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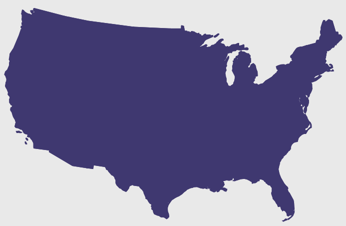
Policy Report

Executive Summary

policy implications of

deep decarbonization

in the United States



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Policy Implications of Deep Decarbonization in the United States

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US 2050 REPORT, VOLUME 2
EXECUTIVE SUMMARY

Policy Implications of Deep Decarbonization in the United States

Energy and Environmental Economics, Inc. (E3)
Deep Decarbonization Pathways Project (DDPP)

Energy+Environmental Economics

DEEP DECARBONIZATION PATHWAYS PROJECT

November 2015

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The authors take full responsibility for the contents of this report.

Preface

Deep Decarbonization Pathways Project

The Deep Decarbonization Pathways Project (DDPP) is a collaborative global initiative to explore how individual countries can reduce greenhouse gas (GHG) emissions to levels consistent with limiting the anthropogenic increase in global mean surface temperature to less than 2 degrees Celsius (°C). Limiting warming to 2°C or less, an objective agreed upon by the international community, will require that global net GHG emissions approach zero by the second half of the 21st century.[1] This, in turn, will require steep reductions in energy-related CO_2 emissions through a transformation of energy systems, a transition referred to by the DDPP as "deep decarbonization."

The DDPP is led by the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI). Currently, the DDPP includes 16 research teams from countries representing 75% of global GHG emissions: Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States. The research teams are independent and do not necessarily reflect the positions of their national governments. Starting in the fall of 2013, the research teams have been developing potential high-level roadmaps, or "pathways," for deep decarbonization in their respective countries.

The initial results of this effort were published in September 2014 and officially presented as part of the *Economic Case for Action* session at the Climate Summit convened by UN Secretary-General Ban-Ki Moon in New York. A U.S.-specific report, *Pathways to Deep Decarbonization in the United States*, was published in November 2014. Other individual country studies were announced in September 2015, and all studies by DDPP country research teams including the United States, along with reports synthesizing results across the teams, are available for download at http://deepdecarbonization.org.

[1] Intergovernmental Panel on Climate Change, *5th Assessment Report*, http://www.ipcc.ch/report/ar5/

Executive Summary

I. What is this report?

This report describes the economic and policy implications of deep decarbonization in the United States. "Deep decarbonization" refers to the reduction of greenhouse gas (GHG) emissions over time to a level consistent with limiting global warming to 2°C or less, based on the scientific consensus that higher levels of warming pose an unacceptable risk of dangerous climate change (IPCC, 2013). The analysis builds on results from an earlier report, *Pathways to Deep Decarbonization in the United States* (DDPP, 2014), conducted by Energy and Environmental Economics (E3) in collaboration with Lawrence Berkeley National Laboratory (LBNL) and Pacific Northwest National Laboratory (PNNL) for the Deep Decarbonization Pathways Project (DDPP), an international consortium of research teams studying pathways to deep decarbonization in sixteen of the world's highest-emitting countries.

The 2014 report assessed the technical feasibility and cost of different technology options for reducing net U.S. GHG emissions (CO_2e) 80% below the 1990 level by the year 2050, the long-term target set by the U.S. government (USG, 2009). While evaluating reductions in all types of GHG emissions, the main focus of the analysis was on the deep decarbonization of the U.S. energy system, defined as reducing CO_2 from fossil fuel combustion to 1.7 metric tons per capita in 2050, an order of magnitude below recent U.S. levels.

II. What is this report's intended contribution?

This report is based on a detailed year-by-year analysis of the changes in U.S. physical infrastructure required to achieve deep decarbonization by mid-century. The analysis was performed using PATHWAYS, an open-source tool developed by the authors for this purpose. PATHWAYS uses a bottom-up approach to represent the supply and demand sides of the energy system at a very granular level by economic subsector and geographic region, including a sophisticated model of the electricity grid. Using transparent and conservative assumptions, we built multiple technology scenarios – or "pathways" – to understand the technical requirements and costs of different alternatives for achieving the deep decarbonization goal.

The main objective of this report is to reorient the discussion of climate policy toward a practical focus on implementation. The analytical combination of physical stocks, high granularity, and long time horizon allows this study to make three contributions toward that end. First, it provides policy makers and businesses with a detailed understanding of what deep decarbonization will actually require in terms of scale and timing of investment, rates of technology adoption, distribution of costs and benefits, and risks associated with different options.

Second, this level of analytical detail allows the policy discussion to move beyond emissions targets to the required end state of an energy system that can meet those targets. Working backwards from that end state, the analysis maps out the physical and economic requirements of the transitional steps along the way. This provides unique insight into the challenges and opportunities of the transition across sectors, industries, jurisdictions, and levels of government, and concrete guidance for what policy must accomplish in all these areas.

Third, deep decarbonization provides a new lens on analytical approaches and policy prescriptions in the energy and climate domain, with the key question being whether and under what conditions they are effective in driving an energy system transformation. Some of the policy guidance in this report departs from current conventions, while highlighting new questions that are not yet on the policy radar.

III. What are the main characteristics of a deeply decarbonized energy system in the U.S.?

Our analysis shows that deep decarbonization in the U.S. is both technically feasible and economically affordable. There are multiple alternative pathways to achieving the 2050 emissions-reduction target using only existing commercial or near-commercial technologies, at a net cost equivalent to about 1% of GDP. The main characteristics of a deeply decarbonized energy system in the U.S. can be summarized in three seeming paradoxes:

***Physical energy system**.* Deep decarbonization will profoundly transform the physical energy system of the U.S., with fossil fuel use decreasing by two-thirds from today while decarbonized energy supplies expand by a factor of five. However, this can be achieved while supporting all anticipated demand for energy services – for example, current or higher levels of driving, home heating and cooling, and use of appliances.

Energy economy. Deep decarbonization will profoundly transform the U.S. energy economy, in terms of what money is spent on and where investment will flow. In contrast to today's system in which more than 80% of energy costs go to fossil fuel purchases, in a deeply decarbonized system more than 80% of energy costs will go to fixed investments in low-carbon infrastructure such as wind generation and electric vehicles. However, the net change in consumer costs for energy services is likely to be small.

Macro-economy. Deep decarbonization will have a small net cost relative to U.S. GDP, as increased spending on low-carbon infrastructure and equipment is offset by reduced spending on fossil fuels. In all deep decarbonization scenarios, U.S. energy costs actually decrease as a share of GDP over time, from about 7% today to about 6% in 2050. While the overall impact on energy costs is modest, the transition to deep decarbonization nonetheless offers significant benefits for the U.S. macro-economy, such as insulation from oil price shocks, even without counting the potential economic benefits of avoiding severe climate change.

Some argue that deep decarbonization will entail disruptive lifestyle changes, reduced energy services, high costs, and worrisome risks to the U.S economy. Others assume that a low-carbon energy system will be much like the present one, but we will pay more for it. In fact, our analysis shows that the imperative to transform the energy system in response to climate change brings with it the opportunity to create a system that supports all the energy services that individuals and industries demand at very little difference in net cost and without many of the negative side effects that the current system brings to the economy, society, and the environment. The "paradox" indicated by our analysis is that people should have higher expectations of a decarbonized energy system, not lower ones.

IV. What does the transition from the current energy system to a deeply decarbonized energy system require?

While there are a number of plausible technology pathways for achieving deep decarbonization in the U.S. economy – four distinct pathways are demonstrated in our analysis – they all have certain key features in common.

Three pillars of decarbonization. Across all technology pathways there are "three pillars" that must all be in place in order to reach the 2050 decarbonization goal. It is already possible to establish performance metrics in each of these areas that apply to all scenarios independently of the technical details of how they are implemented:

- *Highly efficient end use of energy in buildings, transportation, and industry.* Energy intensity of GDP must decline by 70% from now to 2050, with final energy use reduced by 20% despite a forecast population increase of 40% and a 166% increase in GDP.

- *Nearly complete decarbonization of electricity, and reduced carbon in other kinds of fuels.* The carbon intensity of electricity must be reduced by at least 97%, from more than 500 g CO_2/kWh today to 15 g CO_2/kWh or less in 2050.

- *Electrification where possible and switching to lower-carbon fuels otherwise.* The share of end-use energy coming directly from electricity or fuels produced from electricity, such as hydrogen, must increase from less than 20% in 2010 to over 50% in 2050, displacing fossil fuel combustion.

Sustained transformation. Deep decarbonization in the U.S. requires the emissions intensity of the economy to decrease 8% per year, and per capita emissions to decrease 5.5% per year. These rates of change are ambitious, but not infeasible. They will, however, require a sustained long-term transformation of energy supply and demand infrastructure. Policies that produce incremental changes without facilitating transformation can lead to technology lock-in and emissions reduction dead ends that make deep decarbonization by mid-century unattainable. “Solutions” can quickly evolve into problems. Examples include policies that focus on internal combustion engine fuel economy and ethanol-gasoline blends without widespread deployment of electric or fuel cell vehicles, and those that focus on a coal-to-natural gas transition in power generation without an accompanying build-out of renewable, nuclear, or carbon capture and storage (CCS) generation.

Timely replacement. Deep decarbonization can be achieved in the U.S. without retiring existing equipment and infrastructure before the end of its economic lifetime**,** which reduces the expected cost of the transition. However, because these lifetimes are typically long, there is only one natural replacement cycle before mid-century for some of the most important infrastructure, such as electric power plants, buildings, and industrial boilers. When replacement time arrives, the new equipment must be consistent with the low-carbon transition path. Failure to replace retiring infrastructure with efficient and low-carbon successors will either lead to failure to meet emission-reduction targets or require early retirement of the replacement equipment.

Technical progress. Deep decarbonization can be achieved in the U.S. using existing commercial and near-commercial technologies, and does not require deployment of technologies that are currently in an early stage of development including Gen IV nuclear, deep offshore wind, advanced geothermal, advanced cellulosic ethanol, advanced biodiesel, or CCS with greater than 90% capture rate. While these could help facilitate the transition, they are not necessary conditions for it. What *is* required is steady progress in current technologies that leads to rapid and widespread consumer adoption, high volume production, and corresponding price declines.

Cross-sector coordination. The interaction between energy supplies and end-use equipment becomes increasingly important over time in determining overall carbon intensities. For example, the emissions benefits of electric vehicles (EVs) grow in proportion to electricity decarbonization. EVs that charge on an average U.S. power grid today have one-third lower emissions per mile than fuel-efficient conventional vehicles, but as grid electricity approaches full decarbonization, EV emission intensities become 30 times lower. Achieving the full emissions benefit of parallel investments in supply side carbon intensity reduction and demand side fuel switching requires well-coordinated timing of deployment, for example in ensuring the readiness of charging infrastructure for EVs. This indicates a need for joint planning and coordinated policy and market signals across economic sectors that traditionally have little in common, such as power generation and transportation.

Network supply. In a deeply decarbonized system, two-thirds of final energy will be delivered through the electricity grid and natural gas pipeline. This energy is supplied by network providers, typically either regulated or publicly-owned utilities. The role of network providers in a low-carbon transition is crucial, since they constitute one of the main institutional vehicles for acquiring long-lived, high capital-cost equipment and infrastructure. Policy makers must ensure that regulatory signals to network providers related to procurement, rate-making, and cost allocation are consistent with deep decarbonization, and support a sustainable business model in the face of new challenges such as high levels of distributed generation.

V. What are the main benefits of deep decarbonization for the U.S.?

Stable climate and clean environment. Domestic deep decarbonization is the most important action the U.S. can take to protect the climate, providing leadership to the rest of the world by reducing by two-thirds or more U.S. consumption of the remaining global CO_2 budget for keeping anthropogenic warming below 2°C and avoiding the worst impacts of climate change. These impacts include increased severity of hurricanes, drought, heat waves, and flooding, and the damages these inflict on infrastructure, agriculture, and human well-being (IPCC, 2014). Deep decarbonization will also dramatically reduce air pollutants such as fine particulate matter, nitrogen oxides, and sulfur dioxide, and the resulting health impacts.

Macroeconomic and energy security. The predominance of fixed costs in a deeply decarbonized energy system will create a stable environment for investors and predictable energy costs for consumers. At the same time, deep reductions in fossil fuel consumption will dramatically reduce U.S. exposure to energy-related economic and security risks. By 2050, oil consumption would decrease to pre-1950 levels and oil's share of the economy to less than 1% of GDP. This will strongly limit the potential impact of oil price volatility on the U.S. economy, where it has historically triggered recessions, as well as the problems arising from insecurity over strategic resource availability and excessive engagement with unstable oil-producing regions.

Widespread economic benefits. Many U.S. industries and regions will benefit economically from the transition to a deeply decarbonized energy system. The shift from fossil fuel to low-carbon energy will mean vastly increased investment in efficient building technologies, decarbonized power generation and fuels, and alternative vehicles, together reaching more than $1 trillion annually by 2050. This investment will be widely distributed across regions, industries, and energy types. Revenues that are currently concentrated in a few industries and regions involved in supplying fossil fuels will decline, but the gradual timeline of the transition will provide opportunities for a successful shift to a low-carbon business model.

Modernization, competitiveness, and jobs. A deeply decarbonized energy system will necessarily be built on a sophisticated scientific and technological foundation, which plays to U.S. strengths in areas such as information technology, biotechnology, and nanotechnology, and provides a major competitive advantage in global markets for low-carbon energy. While deep decarbonization is likely to have a relatively small net impact on employment, building an efficient, high-tech 21st century energy system can work hand in hand with modernizing American infrastructure and fostering "re-industrialization," with the potential to generate many attractive science and engineering, manufacturing, and building trades jobs.

VI. What must policy accomplish to enable deep decarbonization?

Policy design must begin with an understanding of what policy actually needs to accomplish, namely the physical, financial, and institutional outcomes required by deep decarbonization. Key requirements indicated by our analysis include:

Anticipate investment needs and build a suitable investment environment**.** The annual investment requirement for low carbon and efficient technologies rises from under $100 billion today to over $1 trillion in a span of about 20 years. Financial markets can supply this level of capital if investment needs are anticipated and a policy framework is constructed that limits risk and ensures adequate returns.

Incorporate future carbon consequences in current purchasing decisions**.** Deep decarbonization in the U.S. can be achieved by replacing existing equipment and infrastructure at the end of its economic lifetime, but for a natural replacement strategy to succeed, current purchasing decisions must incorporate future carbon consequences through pricing, technology mandates, or emission standards.

Create stable drivers for sustained long-term transitions**.** Timely replacement of infrastructure and equipment with efficient and low-carbon substitutes must be sustained over decades. This requires stable policy and a predictable investment environment. Deferring all responsibility to a carbon market or relying on *ad hoc* decision-making and inconsistent incentives will not produce a sustained transition.

Develop institutional structures for coordination across sectors**.** Cross-sector interactions (for example, electricity and transportation) will grow increasingly important in a low-carbon transition. Anticipatory development of shared institutional structures, both market and regulatory, is needed for efficient coordination of operations, planning, investment, and research.

Integrate supply- and demand-side planning and procurement**.** Maintaining reliability in an electricity system with high levels of wind, solar, and/or baseload nuclear will require corresponding levels of flexible demand, such as EV charging and hydrogen production. A system that matches supply and demand resources at the required spatial and time scales requires integrated planning and procurement.

Create the right kinds of competition**.** Competition is potentially an important tool for driving innovation and reducing costs, but poorly informed policies can lead to unproductive competition, such as biofuels competing with gasoline. Long-term pathways analysis will help policy makers and investors understand what types of competition have value.

Enable the required rates of consumer adoption**.** Achieving necessary rates of consumer adoption of equipment ranging from heat pumps to alternative vehicles will require a combination of incentives, financing, market strategies, and supporting infrastructure. This requires a high level of public-private cooperation, for example among government agencies, auto manufacturers, and utilities in rapidly expanding alternative vehicle markets in tandem with fueling infrastructure.

Catalyze the needed cost reductions in key technologies**.** Policy makers can drive cost reductions in key technologies by helping to create large markets. High production volumes drive technological learning, efficient manufacturing, and lower prices. This effect - called "Moore's Law" in the computer industry - is already seen in wind and solar PV. Large markets can be built through technology standards, consumer incentives, coordinated research and demonstration, trade, and long-term policy certainty.

Limit cost increases faced by consumers**.** Businesses, utilities, and policy makers have a mutual interest in limiting the level and rate of consumer cost increases during a low-carbon transition. Coordinating energy efficiency improvements with decarbonization of energy supplies limits increases in total consumer bills even if per unit energy prices increase. Long-term pathways planning facilitates financial strategies that spread the impact of large, lumpy costs.

Minimize inequitable distributional effects**.** The sustainability of a low-carbon transition requires minimizing regressive cost impacts. A powerful tool in an energy system that depends on network suppliers is public utility commissions, which can mandate lower rates for low income customers through utility ratemaking. Distributional effects across regions, sectors, and industries are largely a function of technology strategies, which can be tailored to mitigate these effects.

VII. What are the keys to developing effective policy for an energy transformation?

The first key to developing effective policy for an energy transformation is understanding what policy needs to accomplish, as discussed in the previous section.

The second key is understanding the market and jurisdictional landscape in which the U.S. energy system operates. Some important characteristics of this landscape include:

- Energy markets are highly imperfect in ways that often require regulatory remedies, including natural monopolies, market power, underinvestment, geographic fragmentation, environmental externalities, and information asymmetries.

- Energy systems have strong geographic identities that can affect low-carbon strategies, including local resource endowments and associated industries, construction practices influenced by regional climate, and transportation choices driven by regional patterns of settlement.

- Energy policy is divided across federal, state, and local jurisdictions. In general, states have the strongest jurisdictional levers over the key infrastructure investment decisions underlying the “three pillars” of decarbonization: energy efficiency, decarbonized electricity, and electrification.

The third key is understanding the available policy toolkit and how best to fit the tools to the task.

- Common tools include pricing, emissions caps, consumer rebates, producer subsidies, performance standards, technology mandates, public-private partnerships, and (research, development, and demonstration) RD&D support.

- Sectoral characteristics largely determine the suitability of different policy instruments. For example, pricing and other market instruments are less likely to succeed in sectors that have short payback period requirements, limited access to information, unsophisticated market participants, a lack of substitute products, and an inability to mitigate regressive impacts.

The fourth key to effective policy is to begin policy discussions with questions, observations, and rigorous analysis that provides a foundation for well-tailored policies and avoids reliance on "silver bullet" solutions. Many commonly accepted policy prescriptions and analytical approaches have important limitations as they relate to deep decarbonization. Some key examples:

- Carbon prices have a role in the policy toolkit, but by themselves are unlikely to provide a sufficiently stable or large signal to drive the long-term investments required for deep decarbonization. The benefits of carbon prices tend to be taken for granted but their actual effects in specific contexts are often poorly understood.

- Marginal abatement cost, a staple of climate policy thinking, is a poorly suited guide to systemic change, and if applied literally has the potential to lead to a low-hanging fruit strategy that results in emissions dead ends inconsistent with deep decarbonization by mid-century.

- Societal cost-benefit analysis is a problematic tool for evaluating policy options when society is already committed to deep decarbonization. An example is social cost of carbon, which limits the ambition of current mitigation efforts based on unknowable future damage costs.

- International climate negotiations have long revolved around a theoretical debate on how to allocate the costs of mitigation, which were often poorly understood by the negotiators. Pathways analysis suggests that countries should be less concerned with mitigation as a free-rider problem than with missing the bus on the benefits of an energy transformation.

VIII. How can current federal policies better support deep decarbonization?

Our analysis supports the following recommendations in four key areas of current U.S. federal energy policy:

Electricity decarbonization and the Clean Power Plan. Electricity policy must drive near-complete decarbonization, achieving emission intensities 30 times lower than present by 2050. Policies (including state-level) that drive a "natural gas transition" without also driving a major expansion of renewable, nuclear, or CCS generation will not achieve the required emission intensities. Beyond decarbonizing generation, policies are needed to encourage system changes such as regional integration, electrification, flexible loads, wholesale market redesign, and cross-sector coordination.

Fuel decarbonization and the Renewable Fuel Standard. Low-carbon fuel policy must be weaned away from production of corn-based ethanol, specifically, and gasoline substitutes more broadly. Policy going forward should encourage the development of fuels produced from electricity, redirect biomass resources toward high value uses such as freight transport and industry that are less amenable to electrification, and create a glide path for eliminating biofuels with marginal emissions benefits.

Transportation energy and CAFE standards. The priorities for transportation policy should be to focus Corporate Average Fuel Economy (CAFE) standards on the transition to alternative vehicles so that by 2030 the majority of new sales are electric, fuel cell, or plug-in hybrid vehicles. Other priorities include development of fueling/charging infrastructure, RD&D on low-carbon freight and air transport technologies, and promoting large global markets to bring down vehicle costs.

Building electrification and energy codes and standards. Energy policy for buildings and appliances must shift focus to carbon emissions rather primary energy use, and from traditional energy efficiency to fuel switching. Other priorities include rethinking cost-effectiveness and enabling better use of advanced meter data to target demand-side opportunities.

IX. Beyond this study, how is deep decarbonization pathways analysis contributing to policy and public understanding?

Deep decarbonization pathways (DDP) analysis has been embraced as a policy tool by the international community. For example, a key U.S.-China joint declaration on climate change cooperation in September 2015 emphasized "the importance of formulating and making available mid-century strategies for the transition to low-carbon economies" (USG, 2015). In the policy discussion in advance of COP 21, the pathways developed by DDPP research teams for sixteen high-emitting countries provide benchmarks for evaluating short-term national emission-reduction commitments and examples of how to increase their ambition over time.

California illustrates the value of DDPs as a subnational policy formation tool. California's leaders conducted a DDP analysis to inform the setting of the state's 2030 GHG reduction target announced in January 2015, and the process was used to elicit input from public and private sector stakeholders. DDPs also provide a conceptual map within which more detailed analysis can be situated. For example, two new areas of research – on coordination of land use planning with renewable energy procurement to maximize conservation value and minimize ratepayer costs (TNC 2015) and on integration of power system operations and planning among separate balancing authorities across the western United States – are grounded in long-term electricity scenarios from California DDP analysis (Williams, 2012; Wu, 2015), and are already incorporated in state agency planning and proceedings.

DDPs provide a concrete foundation for improving the U.S. climate policy discussion. For example, the U.S. DDPP report was the source of the scenarios used in a November 2015 study by ICF International of the macroeconomic effects of deep decarbonization in the U.S., including impacts on GDP, employment, and household disposable income (ICFI, 2015). This work may help improve the U.S. climate policy discussion by addressing concerns about the economic effects of a low-carbon transition at a more granular level.

X. What are the next steps for this research?

Vertical DDPs. This report is not intended to be the final word, but a basis for policy discussion and further research, and to provide a demonstration of concept that encourages the widespread use of DDPs in energy planning, policymaking, and business decisions. As a next step, the U.S. DDPP team is planning to develop a set of "vertical" pathways studies linking national, state, and city levels to provide a more detailed understanding of actions required at different jurisdictional levels and how public and private sectors can collaborate on deep decarbonization.

PATHWAYS model. The U.S. DPPP team has developed an open source version of the PATHWAYS modeling tool used in this study, adaptable for use in any geography. We expect it to be publicly released and freely available in the spring of 2016 (USDDPP, 2015). The goal of this effort is to enable DDP analysis around the world that is transparent, comparable, and state-of-the-art.