TECHNOLOGY PATHWAYS TO NET-ZERO

EXECUTIVE SUMMARY

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The Challenge

The 2018 IPCC special report on Global Warming of 1.5°C catalyzed a new consensus that warming should be kept below 1.5°C to avoid the most catastrophic impacts of climate change. This will require reaching zero net emissions of CO_2 globally by mid-century.[1] Some scientists argue that a return to 1°C by the end of the century, consistent with decreasing the atmospheric CO_2 concentration to 350 parts per million, is necessary, requiring not only decarbonization of the economy but negative net emissions that draw CO_2 out of the atmosphere.[2] Following the scientific evidence, jurisdictions around the world have begun adopting the target of reaching net-zero or net-negative emissions by mid-century.

The Technology Pathways chapter describes strategies by which the U.S. can achieve carbon neutrality by 2050, based on detailed modeling of the energy system. The analysis focuses on how to eliminate CO_2 from the use of fossil fuel in energy and industry, which constitutes more than 80 percent of current U.S. GHG emissions.[3] The analysis shows that, despite the pace and scale of infrastructure transformation required, carbon neutrality in the U.S. is achievable from both a technical and cost standpoint.

The Solution

The transition from a high-carbon to a low-carbon energy system is based on three pillars: (1) using energy more efficiently, (2) decarbonizing electricity, and (3) switching from fuel combustion in end uses to electricity.[4] Reaching net-zero or net-negative emissions requires an additional strategy: (4) carbon capture (though not necessary carbon sequestration). Carbon neutrality requires coordinated implementation of these four foundational strategies economy-wide.

Based on rigorous modeling, we developed six scenarios that meet the net-zero target or below. Decarbonized scenarios were required to meet the same demand for energy services as a Reference Case based on the Department of Energy's long-term forecast, the Annual Energy Outlook (AEO). All scenarios used the same AEO assumptions for population, GDP, and industrial production. Only commercial or near-commercial technologies were assumed.

Central case: This was the least-cost carbon-neutral system, based on our assumptions about future costs. The net cost of reaching carbon neutrality in the *central case* was $145 billion in 2050, equivalent to 0.4 percent of forecast GDP for that year. Across cost sensitivities for fossil fuel prices and technology costs, the range for the *central case* was 0.2-1.2% of GDP.

The *central case* had the fewest constraints on decarbonization options. In five alternative pathways, decarbonization options were constrained to represent environmental or societal limits. All of these met the emissions targets, but had higher costs than the *central case*.

Limited land: Biomass supply was limited to 50 percent of the technical potential, and the land area available for onshore wind and utility-scale solar was limited to 50 percent of the *central case* value.

Delayed electrification: Consumer adoption of electrified end-use technologies such as electric vehicles and heat pumps was assumed to be delayed by 15 years relative to the central case.

100 percent renewable primary energy: This scenario was constrained to have no remaining fossil fuel or nuclear energy by 2050, including for feedstocks.

Low demand: To explore the effects of aggressive energy conservation, energy service demand in key end-uses was reduced 20-40 percent below reference case levels.

Net negative: This scenario produced net negative emissions of -500 Mt CO_2 in 2050, consistent with a 350 ppm or 1°C global trajectory in 2100.

Modeling Outcomes

In the *central case*, the optimal electricity generation mix was about 90 percent wind and solar and the carbon intensity of electricity was reduced by 95 percent. The share of electricity in meeting final energy demand tripled, from 20 percent to 60 percent, including fuels derived from electricity. Per capita energy use was reduced 40 percent, and energy intensity of GDP reduced by two-thirds, as a result of increased efficiency. Carbon capture was 800 Mt CO_2 of which about 500 Mt was recycled in producing carbon-neutral fuels, and about 300 Mt was geologically sequestered.

The range of net costs across the six scenarios was 0.4 percent to 0.9 percent of GDP in 2050, with the 100 percent renewable primary energy case being the highest. Even with these net costs, energy spending as a share of GDP declined in our modeling relative to historical levels. The net costs calculated in our analysis apply only to the energy and industrial system, and do not include the benefits of avoided climate change, air pollution, and other impacts of the current energy system. Other researchers have found the economic value of avoided climate change to be much higher than the energy-related costs described here.

Other key modeling outcomes (central case):

- The energy economy shifts from fuel-based to technology-based
- Coal as an energy source is eliminated
- Natural gas use declines by 75 percent
- Petroleum use falls by 90 percent
- Power generation consists of 90 percent wind and solar
- Reliability is maintained by a large thermal generation fleet that is operated infrequently
- Non-electricity fuel requirements are met with biomass fuels, electricity-derived fuels such as

hydrogen, and fossil fuels

- Residual CO_2 emissions from difficult-to-decarbonize applications in energy and industrial processes are captured or offset technologically

Pathway Tradeoffs

The scale and pace of infrastructure buildout potentially entail competition among social, environmental, and economic priorities, for example in the area of land use. Our scenarios illustrate these tradeoffs: limiting technology choices in one area typically requires compensating changes in other areas to reach the same carbon goal. If consumer adoption of electric end-use technologies is delayed, more decarbonized fuels are required, resulting in higher land requirements for biomass feedstocks and the siting of renewable generation to produce electric fuels. The 100 percent renewable primary energy case has the highest land requirements for these purposes, as well as the highest cost of any scenario. The low demand case has the lowest land requirements and cost but requires a high level of societal commitment to conservation. When siting and biomass were constrained in the low land case, nuclear power, natural gas use, and carbon sequestration all grew substantially, raising different social acceptance issues. Given that such tradeoffs can be anticipated in a transition to carbon neutrality, it is important for the public and decision-makers to engage with the choices and understand their consequences. Ongoing high-quality analysis is essential for informed decision-making, including high standards for analytical rigor and clear communications.

References

1. Intergovernmental Panel on Climate Change, 2018. 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.

2. Hansen, J.,et al. 2017. Young people's burden: Requirement of negative CO2 emissions. Earth Syst. Dynam., 8, 577-616, doi:10.5194/esd-8-577-2017.

3. Environmental Protection Agency, 2020. Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2018. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.

4. Deep Decarbonization Pathways Project. 2015. Pathways to deep decarbonization 2015 report, SDSN - IDDRI; White House. 2016. United States Mid-Century Strategy for Deep Decarbonization.