

Navigating America's net-zero frontier: A guide for business leaders

The US government has a goal: net-zero emissions by 2050. Our analysis maps out a pathway to this net-zero frontier—and the growth opportunities that \$27 trillion of capital spending could create.

This article is a collaborative effort by Rory Clune, Laura Corb, Will Glazener, Kimberly Henderson, Dickon Pinner, and Daan Walter, representing views from McKinsey's Sustainability Practice.



With the United States' announcement of targets to halve US greenhouse-gas (GHG) emissions by 2030 and reach net-zero emissions by 2050, the world's largest economy (and second-largest emitter) has joined some 130 nations in its intention to act on climate change.¹ Some 400 large US-based companies have also committed to net-zero targets of their own, many of which have set ambitious emissions reductions targets for 2030 or sooner.² In our experience, few have yet turned those pledges into detailed plans for adjusting their business models to thrive in a net-zero economy.

Creating an effective business plan for the net-zero transition won't be easy, for uncertainty surrounds the pace and scale at which this transition will progress in America and in other countries. That uncertainty has been compounded by the conflict in Ukraine, which has increased the world's attention to energy security, creating both tailwinds and headwinds for the energy transition. In light of this uncertainty, US companies may wish to assess the business risks and opportunities and the socioeconomic impacts associated with the transition. We believe the companies that understand these factors can better position themselves for long-term success and positive impact. Those that delay action may miss out on growth prospects that should arise as institutions in America and elsewhere strive to eliminate GHG emissions in pursuit of national and corporate targets.

This article is intended as a guide to America's net-zero transition. It examines four topics critical for business leaders as they shape strategies for this defining decade. First, we describe America's starting point and trace a pathway that we modeled for achieving federal net-zero targets. Next, based on this pathway, we identify five areas in which climate solutions could offer enormous potential for both emissions abatement *and* economic growth through 2025: renewable power, electrification, operational efficiency, clean fuels, and carbon capture. We then examine several macro trends that business leaders

should anticipate. Finally, we suggest how executives might define their company's approach to the transition. Even if the transition plays out differently from what our scenario envisions, it appears that a time of climate-focused innovation, investment, and change has arrived—and that leaders would do well to prepare for it.

America's net-zero frontier

For the United States, the path to net-zero emissions by 2050 entails a comprehensive and rapid effort to decarbonize the economy. A comprehensive effort is necessary because America's 7.2 billion metric tons of annual GHG emissions come from a variety of sources, spanning every sector (Exhibit 1). While there is a range of future decarbonization scenarios, our pathway modeling highlights a few points of emphasis for America's net-zero transition:

- *Reducing emissions from existing facilities and infrastructure is a major part of the decarbonization agenda.* Much of the necessary reduction can come from retrofitting emissions-intensive assets, such as chemical, manufacturing, and power plants, through electrification, the use of low-emissions energy sources (such as hydrogen and biofuels), and carbon capture.
- *Decarbonizing transport presents challenges.* Airplanes, cars, trucks, and ships produce around one-quarter of US emissions. Transportation emissions could be eliminated through a mass shift to zero-emissions powertrains that run on electricity, carbon-neutral fuels, or hydrogen. However, the decarbonization of transport is subject to inertia created in part by the United States' large stock of vehicles and airplanes, poor rail infrastructure, and long journey distances.
- *Natural gas and methane emissions are significant.* The US power sector's shift from

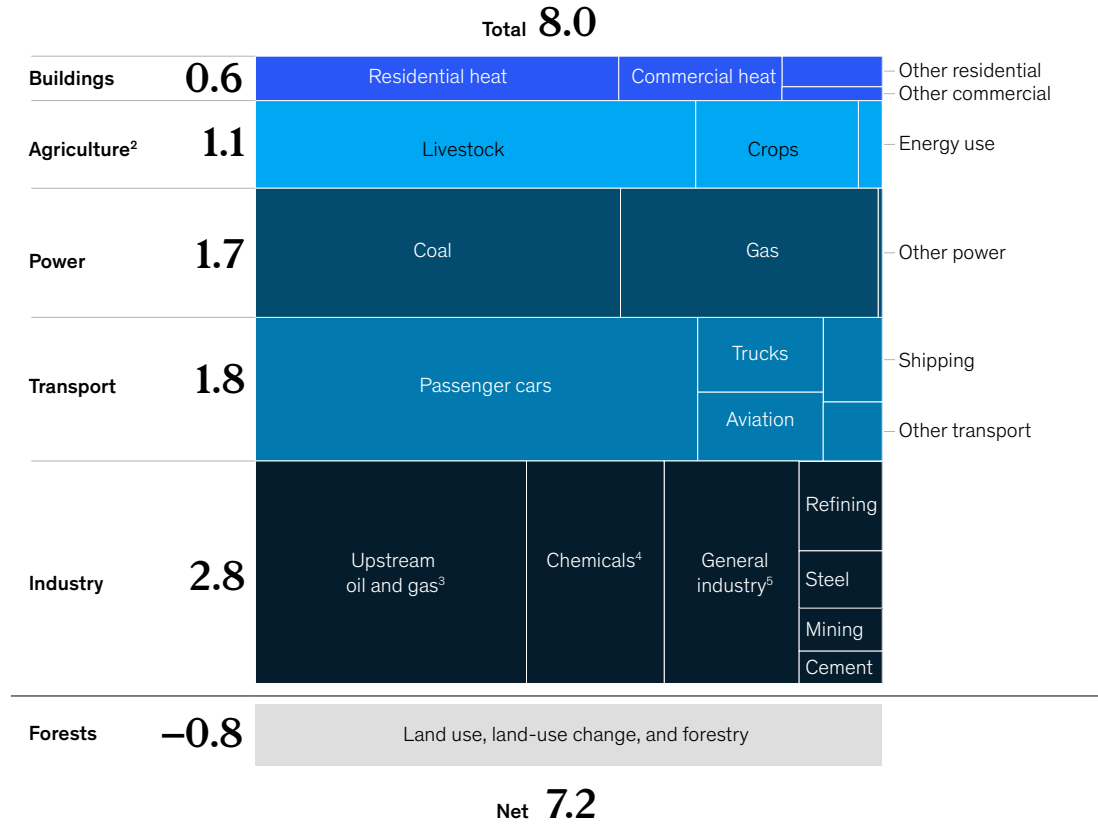
¹ Data-Driven EnviroLab; Energy and Climate Intelligence Unit; NewClimate Institute; Net Zero Climate; Net Zero Tracker; sites accessed in April 2022. Includes countries that have achieved their net-zero targets or have put them into law, in policy documents, or made a declaration or a pledge.

² The Science Based Targets initiative, Science Based Targets, site accessed in April 2022.

Exhibit 1

US emissions sources are diverse, covering all parts of the economy.

2019 US greenhouse-gas (GHG) emissions, by sector, metric gigatons of CO₂ equivalents¹



¹A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact. ²Livestock emissions are primarily methane; crops emissions are primarily nitrous oxide; and energy-use emissions are carbon dioxide. ³Includes upstream methane and carbon dioxide. ⁴Includes ethylene, ammonia, and other chemicals (eg, sulfuric acid). ⁵Manufacturing, waste, and other industrial processes.
Source: McKinsey EMIT database (Sept 2021); McKinsey Sustainability Insights

coal to natural gas as a primary fuel has led to a significant reduction of emissions since 2005. CO₂ emissions from natural-gas combustion now account for more than 20 percent of US GHGs, and methane emissions from all sources account for another 25 percent. To reach net zero, our analysis shows that at least 60 percent of the natural gas that’s now being used would need to be replaced by zero-carbon energy sources, primarily in the

power, manufacturing, chemicals, and buildings sectors. And methane emissions from venting and from fugitive leaks in oil and gas production would need to be curbed by nearly 80 percent by 2030.³

- **Abundant natural resources can support deployment of climate solutions.** Resources such as sunlight and wind for generating renewable power and geological capacity

³“Curbing methane emissions: How five industries can counter a major climate threat,” McKinsey, September 2021.

for storing captured CO₂ could enable the United States to deploy climate solutions such as renewable electricity, hydrogen, and direct air capture at large scale and low cost. The managed forestland of the US interior, a vast carbon sink, already offsets more than 10 percent of gross domestic CO₂ emissions and could help the US go beyond net-zero emissions and become “carbon negative.”

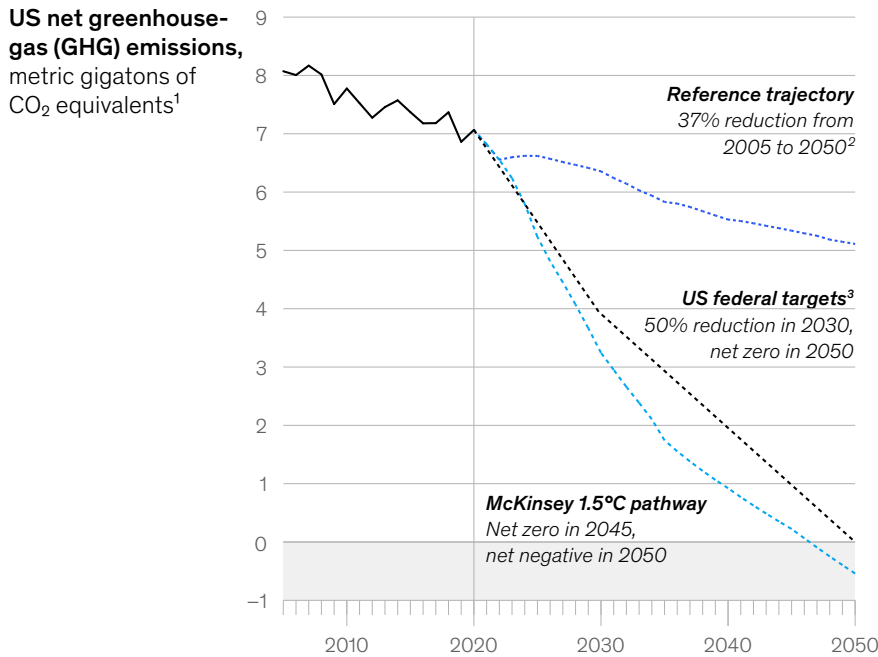
As for the pace of America’s net-zero transition, it will take accelerated action to halve emissions by 2030 and bring them to net zero by 2050 in accordance with federal goals that honor the 2015 Paris Agreement. (Other federal goals call for achieving 100 percent clean-power generation by 2035 and, under the Global Methane Pledge,

reducing methane emissions 30 percent by 2030. Furthermore, 24 US states, representing 40 percent of national GDP, have set net-zero targets.) Our analysis indicates that to reach its 2030 target, the United States would need to cut emissions by 6.0 percent per year—nearly ten times faster than the 0.8 percent average annual reduction of the previous decade (Exhibit 2).

It will not be easy for the United States to reduce emissions at a pace consistent with limiting global warming to 1.5°C. The transition is likely to be disorderly at times, but our analysis shows how it might be done (Exhibit 3). The emissions pathway that we modeled is one of many the United States could take; it is not a forecast. It calls for bringing together the nation’s rich natural resources

Exhibit 2

There is a wide gap between the current US emissions trajectory and the trajectories needed to meet emissions targets.



¹A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact. Reductions are measured relative to 2005.

²The reference scenario is based on McKinsey’s 2021 Global Energy Perspective Reference Case.

³Federal emissions reductions targets are measured relative to 2005.

Source: McKinsey EMIT database (Sept 2021); McKinsey Sustainability Insights

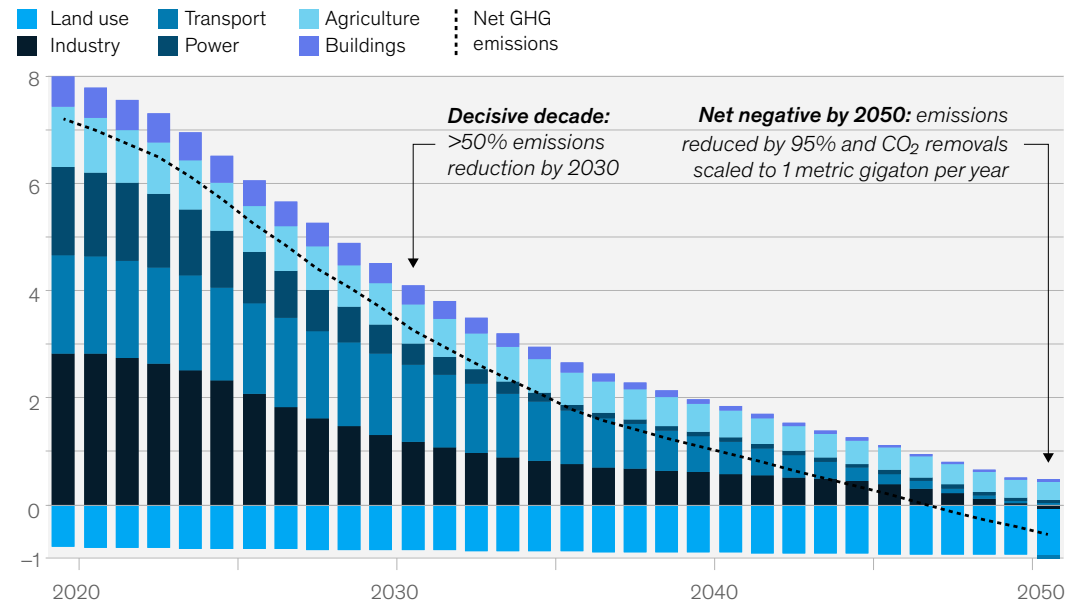
Please see Appendix for full version of Exhibit 3.

Exhibit 3

A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US emissions, by sector

Estimated greenhouse-gas (GHG) emissions in a 1.5°C scenario, metric gigatons of CO₂ equivalents¹ per year



Major changes

- Zero-emissions power by 2035, met by coal phase-out by 2025 and rapid expansion of renewables generation and grid transmission
- Industrial asset transition: 50% of natural-gas demand replaced with electricity, hydrogen, and biogas by 2030; 80% by 2050
- Rapid electrification of mobility: 75% of all new-car sales are electric vehicles by 2030
- Curbing methane emissions: 80% reduction of oil and gas methane by 2030

Note: This 1.5°C pathway is a McKinsey analysis of one possible emissions reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

¹A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

Source: McKinsey Sustainability Insights

and its immense stores of human, financial, and technological capital to deliver a range of climate solutions, which we describe below. This innovation-centered approach, we believe, could allow US-based companies to grow and thrive during a net-zero transition, while enabling the nation to reach its climate goals.

Five high-potential climate solutions for 2025

In the emissions-reduction scenario we developed, five cross-sector climate solutions would reduce GHG emissions 25 percent by 2025 and 45 percent by 2030⁴—more than the federal target and in line with the global goal of limiting warming to 1.5°C. These solutions would require capital spending of some \$650 billion per year by 2025, which in turn

⁴Compared with emissions in 2019. These five solutions would account for nearly 85 percent of total emissions reductions in 2025 and 2030.

would create growth opportunities for companies. The key solutions focus on renewable power, electrification, operational efficiency, clean fuels, and carbon capture (Exhibit 4).

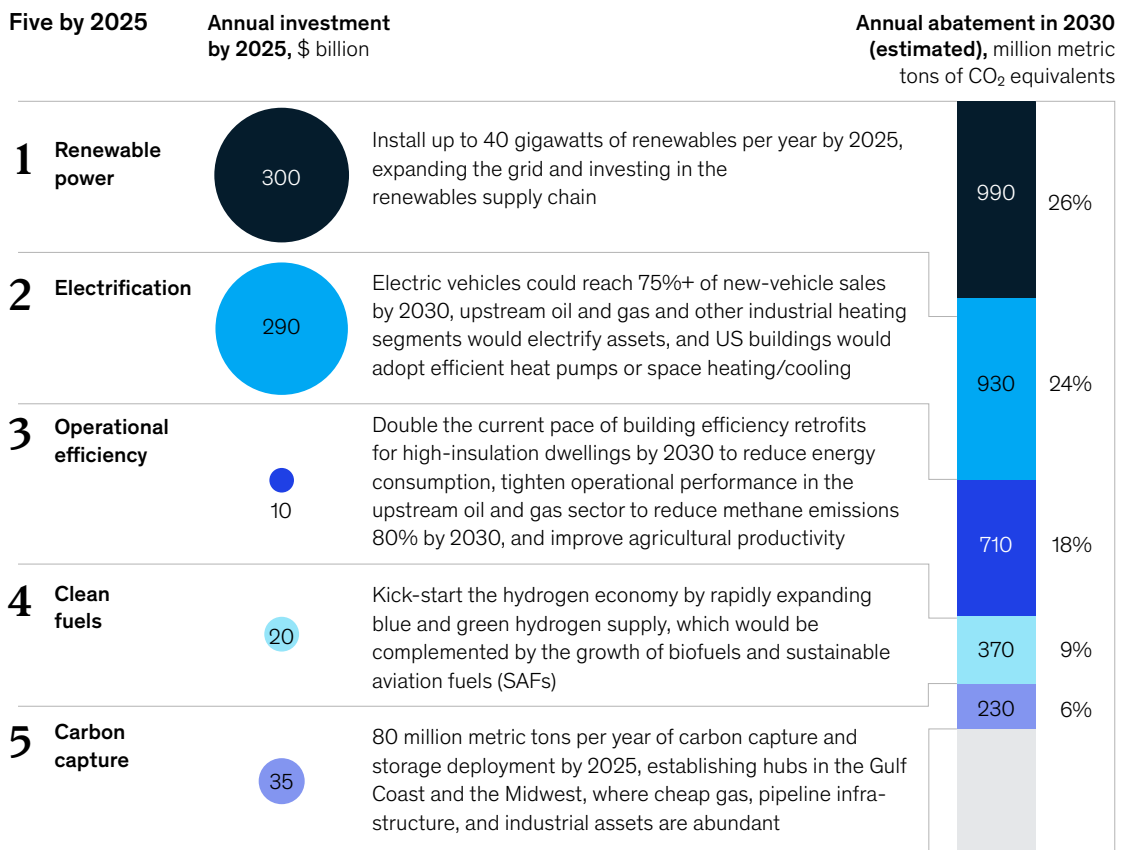
1. **Renewable power.** In a net-zero scenario, the country's energy system would be reconfigured. Indeed, the United States has set a target to create a "carbon-pollution-free power sector by 2035."⁵ Energy consumption would shift away from fossil fuels, which provide 90 percent of primary energy today, and toward renewables, which would produce just over 75 percent of

primary energy in 2050. This shift would result in more than 35 percent of the emissions reduction that is needed in 2025 and more than one-quarter of the reduction in 2030.

To expand the use of renewable power, the United States would install 40 gigawatts per year of renewable capacity in 2025. By 2030, the installation rate for renewables would reach 100 gigawatts per year, three times what it is now, as utilities tap the best solar resources from Texas to California and wind resources in the Midwest. Utilities would also build out power grids and

Exhibit 4

Five key markets for climate solutions would boom by 2025.



Note: Estimates shown here are based on McKinsey analysis of one possible 1.5°C emissions reduction scenario for the United States and are subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.
Source: McKinsey Sustainability Insights

⁵"Net zero by 2035: A pathway to rapidly decarbonize the US power system," McKinsey, October 14, 2021.

modernize them with flexibility resources including storage and dispatchable low-carbon power (for example, gas power plants with carbon capture, utilization, and storage) to prevent interruptions in electricity supply. Makers of renewable-electricity and storage equipment would expand production capacity to meet this demand, supporting \$300 billion of capital investment per year by 2025.

2. **Electrification.** The single most capital-intensive climate solution is the replacement of equipment that burns fossil fuels with equipment powered by electricity. (For this solution to reduce emissions significantly, the electricity would need to come from the renewable sources described above.) Cars and trucks with gasoline and diesel engines would be phased out nationwide in favor of electric vehicles (EVs). In every major metropolitan area (including Chicago, Dallas–Fort Worth, Los Angeles, New York, and Washington, DC), buildings that rely on oil- or gas-fired furnaces would instead be kept warm by electric heaters and heat pumps. And in major manufacturing hubs, such as the Gulf Coast, factory owners would install a wide array of new electric machines. Meeting the nation’s electrification needs would take \$290 billion of capital spending per year by 2025, according to our analysis. Electrification would account for roughly 15 percent of the emissions reduction needed for a net-zero pathway in 2025, one-quarter of the reduction in 2030, and more than one-third in 2050.
3. **Operational efficiency.** Improving operational efficiency represents the third-largest source of emissions savings, accounting for about one-fifth of the necessary reduction in 2025 and 2040. It is also the least capital-intensive solution, requiring an investment of \$10 billion by 2025. Opportunities to boost efficiency span sectors. Building owners, for example, could insulate existing buildings to reduce their energy consumption, particularly in colder
4. **Clean fuels.** The shift toward renewable power would also expand production of green hydrogen, which would serve as a zero-emissions energy carrier and as a clean-fuel feedstock for hard-to-abate sectors. The US Department of Energy’s “Hydrogen Shot” initiative⁶ aims to reduce the cost of clean hydrogen 80 percent in one decade, to \$1 per one kilogram, which would bring hydrogen much closer to cost parity with natural gas for most applications.⁷ Our analysis suggests that by 2030, US output of green hydrogen and blue hydrogen could reach three million metric tons per year. By 2050, hydrogen and hydrogen-based fuels would meet about 15 percent of US final energy demand. Other clean fuels, such as biofuels, could replace fossil fuels in applications where hydrogen is less practical, notably aviation. Regions that have both the resources to supply these fuels and the demand for them from local industries could become important hubs for clean-fuel adoption; these regions include Chicago, Houston, and Los Angeles.
5. **Carbon capture.** The US Gulf Coast and the Midwest have qualities that make them well suited to serving as hubs for carbon capture and storage. They are home to many emissions-intensive industrial sites, such as chemical plants. And their extensive gas pipeline infrastructures might transport captured CO₂ into their natural underground reservoirs. What the regions lack is equipment for capturing CO₂ from the flue gases of industrial facilities and transporting it to a permanent storage location. Filling this need would

regions such as the Northeast. Upstream oil and gas companies could stop flaring and venting emissions and enhance leak detection and prevention technology, primarily in the oil and gas fields of West Texas’s Permian Basin. Farm operators could use genetic technologies and other techniques to improve the GHG efficiency of livestock in ranching areas, such as Kansas, Montana, and Wyoming.

⁶“Hydrogen Shot,” Hydrogen and Fuel Cell Technologies Office, site accessed April 2022.

⁷*Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness*, Hydrogen Council in collaboration with McKinsey, February 2021.

require capital spending of \$35 billion per year. With such infrastructure in place, companies that also switch to bio-based fuels could consider their assets carbon negative.⁸

manage socioeconomic impacts. Below, we look at four significant trends in detail.

Macro trends during the net-zero transition

The five climate solutions described above would come with profound changes in America's economy and industrial systems, including employment shifts, asset stranding, and capital reallocation. To mitigate risks and realize growth prospects as the transition advances, companies will want to anticipate these developments, think through their implications, and plan strategies for responding. Companies and government agencies, too, could consider various policy interventions to

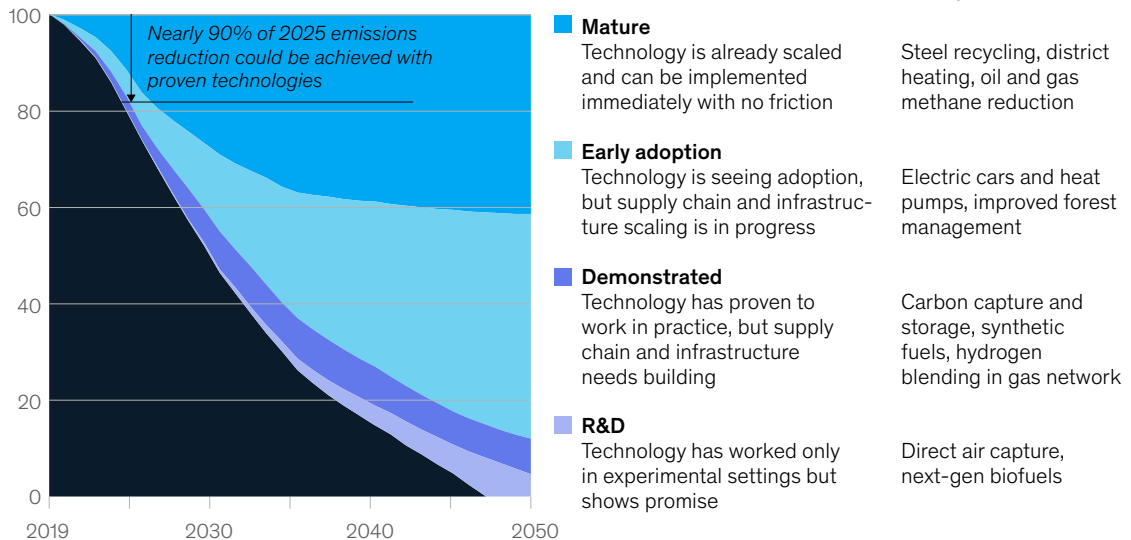
Accelerated deployment of climate technologies and infrastructure

Most of the technologies that enable climate solutions are known. On the emissions pathway we have described, nearly 90 percent of the abatement needed by 2025 could come from two sets of technologies: those that can be considered mainstream, insofar as they are mature, commercially viable, and being widely deployed, such as solar-power generation; and those that are in the early stages of adoption, such as heat pumps (Exhibit 5). Solar-power installations, for example, would go up eightfold, from five gigawatts per year in 2019 to 40 gigawatts per year in 2030.

Exhibit 5

By 2025, nearly 90 percent of the carbon abatement needed could come from technologies that are mature or in the early stages of adoption.

Carbon abatement split, by technology maturity, % share of abatement



Note: Estimates shown here are based on McKinsey analysis of one possible 1.5°C emissions reduction scenario for the United States and are subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.
Source: McKinsey Sustainability Insights

⁸There are still uncertainties in how the market for carbon removals, also called negative emissions, will work with no announced federal-level policy measures for removals in the United States. Should there be a value placed on carbon removals credits, carbon-negative asset owners might be able to monetize removals and improve the business case for combined bioenergy and carbon capture solutions.

Deployment of mainstream and early-stage climate technologies will also require new infrastructure: charging stations and battery supply chains for EVs; rare-minerals supply and transmission lines for renewables; electrolyzers to make hydrogen and pipelines to transport it. This expansion could allow companies to invest in developing new low-emissions capital projects and in decarbonizing existing assets.

Shifting economics of abatement

The cost of climate solutions is declining quickly as technologies mature. Our analysis suggests that,

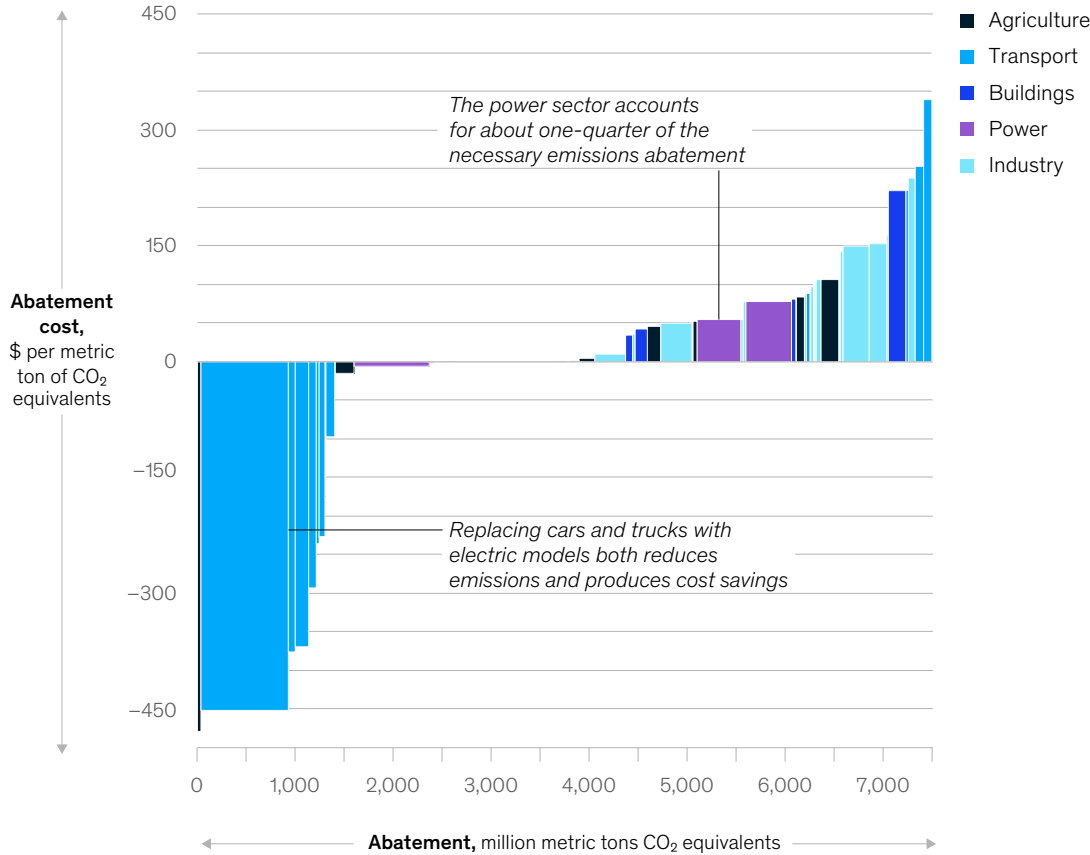
in the aggregate, organizations could presently abate some 40 percent of US GHG emissions at no net additional cost, or even save money by doing so. And because innovation and economies of scale should lower technology costs over time, we believe it may be possible for companies to abate another 10 percent of emissions without cost increases by 2050.

Even so, we find that about 50 percent of GHG emissions in 2050 would likely need to be addressed with climate technologies that cost more than conventional technologies (Exhibit 6). The

Exhibit 6

About half of the climate technologies needed to reach net zero would require additional support to be cost competitive in 2050.

Projected US abatement cost curve, by sector, in 2050



Note: Estimates shown here are based on McKinsey analysis of one possible 1.5°C emissions reduction scenario for the United States and are subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.
Source: McKinsey Sustainability Insights

most expensive climate technologies—at more than \$150 per metric ton of CO₂ abated—include sustainable aviation and marine fuels, direct air capture of CO₂, and electrification of high-temperature industrial heat. Companies are unlikely to take on additional costs voluntarily, particularly if current inflationary trends in the United States persist. Therefore, the investments needed to achieve net zero might take place only if companies face changes to public policy or new demands from shareholders—including investors, joint-venture partners, and customers, as we discuss below.

Significant capital spending

Deploying climate solutions at scale would require large capital spending: \$27 trillion through 2050 (\$900 billion per year, on average), according to our estimates under the 1.5°C decarbonization scenario.⁹ This spending is equal to 4 percent of 2021 GDP, or 13 percent of capital outlays across the US economy in 2021. Our analysis suggests that nearly four-fifths of the total investment would be needed for mainstream and early-adoption technologies; the rest would be devoted to nascent technologies.

Our analysis suggests that much of this capital would be used to decarbonize or phase out existing high-emissions assets before the end of their useful life as part of managing the challenge of stranded assets. Alongside systemic interventions supporting a transition to net zero, such as climate policy or technology innovation, organizations could use a catalog of financing mechanisms that may facilitate the deployment of capital and improve the risk/return profile of deals. These mechanisms could include raising debt capital through loans that provide low-cost funding if sustainability performance goals are met, generating carbon credits (from emissions abatement resulting from decarbonization retrofits) that could be sold to voluntary carbon markets, and securitizing loans to the owners of low-carbon assets and using funds from those securities to finance the decarbonization of high-emissions assets.

In financing the decarbonization of existing holdings, it would be wise for asset owners and investors to manage reputational or financial risks from their portfolios' exposure to high-carbon assets, create standards and tools for evaluating and implementing decarbonization investments, and maintain service to customers.

Value-chain decarbonization led by companies

As mentioned earlier, hundreds of US-based companies have set net-zero targets for themselves. Many of these targets apply to the emissions from not only their own operations but also their suppliers and the use of their products. Similarly, the White House issued an executive order in December 2021, calling for the federal government to buy zero-emissions goods and services in categories ranging from electricity to vehicles to building materials. Commitments such as these could put pressure on businesses to decarbonize, even if they themselves have not yet set emissions targets (Exhibit 7).

Some automakers with net-zero targets, for example, have prompted decarbonization in their supply chains by committing to purchase low-emissions or zero-emissions versions of inputs such as steel. Steel producers, in turn, are beginning to build plants that make green steel and to source iron ore from mining companies that are lowering their carbon emissions. Effects such as these are likely to ripple throughout the economy. Even companies whose operations are not emissions intensive may find it advantageous to decarbonize their value chains, whether to fulfill demands from customers, to adapt to changes in the costs of key inputs, or to deal with other material business issues.

Decisions and actions for business leaders

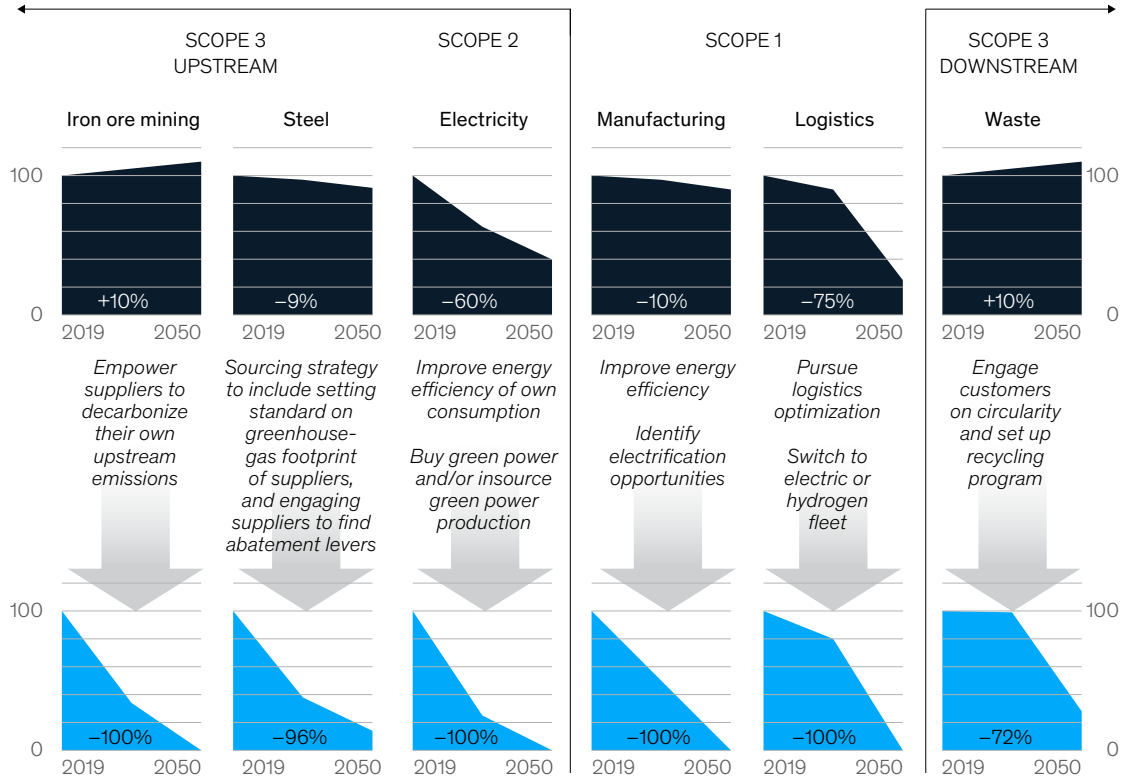
Although the pace of America's net-zero transition is uncertain, the direction is clear, as are the opportunities and trends that could emerge. Companies that prepare now could gain an edge. Below, we outline a few questions that may help

⁹This estimate focuses on the investments required to deploy the climate solutions that have a direct impact on reducing emissions. It is not a comprehensive estimate of all future indirect spending that might be needed to pay for such things as infrastructure and supply chain capacity.

Exhibit 7

The potential for one manufacturing company to decarbonize its value chain highlights economy-wide abatement opportunities for the United States.

Sector emission intensity, by decarbonization level, index (2019 = 100) ■ Business as usual ■ 1.5°C pathway



Note: Illustrative; not exhaustive.
Source: McKinsey Sustainability Insights

executives decide how their companies should move toward America’s net-zero frontier.

Where would my current business stand in a net-zero economy? For companies that are just beginning to think about what the net-zero transition could mean, it may be useful to envision the US economy in 2030 under a 1.5°C scenario: larger markets for low-emissions goods and services and smaller markets for high-emissions goods and services; new zero-emissions assets working alongside decarbonized legacy assets; competitive advantages for companies whose offerings feature low climate impact along with traditional desired qualities such as cost effectiveness and reliability.

Exercises such as this have compelled some US companies to begin overhauling their business models and portfolios. Companies could start with developing (or acquiring) capabilities to analyze the exposure of one’s core business to risks and opportunities under different decarbonization and warming scenarios.

What moves could my company make to create value in a net-zero economy? Rising demand for climate solutions should create growth opportunities in virtually every sector. To capture them, businesses could expand their net-zero playbook—going beyond defensive moves, such as analyzing and reporting risk exposures, to make

value creation a priority. Here are four ways that leading companies are seizing early advantages.¹⁰

1. **Portfolio transformation.** Some companies that have reoriented their business portfolios toward the growth segments of the net-zero economy have begun to outperform their slower-moving rivals. They are shifting resources away from business units that compete in markets where growth is likely to slow or even go into reverse (for example, power-generation companies shifting investments from coal-fired capacity to renewables) and reconfiguring assets to provide value in a net-zero economy (for example, those same power-generation companies investing in carbon-capture-and-storage retrofits for their existing gas plants).
2. **Green business building.** In addition to realigning the core business, leading organizations are investing in new, scalable business models to serve fast-growing markets for climate technologies and low-emissions goods and services such as green steel.
3. **Green premiums.** In markets for goods such as plastic and steel, customers are already willing to pay a price premium for offerings with legitimate green attributes. As the race to procure green materials heats up, more products could command such premiums.
4. **Decarbonized operations.** Our experience suggests that many technologies and operational changes that can reduce emissions

have a positive net present value—thus providing companies with a sound rationale for decarbonizing to a certain degree. If improvements in environmental performance also let the company charge a green premium, the case for decarbonization could become even more compelling.

What partnerships can help my company thrive?

Reaching net zero requires extensive changes for most companies, including changes to capital allocation, operations, and performance management. Some changes will be possible only if other entities also make changes; for example, mass uptake of electric vehicles depends significantly on the utility sector expanding grid capacity to support charging networks. In these cases, companies may find it helpful to join other organizations in addressing shared needs, such as the need for industrial-scale networks in hydrogen production and distribution.

The net-zero scenario described in this article is one path that the United States could take—a path entailing rapid transformation across multiple sectors. Although other outcomes are possible, commitments by government entities and businesses make it likely that some degree of technology adoption, innovation, capital spending, and value chain decarbonization will happen. The sooner that companies act on the opportunities emerging across America's net-zero frontier, the better off they could be in the long run.

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¹⁰See "Playing offense to create value in the net-zero transition," McKinsey, April 2022.

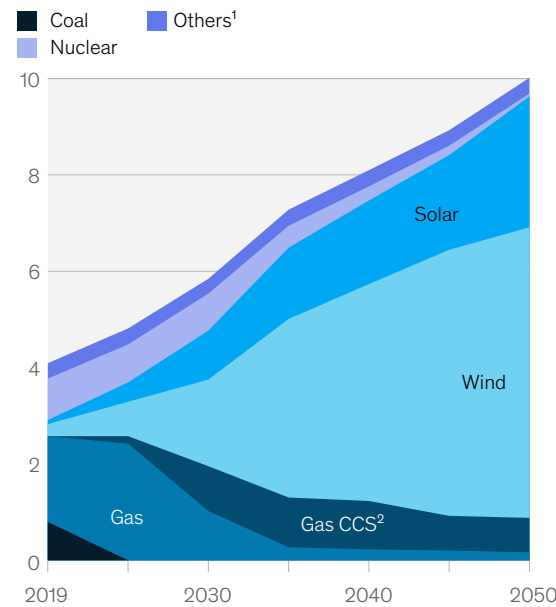
Appendix: Exhibit 3 (continued)

Exhibit 3b

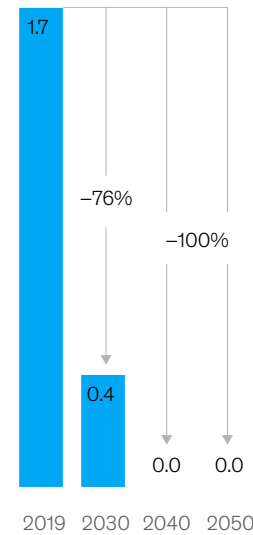
A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US power sector

US electricity generation,
thousands of terawatt-hours



Sector emissions,³ metric gigatons of CO₂ equivalents



2019 greenhouse-gas emissions, % share



Major changes

- Coal phase-out by 2025
- 3× faster build rate of wind and solar by 2030 vs today
- Rapid expansion of transmission capacity and grid flexibility resources
- Most gas turbines fitted with carbon capture or fueled by hydrogen or biogas by 2050

Note: This 1.5°C pathway is a McKinsey analysis of one possible carbon reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

¹Includes hydrogen, biomass, and hydroelectric power generation.

²Carbon capture and storage.

³A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

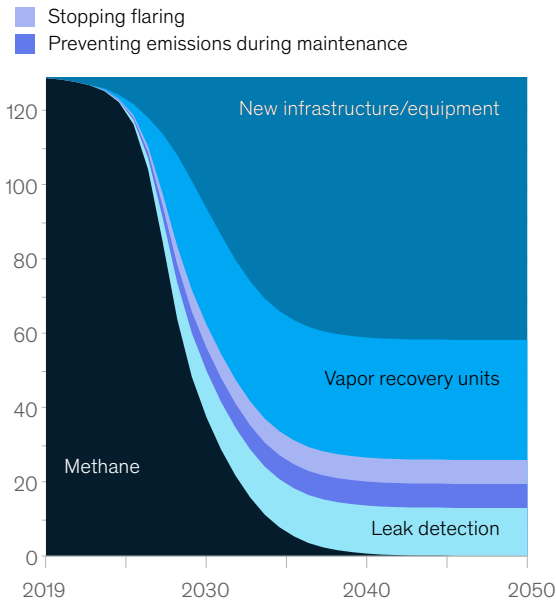
Source: McKinsey Power Solutions; McKinsey Sustainability Insights

Exhibit 3c

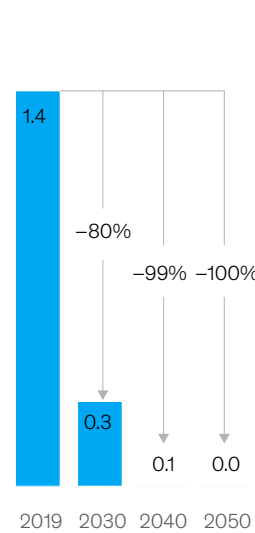
A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US oil and gas sector

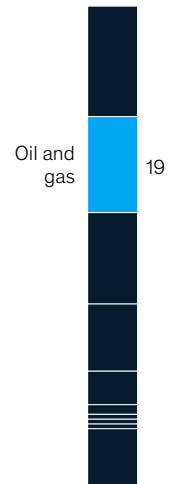
Oil and gas upstream methane intensity,¹
kilograms of CO₂ per barrel of oil equivalent



Sector emissions,² metric gigatons of CO₂ equivalents



2019 greenhouse-gas emissions, % share



Major changes

- Consumption of oil and natural gas drops 30% and 20%, respectively, by 2030
- Methane emissions reduced 80% by 2030 through operational efficiency and new infrastructure
- Flaring reduced 50% by 2025, 100% by 2030
- 40% of producing assets electrified by 2030
- Refineries pursue near-term energy efficiency measures, electrification, and low-CO₂ hydrogen use

Note: This 1.5°C pathway is a McKinsey analysis of one possible carbon reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

¹Methane accounts for 73% of all Scope 1 sector emissions. Abatement levers for upstream CO₂ and downstream petroleum refining are not shown.

²A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

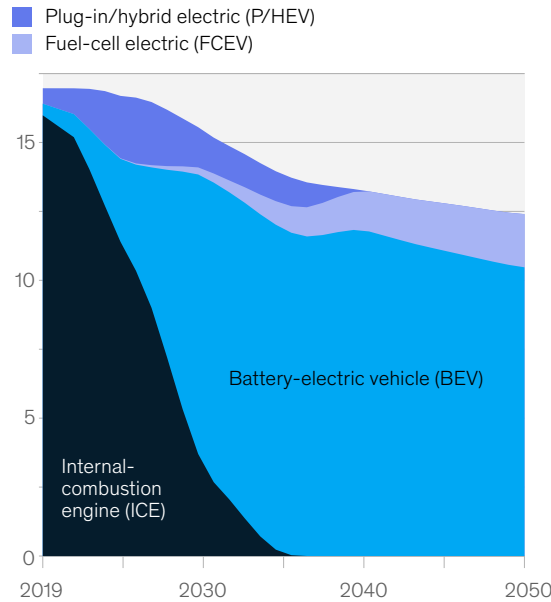
Source: McKinsey Energy Insights; McKinsey Sustainability Insights

Exhibit 3d

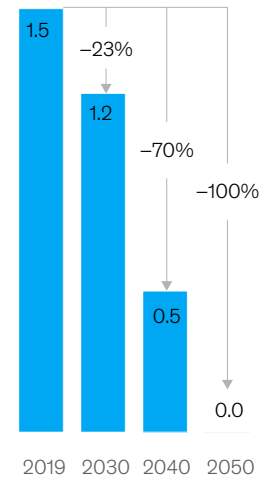
A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US road transportation sector

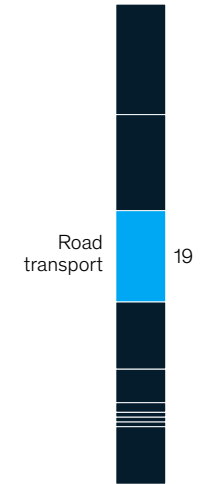
Passenger car and truck sales, millions of vehicles per year



Sector emissions,¹ metric gigatons of CO₂ equivalents



2019 greenhouse-gas emissions, % share



Major changes

- ICE vehicles eliminated from roads by 2050
- Rapid uptake of BEVs in passenger vehicle (75% of new sales by 2030) and small commercial-truck segments
- Improvements in BEV range and adoption of FCEVs in medium- and heavy-duty truck segments
- New infrastructure and services for BEV charging, FCEV refueling, and alternative modes of travel (eg, rail)

Note: This 1.5°C pathway is a McKinsey analysis of one possible emissions reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

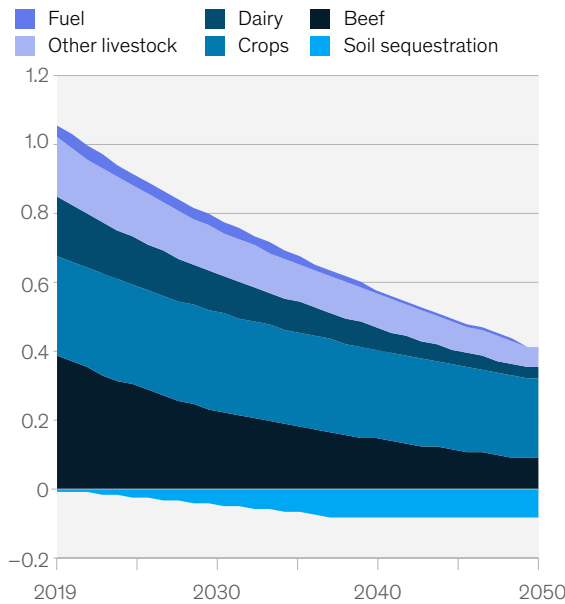
¹A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

Source: McKinsey Center for Future Mobility; McKinsey Sustainability Insights

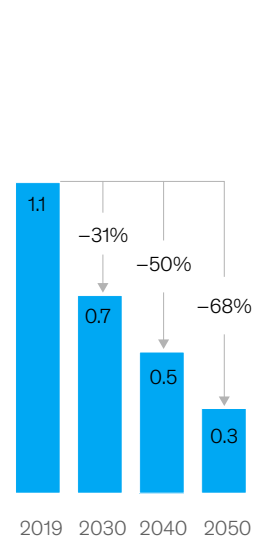
A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US agriculture sector

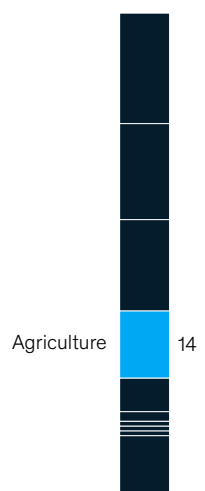
Agricultural emissions,
metric gigatons of CO₂



Sector emissions,¹ metric gigatons of CO₂ equivalents



2019 greenhouse-gas emissions, % share



Major changes

- On-farm levers reduce emissions by 15% by 2030
- Retailer- and consumer-driven waste (30% of food produced) is cut in half by 2050
- By 2050, half of beef cattle protein is supplied by alternative proteins (eg, chicken, legumes, cultured meat)
- Regenerative agriculture practices sequester carbon, reducing emissions a further 10% by 2050

Note: This 1.5°C pathway is a McKinsey analysis of one possible emissions reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

¹A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

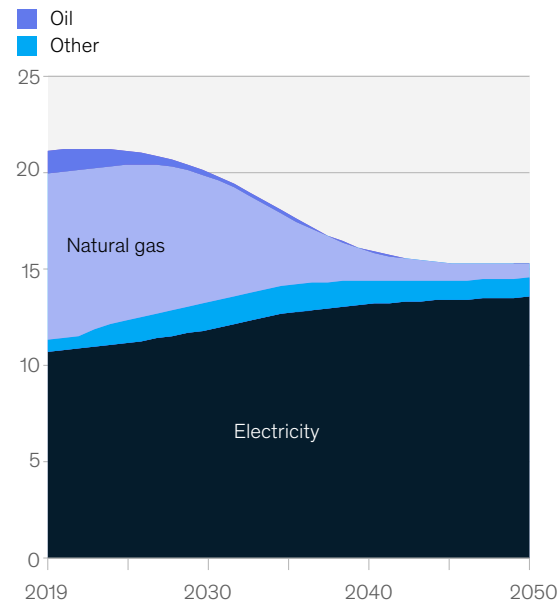
Source: McKinsey Sustainability Insights

Exhibit 3f

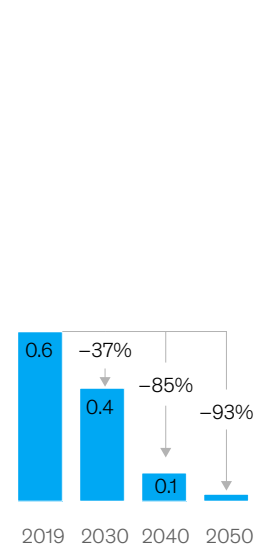
A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US buildings sector

Residential and commercial energy use, exajoules



Sector emissions,¹ metric gigatons of CO₂ equivalents



2019 greenhouse-gas emissions,² % share



Major changes

- By 2030, double the rate of energy-efficiency retrofits (eg, smart appliances and better insulation)
- Rapid conversion to electric equipment drawing power from grid and distributed sources
- Gas networks upgraded to distribute blended biogas and hydrogen
- Growing share of low-emissions construction materials (eg, steel and cement) to reduce embodied carbon in new buildings

Note: This 1.5°C pathway is a McKinsey analysis of one possible emissions reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

¹A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

²Buildings indirectly contribute an additional 17% of total US emissions stemming from the electricity generated for the buildings sector and additional Scope 3 emissions from building materials such as steel and cement. Improving energy efficiency and sourcing low-carbon materials could achieve substantial near-term reductions of Scope 2 and Scope 3 emissions not accounted for in buildings operations.

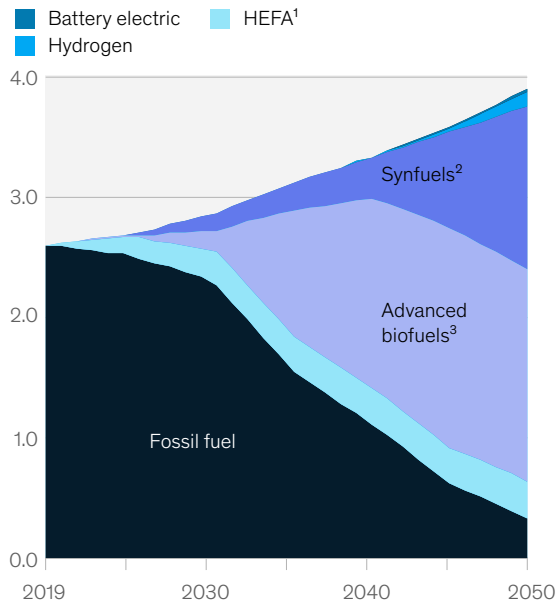
Source: McKinsey Sustainability Insights

Exhibit 3g

A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US aviation sector

Jet fuel consumption,
exajoules



Sector emissions,⁴ metric gigatons of CO₂ equivalents



2019 greenhouse-gas emissions,² % share



Major changes

- Production of sustainable aviation fuel (SAFs) surpasses 3 billion gallons per year by 2030
- Jet fuels contain 20% blend of bio-based or synthetic SAFs by 2030
- Novel propulsion systems (battery-electric, hydrogen) would become commercially available in the 2040s

Note: This 1.5°C pathway is a McKinsey analysis of one possible emissions reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

¹Hydroprocessed esters and fatty acids, which are biofuels made from waste/residue oils and fats as raw materials. ²Refers to the production of a syngas by electrolyzing water with renewable electricity and combining it with captured CO₂ to produce a liquid synthetic hydrocarbon. ³Includes alcohol-to-jet and gasification/Fischer-Tropsch from bio feedstocks. ⁴A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

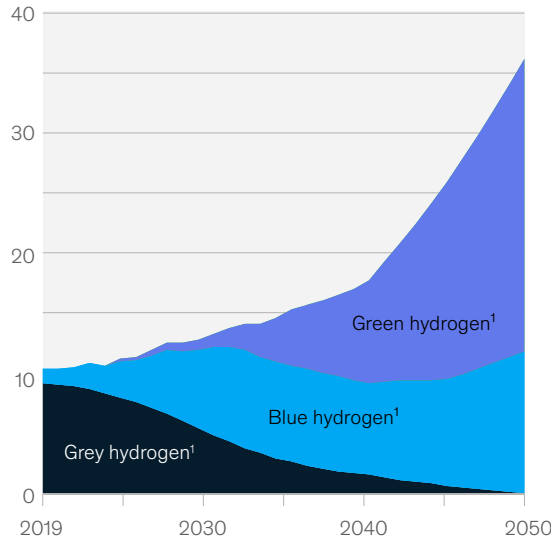
Source: McKinsey Sustainability Insights

Exhibit 3h

A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US hydrogen sector

Hydrogen production,
million metric tons per year



Sector emissions,² metric gigatons of CO₂ equivalents



2019 greenhouse-gas emissions, % share



Major changes

- Production nearly quadruples by 2050 as sectors shift from fossil fuels to hydrogen
- Low-carbon hydrogen production grows 20% per annum through 2030 as gray hydrogen is rapidly converted to blue
- Green hydrogen becomes the most produced variety in 2040, as costs of renewable electricity and electrolysis fall
- Transportation, primarily fuel-cell electric trucks and aviation synfuels, becomes the largest market for hydrogen

Note: This 1.5°C pathway is a McKinsey analysis of one possible emissions reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

¹Grey hydrogen is produced from natural gas in a process that releases CO₂ emissions; blue hydrogen is made from the same process but with carbon capture installed; green hydrogen is made from the electrolysis of water using renewable electricity with no emissions.

²A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

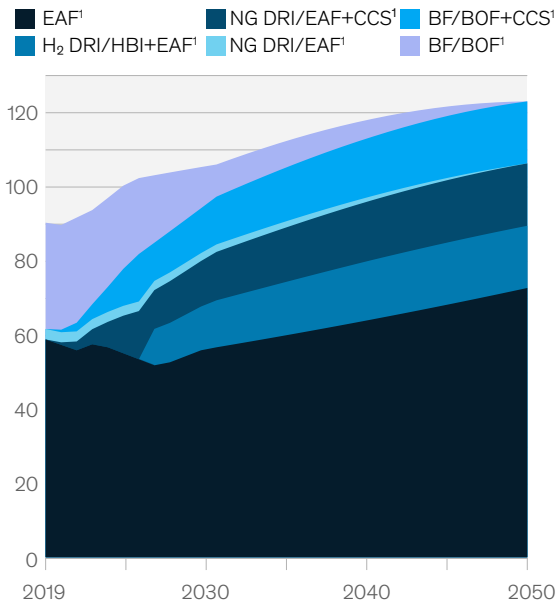
Source: McKinsey Power Solutions; McKinsey Sustainability Insights

A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US steel sector

Steel production,

million metric tons of liquid steel per year



Sector emissions,² metric gigatons of CO₂ equivalents



2019 greenhouse-gas emissions, % share



Major changes

- Half of all existing blast furnaces retrofitted with carbon capture by 2030
- Hydrogen-based DRI-EAF plants emerge by 2025 and reach about 10% of production by 2030
- 9% per year expansion of DRI capacity
- EAF production is continually maximized, limited only by availability of scrap steel inputs
- Steel recycling rates maintained above 90%

Note: This 1.5°C pathway is a McKinsey analysis of one possible emissions reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

¹BF/BOF: pig iron produced from iron ore in a blast furnace (BF), followed by steel production in a basic oxygen furnace (BOF); BF/BOF + CCS: the BF/BOF production technology outfitted with carbon capture and storage (CCS); NG DRI/EAF: pig iron produced from directly reduced iron ore (DRI) using natural gas (NG), followed by steel production in an electric arc furnace (EAF); NG DRI/EAF + CCS: the NG DRI/EAF production technology outfitted with CCS; H₂ DRI/HBI + EAF: the NG DRI/EAF production technology using hydrogen (H₂) instead of NG; EAF: steel produced from primarily scrap steel in an electric arc furnace.

²A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

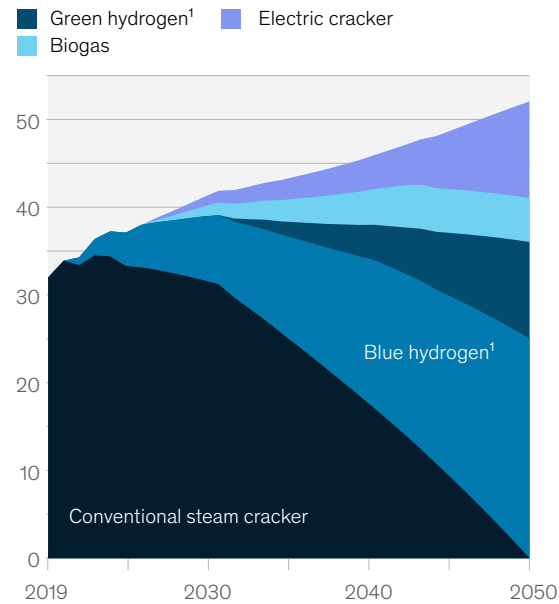
Source: McKinsey Sustainability Insights

Exhibit 3j

A 1.5°C emissions pathway for the United States would entail the transformation of every sector.

US ethylene sector

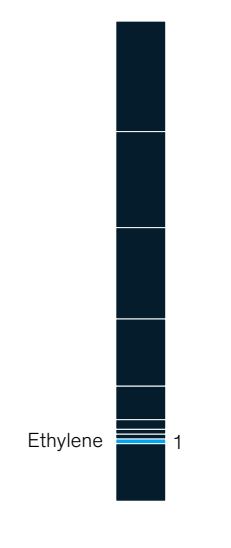
Ethylene production,
million metric tons per year



Sector emissions,² metric gigatons of CO₂ equivalents



2019 greenhouse-gas emissions, % share



Major changes

- 20% of conventional steam crackers retrofitted with carbon capture by 2030
- 30% of production capacity converted to green hydrogen or biogas fuel sources by 2050
- New electric-cracker technology provides more than 20% of production capacity by 2050
- Growing share of production from bio-based or recycled feedstocks

Note: This 1.5°C pathway is a McKinsey analysis of one possible emissions reduction scenario for the United States and is subject to change according to the dynamic context of climate regulation, technology, demand, and macroeconomics observed today.

¹Gray hydrogen is produced from natural gas in a process that releases CO₂ emissions; blue hydrogen is made from the same process but with carbon capture installed; green hydrogen is made from the electrolysis of water using renewable electricity with no emissions.

²A global-warming potential of 20 years (GWP20) is used to convert non-CO₂ GHGs into CO₂ equivalents in a way that better accounts for the short-term (20-year) warming impact relative to the long-term (100-year) impact.

Source: McKinsey Chemicals Insights; McKinsey Sustainability Insights