# I. Executive Summary


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To stave off the worst impacts of climate change, the world must limit warming to no more than 2 degrees Celsius above preindustrial temperatures. The Intergovernmental Panel on Climate Change (IPCC) says this will require developed countries—especially the United States as the world's second-largest emitter—to cut their greenhouse gas (GHG) pollution by at least 80 percent by 2050, relative to 1990 emissions levels.[1,2] The Natural Resources Defense Council (NRDC) partnered with the internationally recognized consultant group Energy + Environmental Economics (E3) to determine whether, and how, the United States could achieve this target.

NRDC's groundbreaking analysis demonstrates clearly that with bold action on energy efficiency, renewable energy, electrification of vehicles and buildings with clean power, and electric grid enhancements, the United States can reach its 80 percent by 2050 climate goal. Moreover, we can get there at a much lower cost than any comparable study predicts.

Between 2015 and 2050, our plan's costs are just 1 percent more than current U.S. energy costs, but deliver benefits 7 times greater than these costs. This translates to average costs of $22 billion a year and more than $154 billion a year in environmental benefits—in extreme weather, heat waves, and climate-induced illnesses avoided. If we include resulting additional health advantages, the net benefits would be even greater. It's notable that NRDC's pathway incurs low additional costs cumulatively by 2050 compared to a scenario in which no action is taken, but costs less in 2050, and may be the lowest-cost option beyond 2050. The additional expense arises from more up-front capital investments in clean and efficient power, appliances, and vehicles. But these technology investments result in significant and growing fuel savings that help offset the incremental costs over time. In fact, our scenario costs $30 billion less in 2050 than a no-action scenario. Lastly, while we did not model post-2050, our approach may be the least-cost option beyond 2050, thanks to the continuing fuel savings. Furthermore, there is no need for technological breakthroughs—we have the tools now. The United States can cost-effectively reduce GHG emissions with proven clean energy solutions, most of which are deployed at commercial scale today.

While other studies also conclude that an 80 percent emissions reduction by 2050 is feasible, our report breaks new ground by combining more aggressive—but achievable—assumptions on the potential to scale up energy efficiency, renewable energy, and clean electrification, with a more robust technical analysis incorporating grid reliability impacts. Our modeling also maximizes the co-benefits of energy efficiency (e.g., consumer bill reduction, reduced stress on the electricity grid, reduced air and water pollution, and fewer land use impacts). The modeling in other reports relies more on costlier or riskier technologies such as biomass or nuclear, or those currently deployed at a much lower scale like carbon capture and storage (CCS), to help meet U.S. climate objectives.[3,4] NRDC's study reveals new insights into what we believe to be a better, safer way to achieve America's deep decarbonization goal, strengthening our grid and economy.

Since we began our analysis, President Trump announced his intention to withdraw the United States from the global Paris Climate Agreement, which pledges to limit the increase in global warming to well below 2 degrees (Celsius) while making best efforts to keep it beneath 1.5 degrees. Even if the federal government defaults on climate action for a period of time, it is essential that we continue to pursue aggressive emissions reductions to rein in runaway climate change. The efforts of state and local governments and businesses are even more crucial now, and fortunately there has been encouraging progress on that front.[5,6]

## KEY FINDINGS

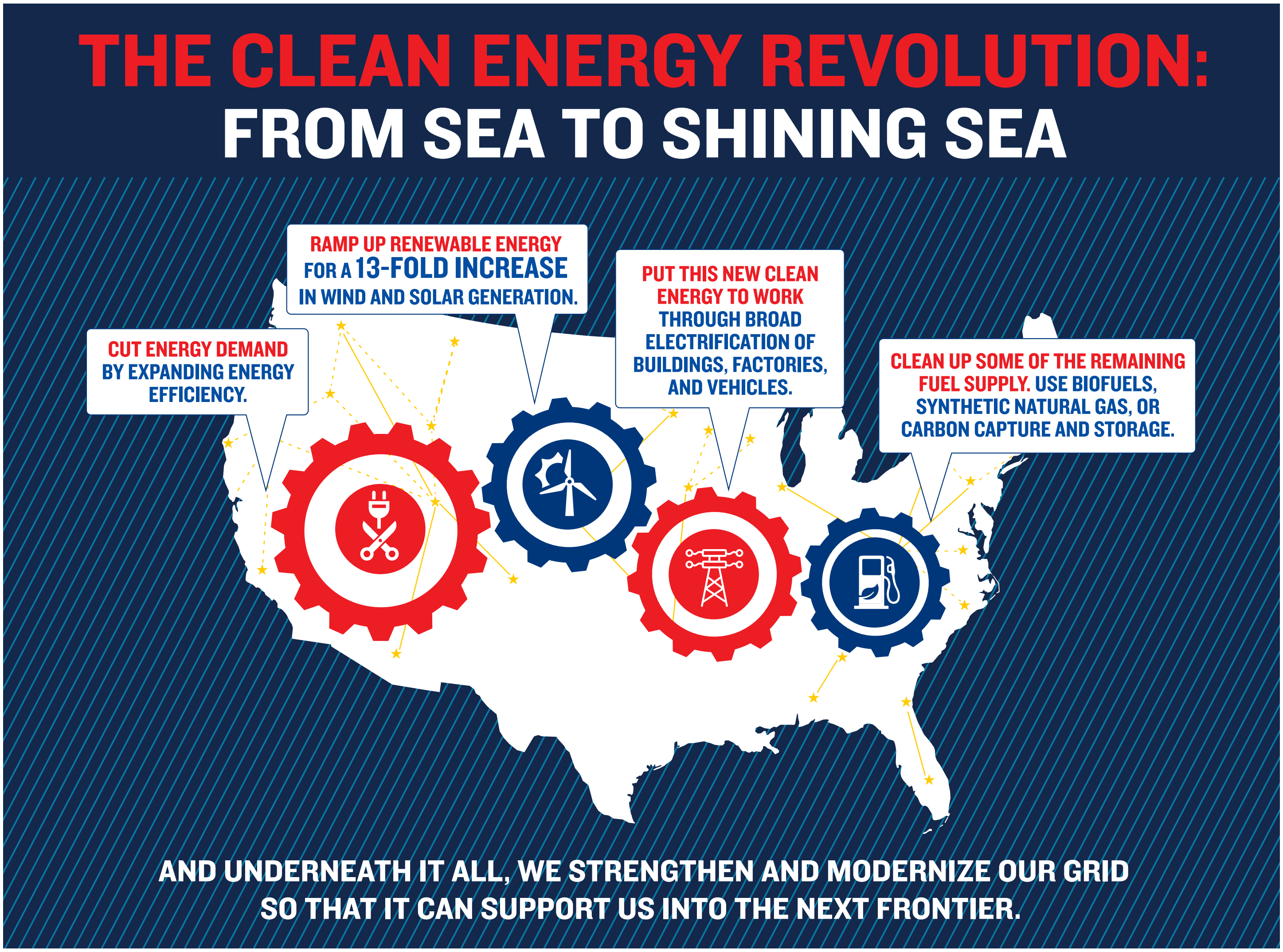
Our analysis shows that expanding **proven clean energy solutions—most of which are already deployed at commercial scale—can reduce U.S. GHG emissions across the entire economy by 80 percent by 2050**. Under our NRDC Core Scenario, the United States will:

1. **Implement energy efficiency technologies and system-wide approaches to reduce total U.S. energy demand by 40 percent** (compared with our reference case in which America's energy system evolves as it has historically). These reductions are achieved by aggressive efficiency improvements in buildings, factories, appliances, and vehicles based on what multiple, peer-reviewed sources have determined is feasible. New homes and office buildings would conform to much more stringent building energy codes, existing buildings undergo energy-saving improvements, the efficiency of appliances and equipment continues to increase, and the United States universally adopts light-emitting diode (LED) lighting in the buildings sector, helping consumers save energy and money while reducing the nation's carbon footprint. The industrial sector also must make significant investments in efficiency, ultimately achieving sector-wide energy savings in line with those already attained by some leading industrial players. Lastly, passenger vehicles continue to become more efficient, with the gasoline vehicle fleet achieving an average fuel economy of around 80 miles per gallon (mpg) by 2050 (exceeding 100 mpg in gasoline equivalents if electric cars are included). This is accompanied by about 25 percent reduction in annual average passenger vehicle-miles traveled (VMT). These levels of energy efficiency require multiple, complementary efficiency investments that can be driven by federal, state, and local policies and standards, in coordination with businesses and communities.

2. **Significantly expand renewable energy, like wind and solar, to generate more than 70 percent of our electricity supply by 2050**, compared with today's 8 percent from wind and solar. This will require a sizable increase in large-scale renewable energy facilities. Distributed (locally generated) renewable power production also can play a significant role. While ambitious, this expansion is achievable given the dizzying pace of U.S. renewable energy development amid steep price declines. For example, the costs of solar modules, the building blocks of photovoltaic panels, have declined by 80 percent in less than a decade, and average long-term power purchase contracts for wind have plummeted from $70 per megawatt-hour (MWh) in 2009 to less than $20 per MWh in 2016.[7] Even as the federal renewable energy tax credits phase out, analysts expect solar and wind to become the lowest-cost form of new power by 2023 and to be less expensive than even existing fossil generation by 2027 nationwide.[8] (It is already cheaper in some U.S. locations.[9]) This buildout also is in line with other peer-reviewed modeling and government reports.

3. **Employ the resulting near-zero-carbon electricity to the greatest practical extent to directly displace fossil fuels in transportation, residential and commercial buildings, and industry.** By 2050, electricity produced largely from renewable resources could supply up to 45 percent of U.S. energy needs, up from just one-fifth today. Although this transformation is in its early stages, recent progress includes more than a half-million electric or hybrid cars on America's roads.[10] While our analysis electrifies a substantial portion of the economy, customer preferences and technological hurdles also were incorporated. This results in a scenario with more minimal electrification of some items, such as gas stoves, long-distance freight trucks, and the most energy-intensive industries. Electrification technologies result in an additional 10 percent reduction, approximately, of overall energy demand, bringing the total energy demand reduction to about 50 percent.

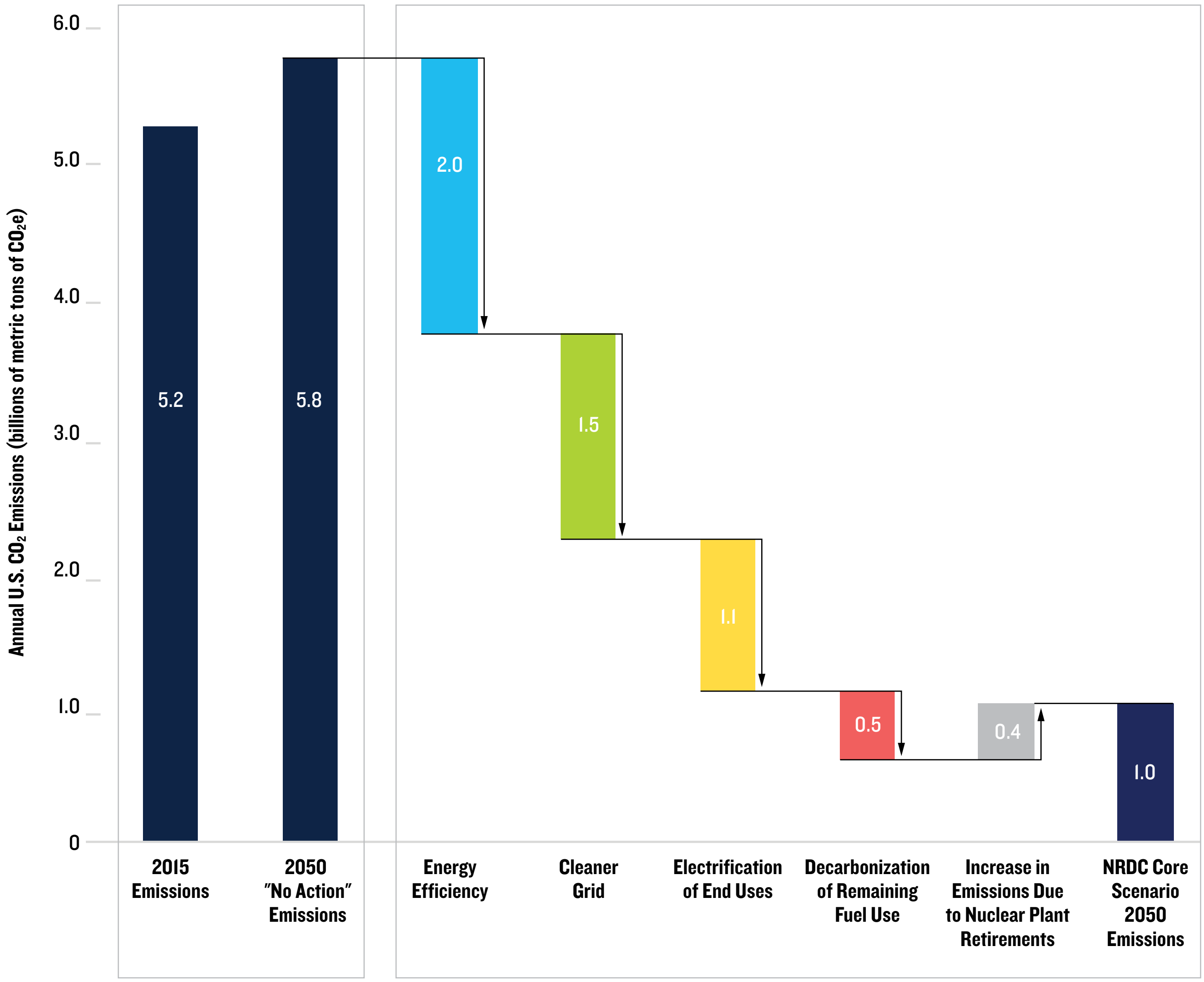
4. **Decarbonize some of the remaining fuel use**, mainly in transportation and industry. For applications that would be difficult to directly electrify (e.g., airplanes or long-haul trucks), we will need to replace oil or natural gas with decarbonized alternative fuels, derived from sustainable biomass or synthetic gas, and utilize carbon capture technologies to reduce the emissions footprint of these sub-sectors.[11] Such strategies will contribute a vital 10 percent of emissions reductions.




**Our analysis demonstrates that the projected level of renewable energy resources can be reliably integrated into the U.S. electricity grid, but it is critical that we modernize and expand it.** The grid needs to be updated no matter what the future U.S. energy system looks like, as most of it was built more than 40 years ago and it is vulnerable to extreme weather events. Prioritizing grid investments that better accommodate large-scale renewable energy generation, distributed energy resources, storage technologies, and flexible demand patterns will ensure the biggest bang for our buck. Achieving a clean electric grid will require transmission and distribution infrastructure investments, expanded grid-oversight regions, reforms to energy market rules and operations, improved operational practices, advanced forecasting, and demand-side upgrades, as well as mechanisms that better utilize and value these clean energy solutions.[12] These investments also can better optimize energy supply and demand, mitigating the incremental costs of an expanded clean electric transmission system by hundreds of billions of dollars.

Our four clean energy drivers, supported by a modernized grid, would reduce emissions to 1 billion metric tons compared to the approximately 5.8 billion metric tons anticipated if no action is taken, as shown in Exhibit ES-1.

### EXHIBIT ES-1: ACHIEVING NRDC'S EMISSIONS REDUCTIONS IN 2050




Our analysis also incorporates estimated feasible reductions in all greenhouse gases beyond carbon dioxide, including methane emissions from oil and gas operations and the meat industry, nitrous oxide from the agricultural industry, and hydrofluorocarbons (HFCs) from refrigeration and cooling equipment. Reducing these GHGs is critical to achieving the overall U.S. emissions reduction target.

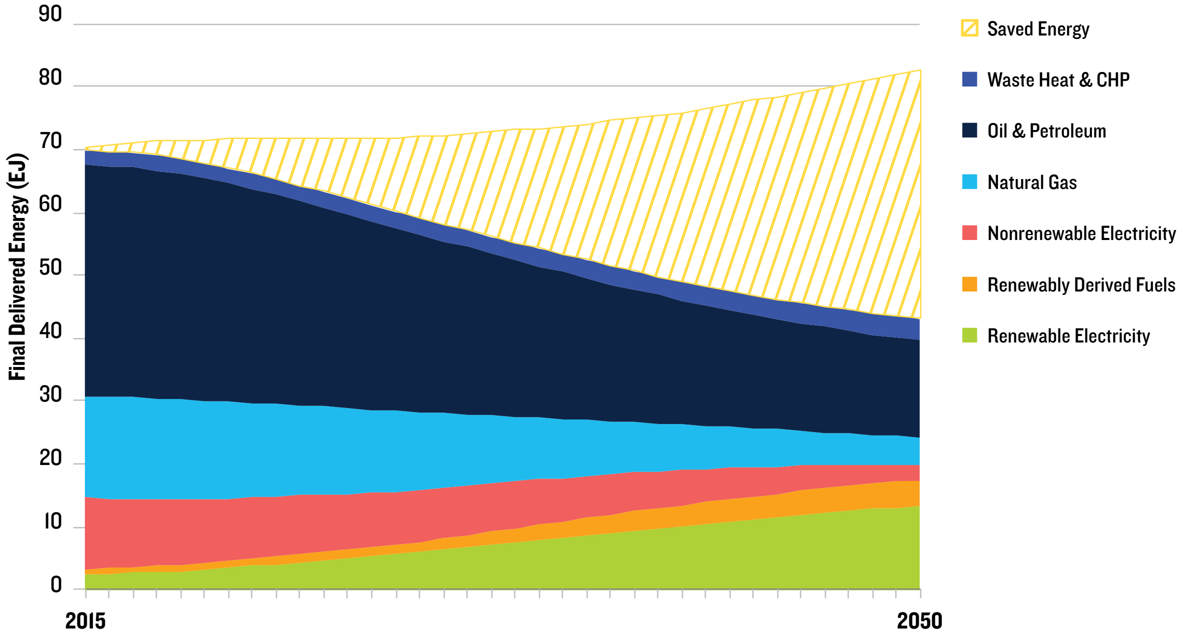
NRDC's pathway would reduce fossil fuel use by 70 percent in 2050, as shown in Exhibit ES-2. Among other actions, with additional shifts in higher- to lower-carbon fossil fuels and the use of carbon capture technologies, total GHG emissions can be cut by 80 percent, meeting our 2050 goal. Fossil fuels are the current main contributor to U.S. GHG emissions.

NRDC's Core Scenario relies on a broad, diverse portfolio of resources and technologies to achieve a decarbonized energy system, which allows for a more practical and lower-cost pathway forward. Exhibit ES-2 also shows how total energy demand drops by nearly half, while clean electricity use increases to enable shifts in ways energy is used (e.g., electric instead of gasoline cars). This break from fossil fuels will mitigate myriad health and environmental concerns related to their extraction, transportation, and consumption, and achieve a massive reduction in U.S. GHG emissions.[13]

***NRDC's pathway would reduce fossil fuel use by 70 percent in 2050.***

The energy shift will vary considerably by industry, region, and fuel type, depending on available infrastructure and technologies, and the comparable costs of possible solutions. For example, coal use declines by 90 percent from current levels under our scenario. Natural gas consumption declines by about two-thirds as there may be some gas use to replace fuels with higher carbon emissions, like coal and oil, in the industrial and transportation sectors.

## EXHIBIT ES-2: ENERGY USE BY ENERGY SOURCE IN THE NRDC CORE SCENARIO




Total energy demand drops by nearly half. Fossil fuel usage declines sharply, while clean electricity use increases to enable modal shifts.

Technologies like efficiency and renewable energy already exist. Nonetheless, robust support for research and development (R&D) will remain crucial to improving them and decreasing the costs of moving to a lower-carbon energy system. Continual innovation, such as manufacturing and design refinements, can help further reduce costs as well as the potential operation and integration challenges of transitioning to a much cleaner system. Furthermore, innovation almost certainly will produce improved technologies by 2050 that we cannot even anticipate now.

However, failure to achieve the required clean energy deployment levels we know are possible will contribute to enormous climate disruption, or reliance on approaches that are costlier or riskier or currently deployed at a smaller scale to achieve our emissions target—or both. Strategic R&D investments to improve options like nuclear, biomass, and CCS could provide a hedge in the event that we wind up needing more of them because of insufficient clean energy investments.

Finally, the benefits of our plan will far exceed the costs. Even with conservative cost assumptions, the NRDC Core Scenario only costs about 1 percent more, or about $22 billion a year on average, than the Reference Case (in which the U.S. energy system evolves as it has historically). But the climate benefits—like avoided property and crop damage from extreme weather, fewer heat waves, and less climate-induced illnesses—would total more than $154 billion in additional benefits a year. That is 7 times greater than the costs, and does not include additional health benefits from reductions in ground-level smog and ozone.[14] While there are modest energy costs over the 35-year period arising from clean energy-related capital investments, these costs decline over time due to the considerable fuel savings from reduced energy demand and growing renewable power. In fact, in 2050, NRDC's pathway costs $30 billion less than the Reference Case thanks to these fuel savings from clean energy investments. These cost savings are likely to continue or grow after 2050, which could make the NRDC Core Scenario less expensive overall than the Reference Case over a period that extends beyond 2050, though the post-2050 timeframe was not modeled.[14] In sharp contrast, our modeling shows that delayed implementation by up to a decade would cost 10 to 15 percent more annually than the Reference Case by 2050.

Our Core Scenario also would drive substantial employment growth in clean energy sectors such as wind and solar, alternative fuels and vehicles, and energy efficiency manufacturing and construction. The clean energy economy today employs 2.8 million Americans—more than twice the number working in the fossil fuel industry—and would continue to increase. Clean energy also brings economic activity and has positive tax revenue implications at the local and state levels. Continued investment now will allow the United States to remain a global leader—and perhaps strengthen its position—in a sector that will only expand considerably and rapidly.

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## OUR MODELING APPROACH

NRDC's analysis used E3's PATHWAYS model, which shares a common architecture with the U.S. Energy Information Administration's (EIA) National Energy Modeling System (NEMS), which was used to generate annual projections of energy production, demand, imports, and prices. However, the PATHWAYS model incorporates a more detailed representation of America's energy resource portfolio, the electricity sector, and grid operations and expansion. The data, costs, and other pertinent assumptions used in our modeling are largely from the EIA's Annual Energy Outlook (AEO) 2013 in order to facilitate an apples-to-apples comparison with other deep decarbonization reports using the same information. However, since 2013, there have been unforeseen rapid and continuing cost declines for wind and solar energy, and natural gas prices have plummeted, which means our cost projections may be higher than the most recent data indicates.

## POLICY IMPLICATIONS

Finally, this report considers the policy implications of the NRDC Core Scenario and discusses high-level recommendations that can be taken at the federal, state, and city levels to meet the goal of an 80 percent reduction in emissions by 2050. They are based on these principles:

- To stave off the worst effects of climate change, we need an immediate, orderly, economy-wide transition to a clean energy system, which demands a **comprehensive approach leveraging effective policy frameworks and powerful market drivers to unleash the necessary investments**.
- Until the federal government resumes leadership on addressing climate change, **numerous actions can be taken at the regional, state, and city levels and by businesses and communities**. However, a national economy-wide approach is required for ultimate success.
- To meet the 2050 goal at the lowest cost, **policymakers and market participants should proactively accelerate widespread deployment and expansion of proven clean energy technologies** to avoid reliance on riskier and more expensive options.
- **Policies should provide forward-thinking guidance** to avoid undermining long-term emissions goals and creating stranded assets in the form of power plants, pipelines, or infrastructure no longer needed or desired. In the absence of sound, long-term planning, progress will be uneven and could fall short in the long-term.
- To achieve deep decarbonization, **all GHG emissions must be reduced**.

With these principles in mind, a range of tailored policies can drive the rapid and widespread deployment of proven clean energy technologies. To start, federal and state governments should expand and accelerate the adoption of performance-based standards for energy use and carbon pollution for vehicles, power plants, buildings, and appliances and equipment. Renewable energy portfolio standards, tax incentives, and other federal and state policies can continue to drive renewable energy progress forward. To reduce emissions from the transportation sector, we need to expand access to healthier, cleaner, more affordable, and faster transit alternatives. Since cars and trucks are a major part of the sector, clean vehicle and fuel economy standards will play a critical role. Policies that spur the adoption of mass transit, biking, or electric vehicles will also be vital.

Utilities should continue to play a central role in supporting this clean energy transition. State regulators must work with utilities to reform their business models to incentivize more investments in cost-effective energy efficiency and renewable energy. In particular, utilities need to take bolder steps to target the industrial sector, building decarbonization, and electric vehicles. Utilities can also be key players in upgrading our grid to facilitate the deployment and integration of clean electricity and emerging demand-side technologies (e.g., electric vehicles and rooftop solar). Policies must support the modernization of the power grid—its infrastructure, oversight, and operations.

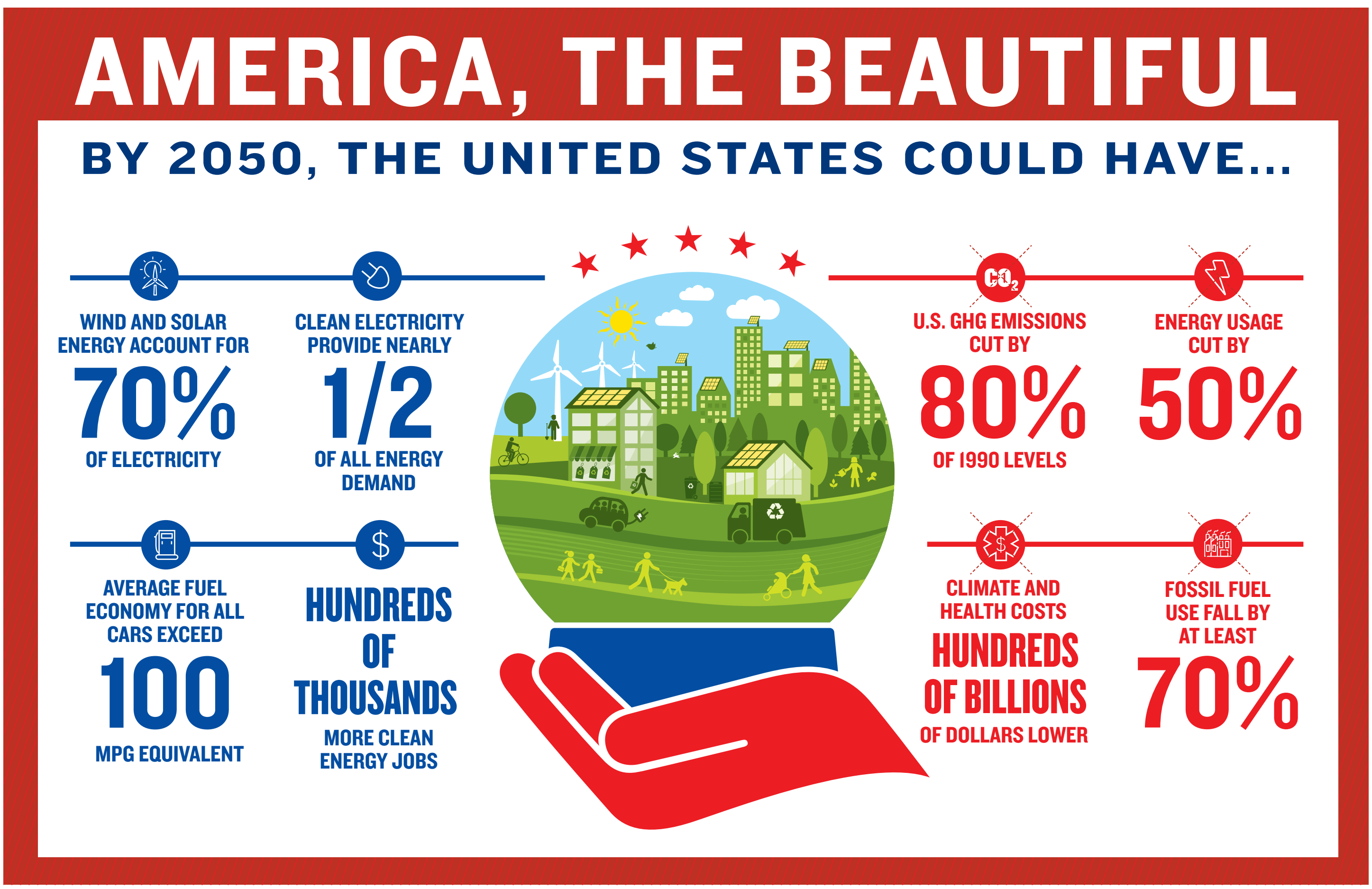
Investments in fossil fuel infrastructure, like power plants and natural gas pipelines, should be critically assessed to reduce the risk of stranded assets and the overall costs of transitioning to a decarbonized energy system. Meanwhile, innovation can lower the cost and environmental impact of current technologies, improve their integration into the energy system, and open doors to new options that could make it even easier to meet or exceed our 2050 goal.

Finally, policymakers should work with affected communities to ensure the clean energy transition is equitable and just, and that it maximizes the benefits of climate action. All Americans should have access to the benefits of clean energy, regardless of region or income. We can and should build this economy to benefit all communities, particularly those that have been adversely affected by the fossil fuel industry. Policies should also recognize and mitigate economic and employment impacts in regions and portions of the workforce that currently depend more on fossil fuel energy and reserves.

## CLEAN ENERGY: THE NEXT AMERICAN FRONTIER

With the looming threat of worsening climate change, America's energy system must now evolve even more quickly to a cleaner energy future. The timing is urgent—and standing idle is not an option. Strategic and bold investments in energy efficiency, renewable energy, clean vehicles, and a stronger electricity grid will keep us on the right path. But if we collectively fail to act, we will lock ourselves into a dirtier energy system and may not be able to thwart the most dangerous impacts to our environment and our health.

This is an all-hands-on-deck moment. All levels of government must summon the political will to work with communities and businesses to adopt the policy framework and market structures that can guide investments in our long-term clean energy future. As NRDC's analysis shows, a clean energy transition is achievable at low cost and with today's technology. Success will enhance the safety and reliability of our energy system while putting Americans to work, lowering energy costs, curbing dangerous climate change, and protecting communities and natural resources. This transition will not be without challenges, but the choice is clear.



Executive Summary Endnotes

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