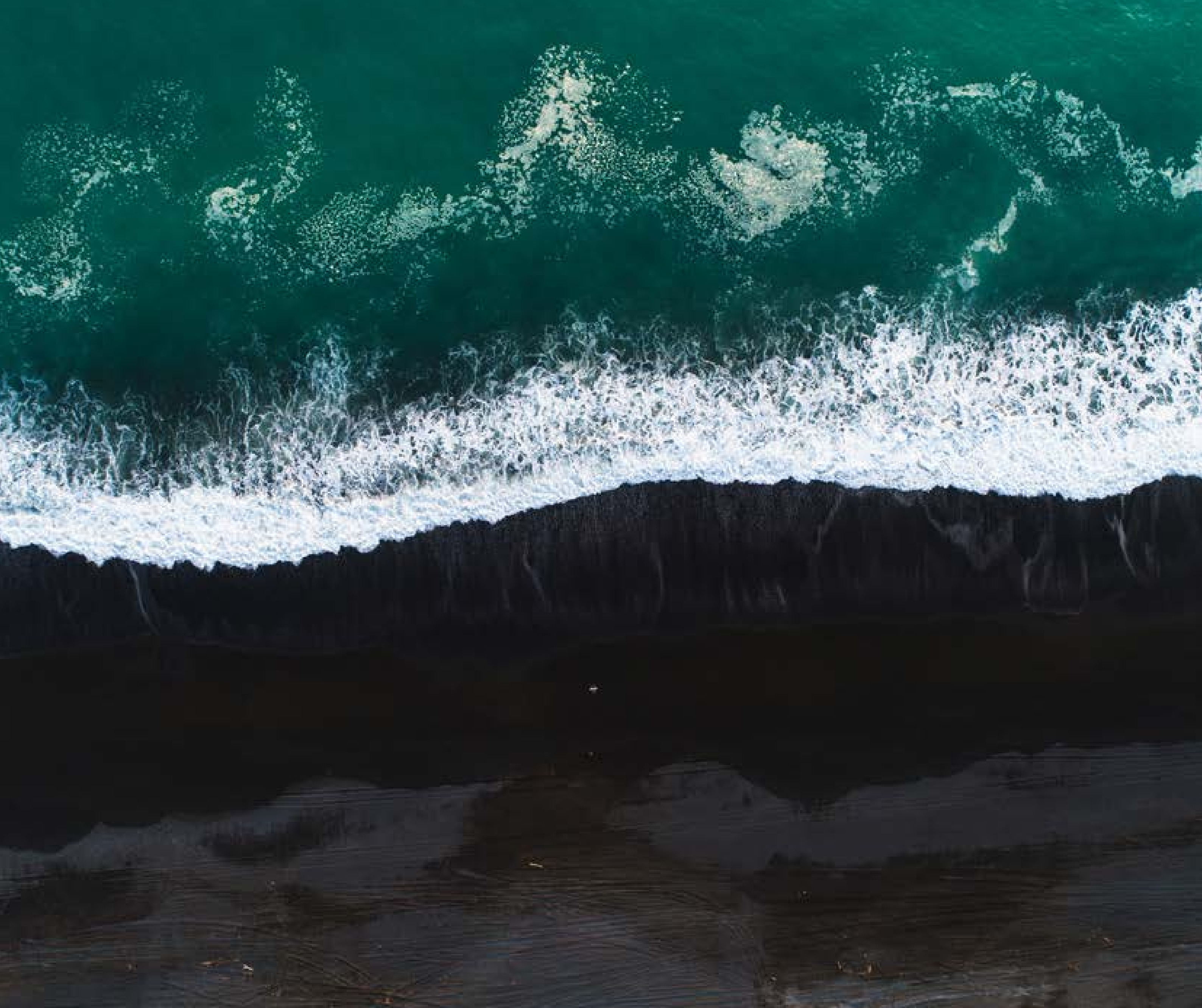
Look Forward

Multidimensional Transition

Volume 6 | March 2024



S&P Global

We are at a pivotal moment in the energy transition.

Sweeping financial investments have set the stage for a decade of deployment. Thousands of new projects and new technologies will enter the world's energy ecosystem, from hydrogen to carbon capture and more. In addition, artificial intelligence is transforming capabilities in data processing and decision-making that will impact the energy industry.

While evidence of the transition is clear, uncertainties remain. In this edition of *Look Forward: Multidimensional Transition,* our economists, analysts, researchers and data experts examine the challenges and opportunities of decarbonization, focusing on topics with the greatest potential for large-scale disruption and deployment.

This issue explores a spectrum of topics: energy security, geopolitics of energy and climate change, critical minerals for energy transition, natural gas, carbon markets, methane emissions, transportation, and material transition.

It is intended to help decision-makers in asset management, asset ownership, companies, multilateral institutions, nonprofits and governments look beyond the near term and explore the trends that will shape our future.

I encourage you to seek out previous volumes of *Look Forward* as well, which cover a range of topics to help navigate an uncertain world. Get in touch with us to share your own views on these topics and ask questions. We want to hear from you.

Saugata Saha
President, S&P Global Commodity Insights

Multidimensional transition

The global energy system has been in continuous transition for centuries, but it is the current transition that has everyone talking.

Developments over the last three years have shaken expectations of a linear global transition as climate goals compete with economic development, energy access, energy security and affordability. We are beginning a multidimensional transition: a multispeed, multifueled and multi-technology transition with different road maps and end points for different countries.

The world has been in "energy addition" mode for decades. The primary energy mix has barely changed, from 86% hydrocarbons in 1997 to 82% at present, while energy consumption has increased 55% in the same period. This is why we are yet to see a peak in global emissions. At the same time, climate change is having a visible impact, with the most vulnerable people being the most heavily affected.

As demonstrated by the contributors to Volume 6 of *Look Forward,* energy is essential for economic growth and for the well-being of populations. The events of the last few years have made it clear that there cannot be an energy transition without energy security. Wars, polarization and political division are challenging governments and the private sector to secure energy supplies while also securing investments for this transition.

COP28 declared the goal to "transition away from fossil fuels in energy systems," but doing so will take decades. Today, nearly 3 billion people still depend on traditional biomass sources for cooking and heating. For many, access to energy, or "carbonizing," is likely the first step before "decarbonizing," with natural gas a viable option to deliver fast and deep decarbonization. New technologies are expected to significantly and rapidly reduce methane emissions associated with natural gas production.

Clean energy technologies in various stages of deployment provide a road map to reducing emissions. Electrification of the world's vehicle fleet is gaining momentum, yet progress remains concentrated on select markets. Solar and wind are already being deployed at scale, and S&P Global analysis shows that capacity could double globally by 2037.

Hydrogen is fast emerging as a vector for clean energy delivery. Consensus continues to grow on the need for carbon-removal technologies to meet net-zero targets, with projects under development forecast to increase CO_2 capture capacity tenfold by 2030. The consumption of materials will expand alongside populations and GDP. Choosing the right mix of low-carbon materials will be an essential component of the energy transition. This transition will likely be an evolution — energy systems are made of hardware that takes decades to change. Although in early stages, advancements in AI have the potential to accelerate the pace of this evolution.

The role of carbon markets will become increasingly important as voluntary and compliance markets converge. The availability of money is a significant barrier, especially for investments in energy access and for energy transition in the Global South.

This edition of *Look Forward* provides in-depth analysis of the major geopolitical, technological, financial and regulatory drivers that are shaping the direction and pace of this multidimensional transition. Our goal is not to offer recommendations or conclusions but to highlight a wide spectrum of issues and opportunities and consider what is needed to bend the emissions curve. We hope this research will contribute to the overarching endeavor of understanding and meeting the challenges of the energy transition.

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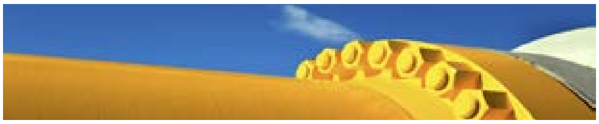
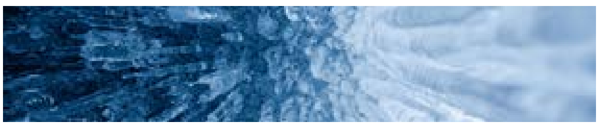
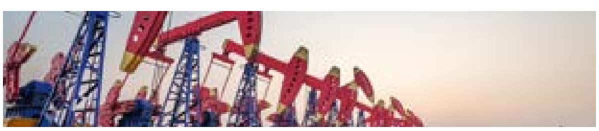
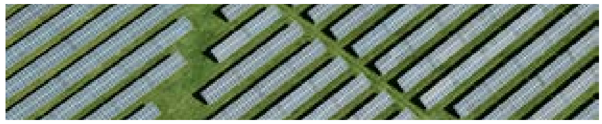
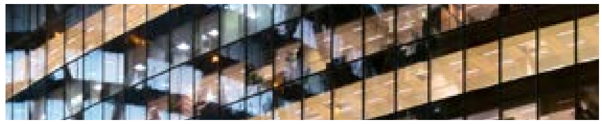
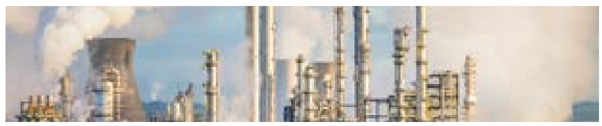


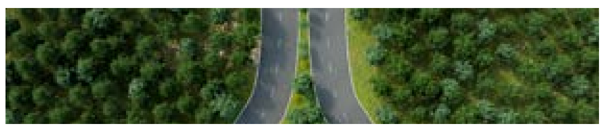


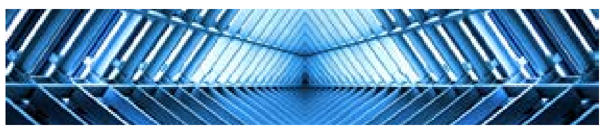


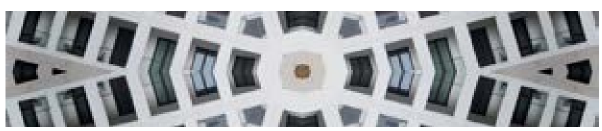












The return of energy security

Ensuring energy security is a high priority for the energy transition.

Daniel Yergin, Ph.D.
Vice Chairman, S&P Global
Chairman of CERAWeek

Climate policy is a priority around the world. But current experience also demonstrates what has been learned and relearned again and again — that energy security is also a priority. And that requires continuing investment to assure reliable and affordable energy. To downplay energy security or dismiss its importance is to risk fueling backlash, derailing climate objectives and generating crises.

Highlights

Events in the last few years have demonstrated that the energy transition depends on energy security to proceed at a steady pace and at scale. The biggest emphasis on the need for reliable and affordable energy is in the developing world, where 80% of the world's population lives.

The use of natural gas provides a major path to decarbonization in two ways.

Energy security is a fundamental imperative for countries as energy undergirds economies and is essential for the well-being of populations. Although muted during the COVID-19 pandemic, its salience has reemerged with a new urgency. Today, energy security — assuring the availability of reliable and affordable supplies — encompasses both conventional oil and gas and renewables as well as electric grid reliability. But, in terms of sources of supply, the main focus of energy security remains assuring needed supplies of oil and gas, which provide 55% of world energy, compared with 7% for renewables. Coal supplies 27%, while nuclear and hydro provide much of the rest of commercial energy. The engine of energy security is investment in supplies and infrastructure needed to meet increasing demand. Moreover, given a natural decline of about 3%-4% per year in existing oil production, substantial investment is needed merely to maintain current levels of supply.

Events in the last few years have demonstrated that energy transition can only proceed steadily and at scale if energy security is assured. Otherwise, backlash develops against climate policies, as is evident in some parts of Europe today. Further risks not only include disruption and conflict but also future political upheavals. Case in point: Africa's population is expected to double in the next quarter century. Without energy security to underpin economic growth and job creation, migration to Europe will eventuate on a far greater scale than today. In turn, this is likely to magnify the political reaction now seen in Europe.

Attention to energy security certainly slipped away during the COVID-19 pandemic. Owing to the partial shutdown of economies, consumption plummeted and energy prices collapsed. Yet projections were generalized from those very specific conditions

to what would be the very different conditions of the post-pandemic world. High-profile scenarios were proposed that laid out a linear transition to net-zero by 2050. Predictions were made that oil consumption had reached its peak in 2019, just before the pandemic, and would thereafter decline. That has turned out to be incorrect. World oil demand by the end of this year will likely be about 3 million b/d higher than in 2019.

'Wake-up call'

This "pandemic thinking" persisted even as the world began to recover from the shock of the pandemic. Yet, by fall 2021, as markets tightened and prices increased, energy security was returning to the table. In November 2021, US President Joe Biden authorized the release of oil from the US Strategic Petroleum Reserve, established as a backstop for energy security, to compensate for a shortfall in petroleum supply, and he called on oil companies to increase production. This was before Russia's invasion of Ukraine.

Then came the Russian invasion in February 2022, setting off a global energy shock and a far-reaching disruption of the global supply system. As Tatsuya Terazawa, chairman of Japan's Institute of Energy Economics and former vice minister of Japan's Ministry of Economy, Trade and Industry, observed, the crisis was "a wake-up call and reminder for the world to look not only through the lens of climate but also seriously look at the importance of energy security and the stability of energy markets." Reflecting the viewpoint of the Japanese government, he further added, "Discouraging investment in the upstream oil and gas is inconsistent with the need to reduce dependence on Russian energy."

Indeed, energy security suddenly returned as an urgent priority for governments worldwide. They scrambled to secure and encourage more supplies — with varying degrees of success — to keep their economies running and avoid heaping pain on consumers. Russian President Vladimir Putin sought to break the EU coalition supporting Ukraine and bring Europe to its knees by wielding the "gas weapon" — cutting off most of Russian natural gas supplies to Europe. But the weapon failed, although the economic costs of repelling the attack were high.

To help compensate for the shortfall, Europe turned to liquefied natural gas (LNG), which provided almost 40% of Europe's total gas supply. Half of that LNG came from the US, which had only become an LNG exporter in 2016. In September 2022, the Netherlands secured two floating terminals for receiving LNG, with the first shipment arriving from the US that same month. Germany received its first-ever full shipment of LNG in January 2023, also from the US. LNG and alternative supplies covered about half the gap left by Russian gas cuts. Norway, now the bedrock of Europe's pipeline gas, surged supplies in 2022. The other half of the gap was met through deep cuts in European gas consumption, particularly in industries.

Political leaders hastened to secure additional supplies of oil and gas and called for more production. German Chancellor Olaf Scholz flew to Senegal to, he said, “intensively” encourage Senegal to develop its natural gas reserves for shipment to Europe as LNG. In Canada, he said, “We would really like Canada to export more LNG to Europe.” EU officials and ministers from European governments traveled to the Middle East and the US and across Africa in quest of new supplies. US Energy Secretary Jennifer Granholm called on US oil companies to increase investment and production, explaining, “We need oil and gas production to rise to meet current demand.” The Biden administration authorized subsequent releases from the Strategic Petroleum Reserve. China prioritized energy security ahead of climate policy in its new Five-Year Plan. In February 2024, the German government approved plans to finance up to 20 new natural gas-fired electric generating plants to avoid a shortage of electricity (with the proviso that they must be able to convert to hydrogen by 2040).

It was not only the consequences of the Russia-Ukraine war that recharged the focus on energy security. It was also the energy transition itself, which generated a new dimension of energy security. In recent years, a host of governments and international organizations have raised alarms about a potential shortfall of minerals required for renewable energy, including wind turbines, solar panels and electric car batteries. The concern extends beyond mining to processing, refining and manufacturing. Last year saw a new record in renewable deployment, with half of that in China. Yet, at the same time, parts of the renewable industry are being challenged by rising costs, inflation, high interest rates, supply chain constraints and protectionism. Offshore wind projects in the US and Europe have been canceled or postponed because of those problems. Moreover, permitting delays around the world are slowing the execution of new projects. At the current pace of renewables investment and deployment, predictions for near-term peaking of oil and gas demand are likely to prove unrealistic. As Joe Biden said in the 2023 State of the Union address, “We will need oil and gas for a while.”

Energy security in the Global South

The biggest emphasis on the need for reliable and affordable energy is in the developing world, where 80% of the world’s population lives. Summarizing the conclusion of the 2023 G20 Energy Transitions Working Group (the G20 is composed of major developing countries and developed nations), the Indian government reported that “amongst the G20 members, there is a broad consensus that energy security, energy access, market stability and energy affordability need to be advanced.”

Attaining energy security is basic to making progress out of poverty in general and remedying the lack of access to commercial energy and electricity. African leaders argue that renewables at this time can only meet a small portion of what their countries need to promote economic development, reduce poverty and improve health. These countries require increased supplies of oil and gas to fuel growth in their economies, which in turn will require continuing investment in oil and gas both in Africa and globally. The disparities in per capita GDP (purchasing power parity) underline the urgency for the Global South: Germany’s per capita GDP is $63,000, France’s is $55,000, Belgium’s is $65,000 and the Netherlands’ is $71,000. By contrast, Senegal’s is $4,200, and Uganda’s is $2,600. The same disparity shows up in energy. Per capita electricity consumption in sub-Saharan Africa, excluding South Africa, is less than 4% that of Europe. More than 3 billion people in the developing world use less electricity, on an annual per capita basis, than a standard refrigerator does in the US.

> Attaining energy security is basic to making progress out of poverty in general and remedying the lack of access to commercial energy and electricity.

Without sufficient energy, the economic gaps will only grow — and with that will come greater risks. Africa’s expected doubling of population by 2050 will mean that by then, one-quarter of the world’s population will live in Africa. Can growth be achieved and stability maintained if the African continent is energy-starved because of inadequate investment in energy supplies? The relief valve from the resulting lack of economic development and job growth would be mass emigration to Europe, far larger than today’s flow. As noted above, the resulting impact on the stability of European political systems would be very concerning.

The role of natural gas

Natural gas is a particular focus for promoting economic development — and for reducing emissions. "If we are not getting reasonably priced finance to develop gas, we are denying the citizens in our countries the opportunities to attain basic development," Nigeria's finance minister said in 2022. As a new report from the Center for Strategic and International Studies put it, "Natural gas is central in delivering both energy justice and climate progress in Africa." Natural gas' role is further enhanced by the global drive to capture fugitive methane emissions.

The use of natural gas provides a major path to decarbonization in two ways. First, it helps stabilize the grid by providing balance to the variable generation of electricity by wind and solar. Case in point: In the US, California is seen as a leader in promoting renewable power. Today, wind and solar provide about 25% of California's electricity. But the state depends on natural gas-fired generation — almost 50% of the total — to keep the system balanced.

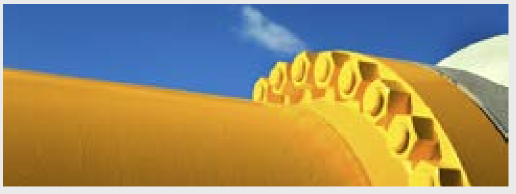
The second way in which natural gas promotes decarbonization is by replacing coal. The US provides another case study: Its CO_2 emissions from electric generation in 2022 had declined by a third since 2010, while the economy in the same period had grown by almost a third. The number one reason for the reduction in CO_2 is natural gas replacing coal in electric generation. Southeast Asian countries would like to move in the same direction. For them, increasing both natural gas production and LNG imports is essential to push coal out of electric generation — and thus reduce the emissions from burning coal. In India, a massive campaign was launched in 2016 to use natural gas liquids for home cooking in villages across the country to reduce harmful indoor pollution and carbon emissions that come from cooking with wood and waste.

In February 2024, Prime Minister Narendra Modi announced a $67 billion investment program to expand India's natural gas supply system. This is meant to help achieve the goal of increasing gas' share of the national energy mix from 6% to 15% — and do so even as total energy demand doubles by 2045. At the same time, Modi met with 20 leaders from the international oil and gas industry to urge them to invest in oil and gas production in India to avoid a shortfall in the energy supplies necessary to fuel India's economic growth ambitions.

Europe's sudden turn to LNG after the Russian gas cutoff, while staving off deep recession in Europe, created an energy security crisis for developing countries in South and Southeast Asia that could not afford to compete in the global marketplace against European buyers. The result was a return to coal for electricity generation and, in many cases, the shuttering of factories that could not get sufficient electricity. Natural gas development in India and Africa is a priority not only for energy security and economic development but also for basic human health. It is estimated that 3.2 million people die prematurely from household air pollution each year from cooking with wood, waste and other such fuels.

Looking forward: Crises to be avoided

While climate was the main focus of the COP28 climate conference at the end of 2023, the importance of "ensuring energy security" was also part of the final UAE Consensus document. That represents recognition that the COP28 goal of "a just, orderly and equitable" energy transition requires a foundation of energy security. The last two years have provided many warnings of what "disorderly" transitions can mean: price shocks, shortages, disruptions, scramble for supplies, backlash, rancor, bitter divisions and conflict — in short, cycles of crises that the world would do well to avoid in the years to come.



Learn more

[The road map for a Multidimensional Energy Transition]

One planet, two realities: Realizing energy transition in the Global South

Climate change is a global issue that requires global cooperation. This starts with accepting the challenges and realities of the Global South.

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Climate change is a global issue that requires collective action and solidarity across nations. Developing countries are indispensable partners in addressing climate change, given their vulnerability to its impacts and their potential for emissions reductions and sustainable development. By promoting inclusive and equitable climate solutions, fostering international cooperation and providing support to the Global South, the world can advance along a more sustainable, resilient and just energy transition path.

State of play

Climate change poses a formidable global challenge, transcending borders and affecting every corner of the planet. Its impacts, ranging from extreme weather events to sea level rise and ecosystem disruptions, threaten the stability of economies and societies worldwide. Addressing this complex issue requires a concerted effort from all nations.

Highlights

Climate policies and investments in the Global North alone are not sufficient to solve climate change issues worldwide. Any effective solution will need to engage the developing economies of the Global South.

Expectations of a linear transition in the Global South overlook the complexities of economic development, poverty alleviation, energy security and affordability, which are priorities over energy transition.

The transition will be multidimensional — multifueled, multispeed and multi-technological — with different starting and end points for different countries.

Understanding challenges in the Global South will be key to navigating and charting a successful energy transition and meeting the goals of the Paris Agreement on climate change. Collaboration between the Global North and Global South on technology, financing and capacity building will be critical in addressing climate change.

The first-ever global stocktake concluded at the COP28 climate conference. This stocktake is a two-year process, scheduled to recur every five years, that is conducted by the UN to assess progress by countries against the goals of the Paris Agreement on climate change.

The global stocktake shows that the world is significantly off track in meeting the objectives of the Paris Agreement, with national commitments falling short by 20.3 billion-23.9 billion metric tons of CO_2 equivalent (tCO_2e) compared with the levels required to limit warming to 1.5 degrees C by 2030. This is consistent with analysis from S&P Global Commodity Insights showing that current national commitments would only reduce emissions 10% by 2030 instead of the 43% cut needed.

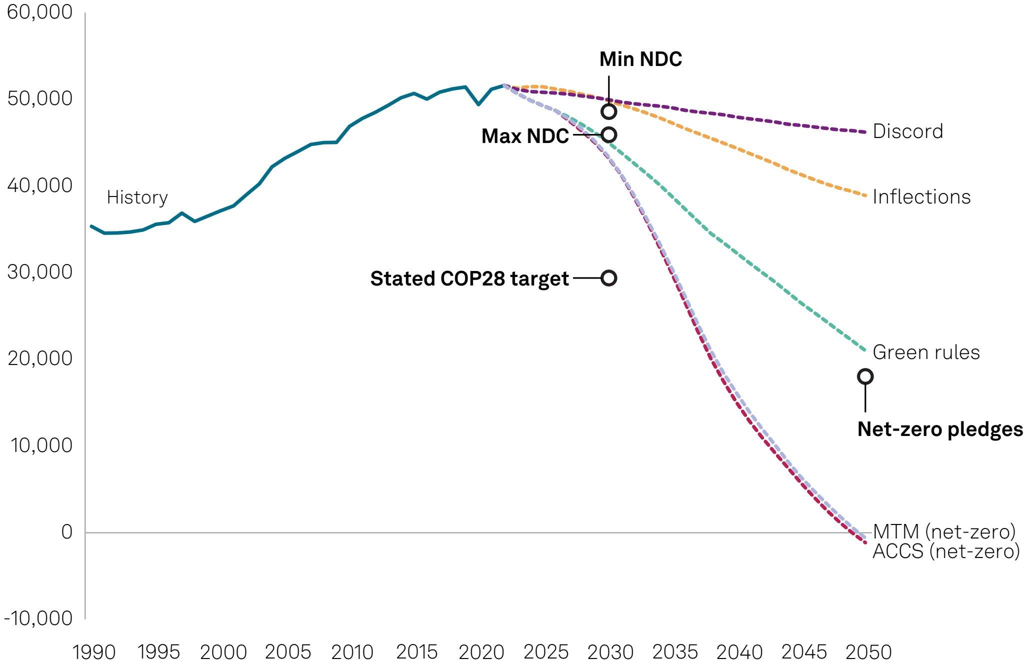
The widening gap between emissions trajectories and the pathway required to achieve net-zero by 2050 is illustrated by S&P Global Commodity Insights emissions scenarios. Current trajectory/baseline scenarios project that emissions will fall less than 25% by 2050; achieving the 1.5 degrees C goal will likely require a reduction of 90% or more. This trajectory includes the recent surge in climate ambition and policy initiatives, especially in the Western world, including the US Inflation Reduction Act and the EU's Fit for 55 plan (see chart).

But more needs to be done.

Emissions in the US and EU have peaked and are declining, but not fast enough. Chinese emissions have nearly peaked after growing at an extraordinary rate for about 20 years, and they are forecast to plateau before declining later this decade.

Emissions mitigation: No easy pathway to net-zero

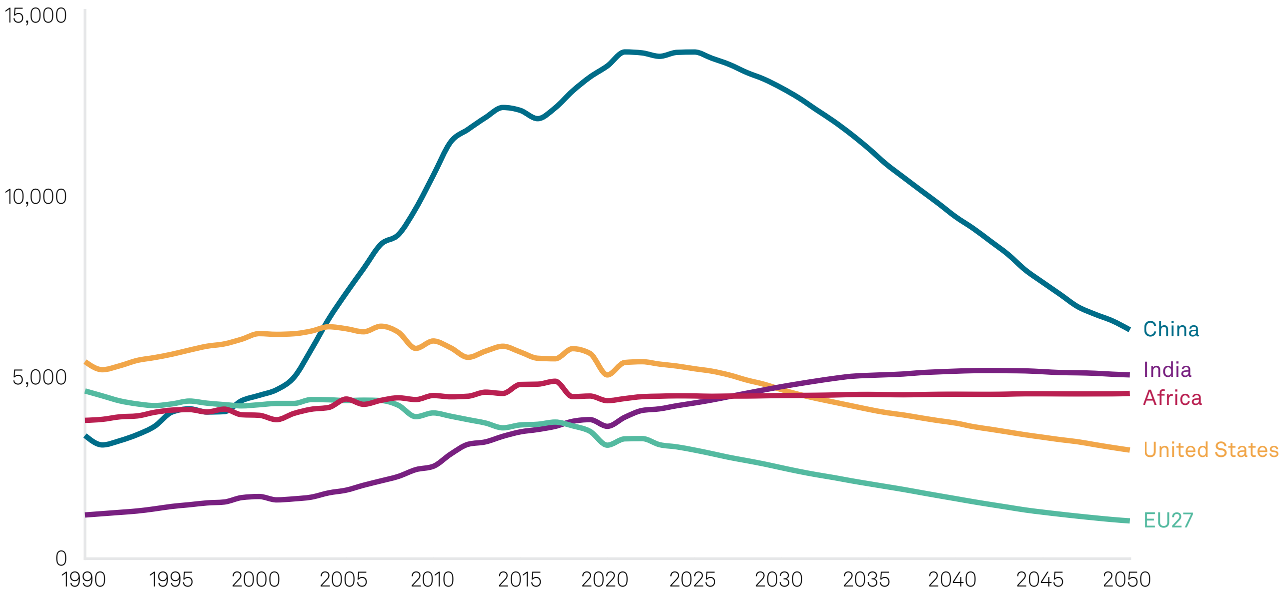
Total GHG emissions in S&P Global Commodity Insights global scenarios, NDC targets and net-zero pledges ($MMtCO_2e$)



Data compiled Oct. 2, 2023.
$MMtCO_2e$ = million metric tons of CO_2 equivalent.
ACCS = accelerated carbon capture and storage; MTM = multitech technology mitigation; NDC = nationally determined contributions.
Source: S&P Global Commodity Insights.

US, EU emissions declining but not fast enough; China finally peaks; India, Africa emissions to grow

Total GHG emissions ($MMtCO_2e$)



As of February 2024.
$MMtCO_2e$ = million metric tons of CO_2 equivalent.
Source: S&P Global Commodity Insights.

However, India, Africa and other emerging markets, often referred to as the Global South, are projected to experience continued emissions growth for the foreseeable future (see chart).

This situation fosters a narrative that the Global South is to blame for the world's failure to meet climate goals. However, many in the Global South perceive this narrative as unjust, considering their relatively small contributions to historical emissions. For instance, present energy consumption levels in sub-Saharan Africa mirror those of France and Germany in the 1860s. In India, per capita emissions stand at approximately 2.9 tCO_2e, much lower than figures of more than 16 tCO_2e in the US and more than 7 tCO_2e in the EU.

The notion of a linear global transition to net-zero overlooks the complexities of economic development, poverty alleviation, energy security and affordability. S&P Global Commodity Insights believes that the energy transition will be multidimensional: a multispeed, multifueled and multi-technology transition, with different road maps and end points for different countries.

In addition, any realistic solution to climate change needs to involve countries in the Global South, given their continued economic growth and emissions trajectories.

Considering the significant role the Global South must play in addressing climate change, it is crucial to examine the region's challenges. This exploration should stimulate dialogue around developing effective solutions for the energy transition that align with the priorities of the people and governments of the Global South.

Key challenges in the Global South

Affordability of energy

Based on 2024 statistics from the International Monetary Fund, per capita income in India is approximately US$2,900; in sub-Saharan Africa, it is less than US$1,800. This compares with per capita income of more than US$63,000 in North America and more than US$51,000 in Western Europe. The significant disparity in per capita income between the Global North and Global South underscores the critical importance of affordable energy. Solutions feasible in the Western world, such as electric vehicles, carbon capture, utilization and storage (CCUS), and hydrogen production or importation, may be financially inaccessible in the Global South.

While governments in developed countries offer incentives, subsidies or mandates to alleviate costs associated with these transition pathways, those in the Global South often lack the financial flexibility to implement large-scale subsidies. Their priority is providing the cheapest available energy, hydrocarbons in many countries, and subsidizing this energy to ensure mass affordability.

Economic growth emerges as the primary solution to bridge this gap, enabling countries in the Global South to offer incentives and subsidies for energy transition akin to those in the developed world. However, access to cheap, affordable energy is crucial to achieving such economic growth, leaving developing nations in a Catch-22 situation.

Economic and political dependence on domestic fossil fuel endowment

Domestically available coal, oil and gas serve as critical pillars for ensuring the security of supply and are primary sources of revenue for numerous countries in the Global South. They are vital in funding country budgets and supporting social programs. Moreover, the sector typically stands as one of the largest direct and indirect employers in this region. Governments cannot afford to swiftly transition away from fossil fuels, which they depend on for national operations, without viable alternative revenue sources.

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A rapid phaseout of fossil fuels could result in widespread unemployment, political unrest and destabilization — all counterproductive to addressing climate change.

Infrastructure bottlenecks

Energy is fundamentally an infrastructure business that involves building massive supply nodes (power plants, solar farms, CCUS and hydrogen hubs, nuclear plants) and interconnections (transmission lines, pipelines) over large distances. Such endeavors necessitate land procurement, siting and permitting processes before projects can proceed. In many developing countries, land ownership is fragmented, and procurement and permitting procedures involve multiple layers of engagement with local, state and federal stakeholders. As a result, setting up large-scale solar farms, gas pipelines and electric grids can encounter prolonged delays, especially when projects must navigate multiple jurisdictions and cross county and state lines.

Access to technology and skilled workforce

Lack of access to technology and a skilled workforce present significant hurdles for energy transition in the Global South. Many countries do not have the technological infrastructure and expertise needed to deploy and maintain new energy systems such as carbon capture and storage, direct air capture, and hydrogen projects. Limited access to advanced technologies impedes progress toward sustainability. Additionally, a shortage of skilled workers trained in emerging energy technologies complicates efforts to implement efficient and sustainable energy solutions. Bridging the technology gap through global collaboration and investing in workforce development is essential to overcome these challenges and facilitate a successful transition.

Financing and cost of capital

Financing and the cost of capital pose substantial challenges for energy investment in the Global South. Limited access to capital markets, high borrowing costs, and real or perceived investment risks deter domestic and foreign investors. This problem is even more pronounced in today's high-interest-rate environment. The lack of creditworthy offtakers and uncertain regulatory environments undermine investor confidence. Currency volatility and political instability amplify investment risks, discouraging long-term commitments. Infrastructure projects require substantial up-front capital, which many developing countries struggle to mobilize independently. Consequently, attracting capital and securing favorable financing terms are paramount for advancing energy infrastructure and transitioning to sustainable energy sources.

Paths to progress

There are a few strategies for policymakers, industry and investors to consider as they design and navigate energy transition pathways in the Global South.

A 'horses-for-courses' approach

We need to recognize that each country has its own opportunities, faces its own challenges and must find its own way forward. Regional energy pathways for poorer countries could focus on basic needs in terms of energy access and affordability — and, once these are assured, consider more ambitious climate goals. To meet these needs, many countries in the Global South want to be enabled, and supported, to build their economic and industrial capacity through conventional fossil fuels, especially gas, to meet economic growth needs and to reduce the burning of wood and waste. A "technology leapfrog" from traditional biomass to renewables may be appropriate in some circumstances, but it will be a difficult transition pathway for many low-income economies.

Capacity building to reduce risks

To make clean technology projects in the Global South less risky and attract investments, there is a need to build capacity in logistics, contracting, financing, policies and regulations. Support should also include working together on nonfinancial options such as technology transfer and research and development, as well as providing direct financing. Using the public-private partnership model to develop local workforces to build, maintain and invest in renewable projects will also improve long-term viability and the scaling-up of renewable projects.

Greater role of multilateral development banks

Seed funding from multilateral development banks (MDBs) has the potential to attract significant private finance. Achieving this will demand more effective collaboration, however. Additionally, MDBs can aid developing nations in establishing robust institutional frameworks and mitigating risks linked to renewable investments. The commitment of US$61 billion of climate finance from MDBs for low- and middle-income economies at COP28 is a good first step.

North-South collaboration

Government-to-government collaboration and sharing of technology and best practices can provide a jump start for developing countries on their path to energy transition. For example, learning from on-the-ground execution of policy programs such as the Inflation Reduction Act could help other governments design even more robust policy frameworks. Technology partnerships on carbon capture and storage, hydrogen, EVs, and other cleantech projects would bring the benefits of experimentation, learning and cost reduction from the Global North to the Global South. Government-to-government collaboration would also help to design effective, transparent and integrated carbon markets that will improve confidence in funding offset projects in the Global South.

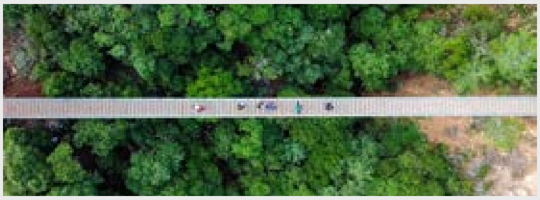
Looking forward

International cooperation and support are essential to unlock the full potential of developing countries in tackling climate change to meet Paris Agreement climate goals.

Developed nations and international organizations have a responsibility to provide financial aid, technology transfer, capacity building and technical assistance to support climate action in the Global South.

Renewable development, particularly solar, is growing rapidly in developing countries. Removing permitting and infrastructure bottlenecks will accelerate deployment, grid connectivity and decarbonization.

The commitment of US$61 billion of climate finance from MDBs for low- and middle-income economies at COP28 is a good first step, but more needs to be done.



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[The multidimensional path to net-zero]

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[Unraveling Uncertainty: 2023 Scenarios and Net-Zero Cases]

[Energy Transition: Gaps in the Pathways]

A shattered global order: Hard truths for energy and climate

Wars, polarization and political divides will challenge governments and the private sector to secure energy supplies while also navigating investments for energy transition.

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An eroding international order and geopolitical competition are making politics and commerce increasingly unpredictable at a time when the world needs confidence in governance to transform the global energy economy. Scaling up private investment in innovation and technology is key to bridge political divides and deliver viable pathways for decarbonization.

Highlights

In 2024, we expect the risk of miscalculation and deepening conflict in the Middle East, China and the US, Russia and Ukraine, and across the North-South divide to intensify.

A politically brutal US presidential campaign in 2024 will increase polarization in the country and globally. Support from US states may preserve the Inflation Reduction Act.

The US and China pledged in November 2023 to avoid veering into conflict. The real test for energy may be competition over clean energy technology and mineral supply chains.

The world has no clear path on how to end the wars in Ukraine and Gaza, which will raise the stakes for oil production and market stability in the face of political risk.

For the developing world, a gap between economic aspirations and access to resources, capital and technology has fueled a North-South divide that demands a multidimensional energy transition reflecting national resources and incomes.

The eroding world order, energy security and climate change are deeply intertwined

Global crises are redefining how the world understands the future of energy. Yet much more than energy is at stake. The international order that emerged after World War II for security, trade and energy has lost sway and impact. Nations and industries must navigate this shattered equilibrium and make strategic investments. In 2024, we expect the risk of miscalculation and deepening conflict in the Middle East, China and the US, Russia and Ukraine, and across the North-South divide to intensify (see chart on next page).

Five hard truths confront industry and countries on geopolitics and energy.

The risk of miscalculation and deepening conflict on every major geopolitical issue will increase through 2024

US elections	China-US	Israel-Hamas	Russia-Ukraine	Developing countries
Can a polarized US stay globally engaged?	Can Presidents Xi and Biden define a course for cooperation?	What is the future of Gaza and the Palestinian cause?	No prospect for diplomatic settlement	Aggrieved, ignored and seeking a just energy transition

As of Feb. 28, 2024.
Source: S&P Global Commodity Insights.

Global conflicts could disrupt capital flows and destroy confidence

The eroding global order will make it hard to leverage massive capital flows to achieve energy security and build an energy system for a net-zero world. Shocks to the international system are pervasive. The UN and major powers could not prevent or stop the wars in Ukraine and Gaza. Trade disruptions since the COVID-19 pandemic have exposed the world to commodity shocks, breaking supply chains for energy, food, metals and minerals. Concerns over energy security and clashing perspectives on climate between developed and developing nations have remerged.

While estimates vary wildly, the world needs to leverage trillions of dollars more in private capital annually to transform its energy systems. Capital flows must double or triple. Despite an estimated $6 trillion invested globally in renewables in the past decade, the share of hydrocarbons in the energy mix has barely budged from 82% to 80%. Achieving net-zero goals will entail unprecedented transformations in the global economy, energy technology, consumer behavior and national politics. Conflicts and polarization in 2024 will further erode confidence in a splintered international order at a time when the demand for clear policy and reliable resource flows is nothing short of historic.

Volatile political landscape could mar US influence

What promises to be a politically brutal US presidential campaign in 2024 will increase polarization in the country and globally. The US political system risks falling into a dysfunctional stalemate. Every few months, Congress faces a crisis over funding its own government, despite the distress for the national economy. Divided internally, the US will increasingly lack the credibility to unite others amid deepening international polarization.

What may not be at risk, however, is the Inflation Reduction Act — or at least most of it. Republican and swing electoral states such as Texas, North Carolina, Georgia, Ohio and Florida have major stakes in renewable energy, electric vehicles, carbon capture and hydrogen. Industries will drive bottom-up demand for the Inflation Reduction Act, even if a future government seeks to slow its implementation. Still, energy politics — the role of oil and gas, LNG exports, EVs, infrastructure permitting, and environmental regulation — will remain a major campaign issue. Inevitably, domestic policy ambiguities will cause US influence on energy and climate policy to wane internationally.

US-China competition could deteriorate or accelerate innovation

The world is watching anxiously to see whether Presidents Xi Jinping and Joe Biden can rescue the relationship between the US and China. Trade restrictions on mainland China's access to advanced semiconductors, 90% originating in Taiwan, hinder its path to supercomputing and AI applications (including in defense). The risk of disruption affecting global supply chains led the presidents to meet in November 2023. Biden said, "We have to ensure that competition does not veer into conflict." Xi took the point further: "Planet Earth is big enough for the two countries to succeed, and one country's success is an opportunity for the other."[1]

But will their pledges hold? At the COP28 UN climate change conference in Dubai, the US

[1] From "Remarks by President Biden and President Xi Jinping of the People's Republic of China Before Bilateral Meeting | Woodside, CA." The White House.

and China took the stage together to pledge action to curtail methane. Engagement between energy companies, especially on carbon capture and hydrogen, is emerging on bilateral agendas. Perhaps the real energy test will be on supply chains, where China dominates the manufacturing of technologies such as solar panels, batteries and EVs as well as the processing of many minerals needed for the energy transition, such as lithium, rare earths, graphite, cobalt and copper. Here, the push for diversification is nonnegotiable for the US. This will fuel competition for mineral access and processing worldwide as well as a race for chemical substitutes and reinvention of mining techniques.

Wars in Ukraine and Gaza could spread into wider conflicts

The world has no clear path to end the wars in Ukraine and Gaza. As these persist, expect further confrontations to gain military and political advantage. Europe and other global markets have suffered the impact of curtailed Russian gas exports since 2022, although robust LNG supplies and curtailed demand mitigated what could have become energy crises. Russia's oil exports have been redirected to Asia. The Middle East and others increasingly supply oil to Europe. We expect oil supplies outside the OPEC+ countries to continue to outpace the growth of oil demand. These strong balances may keep oil in a price band of $75-$90 per barrel. But one cannot assume away risks — to oil flows directly or to maritime transit.

For Ukraine, the biggest risk may be the inability of US Congress to agree on how to fund military and economic aid. Europe remains committed, pledging €50 billion in aid over the next four years. Countering perceptions of a stalemate, Ukraine has driven the Russian navy out of Crimea, reopening its access to the Black Sea. However, shortages in air defense missiles and artillery leave Ukraine increasingly vulnerable as Russia intensifies attacks on civilian infrastructure, especially energy installations. In 2024, neither side has an appetite for diplomatic settlement.

In Gaza, ending the war and risk of a wider conflict are intertwined. For Israel and the people of Gaza, this war is a humanitarian tragedy. But ending a conflict in a dense urban zone where over 27,000 have died and 80% of the population has been displaced requires a security paradigm without precedent. Recall that the withdrawal of US troops in Iraq and Afghanistan led to ISIS emerging and the Taliban returning. A continued Israeli security presence in Gaza will provoke retaliations. No country will volunteer a peacekeeping force without a political agreement on the future of Gaza that provides a point of exit for Israeli troops, and eventually their own.

Iran has perhaps gained the most in portraying itself as the defender of the Palestinian cause. Attacks from Iranian-backed militias on Israel and US interests have sought to raise the stakes of continuing the conflict without falling into a wider war. Most visibly, Houthi rebel attacks on ships in the Red Sea have diverted 80% of shipping containers away from the Suez Canal.

Roughly 7 million to 8 million barrels of oil continue to move daily through the Suez Canal, mostly from Russia to Asia. The Houthis have not attacked

Russian ships, but insurance costs, freight rates and crew fees are rising. Non-Russian tankers traversing the Cape of Good Hope could face two to three weeks of additional voyage time and fuel costs. Diesel and jet transit from Asia and the Middle East are raising costs for European refiners; indeed, exports shut down completely for three days after US retaliations on Iran-backed militias.

Reflecting these developments, the price of dated Brent, despite robust oil supplies, rose $5/b in early February. Escalating or prolonging Red Sea attacks could drive more shippers to circumvent the Suez Canal. The unexpected signpost to watch may be China's reaction. Although no country is more affected by a threat to shipping lanes and the militarization of choke points, China has rejected US appeals to engage Iran to avoid a wider regional conflict. Could China reconsider?

The Global South needs access to capital and technology

The fifth hard truth is the need to respond to the Global South's cries for an international order that helps developing countries access resources for jobs, education, healthcare and energy security. The challenges cited in this article — wars and conflicts, political polarization, and leveraging capital — are deepening the North-South divide. Energy and climate are especially poignant because they cut across national economies and can trigger regional conflicts and migration.

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The international community must realign around the needs of a Global South, which encompasses 80% of the world's population. The demands are clear: energy access, climate adaptation, loss and damage compensation, debt rescheduling, blended finance to lower capital costs, and access to technology. International public funds alone cannot fill the financing gaps, estimated by the UN at $200 billion to $300 billion annually for climate adaptation alone. The Loss and Damage Fund launched at COP28, for example, was seeded with just $700 million. While that will grow, it will face competition for public financing to reduce debts and mitigate risk on private capital.

COP28 brought the private sector directly into tackling climate change, including pledges for $85 billion in private finance and yet more in company commitments. The United Arab Emirates invested $30 billion to seed a private fund to leverage $250 billion. More broadly, Organisation for Economic Co-operation and Development countries met an overdue pledge to finance $100 billion annually through 2025 for climate mitigation and adaptation. The measures at COP28 to close the North-South divide are just a starting point.

Looking forward

Politics and policy as we have known them will not be enough. Without resource transfers and wider access to technologies, energy politics will be a source of tension, not unity. The goal is to transform innovation and technology into a bridge for political divides. Governments need to embrace industry's capacity to innovate and operate at scale. Industry must advance technology breakthroughs that deliver energy security and decarbonization. It sounds aspirational, but the hard truths for geopolitics reveal that relying solely on politics and diplomacy, without a partnership with industry, will be folly.

Learn more

Energy Security Sentinel

Semiconductor supply chain outlook

Infographic: BRICS expansion creates oil producer, consumer supergroup

Atlas of Energy Transition

The COP28 pledge to triple renewable capacity by 2030: Which countries will find it hardest to achieve?

Decarbonizing road transportation: When will we get there?

Electrification trends and challenges across the automotive and truck sectors are affecting oil demand.

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Successfully meeting climate goals requires reducing oil consumption, which necessitates addressing transportation fuel demand. The electrification of the automotive fleet stands out as the most advanced initiative in the transportation sector, with 1 in 3 automobile sales in China being electric. However, the adoption of electric vehicles by American consumers remains lackluster, and the development of EV trucks lags a decade behind that of EV cars. Despite these challenges, the trajectory is clear: EVs are steadily entering key markets, while oil demand is approaching its peak. Nonetheless, the shape of the oil demand curve remains relatively flat due to fuel demand growth in emerging economies, which partially offsets the impacts of electrification in developed markets.

Highlights

Electrification of the global vehicle fleet is gaining momentum, yet progress remains concentrated in select markets.

The automotive sector leads decarbonization efforts, while relatively more challenging technical demands mean the truck sector lags approximately a decade behind and varies across applications.

Evolving trends in fuel economy in the on-road sector are pivotal in shaping S&P Global Commodity Insights' outlook that oil demand is poised to peak within the next five years.

Electrification in progress

Policy and infrastructure play crucial roles in shaping the trajectory of electric vehicle adoption. While all three major EV markets — Europe, China and the US — have established long-standing government regulations and incentives to support EV sales and manufacturing, the scale of policy support in the US lags that of Europe and China. Moreover, Europe and China have made comparatively greater investments in public charging infrastructure, which continues to hold back EV adoption in the US. According to a recent S&P Global Mobility survey, after vehicle purchase price, lack of charging station availability is the largest reason for buyers not to consider an EV, with about half of survey respondents raising this issue.

There are signs that EVs are encountering challenges in attracting buyers beyond early adopters in the US. Despite price reductions, Tesla has indicated that its sales growth for 2024 may see a notable decline, while other automakers such as GM and Ford have cautioned about slowing EV sales and are scaling back investments in EV production capacity, particularly in the US.[1] In contrast, manufacturers such as Hyundai, Kia and BMW are moving ahead at a faster pace, meaning consumers have more models from which to choose. At present, the road to electrification is multispeed.

Despite uneven enthusiasm for EVs among consumers, policy initiatives continue to forge ahead. Notably, the EU has a de facto ban on new light internal combustion engine (ICE) vehicle sales from 2035. Meanwhile, the US Inflation Reduction Act has widened EV sales tax credits and allocated funds to expand public charging infrastructure. In April 2023, the Biden administration unveiled draft greenhouse gas emissions standards through model year 2032. If implemented, these standards would effectively necessitate a greater portion of EVs or other zero-emission vehicles in the sales mix. For now, tensions between government regulations and consumer EV adoption are likely to persist in some key markets as EVs narrow the price gap with ICE vehicles and public EV chargers become more ubiquitous. The outcome of this tug-of-war holds significant implications for automotive manufacturers and fuel refiners alike.

Trucks

When it comes to oil demand, trucks punch above their weight. Despite light vehicles outselling medium and heavy vehicles by a ratio of 30-to-1 in China, Europe and the US, each truck consumes approximately 10 times more fuel on average than a car. Historically, car and truck manufacturers have operated in largely distinct domains.

Each truck consumes approximately 10 times more fuel on average than a car.

Amid government initiatives aimed at decarbonizing the on-road transport sector, policymakers are directing greater attention toward the trucking

industry. Over the past decade, truck fuel economy standards have tightened significantly, with an increasing emphasis on reducing greenhouse gas emissions.

However, the rate of technological advancement in new trucks lags that of cars. Notable distinctions exist among truck subsectors and applications, and these distinctions influence background conditions for electrification, including driving range, payload and, ultimately, profitability. The electrification of medium-duty trucks shows promise in certain near-term applications, particularly in urban and residential delivery, where trucks operate from centralized hubs and daily route charging is feasible. Conversely, longer-haul applications necessitate remote or public charging infrastructure, with considerable electrical load and transformer requirements for moderate-sized truck stops. Due to these challenges, long-haul trucks may be more suited for hydrogen fuel cell technology as an alternative zero-emission solution. S&P Global Commodity Insights forecasts that sales of hydrogen-powered heavy trucks in the US will outpace electric trucks by 2050. Although decarbonization efforts through biofuels are underway, the sheer size of the truck diesel market suggests that these sources are unlikely to replace even half of the demand, given the competition for biofuels from other transportation sectors such as aviation and marine.

A counterpoint to the relatively slow pace of truck adoption is the responsiveness of truck buyers to total cost of ownership compared with personal automotive buyers. While the up-front

[1] See Tesla Q4 2023 Financial Results and Q&A Webcast, "Car Dealers on Why Some Customers Hesitate With EVs," *Wall Street Journal,* Dec. 10, 2023.

capital investment for an EV and its associated infrastructure is often higher than for ICEs, lower fuel and maintenance costs can reduce long-term ownership costs. As battery and component costs decrease, there is potential for more rapid growth in EV truck sales, particularly in medium-duty applications where infrastructure requirements are more manageable. Trucking companies and their customers are increasingly interested in creating more sustainable supply chains, providing additional motivation to transition to lower-emission vehicles and fuels.

In essence, progress in decarbonizing trucking is underway, albeit initiated later than for cars. In S&P Global Commodity Insights' base case outlook, the adoption of zero-emission trucks lags that of zero-emission automobiles by seven to 13 years in key global markets.

Oil demand

How do trends in road transport decarbonization affect oil demand?

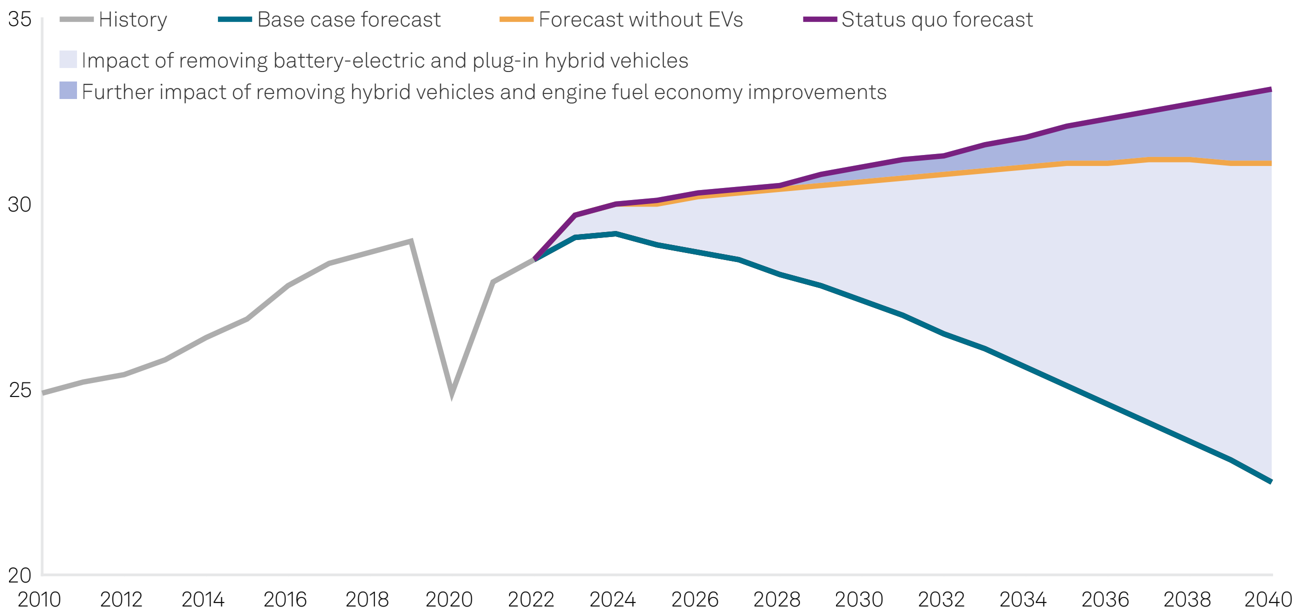
On-road transportation has been a primary driver of oil demand, contributing to 62% of all oil demand growth over the past decade. Looking ahead, both light-vehicle kilometers traveled and trucking ton-kilometers of freight are projected to increase globally at 1.5%-2.0% per annum over the coming decade. However, on-road oil demand will not increase at this pace.

Modern cars and trucks are significantly more efficient than their predecessors, and this trend is expected to continue with the adoption of hybrid technology and electrification. The chart illustrates the breakdown of light-vehicle fuel demand, highlighting the impact of lower-emissions powertrains. In our base case forecast, which encompasses all powertrains, demand is projected to decline. This consumption forecast would be higher without the inclusion of EVs, and higher yet excluding hybrid technologies (cars with small batteries and electric assist motors but without a charging plug), along with the absence of ICE efficiency gains beyond current models.

The majority of on-road emissions stem from the combustion of gasoline and diesel fuel in automobiles, motorcycles and trucks. Global demand for these fossil fuels (gasoline and diesel, excluding biofuels) has steadily increased over the past two decades but is now showing signs of slowing and approaching a plateau (see chart).

Electrification of light-duty vehicles significantly lowers fuel consumption

Relative to a projected status quo (million b/d)

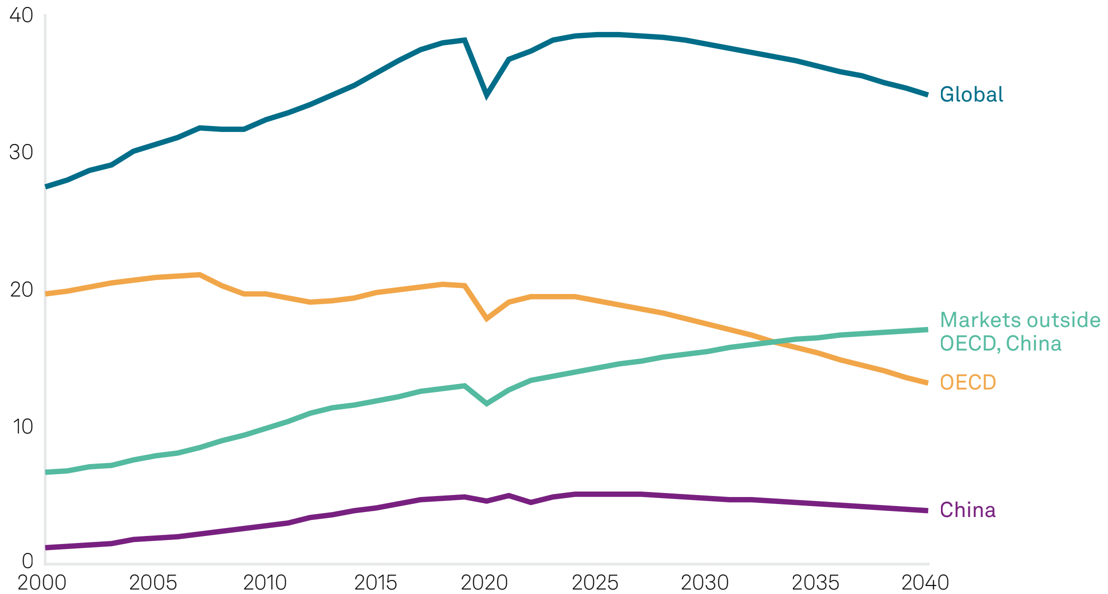


Data as of December 2023.
Includes gasoline and diesel used in light-duty fleet including biofuels.
Sources: S&P Global Commodity Insights; S&P Global Mobility.

[Click here to access interactive chart.]

OECD, China add more efficient vehicles, lowering demand for oil

(Million b/d)



Click here to access interactive chart.

Data as of October 2023.
OECD = Organisation for Economic Co-operation and Development.
Includes two- and three-wheelers. Excludes biofuels and other fuels not derived from crude oil.
Sources: S&P Global Commodity Insights.

As demand declines, so do the associated greenhouse gas emissions, which are closely correlated.

The developed Organisation for Economic Co-operation and Development markets have shown minimal growth in demand since 2000, with emerging non-OECD economies, particularly China, propelling significant expansion (see chart). However, this dynamic is expected to shift, with China no longer the primary driver of gasoline and diesel growth, and on-road demand forecast to peak in 2025. Conversely, demand for these fuels in other non-OECD markets is projected to continue increasing as vehicle activity outpaces improvements in fuel economy throughout the forecast period.

Looking forward

The transition from ICEs to battery-powered cars and trucks will unfold gradually, with large variations by market and application. While oil will remain a primary power source for on-road transportation for decades to come, the energy mix will evolve, offering more alternatives for companies and shippers. Globally, significant progress is anticipated, especially with the ongoing increase in EV adoption in China and tightening fuel economy standards worldwide. This collective momentum is expected to contribute to a peak in global oil demand within the next five years, even as demand for petrochemical feedstocks and aviation jet fuel continues to climb.

Learn more

The journey to further EV adoption

European EV car sales build lead over diesel as region's oil demand shrinks

U.S. States Jump Start Electric Vehicle Charging Infrastructure

When will the heartland embrace electric vehicles?

An Impending Electric Shock For Japanese Autos?

Charting the Course for the Future of Trucking: The Road to Transformation

The role of gas in the energy transition

Gas can contribute to the energy transition by delivering fast and deep decarbonization.

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Gas in its various forms needs to be part of the environmental policy toolkit. The immediate push of natural gas can help achieve fast decarbonization by accelerating the phaseout of coal with a proven alternative technology. A focus on developing low-carbon gases can achieve deep decarbonization, providing a further cut in emissions and a pathway to net-zero.

Highlights

Natural gas can provide significant near-term emissions reductions through fuel substitution.

Low-carbon gases can further reduce emissions in the longer term.

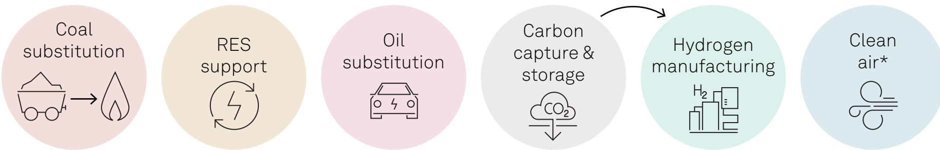
The issues of methane leakage and infrastructure "lock-in" must be addressed if these benefits are to be realized.

Natural gas: Friend or foe?

Natural gas plays a central role in the global economy. Approximately one-fifth of the world's energy used today comes from natural gas. Its applications are widespread and integral to our everyday lives: heating homes, shopping malls and offices; fueling paper and steel mills; powering glass, food and metal factories; providing feedstock for fertilizer plants; and generating electricity — the list goes on. The importance of natural gas came to public attention in 2022 with the cut in pipeline gas supplies from Russia to Europe. This triggered rocketing prices for electricity and fertilizers, creating a global scramble for LNG and, ultimately, leading to power outages in countries as far apart as Pakistan and Myanmar.

What role should natural gas play in the energy transition? The UN's annual climate change conference (COP28), held in the United Arab Emirates in 2023, concluded with a call to "transition away from fossil fuels." But not all fossil fuels are born equal. Any concerted action to reduce greenhouse gas emissions is likely to mean efforts to reduce oil and coal consumption as soon and as much as reasonably possible. For natural gas — the fossil fuel with the lowest GHG footprint — the arguments are more complex. The option exists to transition away from either coal or oil toward natural gas. This brings quick and significant near-term benefits in reduced emissions but does not reach the desired goal of net-zero. As a result, the adoption of natural gas often sets idealists against pragmatists.

6 ways natural gas can support decarbonization and sustainability



As of Feb. 6, 2024.
RES = renewable energy sources.
* The advantage is the reduction of pollutants and noise. The advantage in terms of greenhouse gas emission reduction is minimal.
Source: S&P Global Commodity Insights.

6 ways gas drives decarbonization

There are six ways that natural gas can help push forward sustainability and decarbonization. Each can occur over different time frames, with varying impacts (see chart).

Coal substitution

Coal-to-gas substitution is the biggest near-term opportunity. Coal is responsible for 43% of global energy-related GHG emissions. China alone accounts for half of global steam coal used to generate power and in industrial processes worldwide. India and the US are the other biggest markets for coal generation, and many developing countries continue to add coal-fired capacity. Replacing older and less efficient coal plants with best-in-class natural gas generation should reduce emissions by more than 50% per unit of electricity.

The production of ammonia and methanol provides another opportunity to replace coal with natural gas. Ammonia is a key input in the production of many fertilizers and can also be co-fired with coal in power stations to reduce overall coal burn. Most of the ammonia and methanol produced comes from natural gas, but coal is also used, primarily in China. In the steel sector, metallurgical coal could be substituted by natural gas using direct reduced iron technology.

Partnership with renewable power

Renewable power is critical to the energy transition, and variable sources such as wind and solar are expected to be the primary technologies. Because they are variable, they need support. Improvements in battery technology and demand-side management can go a long way to meet short-term fluctuations. However, thermal generation will most likely be required to help renewable power manage long-duration storage needs. Today's planning horizon, which will determine energy infrastructure for the coming decade, contains few alternatives, and gas-fired power is the principal option. Every unit increase in renewable power is likely to be accompanied by some form of dispatchable generation. This support is sometimes called a backup to renewables, but that term can be misleading since the backup often provides more power than the primary source.

Oil substitution

There is also scope for natural gas to replace oil. The main opportunity in stationary facilities is the 1.6 million barrels per day of oil used to generate power in the Middle East. Another critical area is the rollout of electric vehicles. Although the vision is to power EVs with low-carbon sources of generation, in practice, natural gas will be needed at least at the margin as electricity demand booms. Using gas-fired power to help meet power demand from EVs is a form of oil-to-gas substitution. Moreover, an electric motor is typically more energy efficient than an internal combustion engine. Natural gas could also have an important role to play in medium- or heavy-duty vehicles and shipping, either in the form of compressed natural gas or as methanol or ammonia.

Carbon capture, utilization and storage

Carbon capture, utilization and storage (CCUS) is a long-standing, proven technology with the potential to remove 90%-95% of emissions if properly operated. Its application to date has been mainly in oil and gas production, linked to enhanced oil recovery or gas processing associated with LNG facilities. In future, CCUS will need to be deployed at a much greater scale downstream in industrial clusters or hubs. The principal applications of CCUS will be in "hard-to-decarbonize" factories, such as those processing steel, cement, glass and fertilizer. These sectors typically use natural gas.

S&P Global Commodity Insights projects that carbon capture will increase to 1.5 gigatons-6 gigatons per year by 2050, over 30 times higher than used today.

Hydrogen

Hydrogen — or one of its derivatives, such as ammonia — is now widely recognized as a key component of decarbonization. More than 20 countries have declared hydrogen strategies. Some net-zero projections show hydrogen accounting for as much as 25% of energy end-use by 2050. So-called green hydrogen generated from renewable power via electrolysis will also feature. Given limitations in developing sufficient renewable capacity to meet both strongly growing direct power demand and a new appetite for hydrogen, blue hydrogen produced using natural gas is expected to play a significant role.

Clean air

Sustainability is about more than GHG emissions. Air quality is a major health hazard, especially with growing levels of urbanization across the developing world. Natural gas has a strong card to play here. Its low levels of nitrogen oxides, sulfur oxides and particulates mean that wider gas use can help reduce pollution levels. The running of municipal buses, delivery vans and possibly taxis could improve air quality.

Potential spoilers

While gas can help support decarbonization, two potential spoilers must be addressed to ensure its benefits are reaped.

Methane leakage

The first is methane leakage. Methane is a potent GHG emission. Although natural gas has a relatively low carbon footprint, this advantage could potentially be offset by high levels of associated methane slip, which may occur in production or delivery of the fuel. Approximately 10% to 12% of global anthropogenic methane emissions come from natural gas use. However, the promising news is that methane leakage is a problem with a solution. Technology is evolving fast in the areas of detection, measurement and mitigation, and lasers, drones and satellites are all part of the armory. The oil and gas industry is confident that it can harness these technologies, and a wide group of leading companies at COP28 endorsed a commitment to achieving near-zero methane emissions by 2030. Methane leakage has a disproportionately deleterious short-term impact compared with CO_2, so reducing that leakage will have a magnified positive impact on near-term global warming. It will be critical for the natural gas industry not only to deliver on that commitment but also to demonstrate it at each stage of the supply chain. Risk and prevention protocols around methane leakage need to be analogous to those focused on preventing oil spills.

> The promising news is that methane leakage is a problem with a solution.

Infrastructure "lock-in"

The second issue to address is the risk of infrastructure "lock-in." This is the idea that investments today may enable emissions reductions from a base point but that these investments lock in a fixed level of emissions far into the future without options to reduce them further. The problem is that most natural gas investments have long asset lives. Pipelines that begin construction in 2024 can remain in operation beyond 2050, and liquefaction and regasification facilities operate for at least 25 years, often much longer. Switching from coal to gas offers an immediate but one-off cut in emissions, not a linear decline toward net-zero. The one-off emissions cut does, however, prevent CO_2 from getting trapped in the atmosphere; for every unit of

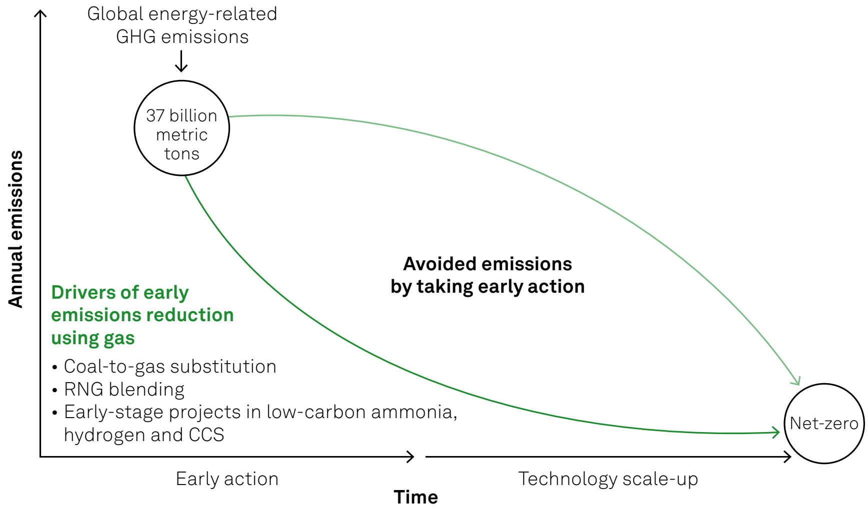
CO_2 saved, hundreds of years of locked-in global warming effects are prevented (see chart).

There are two ways to circumvent infrastructure lock-in, and it is imperative the gas industry demonstrates the viability of both:

– The industry can use existing infrastructure with a different fuel throughput. This might be renewable natural gas (biomethane), e.g., gas from landfills or manure, or synthetic natural gas. Hydrogen blending, within narrow ranges, can also reduce the carbon intensity associated with operating existing infrastructure.

– It may be possible to repurpose existing infrastructure to run on low-carbon gas at a lower cost than building an alternative infrastructure system. For example, much work is underway to investigate how natural gas pipelines and storage facilities could be adapted to transport and store 100% hydrogen. Infrastructure might also be adapted to transport and sequester CO_2. Repurposing assets would counter the risk of emissions lock-in and provide a clear technological pathway to transition from higher carbon, through lower carbon, to zero carbon. Repurposing turns the lock-in argument on its head: Investment in gas infrastructure becomes a pre-build and downpayment for a future decarbonized energy system.

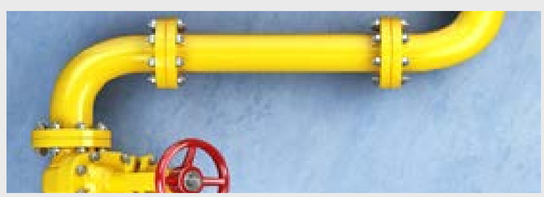
Natural gas is essential to achieve deep and fast decarbonization



As of Feb. 6, 2024.
GHG = greenhouse gas; RNG = renewable natural gas; CCS = carbon capture and storage.
Source: S&P Global Commodity Insights.

Looking forward: Fast and deep decarbonization

Meeting the challenges of climate change is becoming ever more urgent. Gas can make a major positive contribution by leveraging existing energy infrastructure and an existing scaled supply chain. The immediate push of natural gas can help achieve fast decarbonization by accelerating the phaseout of coal with a proven alternative technology. A focus on developing low-carbon gases and making existing infrastructure suitable for conversion can achieve deep decarbonization in the longer term, providing a pathway to net-zero. A two-pronged approach that sees gas infrastructure working together with electrification needs to be part of our global environmental policy toolkit.



Learn more

New Configurations: America's Gas and Power in Net Zero

Natural Gas in Transition

Gas utilities see renewable natural gas investment opportunities expanding

Permian methane: The good, the bad and the ugly

New technologies and industry focus will enable significant reductions in methane emissions in the world's most important oil and gas basin.

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The question of how much methane the oil and gas industry is emitting from leaks and venting has moved to center stage. At the COP28 climate summit, international oil companies made a wave of promises, all revolving around methane. Company spending on solutions has risen sharply. And because methane leakage is the key determinant of the relative climate performance of gas versus coal, it may be the largest factor in whether the Biden administration resumes LNG permitting.

Highlights

The Permian Basin, the world's most important oil and gas production area, is an emissions bellwether since it acts as both a microcosm of the oil and gas emissions universe and a decarbonization laboratory.

Stakeholders are rightfully focused on methane emissions because they are powerful climate influencers and because solutions exist today. Unfortunately, methane emissions have been devilishly difficult to quantify, with estimates generating more controversy and noise than signal.

New technologies have catapulted methane measurement forward. S&P Global Commodity Insights has partnered with Insight M, formerly Kairos Aerospace, to generate reliable, measurement-informed methane emissions estimates for the Permian.

Framing the answer is critical. Expressing emissions in absolute terms or as a percentage of natural gas output results in a surprisingly large number. However, emissions appear relatively contained when considered in the context of total energy or value produced.

Basin averages are essential but misleading if applied to specific companies.

We expect progress in methane reduction to accelerate significantly in the next three years. Many companies will beat their 2030 methane reduction targets well ahead of time.

Permian Basin methane emissions intensity metrics

155 billion cubic feet **2.01** % of natural gas produced **0.92** % of energy produced **0.43** % of value produced

As of Feb. 13, 2024.
2022 estimates.
Sources: Insight M; S&P Global Commodity Insights.

In this article, we offer what we believe to be the most accurate assessment to date of the methane emissions in the heart of the US oil and gas revolution — the Permian Basin of western Texas and southeastern New Mexico.

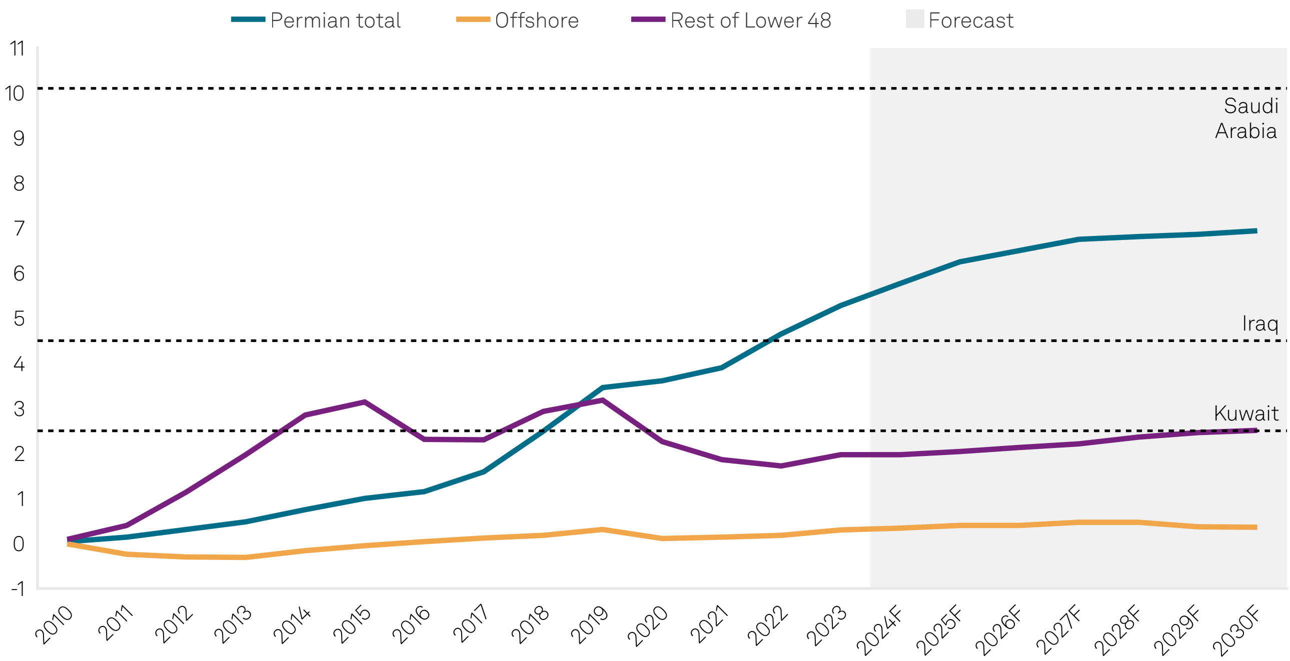
The Permian matters

In the last decade, the Permian Basin has become the most important petroleum basin in the world. Three dimensions drive its prominence:

- Size and scale: Current output of 5.5 million b/d of oil and 23 Bcf/d of gas are concentrated in roughly 20 counties home to just 500,000 people. If it were a country, the basin's oil and gas output would rank as the third-largest producer in the world. The 10-plus GW of installed solar and wind only add to the total energy produced.
- Financial impact: The Permian's explosive growth (see chart) propelled the wave of US output from 2014 to 2019, drove global oil price formation and undercut US natural gas prices by generating huge volumes of associated gas. The Permian's relentless expansion crowded out growth opportunities for established petroleum powers in OPEC+ as well as new entrants. Beyond influencing commodity markets, the Permian also creates wealth, generating approximately $200 billion in annual petroleum revenues, of which approximately $35 billion flows directly to individual and corporate mineral rights holders.

Explosive Permian growth has created an energy powerhouse: Lower 48 oil supply change since 2010

Million b/d of growth (US) or output (international)



As of Jan. 28, 2024.
F = forecast.
Source: S&P Global Commodity Insights.

- Greenhouse gas emissions: The Permian is undeniably an emissions hotspot. More importantly, it acts as both a microcosm of the larger oil and gas emissions universe and a laboratory for testing decarbonization opportunities. Beyond simple scale, the basin has some structural characteristics that drive emissions and tend to exacerbate GHG intensity in upstream operations:
  - Oil dominance: Oil is the dog; gas is the tail. Despite the basin's massive gas output, oil generates 80% or more of total revenue.
  - Remote locations: Most wells are several hours away from oilfield service centers. For example, Loving County, Texas, boasts more than 3,000 active wells but only 42 residents.
  - Decentralized assets: The Permian has over 75,000 individual well pads containing approximately 130,000 active wells, plus a legacy of more than 100,000 shut-in wells. This translates into tens of millions of components handling pressurized natural gas around the clock for decades.
  - Water handling: It is a world-scale water handling business. Mixed in with its oil and gas, Permian wells produce more than 22 million barrels of water every day — about four barrels for each barrel of oil. All this water must be separated, moved by pipe or truck, and reinjected into the subsurface.

In the GHG context, CO_2 emissions are quite large, relatively easy to calculate accurately and fairly difficult to abate. Methane, which comprises more than 80% of natural gas production, is the current focus of the industry's emissions-reduction efforts. Methane is 25 times more climate-forcing over 100 years than CO_2, and emissions represent forgone revenue. Unfortunately, most methane emissions are also devilishly difficult to estimate because they are typically released unintentionally.

> The Permian acts as both a microcosm of the larger oil and gas emissions universe and a laboratory for testing decarbonization opportunities.

Methane measurement is quantifying the invisible

The exact amount of methane emissions from upstream activities in the Permian Basin, or elsewhere in the world, is unknown. The issue is controversial, with available estimates varying by roughly an order of magnitude. Methane is a colorless, odorless substance that disperses almost instantly in the air. It is usually released either as a normal part of oilfield equipment operation or as "fugitive" emissions that appear intermittently and accidentally due to malfunctions, accidents or system upsets. Fugitive emissions also extend beyond upstream activity to midstream, storage and long-distance transportation. Even where atmospheric methane concentrations are accurately measured, the emissions must be attributed to specific sources within the observed area and distinguished from natural sources of methane emissions.

The final source of complexity is the role of "super-emitters," which are leaks of more than 100 kilograms per hour. Usually resulting from malfunctions or other unexpected events, super-emitters occur at less than 1% of sites, making it a challenge to find and repair them quickly. They also offer an opportunity since some studies indicate that they can account for 80% of total emissions.[1]

Nevertheless, measuring methane emissions has vaulted forward in the past decade. While estimates using static emissions factors for various equipment types still dominate regulatory reporting, oil and gas producers have tested a wide variety of technologies to understand the strengths and limitations of each. Industry leaders have been deploying them for a few years now, and the effectiveness of these measurement techniques has given companies confidence that they can achieve good results. The recent methane reduction pledges announced at the COP28 conference stem from this buy-in to the ability to see, quantify and act on methane emissions.

[1] Source: Research Square, "Quantifying oil and natural gas system emissions using one million aerial site measurements."

All the leading technologies for quantifying methane have been deployed in the Permian. Each offers a different trade-off of the six dimensions of the ideal: resolution, frequency, threshold, coverage, reliability and affordability. For the purposes of this discussion, observations made by airplane-mounted detection equipment on regular trips covering at least 80% of the basin offer a unique blend of factors that make it possible to generate reliable and accurate methane emissions figures.

155 Bcf is the answer. What is the question?

S&P Global Commodity Insights partnered with Insight M, the leader in airplane-based detection, to obtain the measurement-informed methane emissions estimates. We believe these are among the most accurate estimates that exist and can provide a sound basis for a benchmark figure against which to assess future progress.

Based on Insight M data, S&P Global Commodity Insights estimates that upstream activities in the entire Permian Basin emitted approximately 155 Bcf of methane (2.9 million metric tons) during 2022. This is equivalent to 70 MMt of CO_2.

Putting this number into context is necessary to understand it, and the most common method is to frame the absolute metric in terms of its relationship to the benefits of the operation. At the same time, these emissions were the cost that was incurred in the process of producing energy. How do those two metrics compare?

The calculation of this methane emissions intensity is a simple ratio, but there are several options for calculating that lead to significant differences and create confusion and debate on the issue. The table provided shows the two most common intensities — as a share of gas production and as a share of energy produced — and includes a novel “intensity related to economics value” metric that S&P Global Commodity Insights has developed, which provides additional insight.

Different perspectives lead to different conclusions: 4 ways to express methane emissions

Intensity metric	Permian upstream in 2022	Pros	Cons
Methane emissions	155 Bcf	• Simple • Consistent with climate impact	• Offers no context/cost benefit • Does not allow meaningful comparison between areas of varying size
Percentage of natural gas produced	2.01% of gas in thousand cubic feet	• Logical elegance in comparing gas with gas • Provides gas loss rate	• Oil production deemed free of methane emissions • Penalizes oilier operations with little gas production • Most methane emissions come from oil-processing equipment
Percentage of energy produced	0.92% of barrels of oil equivalent	• Compares environmental cost with benefit (energy) for society • Reflects reality of full integration of oil and gas operations	• Energy equivalency of 6 Mcf of gas per 1 barrel of oil does not reflect value equivalency of about 20-to-1 • Actual uses of the fuel may be irrelevant to energy content
Percentage of value produced	0.43% of estimated revenue	• Exposes economic considerations, which drive real-world decisions • Reflects location factors influencing gas prices	• Depends heavily on uncontrollable factors (prices) • High volatility makes it unusable as an index to show improvement over time

As of Jan. 28, 2024.
Sources: Insight M; S&P Global Commodity Insights.

The flaw of averages

Using S&P Commodity Insights' preferred metric of methane emissions per barrels of oil equivalent, the Permian registers at about 1%. It is important to remember that this number does not include midstream processes (gas gathering, processing and transport), which, after the allocation of emissions to assets, is estimated to be roughly equal to the upstream emissions. In addition, it equals a loss of 430 MMcf/d and forgone revenue of just over $1 billion dollars at today's gas prices. There is room for great progress to be made.

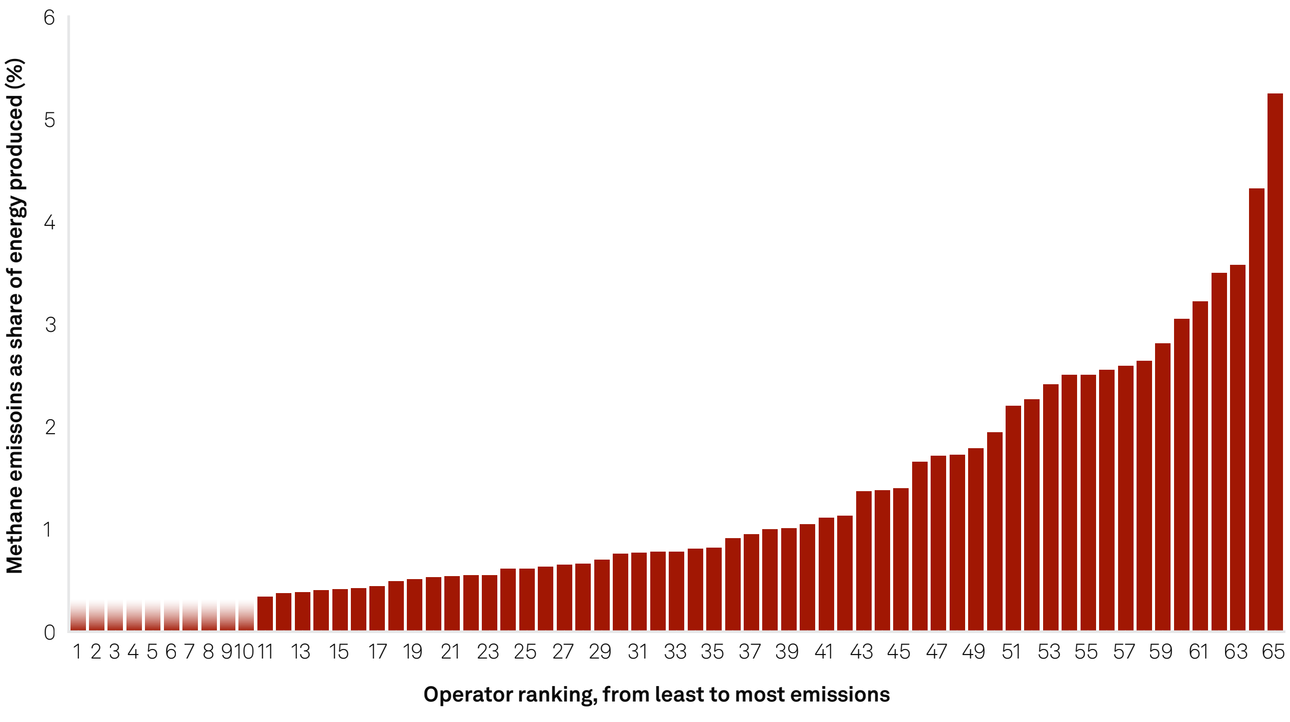
But a thoughtful examination of the current reality and the future path for Permian methane emissions requires moving beyond headline aggregates and accounting for the incredible diversity within the basin. The Permian Basin is a microcosm of the global oil asset base: Cutting-edge, AI-driven automation exists alongside creaky equipment that has been in operation since the 1950s. The basin features supergiant fields next to one-well wonders. There are wells being drilled today that break even below $30/b West Texas Intermediate (WTI) and wells that require $85/b WTI to earn a pittance.

That diversity extends to the competitive landscape; the competitive landscape reflects that diversity. Despite the consolidation that has made recent headlines, the Permian is the least concentrated of any basin in the world. The headline number of 1,200 companies with current operations is misleading because the overwhelming majority of those are micro-operators with one or two wells with scant production. What is more revealing, however, is that no company operates more than 10% of total production.

This heterogeneity and the granularity of the S&P Global data sets offer an opportunity to unlock insights into the methane emissions data by examining granular data and applying emerging machine-learning techniques. Leveraging the Insight M data and focusing on the methane emissions attributed to a set of upstream oil and gas producers, we discover that the Permian basin really is a case of "the good, the bad and the ugly."

From good to bad to ugly

Measurement-informed Permian methane emissions by operator



As of Feb. 9, 2024.
2022 estimates.
Sources: Insight M; S&P Global Commodity Insights.

Some operators in the basin are squeaky clean, emitting well below the factor-driven estimates provided to regulators in some cases. At the same time, some assets show high observed methane emissions.

Looking forward: Expect progress to accelerate rapidly, but with sound and fury

This wide distribution of methane emissions performance has an important implication: The Permian situation defies simple answers. Strategic and economic decisions will result in companies moving at variable speeds. However, the overall direction remains clear, and the industry will continue evolving toward more efficient, less polluting operations. Recent proposed regulations from the US Environmental Protection Agency integrating direct measurement into reported numbers and enacting methane taxes on excess emissions will also force action. The ramifications of the Permian embracing methane abatement will drive behavior changes elsewhere as operators compete on methane.

We expect Permian methane reductions to accelerate over the next three years, with many companies exceeding their 2030 targets well ahead of time. The reality is that the leaders have already made significant progress quietly. The first campaigns have focused on increasingly frequent overflight and site inspection programs and on replacement of certain categories of equipment with high emissions venting rates. They have piloted a wide range of emerging technologies, with mixed success, and are now deploying those solutions best suited to their particular assets. Laggards, meanwhile, have upside from the low-hanging fruit still available to them, and avoiding the EPA-proposed methane fees coupled with the existing benefit of selling captured methane emissions should boost economics.

Along this path, a wide range of stakeholders — investors, policymakers, environmentalists, producers and consumers — will all grapple with how to understand a complex issue, measure success and failure, and design solutions. The inevitable result will be an enormous amount of noise, with claims, counterclaims and materially divergent numbers bandied about. S&P Global Commodity Insights will be part of this debate. Our approach is to marry the rising tide of robust methane measurements that "quantifies the invisible" with a deep, AI-driven analysis and subject-matter expertise that interprets the reality for our customers.

Learn more

S&P Global Webinar: Contrasting Upstream Emissions in the Williston Basin

S&P Global Commodity Insights Upstream Enhanced Emissions

GHG Intensity of Offshore Brazil Production in 2022

North Sea Emissions Uncovered

Is the COP28 pledge to triple renewables capacity by 2030 a surmountable challenge?

At least 1,000 GW of new renewables capacity are needed globally each year to reach the goal, or more than double today's levels.

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The UN's 28th annual climate change conference, known as COP28, ended Dec. 13, 2023, with parties pledging to triple global renewable energy capacity by 2030. How difficult is this goal? For which markets is the objective easier or harder to achieve?

The objective to triple renewables capacity is a tall order for all governments

The outlook for renewables capacity to 2030 derives from the global pipeline of generation projects, the policy environment and market dynamics. From its analysis of these matters, S&P Global Commodity Insights concludes that although the tripling objective is not established country by country — it is global, or a "collective" goal — achieving it will require accelerating renewable deployments in markets with substantially different circumstances.

Highlights

The objective to triple global renewables capacity by 2030 is a tall order for all governments.

At least 1,000 GW of new renewables capacity are needed globally each year to reach the goal, or more than double today's rate.

Markets worldwide face substantially different circumstances to build more renewables.

The projected renewable capacity additions of China alone during 2024–2030 are almost the sum of all other additions worldwide.

Existing renewable penetration levels, project development timelines, power demand growth rates and access to funding affect the potential scale of development.

Our reference-case outlooks suggest that global renewables installed capacity will more than double from the 2022 level to over 7,000 GW by 2030, but it is unlikely to triple before 2037. Among the major markets, China is one of the closest to achieving the tripling objective, but it has not signed the Global Renewables and Energy Efficiency Pledge. Other markets have a slim chance to triple their current capacity before 2035, with the EU and Latin America stretching into the 2040s, assuming hydropower is included in the target.

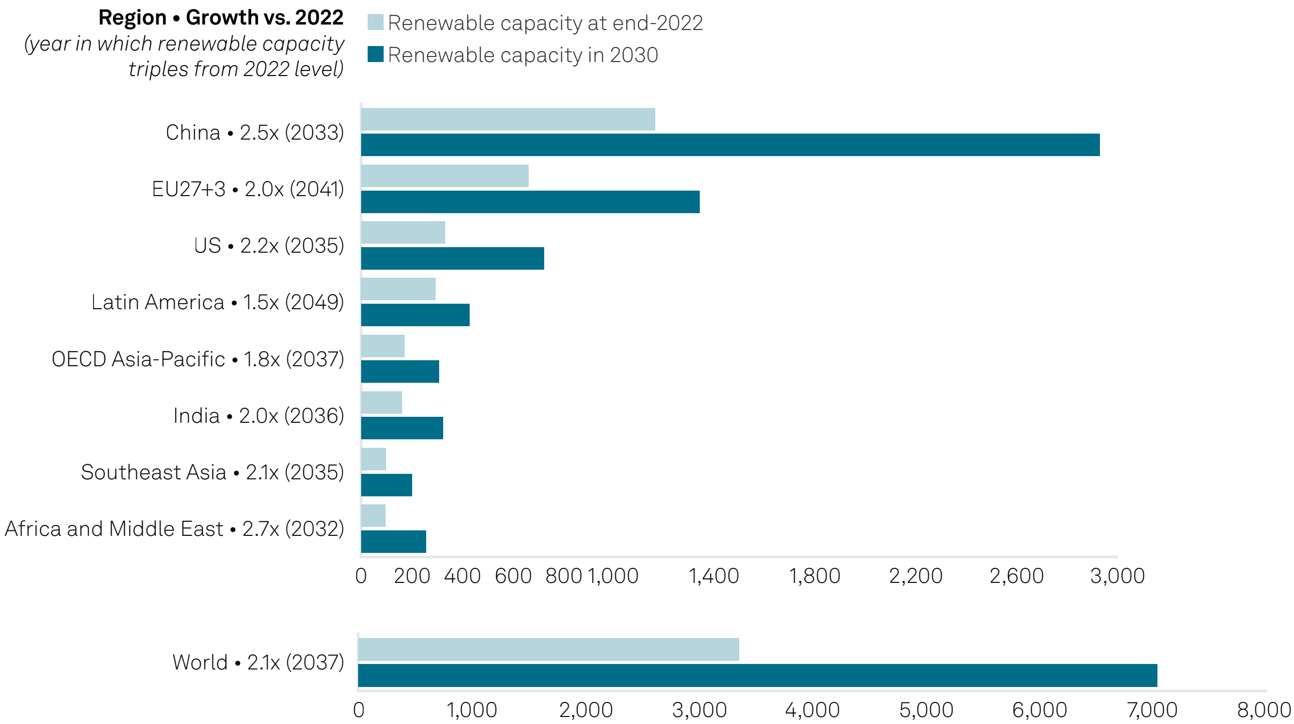
Global renewables capacity grew a remarkable 6% annually over the past five years. Yet a 17% annual growth rate from 2024 to 2030 is needed to fulfill the tripling pledge. Renewable capacity additions soared to more than 400 GW in 2023, but the pace of new additions must increase to achieve the goal. Tripling the 2022 installed capacity will require at least 1,000 GW of new additions per year, more than double the current level.

Tripling the 2022 installed capacity will require at least 1,000 GW of new additions per year, more than double the current level.

However, markets are not contributing to the target equally. Countries with limited renewables capacity today are under less pressure given that their contributions will not move the needle substantially. For instance, if all countries in Southeast Asia quadruple (rather than triple) their installed capacity, it would only represent 10% of the expected effort from the US. The projected renewable capacity additions of China alone during 2024–2030 are almost the sum of all other additions worldwide. In other words, fulfilling the global pledge is nearly impossible without China.

Will renewable capacity triple globally by 2030?

Renewable capacity (GW)



As of Dec. 15, 2023.
OECD = Organisation for Economic Co-operation and Development.
EU27+3 = EU27, Norway, Switzerland and the UK. Values are from reference case outlook.
Renewables include hydro, solar, wind, geothermal, biomass and waste, ocean, and renewable hydrogen.
Source: S&P Global Commodity Insights.

Markets face substantially different circumstances to build more renewables

Several factors impact how much renewables capacity different markets may add in the coming years.

- **The higher the share of variable renewables in a market, the harder it is to add more.** The availability of project sites, grid constraints and reliability risks worsen where renewables growth has been rapid. In Europe, for example, wind and solar already represent more than 25% of total generation, and 42% when including hydropower. Insufficient investment in transmission networks — a common theme in many regions — compounds the reliability challenge. Such markets will need to look beyond simply adding cheap variable solar and wind resources and invest in transmission reinforcements, demand-side management and dispatchable, reliable clean power sources.

45% of generation to come from renewables by 2030

Outlook for renewables generation by region

	Renewables generation (TWh)		Renewables share in total generation (%)	
	2022	2030	2022	2030
China	2,681	6,022	31	49
EU27+3	1,370	2,612	42	64
US	965	1,933	23	44
Latin America	1,043	1,453	63	66
OECD Asia-Pacific	313	625	17	31
India	358	736	20	27
Southeast Asia	279	567	24	35
Africa and Middle East	286	684	12	22
World	**8,267**	**16,268**	**30**	**45**

Data compiled Dec. 15, 2023.
EU27+3 = EU27, Norway, Switzerland and the UK. Values are from reference case outlook.
Renewables include hydro, solar, wind, geothermal, biomass and waste, ocean, and renewable hydrogen.
Source: S&P Global Commodity Insights.

- **Project development timelines vary greatly.** Permitting and interconnection queues are lengthening in several core markets worldwide, owing to the growing demand for renewable energy, local opposition and regulatory complexities. Our research shows that, on average, permitting a utility-scale solar project takes three years in Europe and the US, or 60% of the project development cycle. In Europe, onshore wind permitting can take 3.5 years on average, almost as long as for offshore wind; in contrast, completing projects in China is much faster and can take half to a fifth as long.

- **Power demand growth affects the scope for renewables expansion.** Renewable additions in emerging economies will primarily satisfy growing electricity demand, while in developed economies, they will often replace existing thermal capacity. This shapes the pledge's impact on renewable penetration rates and how renewables fit with other system requirements. China and India, another non-signatory of the Global Renewables and Energy Efficiency Pledge, have favorable fundamentals to build more renewables capacity.

- **Access to public funds and private capital varies.** Many emerging economies will face difficulties competing for green investment while improving basic access to energy. High interest rates and political and economic uncertainty lead investors to retrench to mature markets. According to S&P Global Commodity Insights, the substantial government incentives offered in the US, Europe and China will lead the three markets to comprise more than 70% of global renewables additions during 2024–2030. Changes in the renewables supply chain, stimulated by new policies on local content requirements, will also affect the geographic distribution of builds. A key ask from the Global South is for developed countries to allocate capital and development assistance to developing countries.

In Europe, onshore wind permitting can take 3.5 years on average, almost as long as for offshore wind; in contrast, completing projects in China is much faster and can take half to a fifth as long.

- **There is supply chain capacity to meet the challenge, but nearshoring/onshoring policies can create bottlenecks and increase costs.** Global solar and wind supply chains are expanding rapidly. In 2024, annual photovoltaic (PV) module production capacity will be twice as high as demand, and most of this capacity is from newer, better production lines with higher efficiency and lower cost. Manufacturing capacity for wind energy is also increasing. China continues to lead the world in clean technology manufacturing. This oversupply will make nearshoring cleantech manufacturing difficult. Nearshoring cleantech manufacturing will come at the cost of a more expensive transition; for example, PV modules in the US already cost more than twice as much as elsewhere.

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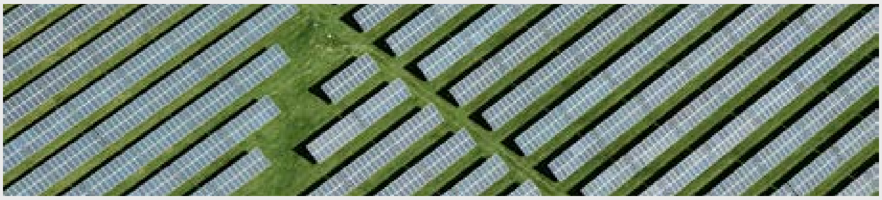
The Global Renewables and Energy Efficiency Pledge includes hydropower in the 2030 target, but the COP28 Global Stocktake agreement does not mention it. This difference has a major impact on the growth potential for power markets with significant hydropower capacity. Latin America and Scandinavia have large-scale hydropower fleets with very limited scope for growth. Even in less hydro-dependent regions, including the resource in the pledge complicates its achievement. For example, in our reference outlook, India will triple its solar and wind capacity by 2033, but it will triple its renewables capacity including hydropower by 2036.

Looking forward

Policymakers and other stakeholders will need to consider these geographic realities when elaborating new strategies that support the landmark pledge. These realities also demonstrate the benefits for governments and companies worldwide to collaborate to reach the objective in an economically and technically practical way.



Learn more

[The COP28 pledge to triple renewable capacity by 2030: Which countries will find it hardest to achieve?]

[Five trends in 2024 for global power and renewables markets]

[Which power markets are the most attractive for renewable energy investments?]

Hydrogen: New ambitions and challenges

Is low-carbon hydrogen ready for lift-off?

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In addition to its role in the oil refining and chemical industries, hydrogen is now emerging as a vector of clean energy delivery. There is genuine interest and investment worldwide as governments and businesses seek to develop this budding industry as part of their energy transition goals. Nevertheless, significant challenges lie ahead to bring this industry up to scale.

Low-carbon hydrogen: A nascent industry

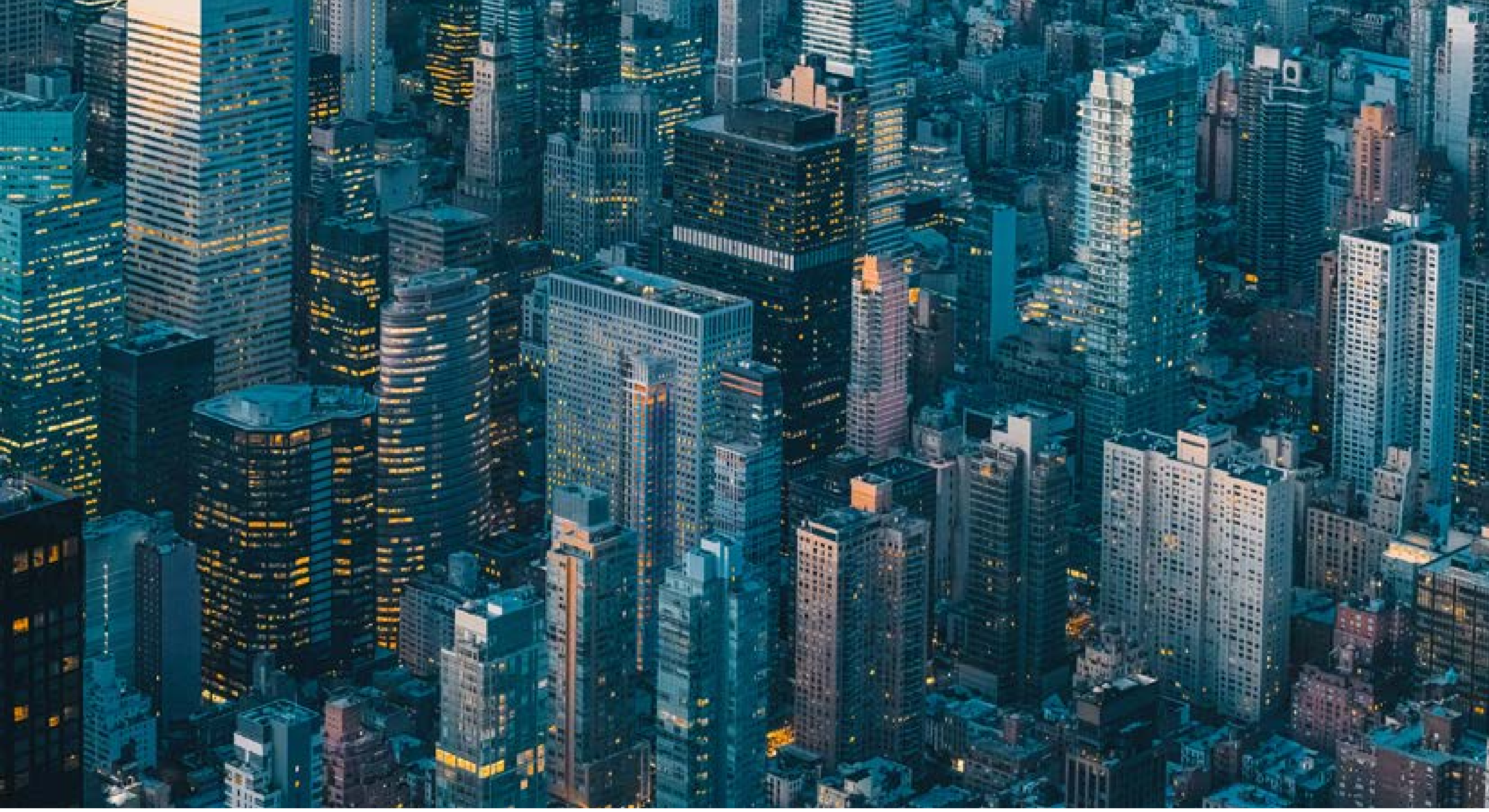
A new industry is emerging to deliver low-carbon hydrogen to energy markets. New companies are being founded, and new business models are being designed. Pilot plants are expanding to commercial scale, and industrial parks are increasingly looking to develop regionwide linkages in "hydrogen hubs" and "hydrogen valleys." Intense efforts

Highlights

The short-term growth of hydrogen globally appears strong based on current order books.

However, several issues are slowing the momentum: Excessive permitting delays are slowing down projects; a lack of clear rules around additionality and carbon intensity is deterring investments; and insufficient government financial support is stymying offtake commitments.

Such challenges must be overcome to realize a global vision in which hydrogen plays a vital part in a transformed energy system.



are underway to reduce production costs and to find economically viable ways to transport hydrogen.

Meanwhile, governments worldwide are working on the detailed design and implementation of subsidy or support regimes, with the conviction that net-zero targets, or even deep reductions in carbon footprint, will need low-/zero-carbon molecules as well as low-/zero-carbon electrons.

A striking characteristic of this emerging industry is that interest and investment are genuinely worldwide. There is potential to establish some part of the hydrogen value chain in advanced, industrializing and developing countries alike.

The global vision

Hydrogen is an important feedstock for the oil refining and chemical industries, primarily supplying on site needs. It is essentially an industrial gas made from fossil fuels in highly carbon-intensive processes.

However, there is a clear vision to transform this into an industry that delivers energy. Technologies to decarbonize hydrogen production could transform it into a vector for delivering low-carbon energy to both existing and new end users.

In almost every corner of the planet, business and political interests overlap in a way that strongly favors developing hydrogen and its derivatives as carriers of low-carbon energy.

For this vision to succeed, three challenges must be overcome:

- Reducing costs and eliminating bottlenecks
- Establishing harmonized definitions and classifications
- Securing reliable customer purchase commitments

Challenge 1: Reducing costs and eliminating bottlenecks

The focus is turning to reducing costs throughout the low-carbon supply chain. The capital and operating costs of hydrogen production are an important element, but infrastructure, pressure and storage are also critical.

Various technical options for infrastructure to deliver hydrogen to consumers are emerging, but all have costs. These delivery costs can more than double the production cost for each unit delivered to a customer. Hydrogen must be delivered at suitable pressures for different types of end uses, and for most uses, hydrogen must also be stored. Cost is added at every stage.

In all these areas, businesses are working to identify the most cost-effective route for their business models. It is hoped that a rapid learning curve will contribute to further cost reductions.

However, other factors are also at work. For a given scale, the complexity of integrating electrolysis at existing facilities and general cost inflation can add substantially to installed capital cost. These factors have more than offset the recent benefits of research and development, automation, and learning-by-doing.

Project complexity and other cost escalation have driven proton exchange membrane (PEM) electrolysis costs higher in the last few years. S&P Global Commodity Insights estimates that between 2020 and 2024, 10-MW PEM electrolyzer costs have jumped from roughly $1,200-$1,300 per installed kW to about $1,700 per installed kW.

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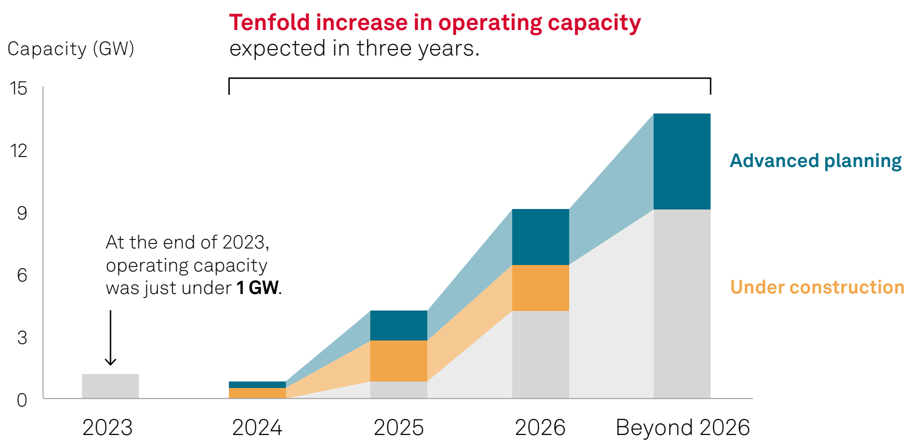
Moreover, because hydrogen is not an energy source, but a vector by which other energies can be delivered in low- or zero-carbon form, cost and scale factors for these energies can be more important than the cost chain for hydrogen itself.

- Natural gas prices: The price of natural gas, the main feed for methane reforming to produce hydrogen, is set in a global market. Its price responds to the vagaries of commodity market conditions, with all their uncertainties. In the past three years, the feed price of gas into unabated hydrogen manufacture has varied in most parts of the world by a factor of two or three. The impact on the cost of hydrogen is substantial.

- Cost of renewable electricity generation: It is widely expected that the cost of generating renewable electricity will continue to fall, reducing future operating input costs. This expected declining cost influences the attractiveness of electrolytic hydrogen over the larger-scale processes of methane reforming with carbon capture and storage. Nevertheless, it remains uncertain.

- Direct competition for renewable sources with all other much-needed electrification needs: For example, in the European Union, we estimate that producing 5 million metric tons of green hydrogen per year would require about 35 GW of electrolyzer capacity (plus 50 GW to 150 GW of renewable generation capacity, which may in turn absorb one-eighth of total EU renewable capacity). Renewable power feed will compete directly with the higher priority goal of zero-carbon electrification.

10 GW of electrolysis capacity is under construction or in advanced planning stage



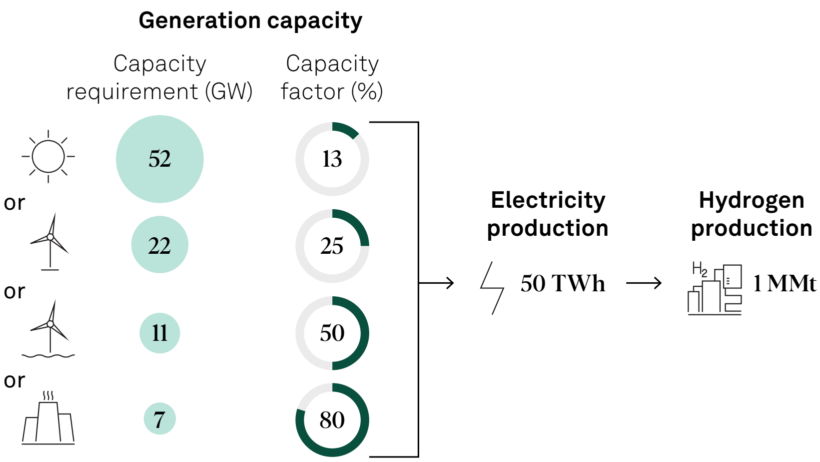
As of Jan. 5, 2024.
Source: S&P Global Commodity Insights.

Despite high costs and uncertainty around inputs, electrolysis for hydrogen manufacture is already an opportunity for decarbonizing hard-to-abate industries. The currently operating 1 GW of electrolysis capacity is likely to increase tenfold within about the next three years. As tax credits (North America), auction offers against guaranteed strike prices (Europe) and various other subsidies (Asia) take effect, the pace of additions is expected to accelerate.

Electricity requirements and planning bottlenecks

Hydrogen production from electrolysis requires large amounts of electricity (see chart). About 50 TWh of electricity are required to produce 1 million metric tons of hydrogen — equal to 5 billion cubic meters of natural gas, or about 80,000 barrels per day of oil. (The world consumes about 800 times this amount of gas each year, and about 1,200 times as much oil every day.) In Europe, for example, over 50 GW of solar power would be needed to generate the amount of electricity needed to manufacture just 1 MMt of low-carbon hydrogen from electrolysis. For nuclear power, with a higher capacity factor, 7 GW of fully operational capacity would be needed. These are big numbers — and bear in mind that a primary call on new electricity capacity in most parts of the world will be to support the direct electrification of customers' final energy uses.

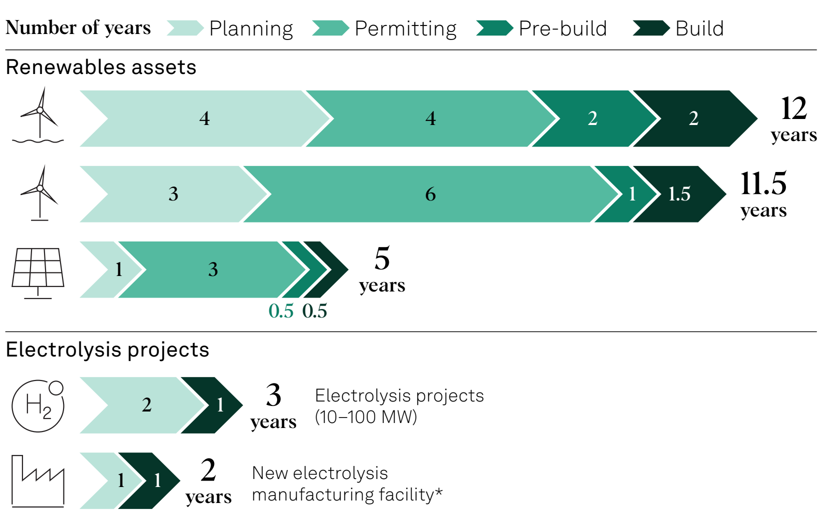
Electricity requirements for hydrogen production



Data compiled Dec. 2, 2022.
MMt = million metric ton.
Based on typical European capacity factors.
Source: S&P Global Commodity Insights.

Furthermore, for low-carbon electrolytic hydrogen to take off in the next five years, pragmatic and even aggressive approaches to planning bottlenecks will be needed. The chart below shows the typical planning lead times in Europe for wind power (offshore and onshore) and solar power. They are significantly longer than the lead times for electrolysis projects or for the construction of large electrolysis manufacturing facilities.

The planning bottleneck



Data compiled Jan. 5, 2024.
* Once heads of terms/purchase contracts are in place.
Source: S&P Global Commodity Insights.

Challenge 2: Classification, definition and harmonization

Official classifications and definitions are paramount for a technology to fit into a taxonomy, opening the door to green credentials, financing and commercialization, at the domestic and international levels. For the latter, harmonization of these classifications could become crucial to envisage a global hydrogen economy.

As a result, a further challenge we see for a future electrolysis industry is the question of "additionality." How can it be known that the dedication of a low-carbon electricity source to making hydrogen will not deprive another customer of the same low-carbon electricity? Will the "deprived" customer be obliged instead to consume high-carbon energy, such that there will be no overall reduction of emissions? What needs to be in place to ensure that new renewable capacity, dedicated to hydrogen manufacture, is in addition to the renewable electricity that is being built to decarbonize the wider use of electric energy?

Harmonized rules, or some basis for mutual recognition of standards around additionality and time stamps, will be needed for international trade to develop rapidly.

Broader issues in the development of standards are at stake as well. Huge variations in carbon intensity of hydrogen exist, depending on the production route and, in the case of electrolytic hydrogen, on the fuel mix and carbon intensity of each supplying electricity grid.

These issues — additionality and low-carbon definitions — matter a great deal to any business whose planned activities and value creation depend on a clear recognition of the low-carbon character of their product or service in multiple markets and jurisdictions. Delays in finalizing the detailed rules have already postponed some proposed projects.

Harmonized rules, or some basis for mutual recognition of standards around additionality and time stamps, will be needed for international trade to develop rapidly.

Challenge 3: Finding customers

While lower costs and harmonized reliable definitions are important, potentially the most important criterion for takeoff will be the willingness of potential customers, or "offtakers," to contract with suppliers to deliver low-carbon hydrogen.

S&P Global Commodity Insights' industry partners are signaling strongly that the focus now needs to turn to the demand side: finding reliable offtakers for low-carbon hydrogen.

Delivered costs of low-carbon hydrogen are far above alternative fuels, which means that a premium price must be asked. In countries where there are carbon markets, the dial moves toward making hydrogen from abated natural gas and away from

Which sectors in the European Union can be tempted, or obliged, to pay a low-carbon hydrogen premium?

Willingness to pay	Sector	Alternative means of meeting European consumption targets
Refuel Aviation	Aviation	Bioliquids
	Maritime – from 2034	Bioliquids
	Refinery hydrogen	No target, but can be used to meet RFNBO target, as replacing existing production potentially lower cost/risk
	Road transport	Electricity, bioliquids
	Existing industrial use: Ammonia	Imports: Unabated ammonia and ammonia from abated natural gas
ETS	New uses: Iron and steel/ power generation	No low-carbon hydrogen consumption targets; RED III includes a nonbinding renewable target only

Data compiled January 2024.
ETS = Emissions Trading System; RED III = Third Renewable Energy Directive; RFNBO = renewable fuels of nonbiological origin.
Source: S&P Global Commodity Insights.

qualifying electrolytic hydrogen as competitive. Consumption mandates and associated penalties, such as European policies around renewable fuels of nonbiological origin (RFNBOs) or Japanese rules on cofiring ammonia in power generation, move the dial further in the right direction. These policies point to the regions and sectors (in industry and transport, for example) that may become first movers. To date, it is only in Europe that a hierarchy of "willingness to pay" is emerging, and even here there is significant uncertainty around the scale of demand and the potential for RFNBOs to be displaced by biofuels or low-carbon hydrogen.

The focus on colocating potential customers from different sectors, by developing hydrogen hubs or hydrogen valleys, is sensible and welcome. Industry recognizes that it will have to play its part for the hub/valley approach and structure, as encouraged by many governments, to be successful.

The critical signpost to sustained market development will be when customers sign up for long-term offtake of low-carbon hydrogen, and with appropriate guarantees and assurances.

Looking forward

Low-carbon hydrogen and hydrogen derivatives are already a growing industry, with strong policy support and serious industry interest worldwide. But the challenges identified — cost and scale, planning bottlenecks, defining rules for what is "green," and lining up customers willing to commit to a product at a premium cost — must be solved so the low-carbon molecule can deliver its full potential in the energy transition.

Learn more

Top Ten Cleantech Trends in 2024

For more detailed analysis, read the full report:
Hydrogen: New Ambitions and Challenges

Making carbon capture, utilization and storage attractive in reaching net-zero

Carbon capture, utilization and storage is critical for decarbonizing hard-to-abate sectors responsible for almost 30% of GHG emissions. S&P Global identifies five key factors that determine the attractiveness of CCUS.

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Highlights

Consensus continues to build on the need for carbon capture, utilization and storage (CCUS) technologies to meet net-zero targets.

CCUS is key to decarbonizing hard-to-abate sectors.

Policy has driven a significant increase in the CCUS project pipeline over the past few years.

Projects under development will increase CO_2 capture capacity to almost 10 times the current operating capacity.

Despite this momentum, only 18% of these projects are in the advanced stage of development. Moreover, private capital investors have deployed little capital into CCUS compared to other clean technology investments, an indicator of the uncertainty that this technology still faces.

The CCUS industry faces several barriers to its large-scale deployment: high costs, market fragmentation, limited infrastructure or storage information, and insufficient policy support. As a result, projects need multiple vectors of revenue to improve their prospects for financing. As the need for CCUS to meet climate goals becomes clearer, many governments and private participants have been working to overcome these barriers. S&P Global has identified five key components that determine the attractiveness of CCUS for a sector or a country.

Why is CCUS important?

Net-zero pledges are expanding globally, and models[1] indicate the need for an exponential increase in carbon capture, utilization and storage (CCUS) from current capacity to reach climate goals by 2050. CCUS is critical to decarbonize the so-called "hard to abate" sectors (e.g., steel, cement, fertilizers, petrochemicals and heavy-duty transport) responsible for 30% of total global greenhouse gas emissions and for which zero-carbon electrification is not yet a feasible solution.

The current energy system relies heavily on fossil fuels, constituting about 80% of our energy needs. Any abrupt transition away from fossil fuels could lead to market disruptions and price spikes. CCUS offers a practical solution by enabling use of cleaner fossil energy supplies while new technologies are developed, thereby addressing security and affordability concerns, factors especially important to the developing world.

For investors analyzing the energy sector and concerned about the capacity to invest in fossil fuels while still meeting net-zero emissions commitments, CCUS presents a way to invest in business models they are comfortable with while adhering to emissions restrictions. Investing in CCUS projects and technologies as energy sector demand for emissions solutions increases gives fossil fuel investors an additional path to participation in the energy transition without abandoning familiar counterparties. Many investors and financiers already know the potential counterparties in CCUS markets — from oil and industrial companies to engineering services providers — and are comfortable with the relative financial simplicity of adding more infrastructure to existing revenue-producing assets.

What are the CCUS market dynamics?

Policy has been the main driver of CCUS project deployment. Most CCUS projects currently operating have benefited from policy support, and recent policy announcements have driven a significant increase in the CCUS project pipeline. Supercharged incentives (e.g., from the US Inflation Reduction Act) for carbon capture projects since 2021 have accelerated the momentum.

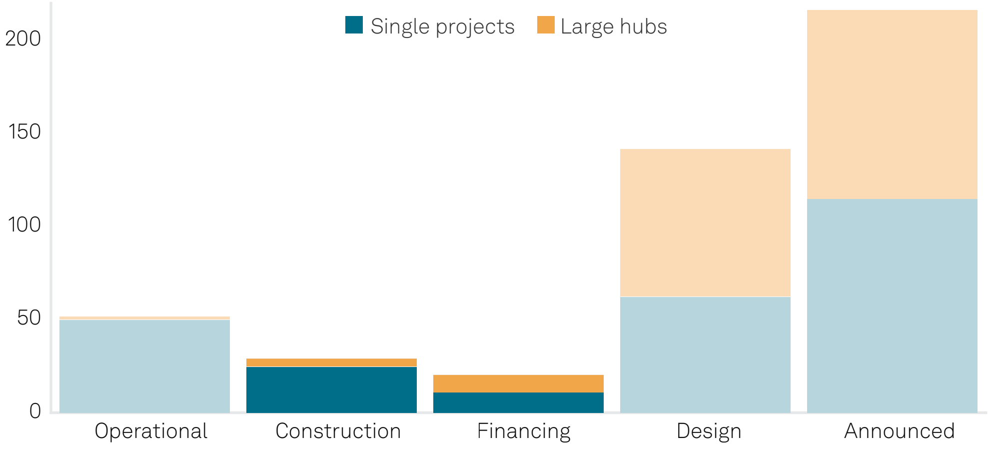
Policy has been the main driver of CCUS project deployment.

However, most of the projects in the pipeline are in the early stages and still have to overcome multiple challenges, including limited financial incentives in some regions, permitting delays, additional guidance on government support and unclear frameworks to develop infrastructure. Only 18% of the current pipeline has moved beyond the final investment decision phase, while 28% remain in the announced stage, posing questions about the robustness of the pipeline. Oil and gas companies and industrial groups are at the forefront of this wave of CCUS developments. They are driven by strong incentives to decarbonize their operations combined with the synergies between their technical expertise and the requirements to develop CCUS technologies.

[1] Models including net-zero IEA, IRENA 1.5 S, IPCC -1.5, and S&P Global ACCS. ACCS refers to Accelerated CCS Case Scenario 2023 edition.

Most projects in CCUS pipeline at early stages

CO_2 capture capacity (million t/y)



Data compiled January 2024.
CCUS = carbon capture, utilization and storage.
Source: S&P Global Commodity Insights.

At the same time, returns-oriented investors are cautious about policymakers' commitment to CCUS amid the rapid deployment of alternative technologies. Despite dominating cleantech investing, private capital investors in the US have allocated minimal funds to CCUS. In the year following the US Inflation Reduction Act, private capital firms invested only $7 billion in CCUS, significantly less than the $100 billion directed toward renewable power projects in the same period.

Investors in CCUS have a few potentially profitable entry and exit points in the coming decade, during which a record number of CCUS projects are likely to reach operation — albeit too few to impact the needed reductions in emissions for net-zero purposes. A technological leap could make early capital commitments to CCUS a winning bet, even as the sector still struggles to find its financial model today.

What makes a market attractive for CCUS?

Evaluating the attractiveness of a CCUS project is not a simple task, unlike other technologies for which the market and the operational requirements are clear. For CCUS, these metrics vary significantly based on the application.

In the past, this technology has encountered several barriers to mass development:

- High costs
- Market fragmentation, as the value proposition of this technology varies by industry
- No infrastructure or storage information
- Lack of policy frameworks

As the need for CCUS to meet climate goals becomes clearer, multiple governments and private players have been working to overcome these barriers to increase its attractiveness.

S&P Global has identified five key factors that play a critical role in determining the attractiveness of CCUS in a country or sector:

- Policy and regulation
- Quality and quantity of emission profiles to create demand
- Information about the availability of CO_2 storage
- Cost outlook
- Ease of doing business

Policy and regulation

Policy is a key enabler of CCUS, and policymakers are removing barriers to CCUS development with measures to improve affordability and clarify demand, standardization, infrastructure development and CO_2 storage availability. Identifying regions with a comprehensive policy and regulatory framework for CCUS will increase the attractiveness for investors.

Building demand and improving affordability: Tax credits, emission trading systems and clear carbon management strategies are providing increasing certainty around demand trajectories for CCUS.

Defining standards: Worldwide, definitions are being published for low-carbon or clean investments. Clarity on carbon intensity goals helps to identify the attractiveness of CCUS projects.

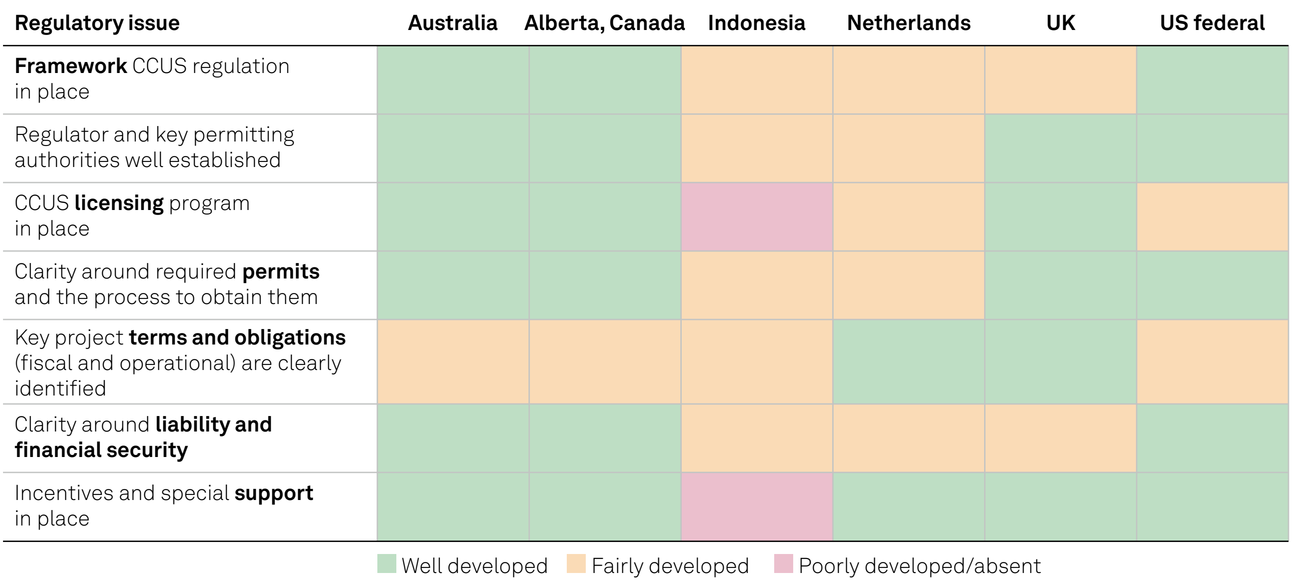
Developing infrastructure and storage availability: Frameworks for the transportation of CO_2 are being developed, and the availability of CO_2 storage information is improving.

Defining key regulatory areas to provide certainty to investors: Many countries have passed CCUS-specific rules offering clarity around areas such as pore space ownership, permitting processes and liability issues (see chart).

Emission profiles

Total available CO_2 emissions and concentration of CO_2 in emission streams by industrial sectors are critical in determining the attractiveness of CCUS as an abatement strategy. The scale of CO_2 emissions affects the volume of available capturable emissions, and their purity and concentration in emission streams affect the ease of capture.

CCUS regulation in key jurisdictions around the world



Data compiled Feb. 12, 2024.
CCUS = carbon capture, utilization and storage.
Source: S&P Global Commodity Insights.

Together, the two factors play a significant role in overall capture technology selection and cost estimates for a CCUS project. The emitting plant's age is also key to the feasibility of CCUS. Therefore, to assess the attractiveness of CCUS for a country, it is important to estimate emissions from various industrial sectors that contribute to the country's total CO_2 emissions, concentration levels in streams and the average facility age. A sector-level score based on these factors can create a ranking of CCUS attractiveness for each sector. A weighted average score of various sectors in the country can then help determine a score for CCUS attractiveness for the country based on emission profiles.

Availability of CO_2 storage

Identifying regions of the world most suitable for permanent underground storage of CO_2 requires a deep understanding of the geological characteristics of target basins. Considering such subsurface factors in combination allows project developers to then "score" a basin's CCUS attractiveness, which in turn can be applied to optimally match emitters with potential storage locations.

This analysis involves first identifying subsurface characteristics that have the greatest influence on a basin's capacity to safely store CO_2 for the long term and then assigning them with an appropriate weighting. Such factors are categorized by the following:

Geological setting: A basin's overall structure — its extent, sedimentary thickness, porosity, number of reservoirs and sealing layers — helps to assess its storage capacity and integrity. Injectivity is determined in part by geothermal gradient (with higher temperatures less desirable owing to increased buoyancy) and in part by reservoir depth (with a sweet spot between the ability to store CO_2 in a supercritical state and avoiding excessive overburden pressures that reduce permeability). Finally, local stress regimes dictate the long-term seismic stability of storage sites.

Operating environment: Onshore storage sites are typically favored over offshore (and especially deepwater) sites owing to lower development costs. Additionally, while mature basins that have undergone extensive oil and gas development often yield more robust subsurface data, they also tend to have more well penetrations (i.e., potential CO_2 leak pathways) that must be managed.

Understanding these factors and their relative weightings is one thing; securing the necessary data to perform the analysis is quite another. Drawing from extensive subsurface data sets from S&P Global Commodity Insights, we have developed a high-level screening tool that allows developers to score the CCUS attractiveness of over 2,750 global basins. Plotted in map form (see map), the tool offers a quick look at the most attractive CO_2 storage locations around the world and helps to advance industrial decarbonization efforts.

Cost outlook

Costs for every component of the CCUS value chain vary greatly across industries and regions based on the purity of the CO_2 stream, capture technology, plant size, process design, plant utilization, location, type of transportation, type of storage and cost of capital. As a result, a large range of costs associated with CCUS can be represented through the levelized cost of CO_2 avoided (LCCA).[2]

Unlike renewable energy projects, large-scale carbon capture and storage projects have demonstrated minimal unit standardization or cost compression; however, as projects are being deployed, three key levers for CCUS cost reduction are identified:

CO_2 capture technology innovation: Research and development of new capture technologies could help to reduce costs and improve efficiency.

Carbon capture storage hubs: Hubs could significantly reduce the unit cost of CO_2 transportation and storage through economies of scale.

Learning by doing: Engineering and planning costs should decline as companies become more experienced in building CCUS at scale.

Understanding how these levers will accelerate cost reduction, and their implications under current policy incentives, will help rank the countries with the most promising economic landscape for this technology.

[2] This metric assesses the CO_2 capture system as a carbon mitigation option; it considers capital costs, operating costs of the system and the additional CO_2 emissions as a result of operating the capture system.

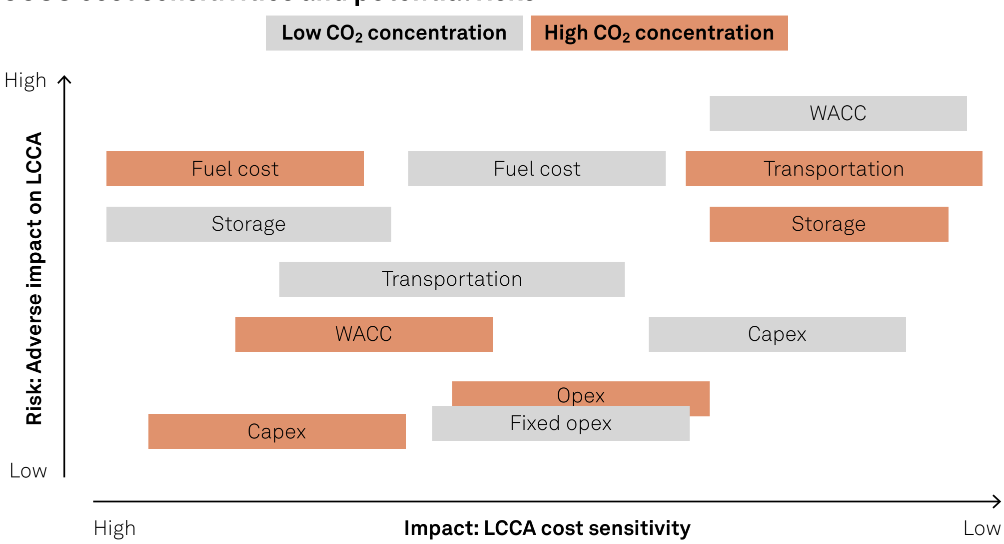
Ease of doing business

Based on S&P Global analysis, countries have been ranked on six broad nontechnical factors to analyze the ease of starting and operating a CCUS project in the country. These are general factors in many cases, but we also look at the CCUS-specific drivers in each category.

CCUS attractiveness ranker

Sources: S&P Global Commodity Insights upstream E&P content (EDIN); World Topographical Map: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, Geobase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, Esri China (Hong Kong) (c), OpenStreetMap contributors and the GIS user community. Hillshade: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N. Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.

CCUS cost sensitivities and potential risks



Data compiled Feb. 12, 2024.
CCUS = carbon capture, utilization and storage; LCCA = levelized cost of CO_2 avoided; WACC = weighted average cost of capital.
Source: S&P Global Commodity Insights.

Political: The prevailing political structure and stability of the government are assessed with an eye toward the risk of institutional failure in the country.

Economic: The current and projected macroeconomic trends in the country; risk of sovereign default and the broader economic climate.

Legal: Risk of expropriation and sanctity of contract; ease of permitting.

Tax: Tax structure and stability; state of regulatory framework to incentivize CCUS deployment.

Operational: Labor availability and issues; infrastructure disruption.

Security: Risk of protests and riots, terrorism, civil war, and interstate wars.[3]

Looking forward: The proliferation of carbon management strategies

The recent announcement of the Canadian and European carbon management strategies with clear CO_2 capture volumes is about to change the market.

Regions with carbon management strategies will provide a clear demand signal for the CCUS market, increasing the perceived attractiveness for technology development in these regions. Clear requirements of CO_2 capture will lead to reducing risk for projects underway and provide clarity on the volumes the market could expect from strategies with aggressive CO_2 targets. Those with aggressive targets could, through economies of scale, see cost reductions sooner. The proliferation of carbon management strategies could be the demand signal the industry needs to start a policy-deployment cost reduction cycle.

Learn more

[CCUS – Too Little, Too Late, Too Slow – It's No Panacea]

[Levelized Cost of CO2 Avoided (LCCA) for CCUS Projects]

[Carbon capture, utilization and storage (CCUS) is the technology with the highest mitigation potential to decarbonize the cement industry]

Risk scores by selected countries

Geography	Post 1 year outlook	Overall	Political	Economic	Legal	Tax	Operation	Security
China	→	1.8	2.0 →	1.4 →	2.2 →	2.0 ↗	2.4 →	1.7 →
US	→	1.6	1.5 →	0.8 →	1.2 →	1.5 →	1.6 ↗	2.2 ↗
Australia	→	1.3	1.5 →	1.2 →	1.1 →	1.6 ↗	1.3 →	1.2 →
Brazil	→	2.4	2.0 ↗	2.0 ↘	1.9 →	2.9 ↗	3.0 →	1.8 ↗
Indonesia	→	2.2	1.9 →	2.0 →	2.3 →	1.9 →	2.7 →	2.4 ↗

Low risk High risk

Data compiled Feb. 12, 2024.
Arrows for each risk category capture whether we expect the risk level to rise, fall or remain level following that 12-month period.

[3] Outlook arrows for each risk category capture whether we expect the risk level to rise, fall or remain level following that 12-month period.

A tale of two carbon markets

In 2024, we expect carbon compliance expansion alongside reflection on the voluntary carbon market.

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This year will see the continuation of a tale of two carbon markets — compliance and voluntary — facing rather different dynamics. After a few years of strong growth, the voluntary carbon market in 2023 hit a crisis of confidence, driven by media scrutiny, which challenged the quality and veracity of underlying reductions in carbon emissions. This has raised questions about the supply of viable credits, even as increasing numbers of companies are making low-carbon commitments and considering carbon markets as a tool to achieve their goals. A lack of progress on international carbon market negotiations at the COP28 climate conference meant no silver-bullet solution to bolstering market clarity, at least for another year, passing the responsibility back to stakeholder initiatives and governments. Amid this uncertainty in the voluntary carbon market, carbon compliance markets have continued to expand, with a number of high-emitting and fast-growing countries laying the groundwork for implementation. What remains to be seen is the degree to which these different markets can interact and how they can incorporate project-based reduction efforts, the hallmark of the voluntary carbon market, into their designs.

Highlights

COP28 failed to deliver expected progress on Article 6 of the Paris Agreement on climate change, which sets out the principles for international carbon markets.

Consequently, the voluntary carbon market is regrouping around the question of quality, which affects issuance, retirements and price trends.

Simultaneously, national carbon compliance programs are expanding around the globe.

In time, these two markets may converge — particularly if there is agreement on Article 6 at COP29.

After COP28: The market regroups

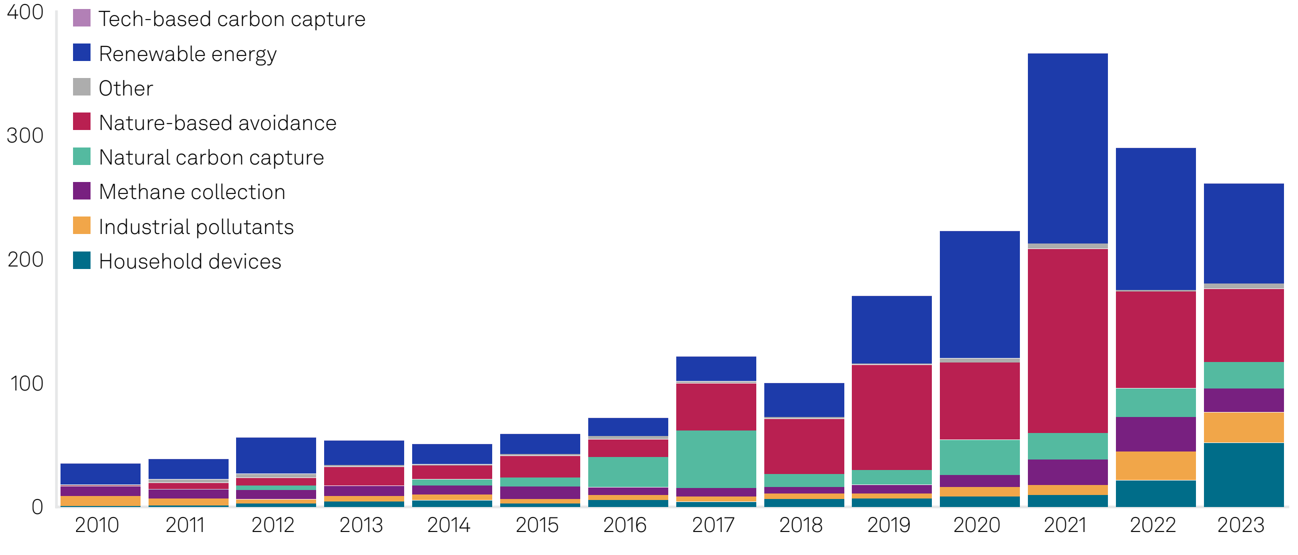
Many project developers were looking for firm decisions at COP28 on Article 6 of the Paris Agreement. In particular, they wanted quality benchmarks to be established to mitigate the negative impacts of integrity challenges that have hit the market in the past year. With these decisions pushed back until COP29, other efforts to bolster confidence in the voluntary carbon market (VCM) have taken center stage. Several initiatives were announced at COP28 in support of the VCM: Six of the main integrity and reporting initiatives in the market will look to provide an end-to-end quality integrity framework to deliver coherent guidance on decarbonization, and six crediting programs will collaborate to increase the impact of carbon markets as mitigation instruments. Financial regulators have also issued guidance and consultations on the VCM. Heightened attention from financial regulators, national governments, and independent standards and initiatives could represent the beginning of a new phase of increased maturity for the VCM.

Shifting supply and record demand

Focusing on the VCM, credit issuances from the four main registries — Verra, Gold Standard, the American Carbon Registry and the Climate Action Reserve — reached a total of 66 million metric tons of CO_2 equivalent in the fourth quarter of 2023, up strongly from the third quarter but down 28% year over year. Project developers limited supply amid low prices across most credit categories, and the negotiations at COP28 failed to deliver guidance on methodologies. Total 2023 supply volumes reached 261 $MMtCO_2e$, 10% below 2022 levels and 29% down from 2021 (see chart). Credits from the nature-based avoidance category, the main target of negative press over 2023, fell 25% year over year to 59 $MMtCO_2e$, while credits from the renewable energy category dropped 30% year over year to 81 $MMtCO_2e$. Household devices and industrial pollutants were the only categories that showed credit increases year over year. While the VCM is often presented as an instrument to channel climate finance to less-developed countries, its top credit issuer in 2023 was the US, followed by India and China, respectively.

2023 voluntary carbon markets issuances total 261 $MMtCO_2e$, down 10% from 2022 levels

Credit issuance by project type ($MMtCO_2e$)

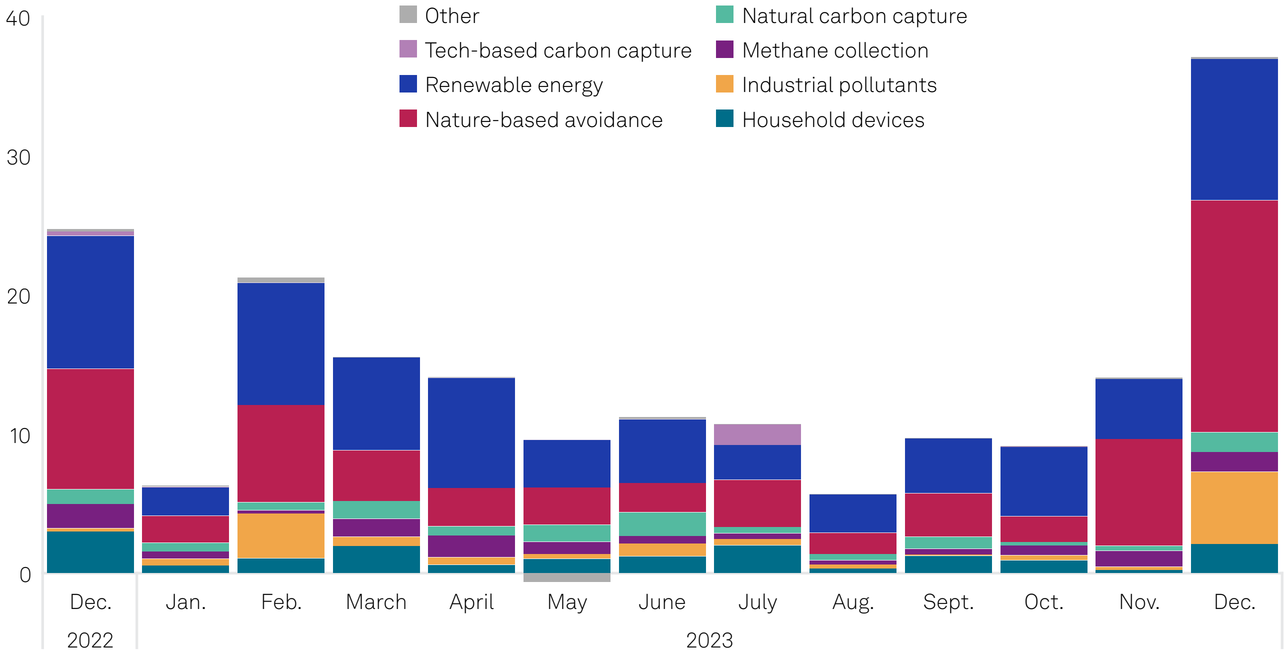


Data compiled Feb. 6, 2024.
$MMtCO_2e$ = million metric tons of carbon dioxide equivalent.
"Other" credits mostly include industrial energy efficiency and fuel switch.
Sources: Verra; Gold Standard; ACR; Climate Action Registry.

Surprising many, VCM credit demand reached more than 60 $MMtCO_2e$ across the four main registries in the fourth quarter of 2023, boosted by December volumes amounting to 37 $MMtCO_2e$ retired, the highest retirement levels ever recorded in any month in the VCM (see chart). Considering that most controversies over the past year were associated with nature-based avoidance efforts related to deforestation projects, it is worth noting that retirements of these projects represented 30% of final 2023 demand. Market participants were potentially being mindful of the various integrity initiatives on the horizon.

December retirements spike to all-time monthly high of 37 $MMtCO_2e$

Credit retirements by project type ($MMtCO_2e$)



Data compiled Feb. 6, 2024.
$MMtCO_2e$ = million metric tons of carbon dioxide equivalent.
"Other" credits mostly include industrial energy efficiency and fuel switch.
Sources: Verra; Gold Standard; ACR; Climate Action Registry.

Diverging price drivers

As a result of the changing landscape the VCM faces, new price drivers are emerging in 2024.

Prices for credits from project types or methodologies that are seen as less rigorous will continue to come under pressure in 2024. In contrast, those from project types or methodologies offering negative emissions by clearly reducing the amount of carbon in the atmosphere will be seen as premium credits.

Nature-based avoidance credit prices, which hit a record low in December 2023, have fallen further in 2024. Credibility and integrity concerns around whether a credit really represents the carbon it claims to avoid are the main reasons for weak demand across the REDD+[1] sector. Platts assessed nature-based avoidance prices to be 81% lower on Jan. 25, 2024, at \$3.05/ tCO_2e compared with the same day in 2023, before the controversy surrounding these credits was first reported in the mainstream media.

[1] "REDD" stands for reducing emissions from deforestation and forest degradation in developing countries. The "+" stands for additional forest-related activities that protect the climate.

Credits that point to greater climate ambitions are likely to continue to fetch more money. Similarly, credits from methodologies with emissions reductions that are easier to verify/measure and predict are enjoying greater demand and higher prices. As a result, technology-based removal credits, such as those generated by carbon capture utilization and storage (CCUS) projects, are attracting growing interest from companies and policymakers as they offer the promise of more easily quantifiable climate action. In 2023, we saw a notable uptick in demand for bioenergy via CCUS projects, with credits due to be issued and delivered in 2026 already being heard in the range of \$200-\$350/tCO_2e in 2023. That trend is expected to continue in 2024.

The VCM will also reorientate around new and emerging signifiers of perceived quality guarantees until the opportunity to advance Article 6 again at COP29. In practice, this means prices for credits that secure a corresponding adjustment (CA) are already rising above those that lack these assurances, even where credits arise from the same project type.[1] If a credit has a CA, this translates into a greater sovereign guarantee that the credit will be accepted in a future Article 6 market and across different jurisdictions, thus reducing the risk for the buyer.

As of the start of 2024, airlines need to purchase credits with a vintage of 2021–2026 and a CA to comply with the first (voluntary) phase of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a program designed to reduce emissions in the aviation industry. Airlines will have until 2028 to retire credits to comply with first-phase requirements.

The value of a CA is already affecting interest and prices of credits today. As noted above, phase one of the CORSIA scheme kicked off at the start of 2024, and now a credit needs to be paired with a CA to be eligible for usage. As a result, household devices credits with the promise of receiving a CA from a host country started trading at a premium to the same types of credits that lacked one. For instance, cookstove credits with a CA were at a \$5-\$10/tCO_2e premium versus equivalent cookstove credits without a CA in January 2024. Similarly, a lack of clarity around implementing CA rules in India and Turkey — key countries supplying renewable energy carbon credits — has meant renewable energy carbon credits, which are from project types eligible for CORSIA first-phase compliance, have not seen CA-related premiums in 2024.

The market is also looking to independent governance bodies such as the Integrity Council for Voluntary Carbon Markets (ICVCM) to set standards or labels to provide a seal of approval to credits verified as high quality. The ICVCM has drafted core carbon principles labels, which are expected to attach a premium to any credit that receives one. Credibility will be key for such labels, as will endorsement by other credible actors such as the Gold Standard.

All of this means that price differentials in the market will provide buyers and sellers with additional transparency and optionality in 2024. Market participants want a granular view of value, and geography, project type or perceived methodological risks all translate into measurable price differences. Many different premiums and discounts are part of a constellation of project type (nature-based versus technology-based), perceived climate action (avoidance versus removal), regulator status and perceived sovereign risk (CA) or geography. Increasingly, the market is focused on the most fungible of the most competitive credits.

Compliance market upswing

Amid this uncertainty in the VCM, the carbon compliance market — where governments impose requirements to achieve reductions and set a price on carbon — has continued to expand. Our modeling of emissions scenarios underscores the findings of the global stocktake at COP28: Countries' emissions-reduction commitments (as noted in their nationally determined contributions) and their efforts to meet them are falling well short of what is needed to limit global warming to 1.5 degrees C. Nations in both the developing and the developed world are increasingly activating plans to use carbon pricing and markets to help achieve these reductions in more efficient and less expensive ways.

In 2023, several of the largest and fastest-growing countries — India, Brazil and Turkey among them — took clear steps to design and implement new national carbon markets. Indonesia launched a

[1] A CA is a carbon-accounting mechanism that avoids double counting emissions when credits are transferred from one country to another and used toward nationally determined contributions or climate pledges.

market targeting coal-fired emissions in the power sector. Other countries in Latin America, Asia and Africa are in the early stages of exploring carbon market options. If these countries were to follow the historic carbon-intensive path of advanced economies, global emissions would shoot well above target limits. Many are also considering the role of project-based credits in their compliance market designs, potentially affecting efforts historically covered by the VCM. The boundaries of these two markets will grow increasingly blurry.

More developed economies are also propelling carbon markets, either through policy-making that increases stringency (the EU, California, New Zealand and Australia) or through brand-new markets and jurisdictions (Canada, Washington state and New York). Europe has also taken clear steps to internationalize its carbon pricing by implementing the Carbon Border Adjustment Mechanism and including maritime emissions in the EU Emissions Trading Scheme. These actions mean that Europe's many trade partners are being exposed to relatively high EU Emissions Trading Scheme prices. In addition, as the CORSIA program is being phased in, another swath of key countries is slated to be covered in 2027 — even though the supply of necessary carbon credits is limited and sustainable aviation fuel solutions face feedstock constraints and will take time to ramp up.

Looking forward

While COP28 disappointed in terms of offering clarity on Article 6, stakeholders — including the Article 6.4 Supervisory Body — are continuing their work to build up capacity and operationalize the carbon crediting mechanism. Additional guidance and recommendations will provide more grounding for an agreement to be reached at COP29 in Baku, Azerbaijan.

Learn more

INTERVIEW: Voluntary carbon market on cusp of gradual comeback: VCMI's Kenber

Shipping firms enter EU ETS at market trough; admin backlogs expected

Compliance market fungibility bolstering VCM confidence: Viridios AI

EU agrees carbon removals certification framework

Commodities 2024: China's domestic carbon market set for revamp; Article 6 in limbo

Energizing innovation: Exploring AI's impact on the energy industry

Energy companies are embracing advances in AI as they navigate the opportunities and challenges of the energy transition.

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Outsized investor appetite for evidence of AI in company strategies will continue to give energy companies financial incentives to embrace this emerging technology in their operations. But there is mixed evidence that individual operators will be able to deploy the technology in a breakout way that redefines the industry, even as almost every role and responsibility within energy companies is remade by AI.

Gauging a surge in AI investment

A breakout in public company valuation and private company investment for business strategies linked to AI is creating broad incentives for energy market participants to rework their operations around AI implementation.

The appeal of technology additions as a productivity enhancer for existing revenue models and as a growth category for emerging revenue models is familiar to energy investors and energy company leadership. In an era where technology companies are disproportionately

Highlights

Energy companies are poised to be early leaders in leveraging recent advancements in AI, a natural evolution for an industry rooted in data, analytics, engineering and complex processes.

Energy transition dynamics may incentivize, or even require, companies to test and use AI approaches to manage the increased complexity created by more renewable generation in the energy mix and accelerating technology and regulatory developments.

Many companies have already made rapid strides, establishing dedicated data science groups and leveraging machine learning. One of the main targets for AI to date has been boosting operating efficiencies, with S&P Global Commodity Insights documenting performance improvements in the 10%-25% range.

attracting capital, it can be difficult to remember that energy and industrials companies are also fundamentally technology driven. The origins of the modern energy sector in high-grade engineering, in repeatable processes underlying value extraction and in constant technological advancement mean the industry is primed to implement and leverage AI strategies.

The financial appeal in recasting businesses as AI-enabled is clear. While the eye-popping quintupling of chipmaker Nvidia Corp.'s valuation has attracted the most media attention, every business model closely tied to AI implementation has received a valuation premium from investors in a manner consistent enough to redefine company operator incentives. Valuations for AI-exposed businesses are consistently higher than similar businesses without AI market exposure (see chart).

AI is often too loosely defined and, for a technology perceived as "changing everything," can be too loosely applied in businesses. The momentous release of a public large language model by Open AI in early 2023 highlighted the capabilities of AI in several professions. However, LLMs and the generative AI features that make these tools so impressive for human users have limited immediate applications for the energy sector overall, regardless of how much they could transform individual roles and workflows.

Fitting AI capabilities to energy needs

Investor enthusiasm for AI will continue to pull company leadership and market attention toward implementing generative AI — including LLMs — in almost any function. However, the more "traditional" AI advancements in applying machine learning and expert systems to physical and market infrastructure are what could revolutionize energy companies.

The need for computer-assisted mechanisms and processes in energy markets to handle high levels of complexity on behalf of human decision-makers

Resurgent investor enthusiasm for AI keeps tech appealing for energy operators

Change in price (%)

As of Feb. 6, 2024.
ETF = exchange-traded fund.
Cumulative year-over-year price change for Invesco AI and Next Gen Software ETF and Invesco S&P 500 Equal Weight Energy ETF.
Source: S&P Global Market Intelligence.

will become particularly acute as the energy transition proceeds. Key components of the energy transition impose additional potential for volatility, with more intermittent renewable energy on grids, more changes to market-setting regulations, and increased sensitivity regarding the security and reliability of energy supply.

In the design and rollout of new products — particularly high-tech and often digitally coordinated energy infrastructure such as large-scale batteries — the role of AI in everything from initial design conception to timing of daily charging operations is increasingly assumed as underway by investors. This means project developers, project financiers and energy company operators need to be ready to explain AI deployment trade-offs and decisions.

Many of these AI advancements will not necessarily entail the kind of generative, self-originated processes that have so surprised the business world with the launch and rapid uptake of ChatGPT and other LLMs. Generative AI is, in many ways, not as much of a leap in functionality as an acceleration in the application of existing systems for managing large data. These developments were expressed first through expert systems and then via machine learning and data science, and they were adopted by energy companies and investors without significant disruption.

In many cases, applications of AI in the energy sector — from improved battery-life performance and better oil refinery design to more targeted energy market financial hedging — will be inputs in other energy market functions rather than a wholesale replacement of an activity currently done by humans.

As an operational matter, the need to leverage AI to stay competitive will almost certainly accelerate the trend of enhanced digital monitoring and "digital twinning" of physical energy assets. The deployment of monitoring devices on physical infrastructure allows for the creation of so-called digital twins to real-world assets, letting engineers and operators monitor and control those assets remotely, as well as permitting digital experimentation that would be too costly or dangerous with a physical energy asset. This will transform physical jobs such as inspecting and maintaining infrastructure into increasingly digitally interfaced and office-based jobs.

Energy companies have been working for years to better integrate digital networks and the resulting data insights into their operations, with mixed results. As firms evaluate ways to more actively deploy capital expenditure against AI strategies and to garner investor attention amid the broader AI revolution, energy companies are following a handful of strategies to incorporate AI into their businesses.

Building on AI progress at energy companies

Data-driven approaches to improving the efficiency and outcomes of analyses are nothing new to energy professionals, particularly individuals with high exposure to large data sets. What has changed over the past decade-plus, however, is the establishment of formal groups to advance overall company capabilities in this rapidly evolving technology area. These dedicated groups are proving invaluable in accelerating the uptake of AI solutions across their organizations, with the aim of moving the needle on overall corporate performance. They also serve as a natural landing spot for the generative AI concepts (and whatever might come next) that offer such great promise.

This centralization of AI efforts is allowing energy companies to take a more structured approach to building data science capability, including via the following:

- Establishing formal relationships with a diverse set of partners (e.g., computing infrastructure providers, platform vendors and technology startups) that augment internal capabilities and bring in new ideas from outside the industry.

- Assessing build versus buy criteria and decisions and establishing related intellectual property protection protocols.

- Positioning AI resources optimally within the organization to ensure effective engagement with the business during solution development, which in turn leads to greater workforce acceptance of the resulting products.

Perhaps the most important responsibility of these groups is developing a prioritized portfolio of solutions that best meet companies' needs — delivering near-term "wins" that build momentum for the technology while also pursuing higher-risk opportunities that can transform the business. Activities tend to fall into three broad buckets:

- **Improving efficiency.** AI in energy received a big boost during the oil price downturn of 2014–2015 that prompted struggling unconventional operators to be among the first to launch formal data science programs, targeting lower well costs and higher productivities. The concepts these programs pursued — applying AI algorithms to learn and automate repetitive tasks, to predict and avert equipment failures, to optimize supply chain and logistics networks, and to assist in other efficiency-boosting activities — are spreading rapidly. Deployed effectively, S&P Global documents operational performance improvements in the 10%-25% range.

- **Managing large and complex systems.** The expanding energy value chains of the energy transition (e.g., renewables-heavy power grids and green hydrogen networks) are proving difficult to manage and optimize using traditional means. Applying AI solutions in conjunction with other digital concepts (e.g., digital twins) allows operators to calculate and then autonomously implement optimal configurations, driving further efficiency improvements and capacity expansions.

- **Accelerating the innovation cycle.** High costs are impeding the uptake of certain clean energy technology segments (e.g., carbon capture, utilization and storage, and small modular nuclear reactors) and therefore creating the imperative to reduce the learning curve more quickly in future projects. AI can quickly identify suboptimal design features once plants are operational and rectify them in the next project iteration. Additionally, a machine learning-enabled, drug discovery-like approach can speed the search for new materials to advance the energy transition, such as higher-efficiency carbon capture materials.

Looking forward

The energy sector continues to seek the right approach to exploiting AI capabilities within its businesses, balancing centralization with innovation at the edges, open innovation with proprietary technology development, and incremental gains with game-changing solutions. Companies that established formal data science groups and that are actively engaging external partners ahead of the curve appear to be getting it right, as these are the businesses that identified generative AI's potential during its early stages and have been running agents for several years. Those with less structured approaches have only recently begun to identify use cases and are now working with their legal and IT organizations to gain approval to proceed with pilots. These strategies will continue to unfold in the coming years.

Learn more

The AI Governance Challenge

Can generative AI create a productivity boom?

Making Sense of Artificial Intelligence

Artificial Intelligence in Automotives

The materials transition: Ensuring we build with low-carbon materials

Everything is made from something. How do we minimize the emissions associated with the materials we use every day?

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The circular economy accounts for a small fraction of plastics supply, principally via mechanical recycling. Although the production of recycled pellets will more than double in the next 10 years, the underlying demand growth for polymers is such that virgin resin demand will continue to grow. We are nowhere near reaching "peak polymer." The bottleneck is the development of capacity to collect, clean and sort waste; these plants are small compared with a world-scale virgin polymer plant.

What is the materials transition?

The path to net-zero will require all parts of the economy to decarbonize, key elements of which are the building blocks we use for construction, manufactured goods, automotive production, packaging and even the textiles for the clothes we wear. Whether steel, aluminum, concrete, glass, paper or plastic, industries must invest in new technologies to reduce the greenhouse gas emissions

Highlights

The materials transition comprises the decarbonization of materials production, the reduction and reuse of waste through the creation of a circular economy, and the substitution of materials to use those with the lowest carbon intensity.

The consumption of materials will continue to grow alongside population and GDP. Choosing the right mix of low-carbon materials will be key to the energy transition.

Plastics are versatile materials with low energy intensity — and a bad rap. They are essential to the energy transition as construction materials for wind and solar power and for lightweighting in the transportation industry. They also have the potential to substitute products that have higher energy intensity such as metals.

Plastic waste is, however, a significant challenge, and future legislation to control plastic pollution is highly likely.

produced in their manufacture. Material waste must be eliminated, and reuse must be promoted by creating a circular economy. Where the material performance envelope allows, products should be designed and manufactured using materials with the lowest carbon intensity possible. Collectively, the materials transition is the combination of reducing GHG intensity when producing materials, decreasing waste and creating a more circular economy, and substituting materials with those with the lowest carbon intensity.

Plastics are indispensable

The chemical industry now finds itself in a world that frowns on its main product: carbon. Thermoplastic polymers and resins are sequestered carbon. Although plastics are an indispensable part of virtually every aspect of life, much of their utility is generally overlooked, including the following:

- Their role in keeping food fresh, therefore reducing waste in agricultural supply chains
- Their role in lightweighting in the transportation industry for improved fuel efficiency
- Their use as essential components of wind turbines and solar panels to decarbonize power generation
- Their use in clothing in the form of polyester, nylon and acrylic fibers

The COVID-19 pandemic highlighted the essential role of plastics in the healthcare industry, but generally plastics are losing the public relations war. Plastics have lower energy intensity than just about every competing material, but the problem is not plastic in itself; it is what we do with it. The world has a litter problem, with inadequate systems to collect and process waste, which has led to a very visible plastic pollution problem.

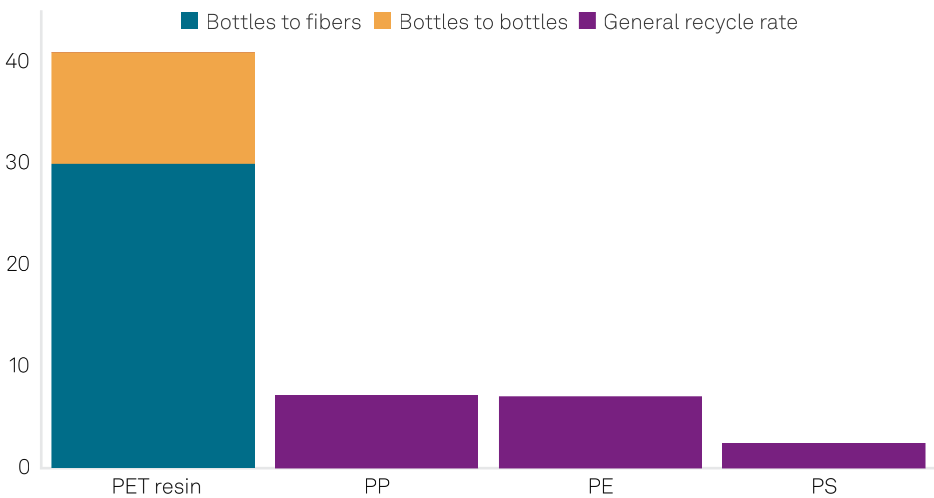
Circular carbon economy is in its infancy

The circular plastics economy is still “under construction.” A mechanical recycling industry is developing, but recycled plastic pellets still account for a small part of polymer demand. The most recycled polymer is PET[1] bottle resin. A PET bottle is easily recognized and separated from the rest of the household waste by the consumer, with producers sponsoring bottle-collection schemes and incentives, such as using schools as collection points. Approximately 11% of PET is reused in bottle manufacture; a further 30% is downcycled to (chemically identical) polyester fiber use.

The recycle rate of other polymers is significantly lower. Recycled polyethylene (PE) accounts for about 7% of total demand. S&P Global Commodity Insights forecasts that the volume of recycled PE will more than double over the next 10 years, but this will still account for less than 10% of supply, given the underlying demand growth. There are regional variations: Europe has the highest recycle rates, whereas in some emerging economies, the recycle rate is still close to zero. High-density PE has more use in durable applications and has a higher recycle rate than low-density and linear low-density PE, which are used more in film applications.

Mechanically recycled polymers as a percentage of total supply in 2023

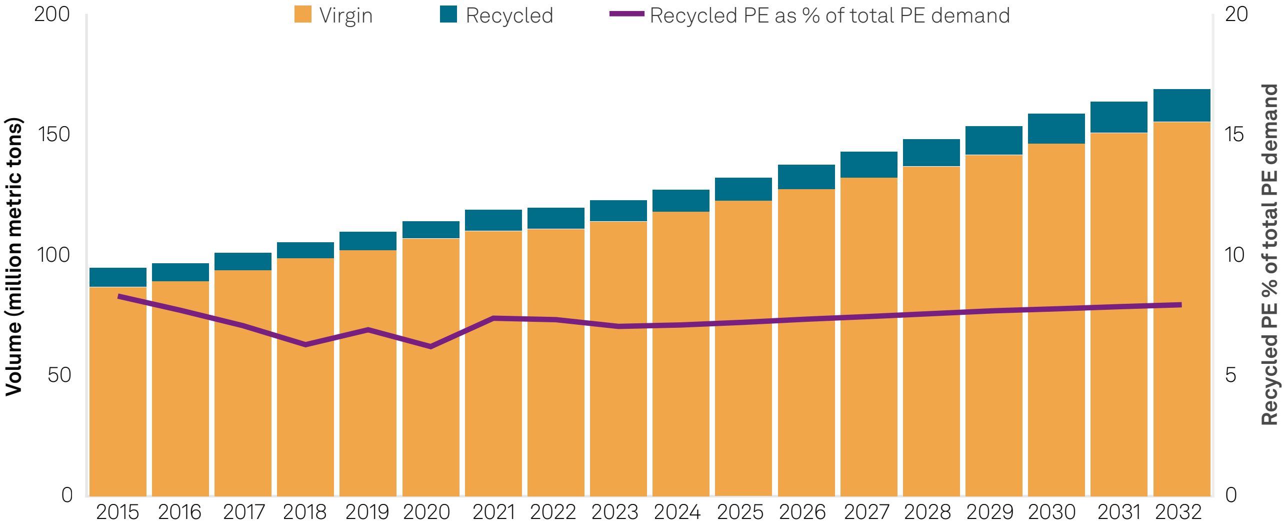
Mechanical recycling (%)



Data compiled Jan. 31, 2024.
PET = polyethylene terephthalate; PP = polypropylene; PE = polyethylene; and PS = polystyrene.
Source: S&P Global Commodity Insights.

[1] Polyethylene terephthalate (PET) is a type of clear, durable and versatile plastic.

Global virgin and recycled PE demand estimates

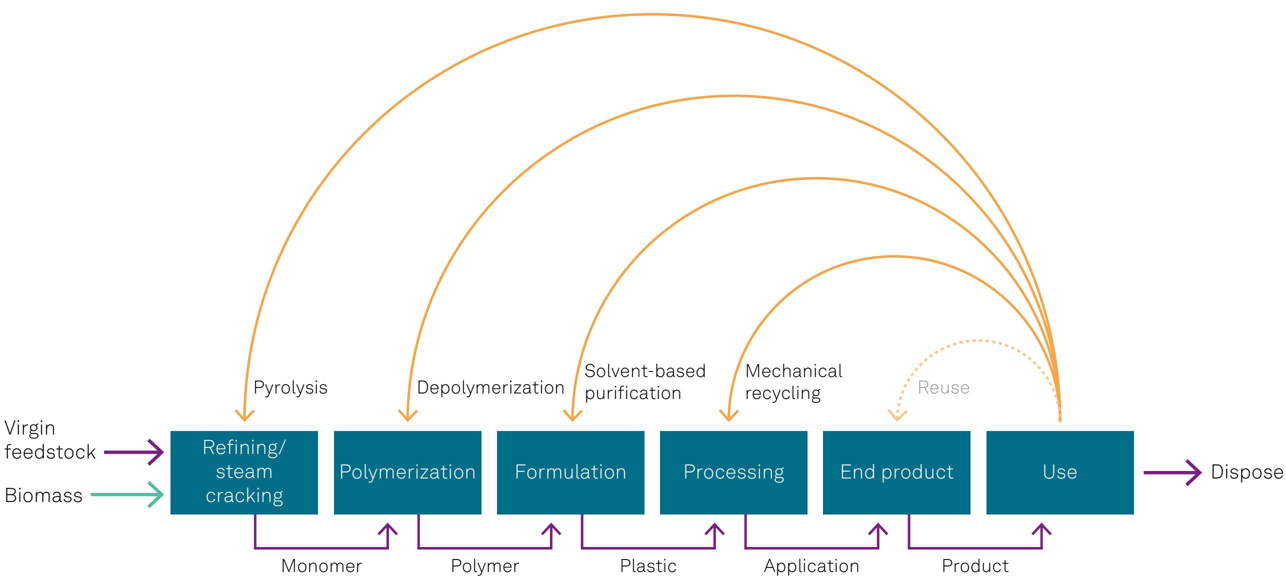


Data compiled Dec. 1, 2023.
PE = polyethylene.
Source: S&P Global Commodity Insights.

Applying a similar analysis across the full suite of commodity thermoplastics, we do not forecast "peak polymer," or a peak in virgin polymer demand, between now and 2050.

Other recycling technologies are also in development. "Advanced" or "chemical" recycling involves turning waste plastic into a hydrocarbon feedstock such as pyrolysis oil, suitable for feedback back into a chemical plant. These technologies can handle a wider slate of polymers as feedstock, requiring less sorting. The first units in operation have a capacity of 30,000-50,000 metric tons per year; units with 300,000-500,000 metric tons of capacity are expected to be developed over the next 10 years. For comparison, a world-scale steam cracker will process up to 5 million metric tons of naphtha per year. Advanced recycling is still

The plastics circularity ecosystem



As of Feb. 26, 2024.
Source: S&P Global Commodity Insights.

not at a scale to impact the petrochemical industry feedstock balance.

Whatever the recycle technology, a major bottleneck in scaling plastics circularity is the collection, cleaning and sorting of mixed waste streams. New virgin polymer capacity is built in increments of as much as 1 million metric tons when a new chemical complex is built. In contrast, polymer waste is collected 1 kilogram at a time by the curbside. The waste supply chain must be developed so that its own carbon footprint does not negate the benefit of recycling.

The availability of right-quality recycled resin has constrained brand owners and resulted in recycled polymer prices exceeding those of virgin resin. An S&P Global analysis of 16 major brand owners with a combined plastic consumption of about 12 million metric tons — approximately 10% of the global packaging industry — indicates approximately 11% recycled polymer content currently in their packaging. They have pledged to increase recycled content and reduce overall plastic consumption (or at least virgin plastic consumption), with targets in the 25%-50% range by 2030. This suggests that, among them, they will consume about 4 million metric tons of recycled polymer by 2030. Resin producers' pledges suggest over 10 million metric tons of circular plastic will be part of their companies' total portfolio by 2030. This amount will still be a small part of total thermoplastic demand, which is roughly 350 million metric tons.

Beyond packaging, plastics use continues to grow and is essential to the greening of society. Renewable power depends on epoxy resins for wind turbines and on PE films for solar panels. Electric vehicles will need less nylon resin in high-temperature applications under the hood but more polypropylene in the body design for lightweighting. Overall, the global demand for materials will continue to grow alongside population and wealth, exacerbating the decarbonization challenge. Along the way, governments are likely to enact legislation to control plastic pollution, yet the options to substitute plastics invariably involve more energy-intensive materials. The wider materials transition will not be possible without plastics as part of the solution.

Looking forward: Scale and technologies

Accelerating the materials transition requires the scaling of circularity and the development of new technologies. Chemical recycling processes need larger-scale and more robust catalyst systems to remove additives and contaminants. However, these requirements are moot if the supply chains to collect plastic waste are not sufficiently developed — and in a manner sufficiently low carbon that there is indeed a net emission savings from the circular economy.

Plastics could substitute higher energy-intensive materials in many applications. But other industries are also decarbonizing, with steel in particular investing heavily in hydrogen. Fundamental research to expand the performance envelope of plastics to replace other materials, such as concrete or steel, is currently aspirational, but countries dependent on fossil fuel sales are incentivized to develop new high-performance plastics and applications as alternate ways to monetize their hydrocarbons.

Learn more

Specialty Chemicals: Essential in Energy Transition

Packaging the Future: A Material Matter

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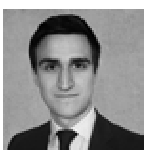

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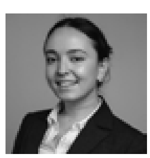

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