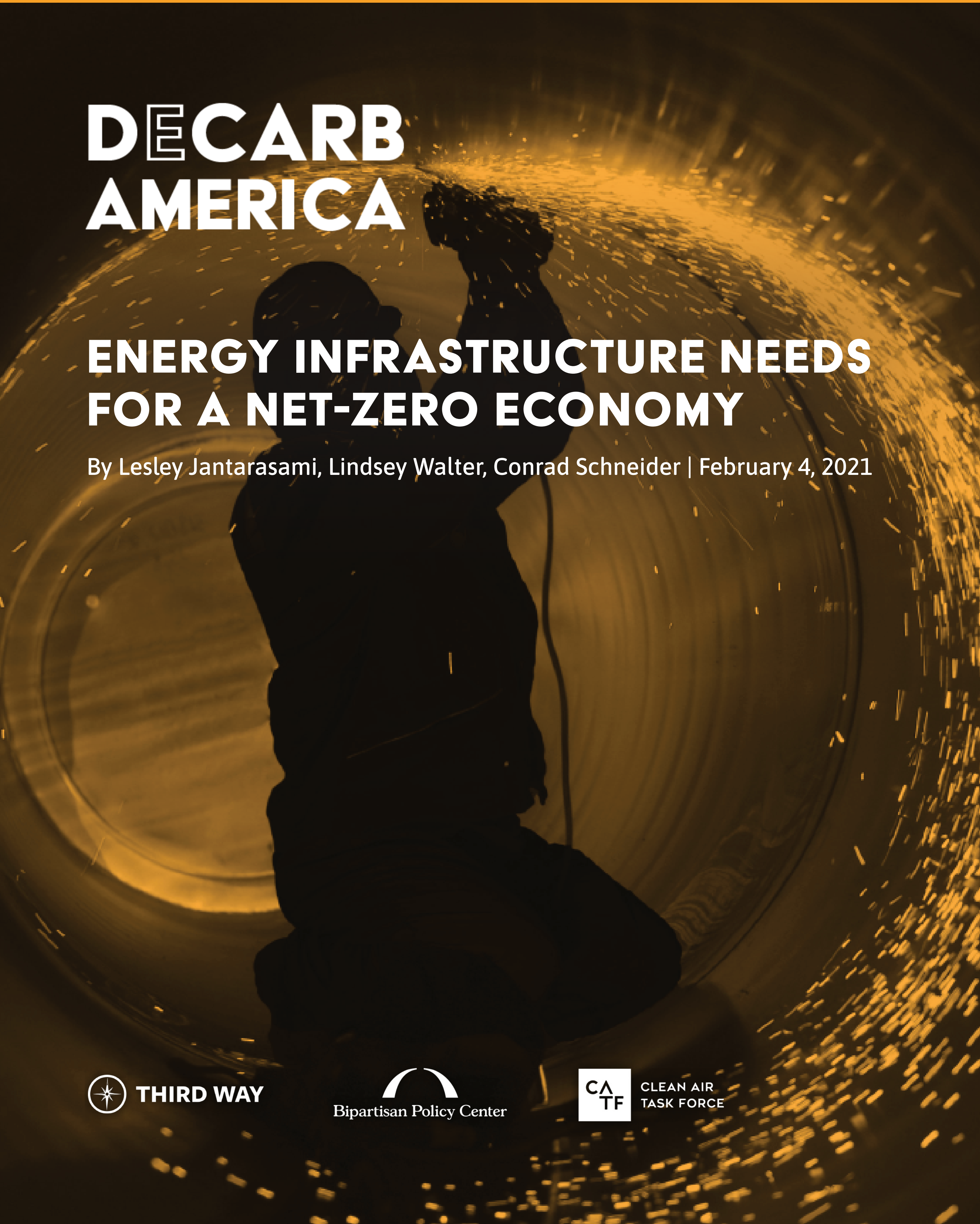

DECARB AMERICA

ENERGY INFRASTRUCTURE NEEDS FOR A NET-ZERO ECONOMY

By Lesley Jantarasami, Lindsey Walter, Conrad Schneider | February 4, 2021

THIRD WAY

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OVERVIEW

The Decarb America Research Initiative analyzes policy and technology pathways for the United States to reach net-zero greenhouse gas emissions by 2050. Our work aims to advance our understanding of the tradeoffs between different proposed strategies for achieving net-zero emissions and to identify the national, regional, and state-level economic opportunities that a new clean energy economy will generate. Our analytical results are intended to inform policymakers as they consider options for addressing climate change and modernizing America's energy systems.

To develop these results, Decarb America commissioned Evolved Energy Research and Industrial Economics, Inc. to undertake a rigorous, multi-part modeling analysis (more information is available at About the Initiative). The analysis explores five main research topics: 1) Pathways to Net-Zero Emissions; 2) Energy Infrastructure Needs for a Net-Zero Economy; 3) Power Sector Deep Dive; 4) Clean Energy Innovation Breakthroughs; and 5) Impacts on Jobs and the Economy.

This report presents key takeaways on topics (1) and (2) from our modeling results to date, with a focus on infrastructure needs for a net-zero economy. These modeling results address four critical questions:

- What types of clean energy infrastructure are we likely to build—and where—to achieve net-zero by 2050?
- How will this infrastructure differ from today's energy systems?
- How much clean energy infrastructure needs to be deployed, and how quickly?
- What are the challenges for achieving rapid deployment on a large scale?

Overall, our early findings underscore the magnitude of the net-zero challenge: decarbonizing the U.S. economy by mid-century will require new clean energy infrastructure to be developed, financed, sited, and constructed at unprecedented rates. But our results also highlight the economic benefits that a major national investment in infrastructure modernization can create: All regions of the country have an opportunity to develop new clean energy industries, and the energy-producing states of today can continue to lead domestic energy production in a net-zero future.

KEY TAKEAWAYS

1. All scenarios show a substantial shift in the U.S. energy mix over the next 30 years, with a greatly expanded role for renewables, contributions from other low-carbon resources including nuclear and carbon capture, increased deployment of energy storage, and significant electrification throughout the economy.
2. There is an opportunity to modernize infrastructure and develop clean energy industries in every part of the United States, especially in the mid-continent regions, including the Midwest, northern and southern Great Plains, and parts of the Southeast.
3. A net-zero economy creates opportunities for existing energy-producing states to remain leaders in the production of new, clean energy resources.
4. To reach net-zero, new clean energy infrastructure will have to be deployed at unprecedented rates.

5. If siting challenges from land use, permitting, and/or social license constrain the deployment of renewables, achieving net-zero will require additional infrastructure for other forms of zero-carbon electricity and alternative resources to produce hydrogen.
6. If electrification is delayed by decades, the United States will need the infrastructure to produce and deliver more than double the amount of hydrogen and other zero-carbon fuels.
7. Expanded deployment of smaller-scale, distributed energy technologies could avoid some challenges associated with siting utility-scale clean energy infrastructure but does not avoid the unprecedented scale of new deployment found across all scenarios.

MODELING APPROACH

To provide a detailed look at clean energy infrastructure needs and opportunities, Evolved Energy Research modeled nine scenarios that make different assumptions about the policy and technology landscape for achieving net-zero emissions over the next three decades. Key assumptions for each scenario are summarized in Table 1.

Table 1. Scenario descriptions

SCENARIO	DESCRIPTION
Reference	Baseline scenario that assumes no additional policy changes. Uses the Energy Information Administration's Annual Energy Outlook (AEO) 2019 with updated fuel prices and clean energy policies from AEO 2020.
Sectoral Policies	Analyzes a package of frequently discussed low-carbon or clean energy policies in the transportation, electricity, buildings, and other sectors. Together, these policies are estimated to cut emissions by approximately 70% below current levels—a substantial reduction, but not enough to fully decarbonize the U.S. economy. This scenario combines a zero-emission vehicle standard, zero-carbon fuel standard (for diesel, gasoline, jet fuel, and hydrogen), electrification and efficiency standards for buildings, clean energy standard for the power sector (100% clean electricity by 2050), and policies to reduce emissions of methane and ozone-depleting substances
High Renewables/ High Electrification	Achieves net-zero greenhouse gas emissions across the U.S. economy by 2050. This scenario applies the sectoral policies analyzed above and then layers on additional actions to achieve net-zero. This scenario represents the most unconstrained economic, or cost-optimal deployment, of technologies and includes assumptions common to other net-zero analyses for achieving high levels of electrification and renewable energy deployment.
Constrained Renewables	Achieves net-zero emissions by 2050 with constraints on deployment of renewable electricity technologies to reflect siting challenges. Reduces available renewable energy to just 5% of the National Renewable Energy Laboratory's estimate of the technical potential for onshore wind, compared to 25% in the "Net-Zero by 2050" scenario. Solar deployment is limited by availability of land, with no more than 0.5% of available land area in any region allowed to be used for utility-scale solar. Constrains offshore wind deployment to 25% of technical potential to reflect potential hurdles in siting supporting transmission infrastructure and avoiding encroachment on existing ocean uses.
Slow Consumer Adoption	Assumes that fuel-switching in the transportation, industrial, and buildings sectors is delayed by 20 years, reflecting slower consumer adoption of efficiency equipment, hydrogen end-use technologies, and electrification technologies. Zero-carbon fuels replace electricity and direct use of hydrogen to meet a large share of energy demands and still achieve net-zero.

SCENARIO	DESCRIPTION
Constrained Renewables & Slow Consumer Adoption	Pairs the demand-side assumptions from the "Slow Consumer Adoption" scenario with the renewable constraints used in the "Constrained Renewables" scenario. Given these constraints, this scenario relies heavily on zero-carbon fuels, electricity generation from non-renewables (e.g. nuclear), and carbon capture technologies to meet energy demands and still achieve net-zero.
High Conservation	Achieves net-zero emissions by 2050 with constraints on the overall footprint of the energy system. Assumes reduced energy demands in buildings, transportation, and industry. To reflect potential hurdles in siting utility-scale energy and transmission infrastructure, this scenario deploys distributed solar and energy storage technologies at 75% of technical potential to meet a significant share of electricity demand.
Low Biomass	Achieves net-zero emissions by 2050 with reduced availability of biomass feedstocks to produce hydrogen, other synthetic gases, liquid biofuels, and on-site heat and electricity. Assumes a maximum available feedstock supply of 460 million metric tons (MMT), compared to 710 MMT in the High Renewables/High Electrification scenario. Assumes that land currently used for corn ethanol will not be converted into land supplying other herbaceous energy crops, reducing available biomass supply by 34%.
No Fossil	Achieves net-zero emissions by 2050 by requiring the complete phase-out of fossil-derived energy by 2050. This is achieved by the use of a zero carbon fuel standard and the elimination of all fossil fuel combustion, resulting in a substantial increase in the use of hydrogen, synthetic hydrocarbons, and biofuels.

Comparing results for different modeling scenarios generates insights about how different policy and technology developments might affect the evolution of key energy systems over the next several decades as America transitions to a net-zero economy. Because these changes will look different in disparate parts of the country, the model produces outputs for 16 distinct regions (Figure 1); these regional outputs are then downscaled to produce state-level results.[1] Details of our state-level results are captured in the State Infrastructure Map Series on the Decarb America website.

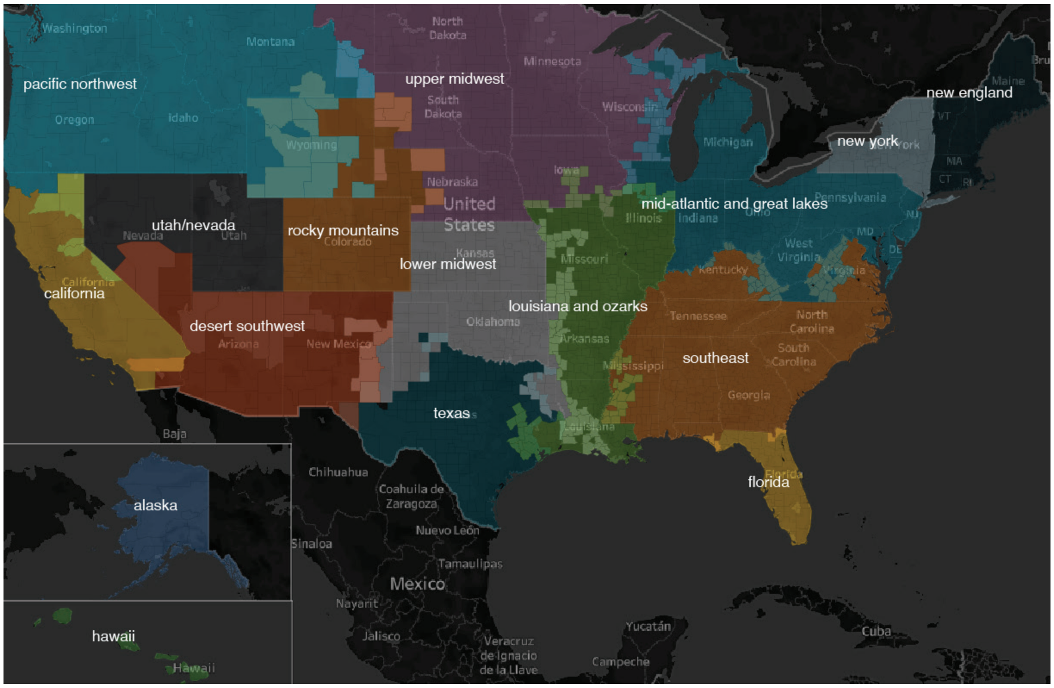

Figure 1. The Evolved Energy Research model represents the U.S. energy system across 16 regions using an aggregation of the U.S. EPA's eGRID geographies.

> What types of clean energy infrastructure are we likely to build—and where—to achieve net-zero by 2050? How will this infrastructure differ from today's energy systems?

KEY TAKEAWAY 1

All scenarios show a substantial shift in the U.S. energy mix over the next 30 years, with a greatly expanded role for renewables, contributions from other low-carbon resources including nuclear and carbon capture, increased deployment of energy storage, and significant electrification throughout the economy.

Across all of Decarb America's pathways to net-zero, we consistently find that use of a diverse suite of clean energy technologies and infrastructure will be critical to position America's energy systems to meet a net-zero target. We identified 12 main categories of infrastructure:

- **Biomass feedstocks:** Production of four types of feedstocks—corn, herbaceous, waste, and woody biomass—that supply zero-carbon fuel substitutes for fossil natural gas and liquid petroleum products
- **Carbon capture:** Technologies that can capture carbon dioxide (CO2) from the exhaust gases of large point sources (such as power plants or industrial facilities), natural gas reformation for production of "blue" hydrogen, and technologies that capture CO2 from the ambient air (also known as direct air capture, or "DAC")
- **Carbon dioxide pipelines:** Pipelines to accommodate interstate flows of CO2
- **Energy storage:** Utility-scale facilities using lithium-ion batteries, long-duration storage, and pumped hydroelectric storage technologies
- **Electric vehicles:** Electric light-, medium-, and heavy-duty vehicles and transit buses, along with associated charging infrastructure
- **Hydrogen production:** "Green" hydrogen production from electrolysis and from bioenergy with carbon capture and storage, as well as production of "blue" hydrogen from natural gas reformation with carbon capture
- **Hydrogen end-use:** Hydrogen end-uses in transportation and industrial manufacturing
- **Nuclear:** Existing reactors (relicensed up to an 80-year useful life) and new facilities using advanced nuclear technologies
- **Onshore wind:** Wind facilities of varying resource potential and capacity factor
- **Offshore wind:** Wind facilities using both floating and fixed-bottom technologies
- **Solar:** Rooftop and utility-scale solar facilities
- **Zero-carbon fuels:** Production of seven types of fuels, including ammonia, biogas with carbon capture, corn ethanol, corn ethanol with carbon capture, Fischer–Tropsch diesel, Fischer–Tropsch diesel with carbon capture, and synthetic hydrocarbon

The costs of all of these clean energy technologies are expected to decline, with continued innovation and deployment at scale. As shown in Figure 2, our modeling assumes declining costs for thermal resources, renewable resources, energy storage, and conservation technologies. These reflect mid-range cost assumptions and do not imply significant technology breakthroughs, indicating the competitiveness of clean energy even under moderate cost assumptions. With additional investments in innovation, we can lower the costs of these technologies further and create an even more affordable transition. We explore the impacts of increased innovation in the research topic: Clean Energy Innovation Breakthroughs. Results on these additional innovation scenarios are forthcoming.

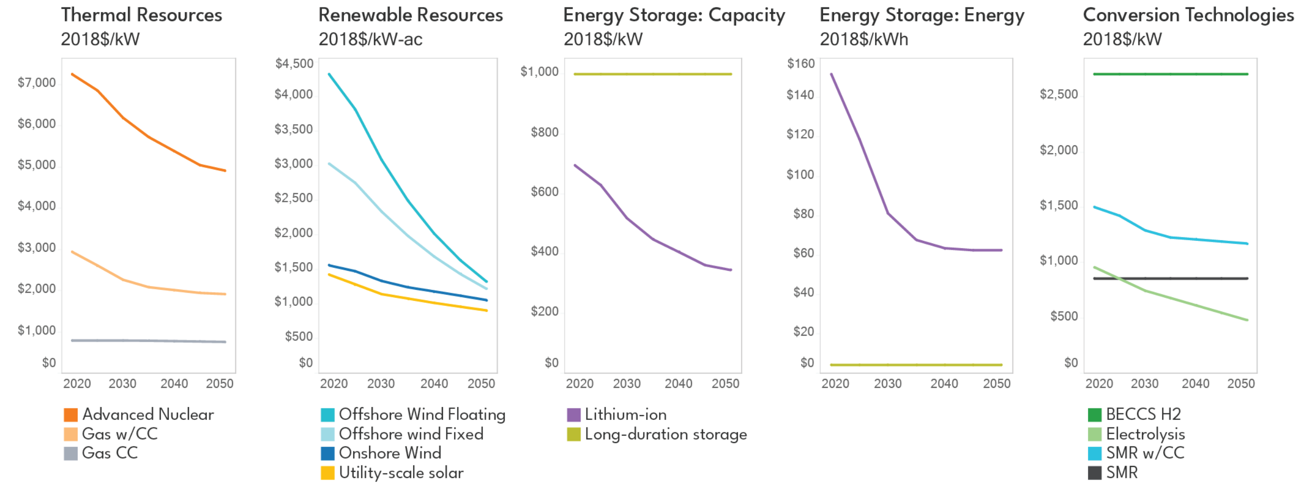

Figure 2. Capital cost trajectories for key technologies.Trajectories generally reflect continued cost reductions for low-carbon technologies.

To get on track to reach net-zero emissions by 2050, in the next decade, the United States needs to:

- Build at least 102 gigawatts (GW) of wind (more than double today's capacity);
- Build at least 174 GW of solar (more than double today's capacity);
- Manufacture and sell 15 million to 45 million zero-emission vehicles (compared to 1.5 million on the road today);
- Capture over 212 million metric tons (MMT) and sequester more than 165 MMT of CO2 annually by 2030 (eight times the capacity of carbon capture facilities that have been complete in the United States);
- Produce over 1.4 quads of zero-carbon fuels (like hydrogen and hydrogen carriers) annually by 2030;
- Begin construction on pipelines and other infrastructure to transport zero-carbon fuels, such as hydrogen, as well as captured CO2; and
- Invest in innovation for a range of clean energy technologies, including carbon capture, advanced nuclear, advanced renewables, energy storage, hydrogen, and zero-carbon fuels so they are affordable and ready to be deployed in the next two decades.

KEY TAKEAWAY 2

There is an opportunity to modernize infrastructure and develop clean energy industries in every part of the United States, especially in the mid-continent regions, including the Midwest, northern and southern Great Plains, and parts of the Southeast.

All of Decarb America's pathways to net-zero show widespread deployment of a range of clean energy technologies and associated infrastructure. This deployment occurs in every state and region across the country, with major opportunities in both 'upstream' clean energy supply (e.g. biomass feedstock producers and refiners of zero-carbon fuels) and 'downstream' electricity production and energy end uses (e.g. industrial manufacturing facilities and electric vehicle sales). While the amount of new deployment for different clean energy technologies and infrastructure changes between scenarios, the state-level (and, to a significant extent, the regional) opportunities to modernize infrastructure and develop clean energy industries remains fairly consistent across all scenarios.

Our State Infrastructure Map Series provides comprehensive results on the deployment of clean energy technologies and infrastructure for all nine scenarios.

Figure 3 shows a sampling of our state infrastructure map series to illustrate the likely location of different infrastructure categories. While the location remains similar, the map series shows how the level of deployment for different categories of clean energy infrastructure changes across scenarios. Across the country—especially near coastal and interior population centers—significant amounts of offshore wind (307-790 GW compared to 0 GW today), solar (1,198-3,562 GW compared to 89 GW today), energy storage (17-307 GW compared to 23 GW today), and electric vehicles (200-300 million compared to 1.5 million today) are projected to be deployed to achieve net-zero emissions by 2050.

Regions in the middle of the country are particularly well-positioned to capitalize on the build-out of a diversity of clean energy resources. Figure 4 illustrates this point by showing the central role many Midwestern and Great Plains states can play as important energy producers in a net-zero economy.

- Abundant high-quality onshore wind resources across the mid-continent lead to a significant increase in installed wind capacity (430-1,290 GW compared to 100 GW today)—from the eastern Rocky Mountain states across to the Great Lakes and all the way down to the Southwest. Assuming that technical and siting challenges can be addressed, our modeling results also point to significant offshore wind deployment in the Great Lakes region.
- Our analysis suggests that it will make sense to co-locate the production of hydrogen and zero-carbon fuel production (biofuels or fuels that use hydrogen as a feedstock) with renewable electricity generation as an economic way to manage renewable oversupply and curtailment. Alongside a massive expansion of wind capacity, our net-zero scenarios envision corresponding growth in a range of new industries, including hydrogen production from renewables or from natural gas methane reformation with carbon capture and corresponding production of ammonia and synthetic fuels from hydrogen feedstocks.

- Similarly, production of zero-carbon fuels increases in areas with abundant agricultural resources to use as biomass feedstocks. Biomass feedstock production doubles or even triples in many Midwestern states in response to the growing demand for zero-carbon fuels.
- Our modeling points to major growth opportunities for the carbon capture industry, with expanded deployment of carbon capture technology in heavy industry (steel and cement), hydrogen production, electricity generation, and biofuels, capturing between 626 and 2517 MMT of CO2 per year by 2050. Captured CO2 can be utilized to produce synthetic hydrocarbons, or it can be permanently sequestered in geologic formations. This practice requires the buildout of pipelines to transport CO2 to sequestration sites.

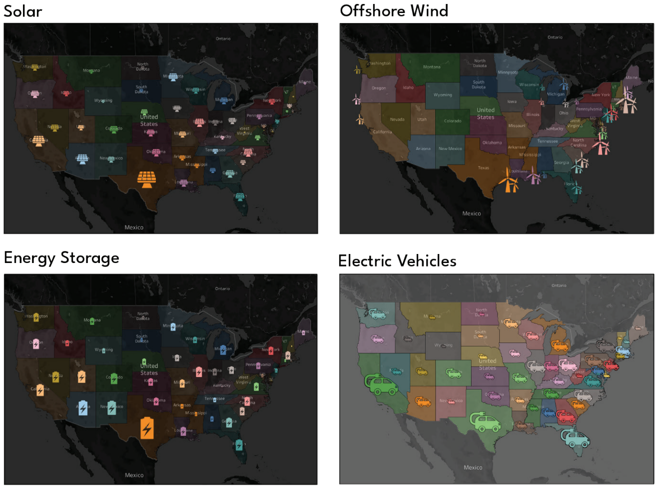

Figure 3. State-level infrastructure deployment required for the Constrained Renewables net-zero scenario: solar (top left), offshore wind (top right), energy storage (bottom left), and electric vehicles (bottom right).

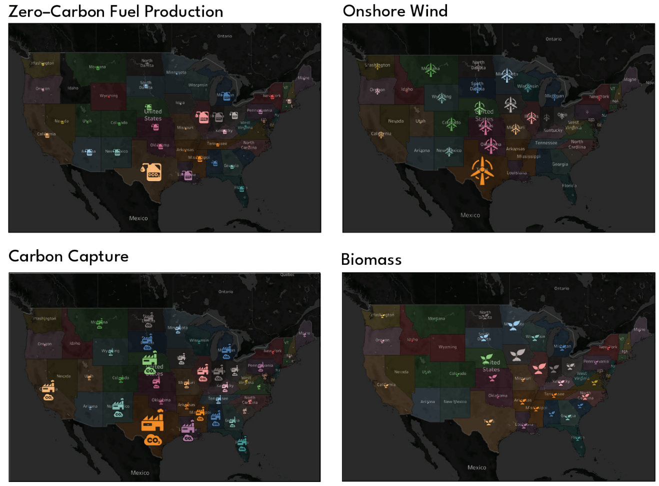

Figure 4. State-level infrastructure deployment required for the Constrained Renewables net-zero scenario: zero-carbon fuel production (top left), onshore wind (top right), carbon capture (bottom left), and biomass feedstock production (bottom right). View the interactive State Infrastructure Map Series on the Decarb America website to see the full range deployment needed for various clean energy infrastructure categories for all nine scenarios.

KEY TAKEAWAY 3

A net-zero economy creates opportunities for existing energy-producing states to remain leaders in the production of new, clean energy resources.

Figure 5 below shows the relative size and composition of each state's contribution to U.S. primary energy production in 2018 and estimates, based on our modeling analysis, for the years 2030 and 2050 in the High Renewable/High Electrification net-zero scenarios. Consistent with Key Takeaway 1, the graphic depicts a major shift in sources of primary energy, with biomass, renewable electricity, and nuclear electricity substituting for fossil fuels (coal, oil, and natural gas). The figure also shows that the transition to net-zero results in a more even geographic distribution of primary energy production across the country. Nevertheless, many of the states that currently account for a disproportionate share of fossil energy

production remain leaders in clean energy production in our modeling scenarios. Texas, for example, maintains its position as the country's dominant energy-producing state in all model scenarios, with a shift away from oil and natural gas toward renewable electricity production.

While many of today's energy-producing states remain leaders in energy production, the resources in which they are likely to invest vary across the scenarios. In Figure 6, we show a subset of states with hugely different resource endowments of renewables, natural gas, available sequestration, and existing nuclear facilities. The energy futures of each state are entirely different regardless of which path to net-zero the United States pursues. Florida relies mainly on a combination of nuclear, solar, offshore wind, and biomass, but the amounts of each vary depending on the scenario. Iowa produces energy from wind and biomass for both in-state use and export, with heavier reliance on biomass in scenarios that constrain renewable deployment. Pennsylvania remains a producer of natural gas in all scenarios except No Fossil, where it turns to renewables, nuclear, biomass and becomes a net energy exporter. Natural gas production in Pennsylvania is mostly used with carbon capture to make hydrogen. Texas has even more variation in the technology pathways it might pursue, with abundant resource endowments of renewables as well as carbon sequestration. Depending on the pathway to net-zero emissions, states will have different energy futures; however, they retain the opportunity to remain leaders in energy production.

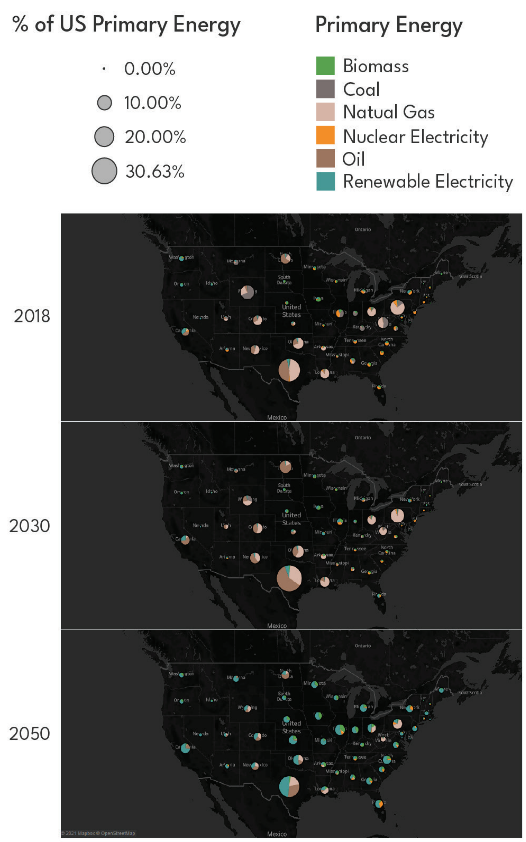

Figure 5. The contribution of each state to U.S. primary energy production historically (2018) and modeled in our High Renewables/High Electrification net-zero scenario in 2030 and 2050. The size of the pie charts correlates to the percentage of US primary energy production.

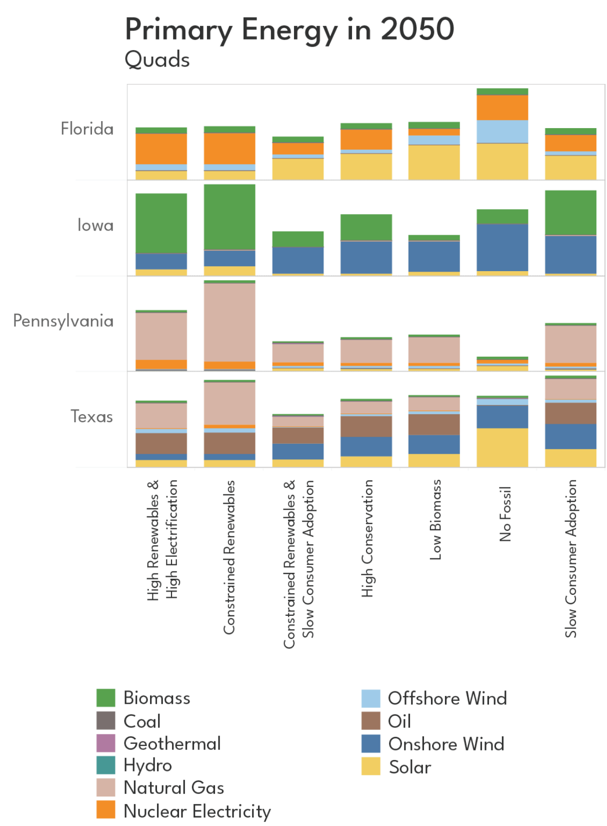

Figure 6. Primary energy needs for seven pathways to net-zero emissions by 2050 for Florida, Iowa, Pennsylvania, and Texas.

How much clean energy infrastructure needs to be deployed, and how quickly? What are the challenges for achieving rapid deployment on a large scale?

KEY TAKEAWAY 4

To reach net-zero, new clean energy infrastructure will have to be deployed at unprecedented rates.

All of Decarb America's pathways to net-zero rely on deploying clean energy technologies and associated support infrastructure at a rate that is unprecedented in the history of the United States. For example, over the next 10 years, across all scenarios, the U.S. power sector alone will have to add at least 25 GW of wind and solar. Compared to the buildout of solar and wind from 2010-2019 (shown as a range in Figure 7), our modeling shows the need to maintain a pace of solar and wind builds 50% higher than any recent historical year. Figure 7 shows the modeled increase in utility-scale solar and onshore and offshore wind generating capacity, in absolute terms (GW/year), across our nine scenarios.

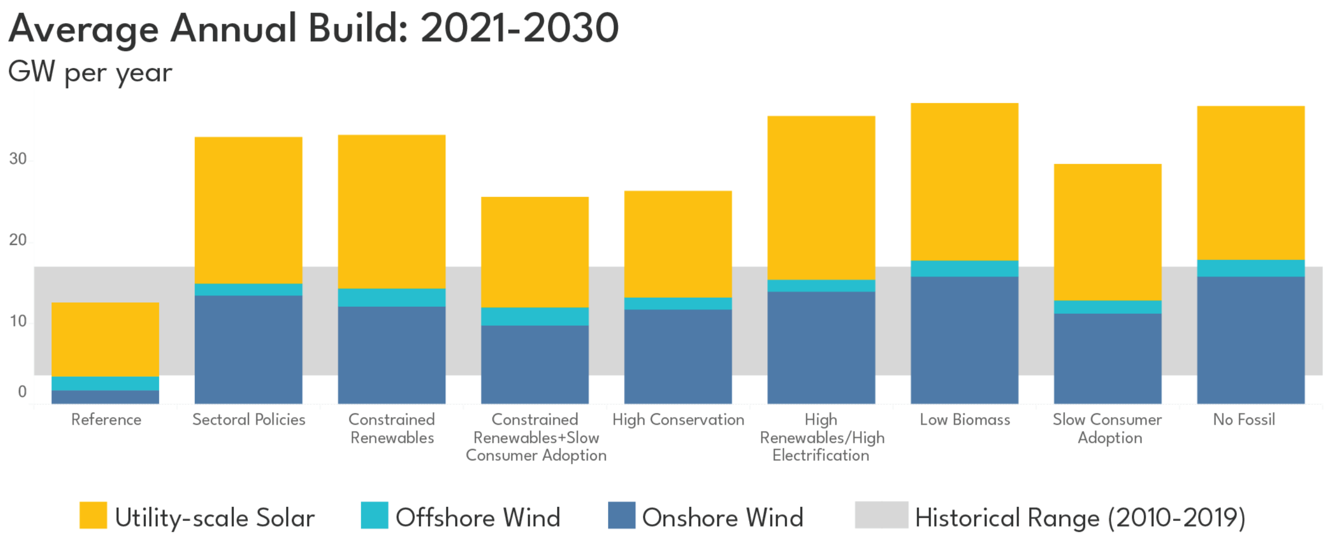

Figure 7. Average annual buildout of wind and solar (GW/year) from 2021-2030 for all nine scenarios.

We estimate that the net cost required to achieve this dramatic scale-up is as low as $151 billion per year by 2050 in our High Conservation scenario, and as high as $797 billion per year by 2050 for our Zero Fossil scenario. Despite this wide range of incremental costs, our estimates are small relative to the projected size of the U.S. economy, constituting only 0.4-2.2% of GDP. Table 1 shows these results, along with the main drivers of cost increases or reductions for each scenario. Historically, spending on the energy system has represented 5-10% of GDP, with volatile fossil fuel prices playing a large role in both the fluctuations and total cost. The share of spending on energy is projected to decline in all scenarios with sustained low fossil fuel prices and as energy intensity declines with business-as-usual efficiency, notably from light-duty vehicle fuel economy.

Table 2. Comparison of net energy system costs by 2050 compared to reference case.

SCENARIO	2018$B/YR	% OF GDP	DRIVERS OF RESULTS
High Renewables/ High Electrification	$405	1.1%	Investments in clean electricity resources, transmission and distribution infrastructure, and end-use equipment are the primary drivers of incremental costs. Costs are reduced by lowering our spending on refined oil products and partially offsetting the cost increase with natural gas.
Constrained Renewables	$440	1.2%	Additional spending on offshore wind, new nuclear, gas with CCS power plants and biomass feedstocks
Slow Consumer Adoption	$607	1.6%	Increased expenditures to meet higher zero-carbon fuel demand and offset emissions via sequestration
Constrained Renewables & Slow Consumer Adoption	$667	$1.8%	Additional spending on natural gas, geologic sequestration, direct air capture and new nuclear
High Conservation	$151	0.4%	Reduced spending on end-use equipment and electricity-related infrastructure
Low Biomass	$421	1.1%	Additional DAC and renewable electricity input costs
No Fossil	$797	2.2%	Additional spending on inputs related to power-to-liquids production (renewables, electrolysis, DAC)

These small net costs belie the significant necessary additional investment needed to decarbonize the economy (which is offset by reduced fossil fuel spending). Our High Renewables/High Electrification scenario realizes over $11 trillion of additional investment by 2050, with $1.5 trillion of this needed over the next decade. This total through 2050 includes over $2.5 trillion in spending on power plants; $1.1 trillion on zero-carbon fuels; $1.1 trillion on zero-emission vehicles and charging stations; and $1.2 trillion on buildings. Large capital investments will be needed to build new facilities, but it will also be important to develop supply chains and manufacturing capabilities to take full advantage of opportunities to strengthen American industries and American competitiveness.

KEY TAKEAWAY 5

If siting challenges from land use, permitting, and/or social license constrain the deployment of renewables, achieving net-zero will require additional infrastructure for other forms of zero-carbon electricity and alternative resources to produce hydrogen.

There is considerable uncertainty associated with the amount of land available to site new wind and solar projects. Wind projects have large land use requirements, which present challenges of siting, scale, and social license, but which can be compatible with other uses, such as farming. Utility solar has

greater energy density than wind, but also requires using the majority of that land area. As shown in Figure 8, renewable development across the net-zero scenarios in our modeling impacts 1.5% to 5% of the contiguous U.S. total land area.

Our Constrained Renewables scenario explores the impacts if we are not able to deploy as many renewables because of land, siting, or social license constraints. The scenario limits available renewable energy to 5% of the National Renewable Energy Laboratory's estimate of the technical potential for onshore wind, compared to 25% in the High Renewables/High Electrification scenario. Solar deployment is limited by availability of land, with no more than 0.5% of available land use in any region allowed for utility-scale solar. This scenario also employs a constraint on offshore renewable potential (25% of technical) to represent that, while not subject to some of the same land-use concerns found with onshore wind, offshore wind may face development issues surrounding the siting of supporting transmission infrastructure and encroachment on existing ocean uses.

Compared to our High Renewables/High Electrification scenario, the Constrained Renewables scenario has the largest impact on onshore wind, where capacity declines by more than one-half. Solar is less affected due to fewer land use impacts and low costs. To compensate for this reduction in renewable energy deployment, we need more than 100 GW of new nuclear and more than 60 GW of additional gas with carbon capture.

This decrease in onshore wind development also discourages hydrogen production from electrolysis. As a result, blue hydrogen (from natural gas with carbon capture) becomes the predominant source of hydrogen production, as shown in Figure 9. This in turn requires an additional 500 MMT CO2 by 2050 of carbon capture and sequestration. Adoption of hydrogen and CCS require their own supporting infrastructure, including pipelines for transportation and geologic storage sites for sequestration.

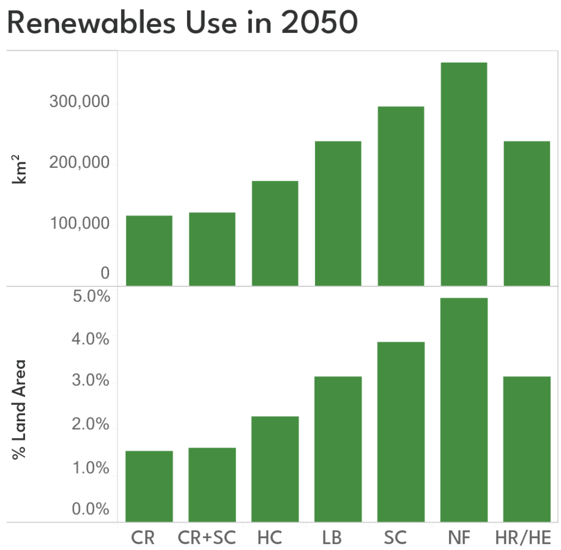

Figure 8. Land use for renewable development across net-zero scenarios: High Renewables/High Electrification (HR/HE), Constrained Renewables (CR), Constrained Renewables + Slow Consumer Adoption (CR+SC), High Conservation (HC), Low Biomass (LB), Slow Consumer Adoption (SC), and No Fossil (NF). Assumes a total land area of 7.65 million km2, utility-scale solar resources use 33.3 km2 per GW and onshore wind uses 200 km2 per GW.

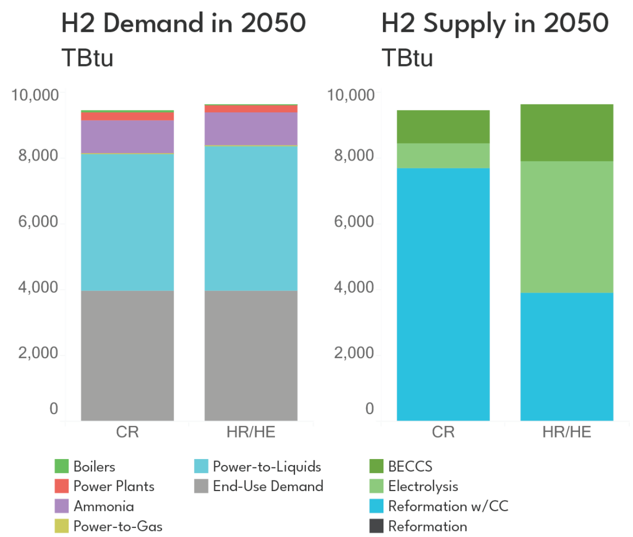

Figure 9. Hydrogen demand and supply in 2050 for the High Renewables/High Electrification scenario (HR/HE) compared to the Constrained Renewables scenario (CR).

KEY TAKEAWAY 6

If electrification is delayed by decades, the United States will need the infrastructure to produce and deliver more than double the amount of hydrogen and other zero-carbon fuels.

In our modeling, as in other studies on this subject, electrification plays a large role in enabling the decarbonization of the economy as a whole. However, we also wanted to explore the potential consequences of electrification proceeding at a slower pace than assumed in our High Renewables/High Electrification scenario. To that end, we modeled a "Slow Consumer Adoption" scenario in which end-use electrification and the deployment of other fuel-switching technologies are delayed by 20 years, which results in higher overall final energy demand and lower end-use electricity consumption.

In the Slow Consumer Adoption scenario, demand for liquid fuels more than doubles compared to the Net-Zero by 2050 scenario (Figure 10). To meet this demand while still achieving the net-zero goal, production of zero-carbon liquid fuels, including ammonia, synthetic hydrocarbons, and biofuels, would have to increase substantially. Low-carbon biofuels can be produced directly from biomass; ammonia and synthetic hydrocarbons require hydrogen,[2] which can be produced either through electrolysis using zero-carbon electricity ("green" hydrogen) or by reforming natural gas with carbon capture ("blue" hydrogen). Overall, expanded reliance on low-carbon fuels to make up for slower electrification in the Slow Consumer Adoption scenario thus results in increased primary energy demand, necessitating larger supplies of biomass, zero-carbon electricity, and natural gas.

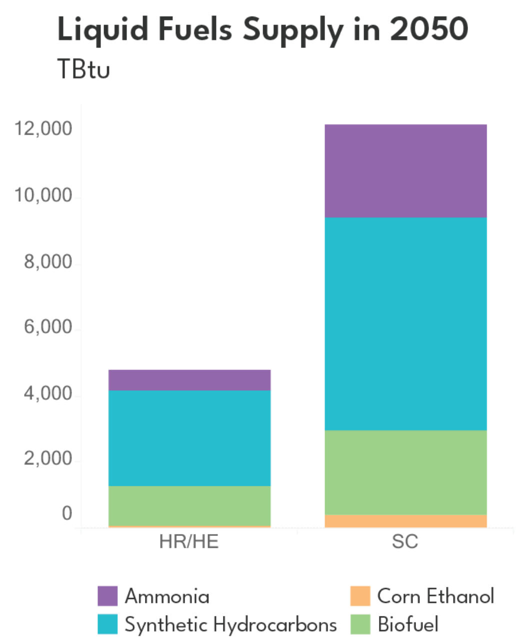

Figure 10. Supply of liquid fuels required for the High Renewables/High Electrification (HR/HE) and Slow Consumer Adoption (SC) scenarios.

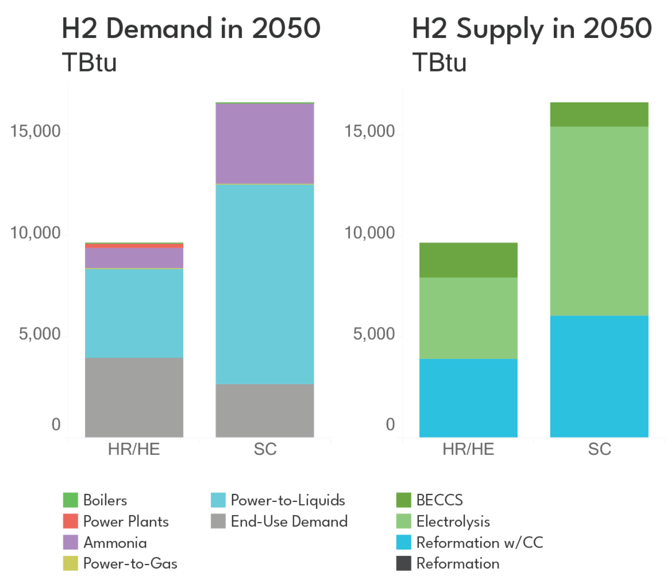

Figure 11. Hydrogen demand and supply in 2050 for the High Renewables/High Electrification (HR/HE) compared to the Slow Consumer Adoption scenario (SC).

Today, hydrogen is used predominantly in oil refining and bulk chemicals production, mainly in California, northern Illinois/Indiana, and along the Gulf Coast. In our High Renewables/High Electrification and Slow Consumer Adoption scenarios, by contrast, a growing hydrogen industry emerges by 2030 to supply fuel needs for medium- and heavy-duty trucks, shipping, freight rail, and other modes of transportation, as well as industrial users, and to provide feedstocks for other zero-carbon fuels (ammonia and synthetic hydrocarbons). These fuel needs spur a near quadrupling of hydrogen demand by 2030 in both scenarios.

By 2050, assumptions about demand-side transformation drive large differences in the scale of hydrogen production. In the Slow-Consumer Adoption scenario, continuing demand for low-carbon fuels that use hydrogen as a feedstock results in 50% more hydrogen production than in the High Renewables/High Electrification scenario (Figure 11). This results in a more than doubling of hydrogen production through electrolysis, which increases the burden on renewable electricity production, and a 55% increase in the amount of hydrogen produced by natural gas with carbon capture.

KEY TAKEAWAY 7

Expanded deployment of smaller-scale, distributed energy technologies could avoid some challenges associated with siting utility-scale clean energy infrastructure but does not avoid the unprecedented scale of new deployment found across all scenarios.

To better understand how a more distributed energy system might change the type and scale of infrastructure needed to reach net-zero, we modeled a "High Conservation" scenario that features high levels of energy conservation (including lower vehicle-miles traveled) and substantial energy efficiency improvements on the demand side, together with aggressive deployment of rooftop and community solar systems and distributed batteries on the supply side.

In this scenario, lower overall energy demand and a greater emphasis on distributed energy resources substantially reduces the need for large new utility-scale energy facilities. Utility-scale solar deployment in the High Conservation scenario is half that modeled in the High Renewables/High Electrification scenario; wind deployment (both onshore and offshore) is also substantially reduced. Lower loads and more distributed energy storage, meanwhile, also reduce the need for gas-fired electricity generation capacity and long-distance, high-voltage transmission lines: For 2050, gas-fired capacity is reduced by 100 GW and inter-regional transmission capacity is reduced by more than 30 GW in the High Conservation scenario compared to the High Renewables/High Electrification scenario.

The need to site and construct fewer large, utility-scale energy facilities and associated infrastructure (such as transmission lines) is a potentially significant benefit of net-zero pathways that emphasize conservation and distributed technologies. Given the nation's mixed track record of delivering timely infrastructure projects and the significant uncertainty introduced by complex siting and permitting processes, this will be an important factor for policymakers to consider as they weigh the practicality of building new systems on the ambitious timeline required to achieve net-zero by 2050.

Significant implementation challenges exist, of course, for all pathways to net-zero. Figure 12 highlights the distinctive features of the High Conservation scenario in terms of the mix of energy technologies deployed, but it also shows that the rate of deployment for these technologies is similarly aggressive, particularly over the next two decades. In sum, the need to build an unprecedented amount of clean energy infrastructure in a short time frame is a consistent theme across all of our modeling scenarios.

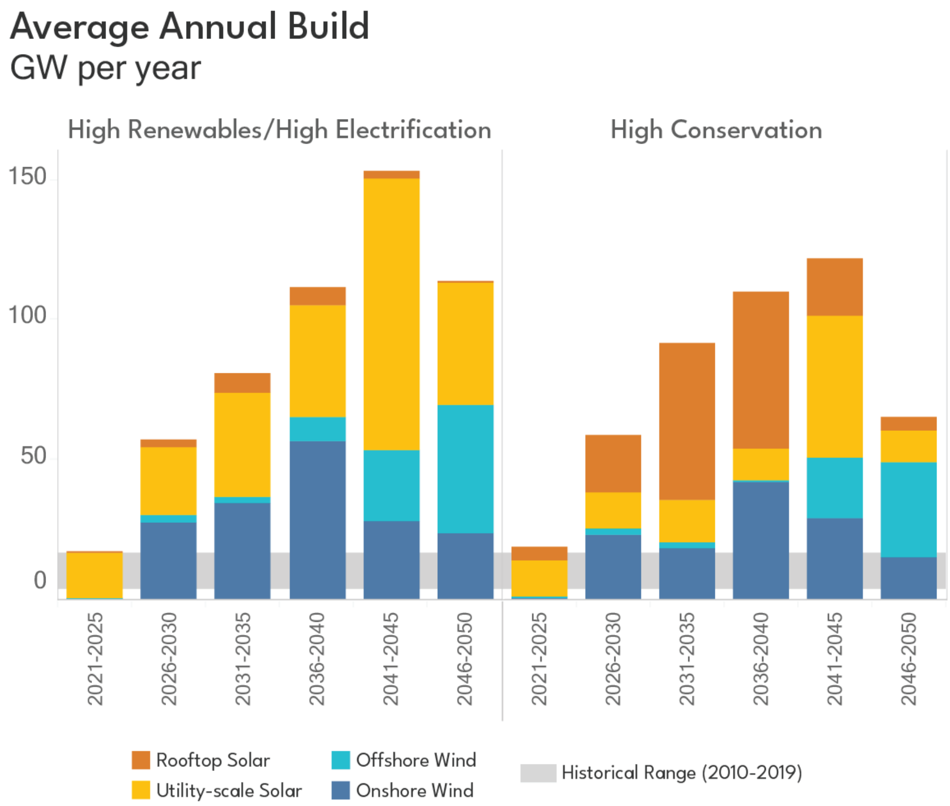

Figure 12. Average annual build rates for rooftop solar, utility scale solar, offshore wind, and onshore wind in the High Renewables/ High Electrification and High Conservation scenarios.

CONCLUSION

Together, these takeaways underscore both the challenge and the opportunity implicit in charting a course to net-zero carbon emissions by 2050. As Decarb America continues to explore the full set of research questions outlined in the introduction to this report, we expect to elaborate on the implications of these findings with respect to job creation, policy impacts, and the potential for technological disruption in future studies. In the meantime, it is clear from our analytical work to date that the infrastructure implications of achieving the net-zero objective are nothing short of transformative. They are also widely distributed: Our results point to the need to develop robust clean energy industries in every region of the country.

Though not the focus of this initial analysis, it is worth emphasizing that the infrastructure investments needed to bring about a clean energy transformation also represent an important opportunity to address other economic and social objectives, from preserving American competitiveness and global

leadership in technology innovation to improving quality of life and ameliorating long-standing socio-economic disparities. These benefits are critical to build and sustain the public and political support needed to advance a major infrastructure campaign. Government funding for new clean energy projects and clean technology manufacturing, for example, can be prioritized to benefit historically disadvantaged communities and offset negative impacts on workers in traditional fossil fuel industries. In short, impacts on workers, jobs, and communities should be a core consideration, not an afterthought, as policymakers weigh specific policies and programs to achieve the net-zero goal.

Major investments in new infrastructure are unavoidable in all of our modeling scenarios, but the transition to net-zero need not leave all the infrastructure built for our current fossil-fuel-based energy economy stranded. Repurposing existing infrastructure can substantially reduce costs and other hurdles (notably with regard to siting) by leveraging trillions of dollars of historic investment in assets ranging from transmission lines and transportation networks to buildings and land-use rights.

Opportunities to repurpose or retrofit infrastructure, or to use existing assets in a support role, exist throughout the economy. In the electric power sector, natural gas combined-cycle power plants may no longer operate much of the time in a net-zero future, but can still provide critical reliability services to the grid by operating for limited hours of the year on low- or zero-carbon fuels such as methane, ammonia, or hydrogen.[3] Coal-fired power plants have significant transmission interconnections and infrastructure that could be used to support alternative resources as the coal plants themselves are retired, and it may be feasible to deploy more advanced nuclear heat source technologies at some existing nuclear power plants. Other possibilities could involve upgrading portions of existing gas pipelines to deliver gas blends with an increasing zero-carbon hydrogen component and retrofitting large industrial plants, whether for fuel production (e.g. hydrogen reformation, ammonia production, and ethanol) or in heavy industry (e.g. cement, iron, and steel), with carbon capture systems. Designing policies that take advantage of these and other opportunities will be critical to success.

ENDNOTES

[1] See Methodology on the Decarb America website for more information about our downscaling methods. Note that all of our scenarios for achieving net-zero also account for some contribution from land-based carbon sequestration, whether through reforestation or soil carbon management. However, downscaling estimates for this contribution at the state level was outside the scope of this analysis.

[2] To produce ammonia, hydrogen (H2) is combined with nitrogen to form NH3. To produce synthetic hydrocarbons, hydrogen is combined with captured carbon to produce different carbon-hydrogen compounds.

[3] In our modeling, the typical gas combined-cycle plant's operation drops from more than 5,000 hours per year currently to approximately 200 hours per year.