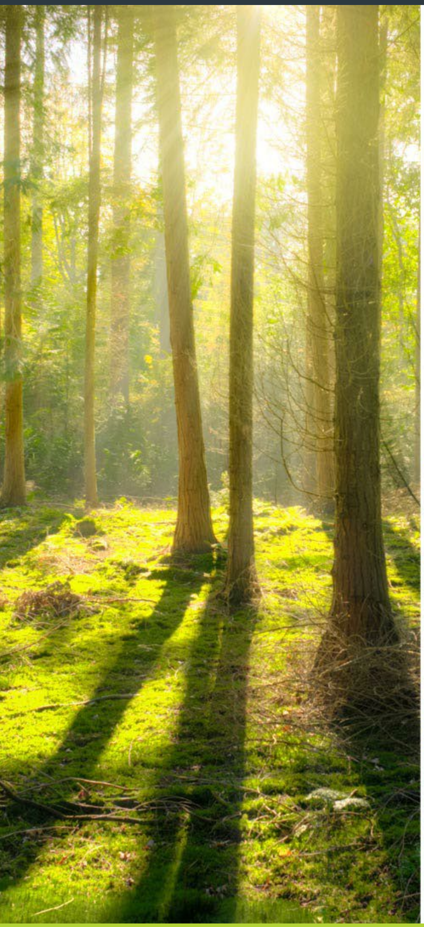
CJP CLIMATE JUDICIARY PROJECT™

CLIMATE SCIENCE AND LAW FOR JUDGES

Solving the Climate Change Problem

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ENVIRONMENTAL LAW INSTITUTE

CJP CLIMATE JUDICIARY PROJECT™

Solving the Climate Change Problem

by Climate Judiciary Project Team[1]

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[1] This module is based largely on the research and findings from the National Academies of Sciences, Engineering, and Medicine (NAS) consensus study report on decarbonization, *infra* note 3, which underwent a rigorous and independent peer review. An update of this report, focused on analysis of existing gaps, is expected to be released in 2023. Discussions of the Inflation Reduction Act of 2022 are informed by reports from Princeton's REPEAT project, the Rhodium Group, and Energy Innovation. The authors would like to thank Prof. Stephen W. Pacala, Chair of the Committee on Accelerating Decarbonization in the United States of the NAS, for his advice and critical reading of this module.

I. Introduction

As described in the module on What Is Causing Climate Change?, the scientific evidence is indisputable that rising levels of greenhouse gases in the atmosphere are causing global temperatures to increase. The changing climate is already having severe, negative impacts around the world, and these impacts are growing and will continue to grow (see Impacts module). The world will need to achieve massive reductions in greenhouse gas emissions to avoid major disruptions to human life. Working toward this goal, an increasing number of countries, states, cities, and companies have set an unambiguous objective, resolving to reduce their net greenhouse gas emissions to zero by the year 2050.[2] This objective may seem ambitious, but the scientific community has ascertained that it is technologically feasible. According to the consensus report from the National Academies of Sciences, Engineering, and Medicine (NAS), reaching what is known as net-zero emissions (where remaining emissions of greenhouse gases into the atmosphere are balanced by an equivalent removal of atmospheric greenhouse gases) by the middle of the century has the potential to strengthen the U.S. economy and to make people healthier and more secure.[3] National Academies Consensus Reports are generally recognized as authoritative documents on a topic. They are prepared by leading experts, and "document the evidence-based consensus" subject "to a rigorous and independent peer-review process."[4] For more on the topic of consensus reports, see the How Climate Science Works module.

Pathways to net zero by 2050 have become much clearer over the past few years. Figure 1 shows one such pathway for the United States, drawn from the NAS report. This pathway relies on a linear reduction in carbon dioxide emissions, a less dramatic reduction of other greenhouse gas emissions, the capture of atmospheric carbon in regrowing forests, and the use of other processes to sequester carbon away from the atmosphere. If this pathway were replicated around the world—as discussed later in this module—global warming could be held to less than 2 degrees Celsius (°C) (3.6 degrees Fahrenheit (°F)), as called for by the Paris Agreement (see Box 1).[5]

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[2] *See* Eric Larson et al., Net-Zero America: Potential Pathways, Infrastructure, and Impacts (2021).

[3] Nat'l Acad. of Sci., Eng'g and Med., Accelerating Decarbonization of the U.S. Energy System 4 (2021), https://nap.nationalacademies.org/catalog/25932/accelerating-decarbonization-of-the-us-energy-system [hereinafter Accelerating Decarbonization of the U.S. Energy System] (noting that the committee's charge was to "assess the technological, policy, social, and behavioral dimensions to accelerate the decarbonization of the U.S. economy" and "focus its findings and recommendations on near- and midterm (5–20 years) high-value policy improvements and research investments."). A public briefing video of the report's findings is also available. *See* The Nat'l Acad., Accelerating Decarbonization of the U.S. Energy System – Public Briefing (Feb. 3, 2021), https://vimeo.com/507993412.

[4] *Id.* at iv.

[5] Conference of the Parties, Adoption of the Paris Agreement, Dec. 12, 2015 U.N. Doc. FCCC/CP/2015/L.9/Rev/1 (Dec. 12, 2015).

[6] IPCC, Global Warming of 1.5°C (2021), https://www.ipcc.ch/sr15/download/.

[7] David I. Armstrong McKay et al., *Exceeding 1.5°C Global Warming Could Trigger Multiple Climate Tipping Points*, 377 SCIENCE 1 (2022), https://doi.org/10.1126/science.abn7950.

Box 1. Limiting Warming to 1.5°C (2.7°F) Above Pre-Industrial Levels

Signatories of the Paris Agreement, including the United States, have committed to limiting warming to 2°C (3.6°F) above pre-industrial levels. However, to avoid severe climate impacts, governments around the world have called for a more ambitious target of limiting warming to 1.5°C (2.7°F). In a special 2018 report on the topic, the Intergovernmental Panel on Climate Change (IPCC) noted that this more modest temperature rise will reduce negative impacts on resources, ecosystems, biodiversity, food security, cities, tourism, and carbon removal.[6] For example, recent research shows that multiple tipping points in Earth's climate system, such as the collapse of ice sheets in west Antarctica and Greenland, may be reached even at warming of less than 2°C.[7] Ice-sheet collapse would accelerate sea-level rise, which would be devastating for low-lying coastal communities and infrastructure.

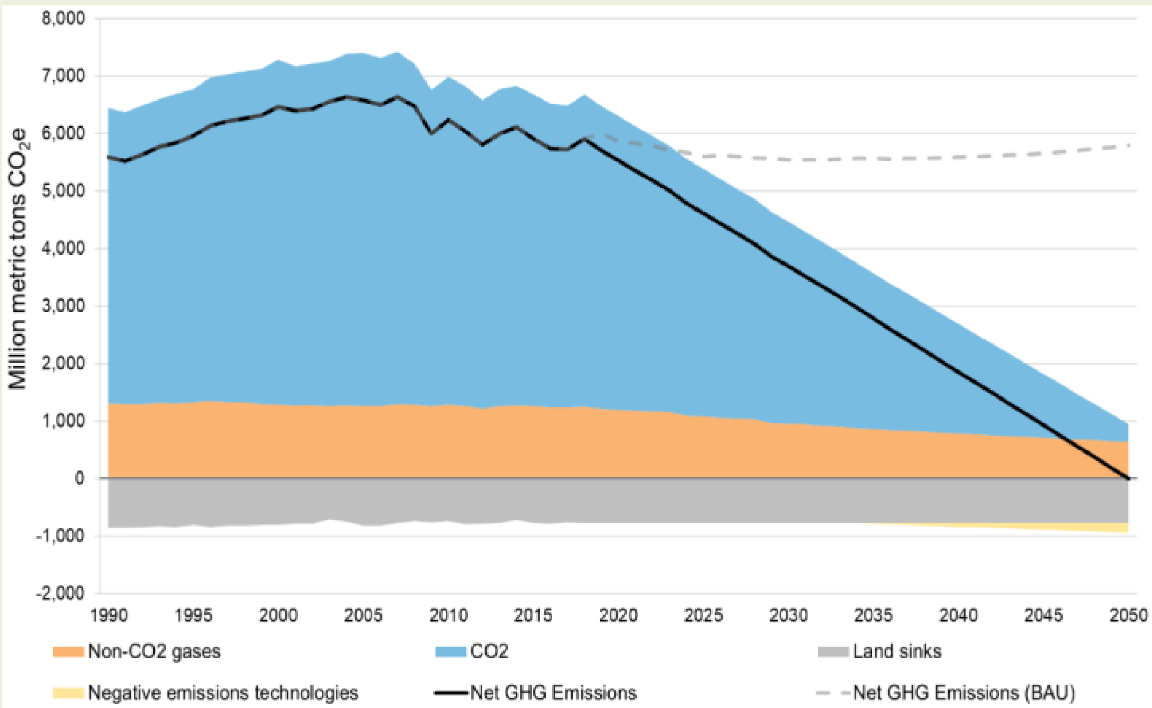

Figure 1. Net greenhouse gas emissions by the United States, shown by the solid line, could reach zero by 2050 if carbon dioxide emissions from fossil fuel combustion and other sources decline to 5% of 2005 levels while emissions of other greenhouse gases undergo a moderate reduction, leaving only residual emissions from hard-to-abate sectors. This is one of many possible pathways to net-zero emissions, and illustrates the key building blocks of a net-zero emissions economy: (1) deep reductions in carbon dioxide emissions, (2) moderate declines in non-carbon dioxide greenhouse gases, (3) maintenance or expansion of land carbon sinks, and (4) expansion of negative emissions technologies. Source: NAT'L ACAD. OF SCI., ENG'G AND MED., ACCELERATING DECARBONIZATION OF THE U.S. ENERGY SYSTEM 58 (2021).

In 2021, pursuant to the Paris Agreement, the U.S. Department of State released a long-term strategy for achieving net zero by 2050 that "will keep a 1.5° C limit on global temperature rise within reach and prevent unacceptable climate change impacts and risks."[8]

Further, three major pieces of U.S. legislation enacted in 2021-22—the Infrastructure Investment and Jobs Act, the CHIPS and Science Act, and the Inflation Reduction Act (IRA)—have the potential for achieving a substantial portion of what the United States needs to do to reach net-zero emissions. Through a combination of tax incentives, grant and loan programs, emissions fees, infrastructure construction, energy-efficiency requirements, regulatory reform, investments in energy and community justice, and agriculture and forestry programs, these three laws are projected to drive major progress toward decarbonizing the U.S. economy. These laws provide funds and incentives — but not guarantees of solutions. Solutions will come only if the incentives generate real solutions—that is, if they are implemented successfully

Going from an economy fueled largely by fossil fuels to net zero will require additional steps, including actions by government, industry, and the individual consumers of energy. Human ingenuity and creativity will be needed to develop the technologies, policies, and practices that will make net zero possible, and public support will be essential. Further, actions of even greater magnitude will be needed to limit global warming to 1.5°C (2.7°F) (see Box 1), a goal reaffirmed by the 2022 United Nations Framework Convention on Climate Change Conference of the Parties.[9] Still, it is now possible to envision a realistic way for humanity to cut its greenhouse gas emissions while continuing to prosper on this planet.

According to the NAS, achieving net zero by 2050 requires meeting five technological goals: invest in energy efficiency and productivity; electrify energy services in transportation, buildings, and industry; produce carbon-free electricity; plan, permit, and build critical infrastructure; expand the innovation toolkit.[10] The NAS report similarly describes socioeconomic goals of a strengthened U.S. economy that cost-effectively supports communities, businesses, and workers, while promoting equity and inclusion.[11] All are large and complex, but doable, according to the NAS.

II. Provide the Energy Services That People Demand

Most scientific studies accept the societal reality that solutions to the global warming problem will need to provide the energy services that people demand. People everywhere in the world do not want to lower their standards of living to reduce emissions of greenhouse gases. Countries want their economies to grow and the lives of their people to improve. Calls for sacrifice do not resonate with the legislators, regulators, executives, and consumers who need to take action to achieve net zero.

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[8] U.S. DEP'T OF STATE, THE LONG-TERM STRATEGY OF THE UNITED STATES: PATHWAYS TO NET-ZERO GREENHOUSE GAS EMISSIONS BY 2050 (2021), https://bidenwhitehouse.archives.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf

[9] FCCC/CP/2022/10/Add. 1, Report of the Conference of the Parties on Its Twenty-Seventh Session, Held in Sharm el-Sheikh From 6 to 20 November 2022 4 (2022), available at https://unfccc.int/event/cop-27#decisions_reports.

[10] ACCELERATING DECARBONIZATION OF THE U.S. ENERGY SYSTEM, *supra* note 3, at 7-9.

[11] *Id.* at 10-11.

Fortunately, major sacrifices are not necessary, as the IPCC have demonstrated.[12] People can continue to seek better lives while having access to the energy that they need to do so. Ensuring plentiful energy supplies without greenhouse gas pollution will require greater deployment of technologies that already exist, as well as the development and implementation of some new technologies. Both basic science and engineering will be needed to achieve the goal, but the steps that need to be taken between now and the year 2050 are known and scientifically straightforward.

III. Provide Zero-Emissions or Very-Low-Emissions Electricity for the Economy

To achieve net zero by 2050, zero-emissions or very-low-emissions electricity needs to be available for homes, industry, and transportation throughout the economy. Even a decade ago, this task would have seemed far-fetched. But decarbonizing the energy system has been radically transformed by a largely unheralded revolution in energy technologies.[13]

From 2010 to 2020, the cost of solar power declined by nearly 90%.[14] That means that the cost halved every three years. Over the same period, the cost of wind energy declined by more than 60% (68% for onshore wind),[15] and the cost of lithium-ion batteries that are critical for energy storage declined by over 85%.[16] As a result, solar and wind energy are now the cheapest forms of energy available to human societies. Despite supply chain disruptions, supply cost volatility had not resulted in measurable total cost increases as of 2023.[17] In 2010, decarbonizing the transportation system—to take one example—was a problem without a solution. A decade later, some car manufacturers were setting deadlines for when they would stop manufacturing gas-consuming automobiles because of the ready availability of ways to electrify the transportation system.[18]

Other forms of energy may also play roles as nations decarbonize their electrical systems. Advanced nuclear, advanced geothermal, and natural gas power plants and biopower plants with carbon dioxide capture and sequestration could all produce electricity without adding to carbon dioxide

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[12] *See generally* IPCC, CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE: CONTRIBUTION OF WORKING GROUP III TO THE SIXTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (2022), https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf [hereinafter WORKING GROUP III].
[13] *See generally* NAT'L ACAD. OF SCI., ENG'G AND MED., THE FUTURE OF ELECTRIC POWER IN THE UNITED STATES (2021), https://nap.nationalacademies.org/catalog/25968/the-future-of-electric-power-in-the-united-states.
[14] IRENA, RENEWABLE POWER GENERATION COSTS IN 2021 79 (2022), https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021.
[15] *Id.*
[16] DEP'T OF ENERGY, *FOTW #1272, January 9, 2023: Electric Vehicle Battery Pack Costs in 2022 Are Nearly 90% Lower Than in 2008, According to DOE Estimates* (Jan. 9, 2023), https://www.energy.gov/eere/vehicles/articles/fotw-1272-january-9-2023-electric-vehicle-battery-pack-costs-2022-are-nearly.
[17] IRENA, RENEWABLE POWER GENERATION, *supra* note 13, at 26.
[18] Jim Motavalli, *Every Automaker's EV Plans Through 2035 And Beyond* (updated Oct. 4, 2021), https://www.forbes.com/wheels/news/automaker-ev-plans/.

levels in the atmosphere. Innovative technologies could also lead to new sources of electricity, such as new forms of bioenergy or synthesized fuels used in advanced turbines.

The costs of an economywide transition to electricity are low when compared to the cost of the impacts driven by unabated climate change, as detailed in The Risks and Costs of Climate Change module. Through the 2020s, the NAS reports the estimated cost of the transition is $100 billion to $300 billion—a small fraction of the nation's projected gross domestic product (GDP) during the decade.[19] This cost is less than the savings in health care costs realized just by eliminating all emissions from the nation's coal-powered electricity plants. On purely economic grounds, the United States would benefit financially by making this transition even if climate were not a consideration.

Moreover, in the 30 years between 2020 and 2050, the United States would spend a smaller fraction of its GDP on energy while electrifying its economy to achieve net zero than it has over the 30 years from 1990 to 2020, as shown in Figure 2.

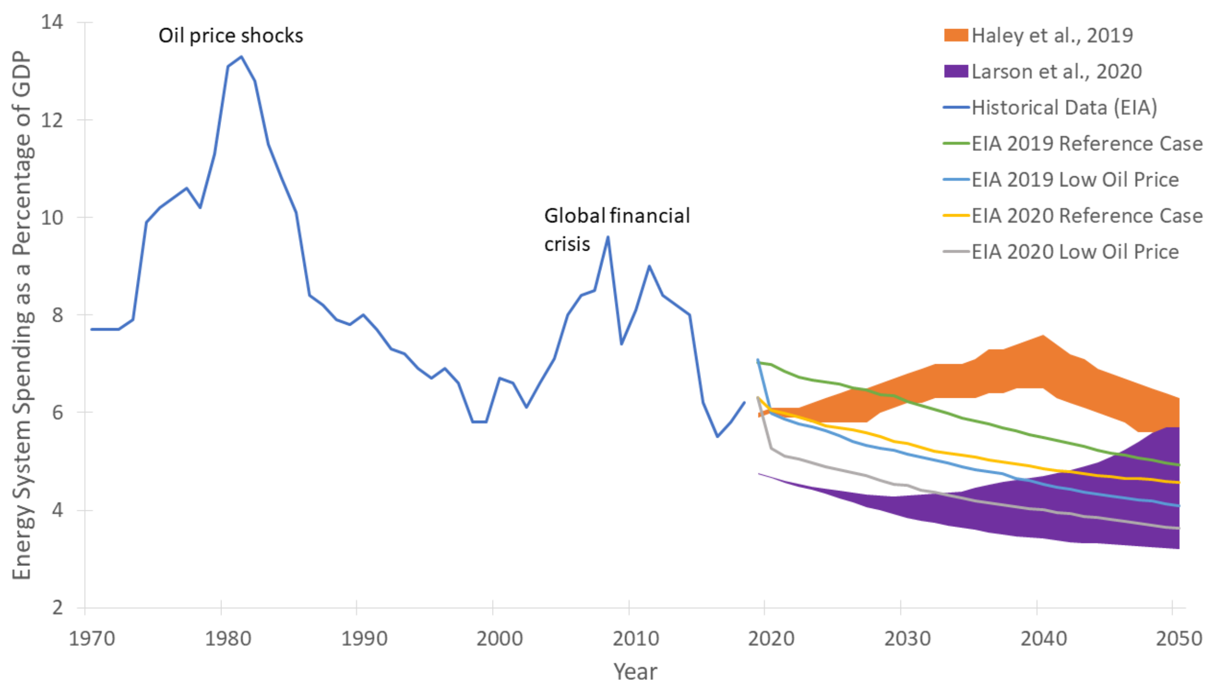

Figure 2. Historical energy system costs as a percentage of GDP, with representations of the ranges of projected energy system costs under two different net-zero studies (solid areas) and four Energy Information Administration (EIA) projections (lines), demonstrate that projected costs for achieving net-zero emissions from 2020 through 2050 are less than energy system spending from 1990 through 2020. Source: NAT'L ACAD. OF SCI., ENG'G & MED., ACCELERATING DECARBONIZATION OF THE U.S. ENERGY SYSTEM 61 (2021).

However, unconstrained market forces will not suffice, and according to the NAS report, government policies will be needed for the transition to occur by 2050. Congress' enactment of the

[19] Accelerating Decarbonization of the U.S. Energy System, *supra* note 3, at 82.

IRA, with incentives to encourage the development and adoption of renewable technologies, is one such policy. Again, governments could build on policies that have succeeded in the past.[20] For example, countries throughout the world have been subsidizing wind and solar technologies since the 1970s. These subsidies helped to create a market for wind and solar power well before the technologies would have been economically competitive otherwise. As technologies competed in the marketplace, innovation and economies of scale drove down prices. Subsidies and the free market worked together to create a technological portfolio that has made decarbonization possible (see Figure 3).[21]

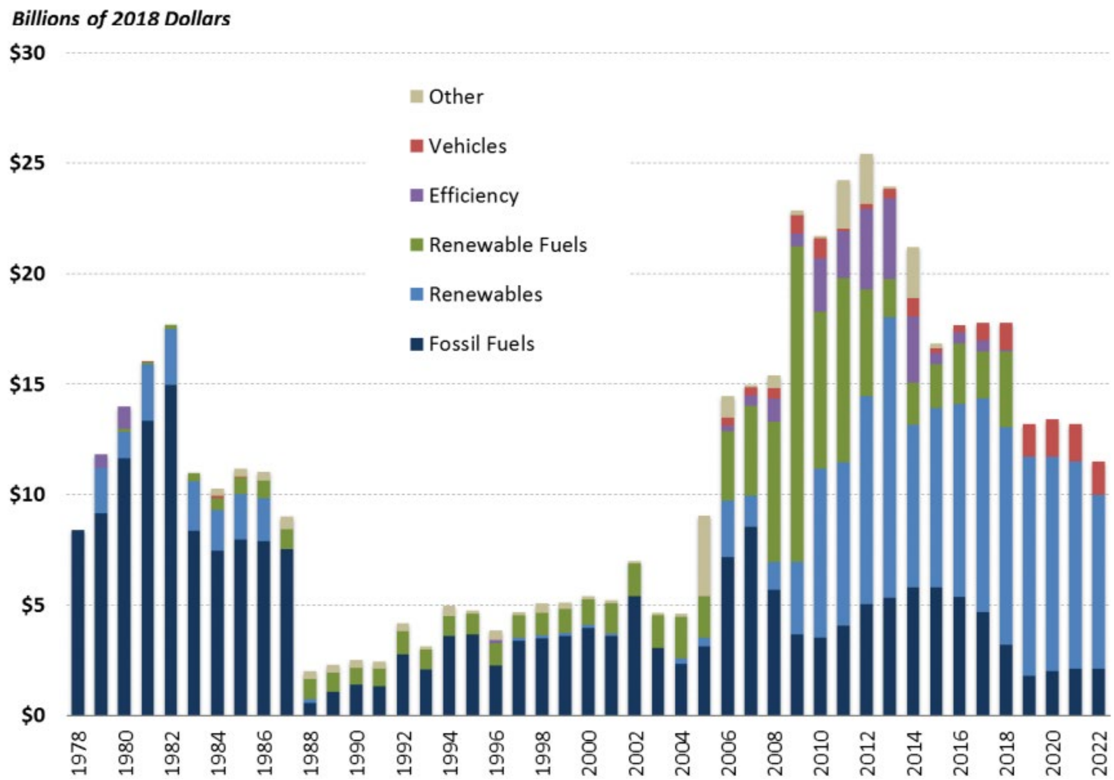

Figure 3. Increased subsidies to renewable forms of energy have lowered their costs and increased their competitiveness. Source: CONG. RSCH. SERV., R44852, THE VALUE OF ENERGY TAX INCENTIVES FOR DIFFERENT TYPES OF ENERGY RESOURCES 10 (Mar. 19, 2019) (Figure 1).

A major task is to electrify transportation.[22] The lithium-ion battery technologies available today can electrify cars, light- and medium-weight trucks, and heavy trucks that travel less than about 250 miles. Charging times for the fastest batteries are already down to 20 minutes. If further technological advances take this time down to 10 minutes, charging batteries will take no longer than going to a filling station in 2023. The IRA includes tax credits for the purchase of electric vehicles, plug-in hybrids, and hydrogen fuel cell vehicles and for the development of charging infrastructure

[20] *See* Michael Taylor, *Energy Subsidies: Evolution in the Global Energy Transformation to 2050*, International Renewable Energy Agency (2020).

[21] Accelerating Decarbonization of the U.S. Energy System, *supra* note 3, at 134.

[22] *See generally* Nat'l Res. Council, Transitions to Alternative Vehicles and Fuels (2013).

(see Box 2). Federal agencies, such as the U.S. EPA, are taking action as well. In 2023, EPA issued proposed regulations aimed at reducing greenhouse gas emissions from the transportation sector,[23] as well as from fossil-fuel-fired power plants.[24] In addition, states have begun setting dates to phase out the sales of new gasoline-powered cars,[25] and major car companies have committed to an all-electric-fleet future.

Economywide electrification also involves transitioning how people cook and heat their homes.[26] Today, 38% of Americans use a gas stove, and buildings that use gas or oil for heating and other purposes account for 13% of U.S. greenhouse gas emissions.[27] Carbon dioxide cannot be captured from gas stoves or from most furnaces burning fossil fuels; replacing these over time will translate to emissions reductions. Heat pumps can use electricity to heat and cool homes, while electric stoves and burners can be installed in kitchens. The IRA includes tax credits and rebates to drive improvements in home energy efficiency. Manufacturing standards for home heating and cooking, similar to the manufacturing standards for air conditioning, are another way that policymakers could encourage this transition.

Building more electricity transmission capacity, including long-distance transmission from areas where wind and solar energy are abundant to areas where they are not, will be a

Box 2. Inflation Reduction Act

The Inflation Reduction Act (IRA) signed into law by President Joseph Biden on August 16, 2022, authorizes nearly $400 billion in spending related to climate change and energy security, including provisions to incentivize electric vehicles, develop and deploy low-carbon technologies, and expand renewable energy systems. A preliminary report by Princeton University's Rapid Energy Policy Evaluation and Analysis Toolkit (REPEAT) Project found that the IRA could reduce U.S. emissions approximately 42% below 2005 levels by 2030, which approaches the national reduction goal of 50% below 2005 levels by 2030. The report also notes that the IRA could save households, businesses, and industry around $50 billion annually in energy costs.[28]

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[23] At publication, the ultimate contours of these rules are uncertain. *See* Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles-Phase 3, 88 Fed. Reg. 25,926 (Apr. 27. 2023); Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles, 88 Fed. Reg. 29,184 (May 5, 2023).

[24] New Source Performance Standards for Greenhouse Gas Emissions From New, Modified, and Reconstructed Fossil Fuel-Fired Electric Generating Units; Emission Guidelines for Greenhouse Gas Emissions From Existing Fossil Fuel-Fired Electric Generating Units; and Repeal of the Affordable Clean Energy Rule, 88 Fed. Reg. 33240 (May 23, 2023), https://www.federalregister.gov/documents/2023/05/23/2023-10141/new-source-performance-standards-for-greenhouse-gas-emissions-from-new-modified-and-reconstructed.

[25] States include California, Maryland, Massachusetts, New Jersey, New York, Oregon, and Washington. *See, e.g.*, Nadia Lopez, *California Phases Out New Gas Cars – So What's Next for Electric Cars?*, CALMATTERS (Aug. 25, 2022), https://calmatters.org/environment/2022/08/electric-cars-california-to-phase-out-gas-cars/; Zack Budryk, *Maryland Governor Unveils Plan to Phase Out New Gas-Powered Cars*, THE HILL (Mar. 14, 2023), https://thehill.com/policy/energy-environment/3900009-maryland-governor-unveils-plan-to-phase-out-new-gas-powered-cars/.

[26] WORKING GROUP III, *supra* note 8, at 91.

[27] U.S. ENV'T PROT. AGENCY, *Sources of Greenhouse Gas Emissions*, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (last updated April 28, 2023).

[28] Jesse D. Jenkins et al., Princeton University Zero Lab, REPEAT, Preliminary Report: The Climate and Energy Impacts of the Inflation Reduction Act of 2022 (2022), https://repeatproject.org/docs/REPEAT_IRA_Prelminary_Report_2022-08-04.pdf.

critical component of broader electrification efforts.[29] That is challenging in the United States, because the country has regional grids and a complex and fragmented permitting process that impedes rapid change. Recent federal legislation includes grants to facilitate and accelerate the siting and permitting of interstate transmission projects and to accelerate environmental review processes.[30] Building the necessary infrastructure will likely also require new regulatory structures to expand and increase the automation of electricity transmission and distribution.

Wind and solar power are already being deployed at a record pace in the United States. The NAS report found that to be on track for net zero by the middle of the century, the current pace will need to roughly double by the end of the 2020s.[31] Over the course of the 2030s, that pace would need to double again. This rate of increase is not unprecedented. For example, the increased use of natural gas and decreased use of coal occurred even more rapidly when hydraulic fracturing techniques became widely used after 2007.

Of course, the wind does not always blow and the sun does not always shine, so other technologies are needed to supply energy during the doldrums. The National Academies offer several possibilities that can provide some of this backup: batteries, hydroelectric power, and nuclear power. The United States is also endowed with plentiful supplies of natural gas that could generate backup power for renewable forms of energy. A natural gas electricity plant, which is essentially a set of jet engines tied to electric generators, can be throttled up when renewable energy sources are not available. As more wind, solar, and transmission capacity is installed, the use of backup power can decline.

Natural gas produces about half the carbon dioxide of a coal-fired electricity plant, but achieving net zero will require that these emissions be controlled as well. One option would be to capture the carbon dioxide emitted by electricity generation and reinject, or sequester, it into the reservoirs from which the gas was extracted.[32] Carbon capture and sequestration (CCS) projects at multiple scales are now operating around the world, but this technology will have to be scaled up dramatically. The U.S. EPA's proposed rule that sets limits on the emissions from fossil fuel-fired power plants is based on technologies such as CCS.[33] The nation would also need a national transportation and storage network to ensure that carbon dioxide can be captured not just from power plants, but from scattered and small-scale sources across the country, and moved to geologic reservoirs where it can be kept out of the atmosphere. Further, for a transportation and storage network to be available when it is needed in the 2030s and 2040s, construction of this network would need to start in the 2020s.

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[29] Patrick R. Brown & Audun Botterud, *The Value of Inter-Regional Coordination and Transmission in Decarbonizing the US Electricity System*, 5 JOULE 115, 115-16 (2021).

[30] *See, e.g.*, Inflation Reduction Act, Pub. L. No. 117-169, §50152 (Grants to Facilitate the Siting of Interstate Electricity Transmission Lines), §§60115, 60402, 60505, 50305, 60505, 40003, 50301, 70007 (providing resources to various federal administrative agencies, including the Council on Environmental Quality, the U.S. Department of Energy, the U.S. Environmental Protection Agency, and others, to accelerate permitting).

[31] ACCELERATING DECARBONIZATION OF THE U.S. ENERGY SYSTEM, *supra* note 3, at 75.

[32] *See* Council on Env't Quality, Report to Congress on Carbon Capture, Utilization, and Sequestration (2021).

[33] *See* U.S. EPA, *Greenhouse Gas Standards*, *supra* note 23. The use and expansion of CCS technology is controversial because most stored carbon dioxide is used for enhanced oil recovery.

If these solutions to the climate change problem are now available, why not institute them in less than 30 years and avoid potentially disastrous climate tipping points? As the NAS report points out, a faster transition is possible, but 30 years is about the lifetime of existing major assets in the energy system.[34] Retiring all those assets over the next decade would be costly, whereas replacing them as they wear out with cheaper, non-emitting alternatives would save money in the long run. Thus, a 30-year transition from 2020 to 2050 balances both the longevity of the capital stock and our current knowledge of the climate system.

The energy revolution of the past decade is unlike any that has occurred in the past century. Thoughtful policies and technological advances have steadily brought down the cost of wind and solar energy. As a result, electricity can now be generated without putting greenhouse gases into the atmosphere, at less cost than in the past.

IV. Provide Energy Sources for Technologies That Cannot Be Electrified

Some sectors of the economy, like aviation, shipping, cement making, steel production, and some manufacturing activities, will be difficult or impossible to electrify by 2050. For instance, a commercial airplane flying long distances could not operate on existing batteries, because it would be too heavy. Similarly, electric kilns used to make cement would be very expensive to operate on stored wind and solar energy when the sun is not shining and the wind is not blowing.

Greater energy efficiency is one of the most effective near-term opportunities to reduce emissions from these sectors. Governments have instituted many policies in the past designed to improve the efficiency of energy use, and building on these efforts could yield quick returns.[35]

To further reduce emissions, several technological pathways are possible. One option relies on the use of hydrogen as a fuel, which produces only water vapor as a byproduct when it is combined with oxygen to produce heat.[36] For example, long-haul trucks could use either advanced batteries, which are now under development, or hydrogen as a fuel. Moreover, to produce hydrogen, the element must be first isolated from its parent molecule. In commercial hydrogen production, methane is commonly used for this purpose. Hydrogen is separated from methane by a technique called steam-methane reformation, but this process also produces some carbon dioxide. It is alternatively possible to split hydrogen from water molecules using electricity, but that electricity could come from either renewable or non-renewable sources. Thus, hydrogen has the potential to be a source of low- or no-emissions fuel, but it is not inherently so. The use of hydrogen as a fuel remains expensive today compared with other alternatives, but greater use might likely bring down the price of hydrogen

[34] Accelerating Decarbonization of the U.S. Energy System, *supra* note 3, at 79.

[35] *See generally* Elizabeth Doris et al., *Energy Efficiency Policy in the United States: Overview of Trends at Different Levels of Government*, NATIONAL RENEWABLE ENERGY LABORATORY (2009).

[36] *See generally* INTERNATIONAL ENERGY AGENCY, THE FUTURE OF HYDROGEN: SEIZING TODAY'S OPPORTUNITIES (2019).

energy, as has been the case with solar and wind power. Research and development (R&D) will need to be expanded during the 2020s to ensure that the costs of these technologies come down enough so that they are cost-competitive for decarbonization in the 2030s and 2040s.

According to another NAS report on negative emissions technologies, natural gas with carbon capture and sequestration is another possible source of energy in sectors that are hard to electrify.[37] Before the hydraulic fracturing and horizontal drilling revolution of the 21st century, supplies of gas were uncertain in the United States, but new sources made available by these technologies have eased concerns about supply. A major remaining concern is that uncombusted methane, the major component of natural gas, will leak as "fugitive emissions" into the atmosphere during its drilling, extraction, and transportation and exacerbate global warming. This is especially concerning since methane is more than 25 times as potent as carbon dioxide in its warming potential over a 100-year period.

If fugitive methane emissions can be controlled along with the carbon from burning natural gas and from burning off excess methane from wells, natural gas with carbon capture and sequestration potentially could provide the United States with a non-emitting source of energy for more than a century. The IRA provides tax credits and R&D funding both for carbon capture and for direct air capture, in which carbon dioxide is removed directly from the atmosphere and sequestered underground. Though carbon capture and sequestration remains expensive and would need to be deployed on a very large scale, solving these problems and applying carbon capture to gas-fired power generation could provide significant employment and economic benefits across a range of economic sectors.

Critical research and development efforts are still needed to determine exactly how non-emitting technologies can help decarbonize the energy system. For example, small modular nuclear reactors could make significant contributions to energy supplies, but issues of cost, safety, spent fuel disposal, and nuclear proliferation remain to be resolved. Hydrogen as a fuel and an energy storage system remains expensive, but it could play a large role later in the transition to net zero. Both are supported through funding provided in the IRA.

V. Reduce Other Greenhouse Gases in Addition to Carbon Dioxide

As described in the What Is Causing Climate Change? module, gases other than carbon dioxide also cause greenhouse warming.[38] Especially problematic is the powerful greenhouse gas methane, which results from agriculture (particularly the raising of livestock), leaks from the natural gas systems mentioned above, decomposition of wastes in landfills, and coal mining. Nitrous oxide, which results from agriculture as well as from the combustion of fossil fuels, also accelerates greenhouse

[37] *See* NAT'L ACAD. OF SCI., ENG'G AND MED., NEGATIVE EMISSIONS TECHNOLOGIES AND RELIABLE SEQUESTRATION: A RESEARCH AGENDA (2019) [hereinafter NEGATIVE EMISSIONS TECHNOLOGIES].
[38] *See generally* IPCC, AR6 Climate Change 2021: The Physical Science Basis (2021).

warming. Another contributor to warming is fluorinated gases, such as hydrofluorocarbons used in refrigeration and air conditioning, that are released into the atmosphere when equipment leaks or is discarded.

The greatest impact on these non-carbon dioxide greenhouse gases would come from changes in the energy system.[39] In natural gas and oil systems, inspection and maintenance of energy plants could significantly mitigate the release of these gases. Controlling uncombusted natural gas emissions from wellheads and pipelines can prevent excess release of greenhouse gases. In coal mining, methane in the air could be extracted and burned for power with subsequent carbon capture or be otherwise sequestered from the atmosphere.

To reach net zero, the use of current refrigerants and other fluorinated gases will need to be reduced, which may require a variety of approaches. Companies may have to employ recovery and recycling methods as well as production techniques that do not involve fluorinated gases. Governments may limit the production of fluorinated gas emissions in sectors such as electronics manufacturing and aluminum and magnesium production. Recently, engineers have developed a high-temperature incinerator for the safe destruction of fluorinated gases.
Despite such advances, the NAS decarbonization report concluded that the most feasible option to meet the nation's climate goals would be to reduce the use of fluorinated gases in all sectors as quickly and as reasonably as possible.[40] Recognizing this, the United States ratified the Kigali Amendment to the Montreal Protocol, which aims to phase down hydrofluorocarbons 85% by 2036. Replacements of these compounds could also be made opportunistically. For instance, when a refrigerator or air conditioner needs to be replaced, the new device might use coolants that are more climate-friendly.

The greatest challenges are associated with the agricultural sector. Demand for food is growing, which puts pressure on increasing the use of land and other inputs to agriculture. However, known techniques applied to livestock and croplands could substantially reduce emissions. Promising examples include better management of manure, cropland strategies such as no-till practices.[41] As prices increase, changes in diets could cut emissions even as the demand for food rises.

VI. Employ Natural Climate Solutions and Negative Emissions Technologies to Compensate for the Remaining Emissions

Even after the economy is electrified and emissions of other greenhouse gases are minimized, U.S. households and businesses will still be releasing some carbon dioxide and other greenhouse gases into the atmosphere. To reach net zero, the United States would need to remove the equivalent amount of these greenhouse gases from the atmosphere and sequester them.

[39] *See generally* Working Group III, *supra* note 8.
[40] Accelerating Decarbonization of the U.S. Energy System, *supra* note 3, at 80.
[41] Accelerating Decarbonization of the U.S. Energy System, *supra* note 3, at 81.

Several negative-emissions technologies can contribute to this job.[42] Practices that increase the amount of carbon stored in living plants or sediments in tidal marshlands, seagrass beds, and other tidal or saltwater wetlands—collectively known as coastal blue carbon—are relatively low cost, though their capacity to store carbon is limited.

Crops, which take up carbon dioxide as they grow, can be used to produce electricity, liquid fuels, or heat, with the carbon dioxide produced in these processes being captured and sequestered underground. However, agricultural land is also used to supply food for people and for livestock, and using land to solve the climate problem might create a food supply problem, especially as demand for food increases.

The most promising ways for the United States to sequester carbon dioxide over the next few decades are to manage forests to retain more carbon, plant more forests, and adjust agricultural practices to enhance carbon storage in the soil.[43] Plants eat carbon dioxide for a living. They use water, nutrients, and sunlight to turn carbon dioxide in the atmosphere into living tissue.

For example, the forests east of the Mississippi River in the United States have been gaining weight for decades as former cropland has reverted to forests and as existing forests have grown. These and other forests in the United States could store more carbon if trees were cut down more selectively and science-based forest management practices were applied. Similarly, agricultural practices can rebuild the carbon content of soils that have been degraded, which improves agricultural productivity while removing carbon dioxide from the atmosphere. If all but the essential emissions of greenhouse gases were eliminated by 2050, the growth of plants in the United States should be enough to compensate for remaining emissions, allowing the United States to reach net zero.[44]

This approach would have many benefits in addition to mitigating climate change. It would improve forests, croplands, grazing lands, and wetlands that support human health and well-being. It would improve habitats for other organisms, increase soil fertility and water-holding capacity, and decrease air and water pollution.[45] In some places, the co-benefits of enabling ecosystems to flourish could be even more valuable than the benefits from climate mitigation.

Current federal legislation relies mostly on incentives and subsidies to reduce the buildup of greenhouse gases in the atmosphere, and a more diverse portfolio of policies, including regulatory changes, the use of carbon markets, and payments for co-benefits, would likely be needed to reach net zero. The barriers to change, including institutional, technological, political, and cultural factors, are substantial, but means exist to address them. For example, storing carbon in plants will require monitoring and verification, which will require adequate governance structures. Also, the availability

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[42] *See generally* Negative Emissions Technologies, *supra* note 24.
[43] Nat'l Acad. of Sci., Eng'g and Med., Land Management Practices for Carbon Dioxide Removal and Reliable Sequestration: Proceedings of a Workshop—in Brief 4 (2018).
[44] Accelerating Decarbonization of the U.S. Energy System, *supra* note 3, at 81.
[45] Joseph E. Fargione et al., *Natural Climate Solutions for the United States*, 4 Sci. Advances 1 (2018), https://doi.org/10.1126/sciadv.aat1869.

of land is finite, and competing uses of land for food production, conservation, and carbon goals will have to be resolved.

Despite the benefits that natural climate solutions could provide, many of the most effective opportunities will not be available indefinitely. For instance, slowing emissions by preventing tropical deforestation requires an intact forest as a starting point. Waiting until too little forest remains to regenerate new forests reduces the possibility of using this technique as part of the climate solution.

Despite the challenges, rapid change is entirely possible. For example, the United States has a large amount of rainfed pastureland and cropland some of which could be converted to forestland if people were to eat less meat. While the demand for meat remains strong today, projections for the growth of U.S. demand have recently been dropping,[46] and the development of the alternative (plant-based or synthetic) meats industry could provide an opportunity to free up land for storing carbon.

As with direct capture of carbon from the atmosphere, negative emissions technologies and natural climate solutions all need concerted research efforts to overcome the constraints that currently limit deployment. This research will need to address not just gaps in scientific and technical understanding, but also the steps that are needed to bring negative emissions technologies to scale, including cost reductions, deployment, and monitoring and verification.

VII. The Social Dimensions

Achieving net zero by 2050 will inevitably change the lives of some people.[47] For example, communities that today are tightly tied to fossil-fuel production will face job and revenue losses, just as the ongoing decline in the coal sector has been hollowing out some communities across the nation. Many other communities will thrive, as new jobs and new industries result from the development and implementation of non-emitting technologies. The social dimensions of the energy transition will necessitate as much attention as the technological dimensions.

In the past, changes to energy systems have caused suffering in the communities that house these systems, and many communities have suffered historically and continue to suffer today because of the pollution and other negative consequences of energy systems (see Climate Justice module). These communities may be resistant to mitigation measures, or demand recompense for past harms as energy systems change. Poor and historically marginalized groups have suffered disproportionate harm from fossil pollution while receiving disproportionately low benefits from fossil energy. High

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[46] USDA, *Per Capita Red Meat and Poultry Consumption Expected to Decrease Modestly in 2022* (Apr. 15, 2022), https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=103767#:~:text=Over%20the%20last%20decade%20(2012,per%20capita%20retail%20weight%20basis.

[47] *See generally* Rachel Morello-Frosch et al., The Climate Gap: Inequalities in How Climate Change Hurts Americans and How to Close the Gap (2009).

energy prices contribute to poverty, and many people who lack adequate capital cannot take advantage of opportunities like tax credits for electric cars or weatherization programs for homes.

The IRA authorizes more than $60 billion for community investments and energy justice, including block grants to states, local governments, and tribes. For example, it provides funding for community-led projects in places that have experienced negative impacts of pollution and climate change. Reducing and eliminating the injustice built into the energy system would in general help create a more just and equitable society.[48]

Governments at all levels have many policy options to address inequities. Communities and workers that have been harmed in the past or are at risk from future changes could be included to a much greater extent in the development of solutions.[49] Comprehensive education and training programs could provide the workforce needed for the transition to clean energy. Regional centers could allow state and local leaders to access resources and knowledge related to climate change adaptation, establishing a baseline of shared information that quantifies and helps to address inequities. A new federal office at the level of the White House could establish targets and advance federal programs aimed at a just and equitable transition. A national organization drawing on resources from both the public and private sectors could provide funding specifically to address the social impacts of the transition to net zero.

The transition to net zero provides an opportunity to build an energy system without the social injustices such as disproportionate impacts of emissions that characterize the current system and to allow communities and individuals to share equitably in future benefits. Public support for the transition may depend in part on how well U.S. policies ensure a fair distribution of costs and benefits.

The upside of the transition to net zero is substantial.[50] A variety of studies have concluded that the transition to net zero will create millions of new jobs.[51] Deep decarbonization could accelerate U.S. innovation, revitalize U.S. manufacturing, and increase employment, mostly in the form of blue-collar jobs. New educational and training opportunities could give displaced workers the skills they need to prosper in the renewable and green energy industries. Workers displaced by the transition could be employed in local projects or new businesses in their communities funded by community block grants, though wages may need to be increased to match those paid in the fossil fuel industry. People who do not have access to such opportunities may need direct assistance in such areas as housing mobility and lost income.

A diverse policy portfolio may help to ensure that communities have equal access to these benefits and are not disproportionately exposed to the risks of new energy systems.[52] Workers and

[48] Accelerating Decarbonization of the U.S. Energy System, *supra* note 3, at 117-62.
[49] *See* Ortwin Renn et al., The Role of Public Participation in Energy Transitions (2020).
[50] *See generally* International Energy Agency, Net Zero By 2050 A Roadmap for the Global Energy Sector (2021).
[51] Devashree Saha et al., *How a Clean Energy Economy Can Create Millions of Jobs in the U.S.*, World Res. Inst. (Sept. 14, 2022), https://www.wri.org/insights/us-jobs-clean-energy-growth.
[52] Accelerating Decarbonization of the U.S. Energy System, *supra* note 3, at 163.

communities will want access to accurate information about how the transition to net zero could affect them, and governments at all levels will need to respond to the prospect of job losses. Transition planning will benefit from ensuring that economic and health disparities are not exacerbated. Strategies will be needed to help local, state, and tribal governments replace revenue lost from the closing of plants, mines, and other industrial facilities. If the technological and social transitions to net zero take place hand-in-hand, and if equity is built into the DNA of any decisions that are made, then the costs, benefits, risks, opportunities, and burdens of decarbonization can be distributed more fairly.

VIII. Leading the World

Unless other nations join the United States in achieving net-zero greenhouse gas emissions by 2050, the levels of greenhouse gases in the atmosphere will continue to increase. However, there are good reasons to believe that the rest of the world can achieve net zero in approximately the same time scale, depending in part on the actions the United States takes in the next few years.

As part of the Paris Agreement, many nations have committed to a rapid transition to net zero.[53] Britain, France, and Germany have said that they will achieve that goal by 2050. China has pledged to reach net zero by 2060. Others have said that they will achieve net-zero emissions well before the middle of the century.

Net zero can create a dilemma for countries that are struggling to raise substantial portions of their populations out of poverty. Despite the rapid price decreases for wind and solar energy, many countries still have incentives to burn fossil fuels using existing technologies.

Issues of fairness also come into play (see Box 3).[54] The United States built massive infrastructure, such as its interstate highway system, using carbon dioxide emissions. It may be seen as unfair to other countries to say that they cannot build similar infrastructure that would improve the quality of life for their citizens. It may

Box 3. Loss and Damage

Not all impacts of climate change can be avoided or mitigated against. Those that cannot are referred to as "loss and damage" in international climate discussions. At the U.N. Framework Convention on Climate Change (UNFCCC) 27th Conference of the Parties (COP27) in 2022, an annual international meeting tasked with assessing global climate progress, the concept of loss and damage was featured prominently. The underlying reason for this is twofold.

First, climate change has not been driven equally by all countries. For example, the United States alone accounted for approximately 20% of historical, cumulative carbon dioxide emissions by the end of 2021. Other large emitters included China (11.4%) and Russia (6.9%).

Second, climate impacts are not felt equally throughout the world. In general, the Global South—largely developing countries whose populations have contributed very minimally to climate change—suffer the worst climate impacts, such as those associated with more intense or frequent extreme events like cyclones, drought, flooding, and extreme heat.

The variety and severity of climate impacts inspired calls for a climate fund at the international level to which wealthier countries contribute to pay for losses and damages that have occurred and continue to unfold under future warming.

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[53] United Nations, *For a Livable Climate: Net-Zero Commitments Must Be Backed By Credible Action*, https://www.un.org/en/climatechange/net-zero-coalition (last visited May 19, 2023).
[54] *See generally* Friedrich Soltau, Fairness in International Climate Change Law and Policy (2009).

also be seen as inequitable that other people should sacrifice so that people in the United States do not face a worsening climate.

Global climate policy experts have proposed a variety of solutions for international inequities. One possibility would be to provide a one-time exception for the construction of infrastructure even as other activities are rapidly converted to non-emitting alternatives. Under this proposal, new infrastructure would be completely sustainable and not dependent on the continued burning of fossil fuels.[55] Every factory or power plant designed to run on fossil fuels comes with an expectation of lifetime emissions extending over many years or, especially for power plants, decades. To avoid such lock-in, a possible solution is to rapidly transition away from the production of new fossil fuel-based products and infrastructure.

The United States is endowed with resources for getting to net zero.[56] Unlike many countries, the United States has abundant land for constructing wind and solar energy-generating facilities. The country has a natural gas reserve that can serve as a solid base of fuel during the transition to non-emitting energy technologies. Abundant and well-characterized storage sites for sequestering carbon dioxide from the atmosphere are available. The country has abundant forests east of the Mississippi River that can remove carbon dioxide from the atmosphere as they continue to grow. Other countries are far more constrained than is the United States.

Princeton University's Net-Zero America project has a website featuring a database that demonstrates how to reach net zero in the United States.[57] For a given political entity like a state or a congressional district, it shows how much capital is required and what needs to be built and where. It shows the number of jobs generated, the health impacts, and other benefits and costs to the population.

IX. On the Verge of a Solution

In sum, the climate change problem of how to decarbonize the energy system can be solved with proactive innovation. Because of the technological revolution that has taken place in the last decades, and because of the resources, natural and otherwise, in the United States, the transition to net zero by 2050 can happen in a way that will not cost the nation more than it would have spent maintaining the status-quo energy regime, with its associated impacts and costs to remedy them.[58]

Human ingenuity and determination have the capacity to drive the costs of alternative energy sources down. For instance, if the cost of electrolysis—using electricity generated from wind and

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[55] *See* The Nat'l Acad., Accelerating Decarbonization of the U.S. Energy System – Public Briefing (Feb. 3, 2021), https://vimeo.com/507993412.
[56] *See* Eric Larson et al., *supra* note 2.
[57] Net-Zero America, *Net-Zero America: Potential Pathways, Infrastructure, and Impacts*, https://netzeroamerica.princeton.edu/?explorer=year&state=national&table=2020&limit=200 (last visited May 19, 2023).
[58] Accelerating Decarbonization of the U.S. Energy System, *supra* note 3, at 109.

solar sources to dissociate water into hydrogen and oxygen—can be reduced by a factor of four, boundless hydrogen would be available to burn in turbines, vehicles, industrial processes, and elsewhere, with only water vapor as a byproduct. The result would be energy systems that can be applied anywhere in the world for almost any purpose. Such systems could give both developed and developing nations the chance to complete the transition to clean energy while saving them money.

Developing and implementing solutions to the climate problem have caught the attention of the best and brightest, including many young people who have begun working in these fields. Many companies, including electric utilities, oil and gas companies, and airlines, as well as car manufacturers GM and Honda, have announced that they are realigning their product offerings to get to net zero by 2050, such as not making gas-powered cars after a particular year.[59] Such moves signal to markets and investors, especially long-term investors like pension funds, that these companies are serious about doing business in a new economy.

The decade from 2020 to 2030 is especially critical. Experts say to achieve net zero by 2050, the United States will need to be on a pathway to that goal by the end of this decade. Federal legislation enacted in 2021 and 2022 authorizes many of the actions that need to take place in the 2020s—but not all of them. Further, actions to build the infrastructure necessary to achieve net zero by the middle of the 21st century, including new transmission lines, an electric vehicle charging network, and a carbon dioxide pipeline network for sequestration, would need to take place right away, not after a years-long delay. . Success will likely require extensive and ongoing collaboration between the public, private, and nonprofit sectors.

The recent technological revolution that has produced inexpensive renewable energy may also enable the United States to become richer and exercise positive leadership on climate matters. With appropriate policies, the transition could produce a more fair and just energy system, improve international competitiveness, revitalize American manufacturing, create high-quality jobs, and enhance energy innovation. The goal of net zero by 2050 is intended to sustain the societal momentum needed to get the job done while involving the creative side of humanity in a great and powerful undertaking. This message resonates with people everywhere no matter what their politics or background. Climate change is a frightening prospect, but achieving net zero and avoiding a climate crisis is within our grasp through technological development, financial investment, and human involvement.

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[59] *See* Motavalli, *supra* note 17; Eric Larson et al., *supra* note 2, at 9.