this model to project all six GHGs targeted for reduction under the Kyoto Protocol.

Energy market, technology, and economic assumptions

To construct our Taking Stock GHG emissions projections range, we revise multiple energy market, technology cost, policy, and behavioral assumptions in RHG-NEMS to be consistent with the most recent research and to reflect the range of market and economic uncertainties. These assumptions are updated yearly to reflect the best available data and information. More granular data for many of these inputs are included on the ClimateDeck. Unless otherwise stated below, we use EIA's AEO2023 Reference case assumptions in our Taking Stock projections.

Sources of uncertainty

To construct the full range of emission projections in Taking Stock, we looked at three key sources of uncertainty:

- Energy markets: We consider a range of energy market variables that shape emissions outcomes, including natural gas and oil resource availability and prices.
- Technology cost and performance: We estimate ranges for key technology cost and performance variables, including capital and operating costs for clean electricity generators and battery costs for light-duty electric vehicles (EVs).
- Economic growth: We use two different projections of US gross domestic product (GDP) growth in TS2023: a baseline growth rate and a high growth rate.

RHG-NEMS inputs that are consistent across the emissions outlook

We make several revisions to input assumptions beyond EIA's AEO2023 Reference case that are consistent across our Taking Stock emissions range:

- Announced power plant retirements/additions: We incorporate all announced coal and nuclear power plant retirements through 2035. We also account for state-level policy actions that will allow for continued operation of certain nuclear power plants in those states.
- Electric vehicle uptake: We revise key parameters to reflect recent historical EV sales as well as expectations relating to ongoing EV research and development and industry investment.
- Electric vehicle charging costs: We alter fuel costs for electric vehicles to reflect current charging behavior.

- Automated vehicle deployment: RHG-NEMS does not capture the impact of autonomous transportation technologies for personal vehicle use.

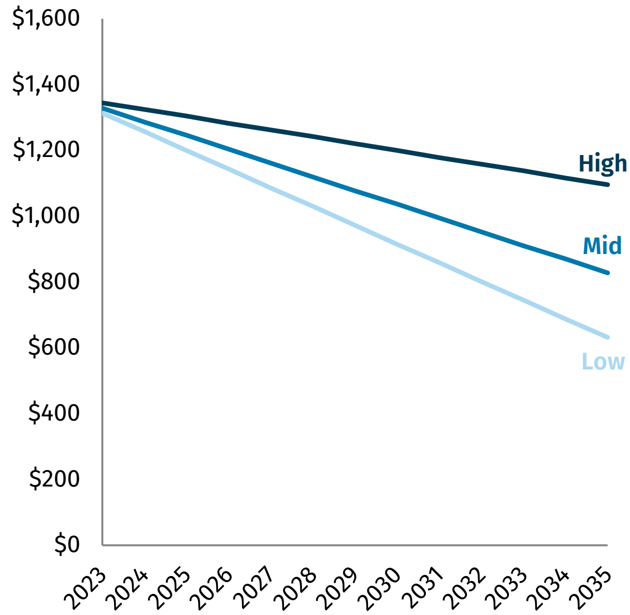
RHG-NEMS inputs that vary to capture energy market uncertainty

Below are the key assumptions that vary across our estimated emission range and underlying data sources. For each input, we defined a mid, low, and high case to reflect a range of potential market and technology cost outcomes.

Electric generating technology costs: We generally assume capital costs for utility-scale and distributed solar photovoltaic, land-based wind, and off-shore wind decline according to NREL's 2023 Annual Technology Baseline's (ATB) technology cost projections. We adjust the costs included in ATB to account for differences between the default technology that NREL assumes for its projections and the comparable technology in RHG-NEMS. Our mid-cost assumptions follow ATB's Moderate Technology Innovation Scenario, while our low- and high-cost assumptions follow the Advanced Scenario and Conservative Scenario, respectively. For utility-scale energy storage, we adopt the costs used in the AEO 2023 Reference case and High and Low Zero-Carbon Technology cost cases as our mid, high, and low costs, respectively.

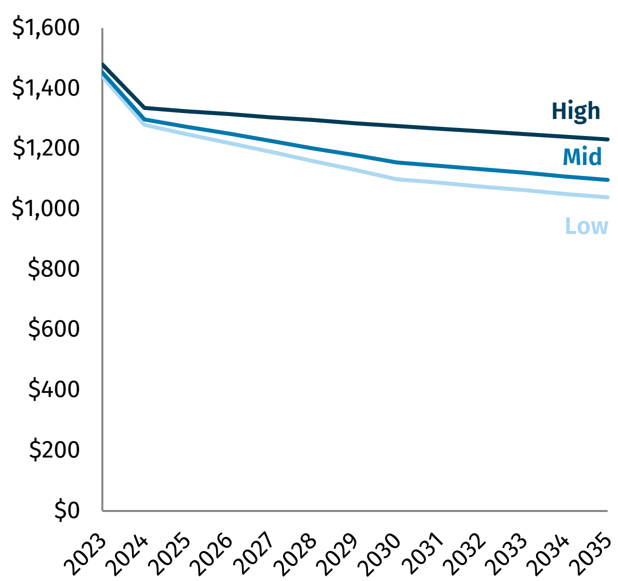
We also change relevant cost and performance parameters for power generating facilities equipped with carbon capture technology, informed by Rhodium analysis and current literature. Of particular note are modified regional transportation and storage costs consistent with those used in Rhodium's Industrial Carbon Abatement Platform (see the section below) and revisions to costs of new-build natural gas plants with carbon capture. We adapt work from the National Energy Technology Laboratory, which details cost and performance of natural gas-fueled direct supercritical CO_2-fired power plants.

FIGURE A1
Utility-scale solar photovoltaic overnight capital costs
2022 dollars per kilowatt



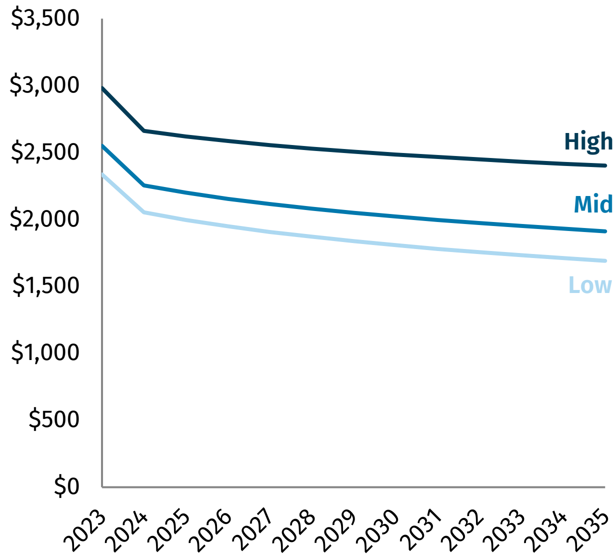
Source: Rhodium Group, NREL

FIGURE A2
Land-based wind overnight capital costs
2022 dollars per kilowatt



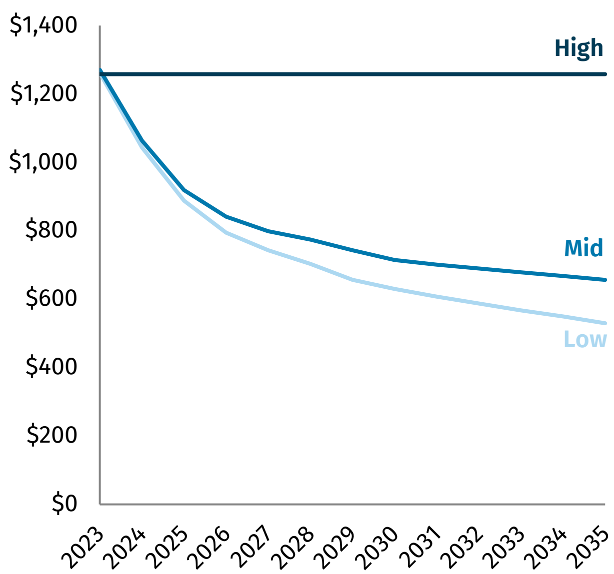
Source: Rhodium Group analysis, NREL

FIGURE A3
Offshore wind overnight capital costs
2022 dollars per kilowatt



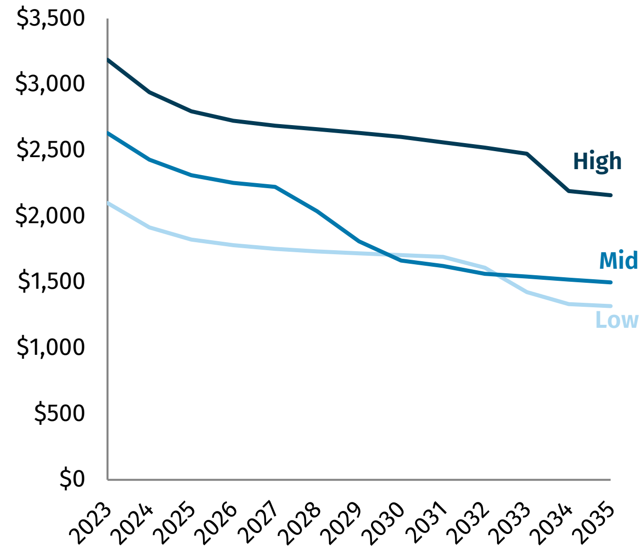
Source: Rhodium Group analysis, NREL

FIGURE A4
Utility-scale energy storage overnight capital costs
2022 dollars per kilowatt



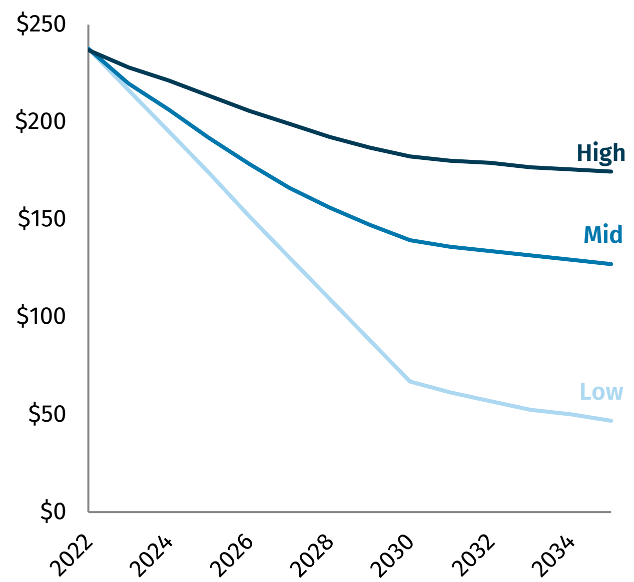
Source: Rhodium Group analysis, NREL

FIGURE A5
Natural gas with CCS overnight capital costs
2022 dollars per kilowatt



Source: Rhodium Group analysis, NETL

FIGURE A6
Electric vehicle battery costs
2022 dollars per kilowatt-hour



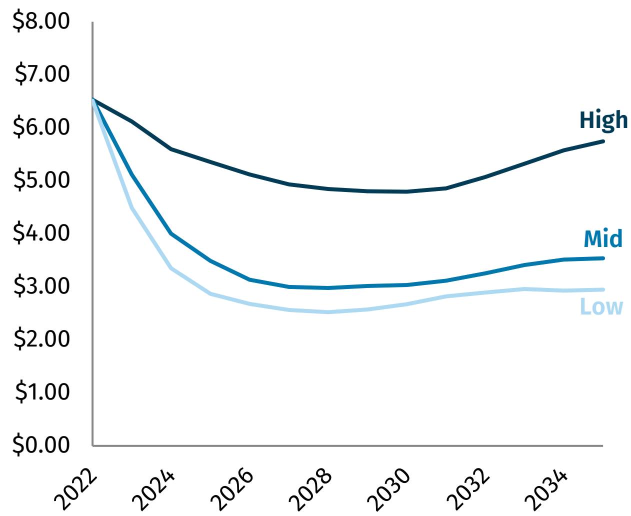
Source: Rhodium Group analysis, BNEF, NREL, EIA

Electric vehicle battery costs: For light-duty electric vehicle (EV) battery costs, we draw on AEO 2023 reference battery cost projections for our mid-cost case and BNEF projections for our low-cost case. In our high-cost case, we assume annual cost reductions are 50% slower than the AEO 2023 Reference electric vehicle battery cost projections. We assume battery costs for the suite of light-duty EV technologies modeled in NEMS match these reduction pathways. [3]

Natural gas and oil resource and prices: For our mid fossil fuel cost case, which we use in our mid emissions scenario, we use the oil and natural gas resource and prices reflected in the AEO2023 reference case. In this case, at Henry Hub, natural gas averages $3.43/MMBtu from 2023 through 2035. On average, the price of Brent crude stays relatively constant, from $92/barrel in 2023 to $93/barrel in 2035. In our low fossil cost case, we use the oil and natural gas resource and prices reflected in EIA's high oil and gas supply side case. The resulting average natural gas price is $2.94/MMBtu from 2023 through 2035, and Brent crude reaches $82 per barrel in 2035. In our high fossil cost case, we use the oil and natural gas resource and prices reflected in EIA's low oil and gas supply side case. Natural gas prices in our high-cost case average $5.24/MMBtu from 2023 to 2035, while Brent crude rises to $97/barrel in 2035.

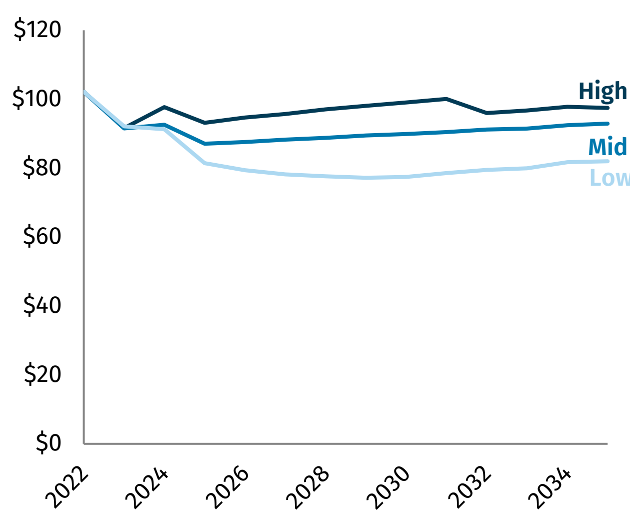
Industrial carbon capture costs: Rhodium has developed the Industrial Carbon Abatement Platform (ICAP) to assess technology deployment and emissions abatement potential in the industrial sector under a variety of scenarios. Using ICAP, we project future carbon capture retrofits at existing industrial facilities under low-, mid-, and high-cost assumptions for CO_2 capture, transportation, and storage. ICAP is integrated with the rest of RHG-NEMS such that industrial facilities see dynamic energy costs and expected revenue from CO_2 sales. New for Taking Stock 2023, we integrate results from our recently updated ICAP model, which included revisions to capture costs as well as integration of electrolytic hydrogen as a decarbonization technology at relevant industrial facilities.

FIGURE A7
Natural gas spot price at Henry Hub
2022 dollars per million Btu



Source: Rhodium Group analysis, EIA

FIGURE A8
Brent crude oil spot price
2022 dollars per barrel



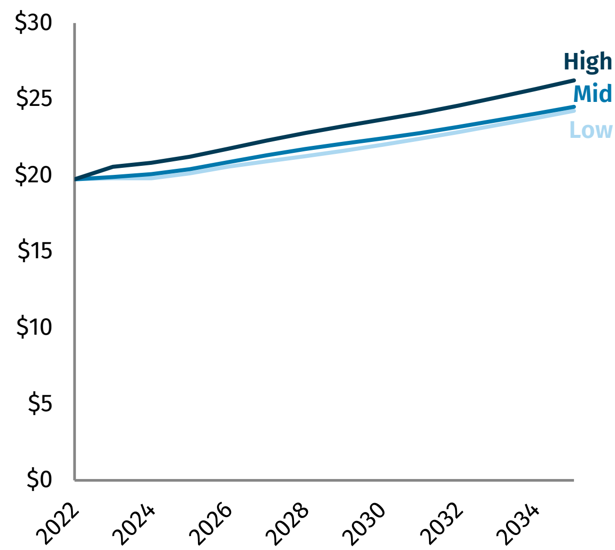
Source: Rhodium Group analysis, EIA

[3] EV technologies modeled in NEMs include EV100- and 200-mile range, plug-in hybrid 20 and 50-mile range, diesel hybrid, fuel cell methanol, fuel cell hydrogen, and gasoline hybrid.

RHG-NEMS inputs that vary to capture macroeconomic uncertainty

We model a range of future economic growth scenarios to capture the emissions impact of uncertainty in the annual growth rate of the US economy. Our baseline economic assumptions deliver an average 1.1% real annual growth rate from 2023 to 2025 and a 1.9% real annual growth rate from 2026 to 2035. In our high economic growth case, GDP grows at an average rate of 2.0% from 2023 to 2025 and 2.1% from 2026 to 2035. These assumptions are aligned with the AEO 2023 Reference and High Economic Growth cases, respectively.

FIGURE A9
US real gross domestic product
Trillion 2012 dollars



Source: Rhodium Group analysis, EIA

Federal and state policy assumptions

Our scenarios include emission reductions from all actionable and quantifiable existing federal and state policies as of June 2023. To remain consistent with United Nations guidelines for reporting the impact of current measures, we include only policies that have been finalized and adopted. We do not include aspirational goals or economy-wide targets that have yet to be solidified in specific, actionable policy, nor do we explicitly include specific city-level or corporate commitments.

CO_2 policies

Carbon pricing: We include the California Cap-and-Trade Program, the Washington Cap-and-Invest Program, and the Regional Greenhouse Gas Initiative (RGGI), which prices electricity sector carbon emissions from 12 states. Carbon pricing policies that have yet to be finalized with clear, implementable milestones have not been included in our analysis. This includes the New York Cap-and-Invest Program, announced by Governor Hochul in January 2023 and directs policymakers to design an economy-wide Cap-and-Invest Program that establishes a declining cap on greenhouse gas emissions. We do not explicitly include the Oregon Climate Protection Program, but we generally find that the program's targets are met in our scenarios.

Electric power: In the power sector, we reflect the Inflation Reduction Act (IRA) and its suite of federal clean energy tax credits, including production and investment tax credits for new clean generation, the zero-emitting nuclear production tax credit, and the tax credit for carbon oxide sequestration (45Q). We allow for direct pay and transferability of the new clean energy tax credits as detailed in the IRA. We also include USDA assistance for rural electric cooperatives and reflect the judicial vacation of the Affordable Clean Energy (ACE) rule. We include a list of state-level Renewable Portfolio Standards (RPS), Clean Energy Standards (CES), and zero-emission credit programs that we include as part of Table A1. We also include state offshore wind mandates that reflect capacity already in operation or for which there are purchase agreements in place and state energy storage mandates. We incorporate all announced power plant additions and retirements through 2035 as of June 2023.

Transportation: In the transportation sector, we reflect IRA tax credits for clean vehicles, clean fuel production, sustainable aviation fuel, and clean hydrogen production. We also include the federal Renewable

Fuels Standard and medium- and heavy-duty vehicle GHG emissions standards. Additionally, we include the National Highway Traffic Safety Administration's CAFE standards finalized in April 2022, which establish a standard for light-duty fuel economy to increase by 8% annually in model years 2024 and 2025 and by 10% annually in model year 2026.

At the state level, we include vehicle emission standards and zero-emission vehicle (ZEV) mandates for California and 17 states that follow California's tighter standards (Advanced Clean Car I) under Section 177 of the Clean Air Act (S177 states). We further include California's Advanced Clean Cars II regulations that require 100% light-duty ZEV sales by 2035. In addition to California, six other S177 states have adopted these higher regulations and are also represented. We include the California, Oregon, and Washington low-carbon fuel standards. California's Innovative Clean Transit regulation (requiring 100% zero-emission bus sales by 2040) and Advanced Clean Truck (ACT) regulation (requiring 100% zero-emission truck sales by 2045) are incorporated. In addition to California, five other states have adopted the ACT rule and are also represented. State ZEV commitments with no underlying regulatory policy are not included in our modeling.

Industry and buildings: We include current federal minimum energy conservation standards for appliances and equipment as well as the IRA's tax credits and rebates for residential and commercial energy efficiency and clean energy expenditures. We also include the tax credits for carbon oxide sequestration (45Q), clean hydrogen production, and clean fuel production. State energy efficiency programs are implicitly captured in RHG-NEMS electric demand projections. We also capture the impacts of federal investment in clean hydrogen and direct air capture hubs that were funded as part of the IIJA.

Non-CO_2 policies

Methane: We assume the reinstatement of federal methane emission rules for the oil and gas industry, following the 2021 Congressional Review Act vote to invalidate the Trump Administration's rollback of Obama-era rules. We assume other major federal oil and gas methane policies undone by the Trump Administration remain effectively rolled back, including EPA's 2016 Control Techniques Guidelines (CTGs) for volatile organic compounds (VOCs) from oil and natural gas; and 2016 Bureau of Land Management regulations to prevent waste of natural gas from venting, flaring and leaks on public lands.

We assume emission reductions from EPA's 2016 updated NSPS and emission guidelines for methane from municipal solid waste landfills rules are delayed—with enforcement starting in 2021 rather than 2016—to reflect EPA's recent update to the Obama-era rule. The following state policies are also reflected: oil and gas standards in 10 states and California's landfill methane control measures from 2010 and updated in 2017. All estimates associated with federal and state oil and gas rules are based on modeled estimates from the Clean Air Task Force that align with oil and gas production from each of our scenarios. For landfills, we used emission reduction estimates from EPA and California's Air Resources Board.

Hydrofluorocarbons (HFCs): All our scenarios assume a phasedown in the production and consumption of HFCs in line with EPA's final rule to phase down HFCs, issued in September 2021.

Pathways to Paris update

In our joint action and federal action-only scenarios, we model a suite of additional policies executed through the executive branch and subnational actors:

Federal regulatory action: We model a set of federal regulatory pathways that rely on authorities that have been used previously to cut emissions or energy use, as listed in Table A2.

Subnational action: We model actions that leading states, defined as the 23 US Climate Alliance states, and corporate leaders can take to deliver earlier and greater emissions reductions than their current targets. We focus on actions that states have implemented under existing authorities and expand them across all leading states. We also accelerate key corporate clean energy targets. See Table A3 for the complete set of policies.

Projection and 50-state downscaling methodology

Carbon dioxide emissions

Projected CO_2 emissions from all energy use in RHG-NEMS are inconsistent with EPA's accounting conventions for CO_2 from fossil-fuel combustion in its GHG inventory. To address this inconsistency, we make the following adjustments to RHG-NEMS output to generate a forecast for CO_2 from fossil-fuel combustion:

- International bunker fuels: Emissions from fuel combustion by ships and airplanes that depart from or arrive in the US from international destinations are not included in EPA's inventory of total US emissions nor are they counted in US climate targets. However, they are included in RHG-NEMS CO_2 output. We subtract these emissions from our projections.
- Industrial non-energy use of fuels: Fossil fuels are used as feedstocks in the manufacture of a variety of products such as steel and chemicals. Generally, EPA accounts for CO_2 emissions generated by consumption of these feedstocks in the industrial processes categories of the GHG inventory, not under fossil-fuel combustion CO_2. We subtract CO2 emissions from non-energy uses of CO_2 from our fossil-fuel combustion projections and account for non-energy use of fuels and feedstocks elsewhere.
- Transportation non-energy use of fuels: A small amount of petroleum fuel used in the transportation sector (largely for lubricants) is not combusted but generates CO_2 emissions through its usage. We subtract this amount from projections of petroleum CO_2 emissions in the transportation sector and account for them elsewhere as non-energy use of fuels.

RHG-NEMS does not provide an Intergovernmental Panel on Climate Change (IPCC) consistent projection output for non-fossil fuel consumption CO_2 emissions from activities such as non-energy use of fuels and industrial processes. We applied the following methods to project non-fossil fuel combustion CO_2 emissions:

- Inventory categories with emissions below 25 MMT: We extrapolate historical trends from EPA's latest GHG inventory in line with EPA's latest GHG projection guidance.
- Inventory categories with emissions above 25 MMT: We follow EPA's latest guidance, scaling inventory data based on category appropriate RHG-NEMS output. For example, recent historical CO_2 emissions from natural gas systems are scaled based on the projected change in dry natural gas production available at the play level from RHG-NEMS. This allows for non-combustion CO_2 emissions to change in line with changes in the economic and technology assumptions we make to account for uncertainty in our projections.

Non-CO_2 and land use emissions and removals

All projections of non-CO_2 emissions (i.e., methane, nitrous oxide, hydrofluorocarbons, perfluorocarbon, and sulfur hexafluoride) follow the same general approach as we take in projecting CO_2 emissions from non-fossil fuel combustion sources. Inventory categories with emissions less than 25 MMt CO_2e are extrapolated based on recent historical trends. Inventory categories with emissions more than 25 MMt CO_2e are scaled based on appropriate outputs from RHG- where possible. In some instances, such as agriculture, there are no appropriate outputs from RHG-NEMS to scale emissions. In these instances, we use alternative public projections, such as the US Department of Agriculture (USDA)'s long-term projections. Additional modifications are made to reflect the impact of state and federal policies, as discussed above.

Historical emissions and removals from land use, land-use change, and forestry (LULUCF) come directly from the 2021 EPA GHG inventory. Projected trends come from the high sequestration scenario from the 2022 Fifth Biennial Report of the United States (the most recent set of federal projections) calibrated to align with EPA's 2021 inventory. For emissions of N_2O and CH_4 from LULUCF, we assume 2021 emissions from LULUCF remain constant.

Downscaling national emissions projections to the state level

RHG-NEMS forecasts fuel consumption by sector at various levels of geographical aggregation, which is then downscaled to the state level using state-level activity data. For the power sector, generation-based emissions are taken directly from RHG-NEMS, which reports individual plant-level emissions. NEMS builds new fossil-fuel fired plants to meet electricity demand, and those plants and their respective emissions are attributed to individual states within an electricity market region based on historical trends. We estimate generation-based power emissions based on the production of electricity within a state, a portion of which may be exported outside the state. We also estimate power sector emissions associated with the consumption of electricity within a state, accounting for the carbon intensity of generation that produced that electricity.

Projections of fuel consumption by other end-use sectors, including industry, buildings (a combination of the residential and commercial sectors), and transportation, are downscaled to the state level from nine census-level regions. In the building sector, we apportion census-level GHG emissions to constituent states using each state's share of historical fuel consumption. In the transportation sector, we use historical demand to allocate fuel consumption by mode in each census region between constituent states. For example, we use the historical share of vehicle miles traveled (VMT) for light-duty vehicle fuel demand, and truck ton-miles for freight fuel demand. For industry, we use EPA's Facility Level Information on Greenhouse Gases Tool (FLIGHT) as weights to apportion census region GHG emissions to constituent states for large industrial facilities, and total value-added as weights to apportion census region fuel consumption for smaller facilities.

For non-fossil fuel combustion CO_2 emissions at the state level, all other GHG emissions, and LULUCF emissions and removals, we use activity data from RHG-NEMS where available. For example, methane emissions from fossil fuel production are downscaled based on production output from RHG-NEMS which is available by fuel basin/play and can be attributed to individual states. In cases where there are no appropriate outputs from RHG-NEMS, we draw on other sources of activity data, including FLIGHT, the EIA, and USDA.

TABLE A1

Federal and state policies included in Taking Stock 2023 baselines

Sector	Federal policy	State policy	State
Power			
	Clean electricity tax credits	Renewables portfolio standard (RPS) and clean electricity standard (CES)	AZ CA CO CT DC DE HI IA IL IN LA MA MD ME MI MN MO MT NC NE NH NJ NM NV NY OH OR PA RI TX VA VT WA WI
	Tax credit direct pay provisions and transferability		
	Zero-emitting nuclear production tax credit		
	USDA assistance for rural electric cooperatives	Offshore wind mandates	CT MA MD NJ NY NC VA
	Tax credit for carbon oxide sequestration (45Q)	Energy storage mandates	MA NV NJ NY OR VA
		Nuclear zero emission credit (ZEC) programs	IL NJ NY
	CCS demonstration and pilot projects		
	Judicial vacation of the Affordable Clean Energy (ACE) rule		
	Cross-State Air Pollution Rules (CSAPR)		
	Mercury and Air Toxics Standards (MATS)		
	New Source Review (NSR)		

Transportation	New clean vehicle tax credit	California light-duty vehicle GHG standards or ZEV mandate (Advanced Clean Cars I regulation)	CA CO CT ME MD MA MN NJ NM NV NY OR RI VA VT WA
	EV charging infrastructure grants		
	Clean fuels tax credit	California Advanced Clean Cars II regulation	CA MA MD NY OR VT WA
	Clean hydrogen production tax credit (45V)	Low-Carbon Fuel Standard (LCFS)	CA OR WA
	Sustainable aviation fuel credit	California Advanced Clean Trucks regulation	CA MA NJ NY OR WA VT
	MY2024-2026 Corporate Average Fuel Economy standards		
		Zero emission bus mandate	CA
	Renewable Fuel Standard (RFS)		
	GHG and fuel consumption standards for heavy-duty vehicles		
	Tier 3 Motor Vehicle Emission and Fuel Standards Program		
	International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI		

Industry and buildings	Clean hydrogen production tax credit (45V)	Energy Efficiency Resource Standards (EERS)	AK AZ CA CO CT DC HI IA IL LA MA MD ME MI MN MO MS NC NH NV NJ NM NY OR PA RI TX UT VA VT WA WI
	Clean fuel production tax credit		
	Programmatic efficiency spending in IIJA		
	Building efficiency tax credits		

	Building electrification and efficiency grants		
	Federal investments in clean hydrogen and direct air capture hubs in IIJA		
	Tax credit for carbon oxide sequestration (45Q)		
	Clean Air Act Amendments of 1990 emission requirements for industrial processes		
Hydrofluorocarbons (HFCs)	EPA's final rule to phase down HFCs		
Methane	Reversal via 2021 Congressional Review Act of Trump-era rollback of EPA's 2012 and 2016 Oil and Gas New Source Performance Standards for transmission and storage sources	State oil and gas standards	CA CO MA MD NM NY OH PA UT WY
		Landfill methane regulation (LMR) and SB1383 agricultural methane targets	CA
	Orphaned mine and well remediation		
	Increased onshore and offshore oil and gas royalty rates		
	Methane emissions reduction program		
	EPA municipal solid waste landfill methane rule		

Carbon removal			
	Agricultural conservation investments		
	Non-federal land forest reforestation projects		
	State and private forestry conservation programs		
	Tax credit for carbon oxide sequestration (45Q)		
Carbon pricing			
		Cap and trade program	CA WA
		Regional Greenhouse Gas Initiative (RGGI)	CT DE ME MD MA NH NJ NY RI VT VA

TABLE A2

Executive branch policies in the joint action and federal action only scenarios

Policy	Target Sector	Description
GHG pollution standards	Power sector	▪ EPA retains 2015 New Source Performance Standards (NSPS) for steam electric generating units (EGU) ▪ EPA adopts proposed NSPS for stationary combustion turbine EGUs ▪ EPA provides flexibilities for states to achieve emission reductions in line with results from EPA's modeling of emission guidelines for existing fossil steam and fossil stationary combustion turbine units, inclusive of standards for existing natural gas-fired EGUs
Mercury and Air Toxics Standards (MATS)	Electric power	▪ EPA tightens MATS in 2027, requiring each coal EGU to achieve a 95% reduction in mercury emissions relative to its uncontrolled mercury emissions.
LDV GHG standards	Transportation	▪ EPA adopts proposed Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-duty and Medium-Duty Vehicles for light-duty vehicles, achieving a roughly 100 gram-per-mile (gpm) standard fleetwide in 2030 (using EPA's calculation methodology).
MDV & HDV GHG standards	Transportation	▪ EPA adopts emissions standards for medium- and heavy-duty vehicles that require a 50% faster annual improvement in new vehicle emissions rates than current standards starting in 2028.
Minimum equipment performance standards	Buildings	▪ DOE exercises Energy Policy and Conservation Act (as amended) authorities to adopt ambitious minimum efficiency standards for covered equipment that prioritize emissions reductions.
Commodity Credit Corporation funding	Carbon removal	▪ USDA leverages discretionary spending under the Commodity Credit Corporation to support implementation of climate-smart agriculture and forestry practices on private lands.

TABLE A3
Subnational actions in the joint action scenario

Policy	Target Sector	Description
Utility clean power targets	Electric power	▪ Utilities with 100% clean energy targets accelerate their target deadlines to 2035.
State clean energy standards (CES)	Electric power	▪ Leadership states require 100% clean energy by 2035.
LDV ZEV Mandate	Transportation	▪ Leadership states require 100% zero-emission light-duty vehicle sales by 2035.
VMT management	Transportation	▪ Leadership states direct new congressional funding to reducing vehicle miles traveled (VMT).
MDV/HDV ZEV Mandate	Transportation	▪ Leadership states require 100% zero emission medium-and heavy-duty vehicle sales by 2045.
Low-carbon fuel standards (LCFS)	Transportation	▪ Leadership states adopt a Low Carbon Fuel Standard reducing carbon intensity of fuel by 20% by 2030.
Methane abatement	Agriculture and waste	▪ Leadership states take actions to reduce agricultural and waste methane 40% from 2013 levels by 2030.
N_2O abatement	Agriculture and waste	▪ Leadership states reduce N_2O via changes to crop management practices.
Energy Efficiency Resource Standards (EERS)	Buildings	▪ Leadership states adopt and revamp EERS to achieve 2.5% electricity savings and 1.25% natural gas savings annually.

About this Report

About Rhodium Group

Rhodium Group is an independent research provider combining economic data and policy insight to analyze global trends. Rhodium's Energy & Climate team analyzes the market impact of energy and climate policy and the economic risks of global climate change. This interdisciplinary group of policy experts, economic analysts, energy modelers, data engineers, and climate scientists supports decision-makers in the public, financial services, corporate, philanthropic and nonprofit sectors. More information is available at www.rhg.com.

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Disclosures

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