CO2 Emission Reductions from Changes in Electricity Generation and Use

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List of Abbreviations

ACEEE	American Council for an Energy-Efficient Economy
AEO	Annual Energy Outlook
AIM	American Innovation and Manufacturing (Act)
ATB	Annual Technology Baseline (“populated framework” managed by NREL)
BECCS	bioenergy with carbon capture and storage
BEV	battery electric vehicle
Btu	British thermal unit
CAGR	compound annual growth rate
CARB	California Air Resources Board
CBO	Congressional Budget Office
CCS	carbon capture and sequestration
CGS	Center for Global Sustainability
CCUS	carbon capture, use, and storage
CH_4	methane
CO_2	carbon dioxide
CPRG	Climate Pollution Reduction Grant
CSP	concentrating solar-thermal power
DAC	direct air capture
dGen	Distributed Generation Market Demand Model (NREL)
DOE	United States Department of Energy
EI	Energy Innovation
EIA	United States Energy Information Administration
EIR	Energy Infrastructure Reinvestment (Program)
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EPS	Energy Policy Simulator
EV	electric vehicle
FT	Fischer–Tropsch synthesis (for biofuels)
g/mi	grams per mile
GCAM	Global Change Analysis Model
GHG	greenhouse gas
GHGI	Greenhouse Gas Inventory (report)
GHGRP	Greenhouse Gas Reporting Program
GIS	geographic information system
GW	gigawatt
H2	hydrogen
HFC	hydrofluorocarbon
HGL	hydrocarbon gas liquids
HUD	United States Department of Housing and Urban Development
HVAC	heating, ventilation, and air conditioning
IIJA	2021 Infrastructure Investment and Jobs Act
IPM	Integrated Planning Model (EPA’s)
IRA	Inflation Reduction Act of 2022
ITC	investment tax credit
JEDI	Jobs and Economic Development Impact (model, NREL)
kg	kilogram
km	kilometer
kW	kilowatt
kWh	kilowatt hour
LBNL	Lawrence Berkeley National Laboratory
LDV	light-duty vehicle
LEEP	Low Emission Electricity Program
LP	linear program
LPO	Loan Programs Office, United States Department of Energy
MAC	marginal abatement cost
MARKAL	Market Allocation
MIT	Massachusetts Institute of Technology
Mt	million metric tons
MWh	megawatt hour
N/A	not applicable
NAICS	North American Industry Classification System
NEMS	National Energy Modeling System
NETL	National Energy Technology Laboratory
NGCC	natural gas combined cycle (method for CO_2 capture)
NHTSA	National Highway Traffic Safety Administration
NO_X	nitrous oxide
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
OP	Office of Policy, United States Department of Energy
PE	partial equilibrium
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
PNNL	Pacific Northwest National Laboratory
PPSM	Power Plant Screening Methodology
PTC	production tax credit
PV	photovoltaic
ReEDS	Regional Energy Deployment System
REGEN	Regional Economy, Greenhouse Gas, and Energy (model)
REPEAT	Rapid Energy Policy Evaluation and Analysis Toolkit (model)
RFF	Resources for the Future
RHG	Rhodium Group
RIO	Regional Investment and Operations (model)
SF_6	sulfur hexafluoride
SMR	steam methane reformation (method for producing hydrogen)
SO_X	sulfur oxides
SO_2	sulfur dioxide
T&S	transport and storage
TWh	terawatt-hour
UMD	University of Maryland
USDA	United States Department of Agriculture
USPS	United States Postal Service
USREP	U.S. Regional Energy Policy (model)
VMT	vehicle miles traveled

Executive Summary

The Inflation Reduction Act of 2022 (IRA) represents a significant legislative commitment to transform energy production and consumption, reduce the risks of climate change, improve environmental quality, and simultaneously spur investments that create economic opportunities. With a comprehensive system of economic incentives, the Act provides substantial support for the development and use of clean energy across the economy. The IRA promotes domestic manufacturing, well-paying jobs, and economic growth. The IRA is expected to reduce greenhouse gas (GHG) emissions by encouraging the generation of low-cost, low-emission electricity and the efficient use of clean energy in buildings, transportation, and industry.

This report presents results from state-of-the-art multi-sector and electric sector models to assess how the IRA's provisions reduce CO_2 emissions. The report is responsive to §60107(5) of the Low Emissions Electricity Program within the IRA, which requires EPA to assess "… the reductions in greenhouse gas emissions that result from changes in domestic electricity generation and use that are anticipated to occur on an annual basis through fiscal year 2031." The report primarily focuses on carbon dioxide (CO_2) emissions because the vast majority of direct electric sector GHG emissions are from fossil fuel combustion and the increased use of clean electricity primarily offsets fossil fuel use in end-use sectors.

The report includes the projected reductions in CO_2 emissions due to the IRA provisions represented in the models. Emissions projections are modeled in an "IRA scenario" that incorporates the effects of the IRA incentives, and these are compared to projections in a "No IRA scenario." (Both scenarios incorporate other state and federal policies finalized prior to the IRA enactment—see Section 1.2). It is important to note that this report does not reflect rules and regulations that are currently being developed or finalized.

The report presents results from recent peer-reviewed research [1], reports from the Department of Energy [2] and the National Renewable Energy Laboratory [3], and EPA-funded modeling. The combined data include results from ten multi-sector models and four electric sector models. Multi-sector models are the appropriate analytic tool to examine emission reductions from changes in both generation and use. However, the power sector accounts for most of the emission reductions, and the single-sector electricity models provide additional complementary perspectives. The report primarily examines the central estimates from the models to provide ranges and identify areas of agreement and disagreement; sensitivity estimates from a subset of models are also explored.

Throughout this report, CO_2 emissions are reported in million metric tons of CO_2 (Mt CO_2). CO_2 emission reductions are also presented as percentage changes from 2005 for comparability to other studies and to U.S. emission reduction goals. Reductions are primarily shown for the years 2030 and 2035 with annual results in Appendix A. Although many provisions of the IRA end in 2031, extending the analysis to 2035 is valuable for multiple reasons. First, certain economic incentives (e.g., clean electricity tax credits, 45Y and 48E) extend beyond 2031. Second, certain advanced technologies supported by the IRA are expected to have more significant impact after 2030. These include advances in electricity storage, carbon capture and storage (CCS), nuclear, distributed generation, clean hydrogen production, and geothermal energy. Third, the available literature extends to 2035.

The IRA spurs substantial emission reductions from the electric sector of 49 to 83% from 2005 levels in 2030. CO_2 emissions decline most steeply in the electricity sector (Figure ES.1). Each blue line in the figure represents the output from a model that includes the effects of the IRA provisions. The orange lines show model results without the IRA provisions. Importantly, results for 2030 and 2035 are emphasized to the right of the chart—each colored shape represents the CO_2 emissions in that year of either the IRA or No IRA cases from the models. The median CO_2 emissions projections for each scenario is represented by the colored horizontal bar.[2] With one exception, the modeling shows that these emission reductions are primarily accomplished through increasing use of solar and wind capacity and generation enabled by a combination of incentives under the IRA; infrastructure buildout (in part enabled by provisions of the Infrastructure Investment and Jobs Act (IIJA; also known as Bipartisan Infrastructure Bill or BIL), and increased use of storage technologies. One of the models relies heavily on fossil CCS to reduce emissions. A robust finding across all models is that generation from low- and zero-emitting technologies (e.g. renewables or fossil CCS) increases while high-emitting generation from coal and gas without CCS declines.

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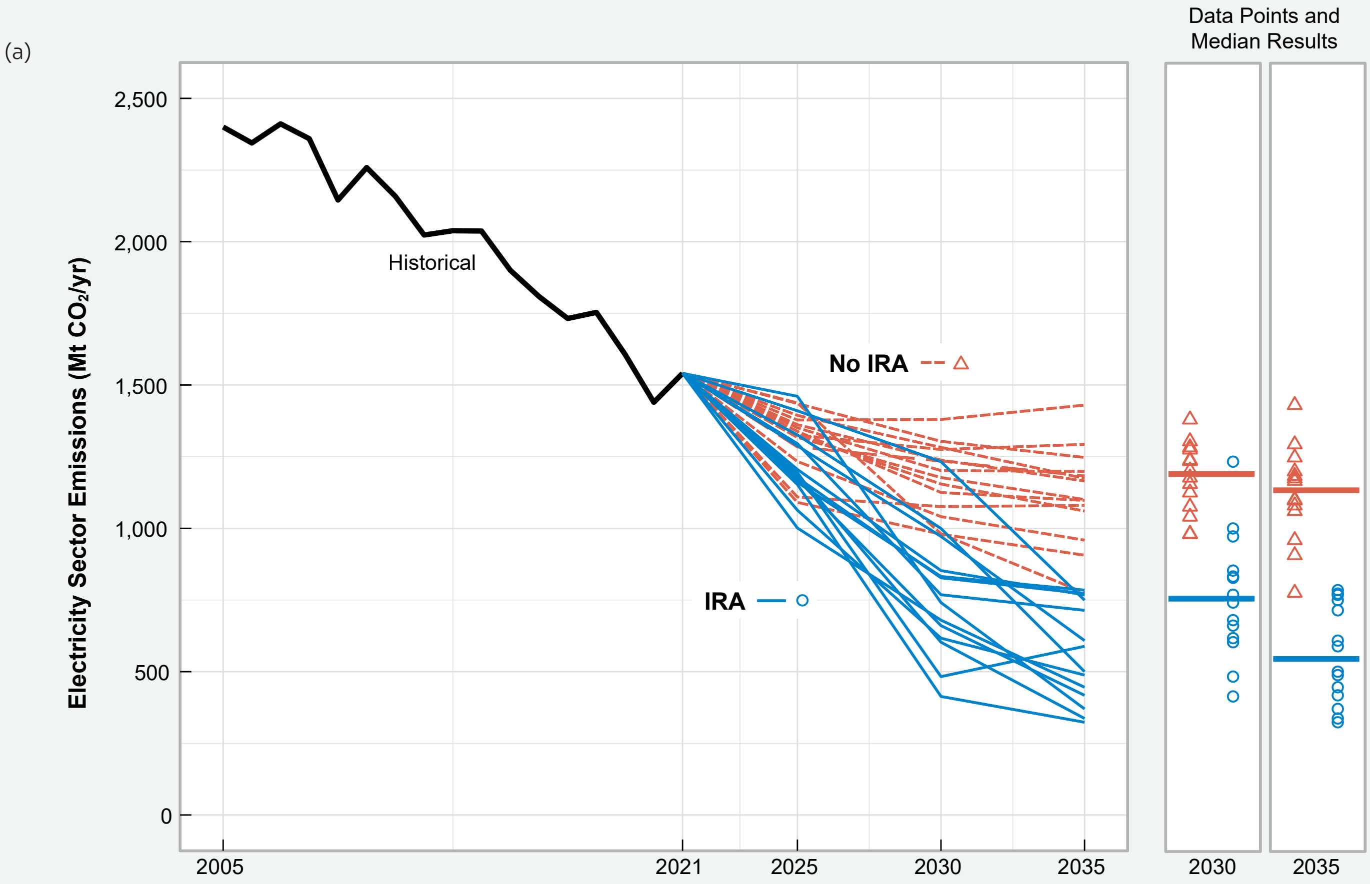
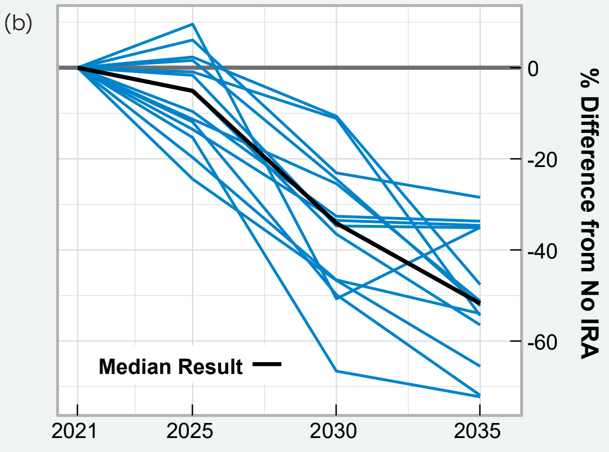
[2] The median value of the results is presented in this report to provide a measure of central tendency, in addition to the range. A median is used instead of a mean because a mean is more heavily influenced by outlier results.

Figure ES.1 U.S. electricity sector CO_2 emissions





In the IRA scenario, U.S. electricity sector CO_2 emissions fall to 49 to 83% (39% median) below 2005 levels in 2030. In 2030, individual models find that electricity CO_2 emissions are 11 to 67% (34% median) below what they are modeled to be in the No IRA scenario, with the median difference falling to just over 50% by 2035. Figure ES.1(a) shows absolute model results for the emissions trajectories (No IRA scenario in orange dashed lines, IRA Scenario in blue) with the historical trend (in black [4]). Data points to the right of Figure ES.1(a) show individual model results from 2030 and 2035 (blue circles for IRA scenario results, orange triangles for No IRA). Horizontal bars represent the median of the model results. Figure ES.1(b) shows the percent difference between the IRA and No IRA for each model (blue lines) and the median across the models (black line).[3] Accessible table available in the Data Annex.

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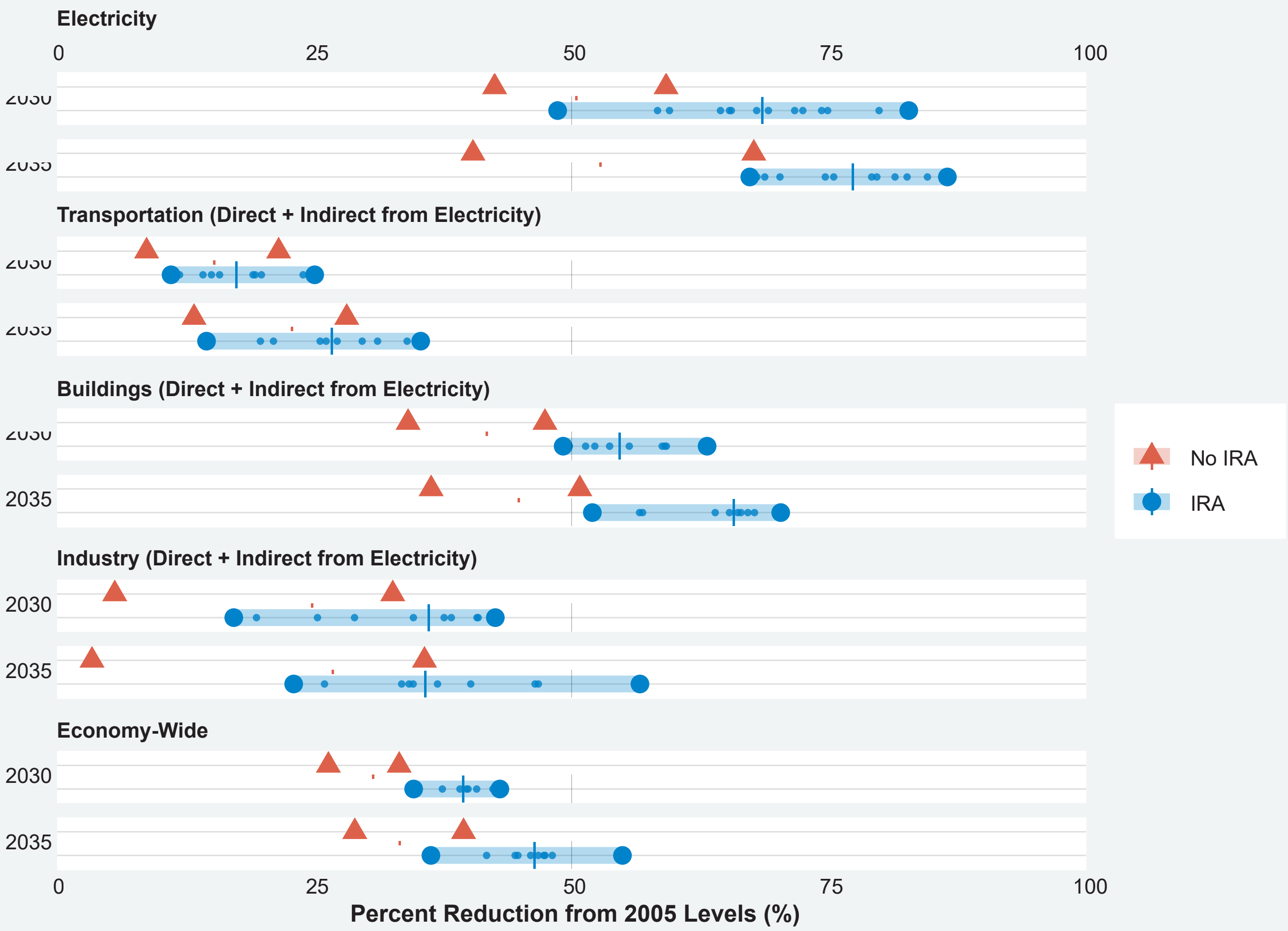
[3] A handful of models show higher emissions under the IRA in 2025. In the No IRA scenario, these forward-looking models have slightly higher levels of near-term investments in renewables in 2025 because the models foresee the expiration of tax credits. Under the IRA scenario, tax credits are extended and investment does not exhibit a near-term spike.

The IRA impacts electric sector-related CO_2 emissions in three important ways: 1) provisions that support clean electricity generation, 2) provisions that encourage the electrification of end uses—increasing the amount of electricity demand and reducing emissions from fossil combustion in the transportation, buildings, and industrial end-use sectors, and 3) provisions that encourage energy efficiency—offsetting overall energy demand, reducing energy costs, and decreasing the amount of spending required to decrease electricity sector emissions while meeting the increased demand from electrification of end uses. To capture the full impact of these provisions, multi-sector models represent both the electricity sector and how electricity competes with fossil energy in the industrial, transportation, and buildings sector end uses.

Across the end-use sectors, emissions reductions are greater under the IRA scenario than the No IRA scenario. Buildings exhibits the greatest reductions from 2005 levels of direct plus indirect CO_2 emissions from electricity followed by industry and transportation (Figure ES.2). By 2030, the IRA drives CO_2 emission reductions in the transportation sector of 11-25% from the 2005 level. In the buildings sector, emissions in 2030 fall 49-63%, and for the industrial sector, the reduction is 17-43%. By 2035, results show that the IRA achieves even further reductions from the 2005 level in these sectors (15-35% for transportation, 52-70% for buildings, and 23-57% for industry). The CO_2 emissions from each of the end-use sectors under the IRA and No IRA scenarios represent both the “direct” emissions from fossil fuel use in each respective sector and “indirect” emissions from fossil fuels used in generating the electricity consumed by each sector. Electrification leads to CO_2 emission reductions directly because it displaces fossil fuel combustion in end-use sectors; in addition, as the share of zero emissions generation increases, the indirect CO_2 emissions from electricity generation will continue to decline. Electrifying efficiently will reduce new electricity demand, enable retirement of high-emitting fossil fuel-based generation, and more rapidly increase the share of zero-emitting generation. Transportation sector reductions are relatively small in 2030 in part because it takes time for the expected, and significant, increase in new electric vehicle sales to be reflected in the light-duty vehicle stock, and because the transportation sector includes CO_2 emissions from multiple transportation modes—personal transportation, trucking, public transit, rail, air, and ships—that may not all see changes due to the IRA. The sectoral chapters provide further information on the degree of electrification.

The IRA lowers economy-wide CO_2 emissions, which includes electricity generation and use, by 35-43% by 2030 from 2005 levels. For comparison, economy-wide CO_2 emissions in the No IRA scenario are 26-33% below 2005. By 2035, economy-wide emissions are projected to continue to fall 36-55% relative to 2005 in the IRA scenarios (Figure ES.2 , Table ES.1).

Figure ES.2 Summary of economy-wide and end-use sector CO_2 emissions reductions from 2005 for the IRA and No IRA scenarios



In the IRA scenario, economy-wide CO_2 emissions fall 35 to 43% (39% median, bottom panel) below 2005 levels by 2030. By the same year, electric power sector CO_2 emissions fall 49 to 83% (69% median, top panel) below 2005 levels; transportation sector CO_2 emissions fall 11 to 25% (17% median); buildings sector CO_2 emissions fall 49 to 63% (55% median); and industry sector CO_2 emissions fall 17 to 43% (36% median) below 2005 levels. Note that transportation, buildings, and industry emissions include reductions from changes in direct combustion as well as indirect emissions from electricity generation.[4,5,6,7] Ranges are summarized in Table ES.1. Accessible table available in the Data Annex.

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[4] Transportation, buildings, and industry CO_2 emissions include reductions from changes in direct combustion as well as indirect CO_2 emissions from electricity generation. Except where reported separately, electric sector CO_2 emissions were allocated to the end-use sectors based on electricity consumption. Emissions are broken out into direct and indirect in Appendix F.2.

[5] The Bistline et al. study [1] presents a range for economy-wide emissions reduction from 2005 as 33-40% in 2030 and 43-48% in 2035 in the IRA scenario. This range is the reduction in net-GHG emissions from a model-reported 2005 value for all models but two: MARKAL-NETL includes energy and non-energy CO_2 only, and REGEN-EPRI includes only energy CO_2. Using data from the Bistline study and the model-reported 2005 values, the range of emissions reductions from 2005 for only energy and non-energy CO_2 (comparable to the range presented in this report) is 33-42% in 2030 and 42-53% in 2035. The Bistline 2030 range is lower than the range in this report due to the Bistline calculations referencing model-reported 2005 values, whereas this report references 2005 GHGI data.

[6] The Bistline et al. study presents a range for electricity emissions reduction from 2005 as 47-83% in 2030 and 66-87% in 2035. This range is the reduction in electricity emissions from a model-reported 2005 value, whereas this report references 2005 GHGI data.

[7] Industrial process emissions are included in economy-wide CO_2 emissions for models that report them, but excluded from industry-specific emissions.

Table ES.1 Summary of ranges of CO_2 emissions reductions from 2005

		IRA			No IRA		
Sector	**Year**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
Electricity	2030	49%	69%	83%	43%	50%	59%
	2035	67%	77%	87%	40%	53%	68%
Transportation	2030	11%	17%	25%	9%	15%	22%
	2035	15%	27%	35%	13%	23%	28%
Buildings	2030	49%	55%	63%	34%	42%	47%
	2035	52%	66%	70%	36%	45%	51%
Industry	2030	17%	36%	43%	6%	25%	33%
	2035	23%	36%	57%	3%	27%	36%
Economy-Wide	2030	35%	39%	43%	26%	31%	33%
	2035	36%	46%	55%	29%	33%	39%

For each sector and for the economy as a whole, model results show greater CO_2 emissions reductions for the IRA scenario compared to the No IRA scenario. This is true for the full range of minimum, median, and maximum reductions reported by any of the models in both 2030 and 2035.

The range of reductions across models is wide, which reflects differences across IRA representation, model structure, and assumptions. The above results reflect a multi-model comparison of IRA Moderate scenarios, that is, results reflecting the central set of unharmonized IRA assumptions reported by the models (see Section 1.2.3). Emissions reductions differ because of several IRA-related factors, including the number of provisions modeled (i.e., representing more provisions is a contributing factor to lower emissions) and the representation of those provisions (e.g., the eligibility to receive bonus production and investment tax credits). Additionally, the models differ structurally (e.g., spatial and temporal resolution as well as technological and sectoral detail). Finally, the range of future CO_2 emissions trajectories for both the IRA and No IRA scenarios reflects assumptions about a variety of important factors including the rate of improvement in technology costs, the ability to deploy low-emission power generation technologies, energy prices, and economic growth.

Emissions Assessment Framework

This report emphasizes the range of CO_2 emissions results across the ten multi-sector energy system models and four electricity sector models listed below. The analytic strengths of these models include their representation of highly complex techno-economic systems, consistent emissions and energy accounting systems, and in the case of multi-sectoral models, interactions across sectors [5].[8] Models, as tractable representations of these complex systems, also have limitations (Section 1.2.4) including assumptions of perfect information, competitive markets, and optimizing decision-makers. The multi-model results are conditional on input and scenario assumptions. They should not be interpreted as statistical distributions nor do they reflect the full range of uncertainty, which would be wider.

MULTI-SECTOR (10)

- Energy Policy Simulator from Energy Innovation (EPS-EI)
- Global Change Analysis Model, two versions
  - one from the Center for Global Sustainability (GCAM-CGS),
  - and another from the Pacific Northwest National Laboratory (GCAM-PNNL)
- Market Allocation model from the National Energy Technology Laboratory (MARKAL-NETL)
- National Energy Modeling System, three versions, one each from
  - the Energy Information Administration (NEMS-EIA),
  - the Office of Policy at the Department of Energy (NEMS-OP),
  - and the Rhodium Group (NEMS-RHG)
- Regional Economy, Greenhouse Gas, and Energy from Electric Power Research Institute (REGEN-EPRI)
- Regional Investment and Operations Model from the Princeton REPEAT Project (RIO-REPEAT)
- U.S. Regional Energy Policy model (Massachusetts Institute of Technology) linked to the ReEDS power sector model (USREP-ReEDS)

ELECTRICITY SECTOR (4)

- Haiku from Resources for the Future (Haiku)
- Integrated Planning Model, two versions, one each from
  - the U.S. EPA (IPM-EPA)
  - and from the Natural Resources Defense Council (IPM-NRDC)
- Regional Energy Deployment System from the National Renewable Energy Laboratory (ReEDS-NREL)

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[8] NEMS-EIA and USREP-ReEDS also incorporate macro-economic feedbacks. All models, except for one simulation model, use optimization to resolve energy markets and technology choices.

Emission reductions are sensitive to IRA implementation, technology costs, and deployment constraints—with electric sector emissions reductions of up to 91% below 2005 levels in 2030 under advanced technology assumptions. Beyond the central set of IRA Moderate scenarios discussed above, a subset of models explore Optimistic and Pessimistic IRA implementation scenarios and find power sector CO_2 emissions in 2030 fall an additional 2.5 percentage points on average in the Optimistic scenario and fall 3.3 fewer percentage points below 2005 levels in the Pessimistic scenario relative to the IRA moderate implementation scenario. The sensitivity scenarios analyzing technology find larger impacts—relative to the moderate technology assumptions, power sector CO_2 emissions in 2030 fall an additional 7.2 percentage points below 2005 levels in the advanced technology scenario with low technology costs and fall 8.8 fewer percentage points below 2005 levels in the scenario with technology deployment constraints. Other sensitivities explored by fewer models include energy prices and economic growth. High and low energy price scenarios can respectively decrease or increase power sector CO_2 emissions by amounts similar in magnitude to the IRA implementation sensitivity scenarios. The effects of sensitivity scenarios for economic growth on power sector CO_2 emissions are an order of magnitude smaller than the effects of the energy price sensitivities. With the caveat that fewer models are represented in sensitivity scenarios, these sensitivities show that minimizing deployment constraints and achieving low technology costs are key to greater power sector CO_2 emissions reductions.

The IRA is an extensive and complex piece of legislation to model for several reasons including the number of provisions and the interpretation and detailed assumptions needed to represent the provisions in a model. As with any energy and economic modeling, there are limitations and caveats to the analysis (Section 1.2.4). There are clear limitations in modeling related to the IRA worth emphasizing here.

1. As noted above, the IRA provides significant incentives for investments in advanced clean energy technologies (e.g., storage, CCS, nuclear, distributed generation, energy efficiency, vehicle and building electrification, hydrogen, and geothermal). The costs and market deployment of these technologies are challenging to model—on one hand, energy models have tended to underestimate cost declines in clean energy technologies such as wind and solar, while on the other hand many models may not explicitly capture recent cost increases in materials and labor or rising interest rates that may offset some of the cost reductions driven by IRA incentives. Representing barriers and bottlenecks to more rapid technology adoption, such as scaling supply chains, infrastructure buildout, and siting and permitting also present uncertainties and challenges.
2. Modeling certain IRA provisions, such as the structure of investment tax credits and residential rebate programs, is uncertain because the impact of the provisions will depend on decisions that were not yet final as of the time of the modeling cited in this report (e.g., U.S. Treasury Department guidance for the clean hydrogen production tax credit [45V] and advanced manufacturing production credit [48X] and consumer home energy rebate programs).
3. Although it is clear from the modeling that the IRA results in reduced costs for clean technology and that this is expected to make additional federal, state, and private climate action more likely, this report does not model the effects of these prospective additional policy impacts of the IRA.

Future analyses of the impact of the IRA will benefit from additional information and modeling to address these limitations.

CHAPTER 1

Introduction

Across the United States and around the world, the harmful impacts of climate change are increasingly apparent. Damage from unusual heat waves, prolonged drought, increasingly strong storms, accelerating sea level rise, and the expanding range of disease-carrying organisms are collectively affecting our economy and the health and welfare of human beings. Drought threatens agricultural production; sea level rise and flooding destroy infrastructure; and tropical illnesses can leave people less able to adjust to changing circumstances. While these risks can affect individuals from all walks of life, those in low-income communities are particularly vulnerable. In 2022 alone, extreme weather resulted in $172 billion in economic damages and 474 deaths in the United States—and the trend in weather disasters continues to get worse [6]. The world experienced its hottest days on record in July 2023 as average worldwide temperatures reached 63° Fahrenheit (17.2° Celsius) [7]. In recognition of these risks, and the economic opportunities available in clean energy investment, Congress passed the Inflation Reduction Act of 2022 (IRA).

The science of climate change is clear—reducing the risk of harm requires reducing emissions of greenhouse gases (GHGs). There are many sources of these emissions from almost every sector of the economy, but the use of fossil fuels in the energy sector is a significant contributor to climate risks. Reducing emissions that contribute to climate change is an urgent task, as every ton of GHGs emitted contributes further to climate damages. Importantly, Congress noted in enacting the IRA that accelerating the transition to low-emission energy gives the country an economic advantage and provides an opportunity to lead the world in clean energy technologies while meeting science-based emissions reductions goals.

Congress also recognized, in both the IRA and the Infrastructure Investment and Jobs Act (IIJA; also known as the Bipartisan Infrastructure Bill or BIL) that reducing GHG emissions across all sectors of the economy—as an imperative and as an opportunity—requires the transition of our energy sources to cleaner technologies and the transition of our energy use to cleaner energy and improved efficiency. These transitions involve simultaneously increasing deployment of low-emitting electricity generation including renewables, fossil fuels with carbon capture and sequestration (CCS), nuclear, energy storage and hydrogen, increased efficient use of electricity to replace fossil fuels in other sectors, and increased energy efficiency and demand flexibility to moderate the increases in electricity demand and enabling infrastructure. The legislation was consistent with recent research that suggests pathways for reducing GHG emissions with reliable, affordable electricity, safe and reliable transportation, comfortable and affordable buildings, and productive and competitive industry [8, 9]. Reducing carbon dioxide emissions from the economy is also an opportunity to improve public health, because the extraction and combustion of fossil fuels are associated with air pollution that kills thousands and harms even more [10].

Congress further recognized in the IRA and BIL that realizing these pathways requires historic investment in the energy infrastructure of our country, particularly in long-lived power grid, transportation, building, and industrial infrastructure, which often have useful lives of 20 to 50 years or longer [11, 12]. The needed technologies are readily available but need to be deployed at a faster rate and at a much greater scale than has been previously achieved. As a result, meeting U.S. and U.N. 2050 emissions goals [13-15] requires immediate action to begin replacing existing equipment reaching the end of its life with lower-emitting, efficient, and electrified technologies. The IRA recognized that this effort has been limited thus far by both economic and non-economic barriers (see Text Box: Overcoming Deployment Challenges for more on some of these barriers), and therefore established incentives to overcome economic barriers to investment and initiatives to reduce technical and knowledge barriers to implementation.

The IRA represents the largest commitment ever made by the federal government to invest in the decarbonization of the U.S. economy. The Congressional Budget Office (CBO) estimates the total support for the broad range of climate and clean energy programs, tax credits, and other incentives authorized through the IRA at $391 billion from 2022 through 2031 [16]. Subsequent analyses of the IRA provisions indicate that the market response may result in even more investment in clean energy than anticipate by CBO with public sector incentives ranging from $800 billion to $1.2 trillion over the ten-year period [17, 18]. The IRA provisions are designed to leverage private-sector investment with estimates of combined public and private-sector investments over the same period spanning $1.8 to $2.9 trillion [17, 18]. Higher investment in clean energy would lead to higher economic activity, additional job creation, and additional emission reductions.

The IRA aims to reduce emissions by incentivizing both the generation of low-cost, low-emission electricity and its efficient use in buildings, transportation, and industry. Through tax incentives, grants, and loan programs the IRA seeks to promote the production of clean energy, domestic manufacturing, and job creation as well as help low-income and underserved communities transition to a low-carbon economy [18]. The BIL provides complementary funding, programs, and incentives for clean energy technologies. It includes $7.5 billion for electric vehicle (EV) charging stations, $65 billion for electric grid upgrades, $8 billion for clean hydrogen hubs, and $6 billion for a civil nuclear credits program.

This report examines results from state-of-the-art modeling tools to show how the IRA reduces emissions during the transition to a cleaner economy. The report presents estimates of IRA investments in clean energy technologies. Consistent with Congress' direction for this report, it also shows where further efforts for climate action offer opportunities to ensure that the United States is on a path to meet our climate goals.

Early analyses of the IRA by models used to inform the legislative deliberations prior to passage show significant reductions in GHG emissions [19-22]. This report builds upon these early analyses to meet EPA's statutory requirement under the Low Emission Electricity Program (LEEP) of the IRA, which calls for an assessment of "the reductions in greenhouse emissions that result from changes in domestic electricity generation and use that are anticipated to occur on an annual basis through fiscal year 2031"[9] .

This introductory chapter describes the methodologies used to assess the emissions reductions and present economy-wide emissions reductions and the underlying energy system transformations. Chapters 2 through 5 will explore these reductions and transformations at a sectoral level for the electric sector, transportation, buildings, and industry, respectively. Chapter 6 concludes with a summary of the findings and suggestions for future analysis.

1.1 OVERVIEW OF THE INFLATION REDUCTION ACT OF 2022

The IRA accelerates the clean energy transition by promoting clean energy, vehicles, buildings, and manufacturing through the inclusion of more than two dozen tax provisions and grant programs. It also provides enhanced/bonus credits to projects that are in low-income communities or energy communities, pay prevailing wages and use registered apprentices, or meet certain domestic content requirements—all with the aim of promoting environmental justice, strengthening America's energy security, creating good-paying, high-quality jobs, and spurring shared economic growth. Initiatives established or expanded by the IRA also seek to address deployment challenges, including practical limitations to implementing new technology and barriers caused by imperfect information. Specific barriers are discussed in the Text Box: Overcoming Deployment Challenges.

The IRA offers funding, programs, and incentives to accelerate the transition to a clean energy economy and will likely drive significant deployment of new clean electricity generation and use. Most provisions of the IRA became effective January 1, 2023. In addition to the abbreviated summary below, more detail on specific IRA provisions is provided in subsequent sector-specific chapters.

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[9] Inflation Reduction Act of 2022. section 60107(5), P.L. 117-169 (August 16, 2022), 136 STAT. 269, 42 U.S.C. 7435(a)(5), Clean Air Act section 135(a)(5).

Electric Generation

The IRA provides significant incentives, including several tax provisions and substantial grant and loan programs to support this deployment of commercially available and innovative clean energy technologies. These include:

- Renewable Production and Clean Energy Production Tax Credit (45 and 45Y): [10] Facilities generating net zero GHG electricity from wind, biomass, geothermal, solar, landfill and trash, and hydropower and marine renewable energy that begin construction prior to January 1, 2025, will receive a credit amount of 0.3 cents/kilowatt-hour (kWh) up to 1.5 cents/kWh.[11]
- Renewable Investment and Clean Energy Investment Tax Credit (48 and 48E): Fuel cell, solar, geothermal, small wind, energy storage, biogas, microgrid controllers, and combined heat and power properties receive credit up to 30% of the qualified investment.
- Nuclear Production Tax Credit (45U): Up to 1.5 cents/kWh for nuclear facilities producing electricity from 2024 through 2032 and not eligible for the advanced nuclear power credit (45J).
- $40 billion in loan authority to guarantee loans for innovative clean energy projects, including carbon capture, new renewable systems, and nuclear.
- $250 billion in loan authority under the Energy Infrastructure Reinvestment (EIR) Program to leverage existing fossil fuel infrastructure.

Multi-Sector

The IRA also includes several provisions that cover and affect more than one sector of the economy. The ten multi-sector models in this study are well suited to estimate the effects of these provisions, which include:

- Carbon Capture and Sequestration (45Q): Up to $85/metric ton of carbon dioxide (CO_2) captured and sequestered from industrial and power generation, and up to $180/metric ton for direct air capture. Credit can be claimed for 12 years after carbon capture equipment is placed in service (construction must begin prior to 2033).
- Hydrogen Production Tax Credit (45V): Up to $3.00/kilogram (kg) for producers of clean hydrogen at a qualified facility.
- Provides funding to the U.S. Department of Agriculture (USDA) for electric loans for renewable energy under the Rural Electrification Act, including for projects that store electricity.

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[10] The abbreviated references capture the section of the U.S. Tax Code where the provision appears (e.g., 26 U.S. Code §45Y)

[11] The 0.3 cents/kWh to 1.5 cents/kWh range reflects the IRA's two-tier credit regime in which the higher tier credit is available for eligible projects that satisfy certain prevailing wage and apprenticeship requirements. The PTC as written is expressed in 1992 dollars which reflects a full value of 2.75 cents/kWh in 2022.

- Funding for the Department of Energy (DOE) Loan Programs Office increases to $40 billion, supporting eligible projects that avoid, reduce, utilize, or sequester air pollutants or GHG emissions, and employ new or significantly improved technologies.
- Energy Infrastructure Reinvestment financing of $250 billion for DOE for projects that (1) retool, repower, repurpose, or replace energy infrastructure, where fossil fuel electricity projects must have controls to avoid, reduce, utilize, or sequester air pollutants of GHG emissions, or (2) enable operating infrastructure to avoid, reduce, utilize, or sequester air pollutants or GHG emissions.
- Tribal energy loan guarantee program increased to $20 billion.

The IRA is expected to promote significant efficiency improvements and electrification in energy end-use sectors—most prominently transportation, buildings, and industry. Energy-efficient measures, like more efficient equipment and building envelope improvements, directly decrease fossil emissions and reduce the amount of grid generation and capacity needed to fuel end uses. Electrification reduces GHG emissions through lower-emitting electric fuel and, inherently, more efficient electric technology like variable speed vehicle engines and building heat pumps. Electrification provides emissions reductions now in most parts of the country, and as lower-emitting or non-emitting generation is deployed, those reductions will increase. Optimizing the efficiency of end uses will also further reduce emissions and ameliorate any near-term emissions increases.

Transportation

EV uptake will increase in the near-term as a result of measures that reduce the cost to purchase and manufacture them, incentivize the growth of manufacturing capacity and onshore sourcing of critical minerals needed for their manufacture, incentivize buildout of public charging infrastructure for plug-in electric vehicles, and promote modernization of the electrical grid that will power them. It includes significant purchase incentives:

- Clean Vehicle Credit (30D): Up to $7,500 for new clean vehicles.
- Used Clean Vehicle Credits (25E): Up to $4,000 for used vehicles, which will have a strong impact on affordability of these vehicles for a wide range of customers.
- Commercial Clean Vehicle Credit (45W): Up to $40,000 for commercial purchase of medium-duty vehicles.

In addition, the IRA includes significant tax credits for certain charging infrastructure equipment, and sizable incentives for investment in and production of clean electricity, such as 30% of the cost for a charging station. It will significantly reduce the manufacturing cost of EV components through the provisions detailed in the “industry” section below.

Buildings

New tax incentives and customer rebates in the IRA reduce the cost of energy-efficient and efficiently electrified home and building upgrades, offset the cost of adding distributed clean energy sources, and make constructing new energy-efficient and efficiently electrified single and multi-family homes cheaper and easier. These incentives are also reinforced by IRA funding to state, local, and tribal governments accompanied by federal partnerships, technical assistance, and training. Relevant IRA programs include:

- Energy Efficient Home Improvement Credit (25C): Up to $3,200 annually in tax credits to lower the cost of residential efficiency upgrades, including efficient electric end-use appliances like heat pumps for heating, air conditioning, and water heating, as well as building envelope measures, including insulation, doors, and windows.
- Residential Clean Energy Credit (25D): Up to 30% tax credit to lower cost of residential energy including rooftop solar, wind, geothermal, and battery storage.
- New Energy Efficient Homes Tax Credit (45L): Up to $5,000 in tax credits for qualifying new homes and up to $1,000 for each unit in a multi-family building. Each must, at minimum, meet ENERGY STAR requirements.
- Energy Efficient Commercial Buildings Deduction (179D): A revamped deduction for energy efficiency in commercial buildings with a $0.50-$1 base credit per square foot, deductions increase to up to $5 per square foot if wage and apprenticeship requirements are met.
- Nearly $9 billion for states and tribal governments for consumer home energy rebate programs, prioritizing low-income homeowners.
- $1 billion for the Green and Resilient Retrofit Program for building benchmarking and efficiency improvements at U.S. Department of Housing and Urban Development (HUD)–assisted multi-family properties.
- $1.2 billion in grants for states and local government to update building codes and provide training for building sector contractors.

Industry

The IRA includes incentives for the manufacture of fuels and technologies that promote decarbonization:

- Carbon Capture and Sequestration (45Q): Up to $85/metric ton of CO_2 captured and sequestered from industrial and power generation.
- Advanced Manufacturing Production Tax Credit (45X): Credit of varying rates for U.S. manufacturers of clean energy components. Manufacturer production tax incentives of $35/kilowatt-hour (kWh) for U.S. production of battery cells.

- $5 billion in advanced industrial facilities deployment funding and $5 billion in vehicle manufacturing loans and grants.
- More than $4 billion in funding for encouraging use of low-carbon materials in federal infrastructure.

Cross-cutting Funds and Grants

IRA creates two major new programs that will fund projects in multiple sectors. The representation of these programs in the analyses varies across models and may not be reflected in some results.

- $27 billion for a GHG Reduction Fund for competitive grants to strengthen institutions that accelerate the transition to an equitable net-zero economy—investing in buildings, distributed solar, and beyond. The fund consists of
  - $14 billion for National Clean Investment Fund competition.
  - $7 billion for Solar for All program.
  - $6 billion for Clean Communities Investment Accelerator.
- $5 billion for Climate Pollution Reduction Grants for states, local governments, tribes, and territories to develop and implement plans across sectors for reducing GHG emissions and other harmful air pollution.
  - $250 million for noncompetitive planning grants.
  - $4.6 billion for competitive implementation grants

1.2 ESTIMATING EMISSION REDUCTIONS

This assessment of emission reductions relies upon available data and analysis from the peer-reviewed literature, government reports, and modeling by EPA. The report incorporates results from ten multi-sector energy system models and four electric sector models. This section describes the report's methodology and models (1.2.1), scenarios (1.2.2), scope and conventions (1.2.3), and caveats and limitations (1.2.4).

1.2.1 Methodology and Models

The economy is interrelated and complex, and the investments made in the IRA are far-reaching—analyzing the impacts of these changes requires the use of sophisticated energy-economy models that can capture the breadth of the IRA's incentives. To estimate the emission reductions, this report relies upon modeling results from recent peer-reviewed literature, government reports, and EPA-funded modeling and analysis. By leveraging the results from multiple energy-economy models, this analysis characterizes the general trends in emission reductions, provides an estimate of the range of reductions, gives insights into what drivers of emission reductions are robust across models, and identifies areas of uncertainty that could lead to differences from central estimates.

The report incorporates results from the following four studies:

- A 2023 multi-model, peer-reviewed study, *Emissions and Energy Impacts of the Inflation Reduction Act*, by Bistline et al. and published in *Science*. This study includes six multi-sector models and three electric-sector models [1]. Much like the present analysis, the study contrasts two scenarios with and without IRA represented. A strength of this study is the large number of models represented including the models that produced early analyses of the IRA last summer.
- The Energy Information Administration's (EIA's) Annual Energy Outlook (AEO) 2023 using the National Energy Modeling System (NEMS) model. This report includes the with and without IRA scenarios.
- An economy-wide study, Investing in American Energy: *Impacts of the Inflation Reduction Act and Bipartisan Infrastructure Law on the U.S. Energy Economy and Emissions Reductions*, using a version of the NEMS supported by the Office of Policy at the DOE [2, 23]. The study contrasts with and without IRA scenarios and explores sensitivities to IRA implementation and technology cost.
- An electric-sector study, *Evaluating Impacts of the Inflation Reduction Act and Bipartisan Infrastructure Law on the U.S. Power System*, using NREL's ReEDS model [3]. This study presents a rich sensitivity analysis of IRA implementation, technology cost, deployment constraints, and fuel prices.

EPA-funded analysis of emissions reductions includes the use of two multi-sector models, the Global Change Assessment Model (GCAM-PNNL) and the U.S. Regional Energy Policy Model (MIT's USREP model) linked to the Regional Energy Deployment System (National Renewable Energy Laboratory's [NREL] ReEDS), and an electric-sector model, IPM-EPA.

The following list describes the ten multi-sector models and four electric-sector models cited and shown herein.

Multi-Sector Models in This Report

- **Energy Policy Simulator from Energy Innovation LLC (EPS-EI):** EPS simulates major sectors of the U.S. economy on an annual basis. The model tracks changes from business-as-usual projections to examine how user-selected policies impact energy demand, costs, and emissions.
- **Global Change Analysis Model (GCAM-CGS) from Center for Global Sustainability (CGS):** GCAM-CGS is based on GCAM 5.3 and models the United States at the state level. It includes detailed sector-specific, state-level climate policies across multiple sectors of the U.S. economy. GCAM solves for prices of energy resources and the associated demand from other sectors, recursively converging to an equilibrium.

- **Global Change Analysis Model (GCAM-PNNL) from Joint Global Change Research Institute (JGRCI):** GCAM-PNNL is based on GCAM 6.0 and models the United States as a single region. It adds detailed sector-specific, climate policies across multiple sectors of the U.S. economy. GCAM solves for prices of energy resources and the associated demand from other sectors, recursively converging to an equilibrium.

- **Market Allocation (MARKAL) from National Energy Technology Laboratory (NETL):** MARKAL solves a linear program defined by the nine U.S. census regions, accounting for trade flows of energy in the form of electricity, gas, coal, and other fuels.

- **National Energy Modeling System (NEMS-EIA) from the Energy Information Administration:** NEMS models the entire energy sector using submodules for 13 subsectors and broader economic feedbacks. Supply-side models use least-cost optimization approaches to track the evolution this system over time. This study incorporates the with IRA and without IRA scenarios from EIA's Annual Energy Outlook for 2023.

- **National Energy Modeling System (NEMS-OP) from the Office of Policy at the Department of Energy:** This version of NEMS incorporates more provisions of the IRA than are represented in EIA's Annual Energy Outlook for 2023 and includes more extensive representation of industrial CCS, hydrogen production, and direct air capture technologies.

- **National Energy Modeling System (NEMS-RHG) from Rhodium Group:** This version of NEMS incorporates more provisions of the IRA than are represented in EIA's Annual Energy Outlook for 2023 and includes more extensive representation of industrial CCS, hydrogen production, and direct air capture technologies.

- **Regional Economy, Greenhouse Gas, and Energy (REGEN) from Electric Power Research Institute (EPRI):** The U.S. REGEN model links a detailed power sector planning and dispatch linear program model with a logit-choice energy end-use model.

- **Regional Investment and Operations Model (RIO) from REPEAT:** The combination of the RIO supply-side model and EnergyPATHWAYS demand-side model developed by Evolved Energy Research and used by the REPEAT project models detailed energy accounting across sectors of the economy with special detail on infrastructure investment and efficiency.

- **USREP-ReEDS:** This modeling framework consists of the MIT U.S. Regional Energy Policy (USREP) model, a computable general equilibrium model of the United States with 12 regions, linked to NREL's Regional Energy Deployment System (ReEDS) model, a capacity planning model of the U.S. electricity system. The linked modeling system combines ReEDS's spatial and technological detail with USREP's representation of other sectors and the macroeconomy. Note that the version of ReEDS linked with USREP is the same as the standalone version (see below) with one important exception. The linked version does not have plant-level CCS retrofit decisions, which leads to less CCS adoption and higher electric sector emissions in the linked model.[12]

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[12] See the USREP-ReEDS documentation for this work, entitled Economic and Environmental Impacts of the Inflation Reduction Act: USREP-ReEDS Modeling Framework. https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=358898&Lab=OAP

Electricity Sector Models in This Report

- **Haiku from Resources for the Future (RFF):** Haiku is a perfect foresight model of the U.S. electricity sector with state-level coverage and detailed sub-national policy representation.
- **Integrated Planning Model (IPM-EPA) from the EPA:** IPM is a detailed power-sector model and provides projections of least-cost capacity expansion, electricity dispatch, and emission control strategies for meeting electric demand and environmental, transmission, dispatch, and reliability constraints [24, 25].
- **Integrated Planning Model (IPM-NRDC) from the Natural Resources Defense Council (NRDC):** IPM is a linear programming model of power-sector capacity planning and utilization.
- **Regional Energy Deployment System (ReEDS) from the National Renewable Energy Laboratory (NREL):** ReEDS is a linear program of electricity supply and demand as well as the provision of operating reserves for grid reliability at 134 different balancing areas.

Table 1.1 contains a list and characteristics of the multi-sector and electric-sector models used in this analysis. The geographic coverage of the models is primarily the United States; however, GCAM models all world regions. Spatial resolution ranges from a single region to state and sub-state levels. Most of the models rely on optimization to find least-cost solutions or balance supply and demand in energy markets; one model (EPS-EI) uses a simulation framework. Temporal resolution ranges from annual time steps to hourly representations of end-use. Most of the models represent fuel price and energy demand endogenously, that is these variables are solved for within the model instead of taken as inputs. The electric sector is represented with perfect foresight in most models. Appendix B contains two summary tables of model representation of emerging technologies (B.1) and policy representation in the No IRA scenario (B.2). The models attempt to represent current policies, though there are variations about which policies are covered. A notable difference with a few models (OP-NEMS, ReEDS, USREP-ReEDS) is that BIL/IIJA has been excluded from the No IRA scenario but included in the IRA scenario to highlight the full effect of both policy measures.

Table 1.1 Characteristics of multi-sector and electric-sector models in this analysis

Model	Geographic Coverage and Spatial Resolution	Model Type and Equilibrium Approach	Temporal Resolution	Endogenous Fuel Prices	Endogenous Energy Demand	Electric Sector
Multi-Sector Models (10)						
EPS-EI Energy Policy Simulator (EPS) *Energy Innovation*	50 U.S. states and D.C. Single national region	Energy systems Economy: System dynamics	Annual for end use Seasonal for electric	Yes, in IRA Scenario	Yes	Recursive dynamic
GCAM-CGS, GCAM-PNNL (2) Global Change Analysis Model *UMD-CGS, PNNL*	50 U.S. states and D.C. States	Energy systems Economy: Logit choice	Annual for end use UMD-CGS: 4 segments for electric PNNL: Annual for electric	Yes	Yes	Recursive dynamic
MARKAL-NETL MARKet ALlocation *NETL DOE*	Contiguous U.S. 9 Census regions	Energy systems Economy: Least-cost LP	Hourly for end use 12 segments for electric	Yes	Yes	Perfect foresight
NEMS-EIA, NEMS-OP, NEMS-RHG (3) DOE Office of Policy – National Energy Modeling System *EIA, DOE Office of Policy, Rhodium Group*	50 U.S. states and D.C. Regions vary by sector	Energy systems Economy: 13 modules with least-cost LP supply and consumer adoption demand	Annual for end use 9 segments for electric	Yes	Yes	Perfect foresight
REGEN-EPRI Regional Economy, Greenhouse Gas, and Energy *EPRI*	Contiguous U.S. 16 regions	Energy systems Energy end use: Lagged logit choice; Electricity: Least-cost LP	Hourly for end use 120 segments for electric	No	Yes	Perfect foresight
RIO-REPEAT RIO (supply-side), EnergyPATHWAYS (demand-side) *Evolved Energy Research and ZERO Lab*	Contiguous U.S. 27 regions	Energy systems Economy-wide LP	Hourly for end use 1,080 segments for energy supply	No	Yes	Perfect foresight
USREP-ReEDS U.S. Regional Energy Policy Model and Regional Energy Deployment System *MIT and NREL*	50 U.S. states and D.C. USREP 12 regions ReEDS 134 regions	Energy-Economy Economy: Constant elasticity of substitution Power sector: Least-cost LP	17 segments for electric Annual for other	Yes	Yes	Recursive dynamic
Electric Sector Models (4)						
Haiku-RFF Haiku Power Sector Model *Resources for the Future*	Contiguous U.S. States	Electric sector Power sector PE: Least-cost LP	24 segments for electric	No	No	Perfect foresight
IPM-EPA, IPM-NRDC (2) Integrated Planning Model *EPA, NRDC*	Contiguous U.S. 67 regions	Electric sector Power sector PE: Least-cost LP	24 segments for electric	Coal, natural gas, biomass	No	Perfect foresight

1.2.2 Scenarios and Sensitivities

The study is structured around two scenarios to evaluate the potential impacts of the IRA on emissions:

- **IRA:** A scenario that reflects all federal and state policies enacted including the IRA.
- **No IRA:** A counterfactual scenario that reflects federal and state policies enacted except for the IRA.

As noted in Section 1.1, the IRA is an extensive and complex piece of legislation to model for several reasons including the number of provisions and the interpretation and detailed assumptions needed to represent the provisions in a model. Table 1.2 summarizes which of the 44 IRA provisions are represented in each model. It is based upon Bistline et al. [1] for consistency across studies. It is not intended to be exhaustive but attempts to capture most of the high economic value and high leverage provisions. Note that the category “not applicable” applies to provisions that cannot be modeled within the current model structure and scope. This contrasts with provisions identified as “not modeled,” meaning that the structure and scope exist, but the provision was not modeled for other reasons. Appendix C contains the IRA implementation assumptions for the EPA-funded models GCAM-PNNL, USREP-ReEDS, and IPM-EPA (C.1), IRA implementation sensitivity assumptions for USREP-ReEDS (C.2) and GCAM-PNNL (C.3), and IRA implementation sensitivity guidance for models in the Bistline et al. paper (C.4).

As shown in Table 1.2, no model represents all 44 provisions. The multi-sector models cover between 16 and 32 provisions. The electric-sector models cover 6 to 8 provisions. All else equal, greater coverage of provisions would be expected to lead to greater reductions. However, some provisions provide greater emission reductions that others (see the sensitivity discussions in Sections 1.3.2 and 2.3). Certain provisions are covered by very few models (see, for example, loan programs, the advanced manufacturing production credit (45X), and cross-cutting funds and grants). Of the end-use sectors, industry has the lowest coverage of IRA provisions.

To understand how changes to various assumptions affect emissions reductions, the report explores several sensitivities as summarized below.

- **IRA implementation** *(Moderate, Pessimistic, Optimistic)*. Results in the report reflect the Moderate IRA implementation scenarios, which is defined as the modeling team’s central case as presented in the literature. The Optimistic implementation means that scenario is favorable toward emission reductions. The Pessimistic implementation means the scenario is less favorable for emission reductions. Results are included for four multi-sector models (EPS-EI, GCAM-CGS, REGEN-EPRI, RIO-REPEAT) and two electric-sector models (ReEDS-NREL, Haiku-RFF) that ran both Optimistic and Pessimistic scenarios from the Bistline et al. study [1]. These sensitivities change the IRA implementation assumptions, and the build rates and availability of clean generating technologies as summarized from Appendix C.3. USREP-ReEDS ran similar scenarios, but without restrictions on build rates (see Appendix C.2).

Table 1.2 Summary of IRA provisions represented in energy models in this report

			Multi-sector										Power sector			
			EPS-EI	GCAM-CGS	GCAM-PNNL	MARKAL-NETL	NEMS-EIA	NEMS-OP	NEMS-RHG	REGEN-EPRI	RIO-REPEAT	USREP-ReEDS	Haiku-RFF	IPM-EPA	IPM-NRDC	ReEDS-NREL
		Total # of provisions covered for each model out of 44.	27	22	23	19	16	32	22	19	29	26	6	7	6	8
Section	Tax code	Program														
Electricity																
13101	45	Production tax credit (PTC) for electricity from renewables	■	■	■	■	■	■	■	■	■	■	■	■	■	■
13102	48	Investment tax credit (ITC) for energy property	■	■	■	■	■	■	■	■	■	■	■	■	■	■
13103	45(e), 45E(h)	Solar and wind facilities placed in low-Income communities	■	▨	▨	□	□	▨	▨	■	■	■	□	▨	▨	■
13105	45U	Zero-emission nuclear power PTC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
13701	45Y	New clean electricity PTC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
13702	48E	New clean electricity ITC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
13703	168(e)(3)(B)	Cost recovery for qualified property (13703)	□	▨	▨	□	□	■	▨	■	▨	■	□	□	□	■
22004	-	USDA assistance for rural electric cooperatives	■	▨	▨	□	□	■	■	▨	■	▨	□	▨	□	▨
50151	-	Transmission facility financing	■	▨	▨	■	□	▨	▨	■	■	▨	□	▨	□	▨
Multi-Sector																
13104	45Q	Credit for carbon oxide sequestration (CCS & DAC)	■	■	■	■	■	■	■	■	■	■	■	■	■	■
13204	45V	Clean hydrogen PTC	■	■	■	■	□	■	■	■	■	▨	□	■	□	▨
22001	-	Electric loans for renewable energy	□	▨	▨	□	□	■	□	□	□	▨	□	□	□	□
50141	-	Funding for DOE Loan Programs Office	□	▨	▨	□	□	□	□	□	□	▨	□	□	□	▨
50144	-	Energy infrastructure reinvestment financing	■	■	■	■	□	■	□	▨	■	▨	□	▨	□	□
50145	-	Tribal energy loan guarantee program	□	▨	▨	□	□	■	□	□	□	▨	□	□	□	□
Transportation																
13201	40A, others	Biodiesel and renewable fuels PTC	▨	■	■	■	■	■	■	□	■	□				
13202	40	Second-generation biofuels PTC	▨	■	■	■	□	■	■	□	■	□				
13203	40B	Sustainable aviation fuel PTC	▨	■	■	■	■	▨	■	□	■	□				
13401	30D	Clean vehicle credit	■	■	■	■	■	■	■	■	■	■				
13402	25E	Credit for previously-owned clean vehicles	□	□	▨	□	□	▨	□	□	■	▨				
13403	45W	Qualified commercial clean vehicle credit	■	■	■	■	□	■	■	■	■	■				
13404	30C	Alternative fuel vehicle refueling property credit	■	■	■	■	□	▨	□	■	■	□				
13704	45Z	New clean fuel PTC	▨	■	■	■	■	■	■	□	■	□				
60101	-	Clean heavy-duty vehicles	□	□	▨	□	□	■	□	□	□	■				
70002	-	U.S. Postal Service clean fleets	□	□	▨	□	□	■	□	□	□	■				

■ Included ▨ Not Included □ Not Applicable

Table 1.2 Summary of IRA provisions represented in energy models in this report

(continued)

			Multi-sector										Power sector			
			EPS-EI	GCAM-CGS	GCAM-PNNL	MARKAL-NETL	NEMS-EIA	NEMS-OP	NEMS-RHG	REGEN-EPRI	RIO-REPEAT	USREP-ReEDS	Haiku-RFF	IPM-EPA	IPM-NRDC	ReEDS-NREL
		Total # of provisions covered for each model out of 44.	27	22	23	19	16	32	22	19	29	26	6	7	6	8
Buildings																
13301	25C	Energy efficient home improvement PTC	■	■	■	■	■	■	■	■	■	■				
13302	25D	Residential clean energy PTC	■	■	■	■	■	■	■	■	■	■				
13303	179D	Energy efficient commercial buildings deduction	■	■	■	□	■	■	■	■	■	■				
13304	45L	New energy efficient homes credit	■	■	■	□	■	■	■	■	■	■				
30002	-	Green and resilient (HUD) retrofit program	□	□	▨	□	□	▨	□	□	□	■				
50121	-	Home energy performance-based, whole-house rebates	■	■	■	□	□	■	■	■	■	■				
50122	-	High-efficiency electric home rebate program	■	■	■	□	□	■	■	■	■	■				
60502	-	Assistance for federal buildings	□	□	▨	□	□	□	□	□	□	■				
Industry																
13501	48C	Advanced energy project credit	■	▨	▨	□	■	■	▨	▨	■	■				
13502	45X	Advanced manufacturing production credit	■	□	▨	□	■	▨	□	□	▨	■				
50161	-	Advanced industrial facilities deployment program	□	□	□	□	□	■	□	□	□	■				
60113	-	Methane emissions reduction program	■	▨	■	□	□	□	▨	▨	■	▨				
Multiple	-	Vehicle manufacturing loans/grants	□	□	□	■	□	□	□	□	▨	□				
Multiple	-	Low-carbon materials	■	□	□	□	□	□	□	□	▨	□				
Multiple	-	Agriculture and forestry provisions	■	■	■	□	□	■	■	□	■	▨				
Multiple	-	Oil and gas lease sales	■	▨	▨	□	□	■	■	□	▨	▨				
Cross-Cutting Funds and Grants																
60103	-	Greenhouse gas reduction fund	■	□	▨	□	□	■	□	□	■	■				
60114	-	Climate pollution reduction grants	□	□	▨	□	□	■	□	□	□	■				
60201	-	Environmental and climate justice block grants	□	□	▨	□	□	■	□	□	□	■				

■ Included ▨ Not Included □ Not Applicable

  - Transferability penalty for tax credits (PTC/ITC/45Q/45V): double and halve penalty.
  - Energy community and domestic content bonus eligibility: ±20% from central case within maximum bound of credit.
  - Energy Infrastructure Reinvestment Program coverage multiplier: ±25% from central case.
  - Build rates for renewables: 7% lower build rate from central case in pessimistic; unconstrained for optimistic.
  - Build rates for transmission: 1% annual build rate for pessimistic; unconstrained for optimistic.
  - CCS availability: unavailable until 2030 in pessimistic; unconstrained for optimistic.
  - EVs eligible for qualifying bonus credits: ±25% from central case.
  - Demand-side incentive programs adjustments: 20% loss in credit value for pessimistic; 10% gain in optimistic.
- **Technology.** These scenarios vary cost and non-cost technology assumptions.
  - **Cost and Performance.** *(All Advanced, Advanced Renewables)*. ReEDS, USREP-ReEDS, and GCAM-PNNL ran the All Advanced scenario. Technology cost and performance in ReEDS are changed from the moderate NREL annual technology baseline (ATB) electricity costs to advanced (Adv) or conservative (Cons) ATB cost assumptions [26]. ReEDS also ran a scenario with only advanced renewables. USREP-ReEDS uses the same electricity assumptions as ReEDS and lowers the costs of transportation, energy efficiency, and CCS. GCAM lowered the costs of solar, wind, and electric vehicles (see C.4).
  - **Constraints** *(Constrained, Constrained Renewables)*. These sensitivities attempt to capture deployment challenges associated with permitting challenges, infrastructure development, and inter-regional coordination between utilities and transmission operators. It reduces the land or resource availability for wind, solar, geothermal, and biomass. It constrains transmission builds to historical national averages and limits builds to within transmission planning regions. It also doubles the cost of CO_2 pipeline, injection, and storage infrastructure [3]. ReEDS ran both sensitivities; USREP-ReEDS ran only the all constrained case.
- **Combined IRA Implementation and Advanced Technology Costs** *(Optimistic-Advanced, Pessimistic-Advanced)*. This scenario combines assumptions on advanced technology costs with IRA implementation assumptions (Optimistic for both USREP-ReEDS and OP-NEMS; Pessimistic for only USREP-ReEDS).
- **Fossil Energy Prices and Economic Growth** *(Moderate, Low, High)*. These sensitivities were explored using the GCAM-PNNL model by taking the high and low oil and natural gas price scenarios and the economic growth assumptions from the EIA's 2023 AEO. Standalone ReEDS also explores the effects of natural gas prices using high and low prices from AEO 2022.

Table 1.3 **Sensitivity scenarios by model.** The dots indicate which models (columns) ran each sensitivity scenario (rows)

		Multi-sector										Power sector			
		EPS-EI	GCAM-CGS	GCAM-PNNL	MARKAL-NETL	NEMS-EIA	NEMS-OP	NEMS-RHG	REGEN-EPRI	RIO-REPEAT	USREP-ReEDS	Haiku-RFF	IPM-EPA	IPM-NRDC	ReEDS-NREL
Sensitivity Scenario Categories	IRA Implementation	•	•				•		•	•	•	•			•
	Technology Costs			•							•				•
	Combined IRA Implementation and Advanced Technology Costs						•				•				•
	Technology Constraints										•				•
	Energy Prices			•											•
	Economic Growth			•											

1.2.3 Scope and Conventions

Scope

Gases. In assessing the reductions in greenhouse gases, the analysis focuses on CO_2 emissions. Over 99% of power-sector GHG emissions are from direct combustion of fossil fuels in generation[13] . Emissions of two non-CO_2 GHGs, methane (CH_4) and sulfur hexafluoride (SF_6), are closely linked to electricity generation and use. As a significant consumer of natural gas, the electric sector may be linked to upstream emissions from natural gas extraction, processing, transmission, and distribution. However, changes in natural gas emissions are not examined herein for several reasons. First, the focus of the statutory language for the report is on electricity generation and use but natural gas emissions come from upstream processes. Second, the available literature on the effect of the IRA contains very limited reporting of upstream natural gas emissions and cannot be assessed with the same robustness as CO_2 emissions. Note that the Methane Emissions Reduction Program within the IRA aims to reduce methane emissions levels from oil and natural gas operations through financial and technical assistance as well as a waste emissions charge (see the text box on the Methane Emissions Reduction Program of the IRA). The emissions of SF_6, a gas used as an electrical insulator and arc quencher in electrical transmission and distribution equipment, are discussed in the text box on Managing SF6 in an Electrifying Economy in Chapter 2.

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[13] See Table 2.11 of the U.S. Greenhouse Gas Inventory [4]

Policy. Following the long-held convention used in the EIA's Annual Energy Outlook, the results in this report reflect on-the-books policies and regulations. The results do not reflect proposed regulations outside the scope of the IRA. In particular, the report does not model or attempt to account for proposed regulations in transportation and the electric sector. In April 2023, the EPA announced new proposed standards to further reduce harmful air pollutant emissions from light-duty and medium-duty vehicles [27], as well as heavy-duty vehicles [28], starting with model year 2027.[14] In addition, in May 2023, the EPA proposed a rule that establishes emission limits and guidelines for CO_2 from fossil fuel–fired power plants based on cost-effective and available control technologies [29]. The proposed rule covers new gas-fired combustion turbines, existing coal, oil and gas-fired steam generating units, and certain existing gas-fired combustion turbines. These and other proposed regulations are not reflected in the modeling results and projections shown in this report.

Conventions

Sector Definitions. The report presents emission reductions and energy consumption at the national level across four sectors of the economy: electric power, transportation, buildings, and industry. Within the power sector, capacity and generation include both large, central station units and distributed generation. Transportation includes personal transportation, trucking, public transit, rail, air, and ships. Buildings include commercial space and residential dwellings. Industry includes production activities such as manufacturing, mining and extraction, and refining—but does not include the electric sector. Note that non-combustion–related industrial process emissions (e.g., from cement) are included.

Direct and Indirect Emissions. Two categories of emissions are reported for the transportation, buildings, and industry sectors: direct and indirect. Direct emissions refer to emissions from the combustion of fossil fuels within the sector (e.g., natural gas combustion for home heating). Indirect emissions, as used within this report, refer only to emissions associated with the electricity consumed in the sector. Emissions associated with other energy conversion processes such as refining are included in the industry sector.

Historical Data Sources. Unless otherwise noted, all historical emissions are based on the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021 [4] and historical energy data are from the Energy Information Agency's Monthly Energy Review [30].

Results Reporting. As described below, the report leverages information from multiple models. Results are typically reported as the multi-model minimum and maximum as well as the median value. Medians do not weight the highest and lowest results as heavily as the mean. Consistent with the majority of the results in the literature, the first reported model year is 2025. Results are presented through 2035, beyond the year specified in the IRA language requesting this assessment, for two reasons—some important IRA provisions extend past 2031 and most of the models we use report projections in five-year increments. Extending to 2035 also captures energy system impacts of the IRA that might not be immediately evident in data through 2031 (e.g., due to slow turnover in end-use capital stock). To estimate reductions in 2031, the

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[14] The proposed rules are not included in this analysis and are mentioned here for broader context of the transportation sector.

emissions need to be interpolated between 2030 and 2035. For tractability, the results do not identify individual models, except for the electricity sector. For numbers reported in the text, modeled results are rounded to two significant figures. The results from individual models are presented in Appendix E. Supplemental results on electrification, direct emissions, sensitivity analysis are presented in Appendix F.

Emissions reductions are presented in two ways: 1) relative to historical 2005 emission levels and 2) as the percentage change between the No IRA and IRA scenarios for each model. The former allows for straightforward comparisons to the literature. The latter better isolates the change in emissions due to the IRA from changes in emissions in the No IRA scenario.

1.2.4 Caveats and Limitations

The models used in this report are simplified representations of the decision-making by all the actors in the economy, and it is important to note that even the most sophisticated modeling and analysis is subject to limitations [31].

The range of results shown across models, which use the Moderate IRA implementation scenario, reflect differences in 1) model structure including technology availability, 2) parametric uncertainty (e.g., technology costs), 3) assumptions and the calibration of the No IRA scenario, and 4) interpretation and representation of the IRA provisions. There was no systematic effort to harmonize assumptions across models, which may affect the relative change in emissions between the scenarios [32]. The value of a multi-model approach is that the analysis reveals results that are robust despite these differences. It should be noted that the multi-model results do not reflect the full range of uncertainty and should not be interpreted as statistical distributions. The full range of uncertainty would cover many more variables and require systematic testing of distributions of input parameters within the models [31, 33, 34].

Energy-economy models represent many highly complex economic activities including energy supply and demand, technology choice, and level of investment. For tractability, most models, including the optimizing frameworks cited within the report, make simplifying assumptions that decision-making occurs under perfect information and markets are perfectly competitive. Recent research suggests that explicitly modeling imperfect information and firm-level decision-making in electricity markets do not significantly alter total new capacity additions but may affect technologies shares [35]. Models represent these activities at various levels of spatial (e.g., nation, state, balancing area) and temporal resolution (e.g., years to hours). Representing technologies at finer-scale temporal and spatial resolution is becoming increasing important to capture technology performance and system interactions [31, 36].

Some of the provisions of the IRA will affect parts of the economy that are difficult to analyze in models, due to, for example, the level of technology aggregation in the model or the details of the IRA provision. Other examples include specific technical characteristics of the transportation, building, and industrial sectors, as well as characteristics of decision-making by individual consumers and companies to invest in efficient and electrified vehicles or appliances, complete energy efficiency measures for buildings or industrial plants, or purchase renewable electricity [37]. There are also dynamics that are challenging to represent in models (see the text box on Overcoming Deployment Challenges) and are therefore explored through sensitivity analysis. Furthermore, economic events, such as recent increases in interest rates and material and labor costs, may offset some of the IRA cost reductions that are not captured explicitly by the models.

The implementation of the IRA depends upon government decisions—some of which have or had not been made as of the time of the analyses. Some specific incentives provided by the Act—such as rules about tax credits to be developed by the Department of the Treasury, depend on guidance that either has yet to be issued (e.g., 45V) or was issued after the provisions were modeled. These details will affect investment decisions and, consequently, they will affect future emissions. To model the impacts of the IRA, modelers have made assumptions about how these details will be resolved, and the scenarios reflect these uncertainties.

Further, multiple technologies are rapidly advancing in a wide range of areas that could significantly change what the future power sector looks like (see the text box on Promising Innovations as well as the sensitivity analyses shown in Figures 1.5 and 2.6) and change how those technologies are to be reflected in future modeling (e.g., distributed generation and long-term storage [38]). Although these technology innovations are less likely to have a significant impact on the 2030 modeling results, they could start to have a more substantive impact in 2035 and beyond. Technology developers, energy companies, and private investors are all investing heavily in a wide range of technologies, many of which will see their first large-scale commercial application between now and 2030. How these technologies evolve could greatly impact future technology choices and potential emission reductions after 2035. This report attempts to capture some of these effects through technology sensitivities for a limited number of models.

Additionally, the IRA represents an unprecedented level of support for clean energy technologies and supply chains. The rate of deployment of these technologies is highly uncertain. For example, solar and wind projects face significant interconnection queues [39]. Furthermore, the rate of expansion may lead to short-term increases in the costs of technologies as supply chains respond to greater demands. These investment dynamics may have small macro-economic effects on materials costs and interest rates that are not represented in the current analysis [40].

Finally, the results of the models are presented at the national level. Some of the models (the electricity sector models in particular), represent generation activities at a relatively fine scale to account for differences in regional markets. The models reflect, for example, how some areas are more conducive to solar or wind power development. These sub-national details are beyond the scope of the report and are not yet widely reported in the literature.

Overcoming Deployment Challenges

INCENTIVES & FUNDING

Many studies have pointed to an economic efficiency gap between actual clean energy deployment levels and higher levels supported by economic benefit–cost analysis alone [41]. Economists often explain the gap as the result of market failures, defined as a violation of one or more of the assumptions associated with the competitive model, for example, the lack of complete information about clean energy opportunities [42]. Economists also recognize a multitude of potential market barriers, which are defined as transitional issues such as supply chain issues or skilled labor shortages. For example, high technology costs for renewable energy can be described as a market barrier but may not be a market failure, unless there are systemic issues that prevent and not just delay market corrections. Lastly, there are non-market or institutional barriers defined as regulatory or administrative measures, technical issues, and environmental and social concerns [41].

The IRA provides significant incentives and funding to overcome market failures facing technologies that lower emissions, which are, in part, reflected in the modeling contained herein. The IRA also aims to overcome market barriers that may not be reflected in the modeling, through programs that increase the knowledge and access to key technologies and facilitate access to capital and labor to promote deployment. Although the IRA and other policies address some of these market obstacles, they will still influence the pace and magnitude of the IRA's impact. Because of the rapid pace at which climate change must be addressed, overcoming these market failures and addressing market barriers is a high priority. Key barriers across electricity generation and end-use sectors are described below. [15] Specific policies responding to these barriers are discussed in the sector-specific chapters of the report:

Market Failures

- **RDD&D as a positive externality.** Firms engaged in research, development, demonstration, and deployment (RDD&D) accrue private benefits from that investment, but there are also spillover benefits, or positive externalities, as others can learn from their experience, bringing down the costs of the technologies and allowing even wider deployment. The existence of these positive externalities means that the market under-invests in RDD&D. Historical analysis suggests that public investment helps correct this type of market failure [43]. Many of the IRA clean technology incentives, like the Advanced Industrial Facilities Deployment Program, can help correct under-investment in RDD&D failure and move us closer to the optimal level of technology learning.

- **Imperfect information/foresight.** Economic models often assume that consumers and businesses have perfect information and foresight about future conditions. In practice, cost-effective solutions may not be selected if stakeholders lack such information. For example, lack of definitions of energy performance levels for efficient electrified technologies and lack of associated labeling make it less clear what equipment

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[15] This list is meant to be illustrative, not exhaustive. Also, while many of the emission reductions projected in this report are not directly linked to programs where EPA has enforcement authority, there are complementary enforceable mechanisms embedded in LEEP. Specifically, Congress included funding and direction for EPA "to ensure that reductions in greenhouse gas emissions are achieved through use of existing authorities…incorporating the assessment" when directing EPA's implementation of the program".

Overcoming Deployment Challenges
(continued)

is eligible for incentives at the state and federal level, and about the relative energy and emission performance of different products generally [44].

- **Risk aversion.** The competitive economic model assumes that consumers or businesses are indifferent between two options with equal net present value, defined as the present value of a future stream of benefits and costs of an alternative, calculated at the appropriate discount rate. In practice, consumers or businesses may apply a higher discount rate to new, unfamiliar technology reflecting perceptions of risk. For example, this affects renewable, efficient, and electrified building technology across the building supply chain—manufacturers, retailers, contractors/trades, and consumers [45, 46]. Risk aversion may also be factored into financing available for projects, resulting in less favorable terms. Risk aversion can have a more significant effect when equipment choices are made with limited time and resources when equipment has failed and must be immediately replaced. Risk aversion can be overcome by having trusted sources communicating the benefits of technologies to these stakeholders, encouraging equipment replacement before failure, and ensuring that equipment suppliers and contractors have appropriate equipment in inventory and knowledge to inform consumer choices when a replacement is needed [47].

- **Split incentives.** The competitive economic model assumes that decision-makers consider all the potential benefits and costs of an alternative. This, however, is not always true in practice. For example, in commercial properties, including many multi-family housing buildings, a landlord or building management company may pay for infrastructure while residents or tenants pay for energy costs, giving the building owner limited incentive to invest in measures that can reduce energy costs, like energy management, efficient equipment, or building envelope improvements [48].

- **Institutions.** Some energy markets are managed as regulated monopolies, and businesses and consumers may have limited access to purchasing clean power supply and the market actors may have limited incentive to do so. The ability of consumers to access, build, or purchase electricity from zero emissions sources is uneven across the United States due to market design and policy issues that can limit a consumer’s ability to choose and use low emissions electricity. Also, utility business models, including retail rate structures, can affect utility decision-making. For example, utilities’ use of building efficiency as a strategy for demand management may be discouraged if compensation is directly related to volume of sales [49].

Overcoming Deployment Challenges (continued)

Market Barriers and Transitions

- **Status quo bias.** The current employment and historical development of each region may be heavily concentrated in existing fossil fuel industries. These industries create state/local revenue streams and may drive a hesitancy in local officials to support transitions to new resources. The same may apply to existing building technology and the construction industry and building trades.

- **High relative costs of information and up-front implementation costs of energy-efficient technology.** For most consumers, energy costs (and potential savings) are a relatively small part of the overall budget. The time and effort to select and implement energy-efficient measures may be perceived as more costly than current costs, even if they provide savings overall. Also, the consumers for whom energy is the largest part of their budget are least able to invest in energy efficiency measures. Product certifications like ENERGY STAR and programs that connect consumers to financing and trusted contractors can play an important role in significantly reducing the costs of product research and quantifying savings. IRA incentive programs, like the whole home rebates, attempt to address the investment challenges for low- and moderate-income customers.

- **Generating, transmission, and pipeline constraints.** In many areas, electricity infrastructure may need to be modernized to support significant new electrified end uses and renewable energy adoption, including providing sufficient power supply and distribution on the utility side and sufficient electrical infrastructure in homes, commercial buildings, and industrial plants [47]. Also, siting and interconnecting new utility-scale renewables, transmission lines, distribution infrastructure, and pipelines for transporting hydrogen or CO_2 may face interconnection scheduling hurdles and siting opposition.

- **Transitional expediency to meet climate goals.** Some market transitions may eventually occur without policy intervention within a competitive market, but not on a time frame consistent with climate goals. For example, a range of supply chain issues, workforce capacity, and equipment availability currently limit the deployment of technology that can significantly reduce GHG emissions [50].

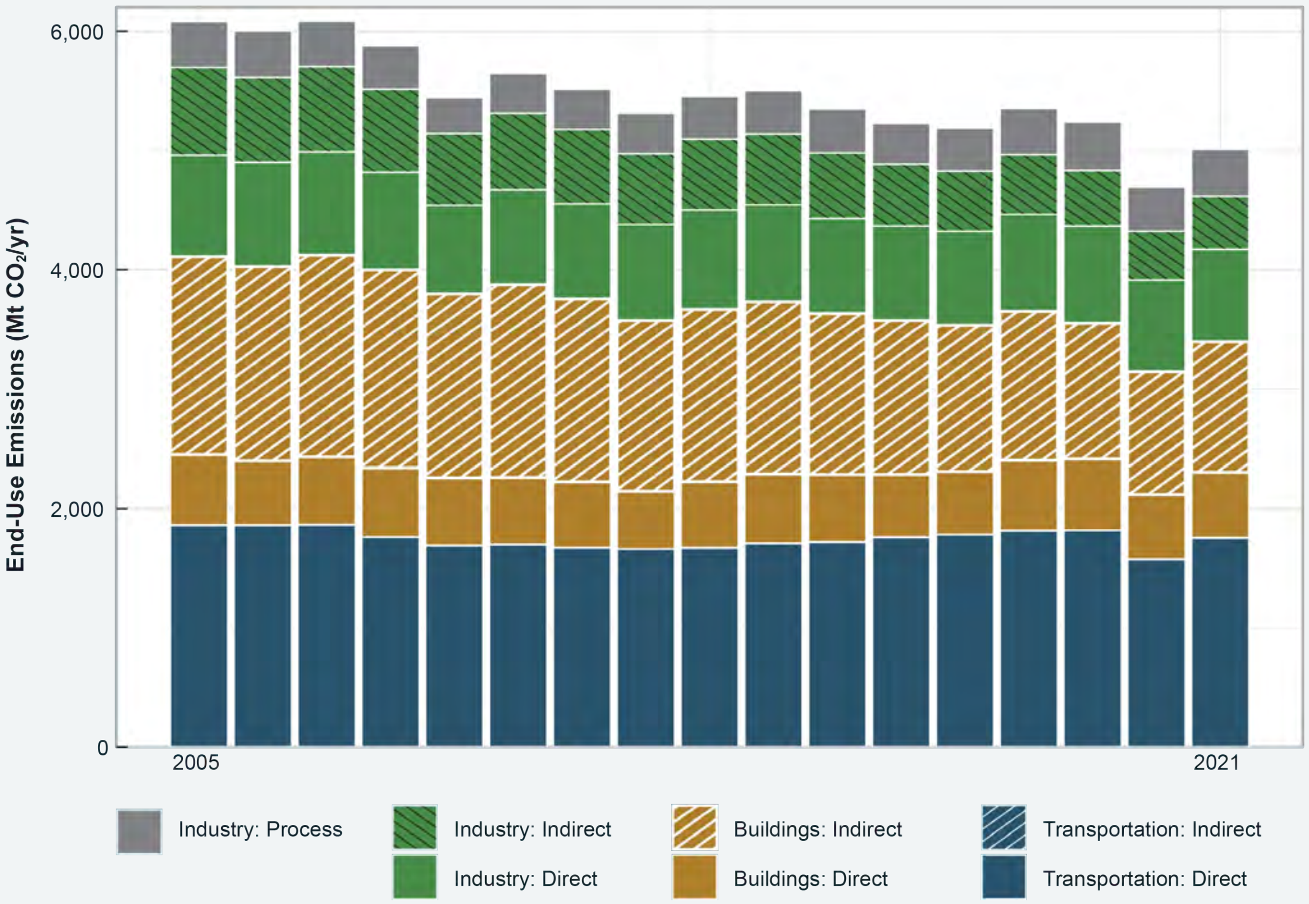
- **Timing of costs/availability of financing.** Implementing building measures often incurs high up-front costs [47]. This interacts with the barrier of lack of financing opportunities for renewable and efficient building strategies, particularly for small business, and low-income and disadvantaged communities [51].

1.3 ECONOMY-WIDE CO_2 EMISSIONS REDUCTIONS

1.3.1 Economy-Wide CO_2 Emissions Snapshot

Economy-wide CO_2 emissions in 2005 were 6,132 Mt CO_2/yr, which decreased to 5,032 Mt CO_2/yr in 2021 (Figure 1.1)[16]. Across the three end-use sectors in 2021, transportation accounted for 35% of direct plus indirect emissions from electricity consumption[17] . Buildings accounts for 33% and industry (including industrial process emissions) accounts for 32%. Indirect emissions from electricity comprise higher shares of emissions in buildings and industry, thus power-sector emission reductions have a greater effect on these sectors.

Figure 1.1 **Economy-wide CO_2 emissions from fossil fuel combustion and industrial processes by end-use sector, 2005-2021**



Total emissions, both direct and indirect (from the use of fossil fuel to generate electricity consumption) in 2005 were 6,132 Mt CO_2/yr, which decreased to 5,032 Mt CO_2/yr in 2021. In 2021, transportation represented 35% of emissions (with negligible indirect emissions from electricity consumed in the transportation sector, not visible in the figure), buildings represented 33%, and industry (including process emissions) represented 32%. Accessible table available in the Data Annex.

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[16] This does not include CO_2 emissions or sequestration from land use activities.

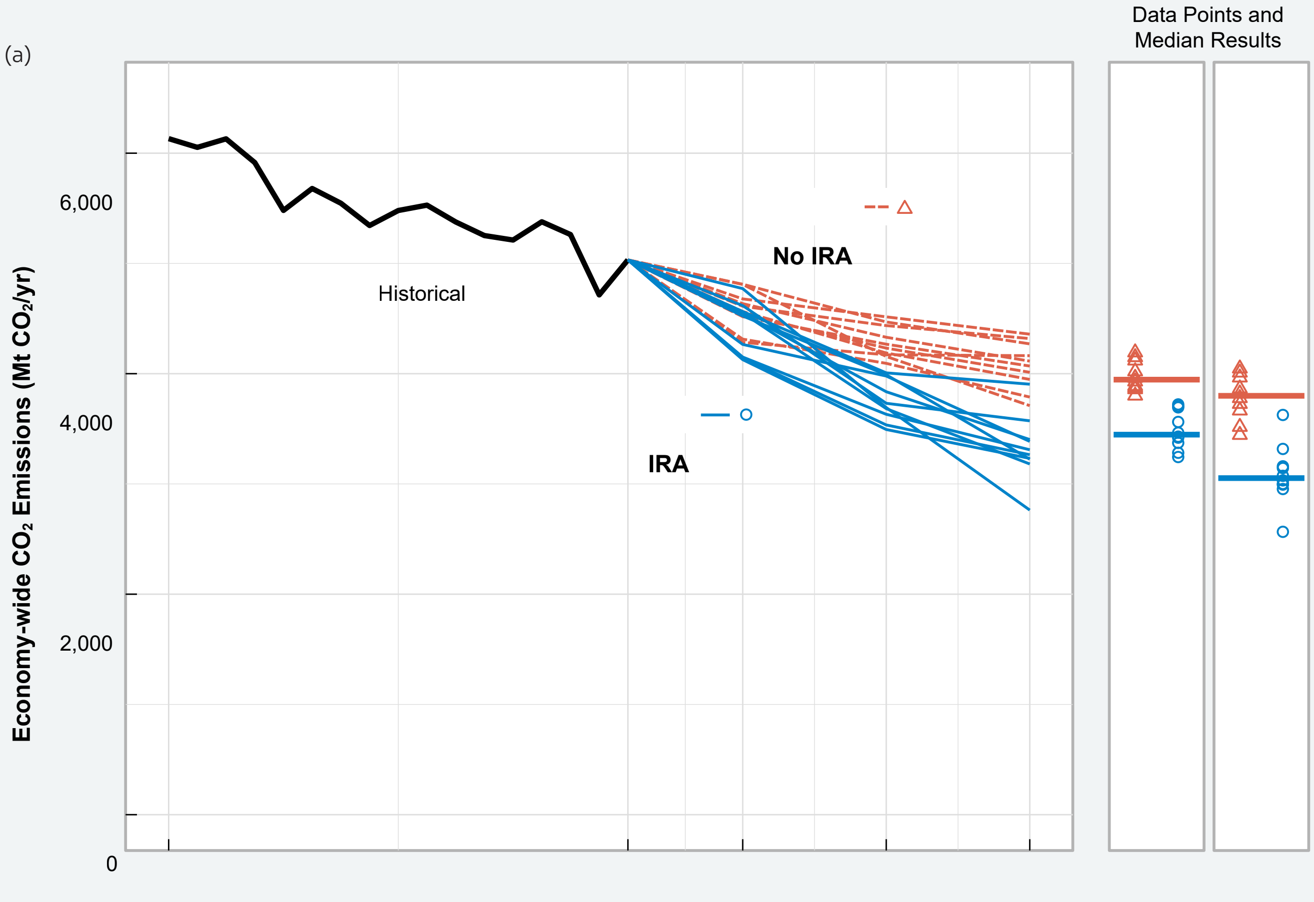
[17] Indirect emissions are apportioned electricity emissions based on the end-use sector share of total electricity consumption.

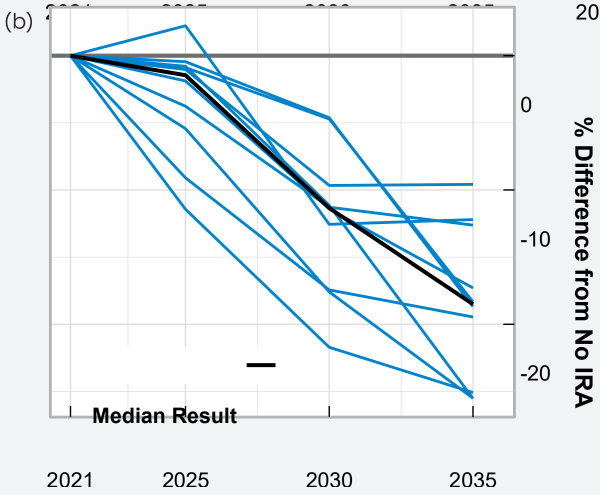
1.3.2 Economy-Wide Emissions Analysis and Results

Economy-wide CO_2 reductions from the IRA Moderate scenarios are 35–43% below 2005 levels in 2030 across the multi-sector models with a 39% median reduction (Figure 1.2(a)). Looking out to 2035, emissions reductions from IRA continue over time and lead to 36-55% declines by 2035 from 2005 levels, with a median reduction of 46%. This reduction exceeds the 29-39% decline by 2035 from 2005 in the No IRA scenario (33% median reduction). Comparing each model's IRA scenario to the same model's No IRA scenario in 2030 shows that economy-wide CO_2 emissions are reduced 5–22% under the IRA scenario relative to the No IRA scenario (Figure 1.2(b)). The range of reductions reflects differences in four areas: model structure and parameterization, input assumptions (e.g., technology costs, economic growth, and energy prices), the number of provisions modeled, and the interpretation and implementation of those provisions.

As shown in Figure 1.1, CO_2 emissions from electricity generation (all indirect emissions) are 31% of U.S. CO_2 emissions in 2021. When electricity-related emissions are distributed to their end-use sectors, transportation CO_2 emissions account for the largest portion, 35%, of U.S. CO_2 emissions, buildings account for 33%, and industry accounts for 32%. Across the end-use sectors, emissions reductions are greater under the IRA scenario than the No IRA scenario. Buildings exhibits the greatest reductions from 2005 levels of direct plus indirect CO_2 emissions from electricity followed by industry and transportation (Figure 1.3).

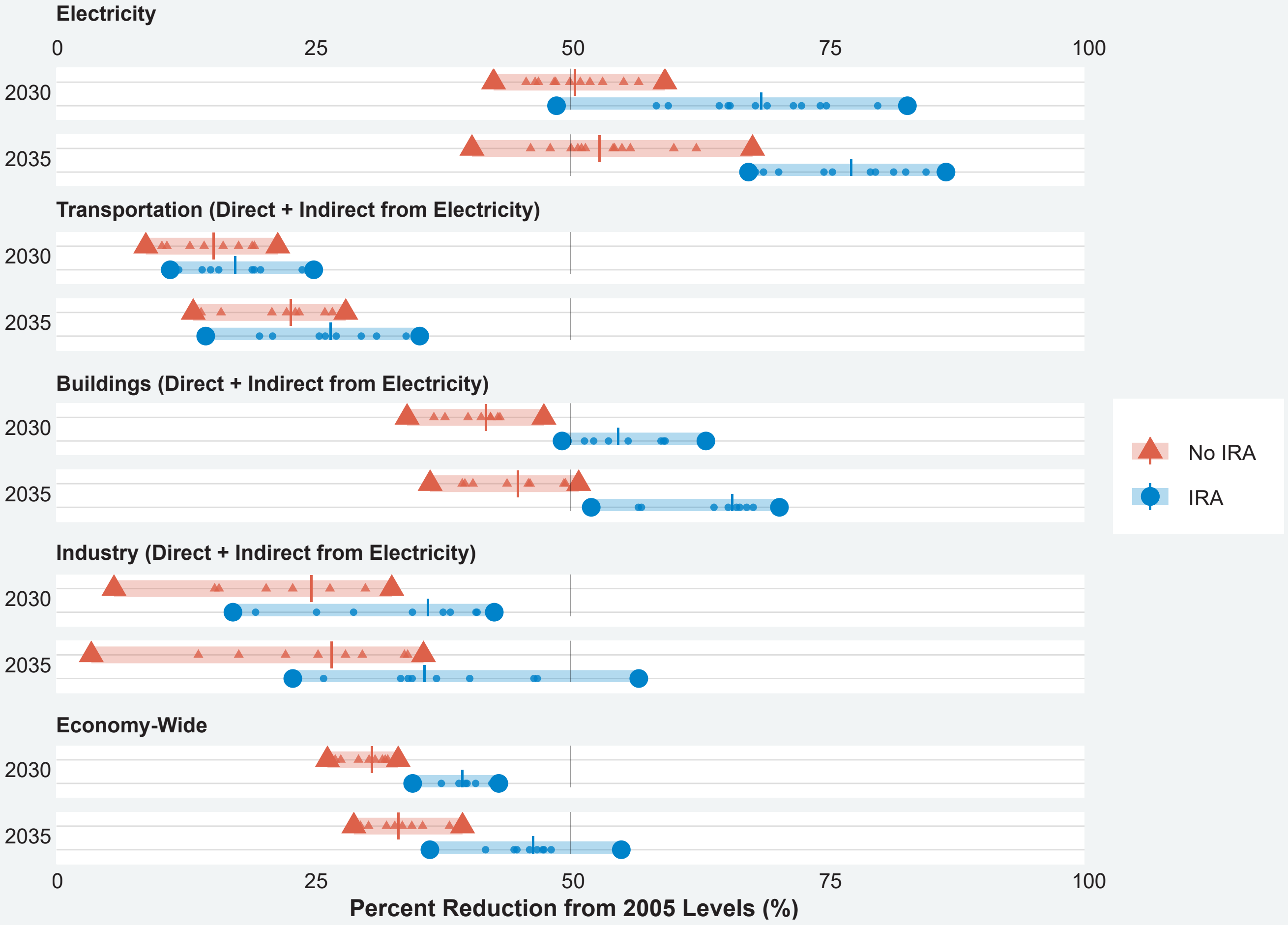
Figure 1.2 Economy-wide CO_2 emissions





In the IRA scenario, economy-wide CO_2 emissions fall 35 to 43% (39% median) below 2005 levels in 2030. In 2030, individual models find that economy-wide CO_2 emissions are 5 to 22% (11% median) below what they are modeled to be in the No IRA scenario, with the median difference falling to nearly 20% by 2035. Figure 1.2(a) shows absolute model results for the emissions trajectories (No IRA scenario in orange dashed lines, IRA Scenario in blue) with the historical trend (in black [4]). Data points to the right of Figure 1.2(a) show individual model results from 2030 and 2035 (blue circles for IRA scenario results, orange triangles for No IRA). Horizontal bars represent the median of the model results. Figure 1.2(b) shows the percent difference between the IRA and No IRA for each model (blue lines) and the median across the models (black line). Economy-wide emissions are broken out into electricity and non-electricity in Appendix F.2. Accessible table available in the Data Annex.

Figure 1.3 Summary of economy-wide and end-use sector CO_2 emissions reductions from 2005 for the IRA and No IRA scenarios



In the IRA scenario, economy-wide CO_2 emissions fall 35 to 43% (39% median, bottom panel) below 2005 levels by 2030. By the same year, electric power sector CO_2 emissions fall 49 to 83% (69% median, top panel) below 2005 levels; transportation sector CO_2 emissions fall 11 to 25% (17% median); buildings sector CO_2 emissions fall 49 to 63% (55% median); and industry sector CO_2 emissions fall 17 to 43% (36% median) below 2005 levels. Note that transportation, buildings, and industry emissions include reductions from changes in direct combustion as well as indirect emissions from electricity generation.[18,19,20,21] Ranges are summarized in Table 1.4. Accessible table available in the Data Annex.

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[18] Transportation, buildings, and industry CO_2 emissions include reductions from changes in direct combustion as well as indirect CO_2 emissions from electricity generation. Except where reported separately, electric sector CO_2 emissions were allocated to the end-use sectors based on electricity consumption. Emissions are broken out into direct and indirect in Appendix F.2.

[19] The Bistline et al. study [1] presents a range for economy-wide emissions reduction from 2005 as 33–40% in 2030 and 43–48% in 2035 in the IRA scenario. This range is the reduction in net-GHG emissions from a model-reported 2005 value for all models but two: MARKAL-NETL includes energy and non-energy CO_2 only, and REGEN-EPRI includes only energy CO_2. Using data from the Bistline study and the model-reported 2005 values, the range of emissions reductions from 2005 for only energy and non-energy CO_2 (comparable to the range presented in this report) is 33–42% in 2030 and 42–53% in 2035. The Bistline 2030 range is lower than the range in this report due to the Bistline calculations referencing model-reported 2005 values, whereas this report references 2005 GHGI data (see Table 1.4)

[20] The Bistline et al. study [1] presents a range for electricity emissions reduction from 2005 as 47–83% in 2030 and 66–87% in 2035. This range is the reduction in electricity emissions from a model-reported 2005 value, whereas this report references 2005 GHGI data (see Table 1.4).

[21] Industrial process emissions are included in economy-wide CO_2 emissions for models that report them, but excluded from industry-specific emissions.

By 2030, the IRA drives CO_2 emission reductions in the transportation sector of 11-25% from the 2005 level. In the buildings sector, emissions in 2030 fall 49-63%, and for the industrial sector, the reduction is 17-43%. By 2035, results show that the IRA achieves even further reductions from the 2005 level in these sectors (15-35% for transportation, 52-70% for buildings, and 23-57% for industry). The CO_2 emissions from each of the end-use sectors under the IRA and No IRA scenarios represent both the "direct" emissions from fossil fuel use in each respective sector and "indirect" emissions from fossil fuels used in generating the electricity consumed by each sector. Appendix F.1 shows how the share of electricity changes across the economy and in each of the end-use sectors. Appendix F.5 illustrates the percent reduction from the No IRA to the IRA scenario across the models for economy-wide and sectoral emissions.

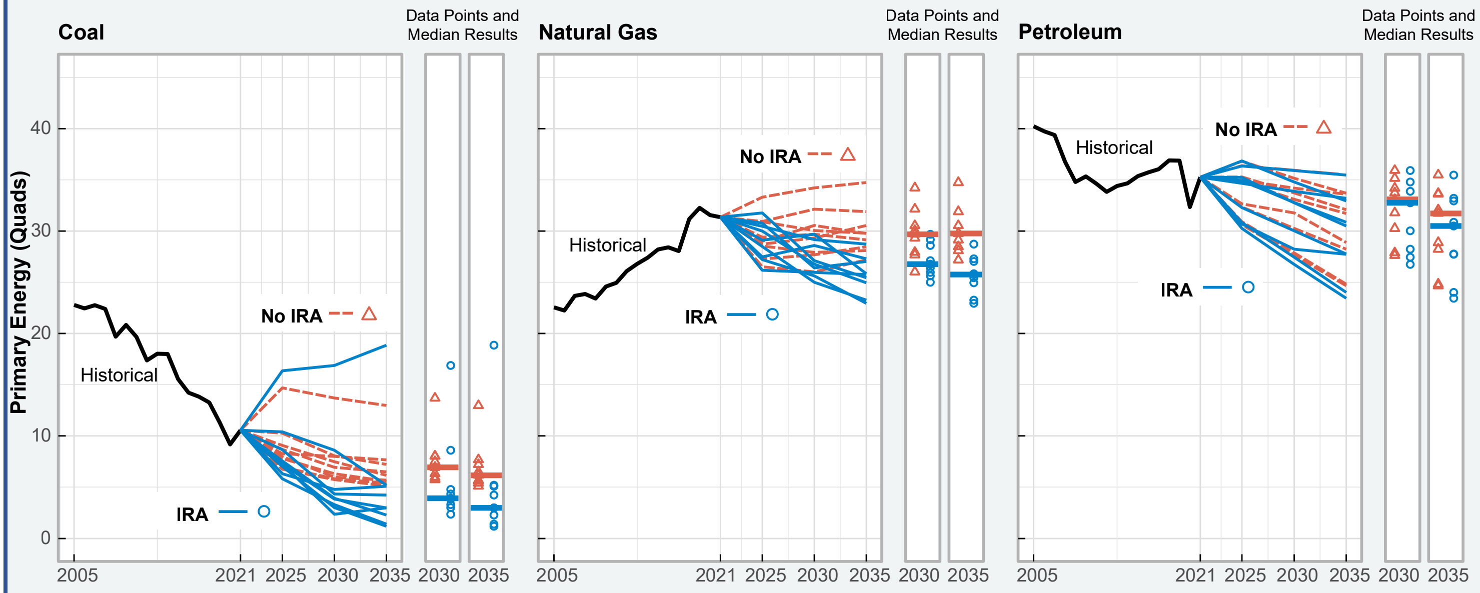
Changes in economy-wide emissions may also be viewed through the lens of fossil fuel consumption. The median consumption of coal and gas falls by roughly four quadrillion Btu (Quads) in 2030 and 2035 with the IRA (Figure 1.4), due predominantly to decreasing demand for those fuels in the electric power sector. Petroleum demand falls comparatively less, as its primary use is in the transportation sector where electric vehicle adoption is not as rapid as the shift towards renewable generation in most models. One model, MARKAL-NETL, exhibits increased coal consumption under the IRA due to greater use of coal CCS technologies in the electric sector. The consumption of petroleum products falls by roughly two quads. These figures present all fossil energy use in the economy (i.e., not only fossil energy use in the electric sector).

Table 1.4 Summary of ranges of CO_2 emissions reductions from 2005

		IRA			No IRA		
Sector	**Year**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
Electricity	2030	49%	69%	83%	43%	50%	59%
	2035	67%	77%	87%	40%	53%	68%
Transportation	2030	11%	17%	25%	9%	15%	22%
	2035	15%	27%	35%	13%	23%	28%
Buildings	2030	49%	55%	63%	34%	42%	47%
	2035	52%	66%	70%	36%	45%	51%
Industry	2030	17%	36%	43%	6%	25%	33%
	2035	23%	36%	57%	3%	27%	36%
Economy-Wide	2030	35%	39%	43%	26%	31%	33%
	2035	36%	46%	55%	29%	33%	39%

Model results show greater CO_2 emissions reductions for the IRA scenario compared to the No IRA scenario for each sector and for the economy as a whole. This is true for the minimum, median, and maximum reductions reported by all models for both 2030 and 2035 results.

Figure 1.4 Fossil energy consumption by fuel

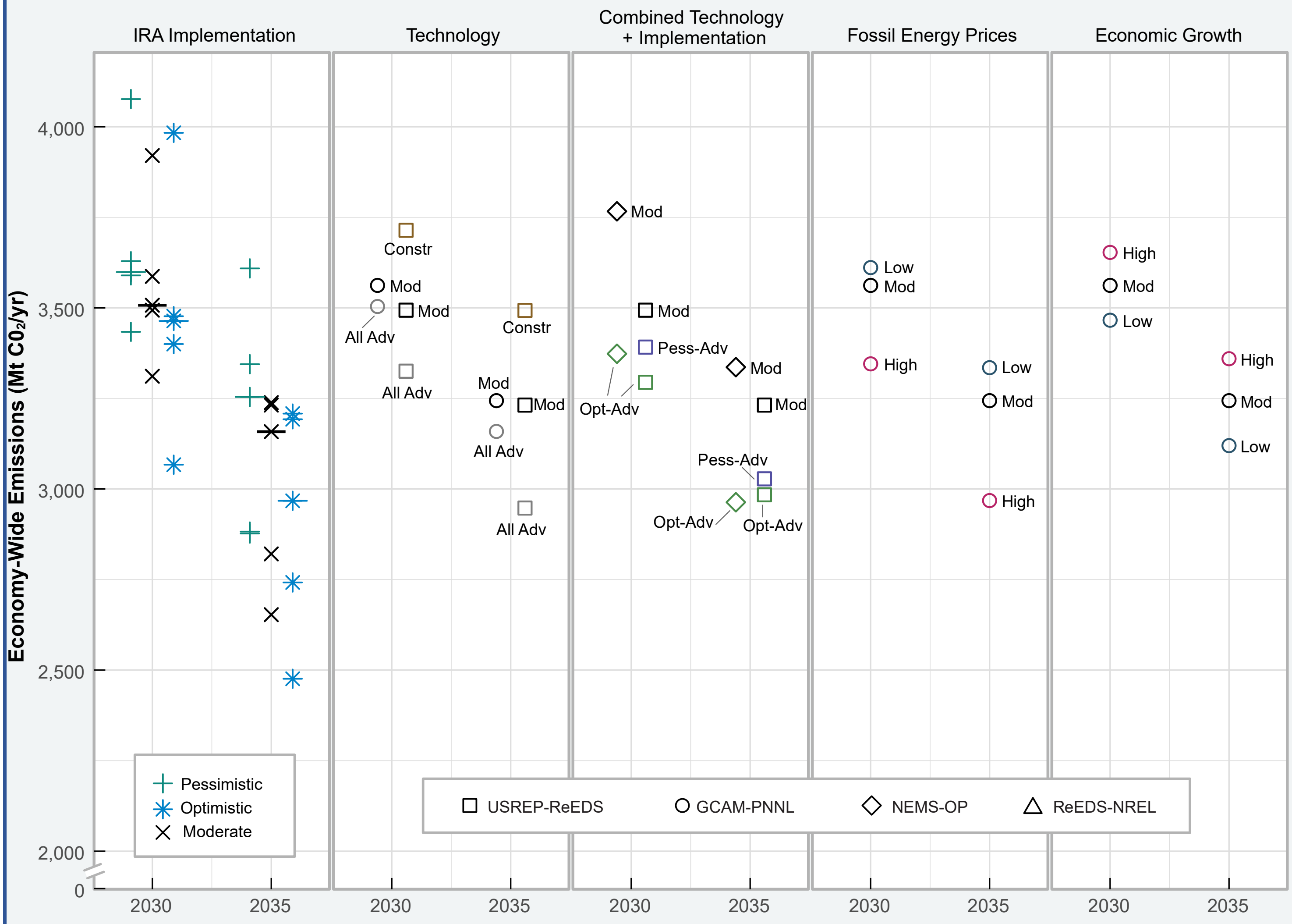


The IRA scenario results show a substantial decrease in the use of coal, gas, and petroleum for energy consumption when compared to the No IRA results in 2030 and 2035. The orange dashed lines represent model results in the No IRA scenario, and the blue lines represent model results from the IRA scenario. The right side of each panel shows data points from different models (blue circles for IRA scenario results, and orange triangles for No IRA), and the horizontal bars represent medians in the years 2030 and 2035. The declining trend in coal consumption shown in the historic data continues in the No IRA scenarios and accelerates in the IRA scenarios (note that one model, MARKAL-NETL, exhibits increased coal consumption under the IRA due to greater use of coal CCS technologies.) The increase in natural gas consumption shown in the historic data generally levels off in the No IRA scenario and generally declines in the IRA scenario, while petroleum consumption begins to fall in the No IRA scenario with a slightly accelerated decline in the IRA scenario. Accessible tables available in the Data Annex.

In addition to the IRA Moderate scenario, the following sensitivities are examined by a limited set of models (Figure 1.5): IRA implementation, technology advances and deployment constraints, combined IRA implementation and advanced technology, economic growth, and fossil energy prices (see section 1.2.2 for scenario descriptions). Four models in the Bistline et al. study [1] and USREP-ReEDS explored the sensitivity of economy-wide CO_2 emissions reductions to IRA implementation and the value of IRA incentives (e.g., PTC, ITC, 45Q, 45V, energy community bonuses, domestic content bonus) and technology build rates and availability (e.g., renewables and transmission build rates, CCS availability, EVs' eligible for bonus credits) (see Appendix C.2 and C.3 for details). GCAM-PNNL, USREP-ReEDS, and NEMS-OP explored the additional sensitivities (see Appendix C.4 and [2] for details).

Results in Table 1.5 are presented as changes from the Moderate IRA scenario for data in Figure 1.5. For reference, a 1% change from 2005 economy-wide CO_2 emissions is 61 Mt CO_2. In 2030, IRA implementation sensitivities increase reductions by up to 4 percentage points (pp) relative to the Moderate IRA scenario when optimistic and increase emissions by up to 2.5 pp when pessimistic, and over 7 pp by 2035. Advanced technology assumptions increase reductions by up to 2.7 pp while constraining it increases emissions up to 3.6 pp. The largest median impact is in the sensitivity case combining Optimistic IRA implementation with advanced technology assumptions resulting in 2030 emissions falling an additional 4.8 pp below 2005 levels. This combined effect is greater than the median changes in either the Optimistic IRA implementation sensitivity or the advanced technology sensitivity alone—indicating positive interaction effects related to the IRA accelerating advanced technology adoption. High fossil energy prices reduce CO_2 emissions relative to the Moderate IRA scenario by a greater amount than low fossil energy prices increase emissions. Sensitivities in economic growth showed the least significant impact on emissions changes, no greater than ±2 pp relative to the Moderate IRA scenario. See Appendix F.4 for a summary of emissions reductions ranges including all sensitivity scenarios.

Figure 1.5 Economy-wide CO_2 emissions sensitivities



The largest median impact in economy-wide CO_2 emissions is in the sensitivity case combining Optimistic IRA implementation with advanced technology assumptions, resulting in 2030 emissions falling an additional 4.8 pp below 2005 levels. This combined effect is greater than the median changes in either the Optimistic IRA implementation sensitivity or the advanced technology sensitivity alone, indicating positive interaction effects related to the IRA accelerating advanced technology adoption. Note that the figure has a y-axis break between 2000 and 0 to better show the results. Economy-wide CO_2 emissions are presented for three sensitivity cases in the first panel, Moderate (black "x"), Optimistic (blue asterisk), and Pessimistic (green plus sign), and the horizontal bars represent the medians of each sensitivity. These scenarios were run by EPS-EI, GCAM-CGS, REGEN-EPRI, RIO-REPEAT, and USREP-ReEDS. The shapes in panels 2-5 represent individual models (circle for GCAM-PNNL, square for USREP-ReEDS, diamond for NEMS-OP). These sensitivities cover a range of results that explore the effectiveness of the IRA to reduce emissions under different assumptions (see Section 1.2.2). Table 1.5 presents changes relative to the Moderate IRA Implementation scenario measured in incremental percentage point (pp) changes from 2005 economy-wide CO_2 emissions (e.g., a value of -1.0 would mean that under that sensitivity, emissions are reduced an additional 1 pp below 2005 levels—equivalent to an additional 61 Mt CO_2 of mitigation). Accessible tables available in the Data Annex

Table 1.5

Economy-wide CO_2 emissions changes (percentage points of 2005 emissions) relative to the IRA Moderate scenario

		IRA Implementation		Technology		Implementation + Tech		Fossil Energy Prices		Economic Growth	
Year	**Metric**	**Optimistic**	**Pessimistic**	**Advanced**	**Constrained**	**Opt.Adv**	**Pess.Adv**	**High**	**Low**	**High**	**Low**
2030	Min	−4.0	0.7	−2.7	-	−6.4	-	-	-	-	-
	Median	−1.7	1.6	−1.8	3.6	−4.8	−1.7	−3.5	0.8	1.5	−1.6
	Max	1.0	2.5	−0.9	-	−3.2	-	-	-	-	-
2035	Min	−3.1	0.3	−4.6	-	−6.1	-	-	-	-	-
	Median	−1.3	1.8	−3.0	4.3	−5.1	−3.3	−4.5	1.5	1.9	−2.0
	Max	−0.4	7.4	−1.4	-	−4.0	-	-	-	-	-

The largest median impact in economy-wide CO_2 emissions is in the sensitivity case combining Optimistic IRA implementation with advanced technology assumptions resulting in 2030 emissions falling an additional 4.8 pp below 2005 levels. This combined effect is greater than the median changes in either the Optimistic IRA implementation sensitivity or the advanced technology sensitivity alone, indicating positive interaction effects related to the IRA accelerating advanced technology adoption. Table 1.5 presents changes relative to the Moderate IRA Implementation scenario for all sensitivity scenarios, measured in incremental percentage point (pp) changes from 2005 economy-wide CO_2 emissions (e.g., a value of -1.0 would mean that under that sensitivity, emissions are reduced an additional 1 pp below 2005 levels—equivalent to an additional 61 Mt CO_2 of mitigation). For a summary of the percent reduction of all IRA sensitivities from the No IRA scenario, see Appendix F.4.2.

Promising Technological Innovation

TECHNOLOGICAL INNOVATION

Although this report focuses primarily on modeling of IRA, additional information about what might happen under IRA can be gleaned from considering projects under development today. Because a combination of IRA, BIL, and CHIPs, provide significant funding for development of new technologies, not all the new technologies that may be available in the 2030 time frame and beyond are fully reflected in all the models used in the present. The following highlights a subset of the technologies in advanced stages of development that modelers may want to consider in future efforts to model IRA and other energy/climate policies.

At least four areas related to IRA modeling are experiencing rapid technology advances. These include energy storage, advanced nuclear, CCS, and distributed generation. With regards to energy storage, there are multiple projects under development. While these projects include demonstration projects at utilities, they also include construction of full-scale factories to supply an increasing demand. These storage projects include a wide range of technologies moving beyond traditional lithium-ion technologies. DOE's pathways report for Long Duration Energy Storage (LDES) focuses on interday LDES (10 to 36 hours) and multiday/week LDES (36 to 160+ hours). The report notes a wide range of technologies that can meet these needs. For interday, this includes traditional and novel pumped storage, gravity based, compressed air energy storage (CAES system), liquid air, and liquid CO$_2$. Both in the United States and internationally, developers are pursuing all these technologies. For instance, in California, Hydrostor is developing a 500 megawatt (MW) CAES system.[22]

With regards to nuclear, there are at least two areas of significant development: small modular reactors and micro reactors. In both cases, these technologies hope to take advantage of both technology improvements in the nuclear plants themselves and just as importantly, improvements in manufacturability by developing smaller, largely factory-built modules that can take advantage of mass production. While the first of these projects will rely significantly on federal funding, utilities are also showing interest in these technologies without additional federal funding. For instance, PacifiCorp is partnering with Terrapower and the federal government on a first of kind 345 MW sodium-cooled fast reactor with integrated molten salt storage that will allow for storage that could boost generation to 500 MW. While this first plant is a federal-private partnership, PacificCorp's most recent integrated resource plan suggests that they are looking at building two more plants by 2033 [52]. All three of these projects take advantage of the fact that building these

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[22] Energy storage is rapidly expanding at levels that may outperform cost and performance assumptions assumed in some current modeling applications.

Promising Technological Innovation

(continued)

projects at repurposed coal plants offers an opportunity for significant savings. DOE suggests that building on existing sites can save 15 to 35% of capital costs and that recently retired coal plant sites could host nearly 65 gigawatts (GW) of new nuclear generation [53]. In addition to the Terrapower projects, DOE's Advanced Nuclear Liftoff Report cites additional public/private projects under development including projects with X-Energy and Terrapower [54].

For carbon capture, there are at least two promising trends. First are improvements to existing post-combustion CCS projects. DOE is cosponsoring a number of projects where technology developers are looking at advanced sorbents. For instance, DOE is working with the City of Springfield, and technology developers BASF and Linde on a 10-MW pilot-scale project. DOE indicates that, "Based on results from small pilot studies, techno-economic analysis indicates the Linde-BASF technology can provide a significant reduction in capital costs compared to the NETL base case for a supercritical pulverized coal power plant with CO_2 capture." Another promising approach is precombustion processes. NETPower has announced plans to build a commercial-size version of their precombustion natural gas generation process with operation scheduled to begin in 2026 [55].

Distributed generation, demand management, and energy storage also have significant ability to provide low-cost, low-GHG power. This is both through the development of improved solar and storage technologies but also through better integration with the grid. For instance, there is a growing trend in integrating individual distributed generation projects into virtual power plants that can provide reliable, low-cost, low-GHG power. The Rocky Mountain Institute suggests that 60 GW of virtual power plants could be available by 2030 [56].

The Methane Emissions Reduction Program of the IRA

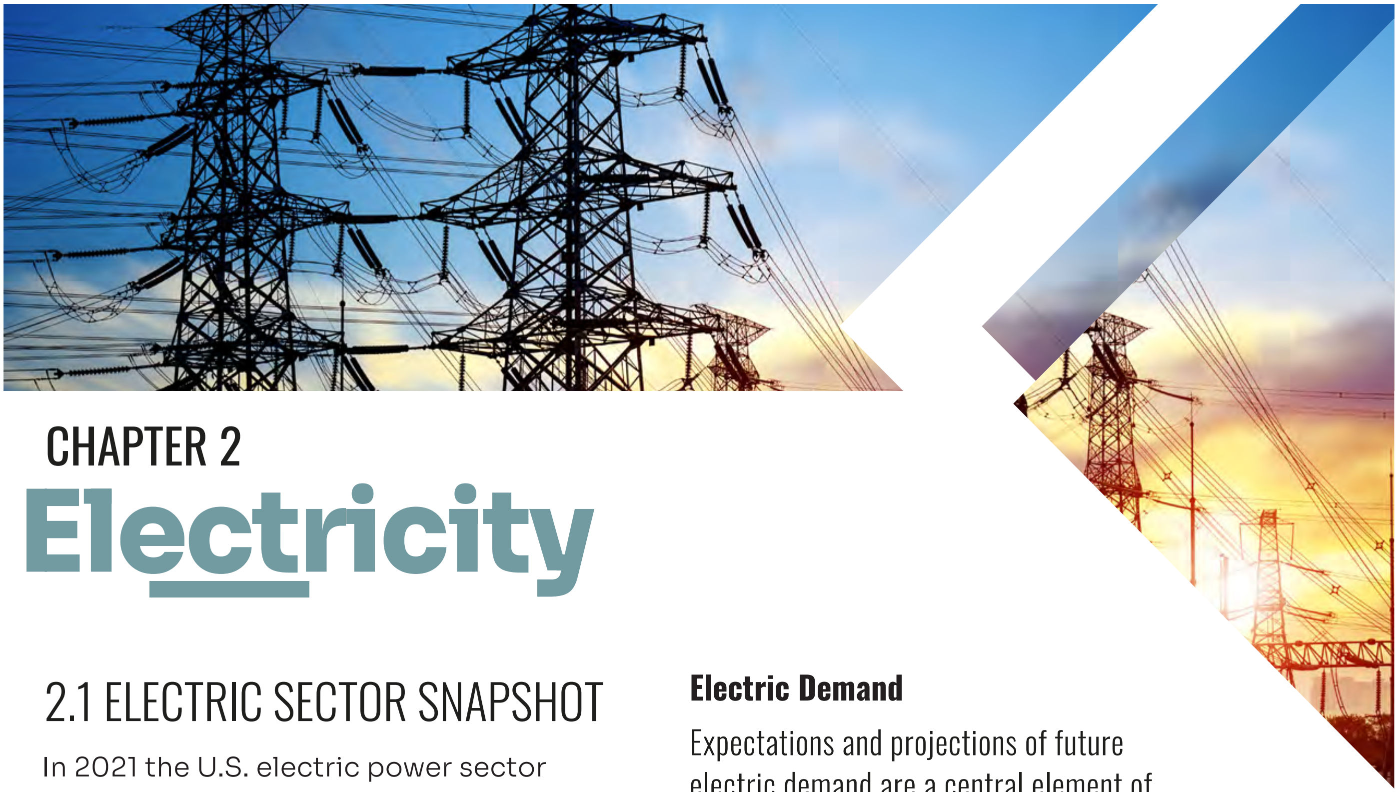
METHANE EMISSIONS

Although this report focuses on CO_2 emissions from combustion, methane emissions from the petroleum and natural gas sector are significant. EPA's proposed New Source Performance Standards and Emissions Guidelines for Oil and Natural Gas Operations, and the Methane Emissions Reduction Program aim to reduce these emissions. Methane (or CH_4) is the primary component of natural gas, which can be used either as a chemical feedstock or as fuel in power plants or residential and commercial buildings. As natural gas travels through the interconnected systems—exploration, production, processing, storage (sometimes), and transmission—from the wellhead to the consumer, methane emissions are released into the atmosphere in a variety of ways. With a global warming potential (GWP) 28 times greater than that of an equivalent mass of CO_2, methane is a potent GHG. Methane emissions from natural gas and petroleum systems were about 3.7% of total GHG emissions in 2021.

The IRA provides new authorities under Section 136 of the Clean Air Act to reduce methane emissions from the petroleum and natural gas sector through the creation of the Methane Emissions Reduction Program. The Methane Emissions Reduction Program includes the following components:

- **Financial and Technical Assistance—**$1.55 billion to reduce methane emissions from the petroleum and natural gas sector by providing financial and technical assistance for preparing and submitting GHG reports, monitoring methane emissions, and reducing methane and other GHG emissions from petroleum and natural gas systems, including mitigating legacy air pollution, improving and deploying equipment to reduce emissions, supporting innovation, permanently shutting in and plugging wells, mitigating health effects in low-income and disadvantaged communities, improving climate resiliency, and supporting environmental restoration. The program specifies that at least $700 million must be used for activities at marginal conventional wells.
- **Waste Emissions Charge—**establishes a waste emissions charge for methane from applicable facilities that report more than 25,000 metric tons of CO_2 equivalent per year to the Greenhouse Gas Reporting Program (GHGRP) petroleum and natural gas systems source category and that exceed statutorily specified waste emissions thresholds. Waste emissions charges start at $900 per metric ton for emissions reported in 2024, increasing to $1,200 for 2025 emissions, and $1,500 for emissions years from 2026 and on. This program includes flexibilities and exemptions, and requires revisions to GHGRP regulations for petroleum and natural gas systems (Subpart W) within 2 years.

New resources and programs in the IRA are complementary to proposed Clean Air Act standards for oil and gas operations, which will incentivize early implementation of innovative methane reduction technologies and support methane mitigation and monitoring activities. These complementary efforts will allow the United States to achieve greater methane emissions reductions more quickly. As background, on November 15, 2021, the EPA proposed new source performance standards and emission guidelines for new and existing crude oil and natural gas facilities (86 FR 63110). On November 11, 2022, the EPA issued a supplemental proposal that updated, strengthened, and expanded upon its November 2021 proposal. The EPA expects to issue a final rule in 2023.



CHAPTER 2

Electricity

2.1 ELECTRIC SECTOR SNAPSHOT

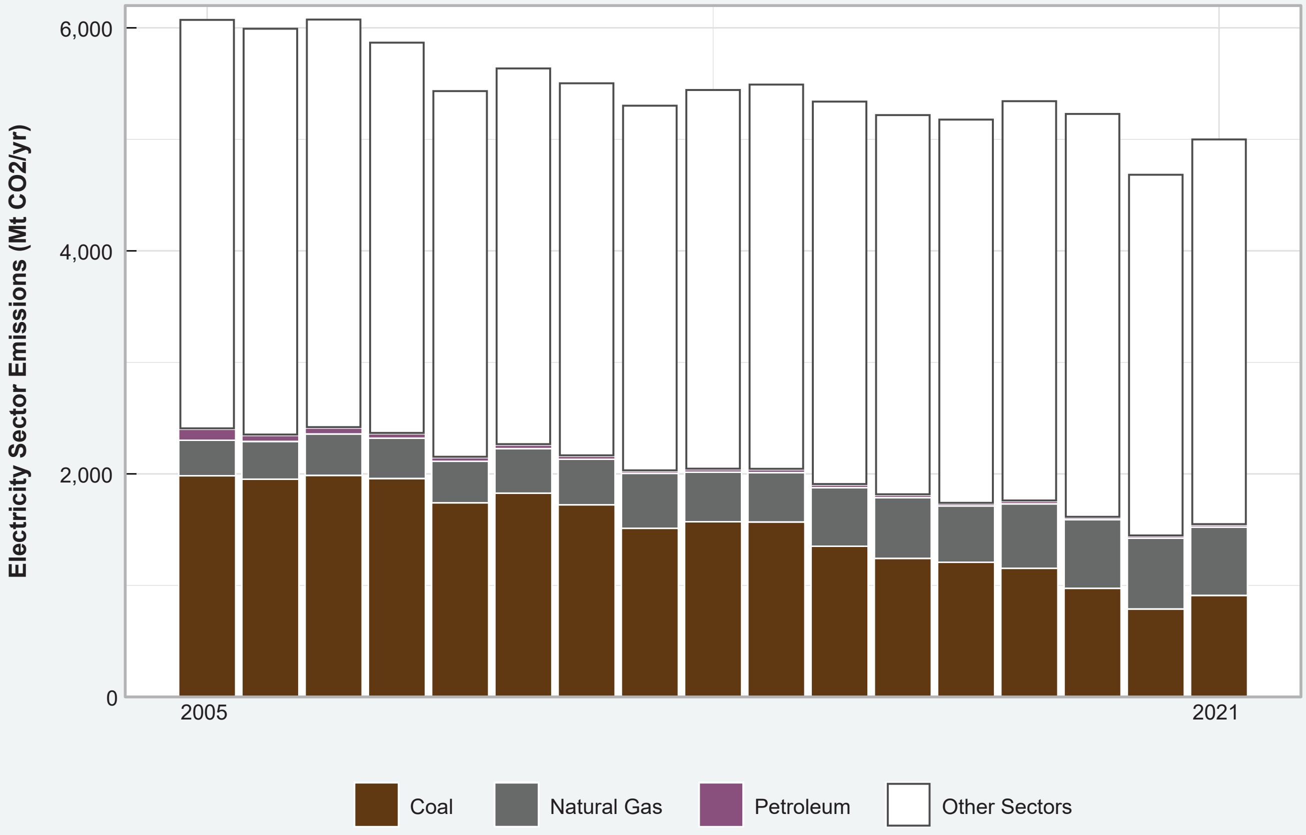
In 2021 the U.S. electric power sector produced 1,540 Mt CO_2, making it the second largest contributor to U.S. greenhouse gas emissions (after the transportation sector) [4]. However, emissions from the power sector are projected to decline considerably in the coming decades. The investments from the IRA are expected to further accelerate this trend.

Electric sector-related CO_2 emissions come from the combustion of fossil fuels to generate electricity. Although natural gas is the largest U.S. fuel source for electricity generation (38% of total generation in 2021), followed by coal-fired generation (22%), coal is the primary contributor of GHGs, contributing 910 Mt CO_2 in 2021, followed by natural gas with 613 Mt CO_2. Most of the remaining electricity delivered to the United States came from low- or zero-emitting sources, including renewable and nuclear sources, at 19% each. The remaining 2% of generation comes from other generating sources including petroleum (see Figure 2.1).

Electric Demand

Expectations and projections of future electric demand are a central element of any electric sector analysis and are subject to a myriad of influences that are uncertain. Two countervailing elements, both of which feature prominently in IRA, are central. The IRA includes many provisions that incentivize efficient electrification across industries to facilitate decarbonization efforts across the economy. These provisions will lead to greater electric demand even with efficient performance. The IRA also includes many provisions that focus on further energy efficiency to reduce energy use across those same industries. Together, along with changes to electric demand across the economy due to other important economic influences, these trends will influence electric demand expectations, and thus any analysis and projection for the electric sector. These influences can affect demand on an annual basis, but also on an hourly basis, affecting the peak demand periods. The net effect of these influences is the most critical aspect, from an analytical and modeling perspective. This important component is explored in sensitivity and alternative scenario exploration, which can be found in this report. As additional work is done to explore how electrification and energy efficiency provisions of IRA influence future expectations of CO_2 emissions, the analytical and modeling community will be able to provide more detailed analysis to inform these important dimensions.

Figure 2.1 CO_2 emissions from the electric sector by fuel in the United States, compared to economy-wide CO_2 emissions, 2005-2021



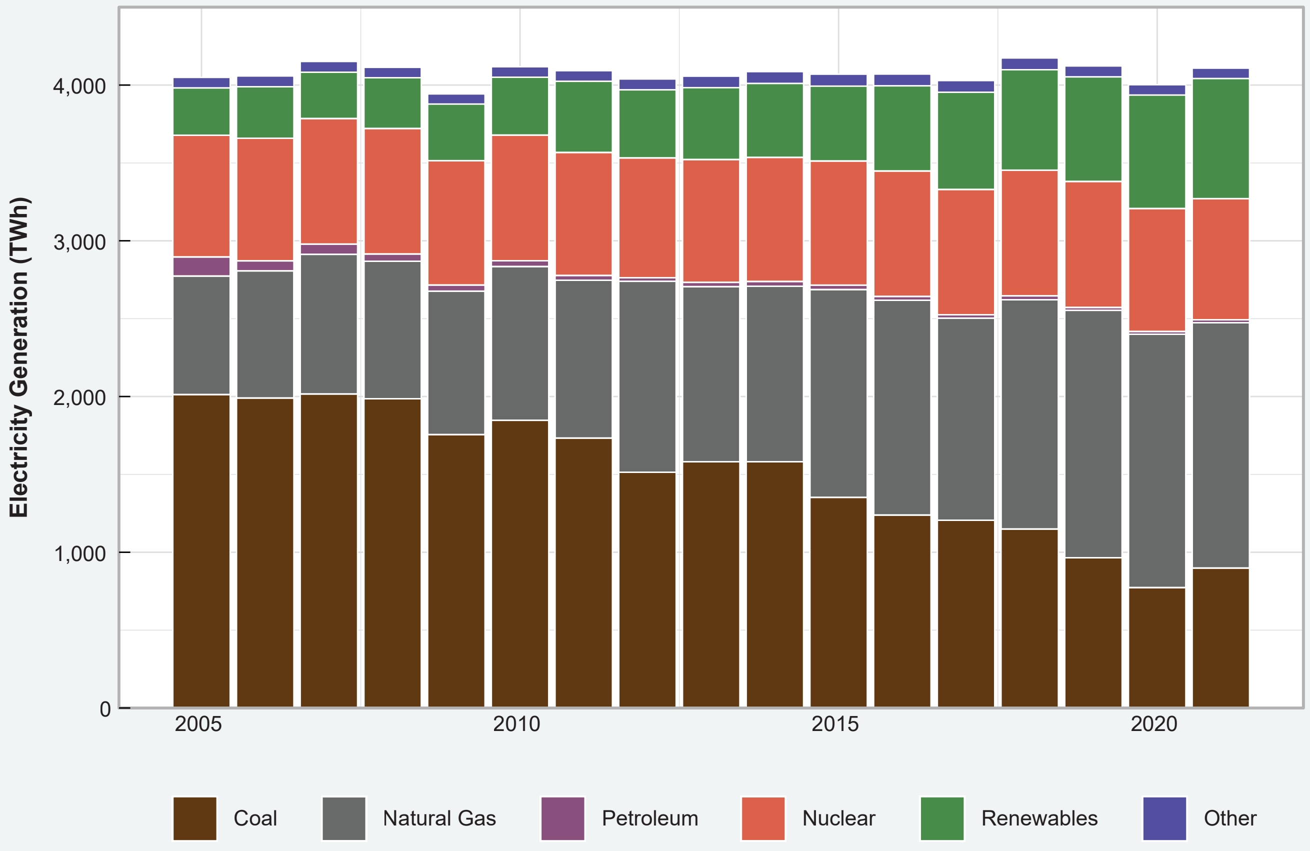
Electric sector CO_2 emissions have declined over time: 2021 emissions are 36% lower than 2005 levels. This overall trend reflects a larger decline in coal CO_2 emissions (54% below 2005 in 2021) and an increase in CO_2 emissions from natural gas combustion (92% above 2005 in 2021). Power sector emissions are shown by fuel: coal (brown), natural gas (gray), and petroleum (magenta). The remaining economy-wide CO_2 emissions in other sectors are represented by the outlined bar. Accessible table available in the Data Annex.

Supply of, and therefore emissions from, coal-fired electricity declined by 54% between 2000 and 2021, from 1,943 terawatt-hours (TWh) in 2000, peaking in 2007 at 1,998 TWh, and declining to 893 TWh by 2021. Coal-fired electricity-generating units delivered 53% of total generation in 2000 and 23% in 2021. Natural gas-fired generation began exceeding coal-fired generation in 2016. In 2022, renewable generation—including wind, solar, and hydroelectric power—also surpassed coal generation [57]. Generation from natural gas increased from 518 TWh in 2000 to 1,474 TWh in 2021. Generation from renewables increased from 315 TWh in 2000 to 790 TWh in 2021, with nearly all of the increase in renewable generation over that period coming from wind and solar, with hydroelectric remaining relatively stable.

Looking forward, generation from cleaner forms of electric generating technologies is expected to continue to grow, amplified by the IRA (see Figure 2.2). As lower-emitting generation increases its share of the generation mix, CO_2 emissions from the power sector are expected to fall. Subsequent sections in this chapter discuss these trends.

In May 2023, the EPA proposed a rule that establishes emission limits and guidelines for CO_2 from fossil fuel-fired power plants based on cost-effective and available control technologies [29]. The proposed rule covers new gas-fired combustion turbines, existing coal, oil and gas-fired steam generating units, and certain existing gas-fired combustion turbines. The proposal is not reflected in the modeling results and projections shown in this report.

Figure 2.2 Electricity generation shares by fuel type, 2005-2021



Since 2000, natural gas and renewable generation have steadily risen while generation from coal has decreased substantially. Source: EIA [30]. Accessible table available in the Data Annex.

2.2 KEY ELECTRIC SECTOR IRA PROVISIONS

The IRA includes the following major provisions and incentives for the electric sector:

- Tax incentives and rebates
  - Extension of Renewable Electricity Production Tax Credit (Section 45)
  - Extension of Renewable Energy Investment Tax Credit (Section 48)
  - Clean Electricity Production Tax Credits (45Y)
  - Clean Electricity Investment Tax Credits (48E)
  - Nuclear Power Production Tax Credit (45U)
  - Carbon Capture and Sequestration Tax Credit (45Q)
- Funding and Financing
  - Greenhouse Gas Reduction Fund (GGRF)
  - Climate Pollution Reduction Grants (CPRG) program
  - USDA Assistance for Rural Electric Cooperatives
  - Grants to Facilitate the Siting of Interstate Electricity Transmission Lines

The IRA modified and extended the availability of the existing Renewable Energy Investment and Renewable Electricity Production Tax Credits. The investment tax credit (ITC) is a 30% tax credit on the up-front capital costs of a project in the year the facility is placed in service. The production tax credit (PTC) provides 1.5 cents per kWh of electricity for the first 10 years a zero- or negative-GHG emissions project operates. The IRA extends the availability of the ITC and PTC until at least 2032. After 2032, the tax credits remain available until the power sector achieves a 75% reduction in CO_2 emission from 2022 levels, after which they begin to phase out. Qualifying facilities for the Clean Electricity ITC and PTC are expanded to include zero- or negative-emitting generating technologies. The provisions also include wage and apprenticeship requirements and allow for bonus credits to be earned if certain domestic content or energy community requirements are met.

The Nuclear Power Production Tax Credit (45U) is a new tax credit that provides financial assistance to existing nuclear facilities. The tax credit provides up to $15/megawatt hour (MWh) for existing nuclear that meets prevailing wage and apprenticeship requirements and earns an average of $25/MWh or less in electricity revenues. Credit is phased out for facilities with average revenues earned above $25/MWh. The credit is available through 2032. Separately, the IRA provides tax credits for both production and investment for new advanced reactors generating electricity (section 45Y and 48D, respectively).[23] The advanced reactor production credit is 0.3 cents multiplied by the kWh base rate for 10 years and starts in 2025.[24]

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[23] Advanced reactor facilities that qualify for production or investment tax credits may only benefit from one, the production credit or the investment credit, but not both.

[24] Energy communities, including coal communities that are new, will receive 10% on top of this credit. The advanced reactors that qualify for this production credit are those that generate electricity, come into service after December 31, 2024, and have a zero greenhouse gas emissions rate. The production credits will only be provided to qualified facilities for 10 years starting when the facility is placed into service.

The IRA also modified and extended the availability of the existing Carbon Capture & Sequestration Tax Credit (45Q). The tax credit provides up to $85/metric ton for CCS facilities.[25] The date by which construction must begin was extended through 2032 and includes wage and apprenticeship requirements to be eligible for higher credit amounts, which can be claimed for 12 years.

Under the IRA, various provisions can alter the incentive levels of tax credits and incentives depending upon how much of a particular project uses domestic content, and whether project developers are paying prevailing wages in the locality where the project is built. While most models do not represent these elements in a detailed manner, they can be explored through sensitivity analysis and side cases (see Section 2.3).

Other relevant tax credit provisions impacting the power sector include New Advanced Manufacturing Production Tax Credit (45X), which creates a tax credit for the production of clean energy technology components that are produced in the United States and the new Clean Hydrogen Production Tax Credit (45V), which creates a new 10-year incentive for clean hydrogen production.

The IRA also provides investments into the power sector in the forms of funding and financing provisions. For example, $9.7 billion is available for financial assistance to rural electric cooperatives to purchase renewable energy, renewable energy systems, zero-emissions systems, and carbon capture and storage systems; $5 billion is available for the DOE Loan Programs Office for the cost of providing financial support in the form of loans and guarantees to 1) retool, repower, repurpose, or replace energy infrastructure, or 2) enable operating energy infrastructure to avoid, reduce, utilize, or sequester GHG emissions; and $2 billion to DOE for direct loans for construction or modification of electric transmission facilities.

Additional IRA provisions target distributed generation, energy storage, energy efficiency, and end-use electrification, with most of these funds supporting distribution grid and end-use projects.[26] Other IRA provisions that would likely impact distributed clean energy technologies include:

- Energy Credit for Solar and Wind in Low-Income Communities
- Rural Energy for America Program (REAP)
- Greenhouse Gas Reduction Fund
- Climate Pollution Reduction Grants

There are numerous developing low-GHG distributed energy technologies, including nuclear (small modular reactors and microreactors) and innovative energy storage technologies, that the IRA will help encourage. These technologies can be applied as a foundation for microgrids, which provide local resiliency and as parts of virtual power plants and can substitute for higher emitting fossil fuel-fired peaking units.

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[25] The IRA also includes an incentive of $180/metric ton for direct air capture (DAC) facilities.

[26] Building-based IRA provisions are specified in Section 4.2.

Environmental Justice

The IRA includes historic investments in environmental justice programs to improve public health, reduce pollution, and revitalize communities that are marginalized, underserved, and overburdened by pollution. Across IRA programs there are also specific requirements to engage these communities and ensure benefits from these programs accrue to them.

In addition to funding to reduce air pollution from trucks and heavy-duty vehicles (Sec. 60101) and ports (Sec. 60102), the IRA provides funds for grants and technical assistance to schools serving low-income communities to address air pollution hazards (Sec. 60105). The Environmental and Climate Justice Block Grants program (Sec. 60201) will advance environmental justice and support projects like community-led air pollution monitoring, prevention, and remediation; mitigating climate and health risks from extreme heat and wildfires; climate resiliency and adaptation; and reducing indoor air pollution. The Greenhouse Gas Reduction Fund (Sec. 60103) will provide competitive grants to mobilize financing and leverage private capital for clean energy and climate projects that reduce pollution—with an emphasis on projects that benefit low-income and disadvantaged communities.

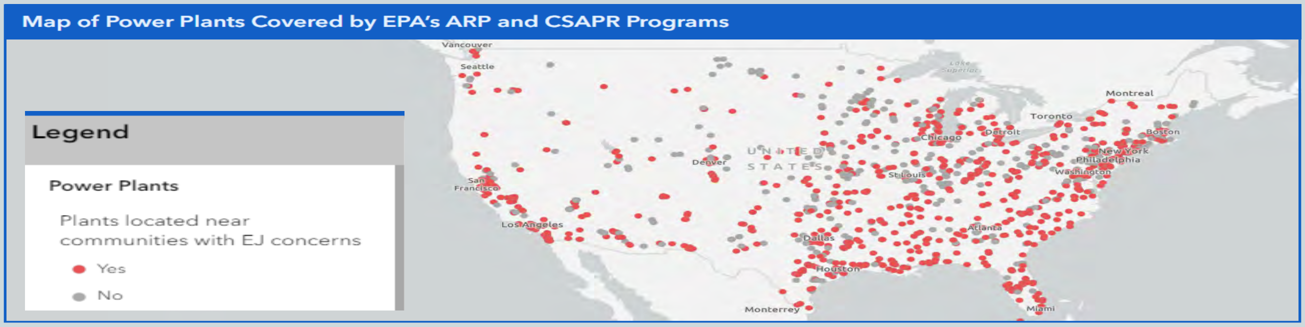
The Low Emissions Electricity Program (Sec. 60107) provides funding for education, technical assistance, and partnerships within low-income and disadvantaged communities with respect to reductions in greenhouse gas emissions that result from domestic electricity generation and use.

While the primary focus of this report is to discuss the impacts of the IRA on CO_2 emissions, changes in other air pollutants will also occur. Resulting climate and air quality benefits will be both broadly distributed and important to communities with environmental justice concerns.

Environmental hazards can be inequitably distributed in the United States, with people of color and low-income populations consistently bearing a disproportionate burden of environmental pollution in some areas. The EPA defines environmental justice as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." This goal will be achieved when everyone enjoys the same degree of protection from environmental and health hazards, and equal access to the decision-making process to have a healthy environment in which to live, learn, and work [60].

EPA has examined the results of its power sector programs through an environmental justice lens to better understand the impacts of those programs on plants located nearby areas of potential concern. In one evaluation using proximity analysis, a frequently used approach to examine potential impacts on people who reside nearby a pollution source, EPA found that 10% of people in the contiguous United States live within three miles of a power plant reporting emissions to EPA under various provisions of the Clean Air Act. These are

Map of Power Plants Covered by EPA's ARP and CSAPR Programs



Environmental Justice (continued)

mostly gas-fired power plants, with approximately 2% of the population living near coal- or oil-fired plants. Compared to the national average, the population living near power plants is characterized by a higher percentage of people of color and low-income population.

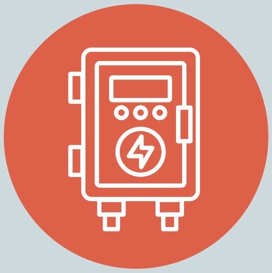
In tracking changes in the power sector as the IRA is implemented, EPA will assess the impacts on disadvantaged communities at various scales. Recent advancements in environmental justice-screening methodologies for the power sector that recognize that air pollution can travel significant distances can enhance our ability to consider the disadvantaged communities that are most exposed to air pollution from each power plant. For example, EPA recently developed the Power Plant Screening Methodology (PPSM). The PPSM incorporates several peer-reviewed approaches that combine air quality modeling with demographic and socioeconomic data to identify geographic areas potentially exposed to air pollution by power plants and quantify the relative potential for environmental justice concern in those areas. This information enables EPA to provide a screening-level look at the relative potential for power plants to affect disadvantaged communities.

This methodology utilizes two approaches to identify areas that are potentially affected by different types of pollutants from each plant: proximity analysis and long-range downwind transport. Each of these approaches uses air quality modeling combined with GIS analysis to identify census block groups that are potentially affected by air pollution from each of the power plants. The proximity analysis approach focuses on the air quality impacts within 50 km of the source. The long-range downwind transport approach focuses on potential air quality impacts within 24 hours of potential emissions release, reaching distances that are considerably greater than 50 km from the sources.

These recent advancements will enable EPA to provide a more robust analysis of how air pollution exposures are changing over time in disadvantaged communities. In future analyses, we plan to characterize the extent to which emissions are decreasing and the generation mix is changing at power plants located nearby and upwind of disadvantaged communities.

To learn more about criteria air pollutant emissions in the context of IRA implementation, see Text Box: Criteria Air Pollutants.

Managing SF_6 in an Electrifying Economy



SULFUR HEXAFLOURIDE (SF_6)

Although the focus of this report is on CO_2, emissions of sulfur hexafluoride (SF_6), the most potent GHG known (100-year GWP = 23,500), need to be managed to meet long-term emission reduction targets. SF_6 is used as an electrical insulator and arc quencher in electrical transmission and distribution equipment (e.g., circuit breakers), and it can be emitted when equipment leaks or is installed, serviced, or disposed. As electrical transmission and distribution (T&D) networks expand, more electrical equipment will be required to support these networks, potentially increasing emissions of SF_6. Fortunately, options to reduce SF_6 emissions are available, including recovery and recycling of SF_6 during servicing and disposal, leak detection and repair, replacement of leaky SF_6 equipment with more leak-tight SF_6 equipment before the end of the old SF_6

Managing SF_6 in an Electrifying Economy (continued)

equipment's normal service life, and replacement of SF_6 equipment with equipment using other insulating gases or not-in-kind technologies either before or at the end of the SF_6 equipment's normal service life. To ensure that increasing emissions of SF_6 do not undermine the climate benefits of decarbonization, it will be important to deploy these mitigation options as T&D networks grow, for example through programs such as EPA's SF_6 Emission Reduction Partnership for Electric Power Systems [61].

- The 2021 U.S. SF_6 emissions from the manufacture and use of electrical equipment are estimated to have totaled 6.0 Mt of carbon dioxide equivalents (CO_2e) (Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021, referred to below as "U.S. GHGI" [4]). Of this total, 5.6 Mt CO_2e are estimated to have been emitted from electrical T&D networks while 0.4 Mt CO_2e are estimated to have been emitted from electrical equipment manufacturing. In the same year CO_2 emissions from the power sector were 1,541 Mt CO_2e.
- Without electrification related to the IRA, U.S. SF_6 emissions in 2030 and 2035 would be 7.8 and 9.1 Mt CO_2e, respectively. These emissions projections assume emissions would grow at a rate of 3% per year from 2021 to 2035, which is the growth rate assumed by the California Air Resources Board (CARB) in their analysis of the impacts of their SF_6 regulations [62]. This growth rate is broadly supported by the trends in SF_6 emissions and SF_6 equipment banks (nameplate capacities) estimated in the U.S. GHGI and/or reported under EPA's Greenhouse Gas Reporting Program (GHGRP). The SF_6 emissions estimated for this source in the U.S. GHGI grew by 2% per year between 2017 and 2021, while equipment banks reported under the GHGRP grew by 4% per year over the same period.[27]
- With electrification, U.S. SF_6 emissions in 2030 and 2035 would be 9.1 and 11.6 Mt CO_2e, respectively. These emissions projections assume that T&D networks would grow 1.8% per year faster than in the "without electrification" scenario and that the average level of SF_6 mitigation would be the same as in the "without electrification" scenario.
- With electrification and full deployment of SF_6 mitigation options, U.S. SF_6 emissions in 2030 and 2035 would be 4.9 and 5.7 Mt CO_2e, respectively. These emissions projections assume that 43% of 2030 U.S. emissions and 40% of 2035 U.S. emissions can be reduced through implementation of options other than uptake of SF_6-free equipment, including improved servicing practices and SF_6 recycling, and that 4% of 2030 U.S. emissions and 11% of 2035 U.S. emissions can be reduced through uptake of SF_6-free equipment.[28] Of note, about half of the emissions avoided through use of SF_6-free equipment are dependent on the availability of equipment that uses alternative insulating gases. The current U.S. supplier of these gases is planning to phase out their production by the end of 2025, which may affect their availability for this application.

2.3 ELECTRIC SECTOR ANALYSIS AND RESULTS

Even before the enactment of the IRA, most long-term modeling showed significant

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[27] The fact that emissions are growing more slowly than banks implies that utilities are reducing their emission rates, probably by deploying recovery and recycling, LDAR, and replacement of leaky SF_6 equipment with other SF_6 equipment. (SF_6 substitutes have not yet achieved significant market penetration.) Eventually, electrical T&D systems will exhaust the reduction potential of these conservation measures and the growth rate for emissions will approach that of the banks.

[28] Reduction options are assumed to be applicable only to emissions from electrical T&D, not to emissions from electrical

declines in power sector-related emissions in the coming decades. The investments from the IRA further accelerate this expected trend. The No IRA power sector emission projections show a large range in expected CO_2 emission outcomes by 2035, from 40-68% below 2005 levels, with the median of 53% below 2005 levels (780 to 1,430 Mt CO_2, with the median of 1,130 Mt CO_2). Comparing across the same set of models, by 2035 the range in projected CO_2 emissions due to IRA both greatly declines and tightens, to 67-87% below 2005 levels, with the median of 77% below 2005 levels (320 to 780 Mt CO_2, with the median of 540 Mt CO_2), suggesting an agreement across models in the direction and magnitude of change in emissions expected for the sector. The reduced emissions intensity of electricity generation also further amplifies the emissions benefits of electrification (see Chapters 3 Transportation, 4 Buildings, and 5 Industry for more information).

The projected decline in CO_2 emissions in the power sector is achieved through a combination of projected declines in electric generation from fossil fuel-based generation technologies (coal, natural gas, and petroleum) without CCS (referred to in later figures as “high-emitting” generation technologies). There are significant increases in electric generation from low- and zero-emitting generation technologies (most models favor new solar and wind, and to a lesser extent fossil fuel-fired generation with CCS, while new nuclear is generally not favored by the models).

Across all the models included in this report, generation from low- and zero-emitting technologies is projected to increase, both relative to current (2021) levels and also across scenarios with and without representation of the IRA. In 2021, generation from low- and zero-emitting sources totaled 1,550 TWh. Generation in the No IRA scenarios is projected to increase for low- and zero-emitting sources, ranging from 1,860 to 3,570 TWh by 2035, with a median of 2,330 TWh. This range increases further in the scenarios with the IRA provisions from 2,440 to 5,260 TWh by 2035, with a median of 3,350 TWh.

Tax credits like the Clean Electricity Investment and Production Tax Credits (48E, 45Y) and the Nuclear Power Production Tax Credit (45U) are the primary drivers for the increases seen in model projections of renewable and nuclear generation technologies relative to future projections under the No IRA scenario. Of renewable technologies, solar and wind see the largest increases in generation; generation in the IRA scenario from wind and solar together ranges from 1,100 to 4,490 TWh, with the median of 2,460 TWh in 2035. Given the expiration of the Nuclear Power Production Tax Credit after 2032, the long-term outcome for nuclear generation remains relatively uncertain, with some model projections showing generation falling precipitously, while others show levels remaining relatively flat. Across all models, nuclear generation in the IRA scenario is between 40 and 800 TWh in 2035 (with a median of 710 TWh), compared to 780 TWh in 2021.

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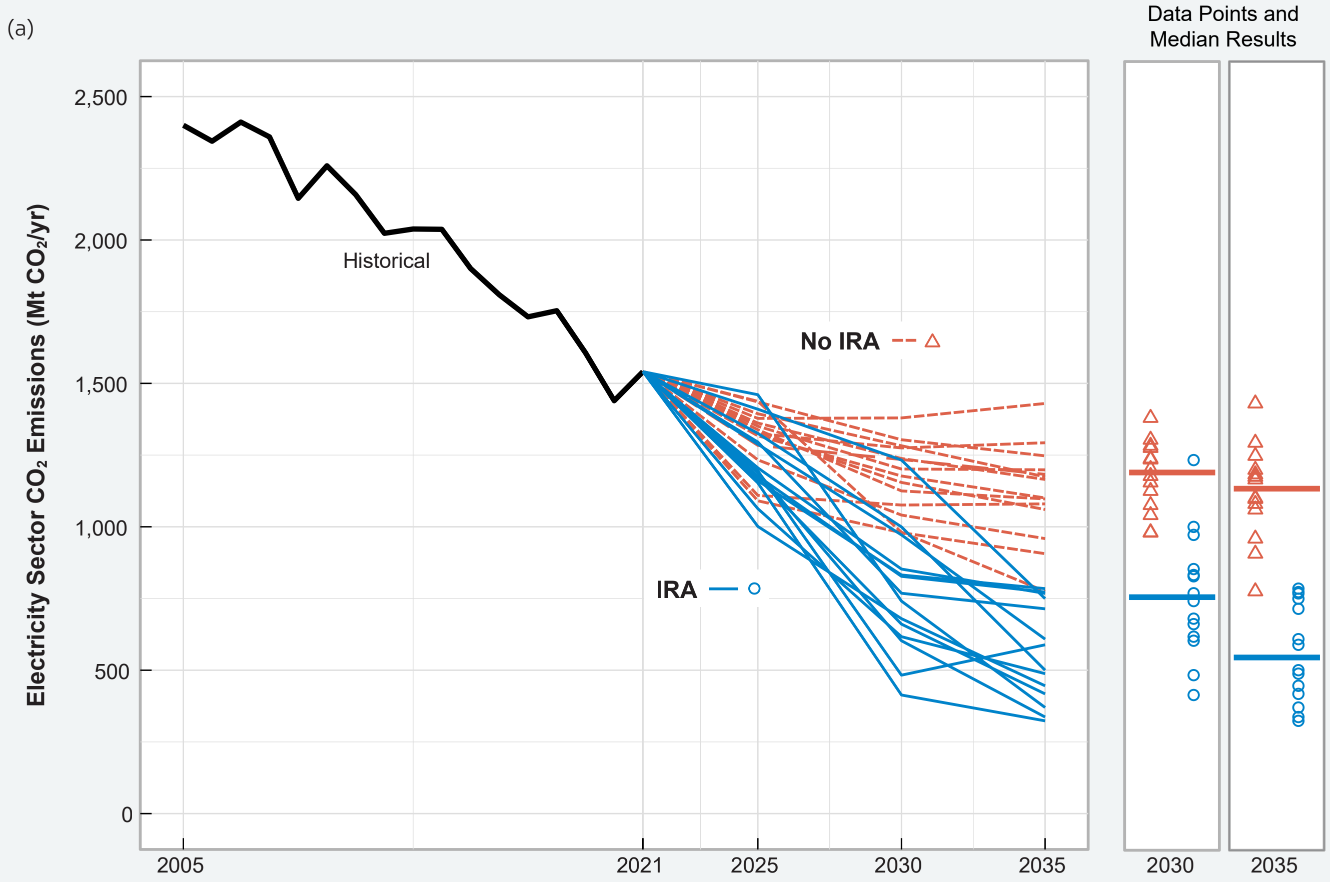
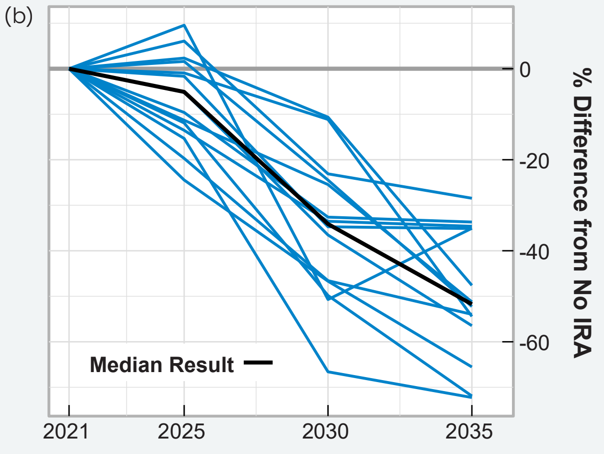
equipment manufacturing. Options other than SF_6-free equipment are assumed to be partially implemented in the baseline, decreasing their remaining reduction potential in later years. On the other hand, the reduction potential of adopting SF_6-free equipment is assumed to grow slowly over time as new SF_6-free equipment replaces retiring SF_6 equipment in each successive year. The figures here assume that replacement of SF_6-containing equipment with SF_6-free equipment begins in 2025.

Figure 2.3 Electric sector CO_2 emissions





In the IRA scenario, U.S. electricity sector CO_2 emissions fall to 49 to 83% (39% median) below 2005 levels in 2030. In 2030, individual models find that electricity CO_2 emissions are 11 to 67% (34% median) below what they are modeled to be in the No IRA scenario, with the median difference falling to just over 50% by 2035. Figure 2.3(a) shows absolute model results for the emissions trajectories (No IRA scenario in orange dashed lines, IRA Scenario in blue) with the historical trend (in black [4]). Data points to the right of Figure 2.3(a) show individual model results from 2030 and 2035 (blue circles for IRA scenario results, orange triangles for No IRA). Horizontal bars represent the median of the model results. Figure 2.3(b) shows the percent difference between the IRA and No IRA for each model (blue lines) and the median across the models (black line).[29] Accessible table available in the Data Annex.

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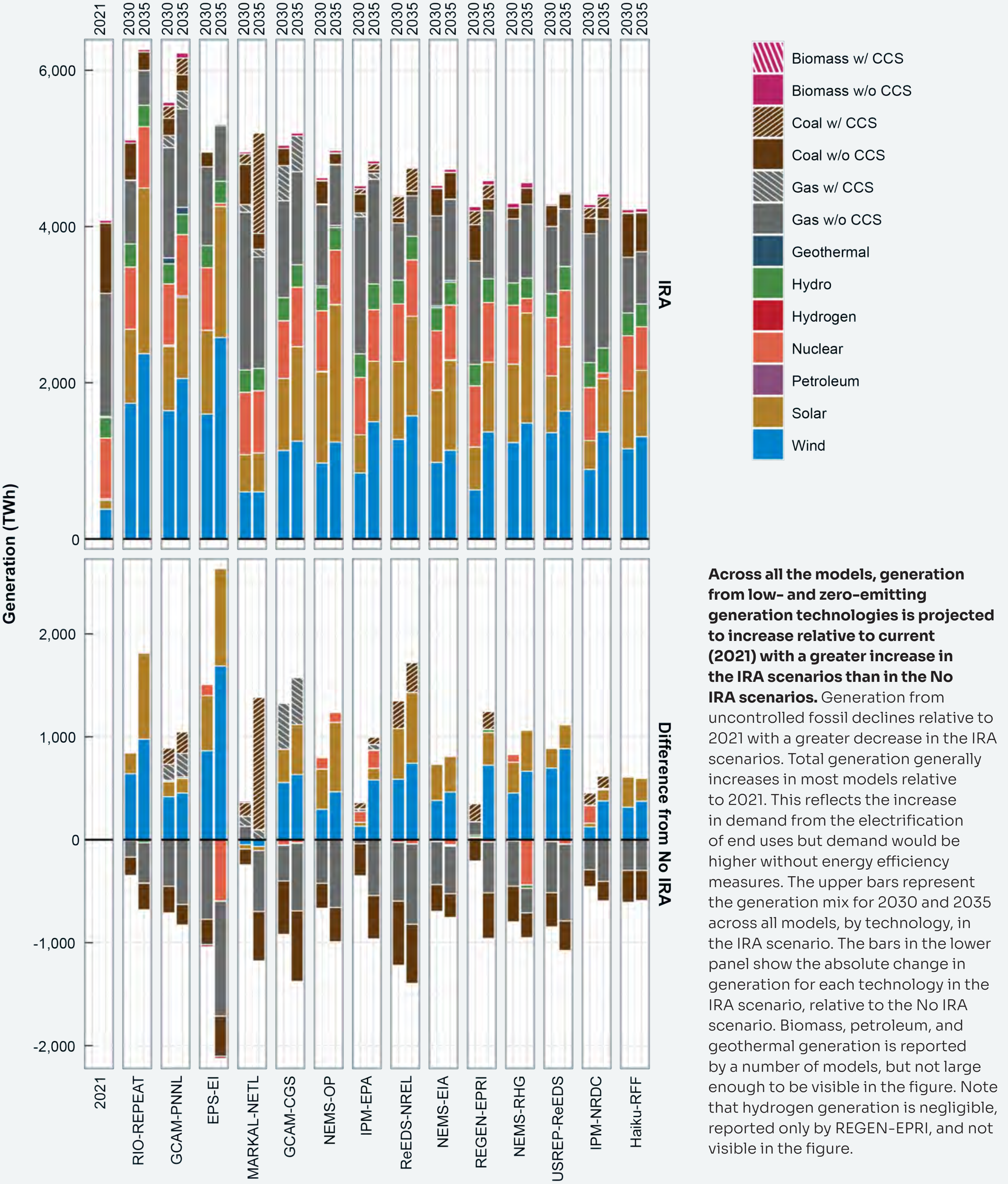
[29] A handful of models show higher emissions under the IRA in 2025. In the No IRA scenario, these forward-looking models have slightly higher levels of near-term investments in renewables in 2025 because the models foresee the expiration of tax credits. Under the IRA scenario, tax credits are extended and investment does not exhibit a near-term spike.

Figure 2.4 Electric sector generation by technology (TWh), 2021, 2030, and 2035



Across all the models, generation from low- and zero-emitting generation technologies is projected to increase relative to current (2021) with a greater increase in the IRA scenarios than in the No IRA scenarios. Generation from uncontrolled fossil declines relative to 2021 with a greater decrease in the IRA scenarios. Total generation generally increases in most models relative to 2021. This reflects the increase in demand from the electrification of end uses but demand would be higher without energy efficiency measures. The upper bars represent the generation mix for 2030 and 2035 across all models, by technology, in the IRA scenario. The bars in the lower panel show the absolute change in generation for each technology in the IRA scenario, relative to the No IRA scenario. Biomass, petroleum, and geothermal generation is reported by a number of models, but not large enough to be visible in the figure. Note that hydrogen generation is negligible, reported only by REGEN-EPRI, and not visible in the figure.

The Carbon Capture and Sequestration Tax Credit provision has a significant impact on future outcomes of CCS technologies in the power sector. Four of 14 models project relatively low levels of CCS expansion in the No IRA scenarios, ranging from 3 to 28 TWh of CCS generation by 2035 across all models, with a median of 10 TWh. In IRA scenarios with the updated Carbon Capture and Sequestration Tax Credit, 11 of 14 models show CCS expansion, ranging from 2 to 1,380 TWh by 2035 across all models, with a median of 150 TWh. There is a range of new capacity deployment across models. In general, the models deploy more wind and solar capacity relative to other technologies, along with energy storage technologies. The tax credits and incentives under IRA help spur greater investments in solar and wind. However, magnitudes vary greatly by model, with an average of 54 GW/yr with IRA versus 27 GW/yr without.

Electric-sector emission reductions are achieved through a shift toward investments in zero- and low-emission technologies such as solar, wind, storage, and fossil generation with CCS and away from high-emitting coal and gas generation (Figure 2.5). Both panels of the figure use the same color scheme with the left-hand panel representing historical additions and retirements in generating capacity and the right side showing average annual capacity additions for 2021-2035 as projected by the modeling. Note, for example, that natural gas generation spikes in the early 2000s as depicted by the gray part of the columns. Wind capacity has grown since the mid-2000s and solar capacity since about 2010. Retirements of generating capacity are depicted below the zero line, including the shutdown of some nuclear capacity and the recent retirements of some coal capacity. The right-side panel shows large average annual increases in solar and wind capacity, followed by gas, electricity storage, some coal, and some coal with CCS. The median total average annual capacity addition from 2021–2031 is approximately 60 GW, which is comparable to the largest historical annual capacity addition in 2002 as well as the projected capacity additions for 2023 [58]. The range of total capacity additions across the models vary widely from as low as 26 GW/yr to 125 GW/yr, which suggests very different power systems development paths.

All the model projections indicate new wind and solar with storage as the preferred mix of new capacity deployed. Other technology types are shown to have outcomes that are more mixed. For example, most models show that existing nuclear is retired, largely due to an assumption about the expected lifetime of existing nuclear units. Natural gas capacity outcomes are diverse across models, with some showing notable levels of new capacity while others show notable levels of retirement.[30] Most models show a notable amount of coal capacity being retired. Several models show that fossil fuel-fired plants with CCS (natural gas and coal) are economic with IRA. Each model's technology-specific capital cost assumptions (outlined in Appendix D) and natural gas price assumptions influence the relative economic competitiveness of each technology and its level of projected future deployment.

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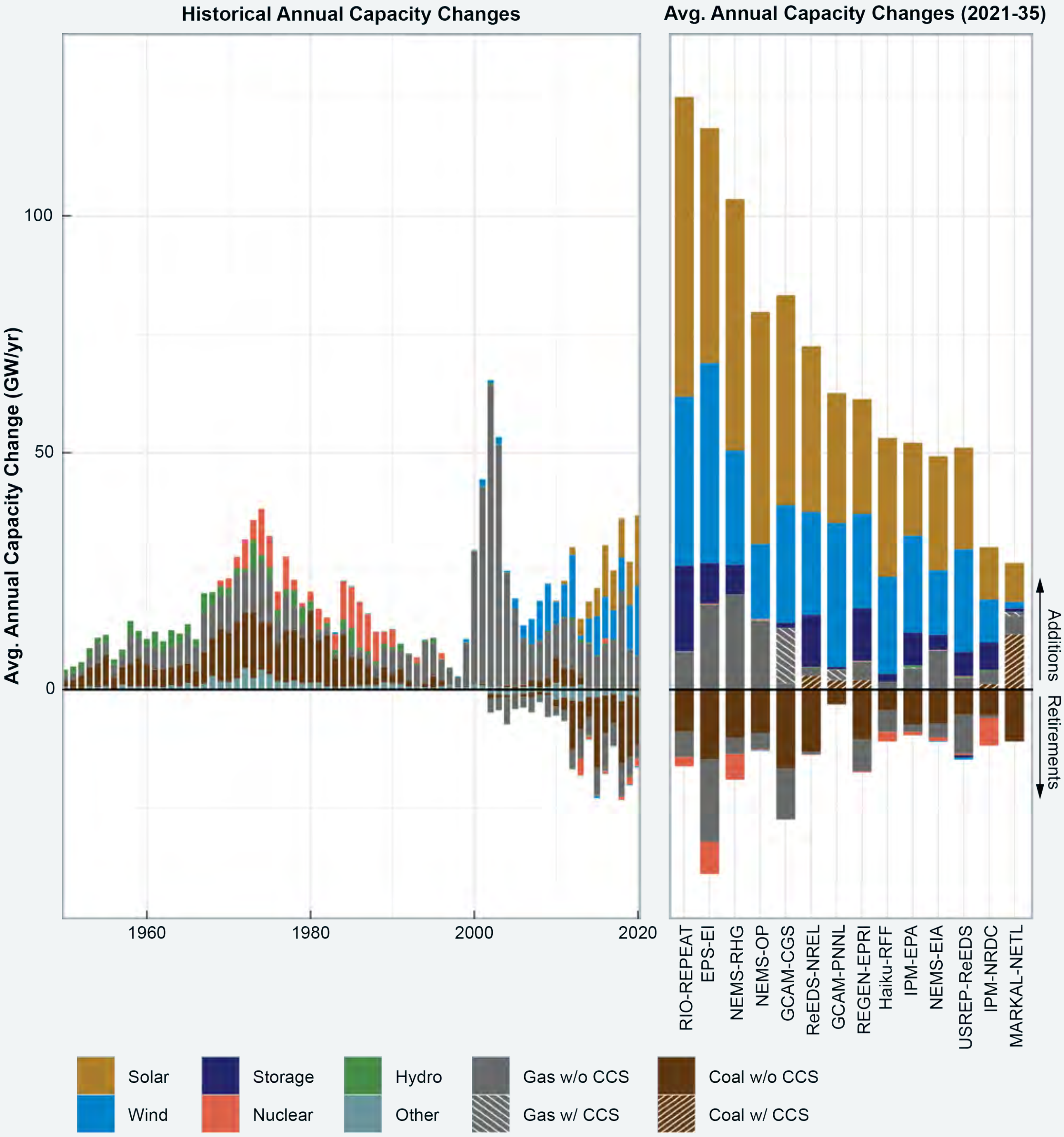
[30] Most models show the capacity factor for natural gas declining in the No IRA scenario and declining by a greater amount in the IRA scenario. In 2021 the capacity factor for natural gas generation was 54%, under the No IRA scenario the median capacity factor falls to 33% (22% min, 83% max) in 2030 and 33% (19% min, 83% max) in 2035, and under the IRA scenario the natural gas capacity factor falls to a median of 26% (14% min, 82% max) in 2030 and 21% (11% min, 82% max) in 2035. The models that project construction of gas CCS generally show higher projected capacity factors for natural gas. See Appendix E, Table E.3. For 2021 capacity factors, see https://www.energy.gov/ne/articles/what-generation-capacity.

Figure 2.5 Historical and projected capacity additions by technology, IRA scenario

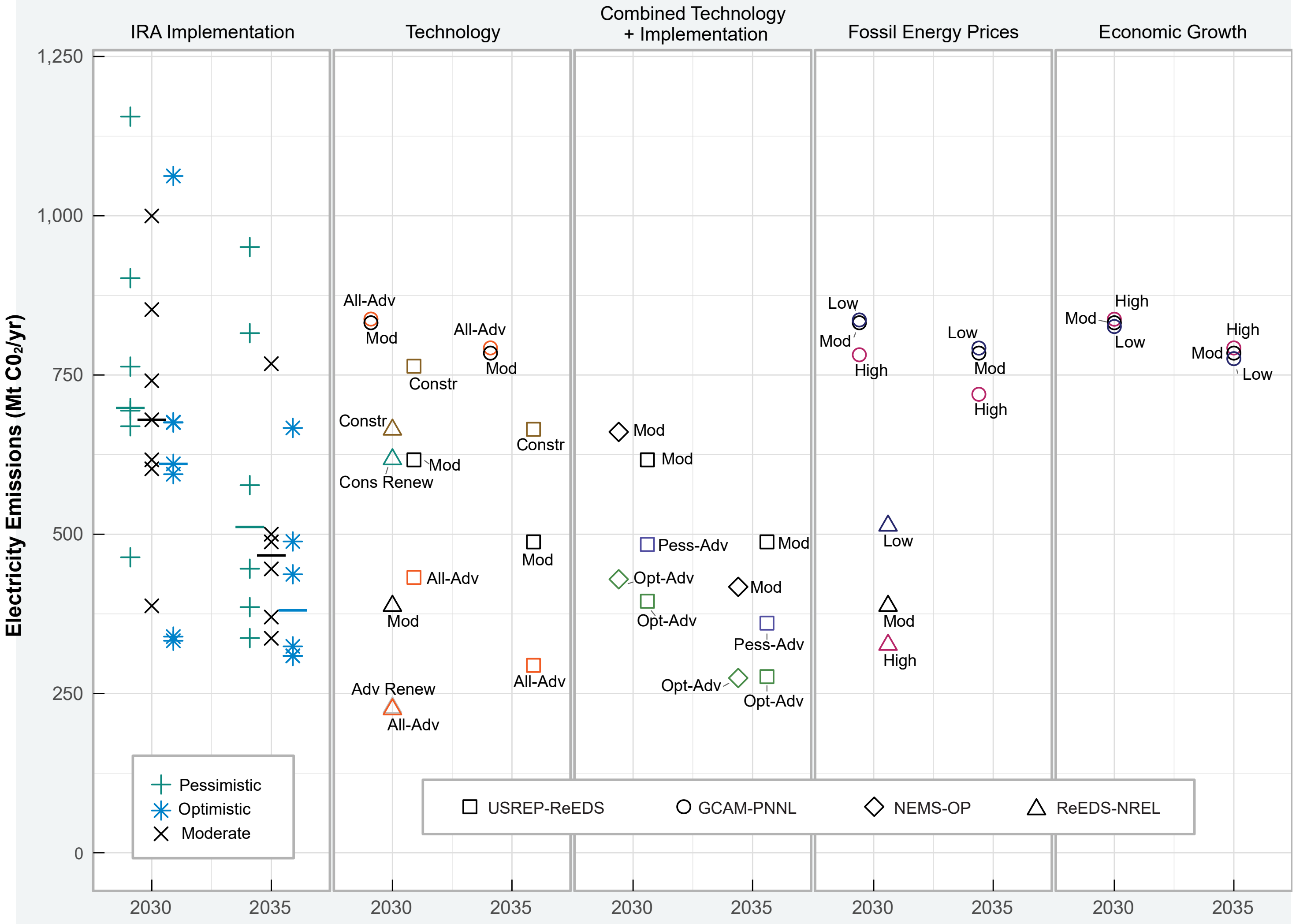


Overall, renewable sources of energy, such as solar and wind, consistently make up the largest portion of capacity additions across models compared to fossil fuel-fired sources. Average annual capacity additions vary significantly across models ranging from almost double the highest historical annual capacity addition to levels roughly in line with 2021 annual capacity additions. Accessible table available in the Data Annex.

In addition to the two scenarios discussed thus far in this chapter, the following sensitivities are examined by a limited set of models (Figure 2.6): IRA implementation, technology advances and deployment constraints, combined IRA implementation and advanced technology, economic growth, and fossil energy prices (see Section 1.2.2 for scenario descriptions). Six models in the Bistline et al. study [1] and USREP-ReEDS explored the IRA implementation sensitivity of power sector CO_2 emissions reductions to the value of IRA incentives (e.g., PTC, ITC, 45Q, 45V, energy community bonuses, domestic content bonus) and technology build rates and availability (e.g., renewables and transmission build rates, CCS availability, EVs eligible for bonus credits) (see Appendices C.2 and C.3 for details). GCAM-PNNL, NEMS-OP, USREP-ReEDS, and ReEDS-NREL ran the remaining sensitivity scenarios (see Appendix C.4, [2], and [3] for details).

Results in Table 2.1 are presented as changes from the Moderate IRA scenario for data in Figure 2.6. For reference, a 1% change from 2005 electricity CO_2 emissions is 24 Mt CO_2. In 2030, IRA implementation sensitivities increase reductions by up to 11 percentage points (pp) relative to the Moderate IRA scenario when optimistic and increase emissions by up to 6.5 pp when pessimistic, and nearly 19 pp by 2035. Advanced technology assumptions increase reductions by up to 7.7 pp while constraining it increases emissions up to 12 pp. The advanced technology assumptions also lead to the greatest projection of electricity emissions reductions from 2005 by 2030, 91% [3]. The largest median impact is in the sensitivity case combining Optimistic IRA implementation with advanced technology assumptions, resulting in 2030 emissions falling an additional 9.4 pp below 2005 levels. This combined effect is greater than the median changes in either the Optimistic IRA implementation sensitivity or the advanced technology sensitivity alone—indicating positive interaction effects related to the IRA accelerating advanced technology adoption. Low fossil energy prices lessen CO_2 emissions reductions relative to the Moderate IRA scenario by a greater amount than high fossil energy prices reduce emissions. Sensitivities in economic growth showed the least significant impact on emissions changes, no greater than ±1 pp relative to the Moderate IRA scenario. See Appendix F.4 for a summary of emissions reductions ranges including all sensitivity scenarios.

Figure 2.6 **Sensitivity of electric-sector emissions to IRA implementation (multiple models) and natural gas prices, technology cost, and constrained deployment (ReEDS-only)**



The largest median impact in electricity CO₂ emissions is in the sensitivity case combining Optimistic IRA implementation with advanced technology assumptions, resulting in 2030 emissions falling an additional 9.4 pp below 2005 levels. This combined effect is greater than the median changes in either the Optimistic IRA implementation sensitivity or the advanced technology sensitivity alone, indicating positive interaction effects related to the IRA accelerating advanced technology adoption. Electricity CO₂ emissions are presented for three sensitivity cases in the first panel, Moderate (black "x"), Optimistic (blue asterisk), and Pessimistic (green plus sign), and the horizontal bars represent the medians of each sensitivity. These scenarios were run by EPS-EI, GCAM-CGS, Haiku-RFF, ReEDS-NREL, REGEN-EPRI, RIO-REPEAT, and USREP-ReEDS. The shapes in panels 2-5 represent individual models (circle for GCAM-PNNL, triangle for ReEDS-NREL, square for USREP-ReEDS, diamond for NEMS-OP). These sensitivities cover a range of results that explore the effectiveness of the IRA to reduce emissions under different assumptions (see Section 1.2.2). Table 2.1 presents changes relative to the Moderate IRA Implementation scenario measured in incremental percentage point (pp) changes from 2005 economy-wide CO₂ emissions (e.g., a value of -1.0 would mean that under that sensitivity, emissions are reduced an additional 1 pp below 2005 levels—equivalent to an additional 24 Mt CO₂ of mitigation).[31] Accessible table available in the Data Annex.

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[31] For GCAM-PNNL, the All Advanced scenario results in greater installed capacity and generation from renewable sources compared to the Moderate scenario. However, the greater use of more variable renewable energy also results in more intermittent generation (backup combustion turbines), leading to higher emissions.

Table 2.1 Electric sector CO_2 emissions changes (percentage points of 2005 emissions) relative to the IRA Moderate scenario

		IRA Implementation		Technology				Implementation + Tech		Fossil Energy Prices		Economic Growth	
Year	**Metric**	**Optimistic**	**Pessimistic**	**All Advanced**	**Constrained**	**Advanced Renewables**	**Conservative Renewables**	**Optimistic + Advanced**	**Pessimistic + Advanced**	**High**	**Low**	**High**	**Low**
2030	Min	−11.0	−2.0	−7.7	6.1	-	-	−9.6	-	−2.5	0.2	-	-
	Median	−2.7	3.2	−6.8	8.8	−6.7	9.6	−9.4	−5.5	−2.3	2.7	0.2	−0.2
	Max	2.6	6.5	0.2	11.5	-	-	−9.2	-	−2.1	5.2	-	-
2035	Min	−8.0	−1.4	−8.1	-	-	-	−8.8	-	-	-	-	-
	Median	−1.5	2.0	−3.9	7.4	-	-	−7.4	−5.7	−2.7	0.3	0.3	−0.4
	Max	0.0	18.8	0.3	-	-	-	−6.0	-	-	-	-	-

The largest median impact in electric sector CO_2 emissions is in the sensitivity case combining Optimistic IRA implementation with advanced technology assumptions resulting in 2030 emissions falling an additional 9.4 pp below 2005 levels. This combined effect is greater than the median changes in either the Optimistic IRA implementation sensitivity or the advanced technology sensitivity alone, indicating positive interaction effects related to the IRA accelerating advanced technology adoption. Table 2.1 presents changes relative to the Moderate IRA Implementation scenario for all sensitivity scenarios, measured in incremental percentage point (pp) changes from 2005 economy-wide CO_2 emissions (e.g., a value of -1.0 would mean that under that sensitivity, emissions are reduced an additional 1 percentage point below 2005 levels—equivalent to an additional 24 Mt CO_2 of mitigation). For a summary of the percent reduction of all IRA sensitivities from the No IRA scenario, see Appendix F.4.2.

Criteria Air Pollutants

The primary focus of this report is to discuss the impacts of the IRA on reducing CO_2 pollution from the atmosphere. However, changes in sources with CO_2 emissions likely affect the emissions of other air pollutants from those sources, including oxides of nitrogen (that also contribute to ground-level ozone pollution as well as particulate matter pollution) and sulfur dioxide (that also contributes to particulate matter pollution). These pollutants are found all over the United States and can harm human health and damage the environment.

SULFUR DIOXIDE (SO_2)

Sulfur dioxide, or SO_2, is a highly reactive gas that is generated primarily when sulfur-containing coal is burned within power plants and large industrial sources. Short-term exposures to SO_2 can harm the respiratory system and make breathing difficult. People with asthma, particularly children, are especially sensitive to these effects of SO_2. High concentrations of SO_2 in the air generally also lead to the formation of other sulfur oxides (SO_x), which can react with other compounds in the atmosphere to form small particles or even sulfuric acid. Sulfate particles are a primary constituent of particulate matter (PM) pollution, which may penetrate deeply into the lungs, and in sufficient quantity can contribute to both lung and heart problems.

In addition to the direct contribution of SO_2 to the formation of acid rain, deposition of sulfate particles can also stain and damage stone and other materials, including culturally important objects such as statues and monuments. Furthermore, sulfate PM can reduce visibility by causing haze in parts of the country, including many of our treasured national parks and wilderness areas.

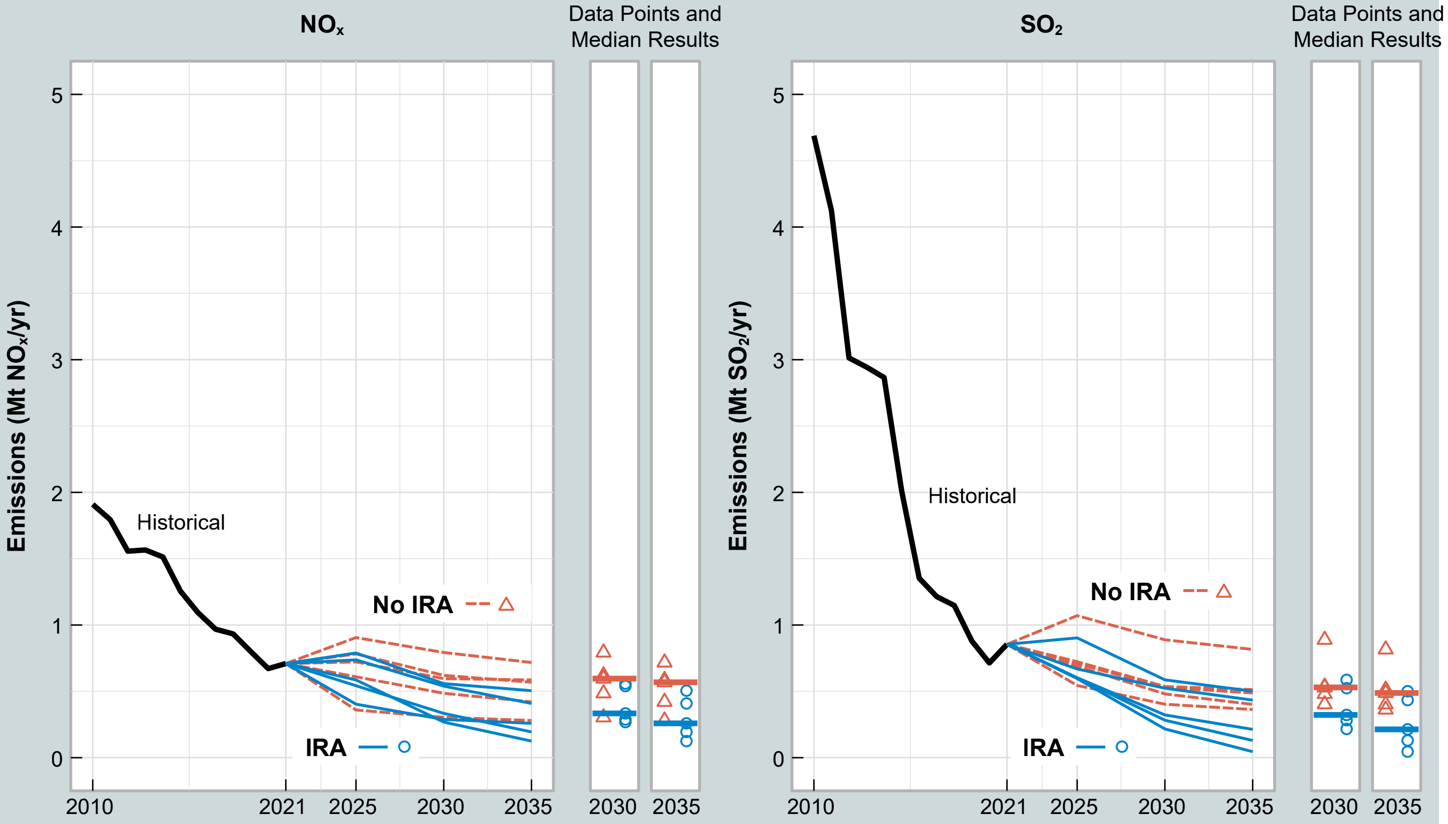
NITROGEN OXIDES (NO_X)

Sulfur is not the only constituent of PM. Nitrogen oxide (NO_X) emissions from cars, trucks and buses, power plants, and off-road equipment contribute to the formation of fine particle pollution as well as ground-level ozone. Ozone can aggravate lung diseases such as asthma, emphysema, and chronic bronchitis and increase the frequency of asthma attacks, leading to increased school absences, medication use, visits to doctors and emergency rooms, and hospital admissions. Ecologically, ozone can affect sensitive vegetation and ecosystems, destroying tissues and killing organisms. This pollution can result in substantial damage to crops, forests, parks, wildlife refuges, and wilderness areas.

Emissions of the pollutants described above have been decreasing. Between 2005 and 2019, the United States saw a reduction in SO_2 emissions from 14.5 to 2.0 million short tons economy-wide, and NO_x emissions fell from 20.4 to 8.7 million short tons. Modeling suggests the IRA will result in substantial reductions in emissions of both SO_2 and NO_x. Up to an additional 0.5 million short tons for each pollutant are expected to be reduced by 2035 compared to a No IRA scenario, resulting in significant health and environmental benefits.

To learn more about how EPA will assess impacts of these pollutants on disadvantaged communities as the power sector evolves under IRA implementation, see Text Box: Environmental Justice.

Figure 2.7 Cross-model comparison of NO_X and SO_2 emissions by model over time



The median modeled projections for both NO_x and SO_2 emissions fall in the IRA scenario relative to the No IRA scenario in 2030 and 2035. Model results for the emissions trajectories are shown as orange dashed lines for the No IRA scenario and in blue for the IRA scenario. Data points to the right of the figure show individual model results from 2030 and 2035 (blue circles for IRA scenario results, orange triangles for No IRA). Horizontal bars represent the median of the model results. Accessible tables available in the Data Annex.

CHAPTER 3

Transportation

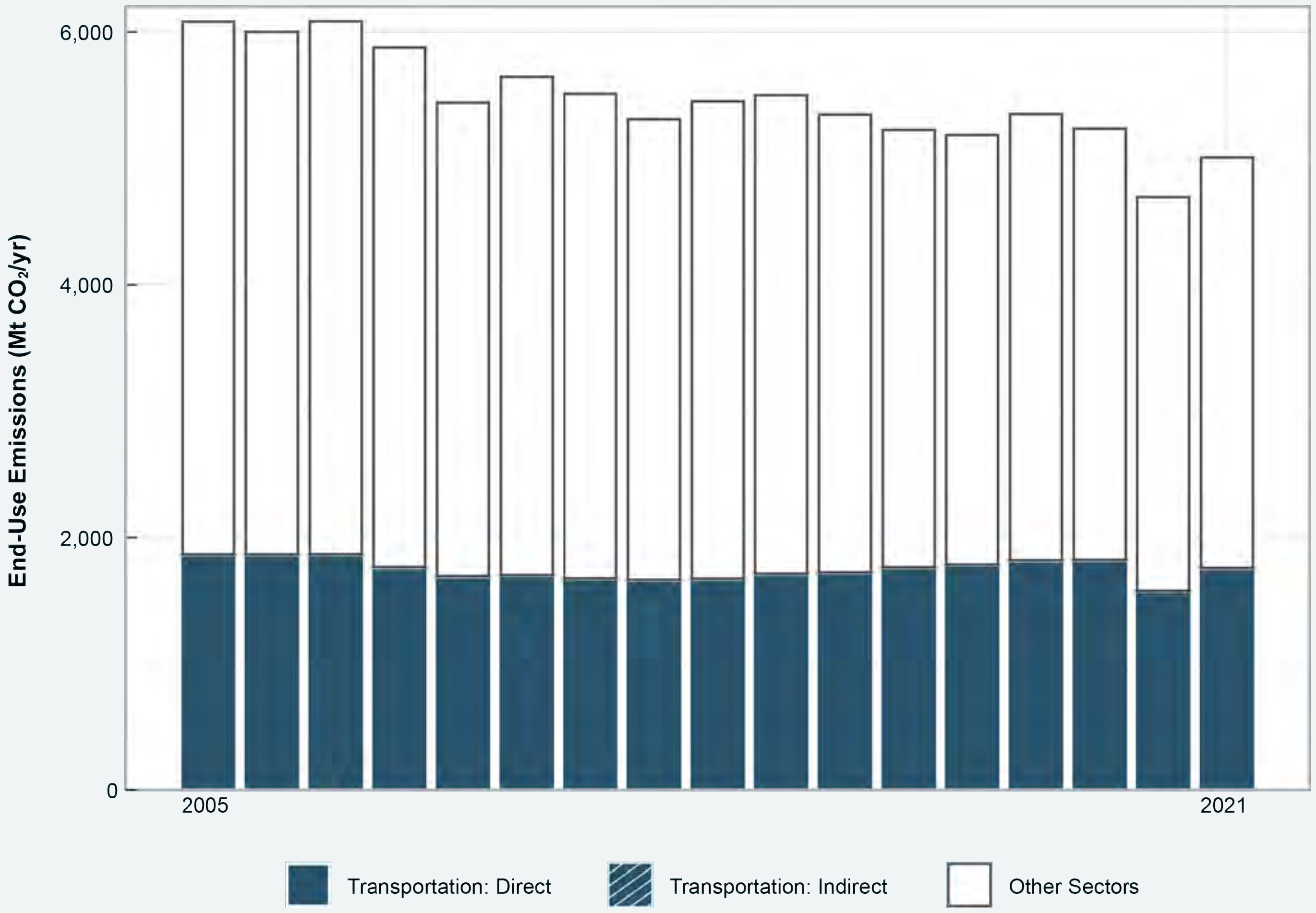
3.1 TRANSPORTATION SECTOR SNAPSHOT

The transportation sector is the largest U.S. source of CO_2 emissions, representing 35% of CO_2 emissions [4] (see Figure 3.1), followed by the buildings and industry sectors. Within the transportation sector, light-duty trucks (including sport utility vehicles, pickup trucks, and minivans) are the largest contributor at 37% of transportation emissions, followed by medium- and heavy-duty trucks (23%), passenger cars (21%), aviation (9%), marine (3%), and rail (2%). Passenger cars and light-duty trucks combined represent 58% of transportation CO_2 emissions, and thus comprise 20% of total U.S. CO_2 emissions [4] (see Figure 3.2). Americans drove an average of 13,476 miles per year [63] and spent $1.6 trillion (9.8% of total national household spending) on transportation in 2021, the fourth largest household expenditure category after health care, housing, and food [64].

Transportation CO_2 emissions rose from about 1,484 Mt CO_2/yr in 1990 to 1,863 Mt CO_2/yr in 2005. Transportation emissions then declined to 1,757 Mt CO_2/yr in 2021, despite a rise of vehicle miles traveled from 2.99 million to 3.13 million [65] and an increase in population. This decline is due to a range of effects from fuel economy and tailpipe emissions standards, as well as the adoption of various technologies, including hybrids, plug-in hybrids (PHEVs), and full battery electric vehicles (BEVs). While nearly all of the energy used for transportation was supplied by petroleum-based products, electricity use in BEVs and PHEVs has recently begun to increase [4].

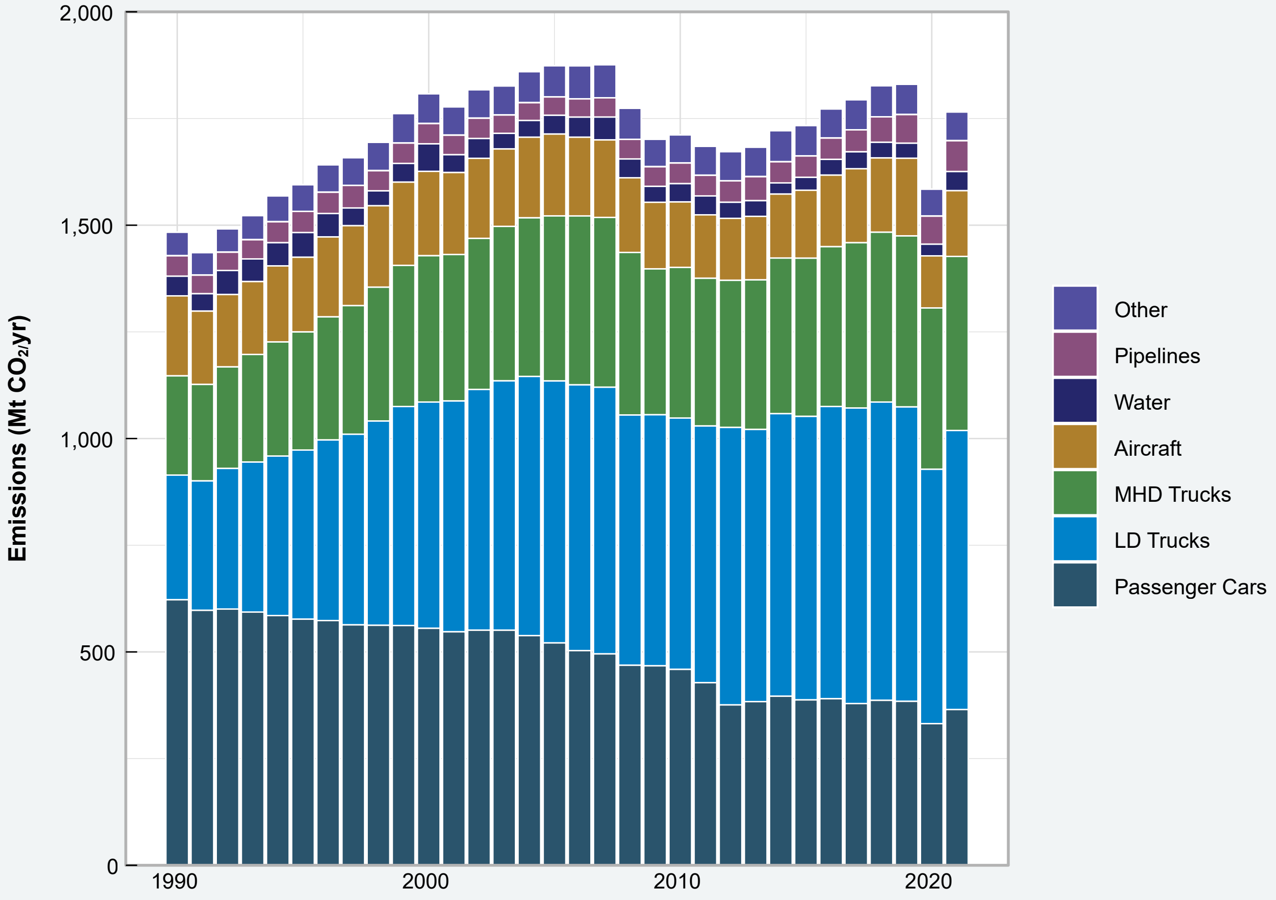
Over the past decade, automakers have developed a range of electrification technologies, including hybrid electric vehicles and, in recent years, plug-in electric vehicles (PEVs), which include PHEVs and BEVs. Before the IRA became law, analysts were already projecting that significantly increased penetration of PEVs would occur in the U.S. and global markets.

Figure 3.1 CO2 emissions from the transportation sector compared to economy- wide CO2 emissions, 2005-2021



Transportation CO_2 emissions have remained relatively flat since 2005 and thus represent an increasing share of total CO_2 emissions. The transportation sector represents the largest share of CO_2 emissions in the United States. Direct transportation CO_2 emissions comprise the majority of total emissions and indirect emissions from electricity use have been negligible and are not visible in the figure (transportation emissions shown in blue). Remaining economy-wide CO_2 emissions are represented by the outlined bar. Accessible table available in the Data Annex.

Figure 3.2 CO2 emissions from the transportation sector, by end use, for 1990-2021



Emissions in the light-duty sector peaked in 2007 and began to decrease despite an increase in vehicle miles traveled. This decrease is due to increased efficiency driven by regulations and advanced technology. "Other" includes rail, buses, motorcycles, and lubricants. Truck emissions are split into light-duty (LD) and medium- and heavy-duty (MHD). These are domestic-only CO_2 emissions.[32] Accessible table available in the Data Annex.

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[32] Emissions resulting from the combustion of fuels used for international transport activities, termed international bunker fuels under the UNFCCC, are not included in national emission totals, but are reported separately based upon location of fuel sales. See Chapter 3 of the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021 [4].

In 2021, IHS Markit predicted a nearly 40% U.S. PEV share by 2030 [66],[33] and Bloomberg New Energy Finance projections suggest that under current policy and market conditions, and prior to the IRA, the United States was on pace to reach a 40-50% PEV share by 2030 [67]. A 2022 survey by Consumer Reports shows that more than a third of Americans would either seriously consider or definitely buy or lease a BEV today, if they were in the market for a vehicle [68]. A report by the Environmental Defense Fund and Environmental Resources Management (ERM) shows how virtually every major manufacturer of light-duty vehicles is already planning to introduce widespread electrification across their global fleets in the coming years [69].

Advancements in technology have enabled these increases in fuel economy and decreased usage of fossil fuels in the transportation sector. For example, battery costs have decreased significantly in the last 20+ years, declining 89% between 2008 and 2022 [70]; micromobility[34] has seen a growth in ridership in the United States, increasing from 2.4 million rides in 2011 to 112 million rides in 2021 [72], and an NREL study estimates that high adoption of shared micromobility can save 2.3 billion gasoline-equivalent gallons per year nationwide [73]. Sales of electric vehicles (BEVs and PHEVs) were about 120,000 worldwide in 2012, but has seen a dramatic increase to 6.6 million in 2021. About half were sold in China in 2021 (3.3 million, 2.7 million were BEVs), representing 16% of domestic car sales. In Europe, electric vehicle sales increased in 2021 more than 65% year-on-year to 2.3 million and accounted for 17% of Europe's auto sales in 2021 [74]. In the United States, about 608,000 electric vehicles were sold in 2021, with BEVs making up 73%. Combined U.S. EV/PHEV production reached 4% of all new vehicles in model year 2021, and is projected to reach a new high of 8% of all production in model year 2022 [75].

Recent regulations from the EPA and National Highway Traffic Safety Administration (NHTSA) have set more stringent emissions and fuel economy standards. In December 2021, the EPA issued new GHG emission standards for new passenger cars and light-duty trucks, requiring automakers to reach an industry-wide target of 161 CO_2 grams per mile (g/mi) in model year 2026, steadily decreasing from 202 CO_2 g/mi in model year 2023 [76]. In March 2022, NHTSA finalized fuel economy standards that increase fuel economy to a fleetwide average of 49 mpg by 2026. In December 2022, EPA issued a final rule that set new standards to reduce nitrogen oxide (NO_X) pollution from heavy-duty vehicles and engines starting in model year 2027. In addition, several other countries and localities have issued their own rules that will transition new light-duty and heavy-duty sales to zero-emission vehicles in the coming years [77].

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[33] The table indicates 32.3% BEVs and combined 39.7% BEV, PHEV, and range-extended electric vehicle (REX) in 2030.

[34] The Federal Highway Administration broadly defines micromobility as any small, low-speed, human- or electric-powered transportation device, including bicycles, scooters, electric-assist bicycles, electric scooters, and other small, lightweight, wheeled conveyances [71].

In addition, on April 12, 2023, EPA announced new proposed standards to further reduce harmful air pollutant emissions from light-duty and medium-duty vehicles [27], as well as heavy-duty vehicles [28], starting with model year 2027.[35] These proposed standards are not reflected in the modeling results and projections shown in this report. Beyond the scope of the IRA and the new vehicle standards, there remain other actions that can further decarbonize the U.S. transportation sector. In January 2023, the departments of Energy, Transportation, and Housing and Urban Development, and the Environmental Protection Agency released *The U.S. National Blueprint for Transportation Decarbonization* [78], a framework of strategies and actions to remove all emissions from the transportation sector by 2050.

3.2 KEY TRANSPORTATION SECTOR IRA PROVISIONS

The IRA includes the following major provisions and incentives for the transportation sector:

- Tax incentives and rebates
  - Biodiesel and Renewable Fuels Production Tax Credit (40A, others)
  - Second-generation Biofuels Production Tax Credit (40)
  - Sustainable Aviation Fuel Production Tax Credit (40B)
  - Clean Vehicle Credit (30D)
  - Credit for Previously Owned Clean Vehicles (25E)
  - Qualified Commercial Clean Vehicle Credit (45W)
  - Alternative Fuel Vehicle Refueling Property Credit (30C)
  - New Clean Fuel Production Tax Credit (45Z)
  - Clean Hydrogen Production Tax Credit (45Q)
- Programs
  - Clean Vehicles
  - U.S. Postal Service Clean Fleets

The IRA extends numerous existing tax provisions that encourage production of fuels. These include tax credits for renewable diesel and biodiesel used as fuel, the alternative fuels tax credit, and the second-generation biofuel producer tax credit. The alternative fuel charging or refueling property tax credit is extended, but modified so that it applies to property placed in service in a low-income area.

New fuel-related provisions are created by the IRA. A new tax credit supports the sale or mixture of sustainable aviation fuel. Another provision supports the production of clean hydrogen for use in the transportation sector. A new clean fuel credit (which begins in 2025) is established that depends on the emissions factor associated with the fuel.

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[35] The proposed rules are not included in this analysis and are mentioned here for broader context of the transportation sector.

In addition to support for fuels, the IRA includes provisions to support production and sales of clean vehicles. The refundable tax credit for partial electric vehicles is modified to include requirements for the use of critical minerals in production and for battery components. A new tax credit is created supporting clean commercial vehicles (with more substantial potential credits for larger commercial vehicles and smaller credits for smaller vehicles). Another new credit is targeted at the purchase of used plug-in and fuel cell clean vehicles—this credit is intended to support clean vehicle purchases by lower income consumers.

New funding and loan programs are also created by the IRA that will affect emissions from the transportation sector. The U.S. Postal Service Clean Fleets program supports the purchase of zero-emitting vehicles. The Advanced Technology Vehicle Manufacturing Loan Program supports for production of advanced vehicles and their components. Through the Domestic Manufacturing Conversion Program, cost-share grants are available for domestic production of clean vehicles.

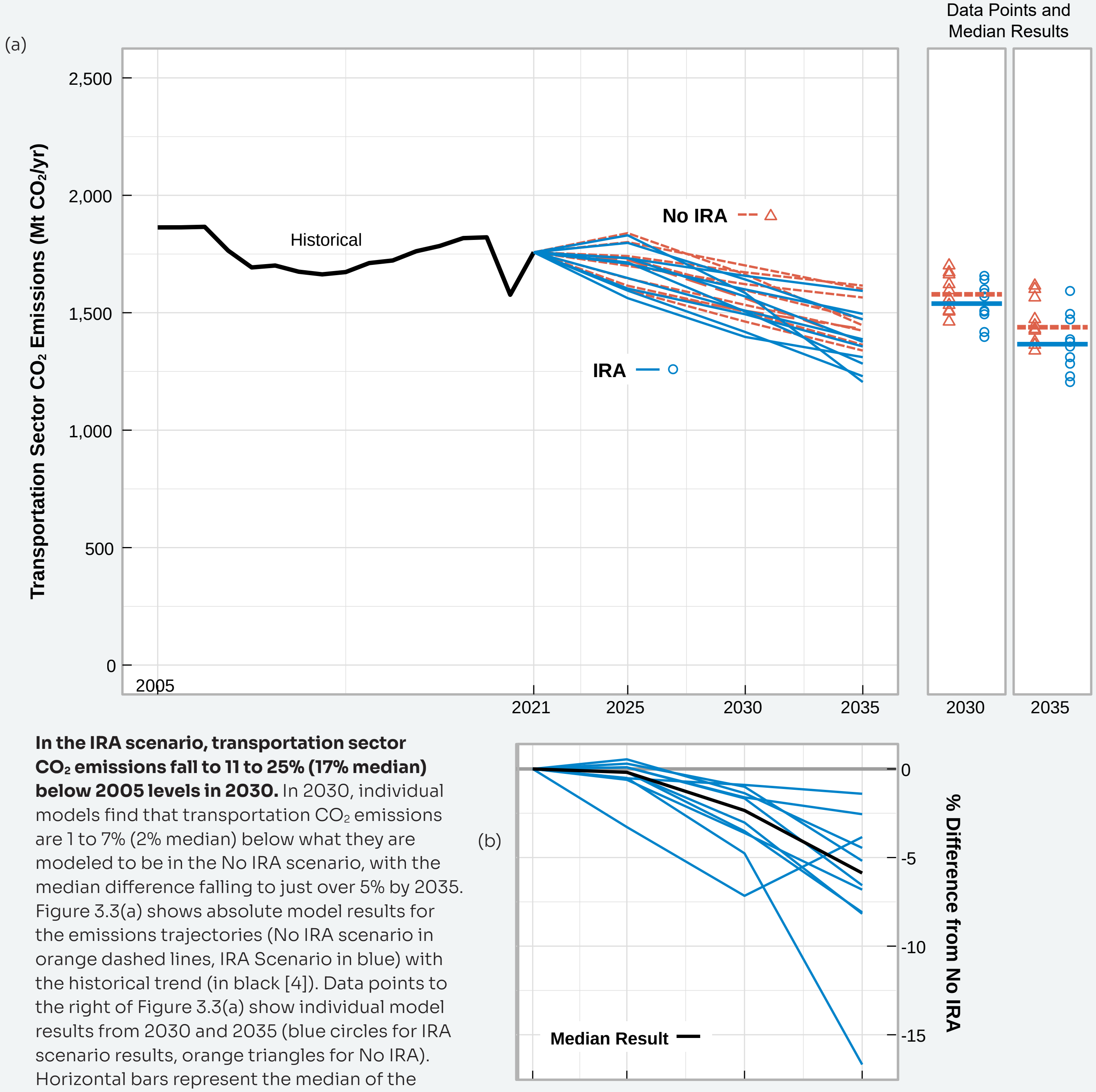
While the breadth of scope of the models included in this analysis offer a great deal of insight to the effects of the IRA, many models reflect the IRA incentives in different ways and may not be able to reflect some of the incentives in the transportation sector. This is due in part to the mix of multi-sector and electricity sector models, which have varying degrees of representation of the transportation sector.

3.3 TRANSPORTATION SECTOR ANALYSIS AND RESULTS

Transportation CO_2 emissions have been declining in recent history due to emissions and fuel economy regulations and technological advances. In 2021, transportation emissions had declined by about 6% relative to 2005. Across the various models, the No IRA scenario had emissions declining from between 13 and 28% in 2035 relative to 2005, with a median decline of 23%. Investments and policies set forth in the IRA results in further reduced emissions, with a range of 15 to 35% in 2035 relative to 2005, and a median decline of 27% (Figure 3.3).

This decline in emissions is largely due to the increased use of advanced technologies in the transportation sector, such as electric cars and trucks. In the No IRA scenario, the models project electric vehicles' share of the market (new sales) increases from 4% in 2021 to a range of 12-43% (median 24%) in 2030, and 15-59% (median 38%) in 2035. With the IRA provisions that range increases to 15-54% (median 36%) in 2030, and 18-81% (median 43%) in 2035 (Figure 3.4). This is similar to an analysis by the International Council on Clean Transportation (ICCT) that finds the IRA results in a range of 48-61% EV sales share in the light-duty sector and a range of 39-48% zero-emissions vehicle (ZEV) sales share in 2030 [79]. The decline in EV sales share in the IRA scenario from 2030 to 2035 exhibited by some models represents the expiring tax credits for EV purchases. In the IRA sensitivity scenarios, electric vehicle sales shares reach as high as 70% in 2030 for NEMS-OP in the combined Optimistic IRA implementation plus Advanced technology scenario and 93% in 2035 for RIO-REPEAT in the Optimistic IRA Implementation scenario.

Figure 3.3 Transportation sector CO_2 emissions



In the IRA scenario, transportation sector CO_2 emissions fall to 11 to 25% (17% median) below 2005 levels in 2030. In 2030, individual models find that transportation CO_2 emissions are 1 to 7% (2% median) below what they are modeled to be in the No IRA scenario, with the median difference falling to just over 5% by 2035. Figure 3.3(a) shows absolute model results for the emissions trajectories (No IRA scenario in orange dashed lines, IRA Scenario in blue) with the historical trend (in black [4]). Data points to the right of Figure 3.3(a) show individual model results from 2030 and 2035 (blue circles for IRA scenario results, orange triangles for No IRA). Horizontal bars represent the median of the model results. Figure 3.3(b) shows the percent difference between the IRA and No IRA for each model (blue lines) and the median across the models (black line). Transportation emissions are broken out into direct and indirect in Appendix F.2.[36,37] Accessible table available in the Data Annex.

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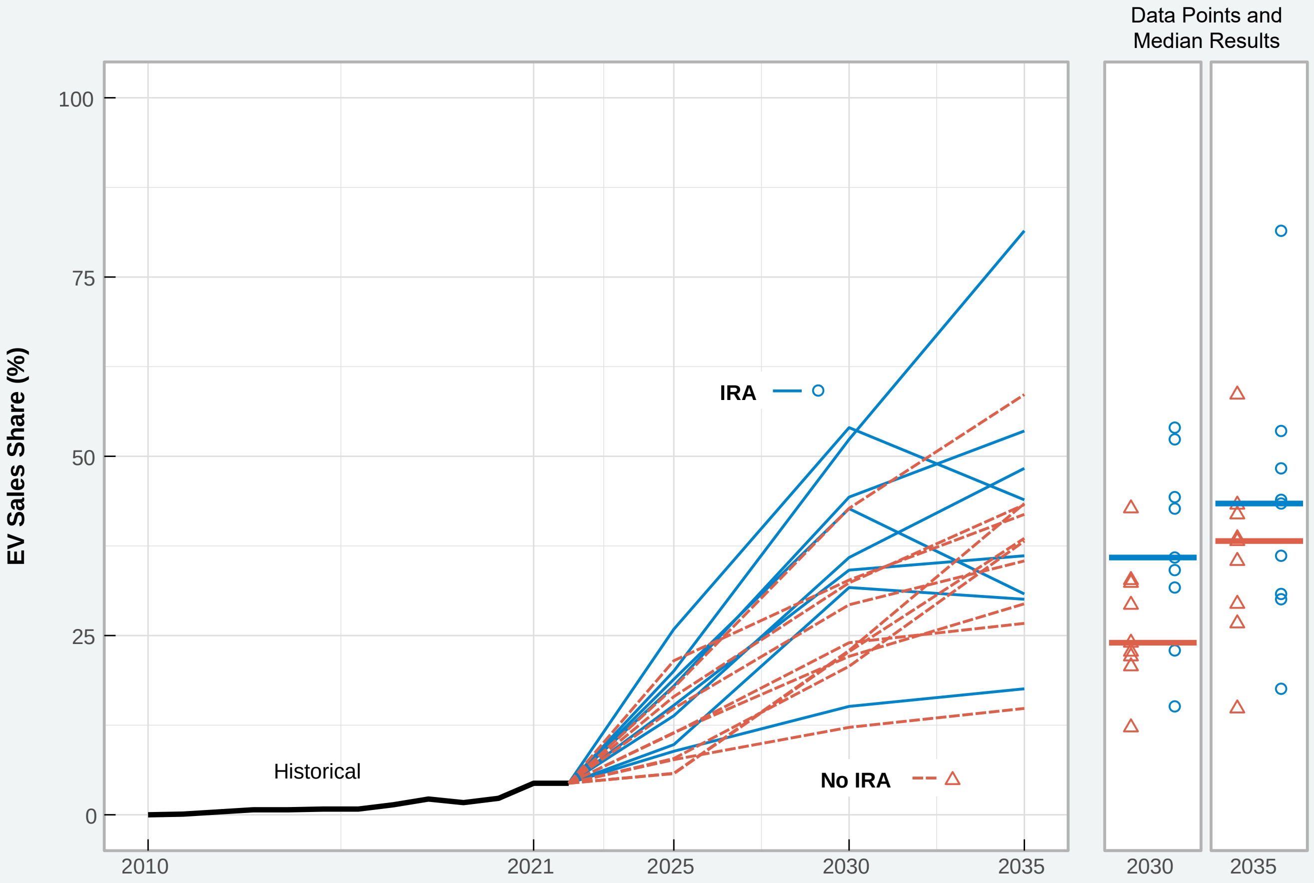
[36] USREP-ReEDS shows a slight uptick in transportation sector emissions in 2025 (Figure 3.3(a)). Falling electricity prices increase the demand for transportation services and therefore emissions. By 2030, the IRA provisions supporting EV adoption offset the electricity effects and emissions fall.

[37] A handful of models show higher total transportation emissions under the IRA in 2025 (Figure 3.3(b)). In the No IRA scenario, the forward-looking models have slightly higher levels of near-term investment in renewables in 2025 because the models forsee the expiration of tax credits. Under the IRA scenario, tax credits are extended and investment does not exhibit a near-term spike.

Figure 3.4 Electric vehicle percent share of new sales



Modeled projections for the IRA scenario (blue lines) shows an increase over the No IRA scenario (orange dashed lines) in 2030 and 2035, but both scenarios show increasing EV sales compared to historical data (black lines). The right side of the figure shows data points from different models as blue circles for the IRA scenario, orange triangles for the No IRA scenario, and the horizontal lines represent the median, for both scenarios in the years 2030 and 2035. Historical data come from the EPA Automotive Trends Report, 2022 [75]. Note: fewer models have this information, this chart contains data from EPS-EI, GCAM-CGS, GCAM-PNNL, NEMS-EIA, NEMS-OP, NEMS-RHG, REGEN-EPRI, RIO-REPEAT, and USREP-ReEDS. Accessible table available in the Data Annex.

This increase in electric vehicles' market share leads to an increase in electricity demand. Figure 3.5 shows the increase in demand for electricity in the transportation sector from light-duty passenger cars and trucks in the United States.

As the sector responsible for the largest source of U.S. CO_2 emissions, existing and future technological improvements mean that this sector has the potential to show the largest decrease in emissions. On-road transportation alone, including light-duty cars and trucks, as well as medium- and heavy-duty trucks, represent 60% of emissions in the transportation sector, and 21% of total U.S. GHG emissions. The shift from fossil fuel combustion to an electrified fleet of vehicles is a rapidly developing, global phenomenon, as several countries and regions around the world have set zero-emission targets for new cars sold within the next 10-20 years [80, 81].

This analysis demonstrates through a variety of energy sector and economy-wide models how the provisions in the IRA reduce CO_2 emissions within the transportation sector. While the modeling results show that the effects are not as large as they are in the buildings and industrial sectors, there is still a substantial reduction in estimated emissions. These sectoral differences reflect the inclusion of electric-sector emissions in values, and the transport share of electricity is relatively low, so it does not benefit as much as when power sector emissions decline by 2035. Modeling shows that the transportation-related provisions in the IRA can result in a potential decline in transportation CO_2 emissions of 27% relative to 2005 levels by 2035, compared to a decline of 23% in the No IRA scenario compared to 2005 levels. However, the modeling suite, consisting of multi-sector models and electricity sector models, may not capture the full range of effects of the IRA in the transportation sector, let alone in subsectors such as aviation or recent transportation trends such as the rise of micromobility (see Table 1.3 for a list of IRA provision coverage by model). Further regulations, such as EPA's proposed greenhouse gas emission standards, will help drive further reductions in the transportation sector. As discussed in Section 3.1, the *U.S. National Blueprint for Transportation Decarbonization* outlines opportunities to reduce GHG emissions from the transportation sector, covering options for every mode of travel. EIA's analysis of the Inflation Reduction Act in Annual Energy Outlook (AEO) 2023 [82] has similar results, with the transportation sector showing a 20% decrease in CO_2 emissions in the IRA scenario (which is incorporated into their "Reference" scenario) compared to a 19% decrease in CO_2 emissions in the No IRA scenario emissions in 2035 from 2005 levels.[38] While the transportation sector may be the largest contributor to U.S. CO_2 emissions, the IRA's provisions in the transportation sector mostly affect the passenger cars and medium- and heavy-duty trucks subsectors, while a significant portion of the transportation sector does not experience as much of a decline in emissions due to the IRA (e.g., aircraft, water).

Future iterations of this analysis will need to evaluate any subsequent changes to the IRA provisions. In addition, EPA's proposed greenhouse gas emission standards rules will need to be implemented in the modeling assumptions upon their finalization. In addition, this analysis is limited in its ability to provide projections for fuel use or transportation demand by mode. This provides an opportunity to expand the scope of the models' capabilities in future research.

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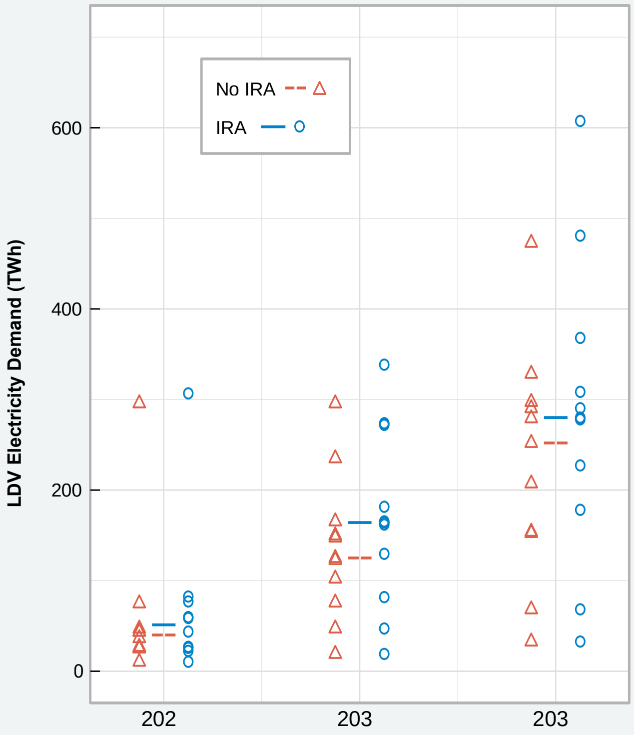
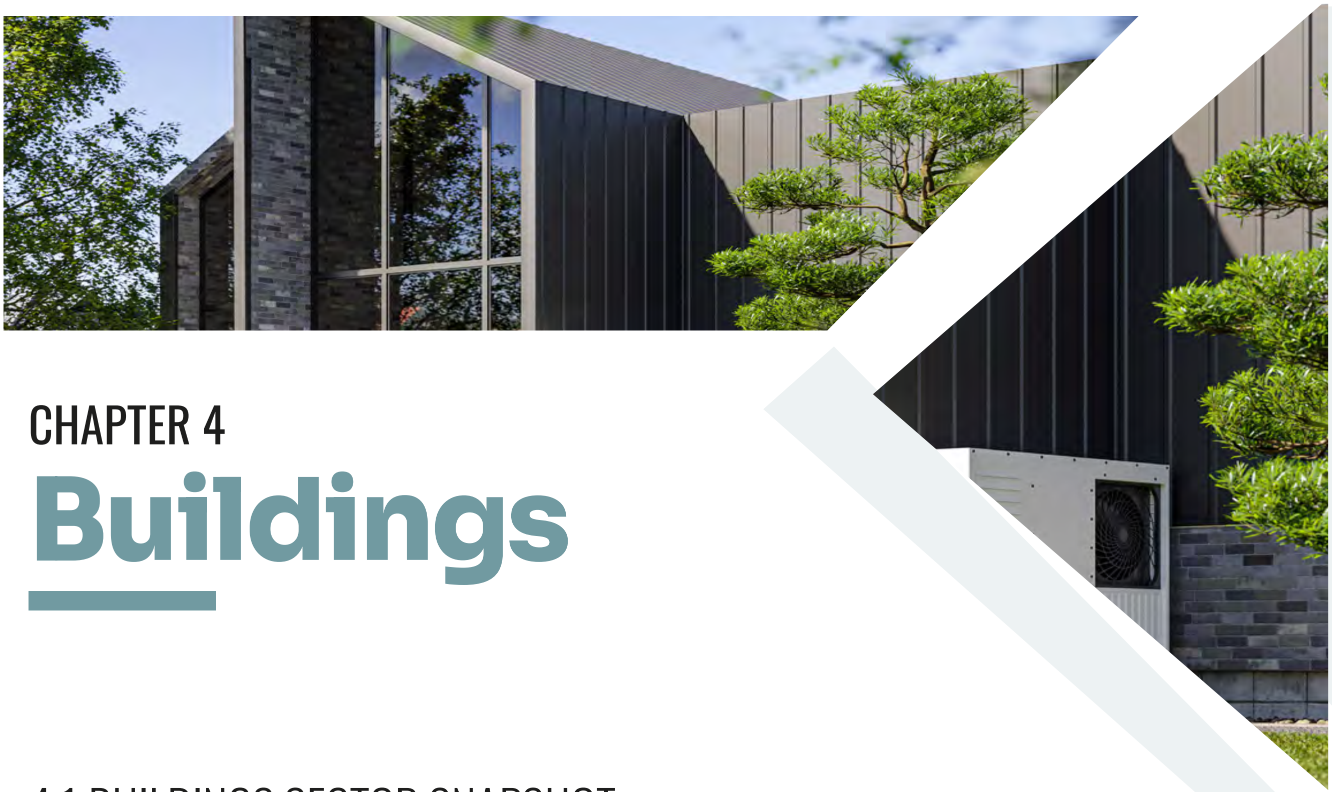
[38] Historical values for this calculation are from the U.S. Energy Information Administration (July 2023). *Monthly Energy Review* [30].

Figure 3.5 Electricity demand from light-duty vehicles in the transportation sector



Model results show increased demand from light-duty vehicles, but the IRA scenario shows a more substantial increase in 2030 and 2035. Individual model results are shown as orange triangles for No IRA and blue circles for IRA scenarios in each year. Horizontal bars represent the median of the result for each scenario in each year. Accessible table available in the Data Annex.



CHAPTER 4

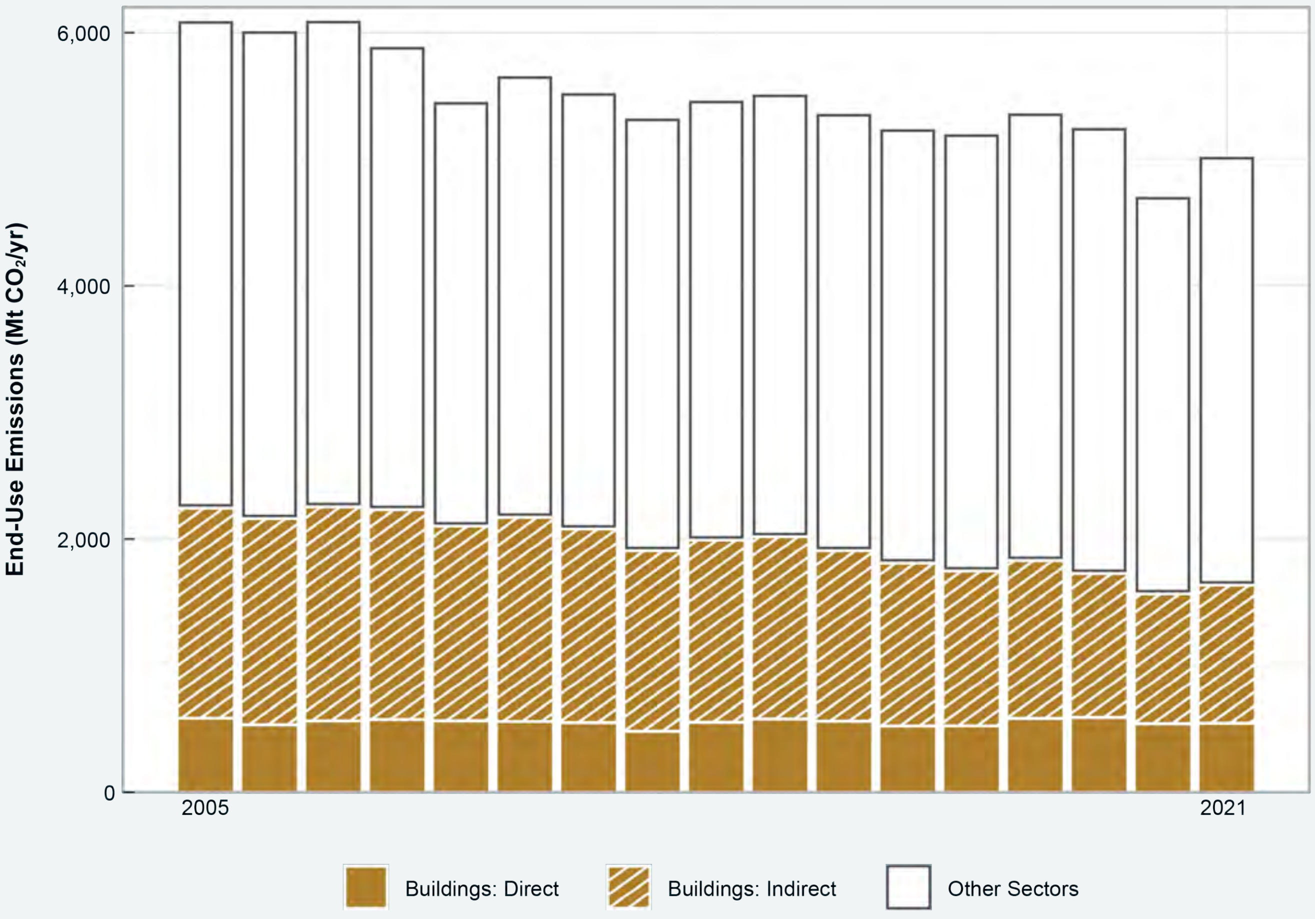
Buildings

4.1 BUILDINGS SECTOR SNAPSHOT

The buildings sector contributes over a third of U.S. CO_2 emissions. On-site fossil fuel combustion at buildings is responsible for 11% of total U.S. CO_2 emissions and 22% of emissions are from electricity used in buildings (see Figure 4.1) [4]. When electricity use is accounted for, the buildings sector is the second largest contributor of CO_2 emissions in the United States, following the transportation sector. The largest sources of building emissions are heating, cooling, and water heating. To substantially reduce building emissions, the most effective strategies are to install energy efficient equipment to reduce energy use overall, ensure that electric equipment is installed—when possible—to avoid fossil combustion, and ensure buildings are constructed and operated in a way that uses energy efficiently.

The needed technologies are already being deployed in buildings but many—like air-source heat pumps for air heating, air cooling, and water heating—are not currently used at the scale necessary for substantial reductions. Because of the long life of buildings and building equipment, it is an immediate priority to install efficient and lower-emitting technology whenever existing buildings are retrofitted or new buildings are built. Immediate action also allows more time to develop effective deployment strategies, to learn more about how to optimize installation and operation as deployment scales, and to understand how these changes can best take advantage of and enable a clean electric grid. To inform future actions, this assessment projects the extent to which IRA spending contributes to energy-related emissions have fallen.

Figure 4.1 CO2 emissions from the buildings sector compared to economy-wide CO_2 emissions, 2005-2021



Since 2005, direct buildings sector CO_2 emissions have remained essentially unchanged, and indirect emissions (from the generation of electricity used to power buildings) have slowly decreased. Buildings direct emissions are shown in gold and indirect emissions in gold with white cross-hatching. Remaining economy-wide CO_2 emissions are represented by the outlined bar. Accessible table available in the Data Annex.

Residential buildings encompass both single-family homes (about 70% of households, 90 million homes), and multi-family buildings of varied sizes from duplexes to high-rises (about 30% of households, over 37 million units) [83]. These figures include a growing number of manufactured homes—7.5% of existing U.S. homes and 9% of new homes are manufactured [84]. Commercial buildings include any building that is not residential, industrial, or agricultural, and they encompass 5.9 million buildings and a little over half of U.S. floorspace [85, 86]. Currently, warehouse, office, and service buildings together account for roughly 48% of all commercial buildings and 42% of total commercial building floorspace [86].

U.S. residential fuel consumption is split evenly between natural gas and electricity, with a small percentage using other fossil fuels such as oil or propane for heating [30].[39] In the commercial sector, about a third of the energy consumed on-site is in the form of natural gas and two-thirds is electricity [86].

Fuel use varies significantly across regions. For example, 60-70% of households in the Midwest and West use natural gas as their primary heating fuel, but only a little over 30% of homes in the South do so [87]. The amount of electricity used for air conditioning also varies significantly across regions. Regionally customized policies that account for this variation can optimize buildings sector reductions [88].

Space heating, air conditioning, and water heating make up around 60% of energy used in buildings and present the greatest opportunity for building emissions reductions—through electrifying new heating, ventilation, and air conditioning (HVAC) and water heating with energy efficient equipment (hereafter referred to as “efficient electrification”) and through lowered demand from better insulated buildings [86, 89] The remaining energy used in buildings goes to activities like cooking and laundry (which also present opportunities for efficient electrification) and other miscellaneous appliances that are generally electric like refrigerators.

Residential buildings have a median age of a little over 40 years and commercial buildings generally have lifetimes of 50 years or more, so decisions made now will have longstanding effects [90, 91]. New buildings are designed to be more efficient because they must comply with updated building efficiency codes, but additional energy management, lower-emitting building equipment, and building envelope measures above current requirements can further reduce long-term emissions. The efficiency of existing buildings can frequently be improved through equipment and building envelope retrofits and efficient management and operation of building systems because many were built before energy codes or when energy codes were less stringent [92].

Currently, most buildings are heated with less efficient technologies—mainly fossil fuel-burning furnaces, boilers, and electric resistance heating. However, this trend is shifting as sales of air-source heat pumps, which provide more efficient and electrified heating and cooling combined, surpassed sales of fossil fuel furnaces in 2022 by over 10%. Heat pump water heaters lag the growth in space conditioning heat pumps, currently representing only 2% of

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[39] Currently, a small percentage of buildings, mostly homes, receive truck delivery of propane or fuel oil for space heating. This is primarily concentrated in colder regions and in rural areas. A small number of homes also heat with wood.

residential water heaters, and around 0.4% of commercial water heaters.[40] IRA has the potential to significantly increase deployment of heat pumps through tax credits and rebates, along with programs to reduce barriers to adoption (see Text Box: Overcoming Deployment Challenges).

The federal government already has a longstanding role in ensuring the energy performance of buildings. The U.S. Department of Energy sets enforceable standards for appliance energy performance and develops model energy codes for state and local communities. The EPA provides voluntary ENERGY STAR efficiency certifications for products, new residential construction, and existing commercial buildings [95, 96]. Through IRA funding, EPA is expanding ENERGY STAR to bring efficiency and emissions reductions to more residential and commercial buildings. The federal government also leads by example by implementing GHG reduction measures in its own buildings, through efforts like the federal building performance standard, and is also expanding that work through the IRA [97].

States commonly require electric and gas utilities to offer incentives for improvement in new and existing building envelopes and energy efficient products in residential and commercial buildings. These incentives will be supplemented through IRA tax credits and rebates. To improve the performance of existing commercial buildings, states and localities are beginning to adopt requirements for energy benchmarking and for building performance standards, which require buildings to meet either a certain energy or GHG performance level, or both.

Other sources of buildings sector emissions include fugitive refrigerant or methane emission from buildings, embodied emissions of construction materials (i.e., emissions produced during manufacture of construction materials) [88], the effect of land use planning related to buildings (on both buildings and transportation sector emissions) [98], and emissions from disposal of construction waste. These are not specifically analyzed in this analysis. Another key concern in the buildings sector that is not addressed in this report is resilience to climate impacts. IRA policies and programs do, however, address some of these priorities, through actions like funding of the American Innovation and Manufacturing (AIM) Act to address refrigerants and the Federal Buy Clean Initiative affecting construction materials [99].

4.2 KEY BUILDINGS SECTOR IRA PROVISIONS

The IRA includes the following policies and incentives relevant to the buildings sector. See Section 1.2.2 for which of these initiatives are represented in the modeling. That representation may be limited based on the capabilities of the models and the extent to which the specifics of the program have been determined.

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[40] The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) reported 42% for residential space heating heat pump sales in 2022. ENERGY STAR reported 2% for residential heat pump water heat sales in 2021. Using a combination of Commercial Buildings Energy Consumption Survey (CBECS) data and AHRI data, commercial space heating sales for 2022 are estimated to be 14%. Using a combination of CBECS and ENERGY STAR data, commercial heat pump water heating sales for 2021 are estimated to be 0.4% [86, 93, 94].

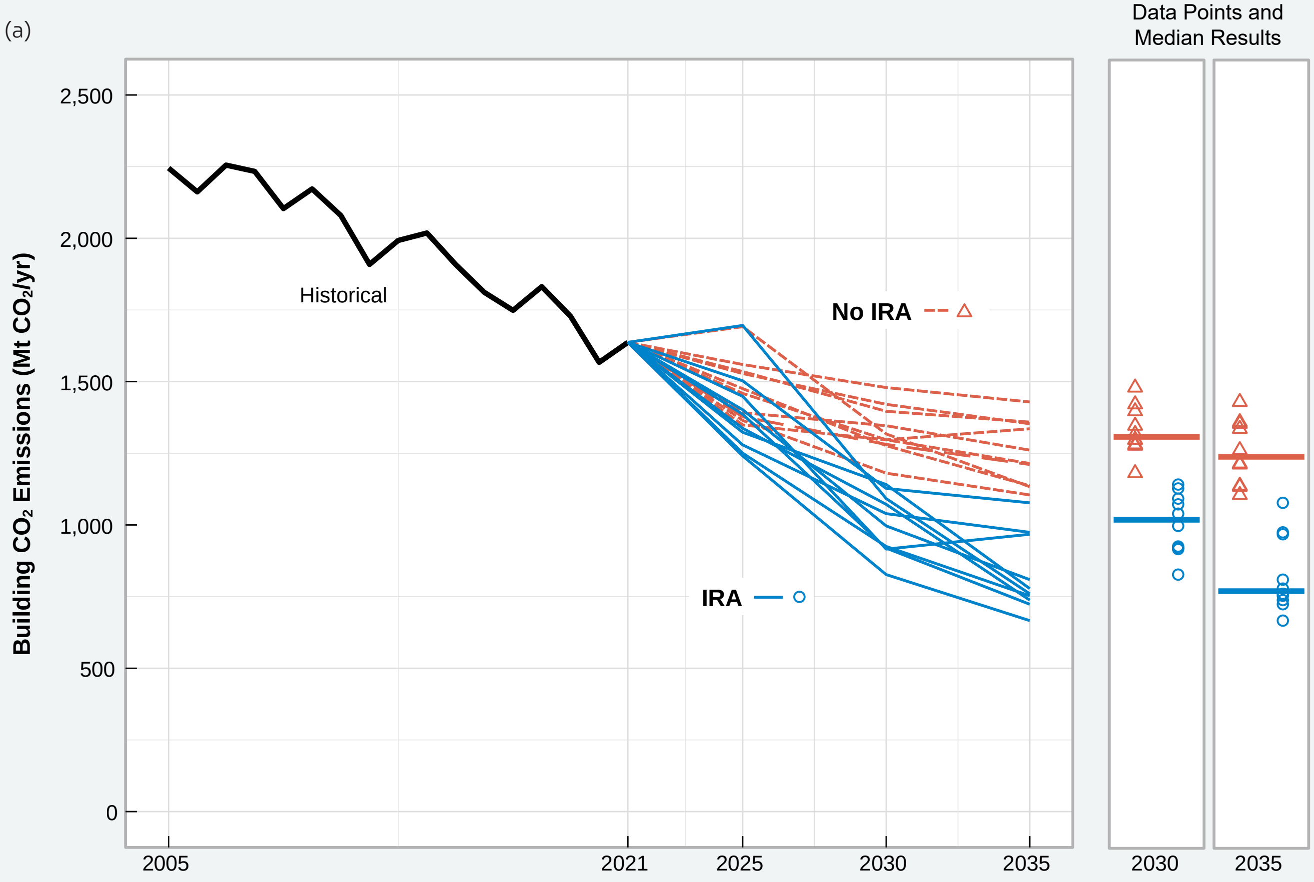
- Tax incentives and rebates:
    - Energy Efficiency Home Improvement Credit (25C)
    - Residential Clean Energy Credit (25D)
    - New Energy Efficient Homes Credit (45L)
    - Energy Efficient Commercial Buildings Deduction (179D)
    - Consumer home energy rebates
        - Home Electrification and Appliance Rebates Program
        - Home Efficiency Rebates Program
- Funding and financing:
    - EPA Greenhouse Gas Reduction Fund
    - Climate Pollution Reduction Grants
    - DOE Building Energy Codes Technical Assistance
    - DOE State-Based Home Energy Efficiency Contractor Training Grants
- Grants:
    - HUD Green and Resilient Retrofit Program
    - General Services Administration Assistance for Federal Buildings
- Programs:
    - Labeling for Substantially Lower Carbon Construction Materials
    - Low Emissions Electricity Program

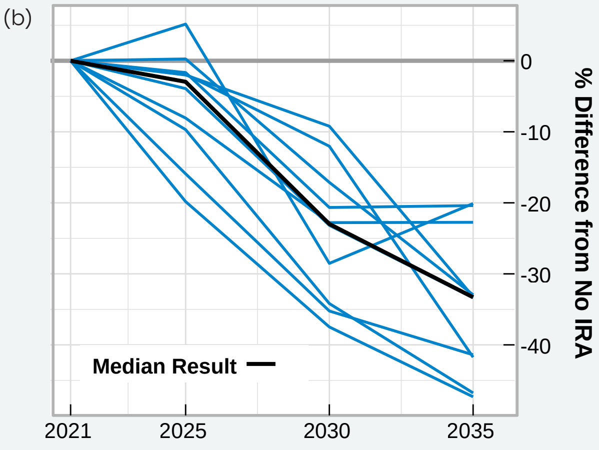
The text box "Building Sector Measures Incented by the IRA" explores in more detail key measures encouraged by these programs—including energy efficiency, efficient electrification, and distributed renewable energy.

4.3 BUILDINGS SECTOR ANALYSIS AND RESULTS

Most of the major IRA provisions for buildings were covered by the models (see Table 1.3). The projected emissions reductions in the buildings sector from scenarios with and without IRA are shown in Figure 4.2. Accounting for all modeled results, IRA provides a reduction in emissions of 52-70% (median 66%) below 2005 levels in 2035. This is relative to the No IRA scenario, which has a substantially smaller decrease of 36-51% (median 45%) below 2005 levels in 2035. Median absolute reductions in 2030 and 2035 are 300 and 390 Mt CO_2, respectively (Figure 4.2(a)). Against each model's baseline (Figure 4.2(b)), emissions reductions are from 9 to 37% in 2030 and 20 to 47% in 2035. In buildings, emissions predominantly fall due to changes in indirect emissions (median indirect reductions in 2030 and 2035 are around 350 and 450 Mt CO_2 respectively). Direct emissions fall by only around 37 Mt CO_2 per year in both 2030 and 2035 (see Figure F.2.3).

Figure 4.2 Buildings sector CO_2 emissions





In the IRA scenario, buildings sector CO_2 emissions fall to 49 to 63% (55% median) below 2005 levels in 2030. In 2030, individual models find that buildings CO_2 emissions are 9 to 37% (23% median) below what they are modeled to be in the No IRA scenario, with the median difference falling to 33% by 2035. Figure 4.2(a) shows absolute model results for the emissions trajectories (No IRA scenario in orange dashed lines, IRA Scenario in blue) with the historical trend (in black [4]). Data points to the right of Figure 4.2(a) show individual model results from 2030 and 2035 (blue circles for IRA scenario results, orange triangles for No IRA). Horizontal bars represent the median of the model results. Figure 4.2(b) shows the percent difference between the IRA and No IRA for each model (blue lines) and the median across the models (black line). Buildings emissions are broken out into direct and indirect in Appendix F.2.[41] Accessible table available in the Data Annex.

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[41] NEMS-RHG shows higher total emissions under the IRA in 2025. Of the total emissions, the indirect emissions are higher, though the direct emissions are lower. In the No IRA scenario, the forward-looking model has slightly higher levels of near-term investment in renewables in 2025 because the model forsees the expiration of tax credits. Under the IRA scenario, tax credits are extended and investment does not exhibit a near-term spike. This leads to a projection of greater indirect emissions from electricity generation under the IRA in 2025.

Under the IRA, the median electricity share of final energy increases by 1.9 percentage points (pp) in 2030 and 2.1 pp in 2035. The maximum increase is 4.1 pp in 2030 and 4.7 in 2035. However, electrification does not increase in all models. There is also a discernible increase in electricity use in buildings over time—across the models there is a median 8% increase in electricity's share of final energy from 2021 in the IRA scenario in 2030 and 13% in 2035, likely reflecting a certain amount of building-based electrification in the near term.

The variation in results across models is at least in part because the multi-sector analyses vary in the methods and the level of detail used in analysis of the buildings sector, as well as varying assumptions about the uptake of IRA incentives. For details on how building policies are represented in the different models, see Table 1.3 and Table C2.

Building on the modeling caveats and limitations provided in Section 1.2.4, there are two types of uncertainties that are particularly applicable to the buildings sector that should be acknowledged. The first type is uncertainty regarding IRA implementation. There is uncertainty regarding the scale and nature of adoption of IRA buildings sector incentives, which in part depends on initiatives that enable overcoming non-market barriers to adoption (see the Overcoming Deployment Challenges Text Box in Section 1.3.2). The IRA provides programmatic funding to target these barriers and to further support uptake of IRA incentives and deployment of emission-reducing technologies. Program design at the federal and state level will have a significant effect on the impact of IRA initiatives. There is also uncertainty regarding technical assumptions, such as whether newly installed equipment will be operated and maintained efficiently over the long term. Also, the buildings sector analysis is dependent on analysis of the rate of power grid decarbonization, another key uncertainty.

The second type is uncertainty due to the limitations of representation of building sector IRA policies and buildings sector modeling in the context of multi-sector models. Not all IRA buildings-related programs are represented (see Table 1.3). The representation of capacity building and technical assistance programs is particularly limited. More generally, multi-sector models are limited in terms of the granularity with which they can represent efficient technology adoption in the buildings sector and the behavior of energy demand [100-102]. This type of analysis would benefit from development of analytical methods that better reflect the buildings sector in economy-wide modeling—something that has not been the focus of these models in the past. The reflection of existing state- and local-level actions will also affect how the impact of IRA is assessed.

Buildings Sector Measures Incented by IRA

The IRA provides incentives for multiple strategies to reduce CO_2 emissions from buildings, including energy efficiency, efficient electrification, and renewable energy from distributed renewables. This section specifies the nature and potential impacts of these measures. Potential impacts of energy efficiency and efficient electrification measures are explored in buildings sector-specific technology scenario analyses separate from the multi-sector modeling. The discussion of distributed renewable energy specifies how it is represented in the multi-sector modeling. Finally, the text box specifies how IRA prioritizes these measures in low-income and disadvantaged communities.

ENERGY EFFICIENCY

Energy efficient strategies include efficient end-use appliances and equipment, energy and building management (including commissioning and optimizing buildings systems and controls), and building envelope measures such as higher performance insulation and windows. Additionally, benchmarking energy use for commercial buildings is an increasingly prevalent way to make building operations more efficient with minimal time and investment—studies have estimated that benchmarking buildings can drive energy efficiency improvements of 1-4% annually. States and local communities are starting to adopt policies that encourage benchmarking [103-107].

In addition to directly acting to reduce emissions, energy efficiency can reduce ratepayer and power sector system costs. Ratepayers realize lower energy bills through efficiency improvements. Energy efficiency also enables the installation of equipment with lower energy requirements by reducing a building's heating, cooling, and water heating load. This reduces equipment costs and, in the case of efficient electrification, can avoid or reduce electricity service upgrades in buildings.

As more end uses are electrified, a focus on energy efficiency will moderate increases in electricity system costs. A significant decrease in demand from aggressive energy efficiency, along with a focus on load flexibility and management, can reduce total power demanded from the grid and smooth out peak demand, thus reducing the infrastructure investment needed for a low-emitting electric grid.

A newly published study by LBNL and the Brattle Group included an assessment of the potential power system cost impacts of increased efficiency and demand flexibility deployment in deep decarbonization scenarios with high demand-side electrification. While generally relevant to potential IRA impacts, this study predates IRA and does not reflect IRA policies. LBNL and Brattle found that aggressive deployment of building efficiency and demand flexibility measures alongside rapid building electrification could offset more than a third of the incremental grid investments required to fully decarbonize the power system.[42] In their scenarios, LBNL and Brattle projected building emission reductions of up to 46-67% below 2005 by 2030 (including reductions from direct combustion and electricity). Demand reductions play a foundational role in the scenarios, providing 44-50% of reductions below 2005 levels in 2030. They also compared costs of decarbonization scenarios with efficient building energy use and demand balancing against scenarios with less efficient electric resistance heating and water heating. LBNL and Brattle found that scenarios with demand-side efficiency and flexibility measures resulted in $6-25 billion less in annual power system costs in 2030 than the less efficient scenario, and $57-107 billion savings per year by 2050, around 35% of incremental power system costs to decarbonize.

Efficient electrification will particularly reduce emissions from inefficient electric and fossil-fueled HVAC and water heating uses, as well as other uses including commercial process heat and cooking.

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[42] Langevin et al., Demand-side solutions in the U.S. building sector could achieve deep emissions reductions and avoid over $100 billion in power sector costs [108].

Buildings Sector Measures Incented by IRA (continued)

EFFICIENT ELECTRIFICATION

Heat pumps use half or less of the electricity needed for electric resistance heating, and ENERGY STAR-certified residential heat pump models avoid more than 4,500 pounds of GHG emissions, on average, over their lifespan compared to standard HVAC systems [109, 110]. Efficient electrification results in emissions reductions in almost all parts of the United States right now, based on current grid emissions as compared to conventional fuel emissions, and emissions per kilowatt-hour will continue to decline in the future as the grid decarbonizes. Cold weather climates in the United States are the regions where specialized cold weather heat pumps or backup heating may be required to ensure sufficient heating during isolated cold weather events [111].

To examine the potential impact of heat pumps with efficient building measures in isolation, EPA conducted a separate building-specific analysis for this report using the DOE Scout tool [112]. For EPA, LBNL and NREL analyzed three technical scenarios for increased heat pump deployment for heating, air conditioning, and water heating in the residential and commercial buildings sectors and increased building efficiency measures. These were compared to a reference scenario with Annual Energy Outlook (AEO) 2022 reference case assumptions.

The three growth scenarios do not explicitly model IRA policy, but they assumed different levels of deployment that are feasible under IRA. For example, in 2030 heat pumps sales were projected to reach 45% of residential HVAC sales in the Low Scenario, 50% in the Central Scenario, and 63% in the High Scenario.[43] For reference, in 2022 heat pumps were 42% of residential HVAC sales. The High Scenario also assumes some accelerated replacements of certain building components that occur before the end of those components' useful life. The scenarios assume building energy efficiency improvements at EIA AEO 2022 reference case (Low Scenario) or moderately above AEO 2022 (Central and High Scenario). See Appendix G.1 for details on all assumptions.

This analysis shows the significant reductions that heat pumps and efficiency measures alone can provide in the near term. The selected improvements in heat pump use and building efficiency resulted in emissions reductions ranging from 46-51% of 2005 levels in 2030 and 52-60% of 2005 levels in 2035. The Central Scenario reached 50% reductions from 2005 levels in 2030 building sector emissions and 57% in 2035. For more details on the results, see Appendix G.1.

RENEWABLE ENERGY FROM DISTRIBUTED RENEWABLES

The emissions impact of building-based distributed renewables is not specifically quantified in this analysis. However, distributed renewables and relevant IRA incentives are reflected in modeling assumptions. For example, IRA modifications to the 25D residential clean energy tax credit are accounted for in all the models. The credit was modified to add battery storage and extended to 2032 with a phasedown to 2034. Also, the Greenhouse Gas Reduction Fund is included in model assumptions. It establishes the $7 billion Solar for All competition will provide up to 60 grants to states, tribal governments, municipalities, and nonprofits to build capacity for residential and community solar investment in low-income and disadvantaged communities. Table 1.3 shows three

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[43] Technical experts across NREL, LBNL, and EPA developed the scenarios to reflect feasible technology deployment levels under IRA, informed by market research. The Scout analysis did not explicitly model IRA policy.

Buildings Sector Measures Incented by IRA (continued)

of the nine economy-wide models included the Greenhouse Gas Reduction Fund in some way [113].

In practice, distributed renewables located at buildings, sometimes paired with energy storage, can generate low- or zero-carbon electricity where the power is consumed and may reduce building owners' energy costs over time. Building-based renewables can play a substantial role in generation—currently, distributed solar photovoltaics provide a third of all solar generation [114]. Distributed renewable energy will reduce demand for electricity from the grid as well as losses in transmission of electricity. Distributed renewables' role on the grid must be managed to ensure grid stability, but well-managed renewables can provide potential benefits to the distribution grid, such as the grid stability provided by renewables integrated into microgrids [115]. Building owners can site renewables on their buildings and properties (e.g., parking areas, available land), or invest in certified green power to provide additional incentives for renewable generation [116].[44] In the longer-term, renewable energy generation could be stored in hydrogen and used as a potential buildings fuel, but there are multiple technical, policy, and other challenges that must be addressed [117].

IRA also prioritizes the significant opportunity for emissions reductions and ratepayer cost savings from buildings located in low-income and disadvantaged communities. In 2020, households with an annual income below $60,000 accounted for 50% of all household energy consumption [89]. Addressing this part of the buildings sector can significantly reduce CO_2 emissions from buildings and address key needs in energy affordability. Twenty-seven percent of households experience energy insecurity and over 25% experience a high financial energy burden [118, 119]. The IRA provides significant home energy rebates and reduces cost-share requirements based on income through programs including the Home Electrification and Appliance Rebates program, which requires ENERGY STAR certification, and the Home Efficiency Rebates program.

Additional IRA programs such as the Greenhouse Gas Reduction Fund (GGRF) offer additional substantial opportunities to provide financing that could accelerate these transitions in low-income and disadvantaged communities and address specific barriers for these populations such as poorer construction quality. As part of the GGRF, the $6 billion Clean Communities Investment Accelerator will provide grants to support nonprofit organizations, enabling them to provide funding and technical assistance to public, quasi-public, not-for-profit, and nonprofit community lenders working in low-income and disadvantaged communities. Another part of the GGRF, the $14 billion National Clean Investment Fund, will provide grants to support national clean financing institutions so that they can partner with the private sector to provide accessible, affordable financing for tens of thousands of clean technology projects nationwide. Consistent with the Administration's Justice40 Initiative, at least 40% of the funds from the National Clean Investment Fund will be dedicated to low-income and disadvantaged communities.

Another policy concern is that if higher-income communities electrify first, low-income and disadvantaged communities would be left to pay higher gas bills due to a declining revenue base for the gas utilities. To address this concern, these communities should be prioritized for investments in both energy efficiency and efficient electric upgrades in buildings in the near term. While no specific results are provided on the impact of IRA on these communities, many of the programs may be reflected in assumptions of some of the models.

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[44] The impacts of green power investments are not analyzed as part of this analysis.

CHAPTER 5

Industry

5.1 INDUSTRIAL SECTOR SNAPSHOT

More than 280,000 manufacturing facilities are currently operating in the United States [120]. These vary widely in the products they produce, their energy consumption, energy intensity, size, number of employees, and emissions of greenhouse gases [121].[45] In 2021 the U.S. industrial sector (which accounts for manufacturing, mining, and construction, and including non-combustion process emissions) emitted over 1,600 Mt of CO_2, or nearly 32% of U.S. CO_2 emissions [4]. Addressing industrial emissions requires reducing emissions from direct combustion and industrial processes—the predominant emissions of heavy industry—and addressing the emissions associated with electricity use, which play a much greater role in light industry emissions.

In the industrial sector, CO_2 emissions originate primarily from three different sources, and they vary in potential for significant emission reductions:

- Direct emissions from the combustion of fuels on site account for 50% of industrial CO_2 emissions (15% of total U.S. CO_2 emissions) [4]. Manufacturers burn fuels at their plants to produce heat, steam, and electricity to run industrial processes and contribute electric power to the plant. Emission reduction potential comes from energy efficiency improvements and upgrades to process heaters, boilers and steam systems, process improvements, and plant operation and management.

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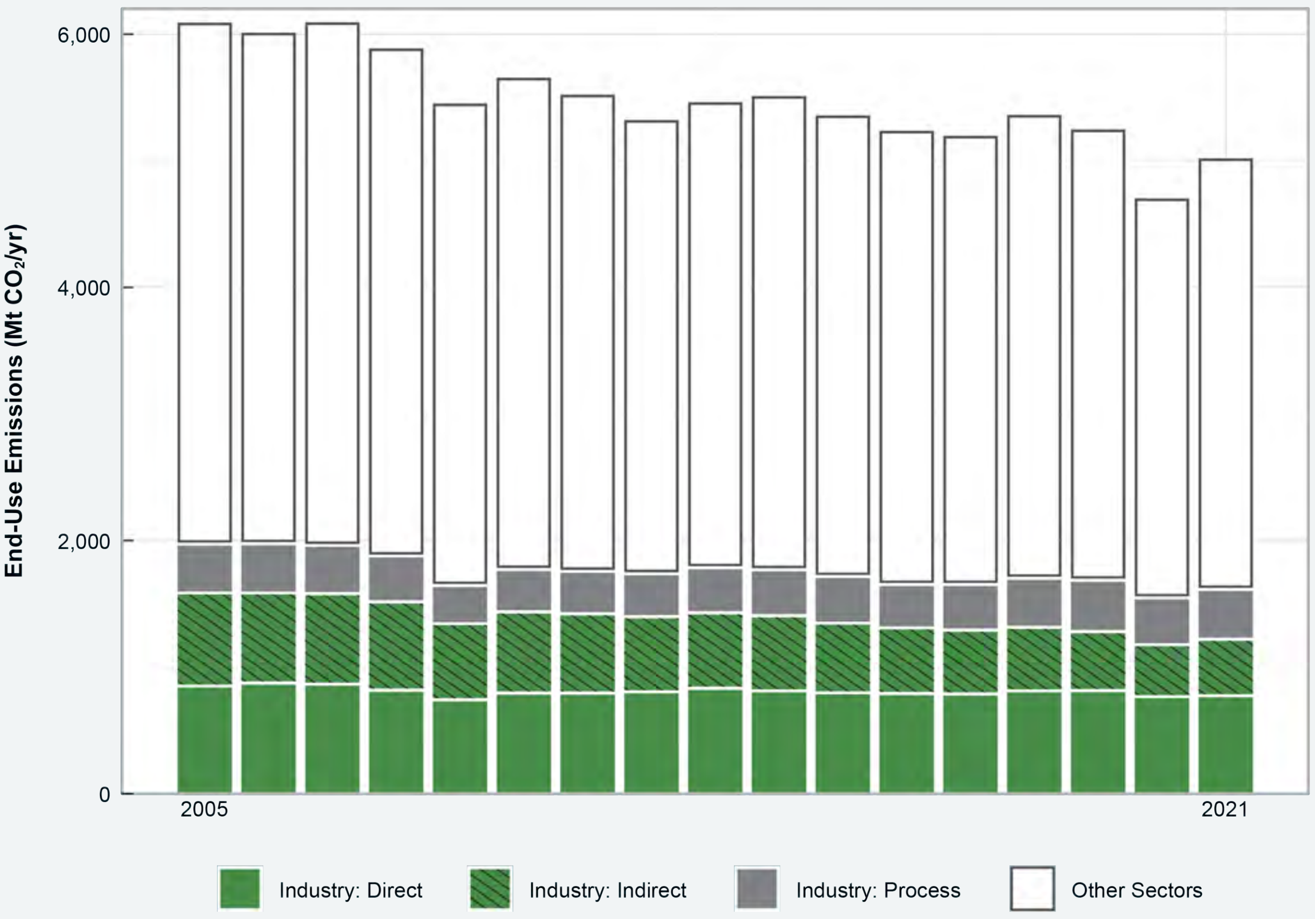
[45] The federal government defines manufacturing by the NAICS according to codes 31-33. Portions of the industries of mining and agriculture are separately catalogued in the NAICS system and are not part of manufacturing; however, they are related to and provide inputs to many of the manufacturing sectors.

Figure 5.1 CO_2 emissions from the industrial sector compared to economy-wide CO_2 emissions, 2005-2021



Direct industry CO_2 emissions have been consistent since 2005, but indirect emissions (from the generation of electricity used by industry) have fallen. Industry direct combustion and indirect emissions are shown in green (with black cross-hatching for indirect emissions) and non-energy industrial process emissions are shown in gray. The remaining economy-wide emissions in other sectors are represented by the outlined bar. The industry sector represents a marginally smaller portion of U.S. CO_2 emissions than buildings or transportation. Accessible table available in the Data Annex.

- Direct process emissions, by-products from industrial processes, account for about 24% of industrial CO_2 emissions (7% of total U.S. CO_2 emissions). These emissions primarily result from the transformation of raw materials, particularly in the manufacture of cement.

- Indirect emissions from electricity purchased from the grid and used at the manufacturing plant account for around 28% of industrial CO_2 emissions in the sector (9% of total U.S. emissions) [4]. This electricity supplies core manufacturing process or support equipment (e.g., motors) and other facility needs (e.g., heating, lighting). As the grid decarbonizes, the use of grid power could be a significant source of emissions reductions.

The IRA provides incentives for new and retrofitted industrial infrastructure to reduce emissions across these categories. The long lifetimes of industrial equipment means that immediate action is needed to take advantage of opportunities when new equipment is being installed or old equipment is being replaced. Industrial equipment is estimated to have an average lifetime of 10-30 years or more. For example, the average lifetime of an industrial boiler is 25 years [122].

The nature of industrial infrastructure also differs across heavy and light industry (see Figure 5.2 for emissions by subsector). In heavy industry, equipment is frequently specialized to the industrial process and heavy industry frequently requires more intensive heat. This applies to chemicals, petroleum refining, steel, and cement—sectors with higher emissions and energy intensities than others—where there are a limited number of plants, but equipment replacements are infrequent and cost-intensive. By contrast, light industry emissions tend to resemble buildings sector emissions, with heating, cooling, and electric-powered equipment being primary energy uses [123]. A list of light industry NAICS codes and corresponding energy use can be found in Appendix G, Table G.2.1.

CO_2 is the major greenhouse gas emitted from the industrial sector, though there are significant emissions of other GHGs, primarily: methane from fossil fuel production; nitrous oxides from agriculture as well as fertilizer and chemical production; and fluorinated gases from metals production and other industrial processes. Non-CO_2 emissions are about 15% of total industrial GHG emissions.

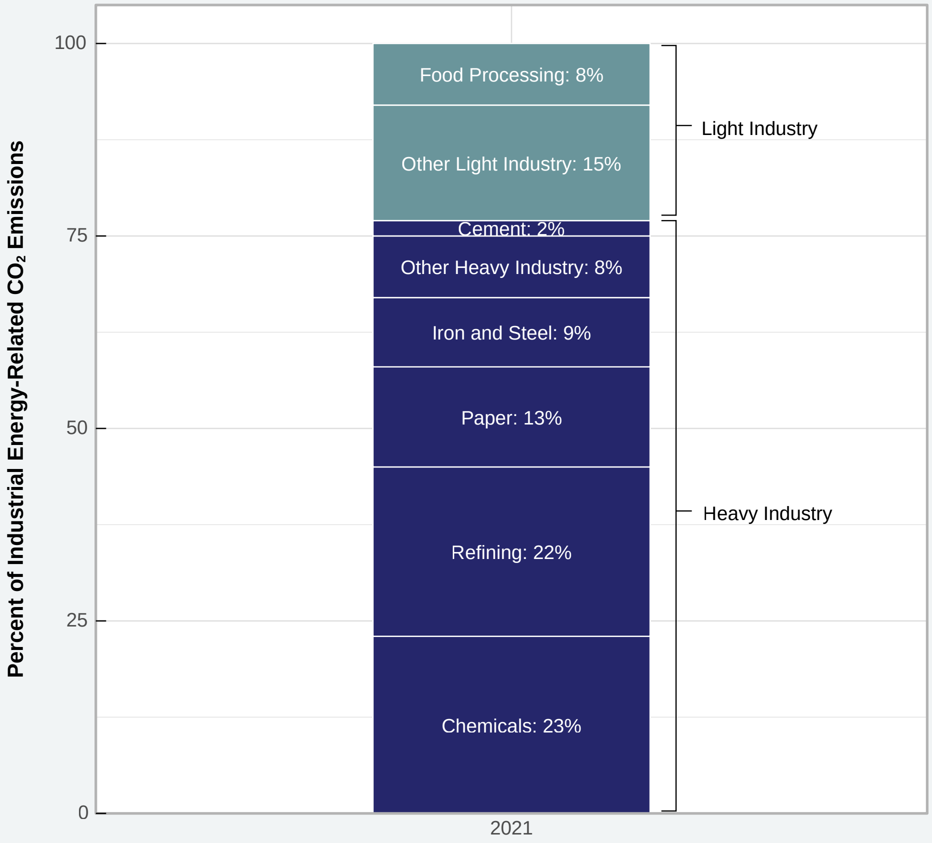
5.2 KEY IRA PROVISIONS FOR INDUSTRY

The IRA sets forth provisions that affect industry and manufacturing across all its sectors. There is potential not only to transform the industrial sector's use of fuel and resulting emissions, but products used by other sectors.

The IRA includes the following policies and incentives relevant to the industrial sector. See Section 1.2.2 for which of these initiatives are represented in the modeling. That representation may be limited based on the capabilities of the models and the extent to which the specifics of the program have been determined.

- Expansion of Advanced Energy Project Credit (48C) to include industrial projects that reduce greenhouse gas emissions by at least 20% at a facility

Figure 5.2 Industry energy-related CO_2 emissions (direct + indirect) by subsector, excluding process emissions



Heavy industry sectors comprise the majority of 2021 industry energy-related emissions (77%, dark blue), with light industry comprising the remaining portion (23%, light blue). This figure shows the composition of industrial sector CO_2 emissions (including direct CO_2 emissions and indirect CO_2 emissions from electricity use) by subsector [124].

- Advanced Manufacturing Production Credit (45X)
- Clean Hydrogen Production Tax Credit (45V)
- Carbon Capture and Sequestration Tax Credit (45Q)
- Advanced Industrial Facilities Deployment Program
- Vehicle Manufacturing Loans and Grants
- Development of Environmental Product Declarations including lifecycle greenhouse gas emissions
- Low-Carbon Materials Labeling for Construction Materials and Funding for Federal Procurement
- Biodiesel, Advanced Biofuels, and Sustainable Aviation Fuel Incentives
- Greenhouse Gas Reduction Fund
- Climate Pollution Reduction Grants
- Methane Emissions Reduction Program
- Agriculture and Forestry Provisions
- Oil and Gas Leases

Potential industrial sector mitigation measures that could be incentivized by IRA include energy efficiency, efficient electrification, hydrogen, carbon capture, and other advanced manufacturing processes that reduce emissions [125]. Each industrial subsector will take advantage of a unique combination of these incentives.

Across light and heavy industry, energy efficiency can play a significant role in reducing direct and indirect emissions. Retrofitting existing plants and building new plants with efficient equipment can be complemented with benchmarking energy use of facilities for ongoing improvement. Ongoing benchmarking of energy use can lower energy intensity of manufacturing plants by 14% across heavy and light industry [125]. Electrification can play a greater role in light industry as many processes require lower-temperature heat.

IRA programs also encourage lower-emitting fuel use economy-wide in ways that affect the industry as the producer of fuel and energy technology and as a consumer of many fuels. These include incentives for renewables, hydrogen, biofuels, and sustainable aviation fuels. Hydrogen and biofuels are potential ways to fuel high-temperature industrial processes. Methane incentives will also help reduce emissions from the industrial sector, particularly in oil and gas refining. Funding for implementation of the AIM Act will also impact both industrial production and use of hydrofluorocarbons (HFCs).

Incentives for carbon capture, use, and storage (CCUS) will ultimately accelerate emissions reductions across a variety of industries and lead to CCUS deployment in the industrial sector, fuel production, and the power sector. In the industrial sector, CCUS is a potential solution to mitigate fossil combustion as well as the bulk of process emissions from cement production. Finally, advanced technology tax credits and funding encourage industry-specific advances, and development of federal Environmental Product Declarations will provide demand from government and private entities for less carbon-intensive products.

5.3 INDUSTRY SECTOR ANALYSIS AND RESULTS

Multi-sector modeling produces a wide range of potential emissions from industry. The results presented are for direct emissions for combustion and indirect emissions from electricity generation only and exclude non-combustion process emissions. Process emissions are excluded from the presentation of results because not all models report industrial process emissions, and those that do cover differing emissions categories. Reductions in direct plus indirect emissions from 2005 levels in 2030 from the IRA range from 17-43% (median 36%) and 23-57% (median 36%) in 2035, versus 6-33% (median 25%) in 2030 and 3-36% (median 27%) in 2035 without it. Median absolute reductions in 2030 and 2035 are approximately 130 and 190 Mt CO_2 (Figure 5.3(a)). Individual models find that industry sector CO_2 emissions are 2 to 21% (12% median) below what they are modeled to be in the No IRA scenario, and in 2035 emissions are 9 to 33% below (17% median) (Figure 5.3(b)). The additional emissions reductions with the IRA are mainly due to changes in indirect emissions. In 2030, reductions in indirect emissions account for around two-thirds of additional industry emissions reductions over the No IRA scenario, increasing to around three-quarters by 2035 (see Figure F.2.4). Increases in electricity use in the industrial sector under the IRA as compared to the No IRA scenario are minimal. Under the IRA, the median electricity share of final energy increases by .06 percentage points (pp) in both 2030 and 2035. The maximum increase is 3.3 pp in 2030 and just 1.3 pp in 2035. Electrification does not increase in all models.

Much of this variation is likely due to differences in how the industrial sector is reflected in modeling assumptions and how the specific model's dynamics affect the sector.[46] Below and in Appendix G, we provide some sector-specific information that helps to supplement the economy-wide analysis.

Building on the modeling caveats and limitations provided in Section 1.2.4, specifically applicable uncertainties for the building sector also apply to the industrial sector. The first type of uncertainty is due to limitations in the level of detail with which the industrial sector is modeled in the multi-sector models. This applies to characteristics of the sector as well as to the policies represented—the IRA industrial sector policies are represented the least of all

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[46] For example, only three of the ten multi-sector models in this study include the advanced manufacturing production credit (45X). Models that do not include this credit may see less U.S.-based manufacturing than if it was included, also potentially resulting in less electricity demand in this sector. See Table 1.3 for a summary of IRA provisions represented across the multi-sector and power-sector models.

sectors across the multi-sector modeling (see Table 1.2). The second type of uncertainty is due to lack of knowledge of how IRA programs will be implemented. For example, it is uncertain the extent to which relevant IRA tax credits will be used by industry and what technologies IRA programs will promote.

Seven models project moderate use of CCS in industry, ranging from approximately 0-240 additional Mt CO_2/yr captured in 2035 in the IRA scenario compared to the No IRA scenario. Figure 5.4 shows captured and sequestered CO_2 emissions in industry in 2030 and 2035, with and without the IRA. Avoided emissions from industry CCS use are reflected in emissions projections in Figure 5.3. The model with the largest amount of industrial CCS is USREP-ReEDS, projecting 240 Mt CO_2/yr in 2030 in the IRA scenario and 0 in the No IRA scenario. NEMS-RHG shows 190 Mt CO_2/yr in 2035 in the IRA scenario and 59 Mt CO_2/yr in the No IRA scenario, for a net addition of over 130 Mt CO_2/yr sequestered, followed by RIO-REPEAT with a net addition of 120 Mt CO_2/yr, and EPS-EI with a net addition of nearly 100 Mt CO_2/yr in 2035. GCAM-CGS, NEMS-OP, and MARKAL-NETL deploy less CCS with no greater than 40 Mt CO_2/yr in 2035..[47]

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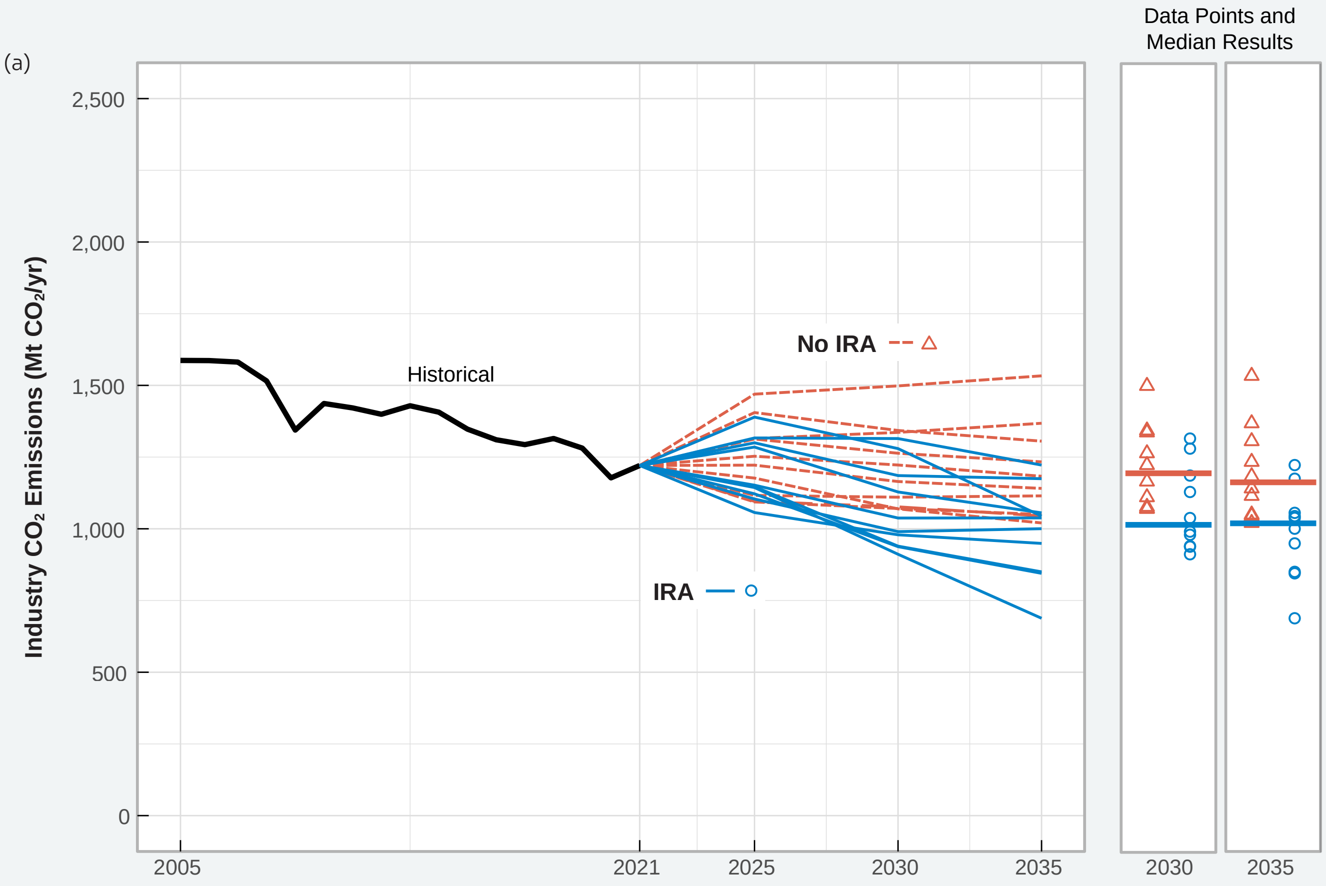
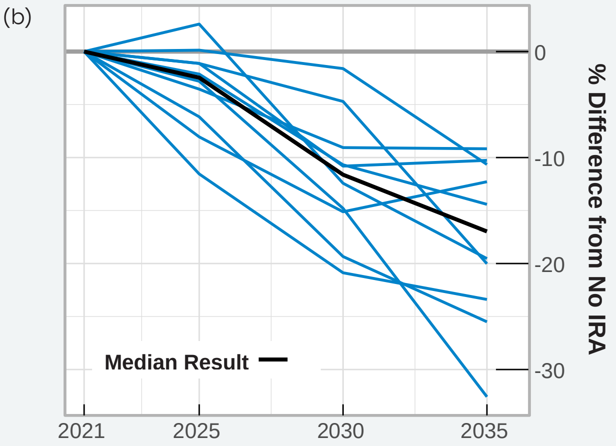
[47] Most models show higher CCS amounts in 2035 than in 2030. The model results for CCS depend on CCS cost relative to the IRA subsidy (fixed at $85/t). Costs vary by CCS technology assumptions and model structure. USREP-ReEDS, a CGE model, has increasing capital costs that, in effect, reduce the penetration of CCS between 2030 and 2035.

Figure 5.3 Industrial sector combustion and indirect CO_2 emissions.





In the IRA scenario, industrial sector CO_2 emissions fall to 17 to 43% (36% median) below 2005 levels in 2030. In 2030, individual models find that industrial CO_2 emissions are 2 to 21% (12% median) below what they are modeled to be in the No IRA scenario, with the median difference falling to 17% by 2035. Figure 5.3(a) shows absolute model results for the emissions trajectories (No IRA scenario in orange dashed lines, IRA Scenario in blue) with the historical trend (in black [4]). Data points to the right of Figure 5.3(a) show individual model results from 2030 and 2035 (blue circles for IRA scenario results, orange triangles for No IRA). Horizontal bars represent the median of the model results. Figure 5.3(b) shows the percent difference between the IRA and No IRA for each model (blue lines) and the median across the models (black line). Industry emissions are broken out into direct and indirect in Appendix F.2.[48,49] Accessible table available in the Data Annex.

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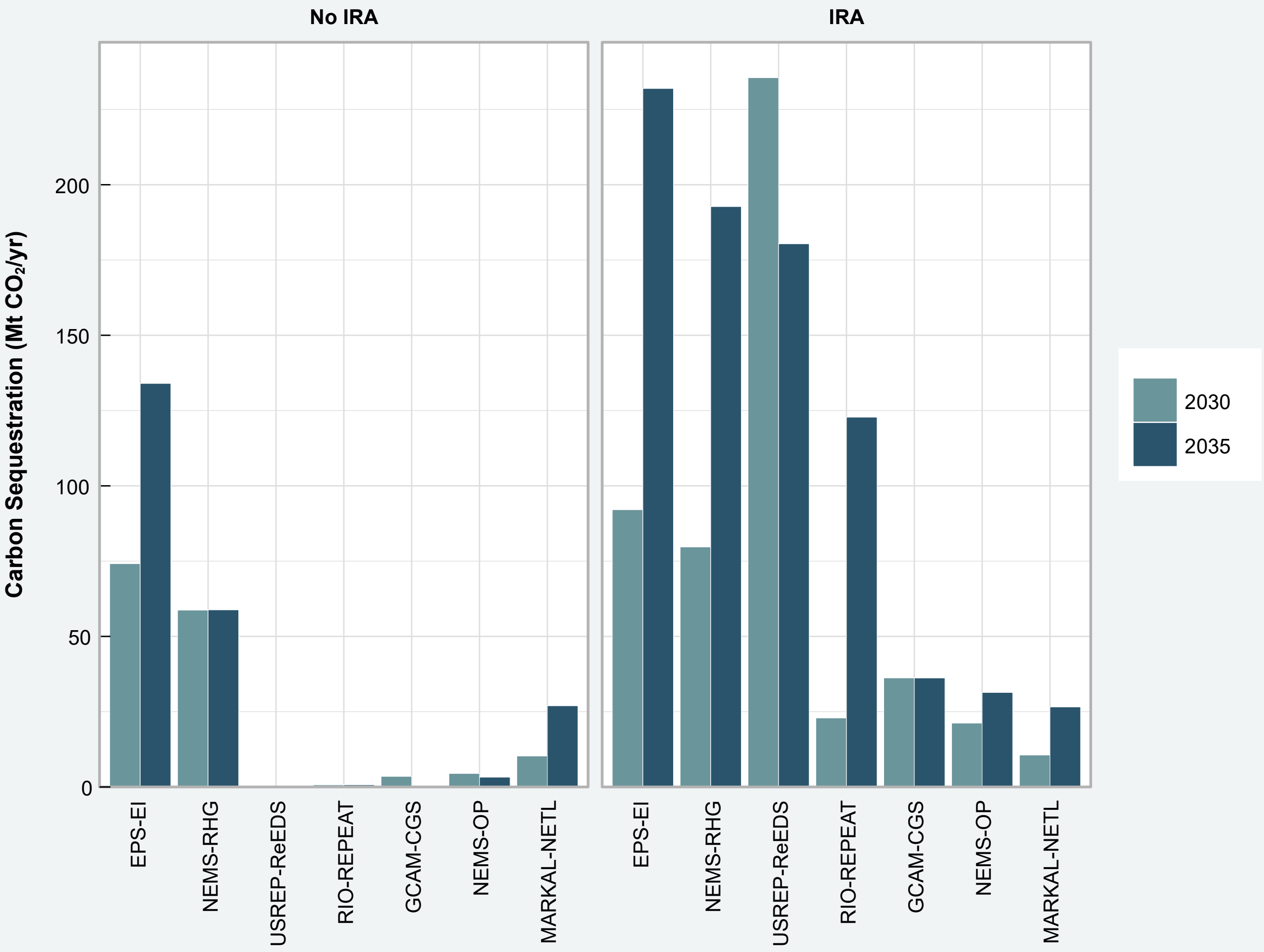
[48] Note that industrial process emissions are not included in Figure 5.3. Not all models report industrial process emissions, and those that do cover differing emissions.

[49] NEMS-RHG shows higher total emissions under the IRA in 2025. In the No IRA scenario, the forward-looking model has slightly higher levels of near-term investment in renewables in 2025 because the model forsees the expiration of tax credits. Under the IRA scenario, tax credits are extended and investment does not exhibit a near-term spike. This leads to a projection of greater indirect emissions from electricity generation under the IRA in 2025.

Figure 5.4 Industry carbon capture and sequestration



Carbon sequestered from the industrial sector grows significantly by 2035 with the IRA. Results are shown by model with the IRA (right panel) and without (left panel) in 2030 (left bar, light blue) and 2035 (right bar, dark blue). Accessible table available in the Data Annex.

Hydrogen

HYDROGEN

Hydrogen offers unique solutions for decarbonization in various sectors because of its potential to provide dispatchable, clean energy with long-term storage and seasonal capabilities. However, while there are zero direct CO_2 emissions from hydrogen combustion, it is important to acknowledge that different processes used to produce hydrogen result in different levels of GHG emissions. In both the 2021 Infrastructure Investment and Jobs Act (IIJA) and the 2022 IRA, Congress recognized that different methods of hydrogen production generate different amounts of GHG emissions and included extensive policy support and financial incentives for increased development of hydrogen produced through low-GHG-emitting methods. The magnitude of these incentives is anticipated to accelerate the production of low-GHG hydrogen for use in a broad range of applications across many sectors, including the utility power sector. For example, Bistline et al. [1] notes that the 45V tax credits for hydrogen combined with credits for captured CO_2, increase the amount of low-emission hydrogen production. Most of the models in the Bistline et al. analysis show little change in total hydrogen production, with only one model showing an increase of 0.6 quads from 1.4 quads to 2.0 quads, as a result of the IRA provisions. However, there is a substantial shift in the processing inputs and technologies used to produce hydrogen, with the models showing a move from predominantly relying on steam methane reforming (SMR), a high-emitting production technology, to SMR with CCS, other processes with CCS, and electrolysis, all relatively low-emissions production technologies (see supplemental materials and Figure S23 from the Bistline et al. publication). [50]

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[50] Separate reports may provide more granular exploration of the emissions impact of varying hydrogen production methods and PTC structures (e.g., Ricks et al. [126]).

CHAPTER 6

Conclusions

Climate change is already harming communities and imposing economic costs around the world. In 2022, the United States passed the Inflation Reduction Act (IRA), which provides a broad range of strategies to reduce greenhouse gas (GHG) emissions across multiple sectors of the economy while simultaneously promoting domestic manufacturing and well-paying jobs. These measures include incentives for clean energy and carbon management, support for accelerating efficient electrification and energy efficiency, policies for reducing methane emissions, and many other provisions affecting electricity generation, transportation, buildings, and industry.

To assess the effects of these measures on GHG emissions (with a focus on combustion emissions) multiple modeling tools are used in this report. The models vary, ranging in scope (e.g., full energy system vs. power sector only) and resolution (e.g., level of technological and sectoral detail). As the report details, these models have different strengths and weaknesses, but they contribute important analytical perspectives to the results.

This analysis presents modeling results through 2035 from two scenarios, a No IRA scenario that reflects current, finalized federal and state policies enacted except for the IRA, and an IRA scenario, that reflects the current federal and state policies enacted in addition to modeled provisions of the IRA. Modeled results show that the IRA results in CO_2 emissions reductions not only economy-wide, but also specifically from the electricity generation, transportation, buildings, and industrial sectors (see Figure 1.2).

For comparison, in the No IRA scenario economy-wide CO_2 emissions decline from 6,130 Mt CO_2/yr in 2005 to a median projection of 4,100 Mt CO_2/yr in 2035, representing a reduction of 33%. The IRA scenario shows a substantially larger reduction, to a median of 3,300 Mt CO_2/yr in 2035, which represents a 46% decline from 2005 levels. (The projected range for 2035 in the IRA scenario is 2,800-3,900 Mt CO_2/yr). In 2030, the IRA scenario shows median CO_2 emissions 11% lower than the No IRA scenario, and 19% lower by 2035.

These economy-wide results are presented with several caveats. First, current modeling does not include the impact of proposed (and potential) federal, state, and private policies that are not yet final. Second, the final details of certain IRA provisions such as the structure of tax credits, are still under consideration by the Treasury Department. Third, several important provisions of the IRA are not amenable to modeling using currently available tools, and so are not included in this analysis. Additionally, there is currently limited data on advanced technologies that are encouraged by the IRA, such as carbon capture and storage (CCS) technologies. All of these caveats increase the uncertainty of model results. Despite the caveats, the modeling shows that the IRA reduces costs and increases acceptance of clean technology, and the legislation is expected to make future climate measures more likely.

Summarizing the results for individual sectors:

Electricity:

- CO_2 emissions from electricity generation are projected to decline in the IRA scenario from 2005 levels by 67% to 87% in 2035 with a median reduction of 77%. This is significantly more than the decline in the No IRA scenario between 2005 and 2035 of 40% to 68%. In terms of emissions quantities, electric sector emissions in 2005 were 2,400 Mt CO_2/yr—the IRA scenario shows a decline by 2035 to a range of 320 to 780 Mt CO_2/yr, compared to the No IRA scenario decline by 2035 to a range of 780 to 1,400 Mt CO_2/yr.

Transportation:

- Total direct (from combustion of fossil fuels) and indirect (from combustion of fuels to generate electricity consumed in the transportation sector) CO_2 emissions are projected to decline in the IRA scenario from 2005 levels by 15% to 35% in 2035 with a median reduction of 27%. This is more than the decline in the No IRA scenario between 2005 and 2035 of 13% to 28%. In terms of emissions quantities, transportation sector emissions in 2005 were 1,863 Mt CO_2/yr—the IRA scenario shows a decline by 2035 to a range of 1,200 to 1,600 Mt CO_2/yr compared to the No IRA scenario decline by 2035 to a range of 1,300 to 1,600 Mt CO_2/yr.

Buildings:

- Total direct and indirect buildings CO_2 emissions decline in the IRA scenario from 2005 levels by 52% to 70% in 2035 with a median reduction of 66%. This is more than the decline in the No IRA scenario between 2005 and 2035 of 36% to 51%. In terms of emissions quantities, buildings sector emissions in 2005 were 2,245 Mt CO_2/yr—the IRA scenario shows a decline in 2035 to a range of 670 to 1,100 Mt CO_2/yr compared to the No IRA scenario decline by 2035 to a range of 1,100 to 1,400 Mt CO_2/yr.

Industry:

- Total direct and indirect industry CO_2 emissions decline in the IRA scenario from 2005 levels by 23% to 56% in 2035 with a median reduction of 36%. This is significantly more than the decline in the No IRA scenario between 2005 and 2035 of 3% to 36%. In terms of emissions quantities, industry sector emissions in 2005 were 1,587 Mt CO_2/yr—the IRA scenario shows a decline in 2035 to a range of 690 to 1,200 Mt CO_2/yr compared to the No IRA scenario decline by 2035 to a range of 1,000 to 1,500 Mt CO_2/yr.

In the electric sector, CO_2 emissions reductions from 2021 to 2035 (in both the No IRA and IRA scenarios) are primarily driven by the shift away from high-emitting generation sources—coal and natural-fired gas generation without CCS—to low- or zero-emitting generation sources (wind, solar, etc.). This shift is consistent across all models (see Figure 2.4). The additional reductions in the IRA scenario result from tax credits like the Clean Electricity Investment and Production Tax Credits (48E, 45Y) and the Nuclear Power Production Tax Credit (45U). Across all but one model, solar and wind see the largest increases in generation.

In the transportation sector, the reduction in CO_2 emissions from the IRA is driven primarily by the increase in electric vehicles' (EV) share of new sales (see Figure 3.4), which is projected to rise from 4% in 2021 to between 15% and 54% in 2030, with a median market share of 36% in the IRA scenario. This level of EV sales represents an increase from the No IRA scenario, which shows a median market share of 38% in 2035. This increase in EV sales share leads to an increase in demand for electricity and results in a decrease in fossil fuel consumption in the transportation sector (see Figure 3.5). As with EV sales share, demand for electricity increases in the No IRA scenario, but increases even more in the IRA scenario. These changes are due to transportation-specific provisions in the IRA, such as the clean vehicle credit (13401), the commercial clean vehicle credit (13403), and the credit for previously owned clean vehicles (13402), among others, which incentivizes demand for EVs.

For the buildings sector, most emissions are associated with the generation of electricity consumed in buildings, but approximately a third of emissions are from direct fossil fuel combustion, primarily for space and water heating (see Figure 4.2). The modeling shows that the IRA results in buildings sector reductions through the decarbonization of the electricity consumed by the buildings sector, and also through incentives for energy efficiency and electrification—reducing total energy required for buildings and fossil fuel use. IRA provisions for improvements for existing homes (25C, 25D, and home rebate programs), new homes (45L), and commercial buildings (179D) along with the Greenhouse Gas Reduction Fund and Climate Pollution Reduction Grants all contribute to reduced sector emissions.

The industrial sector has three sources of CO_2 emissions: direct emissions from on-site combustion, indirect emissions from electricity used in the sector, and direct process emissions (not included in the industry results). The IRA scenario results show a substantial decrease in direct and indirect industry CO_2 emissions, and, consistent with results from the transportation and buildings sector results, reductions are primarily associated with the indirect emissions from the generation of electricity consumed by the industrial sector (see Figure 5.3). The results reflect IRA provisions that provide incentives for industrial energy efficiency, low- or zero-emitting electricity generation, and advanced manufacturing processes. Some of these include the extension of the advanced energy project credit (48C), the advanced manufacturing production credit (45X), and low-carbon materials funding.

In addition to the IRA and No IRA scenarios discussed above, this report includes cases that explore alternative assumptions for the following factors for a subset of models: IRA implementation, technology costs, fossil energy prices, and economic growth. The above results are for the IRA Moderate implementation scenarios; that is, results reflecting the central set of unharmonized assumptions reported by each model. Several models explored Optimistic and Pessimistic IRA implementation scenarios that vary the representation of IRA provisions (e.g., tax credit transferability penalties, domestic content bonus eligibility, and the uptake of demand side programs) as well as limitations on the build rates of renewables and CCS availability in the Pessimistic implementation scenario. Electricity sector CO_2 emissions in 2030 fall an additional 2.5 percentage points below 2005 levels in the Optimistic scenario and fall 3.3 fewer percentage points in the Pessimistic scenario relative to the IRA Moderate implementation scenario. The sensitivity scenarios analyzing only technology costs and deployment find larger impacts—relative to the moderate technology assumptions, power sector CO_2 emissions in 2030 fall an additional 7.2 percentage points below 2005 levels in the advanced technology scenario with low technology costs and fall 8.8 fewer percentage points below 2005 levels in the scenario with technology deployment constraints. Other sensitivities explored in this analysis include high and low energy prices and economic growth. High and low energy price scenarios can respectively decrease or increase power sector CO_2 emissions by amounts similar in magnitude to the IRA implementation sensitivity scenarios. The effects of sensitivity scenarios for economic growth on power sector CO_2 emissions are an order of magnitude smaller than the effects of the energy price sensitivities. With the caveat that fewer models are represented in sensitivity scenarios, these sensitivities show that minimizing deployment constraints and achieving low technology costs are key to greater power sector CO_2 emissions reductions.

Potential future analyses of the IRA can better address factors that are uncertain at this time—such as guidance on tax credit provisions that have yet to be finalized (e.g., clean hydrogen and advanced manufacturing production tax credits), the evolution of complementary federal, state and local policies, and the rate of technological improvement. New information, and improved economic tools such as more detailed sectoral models, can contribute to better understanding of the IRA impacts on the energy sector. Better harmonization across model inputs and assumptions along with more sensitivity testing can also reduce uncertainties and enhance our understanding of key drivers of emissions reductions. The provisions of the IRA are expected to make additional federal, state, and other climate policies and measures more cost effective. The exploration of results at regional and state levels can help inform such actions. Better understanding of the more detailed impacts of the IRA is likely going forward.

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