Union of Concerned Scientists

REPORT

A Transformative Climate Action Framework

Putting People at the Center of Our Nation's Clean Energy Transition

The climate crisis is already manifesting in devastating and costly ways worldwide, taking a disproportionate toll on communities of color and those who live in poverty. Acting together, nations must limit the worst of future climate impacts by cutting global carbon emissions in half by 2030 and achieving net-zero emissions by 2050 (IPCC 2018; IEA 2021), and the United States must contribute its fair share to those efforts.

Cutting fossil fuel use—a core climate solution—will also be a boon to public health. Producing, transporting, and burning these dirty fuels produces enormous amounts of harmful air, water, and soil pollution, contributing to heart and lung ailments, asthma, and cancer. From coal mining communities in Appalachia to fenceline communities living near fossil fuel–fired power plants, coal ash disposal sites, and heavy freight transportation corridors—disproportionately Black, Brown, Indigenous, and low-income communities—people suffer the deadly and destructive costs of fossil fuels that the market has failed to fully account for.

Securing our climate goals is about much more than cutting carbon emissions. By looking beyond carbon to all the ways in which our fossil fuel–based economy affects people, we can unlock new opportunities for progress. Shifting from a fossil fuel–dependent economy to one that is powered by clean energy is an exciting opportunity to advance multiple important priorities: jobs, health, and justice. Tailoring policies and investments accordingly can help ensure these necessary changes happen quickly and the benefits accrue equitably to working people and all communities.

At the same time, history and present-day circumstances show that race, class, health, income, political power, and even traditions are deeply intertwined with our fossil fuel–based energy system. To unwind one challenge, we must unwind the others; a technological transition *coupled with* societal transformation is the surest path to a just and equitable achievement of our climate goals.

This report, a collaborative effort between the Union of Concerned Scientists (UCS) and an expert advisory committee, is motivated by a positive vision for addressing the nation's compound crises of climate change, structural racism, and growing income inequality (Box 1). We start with fundamental guiding principles, rooted in science and justice. We next explore, through a modeling exercise, the magnitude and pace of technological change needed to drive down energy system carbon emissions; we simultaneously use those analytic findings to elevate broader economic and societal implications central to advancing multidimensional solutions that are not captured within the modeling framework. Finally, we couple those principles and pathways to highlight policy interventions that can bring substantial public health and economic benefits to communities around the country.

We urge policymakers and stakeholders at every level of our society, in every corner of our country, to seize this moment and take bold action to help make this vision a reality and

put the United States on a healthier, more sustainable, and prosperous path. Policies and investments that cut carbon emissions sharply can also, if designed intentionally, advance environmental justice, support a fair transition for fossil fuel workers and communities, create millions of good-quality jobs, and promote climate resilience. Such targeted policies and investments must be prioritized within this decade and beyond.

Box 1. A Collaborative Partnership: Developing a Vision for a People-Centered Clean Energy Transformation
UCS and an expert advisory committee engaged in a two-year partnership to develop a more holistic framework for a just and equitable approach to deep decarbonization of the US energy system. The advisory committee members bring a range of perspectives to this topic. This report is a distillation of the major insights that emerged from our shared work. Its themes range wide, and we hope they provide an entry point and a strong foundation for a vision of a people-centered clean energy transition. We all believe in this vision, although there may be a diversity of views on specific policies to achieve it. This work will also be built out through additional materials responsive to a range of stakeholders' needs. Advisory committee members: *Ted Boettner, Senior Researcher, Ohio River Valley Institute* *Chandra Farley, Director, Just Energy Partnership for Southern Equity* *Brett Isaac, Founder, Navajo Power* *Jackson Koeppel, Founding Executive Director, Soulardarity* *Dr. Monica Unseld, Founder, Until Justice Data Partners* *Dr. Shelley Welton, Assistant Professor, University of South Carolina School of Law*

I. Principles for a Transformative Energy Transition

We propose three core principles for a transformative clean energy transition (see Box 2 for our definition of clean energy). This holistic approach must:

- effectively address the climate crisis;
- advance equity and justice;
- drive systemic, not just incremental, change.

These principles for what the transition ahead must aim to achieve are grounded in our understanding of how we got to this place of compounding and intersecting crises, which we describe in more detail below.

CONTEXT FOR PRINCIPLES

The history of our country's dependence on fossil fuels is complex, but at its heart lies an economic and political system whose incentives are heavily skewed toward corporate profits even at the expense of societal well-being—and that has significantly distorted policy choices and outcomes. Long before climate change became an urgent imperative, the immense health and environmental burden of extracting and burning fossil fuels should have clearly signaled a need for shifting to cleaner forms of energy, yet people have continued to suffer the impacts of its use. Today, 135 million people in the United States live in counties with unhealthy air, primarily a result of burning fossil fuels; people of color are over three times more likely than white people to be breathing the most polluted air (ALA 2021). By one estimate, fine particulate matter pollution from burning coal, gasoline, and diesel kills approximately 355,000 people annually in the United States (Vohra et al. 2021). Legacy pollution from resource use—such as abandoned mine lands and oil and gas wells, coal ash disposal sites, and contaminated soils—is also an ongoing challenge for communities. The communities that have borne the brunt of the pollution from the extraction, transport, and burning of fossil fuels are disproportionately Black, Brown, Indigenous, or living in poverty, communities that have been historically marginalized and subject to systemic racism (Donaghy and Jiang 2021; Tessum et al. 2021; Thind et al. 2019).

Labor rights have been increasingly eroded, too, as unions have lost ground and family-sustaining jobs with good pay and benefits are threatened as corporations look for ever-cheaper ways of doing business. Meanwhile, record coal plant retirements in recent years have devastated the livelihoods of coal miners and the economies of coal mining communities, while some coal companies have declared bankruptcy and shirked their obligations for worker pensions and health care, as well as for cleaning up contamination from mining operations.

Past experience also shows that, without proactive and intentional investments, economic transitions can leave working people and communities behind. For example, when industries experience downturns—as the coal industry is experiencing currently—workers and host communities are often left to cope with the economic fallout on their own. As we transition away from fossil fuels, more workers and communities will be affected. As a nation, we must do much more to invest in worker training, education, new job opportunities, economic diversification, and a just social safety net that provides for essential needs such as nutrition, housing, and healthcare.

Against this backdrop, it becomes clear that to secure a low-carbon energy transition to meet climate goals, we will have to reckon with the systemic failures of the past and present. This context also provides the motivation for why we need to think beyond carbon emissions cuts to develop just and equitable climate policies.

Box 2. A Clean Energy System Requires Thinking beyond Carbon Emissions

Although the terms *clean energy* and *low-* or *zero-carbon energy* are sometimes used interchangeably, it is important to look beyond carbon emissions and to carefully distinguish between 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. Appropriately sited renewable forms of energy generation—such as wind and solar—that are used in a sustainable manner are the cleanest resources we have: they produce little to no heat-trapping emissions or other air, water, and soil pollution and have low environmental and social risks overall. Nuclear power and fossil fuel-fired generation with carbon capture and storage (CCS), on the other hand, are low-carbon energy sources but pose additional and significant environmental, public health, and social impacts. For other resources, such as bioenergy and hydropower, project design and level of resource use matters: some applications will have high environmental and social impacts while 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.

THREE PRINCIPLES FOR A TRANSFORMATIVE CLEAN ENERGY TRANSITION

1. EFFECTIVELY ADDRESS THE CLIMATE CRISIS. The transition to a low-carbon economy must be anchored in climate-relevant targets and timelines: cuts in heat-trapping emissions of at least 50 percent below 2005 levels by 2030 and net-zero economywide emissions no later than 2050, prioritizing direct, absolute emissions reductions achieved from deep cuts in fossil fuel use which will also guarantee reductions in other harmful co-pollutants. The science shows that we will have to sharply bend the global carbon emissions curve *within this decade* to have a fighting chance of keeping our climate goals within reach (Cleetus and Spanger-Siegfried 2021; IEA 2021; IPCC 2018; UNFCCC 2021).

As a leading contributor to carbon emissions, the United States has a particular responsibility to cut its emissions deeply and rapidly. The Biden administration has committed to cut US emissions 50 to 52 percent below 2005 levels by 2030 (White House 2021a), a significant step forward that calls for a sharp turn away from fossil fuels. More will be needed in the years ahead—including further emissions cuts and international climate finance for developing countries—to meet our fair share contribution to global climate action (USCAN 2020).

Even if we achieve our most ambitious carbon targets, however, current and past emissions will still force us to confront significant and worsening climate impacts that threaten severe and inequitable societal disruption. Thus, we must also invest in enhancing climate resilience to extreme heat, floods, droughts, wildfires, rising ocean temperatures and ocean acidification, and other climate impacts. Approaches that put the health and well-being of people first must be prioritized, including by ensuring that essential energy infrastructure is climate-resilient.

2. ADVANCE EQUITY AND JUSTICE. A just and fair clean energy transition must be informed by a holistic set of priorities, processes, and metrics that incorporates public health, jobs, and environmental justice priorities and shifts power and decisionmaking to communities (BGA 2019; EJNCF 2019; EPA n.d.; Welton and Eisen 2019). Equity and justice require that all people are protected from environmental, climate, and economic harms that may present in our current energy system and as we transition away from it, and that they have equal access to decision making related to that transition. This is about both an outcome we must strive for, as well as a process for how to get there. Just and equitable outcomes are achieved (1) by promoting inclusive community participation in, and governance over, policy and resource decisions; (2) by recognizing and countering past and ongoing environmental injustices; (3) by ensuring equitable access to the clean energy transition's benefits; (4) by proactively addressing the environmental sustainability of energy materials, supply chains, and deployment choices (Gignac 2020) as well as human rights issues associated with securing critical components; and (5) by providing intentional, robust, and sustained investments in workers and communities displaced by energy system transitions (Richardson and Anderson 2021).

3. DRIVE SYSTEMIC, NOT JUST INCREMENTAL, CHANGE. To rapidly decarbonize our economy in a people-centered way, we will need an accelerated and unprecedented shift to clean energy, as well as societal shifts that enable sustainable consumption, production, and development patterns. We need new investments in a modernized, expanded grid; new incentives in our energy system that reward carbon-free and pollution-free energy; and new forms of governance that ensure all communities, particularly those that have been historically marginalized, can thrive in the new clean energy economy. We will have to take on powerful fossil fuel interests and democratize the decisionmaking processes and the benefits produced by our energy system.

Analyses and policies must go beyond the status quo and challenge market rules and structures that impede rapid and equitable deployment of clean energy. A scan of the energy landscape today shows that the costs of renewable energy are dropping dramatically, and, in many places, renewables are the cheapest form of new power that can be installed. Yet, current market structures, subsidies, and governance systems tend to prop up fossil fuels and reinforce status quo decisions, including keeping uneconomic coal plants running, promoting a rush to natural gas, and doubling down on infrastructure for gasoline-powered vehicles. Market rules and prices fail to account for the public health and climate costs of fossil fuels—especially the cumulative pollution burden in environmental justice communities—resulting in outcomes that harm people and the planet.

Additional needs include promoting community and cooperative ownership models (Welton 2017); driving innovation at all levels—technology, policy, and society; and sharply phasing down fossil fuel infrastructure and use, including by dismantling the outsized power of the fossil fuel industry and electric utilities and loosening their grip on the nation's energy choices at the federal, state, and local levels. To avoid replicating the harms of the past as we shift to cleaner forms of energy, policies and investments must be prioritized for historically disadvantaged communities, such as through the Justice40 initiative announced by the Biden administration (White House 2021b; Justice40 2021).[1]

II. Exploring Carbon Reduction Pathways to Probe Broader Transition Implications

A fundamental component of meeting climate ambitions is achievement of the carbon targets established above: domestically, the United States must contribute to global climate action by cutting its heat-trapping emissions at least 50 percent below 2005 levels by 2030 and achieving net-

[1] The Justice40 Initiative announced by the Biden administration has a goal of delivering 40 percent of the overall benefits of relevant federal investments to disadvantaged communities. Key metrics for defining these communities and monitoring progress toward the goal are being developed by the Council on Environmental Quality through an interagency process.

zero emissions no later than 2050.[2] Assessing the magnitude and pace of emissions reductions required to meet these targets can help to inform the development of energy transition policies, as well as to assess the degree to which proposed policies are sufficiently ambitious. We undertake such a modeling effort here, analyzing technical pathways to achieving carbon reduction targets across the US economy, by sector and as an interconnected whole.

However, while this form of techno-economic modeling can be useful for demonstrating the feasibility and cost-effectiveness of low-carbon pathways, we recognize that it is not able to capture other key issues related to achievement of the principles above, such as access to benefits, governance, and economic transitions, nor does it account for the broader systemic shifts that are necessary for delivering just and equitable outcomes. Transformative change, therefore, requires solving for an outcome with many more dimensions than carbon alone. This makes it critically important that carbon-focused findings are not viewed as definitive solution sets, but rather as initial prompts requiring further assessment within a fuller priority framework.

For these reasons, in addition to highlighting key findings from the carbon pathways analysis, we also spotlight implications for broader priorities related to policy implementation and pathway prioritization. Combining these insights provides a more holistic framework for shaping and selecting policy interventions, as explored in the final section.

CARBON REDUCTION MODELING AND ASSUMPTIONS

There are two primary levers for reducing energy carbon emissions: (1) changing the ways in which energy is used and (2) cleaning up the ways in which that energy is produced. The first covers energy efficiency, structural changes enabling lower overall energy demand, and direct displacement of fossil fuels through end use electrification; the second covers switching from fossil fuels to lower- or non-emitting energy sources and technologies. Remaining emissions have the potential to be countered via natural and technological negative emissions approaches, which remove heat-trapping emissions from the atmosphere. Studies show that these approaches, while at varying levels of readiness today, will likely be needed to keep global average temperature increases well below 2°C and achieve net-zero emissions by mid-century (IPCC 2018; NAS 2018).

To analyze possible carbon reduction pathways, we used a set of energy models developed by Evolved Energy Research allowing for the paired exploration of these demand-side and supply-side options for achieving carbon reduction targets (EnergyPATHWAYS and RIO, respectively). Outside of the energy modeling framework, we also make assumptions about deep cuts in non-carbon dioxide (CO_2) heat-trapping emissions and that the land sink continues to absorb CO_2 at current levels. We describe key carbon constraints underpinning the analysis in Table 1; additional model details and assumptions can be found in the technical appendix. These carbon constraints are applied throughout the analysis.

[2] We use the term *net zero* in its scientific sense—recognizing that the emissions that enter the atmosphere are the difference between total human-caused heat-trapping emissions and what is absorbed by the land and the oceans (or that might be removed by yet-to-be-developed technologies). 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 our climate solutions.

Table 1. Key Carbon Constraints in Modeling Scenarios

Parameter	Details
Heat-trapping emissions covered	Within model: CO_2 from energy and industry (equivalent to 80% of gross US heat-trapping emissions today) External estimates: methane, nitrous oxide, and fluorinated gases from agriculture, forestry, industry, and land-use change
Sectors covered	Electricity generation, transportation, buildings, and industry
Net reductions in heat-trapping emissions	50% below 2005 by 2030; net zero by 2050
CO_2 from energy use and industrial processes	*46.5% below 2005 by 2030 and 100% by 2050*
Non-CO_2 emissions	*30–36% below 2005 by 2030 and 40–50% by 2050*[1]
CO_2 absorbed by the land sink	*Held constant at 0.79 gigatons (Gt) CO_2 per year 2020–2050*
Carbon budget (total cumulative emissions)	80 Gt of CO_2-equivalent 2020–2050

Carbon constraints are applied economywide, including the heat-trapping emissions covered by this modeling framework as well as those falling outside it.
[1] Abhyankar, Mohanty, and Phadke 2021; EDF 2021; EPA 2021; Fargione et al. 2018; Hultman et al. 2021; NAS 2018; NRDC 2021; Larsen, Larsen, and Pitt 2020.

Below, we spotlight results from two modeling scenarios exploring pathways to meeting these carbon constraints: a core scenario, "Zero CO_2 2050," and an iteration thereof, "Low Energy Demand," which also reaches zero CO_2 emissions in 2050 but differs based on assumptions around future levels of societal energy demand. Specifically, whereas the Zero CO_2 2050 scenario relies on energy demand forecasts by the US Energy Information Administration (EIA 2019), the Low Energy Demand scenario probes the energy transition implications of significant societal shifts enabling far lower overall energy use. We advance the latter scenario as a direct challenge to assumptions of the status quo and as a way to illustrate the carbon reduction potential of nontechnological interventions, such as a change in work commutes lowering vehicle miles traveled; urban and rural planning enabling a major increase in use of transit, biking, or walking; uptake of new high-efficiency net-zero and net-energy producing building designs; and a complete redesign of industrial processes to be low carbon.[3] Regardless of scenario, the results from this analysis should be considered as broadly directional, one in a range of possible paths to achieving deep emissions reductions.

[3] This scenario assumes an additional 20 percent reduction in demand in buildings and 33 percent reduction in industry. For transportation, it assumes 40 percent reduction in driving, 100 percent increase in transit and school buses and rail, and a 20 percent reduction in flying and other goods movement. It is similar to scenarios developed for other recent studies (Grubler et al. 2018; KeyBer and Lenzen 2021; IEA 2020; IPCC 2018; Nadel and Unger 2019).

HIGH-LEVEL FINDINGS FROM CARBON REDUCTION PATHWAYS

The carbon targets implemented here are ambitious, but this modeling makes clear that they can be technically achieved at reasonable costs, especially when weighed against the towering climate and health costs of a business-as-usual pathway. Every economic sector has to take action, and each has options available th*at are commercially available today* to deeply reduce carbon emissions. This assessment of technical feasibility broadly aligns with several recent studies that have explored technological deep decarbonization pathways (EDF 2021; Hultman et. al 2021; Larson et al. 2020; NAS 2021; NRDC 2021; Orvis and Mahajan 2021).

We highlight five key findings from the carbon pathways analysis, which set the stage for more detailed consideration below:

1. Deep cuts in heat-trapping emissions are feasible, within this decade and continuing through 2050, in line with rigorous climate targets.

2. To achieve these reductions, every sector of the economy must undergo transformative shifts, including through widespread uptake of energy efficiency, end-use electrification, and carbon-free energy (Figure 1); additional contributions are critical from nonmodeled emissions sources and sinks. Incremental technological improvements are ultimately vital for keeping costs low, but novel technologies were not found to be required to meet climate targets; a viable solution set is within our grasp today.

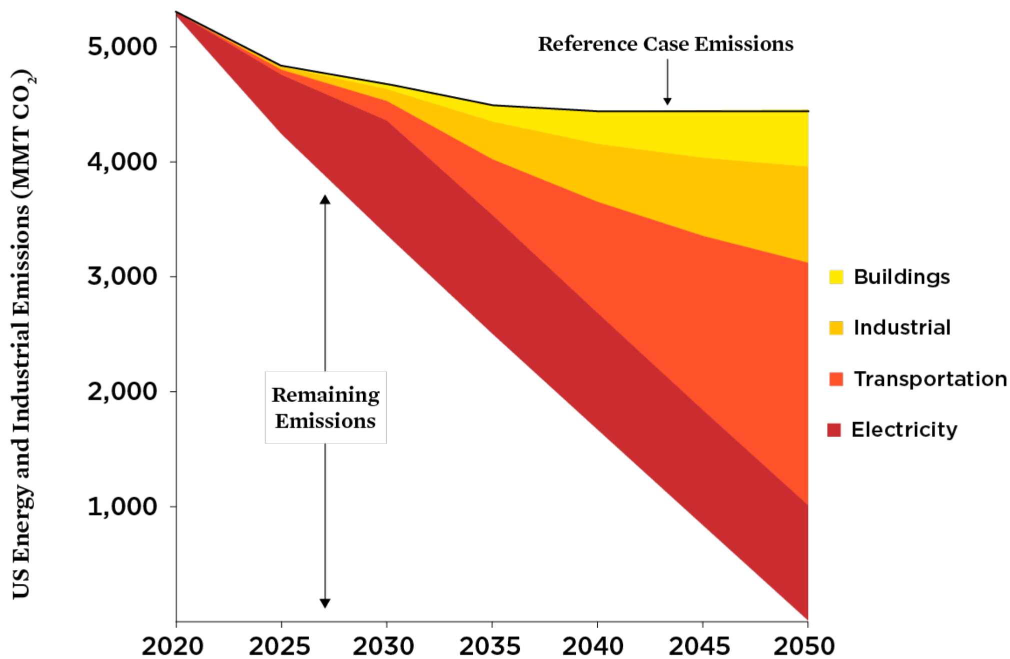
3. The system costs of this transition are comparatively modest—and easily outweighed when compared to the benefits of improved health and avoided climate impacts. Savings from reduced fossil fuel expenditures will either nearly or entirely offset system investments; still, near-term capital outlays could impact consumers if not proactively managed.

4. The technological path to meeting near-future carbon reduction targets is increasingly clear; the path to midcentury increases in uncertainty but provides important context for anticipating required change and laying the groundwork for it in advance. Delaying necessary near-term action is costly and risks stranding assets, foreclosing some solutions pathways, and probably falling short of climate goals.

5. Pathways for reducing carbon provide insights, not precise solutions; broader frameworks are required to shape pathway implementation and advance additional transition elements to achieve transformative change.

The exact path from here to 2050 is uncertain, but this analysis makes clear that we are equipped to pursue ambitious climate targets. It also highlights the pressing need to act; uncertainty in later decades does not diminish the increasing clarity of required near-term actions. And throughout, we see that a singular focus on carbon as opposed to broader systems will miss addressing the bigger picture.

Figure 1. US CO_2 Reductions by Sector, Zero CO_2 2050 Case



The power sector plays a key role in driving near-term emissions reductions and as more cars, trucks, homes, and businesses switch from fossil fuels to low-carbon electricity over time. By 2050, nearly half of total CO2 reductions come from transportation and 30 percent from industry and buildings.

SPOTLIGHT ON PATHWAYS AND BROADER IMPLICATIONS

Here, we look beyond the high-level findings to spotlight more detailed carbon reduction findings—as well as broader, nonmodeled implications. These implications include those prompted by the carbon-focused modeling results, as well as those fully omitted by the modeling framework used. They are not intended to be comprehensive, but rather examples of the importance of applying a multidimensional lens to a problem requiring multidimensional solutions. While the findings are laid out by sector, given how fossil fuels are woven throughout the economy and society there are, unsurprisingly, overlaps in issue areas, technological solutions, and broader implications across different sectors.

Power sector. The power sector has been dominated by fossil fuel–fired generators for decades, first coal and now gas. In pivoting to a deeply decarbonized economy, a low-carbon electricity system becomes key to unlocking economywide transition progress, resulting in the rapid and massive scaling of renewable electricity supply.

- **Power generation shifts from fossil fuels to predominantly renewables.** Wind, solar, and other renewables grow from 20 percent of US electricity generation in 2020 to 60 percent by 2030 and 90 percent by 2050 in the Zero CO_2 2050 case (Figure 2). Meanwhile, coal declines from 20 percent in 2020 to near zero in 2030, and gas declines from 40 percent in 2020 to 26 percent in 2030 and just 3 percent in 2050. Over the same period, nuclear power declines from 20 percent in 2020 to 15 percent in 2030 and 6 percent in 2050 as electricity generation more than doubles, some existing nuclear plants retire (though most are maintained through 2050), and new nuclear resources do not factor into the electricity mix.

- *Broader implication—Accounting for public health:* Coal- and gas-fired power plants are responsible for emitting large amounts of health-harming pollutants alongside CO_2; some of these facilities 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.

- **Use of electricity grows.** Electrification of end uses throughout the economy causes demand for clean electricity to grow over time, reaching 9 percent over 2020 levels by 2030 then nearly doubling between 2030 and 2050. Ambitious energy efficiency programs keep demand from growing far higher.

  - *Broader implication—Labor transitions:* The change in resource mix will lead to a profound shift in workforce needs and local economic investment, from the phaseout of fossil fuels to the ramp up of renewable resources, grid infrastructure, and energy efficiency. Proactive investments will be required on both sides of the equation to ensure a fair transition away from fossil fuels and widespread access to new good jobs meeting high-road labor standards.

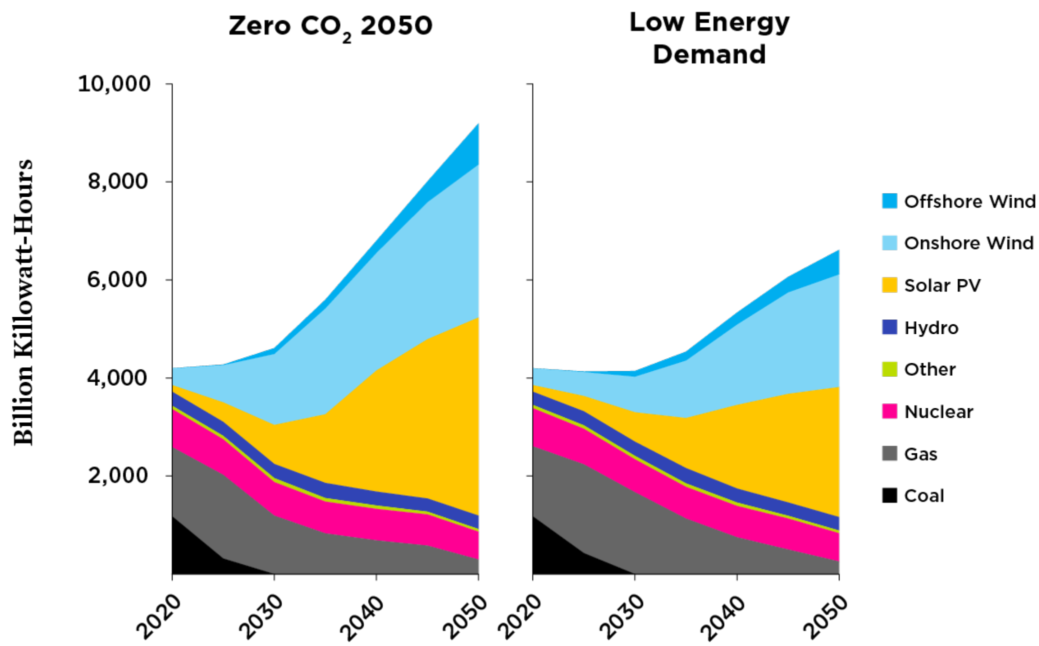
- **New clean energy infrastructure expands.** By 2030, annual average capacity additions for wind and solar roughly double recent levels, climbing to a full four to five times higher by 2050. A significant buildout of energy storage and transmission and distribution grid infrastructure is also required, with transmission capacity nearly doubling by 2050 to help move clean electricity around the country, even with significant deployment of distributed resources.

  - *Broader implication—Sustainability of new resources:* Implementing recycling and other end-of-life programs will be needed for wind turbines, solar panels, batteries, and other technologies to reduce the life-cycle impact of the energy sector and ensure that the clean energy transition to come does not perpetuate past unsustainable practices.

- **Societal shifts ease material transition requirements.** In the Low Energy Demand scenario, electricity use is flat through 2030 and then grows 56 percent between 2030 and 2050, resulting in a much-reduced need for new electricity capacity and supporting infrastructure compared to the Zero CO_2 2050 case.

  - *Broader implication—Challenging status quo:* The preponderance of energy transition policies focus on one-for-one replacements of carbon-free energy for carbon-emitting energy, without substantially considering investments that could facilitate broader societal shifts resulting in lower overall energy use while maintaining healthy, prosperous lifestyles. This modeling demonstrates the value of incorporating such options into transition analyses.

Figure 2. US Electricity Generation by Fuel, Zero CO_2 2050 and Low Energy Demand Cases

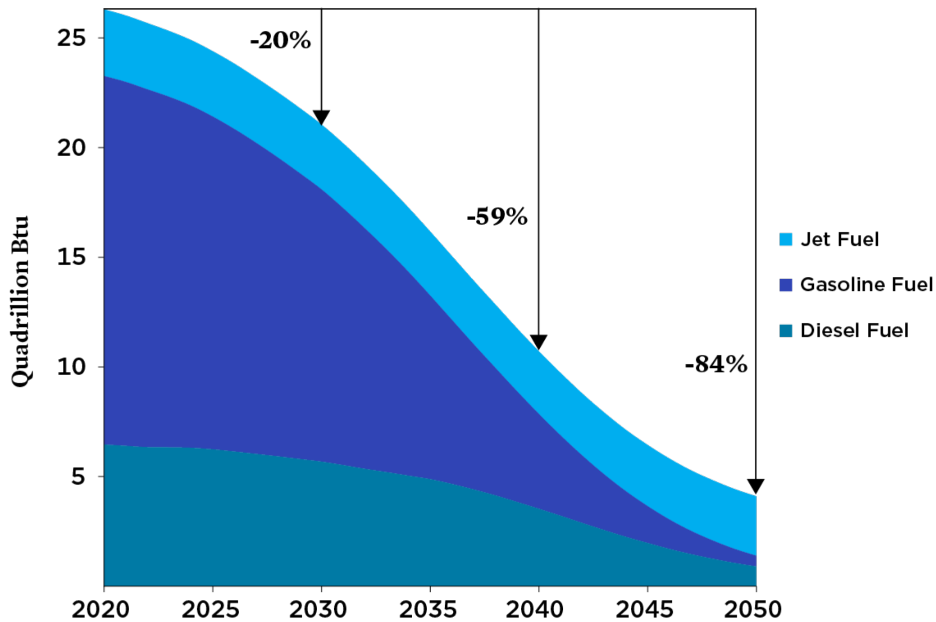


Wind and solar play a key role in decarbonizing the power sector, as coal generation is phased out by 2030 and gas generation steadily declines over time. By 2050, wind, solar, and other renewable energy sources provide about 90 percent of US electricity generation, with nuclear and gas providing the remaining 10 percent. Growth in electricity demand is far lower in the Low Energy Demand case, which reduces the need for new infrastructure.

Transportation. The transportation sector, including both personal mobility and goods movement, is now the largest source of carbon emissions in this country, overwhelmingly from combustion of gasoline, diesel, jet fuel, and other petroleum fuels. Decarbonizing transportation requires investments and policies that expand access and livability while reducing the total amount of private car travel and goods movement, rapidly electrifying vehicles, improving efficiency, and replacing liquid fuels with low-carbon alternatives. These measures can reduce liquid fuel use 20 percent by 2030, 60 percent by 2040, and more than 80 percent by 2050 (Figure 3).

- **Access and mobility choices are expanded.** Expanding the reach, reliability, and safety of public transit, active transportation, and other shared transportation services—as well as rethinking land use planning—can expand access to personal mobility while reducing driving. Together with other policies that support affordable sustainable communities, a transportation system with affordable, accessible, and integrated transportation options can reduce dependence on private car trips and overall energy demand.
    - *Broader implication—Challenging status quo:* Some decarbonization options are unlocked only through structural shifts enabling broader societal change. These structural shifts include prioritization of interventions such as increasing the availability and affordability of transit, along with making coordinated investments in affordable, denser residential and commercial development near transit. These are powerful solutions but not readily modeled here as an alternative means for meeting projected travel needs.

Figure 3. US Transportation Liquid Fuel Use, Zero CO_2 2050 Case



Rapidly transitioning to zero-emission vehicles, powered by both batteries and fuel cells, and making vehicles more efficient can greatly reduce the use of fossil-based liquid fuels. The use of gasoline, diesel, and jet fuel drops 84 percent by 2050, as all new light-duty passenger vehicle sales are zero-emission by 2035 and all new medium- and heavy-duty vehicles sales are zero-emission by 2040.

- **All vehicle types are rapidly transitioned to electric, and efficiency of vehicles and transportation systems is improved.** Achieve 100 percent sales of battery and fuel cell electric vehicles for personal cars and trucks by 2035 and medium and heavy-duty trucks by 2040. Simultaneously maximize efficiency of all types of vehicles and modes of travel and goods movement, including increasing the efficiency of internal combustion engine vehicles in the near term, as they will remain a large share of vehicle sales for the next decade and of the fleet through the mid-2040s.

    - *Broader implication—Countering pollution harms:* Transportation electrification can reduce exposure to harmful tailpipe pollution, which disproportionately burdens Asian, Black, and Latino communities (Reichmuth 2019). Prioritizing the accrual of public health benefits in overburdened communities to address these harms requires program designs that explicitly consider public health impacts rather than focus on carbon alone.

- **Remaining liquid fuels are decarbonized.** Air pollution from combustion, limited availability and high costs of decarbonized liquid fuels, and competing uses of inputs make minimizing liquid fuel use in transportation critical. For aviation and other applications where a full transition to zero-emission technology may be more difficult, remaining liquid fuels can be decarbonized through a combination of biofuels, synthetic liquid fuels produced from renewable electricity, and carbon capture to address emissions from remaining petroleum use.

    - *Broader implication—Sustainability of transition:* Production of petroleum, biofuels, and other liquid fuels each involve a unique set of risks and potential harms across the full supply chain, from extraction and resourcing, to transporting, to refining and producing, that must be addressed with safeguards and community and stakeholder involvement.

Buildings. Emissions from the buildings sector result from the energy used to power the places we live and work, from heating and cooling to keeping the lights on. By converting oil and gas end uses to electric and improving the efficiency of homes and appliances across the board, direct emissions from buildings (i.e., not including indirect emissions from electricity use) can be reduced by 17 percent between 2020 and 2030 and 90 percent by 2050.

- **Efficiency of new and existing homes and businesses is increased.** Weatherizing and insulating homes and businesses and installing high-efficiency equipment reduces energy use in buildings while saving money and increasing health and comfort. By 2030, we assume high efficiency for all new lighting, all new residential building shells, and nearly 90 percent of new air conditioners (most of which are reversible heat pumps), refrigerators, washers, dryers, and other appliances.
    - *Broader implication—Enhancing climate resilience:* While striving to mitigate climate impacts, communities will also be increasingly confronted with climate impacts. Weatherizing and improving the efficiency of homes can simultaneously lower energy needs and provide critical protection in the event of power outages from extreme weather events.
- **Buildings are converted to run on electricity.** Converting gas, oil, and propane boilers, furnaces, and water heaters to highly efficient electric heat pumps can significantly reduce emissions from buildings while saving consumers money on energy bills, as well as provide access to cooling in the summer. By 2030, more than half of sales for new heating systems are assumed to be heat pumps, up from 14 percent in 2020. Electric cooking sales share increases from 62 percent in 2020 to 83 percent by 2030, reducing emissions and providing public health benefits by improving indoor air quality.
    - *Broader implication—Countering pollution harms:* There exist long-standing inequities in the quality, health, and affordability of the nation's housing stock, which in many cases is a direct result of structural racism. Some aspects of health-harming indoor air pollutants, such as from gas-fired stoves, can be addressed through electrification initiatives; these initiatives must explicitly prioritize equity so as to drive investments accordingly.
- **Rooftop solar is widely deployed and electricity use is made flexible.** More than 110 gigawatts (GW) of rooftop and distributed solar is installed on more than 12 million homes and businesses by 2030, increasing to 500 GW on 55 million homes and businesses by 2050. Electricity loads that can be made flexible, from electric vehicle charging to water heating, are optimized to increase use of renewables and lower system costs (McNamara 2020).
    - *Broader implication—Broadening access:* Rooftop solar can lower energy burdens, build wealth, increase resilience to power outages, and lessen the need for fossil fuel generation. However, access has not been evenly shared to date; explicit policy intervention is required to improve access and overcome financial and procedural barriers.

Industry. The industrial sector manufactures goods and materials. Industry consumes a large amount of fossil fuels onsite, including for energy, heat, and as a chemical feedstock. Redesigning industrial processes to reduce energy use significantly and substitute fossil fuels and materials with zero-carbon resources can lower emissions, reduce waste, and increase productivity.

- **Onsite efficiency is increased.** We assumed investments in energy efficiency in industry would result in a 2 percent annual reduction in industrial energy intensity (measured in energy use per dollar of industrial output) between 2020 and 2050 in the Zero CO_2 2050 case, twice as much as historical levels. Strategic energy management and increased deployment of smart manufacturing—including optimizing motor, fan, pump, and compressed air systems—represent underutilized opportunities that exist today that could reduce energy use by an estimated 20 percent (Nadel and Unger 2019).

    - *Broader implication—Challenging status quo:* Onsite efficiency adjustments improve the system as it is; systems-level interventions can shift full consumption pathways. This contrast is acutely important to understand if we are to change unsustainable consumption patterns requiring interventions far outside the reach of individual actors.

- **End uses are electrified and made flexible.** Opportunities exist to increase electrification of industrial process heating in the iron and steel, pulp and paper, glass, aluminum, and petroleum refining industries, which account for 60 percent of all energy used for process heating in the United States (Kirin et al. 2019). Interconnecting energy use across sectors can optimize use of renewables by matching flexible loads with clean energy supply, such as with dual-fuel electric boilers and electrolyzers.

    - *Broader implication—Countering pollution harms:* The industrial sector is a major source of air, water, and ground pollution, all of which is discounted or omitted in carbon-prioritization frameworks. Incorporation of public health and environmental impacts of pollution, including in communities suffering cumulative pollution burdens, can lead to the prioritization of non-combustion solutions.

- **Remaining fuels are decarbonized and carbon emissions captured.** Emerging technologies suggest new pathways to reducing hard-to-electrify industrial systems, including using hydrogen as both a fuel and a reactant, switching to bio-based feedstocks, and using engineered wood products to replace steel and cement in buildings (Nadel and Unger 2019). With contemporary options, the model deploys carbon capture and sequestration (CCS) to reduce CO_2 emissions by 580 million metric tons (MMT), or about 13 percent of economywide reductions by 2050, under the Zero CO_2 2050 case, and by 430 MMT, or nearly 10 percent, in the Low Energy Demand case. Most of this CCS is applied to biofuels facilities using low-carbon energy crops and agricultural residues; the remainder is in the cement, steel, and chemical industries.

    - *Broader implication—Process and governance:* Some amount of CCS is likely to be needed, particularly to lower industrial process carbon emissions. However, this technology comes with other societal and environmental risks that also need to be mitigated, and some applications considering the use of CCS could deploy non-CCS alternatives, such as electrification, instead. Community involvement in decisionmaking, including evaluating options and implementing safeguards, is essential (Box 3).

Notably, the modeling finds that the net system costs of transitioning our energy system as above are comparatively modest, though there is a significant shift in where investments are made. To reach net-zero emissions by 2050 in the Zero CO_2 2050 scenario, there is a net cost of $45 billion by 2030 and $155 billion by 2050, the result of $830 billion in investments against $675 billion in savings from reduced fossil fuel use. With its significantly lower infrastructure requirements, the Low Energy Demand scenario requires lower investment outlays. Ultimately, investments will create jobs, benefit local economies, and grow clean energy industries, but the shift in where investments flow can mean profound impacts for certain industries, workers, and communities.

Box 3. Making Space for Decisionmaking about Challenging Trade-Offs

Our analysis starts with where we are today—with a fossil fuel–dependent economy that has arisen from flawed technologies, policies, and practices that are embedded with structural racism and classism—and from there seeks pathways to transition to a low-carbon energy system. The results and their implications point to rich opportunities ahead that can directly benefit communities. Yet, with that unavoidably problematic starting point, the transition itself is not without challenges.

Two key points emerge clearly: (1) there are multiple pathways to achieve our emissions reduction goals; and (2) the core solution set consists of energy efficiency, renewable energy, and electrification, all of which drive deep and absolute cuts in heat-trapping emissions. We further find that transformational societal shifts enabling significantly lower energy consumption could result in far lower use of energy resources overall, thereby creating additional opportunities for a more equitable transition.

Nevertheless, to meet stringent science-based emissions reduction targets within a climate-relevant timeframe, our modeling shows the potential for a relatively limited deployment of technologies that involve other significant societal and environmental risks and trade-offs. Even with ambitious and rapid adoption of preferred solutions in the energy and land sectors, our results show that some technological CCS and negative emissions technologies will likely be necessary to help meet the goal of keeping the global average temperature increase well below 2°C. These technologies include CCS in the industrial sector, biofuels in the transportation sector, and existing nuclear power in the electricity sector.

These technologies are generally viewed as false solutions by environmental justice communities (Amorelli, Gibson, and Gilbertson 2021), many of whom are legitimately concerned that they will be asked to disproportionately bear the environmental, health, and social costs of these technologies, as they have long borne the costs of fossil fuel technologies. Such an outcome would be unjust and unacceptable. Even the implementation of preferred solutions will inevitably involve some risks and challenging trade-offs and choices, such as decisions about siting transmission, solar photovoltaics, and wind turbines. As a country, we will need to be mindful of our past and ongoing choices that have contributed to structural racism, climate change, and societal inequities and injustices as we structure our future technology decisions. Communities that have been historically marginalized must have the power to choose solutions that they need and reject those they do not, and we need robust governance and decisionmaking processes that provide them the voice and autonomy to do so.

The deployment of less-preferred technologies may increase if policymakers further delay adoption of robust climate policies or if we run into technical or other challenges in scaling up renewable energy quickly enough. This risk reinforces the urgent need for ambitious, effective policies centered on core clean energy technologies and on meaningful consultation with affected communities, which must start at the outset of all policymaking processes. Although we may not be able to escape difficult choices entirely, we must not simply default to imposing the burden of those choices on the same communities that have suffered past injustices. We hope this framework and analysis can serve as a springboard for innovative thinking and new, more equitable and just solutions.

III. Coupling Principles and Pathways to Identify Policy Opportunities

For climate-responsive policies to address equally urgent broader societal priorities, they must center these priorities from the outset, with direct community input. Here, we couple the three principles for a transformative energy transition with the pathways mapped to identify critical policy levers. To achieve fully transformative change, this coupling of principles and carbon reduction pathways must be interwoven throughout the development of all clean energy transition policies.

EFFECTIVELY ADDRESS THE CLIMATE CRISIS

Achieve robust reductions of heat-trapping emissions. US climate action must drive deep, rapid, and sustained reductions in heat-trapping emissions, including robust near-term targets and direct, absolute emissions reductions wherever possible. Policy interventions include the following:

- Regularly review the latest science and adapt climate targets accordingly.
- Within a broad multipollutant strategy, establish climate policies tied to climate targets to provide guardrails within which other sectoral policies are advanced, such as a target-driven clean energy standard for the power sector, zero-emission vehicle standards for transportation, and performance standards for buildings and industry.
- Incorporate monitoring and enforcement mechanisms into target-driven policies to ensure actions are meeting intended emissions reduction amounts.
- Be vigilant about greenwashing and ensure that the framing of net-zero emissions targets is true to the science and not used as a loophole to avoid deep, absolute cuts in emissions.

Enhance climate resilience. Energy transition pathways should simultaneously boost resilience to anticipated climate impacts. Some approaches are particularly helpful on this front. Weatherizing homes improves efficiency year-round *and* helps keep temperatures safer for longer should power go out; transitioning to heat pumps decarbonizes space heating *and* increases access to air conditioning as exposure to extreme heat rises. Distributed solar, batteries, electric vehicles, and clean energy microgrids can provide communities and critical infrastructure sustained access to electricity during power outages following severe weather events, while avoiding the use of dirty diesel generators. Policy interventions include the following:

- Prioritize existing low- and middle-income housing for efficiency upgrades and conversion to heat pumps, with benefits passed through, coupled with broader clean energy, climate resilience, and building upgrades; actively protect against the potential for ensuing gentrification and displacement; and ensure all new housing is highly efficient and resilient.
- Require consideration of climate impacts on supply and demand in energy modeling and resource planning processes as well as transportation and land use planning.
- Analyze and value resilience contributions of decentralized resources and community clean-energy microgrids.
- Require new infrastructure to be built and maintained for impacts expected over the lifetime of equipment, and provide incentives to ensure resilience.
- Advance a right to affordable clean energy and transportation as a critical tool for surviving extreme weather events.

ADVANCE EQUITY AND JUSTICE

Facilitate participation in, and governance of, resource decisions. As decisions arise over the energy transition options ahead, communities must be given a say. This holds true for issues shared across scenarios, such as the siting of large amounts of renewables and related infrastructure. It is also true when pathways diverge and varying preferences and priorities can result in different decarbonization choices by different communities; one example is the relative costs and benefits of distributed versus large-scale resources. Adherence to inclusive processes and local governance will become only more important as delays in action force ever greater trade-offs and ever harder choices. Policy interventions include the following:

- Empower impacted and historically oppressed communities to participate fully and fairly in the decisionmaking process, including by ensuring the removal of obstacles to ready participation, such as resources, language barriers, and schedules.
- Require incorporation of meaningful public participation and intervenor compensation in regulatory decisions at the local, state, and federal levels.
- Open avenues for public ownership at multiple scales, empowering communities to take control of functions traditionally controlled by investor-owned utilities and public utility commissions.
- Ensure community representation, inclusive taskforces, and effective reflection of community concerns and desires to inform choices, especially around hard choices that may involve trade-offs.

Broaden access to clean and affordable energy and mobility. The transition to a low-carbon economy will produce significant economic and health benefits, from massive deployment of capital for building renewable resources and clean transportation infrastructure; to cleaner neighborhood air resulting from electrification of buses and heavy freight; to healthier, cheaper, and more comfortable homes via electrification of appliances and deep energy efficiency retrofits; to cleaner, lower-cost and more convenient transportation options. How these benefits accrue, however, will be dictated by who has access. Today, that access is inequitably shared. Policies must actively intervene to counter this imbalance or risk furthering existing inequities (Generating Equity 2021). Such intervention must include opportunities at the individual level, such as clean and efficient appliances, home weatherization, electric vehicles, and rooftop solar and battery storage. It must also include opportunities at the community level, such as direct investment in the local tax base, footholds for new businesses and community ownership, systemic shifts to enable reduced consumption, and investments in affordable public transit. Policy interventions include the following:

- Enable and promote community ownership models, where appropriate.
- Counter historical inequities in access with explicit targeting of benefits, such as through income and community carve-outs or location-specific investment multipliers, for individual-level and systems-level programs.
- Enable direct pay or refundability for clean energy and clean transportation tax credits to broaden accessibility of widely used financing mechanisms.
- Implement clean energy financing approaches to increase access to low- and zero-interest financing for clean energy projects in marginalized and historically underinvested communities.

- Shift regulatory and program evaluation frameworks from cost-benefit calculations to full valuation of health and wellness attributes, including for benefits that cannot be quantified or monetized, and explicitly account for distributional impacts.

- Develop transportation project evaluation criteria that prioritize increased access to jobs and services, particularly for communities with a history of inequitable investment.

Counter past and ongoing harms of fossil fuels. As we transition to cleaner resources, polluters must be held accountable when rectifying past and ongoing harms from fossil fuels. Furthermore, while electrification via renewable resources will come to dominate the energy system, there will be lingering sources of pollution for some time. Such issues as where these polluting facilities and other end uses are sited, how they are operated, whether noncombustion alternatives are considered, and the degree to which public health impacts are valued must all be addressed. Policy interventions include the following:

- Strengthen air and water pollution standards, broaden regulations to incorporate cumulative pollution burdens, and ensure that polluting sources are actually covered and standards enforced.

- Advance multi-pollutant strategies that maximize public health benefits and directly reduce cumulative pollution burdens in environmental justice communities, for example by shutting down the most harmful fossil fuel plants and extraction sites, reducing emissions at refineries in polluted and populated areas, and investing in eliminating diesel pollution.

- Install and maintain air pollution monitors in overburdened and underserved communities.

- Require full remediation and reclamation of legacy fossil fuel sites and infrastructure, including toxic sites of former polluting sources, as well as abandoned coal mines, oil and gas wells, and coal ash ponds.

- Facilitate community-guided redevelopment of former industrial and brownfield sites.

- Target heavy-duty freight electrification near freight corridors and ports and mitigate truck traffic in communities with intermodal and warehousing clusters.

- Prioritize consideration of health impacts for workers and communities when weighing resource alternatives.

Address labor and community impacts of energy transition. The transition to a low-carbon economy promises the potential for enormous job growth in emerging clean energy fields, from renewables deployment to clean technology manufacturing. It will also require a shift away from our present heavy reliance on fossil fuels. A fair and equitable transformation of the energy system requires intentional, robust, and sustained investments in the workers and communities that have long helped to power this country (Richardson and Anderson 2021). Those investments, combined with centering local leadership, can help prepare workers for new opportunities and support communities in diversifying their economies and cleaning up legacy pollution. Emerging business, manufacturing, and investment opportunities must be broadly accessible and new jobs must pay well and offer good benefits for the clean energy transition to address existing economic inequality. Policy interventions include the following:

- Fund fossil fuel worker and community transition support as national energy consumption shifts from legacy fuels to clean resources.

- Establish high-road labor standards as a required clean energy funding qualifier from the outset.
- Ensure job training facilities are spread across communities, with inclusion of place-based opportunities and skills, and require equitable, affordable access to training and subsequent jobs.
- Deploy federal resources to facilitate intentional transition of manufacturing facilities for clean energy and electric vehicle opportunities, and invest in domestic manufacturing and supply chains.
- Fund incentives for Black, Brown, and Indigenous-owned clean energy businesses, and address barriers to achieving a diverse workforce.
- Develop more holistic approaches to advance a fairer society, with equitable access to education, health, housing, and employment and robust publicly provided services to meet essential needs.

Advance a proactive approach to sustainability of transition. Clean energy technologies have the potential to improve sustainability outcomes significantly but will fall short if full consideration of external costs from resource extraction, consumption, and disposal is not made a priority from the outset. Rigorous life-cycle analyses should be conducted to compare alternatives across the full suite of impacts—not just carbon, and not just at point of use—and resource recycling should be proactively engineered from the outset for technologies such as coolants, batteries, solar panels, and wind turbines. Biofuels used for transportation, power, or industrial processes must be responsibly sourced and limited to a sustainable scale. Such standards must apply to domestic and imported resources. Policy interventions include the following:

- Set, implement, and enforce standards to manage clean energy product lifecycles sustainably, including end-of-life requirements, and provide incentives for efficient end-to-end engineering.
- Require rigorous life-cycle analysis in energy transition pathway considerations, and support development of consistent frameworks for comparing impacts of divergent pathways.
- Ensure that use of agricultural or forest products for biofuels, bioenergy, or other bioproducts are responsibly sourced and used at a scale that avoids food insecurity or unaffordability or expansion of agriculture and plantation footprints at the expense of community livelihoods, natural forests, and other critical ecosystems.
- Develop, implement, and enforce policies to ensure responsible resource extraction in domestic and international supply chains and the protection of human rights and fair market practices.

DRIVE SYSTEMIC, NOT JUST INCREMENTAL, CHANGE

Challenge assumptions about the status quo. Today's energy system fails too many, from the quarter of US households—and two-thirds of low-income households—facing high energy cost burdens (Drehobl, Ross, and Ayala 2020), to the thousands in this country dying prematurely from fossil fuel pollution each year. Clean energy solutions that unquestioningly conform to present systems and structures threaten to sustain embedded inequities long into the future. The pull of the status quo results in a lean toward energy transition solutions that align with the broader system as it is instead of toward novel solutions for how it can be. For example, defaulting to CCS for industrial facilities instead of exploring noncombustion alternatives risks perpetuating inequities. So would swapping low-occupancy internal combustion engine vehicles for low-occupancy electric vehicles without substantively exploring systemic solutions for significantly reducing overall total driving. Such assumptions and inclinations must be repeatedly challenged. Policy interventions include the following:

- Interrogate traditional base-case assumptions, incorporate examination of nonincremental alternatives, fundamentally reimagine federal funding formulas, and change the measures used to evaluate transportation investments.
- Maintain a diversity of viewpoints in all stages of discussions, remove obstacles to participation in decisionmaking processes by historically marginalized communities, and expand power sharing.
- Promote, facilitate, and empower community science and community-based monitoring of air, water, and other environmental pollution.
- Adopt frameworks that promote selection of policy approaches and technological solutions that advance multiple priorities, not just carbon reduction.

Address market rules and structures that impede transformative change. The 21st-century power system must be much more flexible and decentralized than the current one and must account for broader societal costs such as the public health costs of pollution. We need new utilities models that include a mandate to deliver clean, affordable electricity and that are accountable to impacted communities; these models may include public and community ownership structures that enhance democratic accountability and empower communities to achieve their own visions of the clean energy future. Public policy must more assertively balance the need for significant infrastructure buildout alongside robust stakeholder engagement for siting and permitting decisions. Policy interventions include the following:

- Enforce rigorous accountability mechanisms at local, state, regional, and federal levels to ensure electricity operators, public or private, are truly responsive to, and directed by, the people they are intended to serve.
- Create frameworks for the viability of public ownership and local community investment in clean energy.
- Adopt frameworks that incorporate the full value of distributed resources, flexible demand, and energy storage for the grid services they provide, and revisit the governance of energy markets that has allowed for systematic discrimination against cost-effective clean energy resources.
- Elevate the voices of the public and require incorporation of public feedback.

Sharply phase down fossil fuel infrastructure and use. With the urgent need to tackle the climate and public health crises caused by fossil fuels, the nation simply cannot afford to—and does not need to—continue to build out long-lived fossil fuel infrastructure in a business-as-usual manner (IEA 2021). In limited situations, some existing and new infrastructure may be needed. Overall, though, the United States must apply a clear-eyed, systems-level perspective and phase down its fossil fuel dependence rapidly. Policy interventions include the following:

- Apply a systems-level consideration to fossil fuel planning, in part by adopting a default position of rejecting new fossil fuel infrastructure and resource development, including roadway expansions, that allows exceptions only in very limited circumstances that do not perpetuate environmental injustices.

- Confront systems that have perpetuated racist outcomes in the siting, construction, and continued operation of fossil fuel infrastructure and prioritize phaseouts in communities most heavily burdened.
- Address market failures that keep fossil fuels in use even when they are not aligned with economics, policy designs, and climate targets.
- Ensure that the wind-down of fossil fuel infrastructure actively manages leaks of heat-trapping pollutants and remediates harms to water and land.
- Require consistent, comparable, and reliable climate risk disclosure and hold fossil fuel companies—and the financial entities that back them—accountable for quickly transitioning their business models and investments to be aligned with climate goals.

IV. Looking Ahead to Transformative Change

Addressing the nation's compound crises of climate change, structural racism, and growing income inequality requires intersectional solutions and a whole-of-society approach. As we unbraid carbon emissions from every facet of our economy, we have an imperative to reform our systems for the better. Transformative changes to the energy system can sharply cut heat-trapping emissions while ensuring benefits to all communities, in particular those who have been left marginalized or harmed by the current system.

We do not have time to waste. To seize the considerable health and economic benefits of a just and equitable clean energy transition, policymakers and stakeholders at every level must be engaged. Federal, state, local, and Tribal governments must work together in close coordination to drive robust policies and investments. Agencies with mandates that are connected to achieving a just and equitable clean energy transition—including air pollution agencies, transportation agencies, energy agencies, utility commissions, housing agencies, regional transmission organizations, and the Federal Energy Regulatory Commission—must take on the full scope of this work. Direct and authentic dialogue with locally impacted communities, many of whom have already put forth important policy recommendations, will help ensure that each can shape and directly benefit from these changes.

The route from here to 2050 and beyond is rife with uncertainty, demanding humility in the face of assumptions about technology costs and performance, the state of innovation, the potential for societal transformation, and evolving climate impacts. And yet, as shown here, still we see a path to a better future, fundamentally different from the broken, unsustainable, and harmful business-as-usual trajectory. Furthermore, the path to 2030, a critical milestone on the way to midcentury transformation, is coming crisply into view, requiring major—and achievable—leaps forward on renewables deployment and coal phaseout, rapid vehicle electrification, wide-scale implementation of energy efficiency and weatherization, and initiation of industry evolution. This must all be coupled with supporting grid upgrades and buildout in preparation for much higher levels of variable resources and far larger future growth of electricity demand, with diligent attention to reductions in non-CO_2 emissions, and with active, intentional management of the agriculture, land, and forestry sectors.

Even more compelling than these model findings, however, is that which falls outside the technological targets and numbers: the benefits to people that will come from embracing the urgent, unequivocal need and opportunity for a transformative energy transition with justice and equity interwoven throughout. This is the bold and exciting vision that we are called to bring to reality, so that communities around the country and future generations can thrive in a healthier, more sustainable society.

This report was a collaborative effort between the Union of Concerned Scientists and an expert advisory committee. Advisory committee members include Ted Boettner, Ohio River Valley Institute; Chandra Farley, Partnership for Southern Equity; Brett Isaac, Navajo Power; Jackson Koeppel, Soulardarity; Dr. Monica Unseld, Until Justice Data Partners; and Dr. Shelley Welton, University of South Carolina School of Law. The Union of Concerned Scientists report author team includes Youngsun Baek, Rachel Cleetus, Steve Clemmer, Camilo Esquivia-Zapata, Jeremy Martin, Julie McNamara, Cecilia Moura, Sital Sathia, and Sandra Sattler. Modeling was conducted by Ryan Jones of Evolved Energy Research.

ACKNOWLEDGMENTS

This report was made possible by the generous support of the Heising-Simons Foundation, the Joyce Foundation, the John D. and Catherine T. MacArthur Foundation, the Rauch Foundation, and members of the Union of Concerned Scientists.

The authors would like to thank the following people for their thoughtful review of the report: Rachel Fakhry and Starla Yeh, Natural Resources Defense Council; Tom FitzGerald, Kentucky Resources Council; Christina H. Fuller, Georgia State University School of Public Health; Haley Havens, Institute for Energy Justice; Tina Johnson, Johnson Strategies; and Alice Kaswan, University of San Francisco School of Law.

The authors are also grateful to colleagues at the Union of Concerned Scientists for their thoughtful feedback and support, especially Don Anair, Angela Anderson, Colin Byers, Katherine Catalano, Jeff Deyette, Peter Frumhoff, Paula Garcia, Brandon Gibbs, Jonna Hamilton, Adrienne Hollis, Elizabeth Irvin, Brian LaShier, Jiayu Liang, Lisa Nurnberger, Jeremy Richardson, Megan Rising, and Michelle Robinson, and former colleagues Eyal Li, Anusha Narayanan, and Ashanti Washington.

Special thanks go to Leslie Brunetta, Cynthia DeRocco, Gillian Esquivia-Cohen, Michelle Rama-Poccia, Heather Tuttle, Bryan Wadsworth, and Pamela Worth for their roles in the report's editing, translation, and production.

Organizational affiliations are listed for identification purposes only. The opinions expressed herein do not necessarily reflect those of the organizations that funded the work or the individuals who reviewed it. The Union of Concerned Scientists bears sole responsibility for the report's contents.

GLOSSARY OF KEY TERMS

Carbon budget: An estimate of the net cumulative heat-trapping emissions that can still be released into the atmosphere while keeping global average temperatures below critical thresholds, such as well below 2°C. Apportioning the global carbon budget to individual countries requires making critical assumptions about equity and fairness, given that richer countries that industrialized first have already used up a disproportionate share of the carbon budget since the Industrial Revolution began.

Carbon capture and storage (CCS): A technological process by which CO_2 that is a byproduct of industrial or energy-generating processes is separated, compressed, and transported via pipelines to long-term underground storage sites rather than being released into the atmosphere.

Carbon sink/Land sink: Any repository of heat-trapping emissions, such as oceans, forests, and soil. *Land sink* refers to any land-based sink.

Climate resilience: The ability of communities, ecosystems, or infrastructure to withstand and recover from climate impacts such as flooding, extreme heat, droughts, and wildfires.

Energy democracy: A term that has been defined by community-based groups to mean working to advance an energy system that is both cleaner and fairer. Below are two examples of how this term has been defined.

> **Energy democracy** is a way to frame the struggle of working people, low-income communities, and communities of color, and their allies, to take control of energy resources and decisionmaking from the corporate energy establishment and use those resources to empower their communities.
>
> It means a decentralized energy system, one characterized by social and community-based control and ownership of energy resources, a shared resource developed in harmony with the Earth ecosystems.
>
> Democratizing energy is a central aspect of just transition from a fossil fuel economy to a new renewable energy economy grounded in economic and social justice.
>
> *—Fairchild and Weinrub 2017; The Energy Democracy Project, n.d.*
>
> **Energy democracy** represents a shift from the corporate, centralized fossil fuel economy to one that is governed by communities, is designed on the principle of no harm to the environment, supports local economies, and contributes to the health and well-being for all peoples.
>
> *—Climate Justice Alliance, n.d.*

Environmental justice: The US Environmental Protection Agency (EPA) defines environmental justice as follows:

> Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. This goal will be achieved when everyone enjoys:
>
> - The same degree of protection from environmental and health hazards, and
> - Equal access to the decisionmaking process to have a healthy environment in which to live, learn, and work.
>
> *—EPA, n.d.*

The Environmental Justice for All Act, first introduced in February 2020 and reintroduced in March 2021, has a similar definition:

> The term *environmental justice* means the fair treatment and meaningful involvement of all people regardless of race, color, culture, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies to ensure that each person enjoys—
>
> (A) the same degree of protection from environmental and health hazards; and

(B) equal access to any federal agency action on environmental justice issues in order to have a healthy environment in which to live, learn, work, and recreate.

—from the Environmental Justice for All Act (116th Congress)

Equity: Essentially, the principle of fairness. In practice, *equity* can refer to fairness of outcomes (fair sharing of the costs and benefits of a policy, for example); fairness based on characteristics such as income, gender, and race; fairness across timeframe (intergenerational equity); or fairness in processes and governance (procedural equity).

Fair transition: Sometimes called "just transition" (Brecher 2015), the concept that workers and communities adversely impacted by a shift away from fossil fuels should have access to comprehensive, robust, and sustained resources to manage the changes, including through income supports and workforce development opportunities for affected workers, reclamation and remediation of impacted sites to clean up legacy pollution, and support of long-term community-led economic development and diversification (BGA 2021; JTF 2020).

Fenceline community: A community that is located near the boundaries of a power plant or other industrial facility and therefore at greater risk of pollution from that facility.

Intersectional solutions: Solutions that incorporate the interconnectedness of human and natural systems and work across problems in a multidimensional way.

Low-income communities: Communities that have a high proportion of households living in poverty. The official US Treasury definition of a low-income community is a census tract where the poverty rate is at least 20 percent or where the median family income does not exceed 80 percent of statewide median family income.

Net-zero emissions: A state achieved when total human-caused heat-trapping emissions are balanced by emissions that are absorbed by land or ocean sinks and technological removal methods over a particular period of time. This can be defined relative to a single gas (e.g., CO_2) or multiple heat-trapping gases. In this report, *net zero* is specifically *not* used to describe offsets under a market-based emissions trading system, nor intended as a loophole to avoid or delay deep, absolute reductions in heat-trapping emissions.

Public participation/Public engagement: A process that provides a meaningful opportunity for stakeholders (individuals, communities, organizations) to inform and shape a decision and incorporates the framework that "those closest to the problem are the ones closet to the solution" (Parnell 2018). Public participation/engagement should be a continuous effort that takes into consideration access to information, funding, meetings/convenings, and translation. Additionally, as shared by Indigenous communities, in respect to the information received from stakeholders, "consultation is not consent."

Remediation: The cleanup of environmental pollution from historical and ongoing energy and industrial activities, the harms of which have been disproportionately borne by communities of color, via a remedy to restore an area as close to its unpolluted condition as possible. Remediation can both reduce harmful environmental and health impacts and create jobs and open new economic opportunities in places that have been restored.

REFERENCES

Abhyankar, N., P. Mohanty, and A. Phadke. 2021. *Illustrative Strategies for the United States to Achieve 50% Emission Reductions by 2030.* Berkeley, CA: Lawrence Berkeley National Laboratory, Energy Analysis and Environmental Impacts Division. https://eta-publications.lbl.gov/sites/default/files/us_50_percent_ndc_memo_finalap.pdf

ALA (American Lung Association). 2021. "State of the Air." Chicago. https://www.lung.org/research/sota

Amorelli, L., D. Gibson, and T. Gilbertson (eds.). 2021. *Hoodwinked in the Hothouse: Resist False Solutions to Climate Change,* third edition. Climatefalsesolutions.org. https://climatefalsesolutions.org/wp-content/uploads/2021/04/HOODWINKED_ThirdEdition_On-Screen_version.pdf

BGA (BlueGreen Alliance). 2019. *Solidarity for Climate Action*. Minneapolis, MN. http://www.bluegreenalliance.org/wp-content/uploads/2019/07/Solidarity-for-Climate-Action-vFINAL.pdf

BGA (BlueGreen Alliance). 2021. *BlueGreen Alliance National Energy Transition Policy Framework.* Washington, DC. https://www.bluegreenalliance.org/wp-content/uploads/2021/05/Transition-Platform-v1-1-column-5321.pdf

Brecher, Jeremy. 2015. "A Superfund for Workers: How to Promote a Just Transition and Break Out of the Jobs vs. Environment Trap." *Dollars & Sense*, November/December 2015. http://www.dollarsandsense.org/archives/2015/1115brecher.html

Cleetus, R., and E. Spanger-Siegfried. 2021. "Biden's Earth Day Summit Is a Crucial Opportunity for Climate Action." *Scientific American,* April 14, 2021. https://www.scientificamerican.com/article/bidens-earth-day-summit-is-a-crucial-opportunity-for-climate-action/

Climate Justice Alliance. n.d. "What Is Energy Democracy?" Accessed June 25, 2021. https://climatejusticealliance.org/workgroup/energy-democracy/

Donaghy, Tim, and Charlie Jiang. 2021. *Fossil Fuel Racism: How Phasing Out Oil, Gas, and Coal Can Protect Communities*. Washington, DC: Greenpeace USA. https://www.greenpeace.org/usa/wp-content/uploads/2021/04/Fossil-Fuel-Racism.pdf

Drehobl, A., L. Ross, and R. Ayala. 2020. *How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burden Across the United States*. Washington, DC: American Council for an Energy-Efficient Economy. https://www.aceee.org/sites/default/files/pdfs/u2006.pdf

EDF (Environment Defense Fund). 2021. *Recapturing US Leadership on Climate: Setting an Ambitious and Credible Nationally Determined Contribution.* Washington, DC. https://www.edf.org/sites/default/files/documents/Recapturing%20U.S.%20Leadership%20on%20Climate.pdf

EIA (Energy Information Administration). 2019. *Annual Energy Outlook 2019*.Washington, DC. https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf

EJNCF (Equitable and Just National Climate Forum). 2019. Equitable and Just National Climate Platform. https://ajustclimate.org/

Energy Democracy Project. n.d. "What Is Energy Democracy?" Accessed June 25, 2021. https://energydemocracy.us/

Environmental Justice for All Act of 2020, H.R. 5986, 116th Cong. (2020). https://www.congress.gov/bill/116th-congress/house-bill/5986/text

EPA (Environmental Protection Agency). 2021. *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2019.* Washington, DC. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019

EPA (Environmental Protection Agency). n.d. *Environmental Justice.* Washington, DC. https://www.epa.gov/environmentaljustice

Fairchild, Denise and Al Weinrub. 2017. *Energy Democracy: Advancing equity in clean energy solutions*. Washington, DC: Island Press.

Fargione, J. E., et al. 2018. "Natural Climate Solutions for the United States." *Science Advances* 4 (11): eaat1869. https://advances.sciencemag.org/content/4/11/eaat1869

Generating Equity: Deploying a Just and Clean Energy Future, before the Subcommittee on Energy of the

Committee on Energy and Commerce, 117th Cong. (2021) (written testimony of Chandra Farley, Just Energy Director, Partnership for Southern Equity). https://energycommerce.house.gov/sites/democrats.energycommerce.house.gov/files/documents/Witness%20Testimony_Farley_ENG_2021.04.20_0.pdf

Gignac, James. 2020. "Introducing a Blog Series on Recycling Clean Energy Technologies." *The Equation* (blog). October 30. https://blog.ucsusa.org/james-gignac/introducing-a-blog-series-on-recycling-clean-energy-technologies/

Grubler, A., et al. 2018. "A Low Energy Demand Scenario for Meeting the 1.5ºC Target and Sustainable Development Goals without Negative Emission Technologies." *Nature Energy* 3 (June): 515–27. https://doi.org/10.1038/s41560-018-0172

Hultman, N., L. Clarke, H. McJeon, R. Cui, P. Hansel, E. McGlynn, K. O'Keefe, J. O'Neill, C. Wanner, and A. Zhao. 2021. *Charting an Ambitious US NDC of 51% Reductions by 2030*. College Park: University of Maryland School of Public Policy. https://cgs.umd.edu/research-impact/publications/working-paper-charting-ambitious-us-ndc-51-reductions-2030

IEA (International Energy Agency). 2020. *World Energy Outlook 2020*. Paris. https://www.iea.org/topics/world-energy-outlook

IEA (International Energy Agency). 2021. *Net Zero by 2050: A Roadmap for the Global Energy System*. Paris. https://iea.blob.core.windows.net/assets/4482cac7-edd6-4c03-b6a2-8e79792d16d9/NetZeroby2050-ARoadmapfortheGlobalEnergySector.pdf

IPCC (Intergovernmental Panel on Climate Change). 2018. *Special Report on Global Warming of 1.5°C.* https://www.ipcc.ch/sr15/

JTF (Just Transition Fund). 2020. "National Economic Transition Platform." Accessed June 25, 2021. https://nationaleconomictransition.org/platform

Justice40 (Equitable and Just National Climate Forum, Center for American Progress, and Tishman Environment and Design Center). 2021. *Justice40 Recommendations*. https://cdn.americanprogress.org/content/uploads/2021/03/16083513/Justice40-Recommendations.pdf

KeyBer, L., and M. Lenzen. 2021. "1.5ºC Degrowth Scenarios Suggest the Need for New Mitigation Pathways." *Nature Communications* 12: 2676. https://www.nature.com/articles/s41467-021-22884-9

Kiran, T., S. Nimbalkar, A. Thekdi, and J. Cresko. 2019. "Energy Implications of Electrotechnologies in Industrial Process Heating Systems." Paper submitted to 2019 ACEEE Summer Study on Energy Efficiency, Portland, OR, August 12, 2019. https://www.osti.gov/biblio/1564150

Larsen, J., K. Larsen, and H. Pitt. 2020. *Climate Progress in the Year-End Stimulus*. New York: Rhodium Group. https://rhg.com/research/climate-progress-in-the-year-end-stimulus/

Larson, E., C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, J. Drossman, et al. 2020. *Net-Zero America: Potential Pathways, Infrastructure, and Impacts*. Princeton, NJ: Princeton University. https://environmenthalfcentury.princeton.edu/sites/g/files/toruqf331/files/2020-12/Princeton_NZA_Interim_Report_15_Dec_2020_FINAL.pdf

Matthews, J.B.R., editor. 2018. "Annex I: Glossary." In *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty, edited by V.* Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, et al. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/sr15/chapter/glossary/

McNamara, Julie. 2020. *The Flexible Demand Opportunity: How Smarter Electricity Use Can Support a Clean Energy Future*. Cambridge, MA: Union of Concerned Scientists. https://wwww.ucsusa.org/resources/flexible-demand-oppportunity

Nadel, S., and L. Unger. 2019. *Halfway-There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050.* Washington, DC: American Council for an Energy-Efficient Economy. https://www.aceee.org/fact-sheet/halfway-there

NAS (National Academies of Sciences, Engineering, and Medicine). 2018. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. Washington, DC: National Academies Press. https://doi.org/10.17226/25259

NAS (National Academies of Sciences, Engineering, and Medicine). 2021. *Accelerating Decarbonization of the US Energy System.* Washington, DC: National Academies Press. https://doi.org/10.17226/25932

NRDC (Natural Resources Defense Council). 2021. *The Biden Administration Must Swiftly Commit to Cutting Climate Pollution at Least 50 Percent by 2030.* New York. https://www.nrdc.org/sites/default/files/2030-biden-climate-pollution-ib.pdf

Orvis, Robbie, and Megan Mahajan. 2021. *A 1.5°C NDC for Climate Leadership by the United States. San Francisco: Energy Innovation*. https://energyinnovation.org/wp-content/uploads/2021/04/A-1.5-C-Pathway-to-Climate-Leadership-for-The-United-States_NDC-update-2.pdf

Parnell, Whitney. 2018. "4 Truths to Equip the Fight Against White Nationalism." *Sojourners*, August 10. https://sojo.net/articles/4-truths-equip-fight-against-white-nationalism

Reichmuth, David. 2019. "Air Pollution from Cars, Trucks, and Buses in the US: Everyone Is Exposed, But the Burdens Are Not Equally Shared." *The Equation* (blog). October 16. http://blog.ucsusa.org/dave-reichmuth/air-pollution-from-cars-trucks-and-buses-in-the-u-s-everyone-is-exposed-but-the-burdens-are-not-equally-shared/

Richardson, J., and L. Anderson. 2021. *Supporting the Nation's Coal Workers and Communities in a Changing Energy Landscape.* Washington, DC: Union of Concerned Scientists. www.ucsusa.org/resources/support-coal-workers

Tessum, Christopher W., David A. Paolella, Sarah E. Chambliss, Joshua S. Apte, Jason D. Hill, and Julian D. Marshall. 2021. "PM2.5 Polluters Disproportionately and Systemically Affect People of Color in the United States." *Science Advances* 7 (18): eabf449. DOI: 10.1126/sciadv.abf4491

Thind, Maninder P.S., Christopher W. Tessum, Inês L. Azevedo, and Julian D. Marshall. 2019. "Fine Particulate Air Pollution from Electricity Generation in the US: Health Impacts by Race, Income, and Geography." *Environmental Science and Technology* 53: 14010–19.

UNFCCC (United Nations Framework Convention on Climate Change). 2021. *Nationally Determined Contributions under the Paris Agreement: Synthesis Report, February 26, 2021.* Bonn, Germany. https://unfccc.int/sites/default/files/resource/cma2021_02E.pdf

USCAN (US Climate Action Network). 2020. *The US Fair Share*. Washington, DC. http://usfairshare.org/files/US_Climate_Fair_Share_Backgrounder.pdf

Vohra, Karn, Alina Vodonos, Joel Schwartz, Eloise A. Marais, Melissa P. Sulprizio, and Loretta J. Mickley. "Global Mortality from Outdoor Fine Particle Pollution Generated by Fossil Fuel Combustion: Results from GEOS-Chem." *Environmental Research* 195: 110754. https://doi.org/10.1016/j.envres.2021.110754

Welton, S., and J. Eisen. 2019. "Clean Energy Justice: Charting an Emerging Agenda." *Harvard Environmental Law Review* 43: 307–71.

Welton, Shelley. 2017. "Electricity Markets and the Social Project of Decarbonization." *Columbia Law Review* 1067: (2018). https://ssrn.com/abstract=3091297

White House. 2021a. "President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing US Leadership on Clean Energy Technologies." Fact Sheet, April 22. https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/

White House. 2021b. "President Biden Takes Executive Actions to Tackle the Climate Crisis at Home and Abroad, Create Jobs, and Restore Scientific Integrity Across Federal Government." Fact Sheet, January 27. https://www.whitehouse.gov/briefing-room/statements-releases/2021/01/27/fact-sheet-president-biden-takes-executive-actions-to-tackle-the-climate-crisis-at-home-and-abroad-create-jobs-and-restore-scientific-integrity-across-federal-government/

Union of Concerned Scientists

FIND THIS DOCUMENT ONLINE:
www.ucsusa.org/resources/clean-energy-transformation

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with people across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.