Sustainability Practice

Solving the net-zero equation: Nine requirements for a more orderly transition

Net-zero commitments are rising, but the net-zero equation is not yet solved. This can only change if nine interdependent requirements are met with singular resolve, unity, and ingenuity.

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October 2021

As leaders prepare for COP26[1] at the end of this month, the need for addressing the looming climate crisis seems to be grasped more broadly than ever before.[2] Already, 74 countries—accounting for more than 80 percent of global GDP and almost 70 percent of global CO_2 emissions—have put net-zero commitments in place.[3] And more than 3,000 companies have made net-zero commitments as part of the United Nation's "Race to Zero" campaign.[4] Capital markets are increasingly building emissions risk into asset prices, and venture investments in transition technologies are at an all-time high. For their part, an ever-greater number of companies are recognizing how shifting investor preferences—as well as changes in technology, regulation, and consumer behaviors—are changing the basis for competition and are calling for an altogether greater level of global and local collaboration.

Yet, these developments do not mean that net zero is in sight. The well-known words of Winston Churchill, pronounced in another context, seem to apply here too: "Now is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning." Indeed, the struggle to reach net zero requires the world to both rapidly reduce greenhouse-gas (GHG) emissions to the greatest extent possible and also preserve, regenerate, and develop the natural and man-made stores of greenhouse gases to balance all that cannot be reduced. Today, however, emissions continue apace without sufficient abatement and are not counterbalanced by removals. Nor can the goal be achieved on the current trajectory. Indeed, while the International Energy Agency's *World Energy Outlook* report, released earlier this month, acknowledges that the transition to cleaner energy sources is occurring at a rapid pace, it also highlights that it is still not aligned to a pathway that would stabilize global temperature increases at 1.5°C and achieve other energy-related sustainable-development goals.[5]

Thus, even as additional and more extensive commitments, including near-term targets, are discussed by key public-, private-, and social-sector entities, the world would need to advance rapidly from *what* is to be achieved—a net-zero world, within three decades or sooner—to *how* this can best be done. But moving from commitments to action has not proven easy or straightforward so far. There are five main reasons for this.

First, the required step-up in spend on physical assets (both capital expenditures and consumer spend on durable goods) to reach net zero by 2050 would be substantial. Indeed, we currently estimate this spend to represent an about 60 percent increase relative to today (from an estimated annual $5.7 trillion to $9.2 trillion).[6] While many of these investments come up with a positive return, financing for this scale of capital needs to be secured. The scale of the challenge is compounded by the speed at which it is required: entire energy- and land-use systems that evolved over a century or two would have to be transformed over the next 30 years.

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[1] Conference of the Parties (COPs), in this context, are global climate summits organized by the United Nations, typically on an annual basis. The 26th such summit on climate—COP26—is scheduled to be held from October 31 to November 12, 2021, in Glasgow, Scotland.

[2] The sixth assessment report of the Intergovernmental Panel on Climate Change, released in August 2021, reaffirmed that continued emissions of greenhouse gases will result in increasingly severe consequences for the Earth system and potentially abrupt and catastrophic changes that might occur as the climate passes "tipping points"; *Climate change 2021: The physical science basis*, Intergovernmental Panel on Climate Change, August 2021, ipcc.ch. See also: "Climate risk and response: Physical hazards and socioeconomic impacts," McKinsey Global Institute, January 16, 2020, McKinsey.com.

[3] Includes countries that have achieved their net-zero targets, or have put them in law, in policy documents, or proposed legislation. The 74 countries include all EU countries (both EU member states that are covered only by the overarching EU net-zero target, and EU countries that have set their own targets in addition to the EU net-zero target, such as Germany). See Net Zero Tracker, Energy & Climate Intelligence Unit, accessed on October 25, 2021, eciu.net. GDP data for 2019 from World Development Indicators Data Bank, World Bank, databank.worldbank.org; emissions data for 2018 from EDGAR v6.0, EDGAR – Emissions Database for Global Atmospheric Research, May 2021, edgar.jrc.ec.europa.eu; Crippa, M. et al., *Fossil CO_2 emissions of all world countries—2020 Report*, European Commission, 2020, edgar.jrc.ec.europa.eu.

[4] "Race to Zero campaign," United Nations Framework Convention on Climate Change, unfccc.int.

[5] *World Energy Outlook 2021*, International Energy Agency, October 2021, iea.org.

[6] Estimation includes spend for physical assets across various forms of energy supply (for example, power systems, hydrogen, and biofuel supply), energy demand (for example, for vehicles, alternate methods of steel and cement production), and various forms of land use (for example, GHG-efficient farming practices). This includes both what are typically considered "investments" in national accounts and spend, in some cases, on consumer durables such as personal cars.

Second, the transition calls for collective and global action and entails hard choices. This action would need to be taken in a spirit of unity as the burdens of the transition would not be evenly felt, and, for some stakeholders, the costs would be much more difficult to bear than others. Indeed, the effects of climate change and any near-term effects of the climate transition are likely to be regressive and hit the poorest communities and populations the hardest.[7] Without a real effort to address these effects in a spirit of fairness, it appears unlikely that the most affected stakeholders would be either able or willing to do their share to advance the transition. In the words of Frans Timmermans, the European Commissioner for Climate Action: “Without [a] just transition, there will just be no transition.”

Third, stakeholders would need to act now to avoid an unrelenting accumulation and compounding of physical risks in the future, which would require a different time horizon and discount rate than currently guide decisions.[8] The challenge is that there are both perceived and real trade-offs between securing net-zero emissions in the future and capturing growth opportunities today. Indeed, actions to secure the transition are often perceived as *costs* incurred today, rather than *investments* in humanity’s collective future.

Fourth, meeting these requirements would involve changing business practices and lifestyles that have been established for decades, if not longer, and that have provided many benefits in the past. Shifting these patterns and overcoming the prevailing inertia—without immediate benefits necessarily accruing differentially to those who make the shifts—has so far proven elusive.

Together, these four factors highlight why the prevailing notion of (enlightened) self-interest alone is unlikely to be sufficient to help achieve net zero.

Finally, the central role of energy in all economic activity and the profound consequences that disruptions to energy markets can entail highlight the criticality of an orderly transition—one where the ramp-down of high-emitting assets is carefully coordinated with the ramp-up of low-emitting ones and which is supported by the appropriate redundancy and resiliency measures. Such a transition, however, is nontrivial, both intrinsically and against the backdrop of other political, economic, and societal issues (see sidebar “What is an orderly transition?”). Indeed, the transition involves the transformation of the most important systems supporting our life and well-being—energy- and land-use systems. Even small disturbances to these systems could affect daily lives, from raising producer and consumer costs to impairing energy access, and could lead to delays and public backlash.

Achieving net zero is, in its essence, solving an equation that balances sources and sinks of emissions by reducing GHG emissions as much as possible while increasing GHG stores to remove any remaining emissions from the atmosphere. This is what we refer to in shorthand as the “net-zero equation.” In reality, this is not a single equation but a system of equations, as the emissions equation is *coupled* with a capital and a labor equation; demand for capital and labor in a net-zero economy must match with supply, over time and across regions. And, these equations must be solved simultaneously while pursuing economic development and inclusive growth. This is a nontrivial task both for the reasons noted above and because of a number of technical challenges. First, the emissions equation is still *incompletely defined*. The focus has so far been on man-made emissions, but it is becoming increasingly difficult to ignore the natural emissions resulting from biotic feedback loops. Second, the terms of this equation are a function of time and depend, sometimes

[7] For more, see “Climate risk and response: Physical hazards and socioeconomic impacts,” McKinsey Global Institute, January 16, 2020, on McKinsey.com. See also: Mekala Krishnan and Jonathan Woetzel, “Climate change hits the poor hardest. Here’s how to protect them,” World Economic Forum, October 14, 2020, weforum.org.
[8] See also: Mark Carney, “Breaking the tragedy of the horizon – climate change and financial stability – speech by Mark Carney,” Bank of England, September 29, 2015, bankofengland.co.uk.

What is an orderly transition?

What is meant by an orderly transition? And what are the parameters that define what is possible? The debate on net zero often seems to oppose an “orderly” transition to a “disorderly” one in a binary fashion. But orderliness is a relative notion. At one end of the spectrum, instantaneous and abrupt action could jolt economies and societies, impair growth, and lead to public resentment and political backlash. At the other end, delayed or limited action could lead to runaway climate change, threaten the lives and livelihoods of billions of people, bring about massive population displacements, exacerbate political strife and contention, and result in a severe contraction of the world economy. Between these two undesirable extremes lies a range of measured and decisive actions that would enable a rapid ramp-down of high-carbon economic activities in tandem with a corresponding ramp-up of low-carbon ones, supported by a willingness to anticipate and address the social and economic consequences such a shift would entail. What determines the possible levels of orderliness at any given point is the amount of time left before runaway climate change takes hold and the degree to which the main requirements for such a transition have been met.[1]

[1] Stakeholders are increasingly beginning to consider various scenarios of an “orderly” and “disorderly” transition as they plan for the future. The Network for Greening the Financial System (NGFS), a consortium of central banks, has, for example, published six scenarios to be used for risk analysis and strategic planning. These scenarios cover a broad spectrum of warming levels, time frame of action, and degree of collaboration across nations, resulting in a set of orderly and disorderly scenarios. For further details, see Christopher Bertram et al., *NGFS Climate Scenario Database: Technical documentation v2.2*, Network for Greening the Financial System (NGFS), June 2021, ngfs.net.

nonlinearly, on a host of evolving variables. For example, the emissions associated with a given economic sector or geography depend on existing or yet-to-be-developed technologies that are deployed in them. Third, the emissions equation is intrinsically *underspecified* in mathematical terms. It could theoretically be satisfied with many different combinations of decarbonization and offsetting actions, which would require a greater degree of cross-sector and cross-geography coordination. Finally, like all real-world systems of equations, these equations are subject to initial and boundary conditions that will, in practice, constrain the solution space. For example, the age and recency of fossil-power assets in a country would influence how easily and quickly they could be ramped down; or the amount of sunshine a certain region receives will constrain its potential to produce solar power.

Given the complexities involved, a critical step at this juncture is to better understand the fundamental requirements to solve these equations, as well as the interdependencies between these requirements. What we present here is a holistic framework for doing so. Our framework entails nine key requirements (Exhibit 1). These requirements are not specific to a given sector, and indeed all stakeholders—in the public, private, and social sectors—will need to play a role if they are to be met. They can be seen as the fundamental chords that would all need to be resolved in concert, if not in unison, for a net-zero transition to materialize. The nine requirements can be grouped into three categories:

— *Physical building blocks,* encompassing (1) technological innovation, (2) ability to create at-scale supply chains and support infrastructure, and (3) availability of necessary natural resources.

— *Economic and societal adjustments,* comprising (4) effective capital reallocation and financing structures, (5) management of demand shifts and near-term unit cost increases, and (6) compensating mechanisms to address socioeconomic impacts.

— *Governance, institutions, and commitment,* consisting of (7) governing standards, tracking and market mechanisms, and effective institutions, (8) commitment by, and collaboration among, public-, private-, and social-sector leaders globally; and (9) support from citizens and consumers.

Exhibit 1

There are nine requirements for solving the net-zero equation and ensuring an orderly transition.

Physical building blocks

1. Technological innovation

2. Ability to create at-scale supply chains and support infrastructure

3. Availability of necessary natural resources

Economic and societal adjustments

4. Effective capital reallocation and financing structures

5. Management of demand shifts and near-term unit cost increases

6. Compensating mechanisms to address socioeconomic impacts

Governance, institutions, and commitment

7. Governing standards, tracking and market mechanisms, and effective institutions

8. Commitment by, and collaboration among, public-, private-, and social-sector leaders globally

9. Support from citizens and consumers

In what follows, we address each of these nine requirements in the spirit of the critical, collective quest that must be pursued for the *how*. While, along the way, we list potential solutions that have been or could be considered, our main focus is on the key *questions* that would ultimately need to be addressed by the whole world, from individuals to nations and private organizations to public entities. Better questions and answers will come, as they must, if the world is to achieve a more orderly transition to net zero. It is our intent as a firm to contribute to this undertaking by providing analyses of the facts and options available.

Five main conclusions emerge from the examination of these requirements.

First, much of the attention to date has been focused on the first category—physical building blocks—but this needs to be expanded to also encompass the other two categories. In particular, understanding and preparing to address the socioeconomic impacts of the transition appears to be a critical step at this stage. Indeed, there is a very real risk that transition costs and effects would be unbearable to many in the absence of compensating measures; for example, if companies and countries do not manage the shifts in demand or cost impacts to their existing products and services or if communities are left behind as the world transitions to a net-zero economy. There is also a risk that the transition itself is derailed, for example, if sufficient capital is not allocated to low-emissions assets or to responsibly retire high-emissions assets at the pace at which this is needed.

Second, meeting all nine of these requirements is undeniably challenging. Meeting them quickly enough to limit warming to 1.5°C will be even more so. Achieving net zero will require overcoming traditional orthodoxies and ways of working and developing new ways of working collectively. Constructive actions taken during the pandemic have demonstrated the world's ability to innovate and intervene at scale to support both lives and livelihoods. This challenge will require similar efforts, albeit sustained over multiple years and decades and at a much larger scale.

Third, in the meantime, adaptation and resiliency will be of critical importance. Climate science tells us that, because of inertia in the geophysical system, some amount of additional warming is already locked in over the next decade, regardless of emissions pathway.[9] The world would thus need to fundamentally increase and accelerate efforts toward adaptation, so as to alleviate the more immediate and pernicious impacts of the climate change that has already occurred or is locked in irrespective of any decarbonization action.

Fourth, clear principles will be needed to ensure that the world appropriately balances short-term consequences and long-term benefits: seeking to minimize the capital and operating costs of the transition; actively managing the risk of energy-system failures; supporting unequal outcomes across income and demographic groups, countries, and sectors; and driving the transition while sustaining growth and economic development to finance the transition and to enable prosperity and energy access for all.

Fifth, there are no simple silver bullets here. Rewiring the way the world and our economy works is a substantial undertaking and will require all stakeholders to play a role. While specific actions will evolve over time, all stakeholders must begin on their journey now. Indeed, we are starting to see accelerating action in certain sectors. In particular, financial institutions—which play a central role in deploying the capital needed for a net-zero transition—are coming together to set net-zero targets and commitments to climate finance. More broadly, leaders must *understand and commit* to the transition, including understanding the fundamentals of climate science and the transition and making personal and professional commitments; *assess and plan* their actions, including through building risk-assessment capabilities and establishing decarbonization plans; *reduce and remove* emissions in accordance with these plans; *conserve and regenerate* natural capital to support decarbonization; *adapt and build resilience* to manage the physical risk that is already locked in; *reconfigure and grow*, for example, by reallocating capital and ramping down high-carbon businesses responsibly while scaling low-carbon ones; and seek to *engage and influence* those around them, across their investors, customers, suppliers, peers, and regulators.

Physical building blocks

1. Technological innovation

The present state and rate of climate change is an outcome—or, more precisely, an externality in the language of economics—of humanity's astounding technological progress. Human ingenuity, unleashed over 12,000 years of relative climate stability, has given rise to an unprecedented level of global prosperity. At the same time, this prosperity has come with emissions-intensive forms of production and consumption that cannot be sustained at these levels and rates.[10] Yet, just as technological innovation has led us into this crisis, it can also accelerate the recovery. Transforming technologies—across power, mobility, industry, buildings, and agricultural, forestry, and land-use systems—will be essential to reducing global emissions and helping the world achieve net-zero emissions. As one important example, the agricultural sector is in particular need of accelerated innovation to manage its emissions of not only CO_2 but also other greenhouse gases such as methane. More generally, low- and zero-carbon technologies would need to be developed, tested, improved, and made cost-effective. Over time, it will be essential to lower unit costs to scale up and achieve broad commercial adoption. And across all technologies, careful planning would be needed to ensure new technologies link with each other and with existing infrastructure (for instance, safely integrating hydrogen into existing gas-pipeline networks or managing grid intermittency with new sources of renewable power).

[9] H. Damon Matthews et al., "Focus on cumulative emissions, global carbon budgets, and the implications for climate mitigation targets," *Environmental Research Letters*, January 2018, Volume 13, Number 1, iopscience.iop.org.
[10] *Climate change 2021: The physical science basis*, Intergovernmental Panel on Climate Change, August 2021, ipcc.ch.

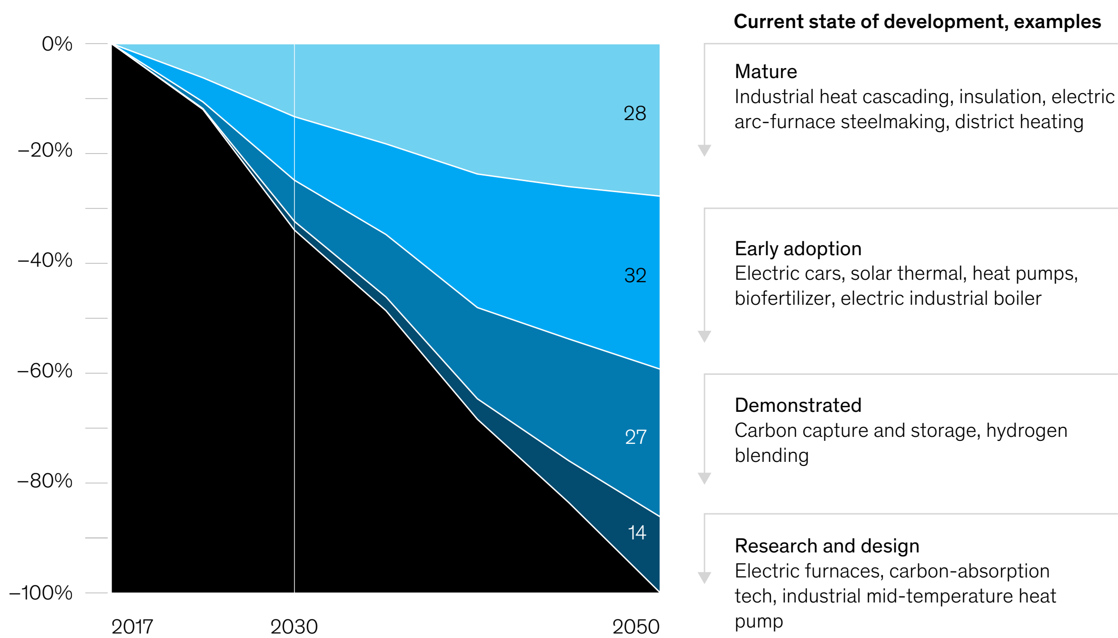
There are a wide range of views about how technically feasible it is to transition to net zero by 2050. Past McKinsey research suggests that there is a line of sight to the technologies needed to limit warming to 1.5°C above pre-industrial levels, though continued innovation is still needed.[11] Our work on decarbonization in Europe, for example, found that more than 85 percent of today's emissions in Europe can be abated with already demonstrated technologies, including 28 percent that are mature and 32 percent that are in the early-adoption phase (Exhibit 2) (although, it is important to note that the pathway to deploying these technologies is still uncertain, and would require addressing a host of other requirements, as described in the rest of this article).[12] Human ingenuity has risen to the needs of the moment in the past, and innovation has the potential to solve the remaining technological challenges ahead of us.

However, the remaining challenges should in no way be minimized, as substantial work lies ahead in developing and refining the required technologies and offering solutions that are

Exhibit 2

In Europe, we estimate that more than 85 percent of today's emissions can be abated with already-demonstrated technologies, though the pathway to deploying these technologies remains uncertain.

EU greenhouse-gas abatement, relative reduction of CO_2e[1] vs 1990, % share of reduction



Note: Figures may not sum to 100%, due to rounding.
[1] CO_2e calculated based on 100-year global-warming potentials (IPCC AR4).
Source: "How the European Union could achieve net-zero emissions at net-zero cost," December 3, 2020, McKinsey.com

[11] Kimberly Henderson, Dickon Pinner, Matt Rogers, Bram Smeets, Christer Tryggestad, and Daniela Vargas, "Climate math: What a 1.5-degree pathway would take," *McKinsey Quarterly*, April 30, 2020 , McKinsey.com. Research from others has had similar findings. Most recently, the *World Energy Outlook 2021* from the IEA has found that technological solutions to close the gap with a 1.5C path are available, and that about 40 percent are cost-effective.

[12] Paolo d'Aprile, Hauke Engel, Godart van Gendt, Stefan Helmcke, Solveigh Hieronimus, Tomas Nauclér, Dickon Pinner, Daan Walter, and Maaike Witteveen, *How the European Union could achieve net-zero emissions at net-zero cost*, December 3, 2020, McKinsey.com.

affordable throughout the globe, subject to evolving constraints on inputs, labor, and capital. It is also important to recognize that—as with the transformative investment booms in railroads, electricity, or the internet—there will be missteps along the way, and, in hindsight, likely misallocation of effort and even of capital. But, given the nature and magnitude of socioeconomic impacts posed by a changing climate, standing still carries significant risk. Viable technologies must be deployed today, and a range of promising technologies must be further developed. Finally, hand-in-hand with the development of mitigation technologies, society would also need to simultaneously prepare for the risk that solutions may not be developed in time to limit warming to 1.5°C, or even 2°C, and to develop the technologies needed to manage the physical impacts which may then ensue. In the words of John Holdren, former president of the American Association for the Advancement of Science and an energy and climate expert, "We basically have three choices: mitigation, adaptation, and suffering. We're going to do some of each. The question is what the mix is going to be. The more mitigation we do, the less adaptation will be required and the less suffering there will be."[13]

Key questions for stakeholders:

— What is the appropriate mix of technologies needed to be deployed to achieve emissions reductions while staying within a "carbon budget," limiting costs, and delivering required standards of performance (for example, ensuring grid stability)? How does this mix vary across geographies? How will it change over time?

— How market-ready and cost-effective are the technologies needed to get to net zero? What are the greatest gaps that remain to be filled? How would these technologies be best prioritized in terms of their scalability and impact?

— What are the policies, funding structures, demand signals, market mechanisms, and other means necessary to accelerate the maturation of promising early-stage technologies (for example, those that could provide 10x performance improvement), sustain innovation in the later stages of the technology-development journey, and make technologies that are now prohibitively expensive more practicable?

— How can technological uncertainties best be managed? What roles should the public and private sectors play in this regard?

Solutions on the table for consideration:

— Accelerate deployment of existing low- and zero-carbon technologies (for example, energy efficiency and renewables in geographies where they remain a small share) by providing incentives and appropriate demand signals.

— Create industry-wide technology roadmaps to reduce uncertainty and align R&D investments, particularly for key technologies such as hydrogen; carbon capture, utilization, and storage; and new forms of electricity storage.

— Facilitate innovation in new technologies by making purposeful, holistically-minded investments in R&D. This requires considering the full basket of technologies needed for net zero, not just those needed to achieve the next milestone (for example, 2025 or 2030). It will require parallel action across the full portfolio of technologies and maintaining perspective of the complete innovation journey—from concept to lab and then to prototype and commercial maturity.

— Foster industrial ecosystems and encourage collaboration across value chains to enable "in the field" innovation and diffusion.

2. Ability to create at-scale supply chains and support infrastructure

To mitigate GHG emissions or remove them quickly, low- or no-carbon technologies would not only need

[13] James Kanter and Andrew C. Revkin, "World scientists near consensus on warming," *New York Times*, January 30, 2007, nytimes.com.

to be created but also need to be widely deployed. Enabling and deploying necessary technologies will, in turn, require scaling up of production and distribution capacity and building out global supply chains. For example, under a 1.5°C pathway, the number of solar panels installed globally per week would be approximately eight times higher than they are today. The rate of wind-turbine installations would need to be increased by fivefold.[14] Building out supply chains to support that kind of step change requires not only significant capital and the right capabilities but also extensive coordination. While mismatches between the steps that actors take across a supply chain could occur, leading to bottlenecks, shortages, and price increases, effective planning will help limit these mismatches.

Additionally, expanded and new infrastructure would have to be built out for low-carbon systems to operate. Consider Europe, where we estimate that the installation rate of public charging stations for electric vehicles would have to increase by a factor of 20 by 2030 to meet the emissions-reduction target for passenger cars. That suggests that capabilities, incentives, and support measures would be needed at an unprecedented pace and scale—even though they cannot be applied on a one-size-fits-all basis. Yet as the recent progress in developing mRNA-based vaccines demonstrates, unprecedented does not mean unachievable. As was the case in response to the pandemic, critical actions along the value chain follow appropriate demand signals, which incentivize producers and help mobilize capital.

As discussed above, it is important to accelerate low- and zero-carbon technology deployment today where it is viable. Indeed, deploying and scaling technologies will enable their continued improvement over time, both in terms of performance and costs.

Key questions for stakeholders:

— Where are supply-chain and infrastructure bottlenecks most likely to occur, based on existing capacity, the ease of building new capacity, and existing capabilities?

— For each industry or country, how might consequences vary based on the pathway to net zero (for example, mix of technologies deployed)?

— What are the foreseeable consequences of any bottlenecks in terms of shortages or price increases? How severe could these be, and are there particular sectors or geographies most at risk? What forms of preparedness or insurance can be developed in advance to mitigate potential bottlenecks?

— What incentives, demand signals, capability building, and broader measures can help expand production capacity of new technologies at a fast-enough pace?

— As new supply chains are built, what are the implications for trade flows, import dependencies, and national competitiveness?

Solutions on the table for consideration:

— Create cross-value chain forecasts and roadmaps that are on the scale of the technology buildup needed, to set consistent targets across industry players and to support multistakeholder coordination and collaboration.

— Encourage and enable collaboration across supply chains and ecosystems to scale production (such as by matching suppliers of new technologies with providers of capital and guaranteed buyers of these technologies).

[14] Kimberly Henderson, Dickon Pinner, Matt Rogers, Bram Smeets, Christer Tryggestad, and Daniela Vargas, "Climate math: What a 1.5-degree pathway would take," *McKinsey Quarterly*, April 30, 2020, McKinsey.com.

— Stimulate demand from downstream consumers for new low-emissions materials and products in each one of the hard-to-abate sectors (for example, from automotive companies for green steel or from retailers for low-emissions logistics provision) and do so at levels sufficient to create the incentive for at-scale investments and reach cost-reduction tipping points in those sectors by 2030.

— Examine the range and mix of demand signals and financial measures needed to create the appropriate incentives and create certainty about the building-out of supply chains and infrastructure, ideally by taking a test-and-learn approach.

3. Availability of necessary natural resources
The deployment of technology and the maintenance and creation of supply chains and support infrastructure—often on a massive scale—will be possible only if sufficient natural resources are available. Three forms will be especially critical.

The first is *raw materials*, both those used in large quantities today (such as copper and nickel) and those which are currently considered relatively niche (for example, lithium, cobalt, and rare-earth metals). McKinsey analyses show that a net-zero transition would require a substantial increase in the use of some of these raw materials. Resulting constraints, for example, in scaling up production, may lead to temporary shortages and price increases.

The second resource is *land*, which is crucial to building out renewables' capacity. Compared with fossil fuels, renewables require more area per unit of energy output. Replacing a typical gas plant of approximately 1 gigawatt with solar power generating the same amount of electricity, for example, would raise total land use from about 350 acres to approximately 40,000 acres.[15] Even counting the land associated with the entire fossil-power value chain—for example, extraction, transportation, and storage of fossil fuels—total land use would still increase by a factor of five to ten. Land is also crucial for carbon stores and sinks such as forests, peatlands, and mangroves. On the other hand, forest land can contribute to emissions if not well managed, for example, through deforestation or forest fires. This suggests that preserving and regenerating natural capital will need to go hand-in-hand with the technological solutions described above. Importantly, natural, high-quality sinks are largely concentrated in a few geographies, and land often has competing uses, including food production and housing development. Its proper management would therefore require careful planning.

Third, *water* will also be a critical resource. Building an economy that is fueled in part by hydrogen will require large amounts of water. Water will also be crucial for extracting key minerals. The reliance on water would thus only increase under a net-zero transition, all while water is likely to be in shorter supply, both from increased demand for other uses and, in some geographies, from the reduced precipitation resulting from a changing climate.

Key questions for stakeholders:

— Which natural resources are required for a net-zero transition, and how much would their use increase? How might this vary based on the pathway to net zero (for example, the mix of technologies deployed), under different scenarios, across geographies, and over time?

— Where are there "hard" resource constraints that may limit the scalability of certain technologies? Where are there "soft" constraints that may lead to temporary shortages and price surges? How might this vary across geographies and over time?

— Where might it be feasible to use technological innovation to "engineer out" the use of certain raw materials?

[15] Assuming a solar-capacity factor of approximately 20 percent, land use of approximately ten acres per megawatt, and a gas-utilization factor of approximately 80 percent, and land use of approximately 0.35 acres per megawatt; based on *The footprint of energy: Land use of U.S. electricity production*, Strata, June 2017, docs.wind-watch.org.

- How can worker safety issues and local environmental impacts related to the extraction of key mineral resources best be addressed?

- How can land and water use be managed within and across regions to limit constraints on a net-zero transition while meeting other key needs (such as for population centers and food production)?

- What incentives, demand signals, and broader measures would be needed, both at the national and global levels, to allow for natural resources to be effectively balanced across multiple needs?

- What would be the consequences of new technologies on production locations and commodity trade flows? For example, would green hydrogen facilities and steel mills be better located near iron ore sources to help produce green steel, rather than the iron ore being shipped, as it is today, to ports where coal is available?

- How could we reimagine or create a new global trade ecosystem to support a net-zero transition so that countries or regions that have abundant solar, wind, or land resources can fruitfully trade with countries or regions where these resources are also needed?

Solutions on the table for consideration:

- Develop a global and granular view of natural resource needs by technology, and identify where key bottlenecks are likely to occur, including over time and across different net-zero pathways.

- Develop a global and granular view of the regions that have key endowments (such as minerals, hydrogen potential, and carbon capture and storage [CCS] potential) and those which lack them.

- Coordinate development plans for additional production capacity for key minerals, create mechanisms for cooperation across countries and companies, and begin scaling up production capacity in "no regret" areas. Explore opportunities for coordination across and within regions to better balance resource availability and need.

- Incorporate potential resource constraints into technology development to help engineer out raw materials which may be difficult or expensive to source.

- Examine the range and mix of incentives and other financial measures that could help scale up resource availability, factoring in lead times that will be needed for planning, permitting, financing, and scaling up production.

- Encourage greater societal buy-in for renewables land use; technical potential may run ahead of social acceptance.

- Build a fact base and accounting system to measure end-to-end impacts from resource use, including on worker safety and broader environmental impacts, to manage a broad set of outcomes, and conceptualize and evaluate trade-offs.

Economic and societal adjustments

4. Effective capital reallocation and financing structures

An orderly transition to net zero would require significant changes to capital allocation. Forthcoming estimates by McKinsey based on a scenario limiting warming to 1.5°C and reaching net zero by 2050 from the Network for Greening the Financial System (NGFS) suggest that spending on physical assets across energy- and land-use systems would substantially increase and shift relative to today. In our current estimation, the net-zero 2050 scenario would entail spending on physical assets of $9.2 trillion per year on energy- and land-use systems until 2050. This represents $3.5 trillion more than current annual spending in these areas, all of which would need to be spent in the future on low-emissions assets.

This incremental spend is equivalent to about half of global corporate profits, 7 percent of household spending, represents a quarter of total tax revenue, and is about 20 percent higher than the average annual increase in public debt seen between 2005 and 2020. If we consider the likely evolution of this spend, given population growth, GDP growth, and current momentum toward the net-zero transition, the capital outlay would be smaller but remain significant. Indeed, if the NGFS “current policies” scenario, which accounts for currently legislated policies and cost reductions in key low-emissions technologies, is taken as a basis, the incremental annual spend in a net-zero scenario would be $0.9 trillion higher (as opposed to the $3.5 trillion number noted above).

Managing stranded assets (the early retirement or underutilization of existing property, plant, and equipment) will also be an important part of ensuring effective capital reallocation. Some geographies will be more exposed than others, based on their age of assets. Coal power plants typically have a useful life of 40 to 60 years, yet the age of coal power plants varies across countries—just 13 years old on average in India, for example, compared with 39 years old in the United States. Moreover, an additional approximate 300 gigawatts of coal-plant capacity (equivalent to close to 15 percent of the global installed capacity) is currently under construction or approved.[16]

At the same time, the massive public outlay over the last two years to blunt the economic and societal impact of COVID-19 gives an indication of the magnitude of the resources that can be mobilized when the danger is clearly recognized.[17] Moreover, the economic adjustments involved in reaching net zero in a planned manner would likely prevent the further buildup of physical risks and the additional costs arising from a more disorderly transition. As stated by the European Central Bank in its recent report, “the short-term costs of the transition pale in comparison to the costs of unfettered climate change in the medium to long term.”[18]

Indeed in the long run and in the aggregate, the upfront capital expenditures for a net-zero transition would result in overall operating savings for the world economy as a whole through reduced fuel consumption, improved material and energy efficiency, and lower maintenance costs. Many of these investments are already cost-effective and come with a return. However, in the short run, various challenges need to be managed: raising capital and securing financing at this scale, managing technological uncertainty of investments, considering risk–return trade-offs, and driving capital flows to both developed and developing countries. McKinsey analysis suggests that lower-income countries, for example, would invest more than others as a share of GDP—about 1.5–2.5 times in Africa and India as in Europe or North America—in large part due to rapid economic growth and the needed expansion of electric-power infrastructure in a net-zero transition. Raising and deploying capital would also be more challenging for specific sectors and geographies.

Key questions for stakeholders:

— What are the biggest capital needs across sectors and geographies? How will these needs vary based on the mix of technologies deployed for the net-zero transition?

— Where is capital already flowing toward needed investments? Where are the biggest gaps?

— Based on the risk–return profiles, pay-off periods, and broader characteristics of capital investments, what is the likely mix of the types of capital that will be required (for example, public equity, public debt, private equity, project

[16] Global Coal Plant Tracker, Global Energy Monitor, July 2021, globalenergymonitor.org.
[17] Governments have provided massive fiscal support to protect companies and individuals. Estimates suggest that global fiscal support totaled $13.8 trillion, with $7.8 trillion in incremental spending and forgone revenue and $6.0 trillion in equity injection, loans, and guarantees since March 2020. See: *The territorial impact of COVID-19: Managing the crisis and recovery across levels of government*, OECD Policy Responses to Coronavirus (COVID-19), Organisation for Economic Co-operation and Development, May 10, 2021, oecd.org.
[18] Spyros Alogoskoufis et al., *ECB economy-wide climate stress test*, European Central Bank, ECB Occasional Paper Series No 281, September 2021, ecb.europa.eu.

finance, and public guarantees)? What are the respective roles that private finance and public finance (for example, sovereign funds and multilateral development banks) would need to play?

— What financial innovations and structures (such as new financial products, carbon markets, or blended finance) could drive capital to the sectors and geographies with the biggest needs and opportunities and drive the brown-to-green transition for high-carbon-intensity companies? Where will the creation of additional, effective compliance markets further help to facilitate the necessary capital allocation?

— How can voluntary carbon markets help facilitate capital reallocation (for example, investments into carbon-removal and avoidance or reduction assets), and how can such markets be scaled? How can the integrity and depth of these markets be ensured?

— What is the value of assets that may be stranded across sectors and geographies? How can the associated risks be proactively managed?

— What financing structures could create incentives for the retirement and decarbonization of carbon-intensive assets instead of merely their divestment?

— What new metrics and analytics are needed to factor into capital planning and to drive capital reallocation (for example, return on carbon, portfolio warming, and stress testing)?

Solutions on the table for consideration:

— Increase transparency and improve robust disclosures of emissions and scenario-based assessments of physical and transition risks to inform capital-allocation decisions.

— Develop and scale new financial products and structures to help companies wind down legacy assets and scale up new low-emissions assets. Solutions could include special-purpose vehicles that would enable companies to ring-fence legacy-emitting assets and retire them in line with a science-based net-zero pathway, financing structures such as long-term purchase agreements from renewables plants (with lower total life-cycle costs) to replace coal generation assets, and new financial instruments (for example, for negative emissions or for nature-based solutions).

— Develop and scale new voluntary carbon markets in the near term (to complement companies' primary imperative to decarbonize their operations) and compliance markets over a longer term. Voluntary carbon markets would include markets both for avoidance credits (for example, to prevent forests from being cut down) and for removal credits (for example, from afforestation or direct air capture).

— Systematically and judiciously use public finance both on a national and global scale to fund key infrastructure investments that provide positive impacts but which may be more difficult to finance through markets (for example, electric-vehicle charging stations, hydrogen fueling stations, and carbon sequestration).

— Derisk private capital aimed at mitigating climate risk through public guarantees or other risk hedges, and support capital flows to sectors and geographies with large financing gaps, for example, refocusing the function of development-finance institutions or multilateral development banks to provide first-loss and currency-risk hedges.

— Establish new, or restructure existing, multilateral or government funds to manage the ramping down of emitting assets and minimize the value at risk from stranded assets.

5. Management of demand shifts and near-term unit-cost increases

Under a net-zero transition, changes in policies, technologies, and consumer and investor preferences would drive demand toward low-carbon goods and services and away from high-carbon ones. The shift in energy mix would likely be the most significant, with the potential for a decline in demand for fossil fuels and an increase in demand for low-emissions power, hydrogen, and biofuels. The energy transition would also affect products that use fossil fuels, as would be the case, for example, in a shift toward low-emissions vehicles and a shift toward low-emissions heating and cooking systems. Similarly, demand could fall for products manufactured with carbon-intensive processes as end users switch to substitutes or reduce their consumption. On the other hand, industries that manage carbon through CCS technologies would benefit and grow. And opportunities would arise in a range of supporting sectors: for example, in upstream manufacturing sectors to support the deployment of new technologies, climate finance, and environmental-assessment and risk-management services. This suggests that companies and countries will need to consider adjustments to navigate these demand shifts, remain competitive, and capture opportunities.

Companies will also have to deal with changes in production costs which could increase in certain sectors, particularly in the near term. In some instances, a cost increase would be due to the high upfront investments that would be needed to build out production capacity, resulting in capital charges (for example, investments in building out additional power-generation capacity and associated transmission and distribution infrastructure). In other cases, the switch to zero-carbon technologies could substantially raise operating costs, such as when carbon capture, utilization, and storage units are added or when more expensive zero-carbon feedstock is used in sectors like steel and cement. Often, those costs would diminish over time as technologies climb the learning curve. We observe that this has already happened in the case of onshore wind and solar-power generation and is currently happening for offshore wind and batteries.[19] In the long run, technological innovation could help drive down costs in other sectors as well.

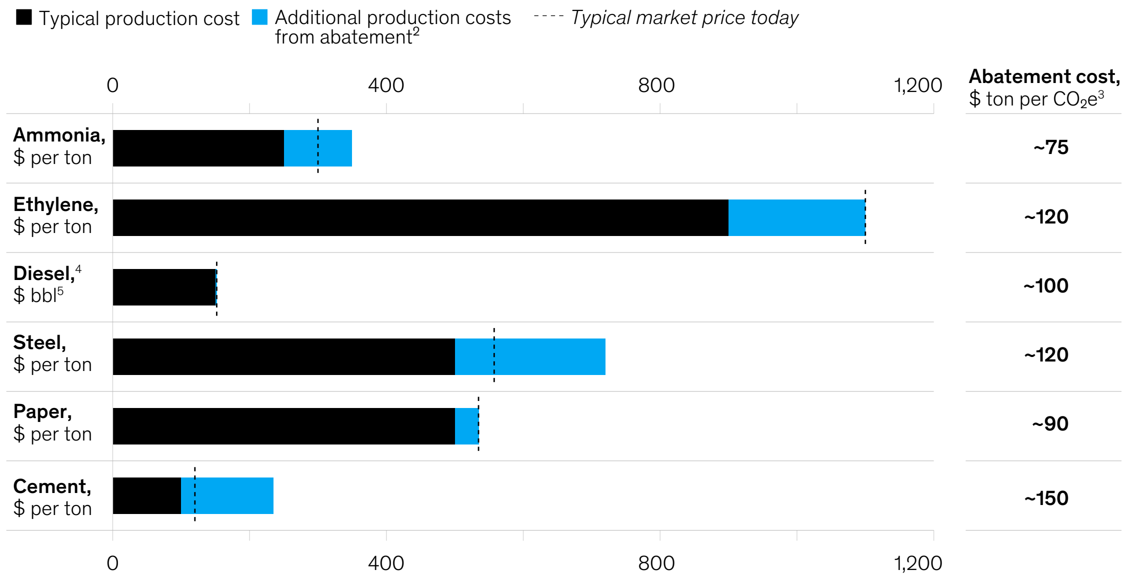
But today, our analysis suggests that the additional cost of decarbonization remains significant in some hard-to-abate sectors; green-steel production costs, for example, are more than 40 percent higher than conventional production routes, and, even in 2050, they are expected to still be 20 to 30 percent higher (Exhibit 3). Various interventions may therefore be needed to provide an incentive for the transition in these sectors, particularly in the near term. Actions to encourage decarbonization could include enabling producers to distribute the costs of transition to stakeholders along the value chain (including end consumers); phasing in commitments to buy increasing quantities of green materials; changing product design to reduce costs; improving productivity, for example, through increased energy or capital efficiency; providing or removing subsidies; and implementing regulatory measures such as new performance standards or zero-carbon quotas. Such adjustments will not be easy, particularly for internationally traded goods such as steel, where producers may face competition from regions with less ambitious climate policies or for businesses that serve customers who are less willing or able to pay a "green premium."

[19] See: Alun Gu and Yi Zhou, "Learning curve analysis of wind power and photovoltaics technology in US: Cost reduction and the importance of research, development and demonstration," *Sustainability*, April 2019, Volume 11, Number 8, pp. 2310, mdpi.com.

Exhibit 3

Decarbonization can raise near-term unit costs for various sectors; these increases will need to be managed.

Production cost and 2030 additional abatement costs per industry[1]



[1]Based on 2030 abatement cost.
[2]Based on earnings before interest, taxes, depreciation, and amortization margin of companies with primary activity in production in a given commodity.
[3]CO_2e calculated based on 100-year global-warming potentials (IPCC AR4).
[4]Additional abatement cost for diesel is small but not zero (~$2 per bbl).
[5]Per barrel.
Source: Company reports; "How the European Union could achieve net-zero emissions at net-zero cost," December 3, 2020, McKinsey.com

Key questions for stakeholders:

— What kind of demand shifts can be anticipated for different products, and how might these vary over time across sectors and geographies? How could costs rise or fall for different sectors and geographies over the net-zero transition? How might this vary depending upon the mix of technologies that are deployed?

— How could the shifting of demand and costs affect competitiveness across companies and countries? What would be the implication for trade flows?

— What new capabilities are needed for companies and countries to navigate these shifts? How can uncertainties on the pace and scale of demand and cost shifts best be managed?

— How can companies, countries, and stakeholder groups—public and private—work together to manage demand shifts and cost changes along the net-zero pathway? What might cause them to be at odds with each other, and how can those pressure points be mitigated?

Solutions on the table for consideration:

- Put in place ongoing capabilities to granularly assess risks and opportunities. Create a granular and scenario-based understanding of demand and cost changes by sector, value chain, and geography.

- Map existing capabilities and how they can best be used to capture new growth opportunities. Identify new capabilities needed and how to go about building them.

- Identify new areas of opportunity from a net-zero economy, considering the end-to-end needs of the transition.

- Identify a range of compensating mechanisms in cases where decarbonization actions increase costs, and understand which measures work best under different sets of circumstances and constraints (for example, standards and regulations, trade-enabling carbon content certificates, national and international subsidies, and global general purpose funds designed to help transition carbon-dependent national economies).

- Identify opportunities to distribute the impact of cost increases along the value chain, and develop industry structures and economic systems to help bear costs and encourage a faster, more orderly transition (such as by charging a green premium).

- Harmonize policies and standards across borders, and facilitate global coordination to drive incentives and limit disruptions to global trade (for example, through carbon free trade agreements).

- Examine the continued viability of subsidies on existing carbon-intensive industries.

6. Compensating mechanisms to address socioeconomic impacts

Net-zero transitions will impact countries, regions, workforces, and households in different and unequal ways. A combination of falling demand for high-carbon products and rising demand for low-carbon ones would result in the reallocation of labor across companies, sectors, and potentially even geographies. The impacts are likely to be geographically concentrated, and specific communities are likely to be disproportionately affected. Specific communities where employment is anchored on high-carbon industries would also need to consider economic diversification programs, including better understanding communities' existing strengths and capabilities and using these strengths and capabilities to the communities' advantage. Certain countries may also see existing trade flows and government revenue affected.

Without robust planning and commitments to equity and environmental justice, impacts would likely tend to be regressive, and the most at-risk communities are likely to carry a disproportionate burden, as transitioning to new employment and building new skills are challenging. In some instances, consumers may face higher upfront capital costs—as is the case, for example, with electric vehicles or retrofitting buildings. While in the long-run, they could benefit from lower operating costs, the upfront spend tends to be more challenging for lower-income households to bear. The transition could also result in energy price increases in the near term, as substantial capital investments are made to build new capacity and supporting infrastructure. This would also disproportionately hurt low-income households, as well as developing countries that are seeking to provide low-cost energy to large portions of their populations.

Unfortunately, climate hazards are themselves also often regressive, worsening the exposure of the most vulnerable. An orderly transition would therefore require appropriate compensating mechanisms to blunt these negative impacts. Such mechanisms would also be critical to facilitating collective will—within and across nations—to embark and persist on the path of net-zero transition. While such mechanisms often fall under the domain of governments, the role of individuals, financial intermediaries, and real-economy companies cannot be underestimated.

Key questions for stakeholders:

- What would be the impact of various transition paths on overall economic activity and in terms of jobs lost, gained, or changed by sector, subsector, country, and region?
- What would be the total cost burden on families within each country and region in these scenarios? How does that vary by smaller regions, such as by zip code or by socially determined, disadvantaged groups? How might these burdens vary based on the mix of technologies deployed for the transition?
- How can governments best manage the negative consequences (for example, through programs for workers and subsidies for consumers) while maximizing the positive effects (including supporting job transitions to new and growing sectors)?
- What can the private sector and industry ecosystems do to help blunt the negative impacts and facilitate new opportunities?

Solutions on the table for consideration:

- Identify skills that will be in higher or lower demand under different transition scenarios. Map potential job losses, opportunities, and gaps across and within sectors and geographies.
- Establish appropriate reskilling programs for workers who are most at risk, and bring together the capabilities of the public, private, and social sectors to design and deliver holistic solutions (such as by forming coalitions to instruct on reskilling or creating pathways to employment).
- Identify and address potential friction points for those who may wish to receive retraining (for example: Are training programs affordable? Are retraining centers accessible? Is childcare available if retraining is conducted during nonschool hours?).
- Establish social support schemes and compensating measures (nationally and internationally) for affected workers, including income-support measures such as unemployment protection and cash transfers, as well as public employment programs.
- Support economic-adjustment and diversification programs for affected communities (including, for example, programs for unlocking natural endowments such as solar and wind to develop new industries or using targeted finance to develop new economic activity).

Governance, institutions, and commitment

7. Governing standards, tracking and market mechanisms, and effective institutions
Although individual actions by companies and governments can support a wide range of stakeholders during the transition, these actions would not be enough to meet all the needs that could arise. The pace, scale, and systemic nature of the required transition likely means that many of today's institutions may need to be revamped, and new institutions may need to be created to enable best-practice sharing, drive capital deployment at scale, manage uneven impacts across stakeholders, and spur collective action. These institutions include standard-setting organizations, global platforms for collective action (including partnerships across public and private sectors), local chapters of larger organizations, and civil society institutions. Further institutional needs will also undoubtedly emerge. As with technological innovation, adapting or creating organizations committed to net zero will likely gain momentum as the transition proceeds—*and* engender resistance. It is the nature of a resilient society to prepare and allow for both.

Hand-in-hand with this will be establishing standards and regulations to specify disclosures of physical and transition risks and measurement of emissions (both direct and financed). Such standards allow emissions to be appropriately factored into pricing and investment decisions, consumer choices, and regulatory and global trade regimes. Just as investors, regulators, and managers today rely on common, transparent, and audited financial standards (for example, generally accepted accounting principles [GAAP]), a net-zero economy would likely be a force for transparency and relative uniformity in terms of how organizations account for GHG emissions. Standards related to climate finance—for example, principles to define carbon credits and govern carbon markets—are also crucial.[20] Standards would need to be supported by appropriate tracking mechanisms to ensure progress is being made apace. Improved tracking and traceability of emissions—across Scope 1, 2, and 3 emissions—could also be needed across value chains and countries.[21] And governance, too, would undergo significant changes to fully take into account and price the carbon externality.

Key questions for stakeholders:

— Where might governments and individual private-sector actors need to be supported by other enabling institutions to achieve the net-zero transition? What roles can cross-sectoral, cross-country, and nongovernmental or quasigovernmental institutions play?

— How can existing institutions (for example, development financial institutions and multilateral development banks) be reconceived to unlock the other requirements for a transition? In what areas may new institutions be needed? How might this change over time?

— What will be best addressed by local institutions and by national or global ones? Where might they be working at cross-purposes?

— How can local, national, global, and cross-sectoral institutions best work together? How can accountability and shared values be facilitated in such collaborative efforts? Where are efforts being duplicated or working at cross-purposes? How could these friction points be mitigated or resolved?

— How can institutional capabilities best be built and evolved over time?

— What areas of standard setting most critically need to be enhanced?

Solutions on the table for consideration:

— Explore solutions from a wide aperture without being too quick to dismiss solutions that seem too bold in light of current constraints (such as global, multilateral funding to buyout high-carbon assets and invest in low-carbon technologies); test ideas from the perspective of what could have *failed* to happen in 2030, 2040, and 2050 to secure the net-zero transition, and consider whether the ideas are bold enough to have prevented such failures.

— Identify how best to build the institutions that might be necessary to ensure collective success, including the new capabilities and resources needed.

— Build new industry collaborations to collectively make commitments, invest in new technologies, build capabilities, and share best practices.

— Enhance and, where needed, establish standard-setting and certifying institutions for common carbon accounting principles across sectors (for example, building on efforts already underway by institutions such as PCAF or the Science Based Targets initiative [SBTi]) and corporate disclosures (for both public and private companies, to ensure appropriate levels of traceability of emissions).

— Improve point-of-source measurement of emissions through digital tracking technologies, for example, through placing sensors at industrial sites and pipelines to measure fugitive emissions or using satellite-imagery data to map

[20] *Taskforce on scaling voluntary carbon markets: Final report*, Institute of International Finance, January 2021, iif.com.
[21] Though definitions can vary to some extent, for purposes of this article, "Scope 1" emissions are direct greenhouse emissions that occur from sources that are controlled or owned by an organization; "Scope 2" emissions are associated with the purchase of electricity, steam, heat, or cooling. "Scope 3" emissions are the result of activities from assets not owned or controlled by the reporting organization but that the organization indirectly impacts in its value chain; thus "Scope 3" emissions result from emissions across an organization's value chain that are not within the organization's scope 1 and 2 boundary. See "Greenhouse gases at EPA," United States Environmental Protection Agency, last updated August 6, 2021, epa.gov.

global carbon and methane emissions. Digitally and comprehensively measure and track all major GHG emissions across Scope 1, 2, and 3 emissions.

- Embed emissions accounting into existing and new market regimes (for example, in carbon prices or across trade-policy agreements).

- Set up governance mechanisms to ensure the quality and integrity of carbon credits to enable the scale-up of well-functioning voluntary carbon markets.

8. Commitment by, and collaboration among, public-, private-, and social-sector leaders globally

Each of the first seven requirements would influence how business leaders, policy makers, and regulators manage the low-carbon transition. Influence also runs in two directions: decisions by businesses (including those driven by both boards and CEOs), investors and shareholders, legislators, and regulators can contribute in a significant way to meeting these requirements. Securing an orderly transition will require public-sector leaders who have the commitment and capabilities to develop coherent, reliable, and workable policies. It would also need private-sector leaders to advance their organization's interests by leaning into the transition through shifts in capital allocation and product portfolios and cooperation within and throughout their organizations' ecosystems. Importantly, it would require leaders to act together, with unity, both to put the physical building blocks in place as well as to secure the economic and societal adjustments needed for an orderly transition.

Key questions for stakeholders:

- How can leadership conviction be built and sustained?

- What are leaders currently incented to do? How do those incentives align with or work against actions that would advance a net-zero transition? How can leaders be incented to make long-term choices and avoid climate short-termism?

- Where might leaders be incented to act in opposition to one of the other eight requirements? How might the dynamics of the other eight requirements change what leaders do—and what leaders should do?

- What can leaders do to support one another?

- How can leaders define and articulate the case for a transition? How can they bring their key constituencies along (for example, for CEOs, bring their employees, suppliers, investors, and customers)? Where might constituencies push back, and how can their concerns be anticipated and addressed?

- What no-regrets moves could be taken right now? What big moves are likely to engender the greatest challenges? What would need to happen for this resistance to be redressed or the constraints resulting in such resistance to be relaxed?

- How should companies think about both offsetting (neutralizing and compensating emissions outside their value chain) and insetting (neutralizing and compensating emissions inside their value chain)?

Solutions on the table for consideration:

- Create real transparency around physical risks. Build awareness, conviction, and momentum among key constituencies—from the board to the C-Suite to the rank and file of the organization—for the net-zero transition and toward collective action. Leaders would need to better understand and communicate the consequences if the transition is slowed or stopped.

- Make climate considerations an essential element of an organization's highest-level decision making, particularly at the CEO and board levels.

- Reexamine strategy, capital allocation, and supply-chain decisions to incorporate the dynamic, system-wide change in which organizations are operating.

— Determine where regulatory intervention is most critical and which policy tools could be most effective (for example, subsidies, incentives, and safety nets).

— Engage with communities, investors, customers, suppliers, and employees on the case for a net-zero transition; try to understand, anticipate, and mitigate their constraints.

9. Support from citizens and consumers

Citizen support is likely to be a crucial part of an orderly transition. In the long run, citizens will benefit greatly from an orderly transition, both as accumulating physical risks are avoided, and as new technologies and infrastructure are able to lower costs, and thus help solve a wide array of societal problems (for instance, low-cost energy can help solve water shortages by making desalinization much more affordable). But in the near-term, citizen support may require a greater shift toward recognizing the magnitude of the challenge, support for compensating mechanisms for those who are negatively affected, and civic participation. An informed public that recognizes the imperative for a net-zero transition can spur action on the part of public- and private-sector leaders.

Moreover, to achieve a 1.5°C pathway, consuming behaviors would likely need to change, for example, by switching to electric vehicles, renovating or retrofitting homes, or reducing carbon footprints in other meaningful ways, such as by eating less meat or reducing travel. In many cases, we would expect that a beneficial cycle could be catalyzed by greater transparency, which can lead consumers to adjust their preferences, which in turn increases adoption of low-carbon goods and helps decrease their costs through economies of scale and movements of technologies up the learning curve.

Ultimately, citizen pull or pushback is likely to be a critical factor for a net-zero transition.

Key questions for stakeholders:

— Where is citizen participation most needed, and what changes could be met with the most resistance? How can consumer and citizen demand be channeled as an opportunity?

— What are the prevailing narratives and social dynamics about the net-zero transition in specific communities, sectors, societies, and countries? How can the needs and concerns of communities best be heard and addressed? How can broad support be cultivated and long-term thinking encouraged?

— Which sectors will most require consumers to shift their preferences and behaviors? How best can incentives be provided for these shifts?

Solutions on the table for consideration:

— Communicate about the collective impacts from rising physical risks and the need for a net-zero transition in order to build awareness, will, unity, and conviction. Make clear what the true base case is and what the most likely outcomes are—including the possibility of runaway climate change and the attendant consequences that will advance nonlinearly over time.

— Create new forums and platforms for dialogue on climate change and the climate transition (both in the real and virtual world).

— Proactively address emergent “hotspots,” such as communities located next to wind turbines, through community engagement.

— Be transparent with consumers to inform their decision making (for example, provide emissions information on product labels).

— Educate consumers on the impact of their choices and focus particularly on high-impact behavioral changes.

— Factor societal support into net-zero-pathway planning.

An agenda for leaders

Each of the nine requirements affects, and is in turn affected by, all the others (see sidebar "An interdependent world"). Addressing them, therefore, will take action and collaboration across sectors and actors—from large industrials to local transport operators and from municipalities to the citizen base that supports them.

The challenge will push public- and private-sector leaders to enter the net-zero arena. The risks in failing to transition or failing to transition in time are high. But the transition is also an opportunity. While the specific actions taken by leaders will change over time as the transition progresses and based on the needs of the moment, they encompass seven key areas:

An interdependent world

The nine requirements of solving the net-zero equation are interdependent—each requirement affects the others. Investments influence technology development; technology development influences operating costs; operating costs influence citizen and consumer support; citizen and consumer support influences public policy; public policy influences investments; and so on. One must therefore take a system-level view of these requirements. The same systemic view would also apply to the actions taken to curtail emissions, as there will be clear interdependencies. For example, in the mining industry, the impact of climate change has increasingly become top of mind. Aluminum and copper, among other elements, are vital to help build and scale out the physical assets needed for a net-zero transition. At the same time, the extraction and processing of these minerals has a high carbon footprint. Another example is hydroelectric power, prized as a renewable energy. The building of dams, however, requires pouring huge amounts of concrete, and the artificial lakes they create can contribute to CO_2 and methane emissions.[1] The overall reduction of emissions may thus require an increase in some areas and can be best achieved through an attempt at system-wide optimization.

Or, consider hydrogen, which will be an essential source of energy for a net-zero world. The rapid growth in the use and deployment of hydrogen in a net-zero transition requires both the simultaneous expansion of production capacity and a rapid increase in demand across sectors. Many hydrogen forecasts project substantial reductions in electrolyzer capital expenditures, along with rapid expansions in installed capacity. For instance, the McKinsey 1.5°C scenario projects an increase in hydrogen production from electrolysis to 100 million metric tons by 2030 (from less than one million metric tons in 2020), along with a 60 percent reduction in the cost of electrolysis.[2] That magnitude of cost reduction is required for green hydrogen technology to reach cost parity with competing technologies. But capital may need to be invested to make the reductions feasible, and investment plans in many cases are conditional on government support. Many early movers would likely seek greater incentives to invest in projects that would otherwise lack a compelling, stand-alone business case.

Moreover, green hydrogen production consumes a significant amount of electricity, which requires that sufficient amounts of additional renewable power be added while hydrogen production ramps up. It's essential to note that for hydrogen use to lead to additional, instead of substitutional, abatements to electrification, additional renewables would likely come on top of already ambitious rollout targets to bring electrification plans to fruition. Supply of hydrogen would, in turn, only roll out on the assumption that demand centers in industry, transport and buildings will be developed. As more hydrogen-production and -consumption technologies are deployed and become mature, we could expect that demand would be cultivated by incorporating hydrogen in steel reduction, building out fleets of fuel-cell trucks, and deploying hydrogen boilers in buildings. The wider the use, the more likely that local ecosystems of hydrogen will be attractive in more circumstances (such as switching an industrial site to hydrogen, running city buses on hydrogen, and heating neighborhoods with hydrogen). And more broadly, a virtuous cycle could emerge between demand and supply. The promise of demand can incentivize producers to ramp up supply; increased supply and scale can help lower consumers' costs; supply and scale would further spur demand.

[1] K. Caldeira and N. P. Myhrvold, "Greenhouse gases, climate change and the transition from coal to low-carbon electricity," *Environmental Research Letters*, February 2012, Volume 7, Number 1, iopscience.iop.org.
[2] Kimberly Henderson and Christer Tryggestad, "Climate math: What it takes to limit warming to 1.5°C," January 29, 2021, McKinsey.com.

— *Understand and commit.* Leaders will be well served by internalizing the fundamentals of climate science and economics. This will help them as they apply the imperative for the net-zero transition and consider how it will affect their sectors and communities. Armed with this knowledge, leaders can commit to the transition. CEOs, for example, could increasingly take ownership of the broad sustainability agenda, working with their chief sustainability officers and other leaders. Setting a clear agenda to learn and adapt continuously and to continually engage with their top teams and boards will likely become even more essential. Leaders will be called on to articulate a coherent case for change to their organizations and to communicate why upskilling is so important. The transition will need to be managed by the organization's best talent—likely with a 50-year mindset.

— *Assess and plan.* Next, organizations would need to develop ongoing capabilities to measure their Scope 1, 2, and 3 emissions and put in place approaches to track and trace emissions across supply chains. They would also need to build capabilities—including using new forms of data and analytical tools—to granularly assess their exposure to risks and opportunities, given the pace and scale of the net-zero transition and the likely acceleration of changes in the basis of competition. As the underlying physical, cost and policy assumptions are constantly changing, and to better identify transition risks and opportunities, these assessments would likely need to be conducted regularly, through scenario-based analysis. To be most actionable, they would need to anticipate as far as possible and capture the ongoing shifts in regulations, investor preferences, consumer behaviors, and the competitive landscape. Leadership in this arena would require a willingness to embrace imperfect information, to base decisions on future projections, to make decisions with agility, and to adopt a continuous test-and-learn approach focused on innovation. However, solving for net-zero emissions globally does create a clear direction. Planning for potential changes will allow leaders to prepare themselves and their organizations for what is to come and to define their own role in shaping the transition. They can use these assessments to prioritize and plan their own net-zero strategy: the actions they need to take to adapt, decarbonize, and thrive in a net-zero economy.

— *Reduce and remove.* Based on these plans, leaders would then need to implement decarbonization actions. These actions would need to include Scope 1, 2, and 3 emissions and include operational transformations to deploy low-emissions technologies, decommissioning or repurposing of emitting assets, and partnering with their suppliers to manage emissions in their supply chains. In doing so, leaders would be able to consider opportunities to both *reduce* their emissions to the greatest extent possible and also to *remove* any residual emissions which they cannot reduce, for example, through capturing and storing greenhouse gases, negative-emissions solutions, and through the use of offsets.

— *Conserve and regenerate.* Conserving and regenerating natural capital such as forests, peatlands, and mangroves will also need to be a key part of managing GHG emissions. Deforestation creates direct emissions (for example, as cut trees are burned) *and* results in the loss of crucial carbon-sequestration capacity, in some cases even turning carbon-absorbing land into carbon-emitting land. Regenerating lost natural capital can also help create additional sequestration potential to help manage emissions. It is vital to acknowledge that natural capital solutions to tackle emissions must be solved jointly with supporting biodiversity, for example, by conserving intact ecosystems and including diverse and endemic species in regeneration efforts. Indeed, addressing these issues together could result in a range of cobenefits, including supporting food security, health outcomes, and broader ecosystem services.

— *Adapt and build resilience.* Decarbonization actions would need to go hand-in-hand with adaptation to manage the impacts of the climate change that has already occurred or is already locked in. Adaptation measures will be important both to manage physical risks that are locked in and to better prepare for new challenges that may arise. Potential actions to consider include protecting people and hardening physical assets, diversifying supply chains, building reserve capacity and stock, reducing exposure to at-risk geographies, and availing of insurance.

— *Reconfigure and grow.* The demand and cost shifts, as well as socioeconomic consequences likely under a net-zero transition, mean that leaders would need to consider compensating measures to manage negative consequences on the one hand and actively seek growth opportunities on the other. Public-sector leaders would have an important role in managing impacts on vulnerable populations, while simultaneously taking steps to support the economic diversification and labor force adjustments of affected communities. Private-sector leaders would need to consider measures to ramp down their high-carbon businesses and grow new low-carbon ones. Throughout, businesses would also need to manage changes to their cost structure and supply chains, for example, through energy-efficiency improvements. For both sets of stakeholders, implementing these strategies might entail clearly identifying existing capabilities that can support new growth areas, reallocating capital and resources dynamically to emerging sectors, investing in research and development, and supporting the training and preparation of workforces for the future, where needed.

— *Engage and influence.* Leaders would also need to engage with and enable all stakeholders (consumers, suppliers, communities, workers, investors, and regulators) along value chains, in communities, and across borders. For example, executives could have to engage with investors and customers to help them understand the actions being undertaken by the organization and the underlying rationale. Public-sector leaders would similarly engage in a dialogue with affected communities. Leaders should identify opportunities to learn, trade ideas, diffuse best practices, and share experiences with peers. One way to do this might be to form or join an innovation ecosystem of peers, investors, and research institutions, to help develop and deploy new technologies. It is understandable and rational to expect that different stakeholders will have different incentives and goals.

There is no set, predefined solution to the net-zero equations. As the above discussion shows, there are dozens of critical questions that need to be addressed and hundreds of solution elements to be considered and combined together. The solution process can, therefore, only be iterative and proceed in parallel with a better understanding of the equations, their constraints, and the means to removing these constraints. It is not hard to imagine that the solution process would be fraught with challenges and setbacks. The sooner and the better the fundamental requirements described above are met, the better the rate of convergence would likely be. And among these, the conviction of private- and public-sector leaders—individually and collectively—and the support of citizens and consumers appear to be critical. While humanity may be facing the most existential challenge in its history, the path is no different than in the previous ones: probing inquiry, followed by collective will and determined action.

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The authors wish to thank their colleagues Marcelo Azevedo, Ryan Barrett, Melanie Bru, Daniel Cramer, Sudeep Doshi, Hauke Engel, Annabel Farr, Will Glazener, Duko Hopman, Danielle Imperato, Matt Rogers, Kevin Russell, Robin Smale, Bram Smeets, and Daan Walter, as well as Dr. Spencer Glendon and the team at Probable Futures, for their contributions to this article.

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