Accelerating Clean Energy Ambition

How the United States Can Meet Its Climate Goals While Delivering Public Health and Economic Benefits

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Introduction

Human-caused climate change inflicts immense suffering on people around the world, harms critical ecosystems, and imposes enormous costs on families and local and national economies (IPCC 2023a; NOAA 2023; WMO 2023). The latest science from the Intergovernmental Panel on Climate Change (IPCC) shows that these impacts will worsen at an accelerating rate as temperatures rise (IPCC 2023b). The primary underlying cause is indisputable and clear: heat-trapping emissions from burning fossil fuels for energy. And beyond the climate impacts, the full lifecycle of fossil fuels—exploration, extraction, processing, storage, transportation, combustion, and waste disposal—imposes further significant harm and cost to public health and the environment, with communities of color and low-income communities often bearing the burden disproportionately (Cushing et al. 2023; Gonzalez et al. 2023; Liu et al. 2021). Taking all this together, the case for phasing out fossil fuels rapidly and transitioning to a clean energy economy is both compelling and urgent (Donaghy et al. 2023, Lelieveld et al. 2019).[1]

The case is made even stronger now that policies, innovation, and increased deployment have significantly lowered the costs of many clean energy technologies, including wind and solar power, battery storage, and electric vehicles. These technologies are competitive with legacy fossil fuels based on market costs alone—and that does not even consider the enormous public health externalities that traditional cost measures overwhelmingly ignore (BNEF 2023; IRENA 2023).

The Inflation Reduction Act (IRA) and the Infrastructure Investment and Jobs Act (IIJA), in particular, provide historic levels of funding for clean energy and investments in the nation's transportation infrastructure (Inflation Reduction Act 2022; Infrastructure Investment and Jobs Act 2021; Bradbury et al. 2023). Another positive factor is the decline in US coal use, although the simultaneous growth in producing and using fossil gas and oil poses a serious risk to meeting goals for reducing emissions.

The Union of Concerned Scientists (UCS) undertook a modeling analysis of technical pathways for achieving sharp cuts in economywide, energy-related, heat-trapping emissions in the United States. We optimized the analysis for the lowest energy-system costs to better understand both the challenges and the opportunities that would arise when taking an expansive, interconnected view of energy, the economy, and society. Our analysis shows that the United States has viable pathways to get to net-zero heat-trapping emissions no later than 2050. And the nation can do so in ways that yield significant economic and public health benefits.[2]

However, the UCS analysis also shows that meeting the nation's 2030 goals—a 50 to 52 percent cut in emissions below 2005 levels—will require concerted, rapid action (UNFCCC 2021). Despite important progress secured through the Inflation Reduction Act and other state and federal policies, the United States will fall short of meeting its 2030 goals in the absence of additional robust policies and investments, a finding that matches the conclusions of other recent studies (Ennis and Levin 2023; King et al. 2023). Our analysis also shines a light on less-explored opportunities that could have considerable potential: actions to help meet climate goals by significantly reducing overall energy demand below conventional projections.

As the leading contributor to historical heat-trapping emissions, the United States, alongside other major emitting nations, has a critical role to play toward meeting global goals to cut emissions in line with the latest science (UCS 2023). The goals of the 2015 Paris Agreement require collectively staying within a tightly constrained "carbon budget," the cumulative amount of remaining allowable global heat-trapping emissions. These goals align with limiting the increase in the global average temperature to well below 2°C and aim for 1.5°C relative to preindustrial levels. Delaying emissions cuts, including failing to meet near-term targets, heightens the risk of breaching the carbon budget and worsening climate change. Recent scientific assessments make it clear: without decisive action within this decade to accelerate US and global ambition, the Paris Agreement temperature goals could slip from our grasp (IPCC 2022c; IEA 2023a).

Model results can be an important tool for understanding the pace and scale of required sectoral changes, but they do not determine what the future will be. Nor do they inform some important realities about what transformative shifts mean for people and communities, especially from the perspective of environmental justice. In this respect, our analysis builds A Transformative Climate Action Framework: Putting People at the Center of Our Nation's Clean Energy Transition (Baek et al. 2021). The core principles of that report from UCS and an expert advisory committee remain our north star, including its key insight: a just and fair clean energy transition requires a holistic, people-centered approach that goes well beyond technological shifts narrowly focused on cutting carbon emissions. The broader approach we advocate will help ensure that the considerable health, economic, and climate benefits of the transition to clean energy are widely and equitably shared.

In taking that approach, the perspectives of communities who have long been marginalized and overburdened with pollution are vital, as are the perspectives of workers and communities who have depended historically and economically on fossil fuels (Declet-Barreto and Rosenberg, 2022; Sheats et al. 2023; Stephens 2022; IAWG 2021). Policymakers must ensure that the clean energy transition does not perpetuate or exacerbate past inequities. Addressing these complex, interconnected challenges can unlock even more opportunities to achieve an energy system that centers on people's needs.

Alongside direct insights from our modeling analysis, we share a set of recommendations for what it will take to make a rapid clean energy transition in an equitable and just way, including policy and governance changes that will be needed to ensure that we cut heat-trapping emissions quickly while also addressing the root causes of the harms from fossil fuels.

This report shines a light on what is needed and possible. It also points to dead ends and dangerous distractions, as well as to genuinely hard issues that our society needs to wrestle with—in a just and equitable way—as we confront the climate challenge. Because the actions to date of policymakers have been grossly insufficient, and because fossil fuel companies have used their outsize power to delay and obstruct climate action, the nation is in a very difficult situation today and the road ahead will require balancing a range of interests and priorities. That balance should clearly favor those who are most marginalized and who have long been overburdened by fossil fuel pollution, not deep-pocketed and powerful fossil fuel interests.

Methodology: Modeling Emissions Reductions Pathways

UCS used two models developed by Evolved Energy Research to analyze changes to the US energy system that would enable the nation to meet not only science-informed goals for reducing emissions but also all our energy needs. The EnergyPATHWAYS model includes a detailed representation of energy use, technologies, and costs in the transportation, buildings, and industrial sectors. We paired this demand-side model with the Regional Investment and Operations model, which represents various supply-side options for producing, transporting, and storing electricity, fuels, and carbon dioxide (CO_2).[3] We also used the resulting changes in the scale and method of energy production and use from the two models to estimate reductions in major air pollutants (including sulfur dioxide, nitrogen oxides, and fine particulate matter). We then ran those estimates through the CO–Benefits Risk Assessment (COBRA) model of the US Environmental Protection Agency (EPA) to calculate public health impacts (EPA 2023a).

EMISSIONS REDUCTION TARGETS

We modeled national targets for reducing carbon emissions that align with meeting the US commitment in the Paris Agreement to reduce net heat-trapping emissions to at least 50 percent below 2005 levels by 2030 and to reach net-zero emissions no later than 2050. This translates to a cumulative US carbon dioxide equivalent (CO_2e) budget of 74 gigatons between 2021 and 2050.[4]

Our modeling framework captures energy-related CO_2 emissions, which represent approximately 80 percent of the nation's current overall heat-trapping emissions (EPA 2023b; EPA 2023c), along with some upstream methane emissions from the oil and gas industry. We estimated changes in non-CO_2 emissions (methane, nitrous oxide, and fluorinated gases from agriculture, forestry, industry, and land-use change) and CO_2 emissions from the land sink (soils and vegetation that absorb carbon dioxide naturally) outside the model, drawing on estimates from the literature. To calculate net heat-trapping emissions across the economy (Figure 1), we combined total CO_2 emissions from energy and industry with other heat-trapping emissions and subtracted CO_2 emissions absorbed by the US land sink.

The emission-reduction targets for these three categories are:

- **Energy and industrial carbon dioxide emissions:** Reductions of 47.5 percent below 2005 levels by 2030 and 100 percent by 2050;
- **Methane, nitrous oxide, and fluorinated gases:** Reductions of 32 percent below 2005 levels by 2030 and 41 percent by 2050 across the mix of gases;[5]
- **Land sink:** Holding CO_2 emissions absorbed by the US land sink constant at 2019 levels of 0.79 gigatons per year through 2050 (EPA 2021). We assume the land sink stays fixed at current levels, given the high level of uncertainty shown in recent studies around whether emissions absorbed by the US land sink will increase or decrease.[6]

MODELING SCENARIOS

UCS modeled two reference scenarios and two decarbonization scenarios for the trajectories of their future emissions:

Reference scenarios: These scenarios do not include a carbon budget.

- **Reference with IRA/IIJA**: This scenario includes the impacts of the IRA and IIJA, as well as other federal and state policies and regulations adopted as of September 2022. It serves as a baseline point of comparison with the deep decarbonization scenarios (Box 1).

- **Reference without IRA/IIJA**: This scenario, based on the Annual Energy Outlook 2022 of the US Energy Information Administration (EIA) reference case, reflects laws and regulations as of November 2021. It does not include the IRA or the IIJA, enabling the analysis to isolate the impact of these policies.

Decarbonization scenarios: These scenarios meet the overall carbon budget of 74 gigatons CO_2e between 2021 and 2050, but they make different assumptions about overall energy demand.[7]

- **Net Zero Pathway**: This scenario represents a least-cost mix of technologies and resources for meeting US climate targets and the EIA's projected demand for energy services under a limited set of technology and resource constraints.

- **Net Zero/Low Demand**: This scenario also meets US climate targets, but it balances implementation of technological changes to the energy system with ambitious but feasible changes to transportation, buildings, and industry that reduce demand for energy services below EIA projections.

LOWERING DEMAND TO ACHIEVE A MORE JUST, EQUITABLE, AND SUSTAINABLE CLEAN ENERGY TRANSITION

Our two Reference scenarios and the Net Zero Pathway scenario rely on the US Energy Information Administration's forecasts of energy demand (EIA 2022). In contrast, the Net Zero/Low Demand scenario highlights opportunities that are outside the energy system and could lower energy use significantly.

The Net Zero/Low Demand scenario challenges assumptions of a status quo demand for energy services and illustrates the carbon-reduction potential of nontechnological interventions. For example, interventions could include more support for transportation options, such as public transit and bike and pedestrian infrastructure; land-use policies that enable people to drive less; new high-efficiency, net-zero, and net energy-producing building designs; and a complete redesign of industrial processes to be low carbon.

The Net Zero/Low Demand scenario deviates from EIA projections across the board. While EIA projects continued per-capita increases in driving, we assume that driving decreases by 5 percent from today's levels by 2050. This amounts to reducing emissions by 20 percent compared with the EIA projection. A 50 percent increase in transit and intercity buses facilitates reduced driving. Additionally, we project a 35 percent increase in freight rail and a 10 percent reduction in flying and other goods movement. Outside of transportation, we assume a 10 percent reduction in energy service demand in buildings (for lighting, heating, cooling, cooking, and other services) and a 17 percent reduction across the industrial sector. These changes roughly reflect the impact of ambitious but feasible demand-reduction strategies.

We also examined an even more ambitious scenario: doubling each of those changes. This scenario is similar in ambition to those included in recent IPCC reports, sustainable development scenarios modeled by the International Energy Agency, and other studies

(Grubler et al. 2018; KeyBer and Lenzen 2021; IEA 2021; IEA 2022; IEA 2023a; IPCC 2022c; Nadel and Unger 2019).

Reducing demand for energy services will require explicit policies and investments, but it will result in more gradual, and thus more achievable, rates of buildout for wind, solar, transmission, storage, and other zero-carbon technologies to meet climate targets. This would reduce the need for minerals, land, and new infrastructure and lessen challenges in siting, permitting, the supply chain, and public acceptance.

LIMITATIONS AND OPPORTUNITIES FOR FUTURE RESEARCH

Our analysis does not yield precise forecasts. Rather, it makes sample projections—broadly directional insights that are indicative of a range of possible technical pathways for meeting climate targets. Other possible decarbonization pathways could optimize for more than meeting least-cost carbon targets. See the Technical Appendix and supplementary materials for details on our modeling scenarios, assumptions, and limitations, as well as the results of additional scenarios we considered that explore outcomes under different technology and resource assumptions and constraints.

Our analysis used an energy-modeling framework focused on the cost and performance of different energy technologies, resources, and related infrastructure that are needed to meet national and regional energy demand in different sectors of the economy. It also used a least-cost optimization framework to meet constraints such as emissions reduction targets and existing state and federal laws and regulatory requirements. While this framework yields useful insights at national and broader regional levels, it is not set up to focus on attributes that might be of core interest to specific communities. For example, while we could estimate public health and climate benefits at national and state levels, we could not specifically model changes to promote distributional equity by prioritizing those kinds of benefits for specific communities that have been historically overburdened. An important area for future research is to use a different modeling framework or couple ours with one suited to exploring localized inputs and outputs drawing from the specific variables of interest for communities.

BOX 1. Driving Investments in Clean Energy: The Inflation Reduction Act of 2022 and Infrastructure Investment and Jobs Act of 2021

UCS based our modeling largely on the Inflation Reduction Act, signed into law in August 2022, and specifically on its federal incentives to invest in energy efficiency, electrification, renewable energy, and other low-carbon technologies and fuels across all sectors of the US economy. If implemented effectively, the IRA could drive significant reductions in heat-trapping emissions and other pollutants (Bistline et al. 2023). The modeling also includes incentives from the Infrastructure Investment and Jobs Act, although these had a minimal impact on the results.

We based the incentives in our modeling on assumptions developed for recent IRA and IIJA analyses by the National Renewable Energy Laboratory (NREL) and the Rapid Energy Policy Evaluation & Analysis Toolkit (REPEAT) Project at Princeton University (Steinberg et al.2023; Jenkins et al. 2023):

- **Power Sector**: Production and investment tax credits for a wide range of renewable energy technologies, energy storage, new and existing nuclear plants, and carbon capture and storage (CCS) at coal and gas plants; incentives for constructing or modifying transmission lines; funding for rural electric coopératives to invest in clean energy and accelerate coal plant retirements.

- **Buildings sector**: Tax credits and incentives (including from the Greenhouse Gas Reduction Fund) to weatherize and insulate new and existing homes and multifamily buildings, increase the efficiency of commercial buildings, and propane boilers, furnaces, and water heaters with highly efficient electric heat pumps that can also provide cooling in the summer.

- **Transportation sector**: Incentives for purchasing new and used battery electric, plug-in hybrid, and fuel cell vehicles for light-duty, medium-duty, and heavy-duty applications.

- **Industrial sector**: Incentives for industrial energy-efficiency retrofits, implementing advanced industrial technology at energy-intensive facilities, and installing carbon capture, utilization, and storage (CCUS).

- **Cross-sector:** Tax credits and incentives for producing hydrogen, biofuels, sustainable aviation fuels, and other clean fuels, with all projects assumed to meet prevailing wage and apprenticeship requirements to unlock the full value of the incentives; partial bonus credits for domestic manufacturing and solar and other clean energy projects installed in energy communities (with coal, oil, or fas facilities or brownfield sites) and low-income communities; direct payment and transferability of tax credits.

- **Other incentives**, such as those to reduce methane and other non-CO_2 gases and invest in agriculture and forestry projects to enhance the land sink, were not modeled explicitly, but assumptions outside the model partially capture them. We also did not include incentives to increase domestic manufacturing from the 45X Advanced Manufacturing Production Credit and the 48C Qualified Advanced Energy Credit; these are already driving billions of dollars of clean energy investment in domestic supply chains and creating jobs for thousands of workers (US DOE 2023a; US DOE n.d.). Several other IRA incentives were also not included.

The IRA does include some harmful provisions. For example, it could expand the use of fossil fuels and generously subsidize applications of CCUS and carbon dioxide removal (CDR) technologies that may not align with climate or environmental justice goals.

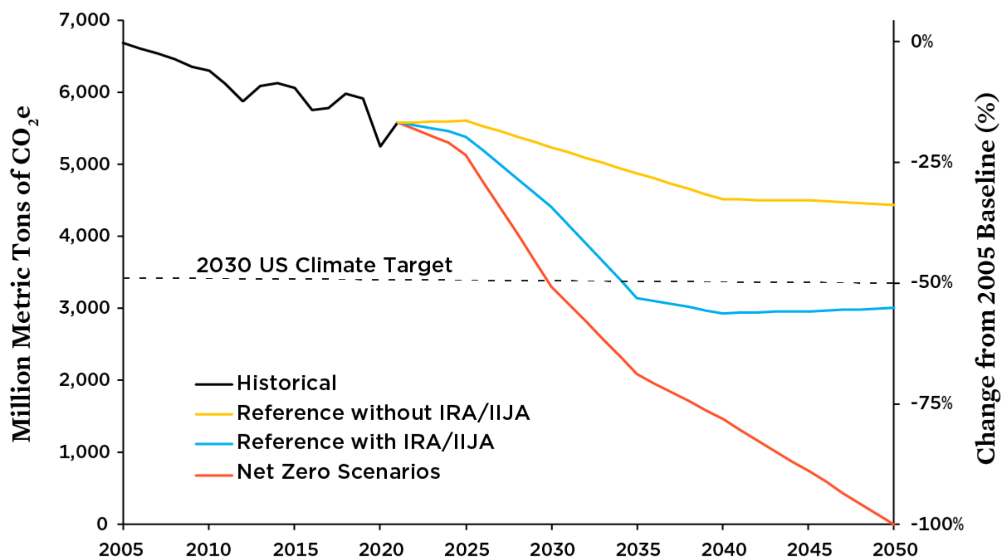
Modeling Results: Economy-Wide Benefits and Costs

Our findings show that the United States can meet its climate targets with near-term cost savings and modest long-term costs by rapidly phasing out fossil fuels and transitioning to clean energy. At the same time, the nation can gain significant economic, public health, and climate benefits. But time is running short.

THE UNITED STATES CAN MEET ITS SCIENCE-INFORMED CLIMATE TARGETS, BUT THE WINDOW IS CLOSING FAST

Our analysis shows that plausible pathways exist for the nation to meet both near-term and long-term climate targets, but doing so will require immediate action that significantly ramps up the deployment of clean energy technologies and related infrastructure. Effective implementation of existing federal and state policies would secure important progress, cutting economy-wide emissions to 34 percent below 2005 levels in 2030 and 53 percent by 2035 under the Reference case with the IRA/IIJA; this is significantly better than 22 percent in 2030 and 27 percent in 2035 without the IRA/IIJA (Figure 1). However, in neither Reference scenario does the United States meet 2030 goals. Moreover, any phaseout of IRA and IIJA incentives would cause emissions reductions to flatten out after 2035, a result consistent with other recent studies (Bistline et al. 2023).[8]

Figure 1. US Net Heat-Trapping Emissions



Effective implementation of the IRA, IIJA, and other existing policies cuts economy-wide emissions 34 percent below 2005 levels in 2030 and 53 percent by 2035. Under the Net Zero cases, we assume bolder action to drive emissions to net zero by 2050. This corresponds to a US carbon (CO_2e) budget—the cumulative amount of heat-trapping emissions, which is what matters for climate change—of 74 gigatons between 2021 and 2050. To achieve its climate targets, the United States needs additional policies and investments across all sectors to increase reductions to more than 5 percent per year.

Thus, additional policies and investments are needed across all sectors just to close the near-term gap of cutting emissions in half by 2030, let alone close the much larger long-term gap to reach net-zero emissions by 2050. The IRA more than doubles the current pace of annual emissions reductions to about 3 percent per year through 2030, but the United States will need to increase reductions to more than 5 percent per year to achieve its climate targets, as outlined in the Net Zero scenarios. The power sector provides most of the overall near-term reductions (two-thirds between 2021 and 2030) under the Net Zero cases. Transportation drives the greatest long-term reductions (35 percent in 2050), followed by the power sector (32 percent in 2050), industry (15 percent 2050), and buildings (12 percent in 2050).

RAPIDLY PHASING OUT FOSSIL FUELS IS KEY FOR MEETING US CLIMATE TARGETS

To reduce the speed and scale of climate change requires rapid, sharp reductions in heat-trapping emissions and fossil fuel use across every sector of the global economy—within this decade and beyond. Our analysis shows that the United States can make significant progress phasing out fossil fuels over the next decade and get most of the way there by 2050, while still meeting energy demand with a primary focus on deep, direct cuts in fossil fuel use.

Key findings for the Net Zero Pathway scenario:

- Overall fossil fuel use falls 50 percent between 2021 and 2040 and 82 percent by 2050.
- Coal is phased out of the power sector by 2030 and the rest of the economy by 2050.
- Oil falls 52 percent between 2021 and 2040 and 85 percent by 2050, with most of the reductions in the transportation and industrial sectors.
- Gas falls 31 percent between 2021 and 2040 and 72 percent by 2050, with reductions spread across the electricity, industrial, and building sectors.[9]

Our modeling finds that very little additional fossil fuel infrastructure is required. Moreover, existing fossil fuel technologies are rapidly rendered redundant. One clear implication is that the United States should sharply limit the building of any new, long-lived, fossil fuel infrastructure, which would likely become a stranded asset in a carbon-constrained world. Another implication is that policymakers must act quickly to ensure a fair, just transition for fossil fuel workers and communities as we move to a clean energy economy.

Beyond the climate-related benefits of phasing out fossil fuels are significant benefits in terms of public health and equity. Many coal- and gas-fired power plants are located in heavily populated areas and in communities suffering from multiple pollution burdens. Understanding and accounting for these health impacts is essential for prioritizing fossil fuel phaseouts and driving clean energy access in ways that directly benefit overburdened communities. Pollution from gasoline and diesel also imposes health burdens on people living near roads—disproportionately affecting people of color, reflecting decades of local, state and national decisions about transportation and land use. The extraction, refining, and transportation of oil and gas also generate air, soil, and water pollution.

TRANSITIONING TO CLEAN ENERGY YIELDS SIGNIFICANT ECONOMIC BENEFITS

The UCS analysis shows that the United States can phase out fossil fuels, transition to clean energy, and meet its climate targets at a modest cost, and even gain near-term savings, while significantly boosting the nation's economy. The IRA stimulates most of the near-term investment in clean energy and related infrastructure to decarbonize the US economy, driving more than 60 percent of the $1.6 trillion in cumulative capital investments between 2023 and 2035 under the IRA/IIJA reference case.[10] More than 80 percent of the investments are in wind, solar, energy storage, and electricity transmission. Under the Net Zero Pathway, these investments are similar over the near-term and much higher over the longer term, reaching nearly $1.8 trillion through 2035 and nearly $3.7 trillion through 2050. While not quantified in our analysis, other studies have shown that clean energy investments due to the IRA and to decarbonizing the US economy will create millions of new jobs, greatly exceeding job losses in the fossil fuel industry (Jenkins et al. 2023).[11]

Fossil fuel savings and IRA incentives offset energy system costs. Transitioning to clean energy also reduces fossil fuel expenditures. When combined with incentives from the IRA, these fossil fuel savings more than offset the additional cost of clean energy investments. The IRA/IIJA scenario results in nearly 3 percent lower energy expenditures: US households, businesses, and industry save nearly $89 billion in 2030 compared with the reference without the IRA/IIJA case; lasting annual savings continue through 2050 (Figure 2). The Net Zero Pathway also results in net savings of more than $101 billion in 2030, with annual savings continuing through 2040; this is largely due to IRA incentives and the increased adoption of more-efficient technologies that lower energy costs. After 2040, investment costs are slightly higher than fossil fuel savings, resulting in modest net energy system costs of nearly $46 billion in 2050. The results showing near-term net savings are consistent with other recent IRA studies (Bistline et al. 2023; Jenkins 2023; Larsen et al. 2022, US DOE 2023b).

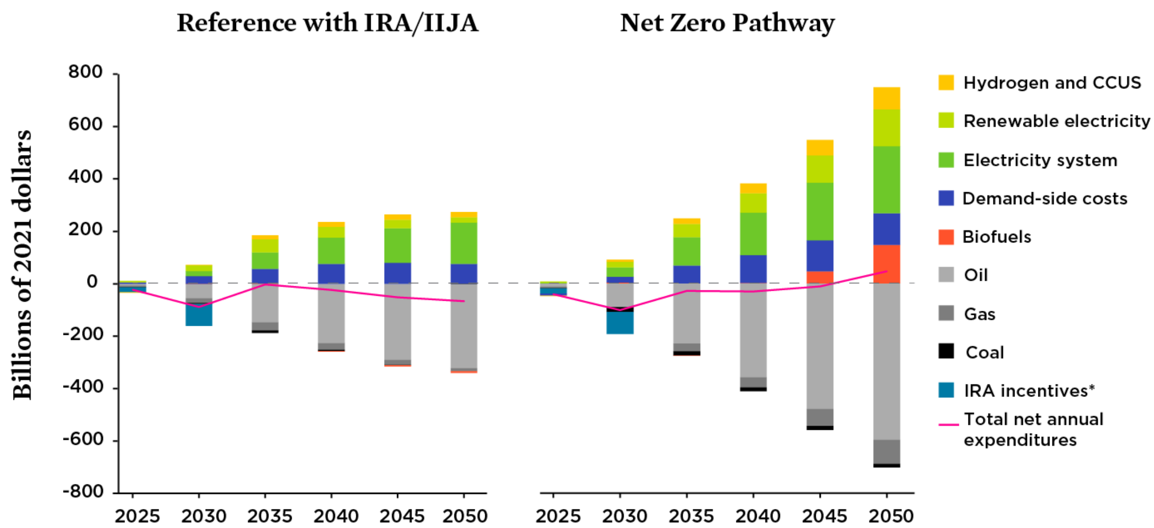
HEALTH AND CLIMATE BENEFITS FROM PHASING OUT FOSSIL FUELS EXCEED THE COSTS

Achieving rapid, deep reductions in fossil fuel use can provide important public health benefits by reducing harmful air pollutants. It can also yield significant economic benefits by reducing future damages from climate change.[14]

The Inflation Reduction Act saves lives and reduces health care costs. Implemented effectively, clean energy investments under the IRA will displace fossil fuel use and thus reduce key emissions of air pollutants, such as nitrogen oxides (NOx), sulfur dioxide (SO2), and fine particulate matter ($PM_{2.5}$) (Table 1). Just reducing emissions of fine particulate matter under the IRA could avoid thousands of premature deaths in 2035 and save hundreds of billions of dollars from avoided mortalities.

Fully realizing and equitably distributing these benefits will require careful attention to how the IRA is implemented. Thus far, the benefits of pollution reduction have not been equitably shared; communities of color and low-income communities have continued to bear a disproportionate burden of pollution even as the nation has seen an overall decline in many types of pollutants (Tessum et al. 2021).

Figure 2. Change in Annual US Energy Expenditures in Two Scenarios[12]



The Reference with IRA/IIJA and Net Zero Pathway scenarios reduce total net annual US energy expenditures (red line) for consumers through 2040 compared with the Reference without IRA/IIJA case; the Net Zero Pathway leads to slightly higher costs by 2050.

** IRA incentives = incentives for efficiency, electrification, and clean energy investments in buildings, industry, and transportation. IRA supply-side incentives for producing low- or zero-carbon electricity, fuels, and related infrastructure are accounted for in the supply-side costs (for hydrogen, CCUS, renewable electricity, electricity system, and biofuels).*[13]

Fully decarbonizing the economy results in even greater health benefits. Achieving the long-term climate targets results in even greater reductions in major air pollutants and more than twice as many avoided premature deaths and avoided health care costs. These additional benefits are due primarily to phasing out coal in the power sector by 2030 and significantly reducing oil and gas use between 2030 and 2050. These public health benefits yield additional near-term savings and exceed the long-term costs of decarbonizing the US economy.

The avoided costs of climate impacts significantly boost the overall benefits. Over the past five years, the United States has experienced 90 extreme weather and climate-related disasters, with damages exceeding $1 billion each time; climate change worsened many of these events. Together, the disasters have caused more than $620 billion in total damages and 1,750 deaths (NOAA 2023). Using the social cost of carbon, we estimated that the avoided climate damages from reducing CO_2 emissions to meet US climate goals will exceed $400 billion by 2035 under the IRA Reference case and nearly $1.3 trillion by 2050 under the Net Zero cases (EPA 2022).

Table 1. Health and Climate Benefits from Reducing US Air Pollution and Heat-Trapping Emissions

	IRA/IIJA Benefits		Net Zero Pathway		Net Zero/Low Demand	
	2035	2050	2035	2050	2035	2050
Air Pollutant Reductions vs. 2021 Levels						
SO_2	-59%	-40%	-87%	-89%	-87%	-90%
NOx	-50%	-44%	-63%	-76%	-64%	-77%
$PM_{2.5}$	-8%	-3%	-11%	-12%	-11%	-13%
Public Health Benefits						
Avoided damages (low estimate, billions of 2021 dollars)	$101	$138	$225	$368	$236	$383
Avoided damages (high estimate, billions of 2021 dollars)	$226	$310	$506	$826	$530	$861
Avoided mortalities (low estimate)	8,800	12,000	19,800	32,000	20,800	33,700
Avoided mortalities (high estimate)	19,800	27,000	44,800	73,000	46,800	75,900
Avoided Climate Damages, billions of 2021 dollars	$410	$420	$575	$1,275	$615	$1,275

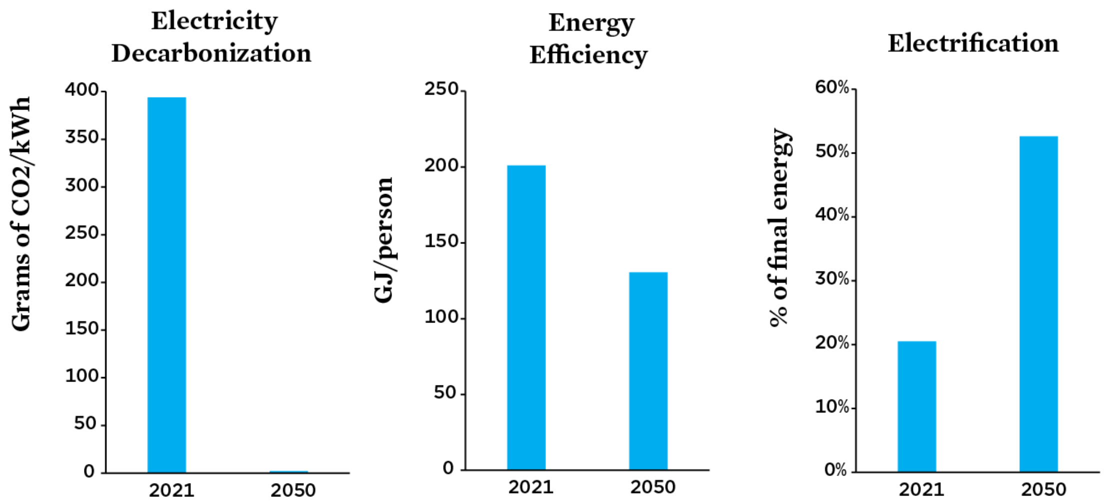
Effective implementation of the IRA/IIJA yields significant public health and climate benefits as clean energy replaces fossil fuels and reduces air pollutants and carbon emissions. Fully decarbonizing the economy more than doubles the benefits. The benefits for all cases represent the net impacts compared with the Reference without the IRA/IIJA scenario. Public health benefits include only those from reducing fine particulate matter from EPA's COBRA model, which provides a high and low range of the estimate for avoided mortalities.

Modeling Results: Decabonization Strategies

Our modeling offers detail on the key solutions needed for the United States to meet its emissions reduction targets, with three solution sets accounting for most of the reductions in energy-related emissions (Figure 3):

- Decarbonizing the power sector primarily with renewable energy;
- Replacing fossil fuels with clean electricity in the transportation, buildings, and industrial sectors; and
- Increasing energy efficiency and lowering overall energy demand in those sectors.

Figure 3. Three Key Solutions for Meeting US Climate Goals under the Net Zero Pathway



Three key solution sets account for almost all of the emissions reductions needed to meet US climate goals: decarbonizing the power sector, primarily with renewable energy; increasing energy efficiency and lowering overall energy demand in the transportation, buildings, and industrial sectors; and replacing fossil fuels with clean electricity in those sectors.

Many of these “no regrets” solutions are proven and commercially available today, can lower energy bills, and can readily be ramped up much further to achieve US climate targets. Transitioning to alternative, zero-carbon fuels in the transportation sector would be another important strategy for reducing emissions, but producing most of such fuels is at an earlier stage of development.

THE POWER SECTOR DRIVES THE GREATEST NEAR-TERM EMISSIONS REDUCTIONS

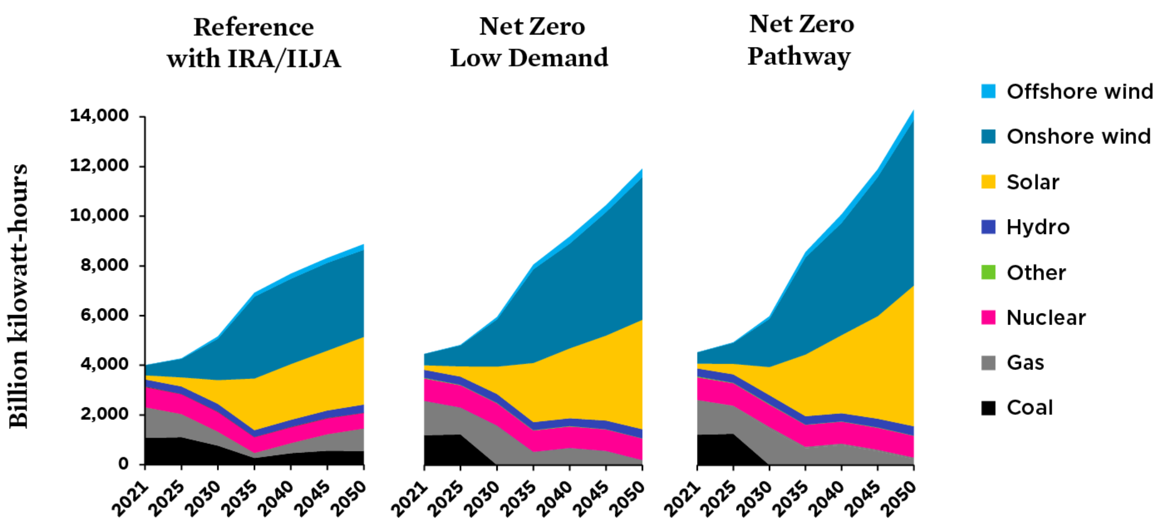
Our analysis shows that decarbonizing the power sector, primarily with wind and solar, is the most important near-term strategy for meeting US climate targets under both Net Zero cases and the IRA/IIJA Reference case. It is also critical for enabling longer-term initiatives that replace fossil fuels and reduce emissions in other sectors. Federal incentives from the IRA and IIJA, combined with existing state-level renewable and clean energy standards, are key drivers for deploying wind and solar and reducing emissions from coal and gas generation.

Key findings:

- ***Power-sector CO_2 emissions decline*** 70 percent between 2021 and 2030, and 86 percent by 2035 under the Net Zero Pathway, compared with 41 percent by 2030 and 80 percent by 2035 under the IRA/IIJA Reference case. These reductions occur even as total power generation rises sharply to meet electrification needs in other sectors.[15]

- ***Wind and solar replace coal and gas***. Wind, solar, and other renewables nearly triple, from 22 percent of US electricity generation in 2021 to 60 percent in 2030, 81 percent in 2035, and 92 percent in 2050 under the Net Zero Pathway (Figure 4). While coal and gas provide nearly 60 percent of US electricity generation today, the increase in renewable energy leads to a phaseout of coal by 2030; gas falls from nearly 40 percent of US electricity generation today to 25 percent in 2030 and 2 percent in 2050. Combining renewables with generation from existing nuclear plants and a small amount of gas with CCUS, the share of low- or zero-carbon generation increases to 76 percent by 2030, 92 percent by 2035, and 98 percent by 2050 under the Net Zero Pathway.

Figure 4. US Electricity Generation



Wind (blue) and solar (yellow) lead the way in decarbonizing the power sector to meet near-term climate targets. Decarbonization also plays a critical long-term role by replacing fossil fuels in other sectors.

- ***New clean energy infrastructure is needed.*** The steep rise in wind and solar requires new energy infrastructure across the country. Under the Net Zero Pathway, wind capacity triples and solar capacity quadruples by 2030 and increases by three to five times again between 2030 and 2050 to meet the emissions targets and growth in electricity demand. While most of this capacity is utility-scale solar and onshore wind, offshore wind and distributed solar capacity also increase significantly. To help integrate high levels of wind and solar and deliver power where it is needed, the capacity for energy storage increases to 148 GW by 2030 (almost a six-fold increase over 2021 levels) and 509 GW by 2050 (a 20-fold increase); US transmission capacity increases 36 percent by 2030, more than doubles by 2040, and quadruples by 2050 under the Net Zero Pathway. Lithium-ion batteries with durations of six hours or less provide most of the new storage capacity; however, a modest amount of new closedloop pumped storage hydropower capacity and other longer-duration storage are also added. No new conventional or advanced nuclear plants are built, being more expensive than other options.

- ***Lower electricity demand reduces the need for new power-sector infrastructure.*** Under the Net Zero/Low Demand case, the reduction in demand for energy in the buildings, industry, and transportation sectors results in a 15 percent reduction in electricity use by 2050 compared with the Net Zero Pathway. The reductions in electricity demand translate into similar reductions in electricity generation, resulting in less deployment of new wind (by 13 percent), solar (by 20 percent), storage (by 21 percent), transmission (by 15 percent), and gas with CCS capacity (reduced to almost zero).

- ***Gas power plants play a changed role in a decarbonized electricity system.*** Overall, gas capacity does not change much over time; some older gas and oil plants are replaced with more efficient plants during the near-term transition away from fossil fuels to wind and solar. However, use of that capacity dramatically declines over time. By 2050, gas plants operate at less than 6 percent of their rated capacity during the year as they help maintain reliability and integrate high levels of wind and solar over longer, seasonal timeframes.[16] The potential also exists for long-duration storage and other alternatives to play an increasing role in meeting these seasonal needs and to help address performance issues that gas plants have recently experienced during extreme weather events (Arbaje 2023a; Arbaje 2023b).

ELECTRIFICATION IS KEY FOR REDUCING FOSSIL FUEL USE IN OTHER SECTORS

Replacing fossil fuel use with clean electricity throughout the economy represents a major strategy for reducing carbon emissions and other pollutants and lowering overall energy costs. The IRA and current state policies recognize this by including incentives for people and businesses to purchase electric vehicles and replace inefficient gas, oil, and propane boilers, furnaces, and water heaters with highly efficient electric heat pumps, which can also provide cooling in the summer. Other opportunities use solar energy and increase electrification of industrial process heating in the iron and steel, pulp and paper, glass, aluminum, and petroleum-refining industries (Kirin et al. 2019; McMillan et al. 2021). Interconnecting energy use across sectors can optimize the use of renewables by matching flexible loads with clean energy supplies, such as with electrolyzers and dual-fuel electric boilers.

Key assumptions in the transportation and buildings sectors for the Net Zero scenarios:

- ***Electric vehicle (EV) sales grow rapidly***. We assume that 100 percent of sales of personal cars and trucks and medium- and heavy-duty trucks are battery electric and fuel cell vehicles by 2035. By 2040, EVs account for 75 percent of all vehicles on the road. By 2050, less than 2 percent of internal combustion engines in all types of vehicle are still on the road.

- ***Heat pump and electric cooking sales grow rapidly***. We assume growth in heat pumps based on recent trends and federal and state incentives, representing more than 60 percent of annual sales for new residential heating systems by 2030 and 85 percent by 2040 (up from 13 percent in 2021). Sales of heat pumps for water heating increase from

2 percent in 2021 to 35 percent by 2030 and 53 percent by 2040. The sales share of electric cooking increases from 63 percent in 2021 to 80 percent by 2030 and 100 percent by 2040, primarily replacing gas stoves. (This shift also results in better indoor air quality.)

Key findings:

- ***Electricity use grows*** 31 percent between 2021 and 2030 and more than triples by 2050 in the Net Zero Pathway. While most of this growth is due to increased electrification of transportation, buildings, and industry, producing "green hydrogen" through electrolysis meets a growing share of demand. Investments in energy efficiency offset some of this growth.

- ***Electricity use grows as a share of US energy demand for different fuels*** from 21 percent in 2021 to 53 percent in 2050 in the Net Zero Pathway compared with 38 percent in 2050 in the IRA/IIJA Reference case (Figure 3).

- ***Gas use in buildings falls*** 19 percent from 2021 levels by 2030 and 88 percent from 2021 levels by 2050. Oil use falls 20 percent by 2030 and 85 percent by 2050 in the Net Zero Pathway. Heat pumps replace gas, oil, and propane space and water heating systems; electric stoves replace gas stoves.

- ***Gasoline and diesel use in transportation falls*** 22 percent by 2030, 71 percent by 2040, and 86 percent by 2050 in the Net Zero/Low Demand case. EVs replace internal combustion engines, vehicle efficiency increases, and mobility expands and improves.

ENERGY EFFICIENCY LOWERS ENERGY COSTS AND SAVES FUEL

Energy efficiency reduces the use of and emissions from fossil fuels by providing the same level of service while using less energy, lowering energy costs, improving health and comfort, creating jobs, and reducing waste. Weatherizing homes and improving their efficiency can simultaneously lower energy needs and offer critical protection in the event of power outages from extreme weather events. Efficiency is also indispensable because it can greatly reduce the amount of new clean energy infrastructure (e.g., power plants, transmission lines) that would be needed to decarbonize the US economy. In addition to sectoral energy-efficiency measures, there are opportunities to lower the overall demand for services (e.g., heating, cooling, lighting, driving, mobility) below EIA projections; our Net Zero/Low Demand case explores these.

Key assumptions under the two Net Zero cases:

- ***New and existing buildings reduce energy use*** by increasing weatherization, insulation, and the installation of high-efficiency equipment for all new lighting and most new air conditioners, refrigerators, washers, dryers, and other appliances by 2030.

- ***Industry reduces the energy intensity*** of manufacturing products by 1.5 percent per year on average, representing a 50 percent improvement over historic levels.

- ***Efficiency is maximized for all vehicle types and travel modes.*** This is important for reducing oil use by and emissions from combustion vehicles in the near-term and managing increased demand for electricity in the longer term.

Key findings:

- ***Per capita energy use falls*** 35 percent between 2021 and 2050 under the Net Zero Pathway, 45 percent by 2050 under the Net Zero/Low Demand case, and 20 percent under the IRA Reference case (Figure 3).

- ***US energy demand declines*** nearly 22 percent between 2021 and 2050 under the Net Zero Pathway compared with 34 percent by 2050 under the Net Zero/Low Demand case and 4 percent by 2050 under the IRA Reference case.

PHASING OUT PETROLEUM BY TRANSFORMING TRANSPORTATION

Petroleum, primarily used to produce gasoline, diesel, and jet fuel for transportation, is the nation's largest source of global warming emissions. Petroleum fuels have supplied more than 90 percent of transportation energy since the 1950s, but the rapid increase in EVs makes it possible for renewable electricity to replace petroleum as the primary source of transportation energy over the next several decades.

Four key strategies enable petroleum phaseout in the transportation sector:

- Reducing demand for driving through improved transit and other mobility options;

- Rapidly deploying EVs;

- Improving vehicle efficiency; and

- Replacing remaining liquid fuels with low-carbon alternatives.

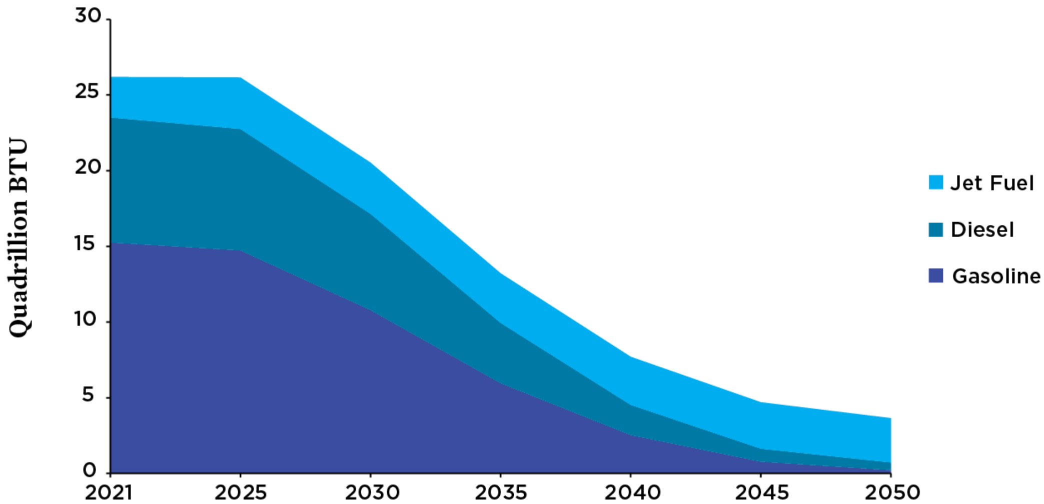
Key results for the Net Zero/Low Demand case:

- ***Electrification and other strategies reduce liquid-fuel use in transportation*** by 22 percent by 2030, 71 percent by 2040, and 86 percent by 2050. By 2050, the remaining liquid fuels are used mostly to produce jet fuel, which accounts for 80 percent of remaining liquid fuels used for transportation (Figure 5).

- ***By 2050, 85 percent of the remaining liquid fuels come from biofuels***; biofuel production is also an important source of CO_2 captured for sequestration or reuse. Synthetic fuels produced from hydrogen and captured CO_2 account for 10 percent of liquid fuels; petroleum makes up the remaining 5 percent.

- The Net Zero Pathway assumes no change in projected demand for various transportation options (e.g., driving, flying), making the 2050 consumption of liquid fuel for transportation 16 percent higher than in the Net Zero/Low Demand case (Figure 5).

Figure 5. Use of Liquid Fuels for Transportation, Net Zero/Low Demand Scenario



Overall demand for liquid transportation fuels falls 86 percent by 2050 under the Net Zero Pathway/Low Demand scenario.

DEEP, RAPID EMISSIONS REDUCTIONS INVOLVE TECHNOLOGIES WITH SIGNIFICANT TRADEOFFS

While renewable energy, efficiency, and electrification are cost-effective solutions and can get the United States most of the way to meeting our climate goals, some of today's polluting processes and technologies cannot at this time be fully replaced with these core clean energy strategies. For example, it is extremely challenging or infeasible to use direct electrification to fully replace fuels for long-distance air travel, steelmaking, cement manufacturing, and producing fertilizer. To meet these needs and address their emissions, the UCS modeling shows the need for a relatively limited deployment of technologies (e.g., biofuels/bioenergy, hydrogen, CCUS) that involve significant environmental and societal risks and tradeoffs. Many of these technologies are at an early stage of development and yet to be deployed at scale, so their future costs are highly uncertain.

Even the renewable energy supply chain, from materials sourcing to eventual recycling and disposal, can create social, environmental, and human rights challenges (Dunn 2023; Dunn, Kendall, and Slattery 2022 ; Hoffs 2022). This underscores the importance of looking beyond carbon emissions to evaluate any form of energy carefully based on its overall environmental, public health, and social impacts.

We highlight three technologies the modeling calls upon to meet energy needs and carbon-reduction requirements: biofuels/bioenergy; CCUS; and hydrogen. Each presents multiple questions and concerns related to broader, non-carbon impacts. As innovation in clean energy accelerates, other superior approaches may—indeed, likely will—compete with these technologies; however, our modeling highlights where and how these technologies may be deployed and how to focus research and policy agendas accordingly.

The modeling shows that lowering energy demand reduces the need for biomass to produce biofuels/bioenergy, CCUS, hydrogen, and related hydrogen and CO_2 pipeline and storage infrastructure. Under the Net Zero/Low Demand scenario, biomass use is 14 percent lower by 2050, CCUS is 20 percent lower, and hydrogen is 16 percent lower than the Net Zero Pathway.

BIOFUELS/BIOENERGY

Biofuels play a small but important role in both Net Zero scenarios, providing liquid transportation fuels and carbon for sequestration or reuse. By 2050 total use of liquid transportation fuel falls dramatically, to just 14 percent of 2021 demand; what remains is needed mostly for jet fuel. Our analysis shows that biofuels can meet 80 percent of this remaining demand for liquid fuel. Biofuel pathways are also important as a source of carbon dioxide for CCUS, with biofuel pathways providing almost half of the CO_2 captured for sequestration or reuse in 2050.

However, the limited availability of sustainable biomass constrains biofuel pathways. Excessive consumption of crops or other resources for biofuels can create problems in food markets and increase cropland at the expense of other ecosystems. Thus, limits on the scale of biofuel production and other safeguards are essential.

Biomass plays a much smaller role in the power sector, with generation declining 32 percent by 2035 and nearly 60 percent by 2050. Existing facilities are retired and cannot compete economically with the falling costs of wind and solar. Biomass share of total US electricity generation falls to 0.06 percent by 2050. This also reduces air pollution and water use in local communities.

CARBON CAPTURE, UTILIZATION, AND STORAGE

CCUS represents nearly 16 percent of economy-wide emissions reductions by 2050 under the Net Zero Pathway. More than 180 MMT of CO_2 are captured annually in 2030 and 730 MMT in 2050. More than 60 percent of this captured CO_2 is sequestered in geologic formations; the remainder is used for producing synthetic liquid fuels. In addition to CO_2 captured as a biproduct of biofuel production, 20 percent comes from the cement, steel, and chemical industries and 30 percent from fossil fuel-based hydrogen production. Virtually no direct air capture is deployed in the model, despite its being eligible for significant incentives in the IRA and IIJA, because it is more expensive than the alternatives.

While CCUS plays a significant role in reducing emissions in hard-to-decarbonize industrial sectors, it is not needed to decarbonize the power sector. The model builds a small amount of gas with CCUS in the power sector (10 GW by 2030) in the Net Zero Pathway, primarily to meet the 2030 target for reducing emissions. However, it does not build CCUS in the power sector in the IRA Reference case or Net Zero/Low Demand case. Studies before the passage of the IRA and IIJA showed that CCUS is not needed to decarbonize the power sector and that it is more expensive than other options (Baek et al. 2022; EER 2022; Larson et al. 2020).

HYDROGEN GROWS RAPIDLY TO PRIMARILY REPLACE OIL AND GAS IN INDUSTRY AND TRANSPORTATION

The production and use of hydrogen grow rapidly, nearly doubling between 2021 and 2030, more than tripling by 2035, and increasing more than ninefold by 2050 under the Net Zero Pathway. While almost all hydrogen produced today is from methane reforming of fossil gas without CCUS, which is carbon emission-intensive, the model rapidly transitions to lower-carbon methods of producing hydrogen, either via electrolysis or reforming of fossil gas coupled with CCUS. In part, this reflects the impact of large new tax credits from the IRA subsidizing CCUS. Electrolytically produced "green hydrogen" represents nearly 50 percent of the total hydrogen supply in 2035 and 70 percent by 2050. This low-carbon hydrogen replaces gas in industrial applications, including those required in high-heat processes, producing synthetic liquid transportation fuels, directly powering transportation, and producing ammonia for subsequent use.

Hydrogen produced via renewably powered electrolysis is vastly preferable to fossil fuel-based production coupled with CCUS. It avoids the harms and risks inherent in fossil fuel-based systems, including extracting, processing, and transporting those fuels, as well as the harms and risks inherent in CCUS. Still, electrolysis is energy intensive, so rigorous production standards should govern its near-term ramp-up to avoid diverting clean energy that would be better used for directly displacing fossil fuels in the energy system. To reflect the limits of fossil-based approaches to producing hydrogen, we also tested supplemental scenarios focused on electrolytic hydrogen production processes (see the technical appendix for details).

Critically, even if the process to produce hydrogen is clean, burning hydrogen can produce NOx emissions. Thus, direct electrification, such as for cooking and building heating and for vehicles (including those powered by hydrogen fuel cells), can deliver public health gains that hydrogen combustion cannot.

Recommendations

Achieving deep, economywide reductions in heat-trapping emissions, alongside equally ambitious cuts in other pollutants that harm public health and drive environmental injustices, will require transformative changes in policies, investments, and institutions within this decade and beyond. We must seize important opportunities for progress enabled by current policies and enact new policies, all with a focus on ensuring that the new clean energy economy does not replicate past inequities or create new ones.

Meanwhile, we must keep in mind that any delay in robust action will only make the task of meeting climate goals much harder and more expensive. Moreover, delay could force an increased reliance on riskier technologies and foreclose some choices. And, quite simply, delay will have profound implications for the severity of climate impacts experienced by current and future generations.

As policymakers design and implement strategies to drive down emissions, they can draw on insights from our modeling as well as from a broader consideration of the enabling conditions for a rapid, fair clean energy transition. Our recommendations are broad in scope, going beyond insights emerging directly from the modeling. Future research is needed to expand on these recommendations in a more granular, more actionable way, including addressing issues related to equity in governance and implementation.

SCIENCE-BASED GOALS FOR REDUCING ALL HEAT-TRAPPING EMISSIONS, INFORMED BY CONSIDERATIONS OF EQUITY[17]

Globally, the scale and pace of reductions in nations' heat-trapping emissions must align with what the latest science shows is necessary to stay within the remaining global carbon budget, which would limit the increase in global average temperatures to well below 2° C above preindustrial levels and as close to 1.5° C as possible. Nationally, climate-aligned goals for reducing emissions must cover all global warming emissions—including those of CO_2, methane, nitrous oxide, and hydrofluorocarbons—with the goals reviewed and updated on a regular basis.

For the United States, we must meet our international commitment of a 50 to 52 percent reduction below 2005 levels by 2030 and achieve net-zero emissions no later than 2050. That said, both equity and science provide strong rationales for the United States to move even more quickly than the global average to achieve net-zero emissions: the nation is not only the biggest source historically of heat-trapping emissions but also a leading producer and exporter of fossil fuels today (Berg et al. 2020; Calverley and Anderson 2022; Civil Society Equity Review 2022; UCS 2023).

AMBITIOUS, ROBUST POLICIES ACROSS EVERY SECTOR

As our analysis shows, a massive shift to clean energy, increased energy efficiency, electrification of energy end uses, and the infrastructure to enable these actions are the core solutions required to cut energy-sector emissions. In addition to ensuring strong implementation of the IRA, IIJA, and other federal and state policies, we need additional robust policies and investments to fully decarbonize all sectors. An ambitious suite of clean energy policies, tailored to specific contexts, should be aligned with targets for reducing emissions. Further, those policies should prioritize public health, environmental, and economic benefits for communities that have historically been marginalized and disadvantaged, and they should be accompanied by high-road labor standards and strong environmental standards.

PHASING OUT FOSSIL FUELS

US investments in clean energy will fall short of achieving our climate goals if we simultaneously keep expanding fossil fuel infrastructure, production, exports, and use. As the UCS analysis shows, there are no plausible scenarios for meeting US climate goals without deep reductions in fossil fuel use, including within this decade—a result that also holds true at the global level (IEA 2023a; IPCC 2022c; Trout et al. 2022). That is why we need near- and long-term plans and commitments, without loopholes, to phase out coal, oil, and fossil gas. Policymakers should reject the expansion of large, long-lived fossil fuel infrastructure that would run contrary to this goal, and instead move us toward comprehensive, systems-level planning for phasing out fossil fuels.

BROADER SOCIETAL SHIFTS DESIGNED TO REDUCE ENERGY DEMAND

Our analysis points toward an important strategy for meeting goals to reduce emissions: lower overall energy demand well beyond sectoral energy-efficiency measures. Our Net Zero/Low Demand scenario models these types of change, which could be achieved, for example, through investments in transit and other alternatives to driving, as well as by reducing energy demand in buildings and industry. Additional options that we did not model directly concern development patterns, diets, clothing, lifestyles, and other broader societal choices.

Scaling up such strategies—including by drawing lessons on sustainable choices from Indigenous, local and traditional knowledge, particularly ecological knowledge—also requires robust and intentional policies, incentives, and investments, as well as shared aspirations for what constitutes a thriving, healthy world (Charles and Cajete 2020; Keyßer and Lenzen 2021; UNESCO 2023). Together, such steps can help reduce pressure regarding the overall rate and scale of the buildout of renewable energy, making it more feasible to meet energy needs using renewable energy and more sustainable land-use practices.

INTENTIONAL ALIGNMENT OF CLIMATE, PUBLIC HEALTH, AND ENVIRONMENTAL AND WORKER JUSTICE GOALS

To align climate, public health, and environmental and worker justice goals, and to ensure the pairing of reductions in heat-trapping emissions with equally robust reductions in harmful co-pollutants in overburdened communities, climate policies must intentionally prioritize those communities for clean energy investments, the phaseout of fossil fuels, and mandatory emissions reductions (Sheats et al. 2023; Sheats 2017). Choices around technology, policy, and investment should be made with a view to reducing all harmful pollution, not just heat-trapping emissions. Simultaneously, investments in a just transition for fossil fuel-dependent workers and communities must be prioritized for communities that are most at risk of economic disruption (Colorado Department of Labor 2020).

INCORPORATE CLIMATE PROJECTIONS AND RESILIENCE MEASURES IN PLANNING AND BUILDING CLEAN ENERGY INFRASTRUCTURE

Climate change will profoundly impact our energy system, such as necessitating a need for greater energy services for cooling as temperatures increase and heatwaves worsen.[18] Meeting that growing need with clean energy, not fossil fuel-based energy, is crucial to avoid a spiral of increasing climate-warming emissions. In addition, climate-related extreme weather conditions such as intensifying drought and storms, as well as slow-moving disasters like rising sea levels, put energy infrastructure at increasing risk. Going forward, policies and standards must ensure that climate resilience measures are routinely included in plans to build, upgrade, and expand the energy infrastructure for a warming world.

INCLUSIVE AND FAIR GOVERNANCE AND DECISIONMAKING PROCESSES

Strong, fair institutions and governance can help ensure a rapid transition to clean energy with equitable benefits for all—especially those most marginalized and disadvantaged—and assertively dismantle the current stranglehold of the fossil fuel industry over energy policy. Bolstering existing bedrock laws like the National Environmental Policy Act, the Clean Air Act, and the Clean Water Act would help ensure that the White House Justice40 Initiative is effectively implemented and durably embedded in federal guidance (White House n.d.).

Further, it includes implementing new federal and state regulatory and governance frameworks that give directly affected communities meaningful access to and influence over decisionmaking.

Inclusive governance and decisionmaking are especially important for technologies (e.g., CCUS and CO_2 removal) that could have significant social and environmental impacts beyond their carbon implications, as well as for the siting and permitting of large clean energy projects. The oft-used frame of "tough tradeoffs" in assessing technological choices is not neutral within a socioeconomic and energy system built on inequities and environmental injustices, tilted toward pushing adverse outcomes onto communities and people who have long borne such burdens.

While energy modeling like ours cannot directly incorporate these issues, a deeper examination of how to navigate the tradeoffs fairly and transparently is an essential recommendation that emerges from this work. Decisionmakers must undertake sustained community engagement rooted in trust, sharing, transparency, and the right to self-determination for historically disenfranchised communities.

HOLDING FOSSIL FUEL COMPANIES ACCOUNTABLE FOR DECEPTION, DAMAGES, AND A ROBUST PLAN TO PHASE OUT FOSSIL FUELS

In many ways, the current energy system, by design, reinforces the power and profits of fossil fuel companies—and they have used that power to obstruct and delay the transition to clean energy. To meet our climate goals, public and private institutions must advance the phaseout of fossil fuels and accelerate the transition to clean energy. Regulations and policies must require fossil fuel companies to make steep near- and long-term emissions reductions and mandate they make climate-aligned purchasing and investment decisions. Fossil fuel companies must cease climate disinformation and greenwashing, and instead be held accountable for environmental and climate damages arising from past and ongoing pollution.

SETTING A HIGH BAR FOR INTEGRITY FOR THE LIMITED ROLE FOR CARBON MANAGEMENT

Given the delay in action to date, natural and technological methods for managing carbon will very likely have to play a role in meeting climate goals (IPCC 2022b; IPCC 2022c; IEA 2023a); indeed, the existing land sink is already making a crucial contribution. However, that role should remain bounded and targeted to addressing emissions from hard-to-decarbonize sectors, rather than a loophole for avoiding rapid, direct, and deep reductions in fossil fuel emissions (Ho 2023).

This is especially important if we are to limit the social, environmental, and other adverse impacts of different approaches to carbon management, as well as the significant harmful and inequitable impacts of prolonging dependence on fossil fuels (WEACT et al. 2023). Within the 2030 timeframe, in particular, approaches to carbon management cannot be scaled up to provide a meaningful contribution to emissions goals. It is critical to keep the focus squarely on clean energy solutions and sharply phasing down fossil fuels.

We must also make robust investments in protecting natural stores of carbon. These are increasingly under threat from human activities, even as our analysis and others show that they are crucial to meeting climate goals.

Conclusion

The UCS modeling shows the feasibility and tremendous promise of a rapid clean energy transition. The core solutions are phasing out fossil fuels and ramping up clean energy, energy efficiency, and electrification.

While the IRA and other recent legislation provide critical momentum toward those strategies, a wholesale transition to clean energy, and in the timeframes necessary to meet climate goals, remains a daunting challenge requiring additional policies. Real technical limits and other barriers must be overcome to ramp up clean energy and transform the nation's energy system at the rates needed to achieve our climate goals—especially within the remainder of this decade. Yet the continued expansion of fossil fuels actively undermines efforts to reach those goals. In that context, we must resist attempts by fossil fuel companies and others who increasingly, often misleadingly, invoke carbon management as a panacea, intentionally muddying the waters about the real but bounded role that such technologies should play.

We also recognize that a full assessment of the implications of transformative changes to the energy system requires looking beyond the confines of what our modeling can show. We must examine how these changes can happen in the real world and what they mean for people and communities. We must and can align climate action—including steep cuts in energy-sector emissions—with goals for public health, sustainable development, equity, and environmental justice (IPCC 2022c; IEA 2023b; Larson et al. 2021; NASEM 2021). But these synergies are not guaranteed; they will require intentional policies, adequate funding, and significant changes to current governance and decisionmaking processes.

Policymakers have the responsibility to follow through, with actions that put the United States firmly on the path to a better future—a future in which we build a healthy, thriving world, running on clean energy, free of the fossil fuel pollution that drives the twin crises of climate and environmental injustice. We need bold action—not only ambitious policies and transformative technological changes but also the will to take on entrenched political and economic interests. And as we fashion just, equitable solutions, we must think beyond carbon emissions, looking at all the ways in which our energy choices are woven into people's lives and livelihoods. Anything less will leave a gravely diminished world. With the future well-being of people, ecosystems, and the planet at stake, our choice is clear.

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ENDNOTES

1. Although the terms “clean energy” and “low- or zero-carbon energy” are sometimes used interchangeably, it is important to look beyond carbon emissions and carefully distinguish among different forms of energy based on their overall environmental, public health, and social impacts. Coal, oil, gas, and waste incineration are neither low-carbon nor clean energy sources. When used in a sustainable manner, appropriately sited renewable forms of energy generation—such as wind and solar—are the cleanest resources we have: they produce little to no heat-trapping emissions and no other air, water, and soil pollution, and they pose few environmental and social risks overall. In contrast, nuclear power and fossil fuel-fired generation with carbon capture and storage pose additional and significant environmental, public health, and social impacts. For other resources (e.g., bioenergy, hydropower), project design and levels of resource use matter: some applications will have high environmental and social impacts; others can meet stringent sustainability, public health, and environmental standards. Recognizing these differences is important for policymakers, communities, and other stakeholders as we make choices about cleaning up our energy system and strive to mitigate its remaining harmful impacts on people and the environment.

2. The IPCC defines achieving net-zero CO_2 emissions as the circumstance in which human-caused CO_2 emissions are balanced globally by human-caused CO_2 removals over a specified period (IPCC 2018). This scientific definition does not justify loopholes or delays to avoid direct, deep, rapid cuts in fossil fuel use to meet climate goals.

3. We used modified Evolved Energy Research models that had led to its Annual Decarbonization Perspective 2022 report (EER 2022). Projections of energy demand and fossil fuel prices for our Reference and Net Zero Pathways cases are based primarily on the Energy Information Administration’s Annual Energy Outlook 2022, while assumptions about electricity generation technology costs and performance come primarily from the National Renewable Energy Laboratory’s Annual Technology Baseline 2021 (NREL 2021). Our assumptions for implementing the Inflation Reduction Act are consistent with recent mid-case IRA analyses by NREL and the Princeton REPEAT project (Steinberg et al. 2023; Jenkins 2023).

4. Carbon dioxide equivalent is the amount of CO_2 emissions that would cause the same integrated radiative forcing or temperature change, over a given timespan, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs. CO_2-equivalent emissions is a common scale for comparing emissions of different GHGs, but it does not imply equivalence of the corresponding climate change responses (IPCC 2018). The carbon budget for our modeling analysis was developed to align with the current nationally determined contribution under the Paris Agreement. We do not mean to imply that this represents the nation’s fair-share contribution toward global climate goals or that this is an equitable US share of the rapidly dwindling global carbon budget. Numerous analyses of fair shares of global mitigation goals indicate that the United States must do more to contribute to these goals. Also, we use the term net zero in its scientific sense. This is not a loophole or offset to allow for continued business-as-usual fossil fuel emissions. Deep, absolute cuts in heat-trapping emissions must be the core of climate solutions.

5. This assumes the United States meets the global pledge to reduce methane emissions to 30 percent below 2005 levels by 2030 and achieves an 85 percent reduction in hydrofluorocarbons emissions as required by the 2020 American Innovation and Manufacturing Act and consistent with the Kigali Amendment to the Montreal Protocol. These reductions and reductions in nitrous oxide emissions are consistent with estimates from other studies (Abhyankar, Mohanty, and Phadke 2021; EDF 2021; EPA 2021; Fargione et al. 2018; Hultman et al. 2021; NASEM 2018; NRDC 2021; Larsen, Larsen, and Pitt 2020). Based on assumptions from the Princeton REPEAT project, our reference cases also capture some reductions in non-CO_2 emissions resulting from incentives and programs in the IRA and IIJA (Jenkins et al. 2023).

6. Some studies show that the land sink could be enhanced with additional policies and investments natural solutions like reforestation, afforestation, increasing soil carbon, and restoring wetlands, but other studies show that increases in wildfires, drought, and other factors could result in a significant reduction in the land sink or even turn it into a source (US State Department 2022; US State Department 2021; USGCRP 2018; Wu et al. 2023). Indeed, across all emissions scenarios considered, the Second State of the Carbon Cycle Report assessed that the North American land sink is likely to either “remain near current levels” or “decline significantly” (USGCRP 2018).

7. None of our energy demand cases include estimates for potential increases in energy services that will likely arise because of climate change—for example, the increased need for cooling services as temperatures increase and heatwaves worsen. This is an important limitation.

8. The uptake and impact of the IRA is uncertain. It relies on incentives to encourage investments in clean energy and reduce emissions rather than national requirements or standards to achieve certain emissions or clean energy outcomes (although many states do include these requirements and standards). Thus, studies analyzing the IRA show a range of impacts depending on their assumptions about how consumers and businesses will respond to these incentives. We believe our analysis represents a mid-case based primarily on assumptions from recent IRA analyses by the Princeton REPEAT project (Jenkins et al. 2023) and NREL (2023) and a meta study by Bistline et al. 2023.

9. Under the Net Zero/Low Demand case, total fossil fuel use falls 85 percent between 2021 and 2050, coal use is completely phased out, oil use falls 86 percent, and gas use falls 77 percent.

10. Cumulative investment values represent the net present value of annual costs discounted to 2021 dollars using a 2.5 percent social discount rate.

11. For example, a recent analysis by the Princeton REPEAT project indicates that the IRA could create 1.4 to 1.7 million new jobs by 2030 and 2.2 to 2.9 million jobs by 2035, accompanied by a decline of 50,000 to 70,000 fossil fuel jobs by 2030 (Jenkins et al. 2023). Previous studies by Princeton show that meeting US climate targets would result in significantly more jobs through 2050 (Larson et al. 2021).

12. We do not include results for the Net Zero/Low Demand case because the model does not include an accurate representation of the costs associated with reductions in energy service demand.

13. The impact of the IRA incentives in reducing US energy expenditures will reduce tax revenues to the US Treasury. However, public health benefits and avoided climate damages would far outweigh the costs to taxpayers. New jobs, income, and tax revenues created by investments in clean energy, low-carbon technologies, and related infrastructure would also result in additional benefits not captured in this analysis.

14. Evolved Energy Research used the changes in energy production and use from their energy models to estimate reductions in criteria pollutants, which are run through the EPA's COBRA model to calculate public health benefits, such as the dollar value of avoided damages and reductions in premature deaths, asthma attacks, hospital visits, lost work days, and other metrics. COBRA only captures some of these benefits, which are due primarily to reductions in fine particulate matter.

15. Clean energy tax credits and incentives in the IRA start phasing out when electricity sector CO_2 emissions decline 75 percent below 2022 levels. This threshold is reached between 2030 and 2035 under the IRA/IIJA Reference and Net Zero cases, with the IRA driving a large share of near-term reductions.

16. For comparison, the average capacity factor for all US gas plants was 38.4 percent in 2022 and 56.7 percent for gas combined cycle plants (EIA n.d.).

17. Our discussions of global equity focus on the international commitments of the United States toward equity between nations, as defined under the UN Framework Convention on Climate Change and the Paris Agreement. Principles of equity and justice that are equally important and complementary apply at the subnational level. They relate to addressing environmental justice concerns and the concerns of historically marginalized and disadvantaged communities domestically, and they align closely with concerns of frontline communities in the Global South.

18. Our modeling did not incorporate estimates for increased energy services due to changing climatic conditions. Nor did we estimate the costs of climate resilience measures for energy infrastructure.

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