PGIM

MEGATRENDS

FUELING THE FUTURE

Investing Across the Global Energy Landscape

SPRING/SUMMER 2024

About PGIM

PGIM is the global asset management business of Prudential Financial, Inc. (PFI). In 41 offices across 19 countries, our more than 1,450+ investment professionals serve both retail and institutional clients around the world.

As a leading global asset manager, with $1.34 trillion in assets under management, PGIM is built on a foundation of strength, stability, and disciplined risk management.* Our multi-affiliate model allows us to deliver specialized expertise across key asset classes with a focused investment approach. This gives our clients a diversified suite of investment strategies and solutions with global depth and scale across public and private asset classes, including fixed income, equities, real estate, private credit, and other alternatives.

For more information, visit www.pgim.com.

All data is as of March 31, 2024.

* PGIM is the investment management business of Prudential Financial, Inc. (PFI). PFI is the 11th largest investment manager (out of 434 firms surveyed) in terms of worldwide institutional assets under management based on Pensions & Investments' Top Money Managers list published June 2023. This ranking represents institutional client assets under management by PFI as of December 31, 2022. Participation in the P&I ranking is voluntary and open to managers that have any kind of U.S. institutional tax-exempt AUM. Managers self-report their data via a survey. P&I sends the survey to previously identified managers and to any new managers asking to participate in the survey/ranking. No compensation is required to participate in the ranking.

INTRODUCTION

Nations have risen and fallen, governments come to power and been ousted, and businesses created and destroyed, all in the quest for energy.[1] Today we stand at a critical inflection point for the energy system.

For decades, the world has wrestled with an energy trilemma: balancing the three goals of (1) a secure, resilient, and reliable energy supply; (2) universal access to affordable energy for domestic and commercial use; and (3) an energy system that mitigates and avoids environmental harm.

However, the complexity of balancing these competing priorities has dramatically increased in a world facing multiple interlocking crises. The shocks have kept on coming: the COVID pandemic and its aftermath, international conflicts in Ukraine and the Middle East, pressure to decouple from Chinese supply chains, and more frequent extreme weather events and natural disasters.

Navigating this unprecedented and uncertain energy landscape is critical for long-term investors for four key reasons:

1. **Energy is critical for everything humans do.** It not only accounts for 10% of the global economy but is also a crucial input into the other 90%. Energy prices also drive key macroeconomic indicators, including inflation, consumer spending, economic growth and external balances. Government responses to surging energy prices can also have fiscal consequences. And energy price shocks generate market turbulence through trade, commodity markets and monetary policy, creating significant investment uncertainty.[2]
2. **Energy security is national security.** Establishing and maintaining dependable access to energy lies at the heart of many geopolitical fault lines. These geopolitical risks are critical for understanding sovereign risk, evaluating potential capital restrictions on less liquid investments and monitoring country-specific risk factors across the portfolio.
3. **The energy transition – the shift towards electrification and a low-carbon energy mix – creates an array of attractive new investment opportunities**. However, the energy transition also leads to obsolescence risk in waning energy sectors that may still be overrepresented in investors' portfolios, while simultaneously requiring vigilance against overhyped innovations that are often too distant, uneconomic or politically unfeasible.
4. **For investors with ESG goals or decarbonization commitments, the inescapable arithmetic of global energy demand and supply means that fossil fuels will remain a major source of energy supply for decades to come – despite the ongoing and necessary transition to a low carbon economy.** Such a world will need considerable nuance – and a simplistic strategy that divides the investment world into "brown" villains and "green" heroes will *not* be the most effective approach to achieve either environmental or fiduciary objectives.

To understand the emerging investment opportunities and hidden risks from a global energy system in transition, we have drawn on the insights of 30 investment professionals across PGIM's fixed income, equity, real estate, and private alternatives managers – as well as leading policymakers, academics, entrepreneurs, private equity and venture capital investors.

We lay out the key drivers reshaping the energy system in Chapter 1. Electrification is a critical and growing component of this system, and the resulting tradeoffs amidst a prolonged energy transition are summarized in Chapter 2. These foundational hypotheses and concepts allow us to highlight the most attractive investment themes across the energy system in Chapter 3, where we also lay out the case for avoiding speculative opportunities that garner much media hype. Finally, Chapter 4 lays out an action plan for chief investment officers as they evaluate the impact of the evolving energy system across their portfolio.

TABLE OF CONTENTS

CHAPTER 1

THE NEW ENERGY LANDSCAPE

"While it will take decades for every contour of the new energy landscape to fully appear, we are at a critical inflection point."

01

CHAPTER 1

THE NEW ENERGY LANDSCAPE

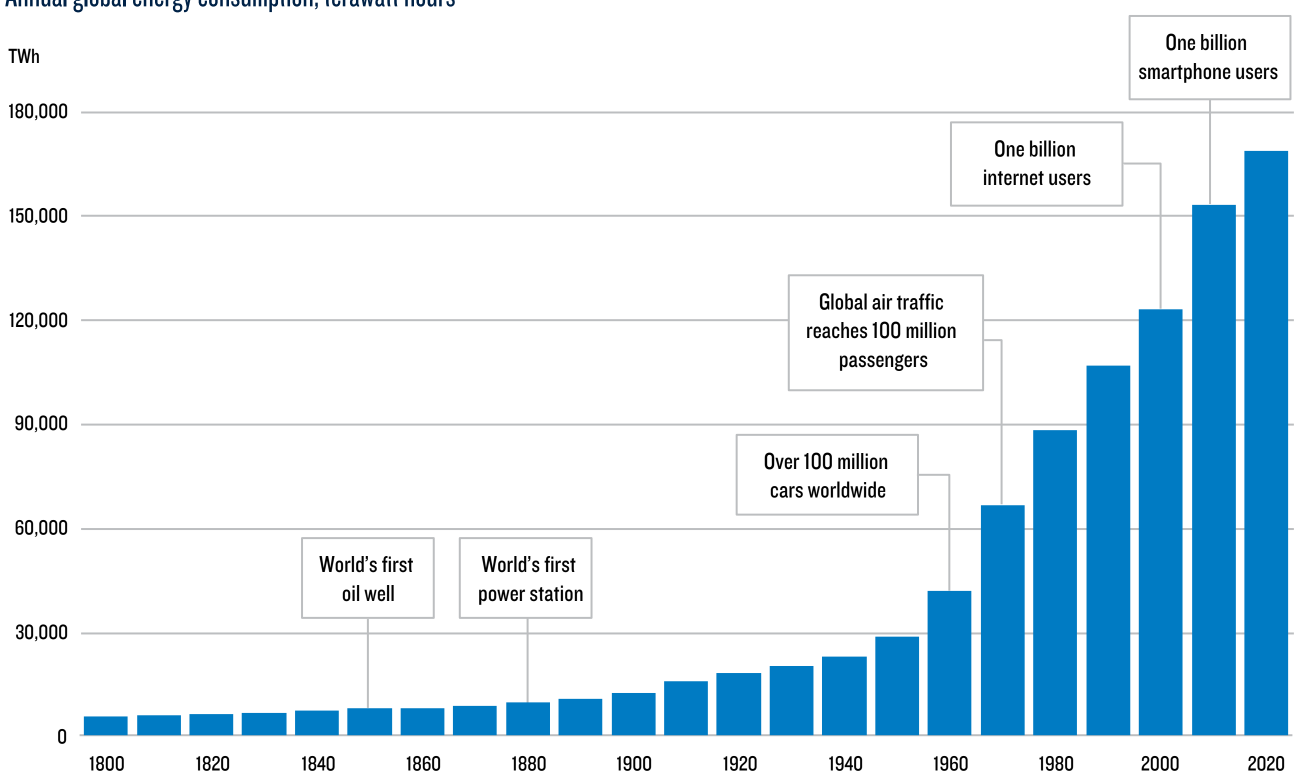
Global energy production in 1800 relied mostly on biomass – wood, crop waste, charcoal – and would have powered today's world for only 12 days. With the second industrial revolution and the dawn of the 20th century, our demand for energy began increasing, a combination of rising populations, growing economies and new energy-intensive technologies – ranging from steam engines and automobiles to airplanes and computers (Exhibit 1). To meet our seemingly insatiable demand, the energy system has become ever more complex, adding an array of new energy sources – first coal, then oil and gas, and most recently renewables. Importantly, through each evolution of the energy system, legacy fuel sources have been *supplemented* rather than completely replaced.

With regard to supply, energy sources are often segmented into two groups: (1) fossil fuels like coal, oil and natural gas which emit carbon; and (2) zero-carbon sources – including renewables (e.g., solar, wind, hydro) and nuclear power – that generate electricity without carbon emissions. Note that electricity itself is not an energy source, but rather a critical intermediary that delivers power generated from these sources (Exhibit 2A). Combined, these two groups comprise all primary energy sources.

As for consumption, it is often segmented into four groups: industrial, transportation, residential and commercial (Exhibit 2B).

Exhibit 1: Energy consumption took off in the late 20th century

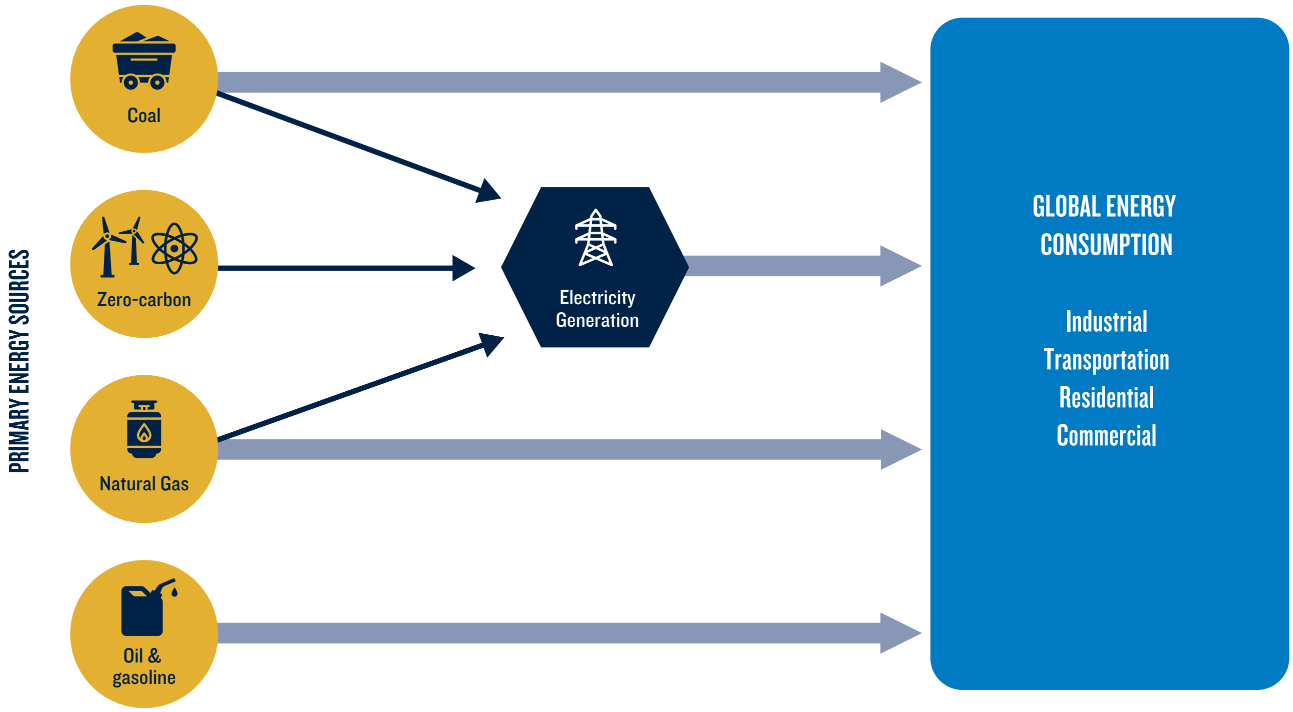
Annual global energy consumption, terawatt hours



Source: PGIM Thematic Research, International Telecommunication Union, US Bureau of Transportations Statistics and International Air Transport Association. March 2024.

Today's energy system

Exhibit 2A: The energy system – a simplified schematic



Note: A small portion of oil is used for electricity generation and some renewables are directly used within sectors.
Source: PGIM Thematic Research.

Exhibit 2B: Primary energy usage by sector

Uses of primary energy; quadrillion British thermal units (2022)

	Industrial	Transportation	Residential	Commercial	Total	Share
Oil	65	110	11	5	190	30%
Natural Gas	89	5	38	20	153	24%
Coal	110	2	32	22	166	26%
Renewables	60	2	23	16	101	16%
Nuclear	13	1	8	6	28	4%
Total	336	120	113	69	638	
Share	53%	19%	18%	11%		

Note: Numbers are rounded to full digits. The primary energy per sector includes the amount that is used through electricity generation but does not consider the different efficiency rates of primary energy sources, leading to deviation from the usual calculation of consumed energy seen in Exhibit 5. For a detailed breakdown of electricity generation see Appendix A.7.
Source: US Energy Information Administration. April 2024.

Today our energy system sits at a critical inflection point – shifting away from fossil fuels where possible, promoting electrification and adding renewables to the energy mix. While it will take decades for every contour of this new energy landscape to be fully realized, three foundational themes will be critical.

> *Energy security issues will be a key factor in the pace of energy transition.*

1. With rising geopolitical tensions, energy security is national security

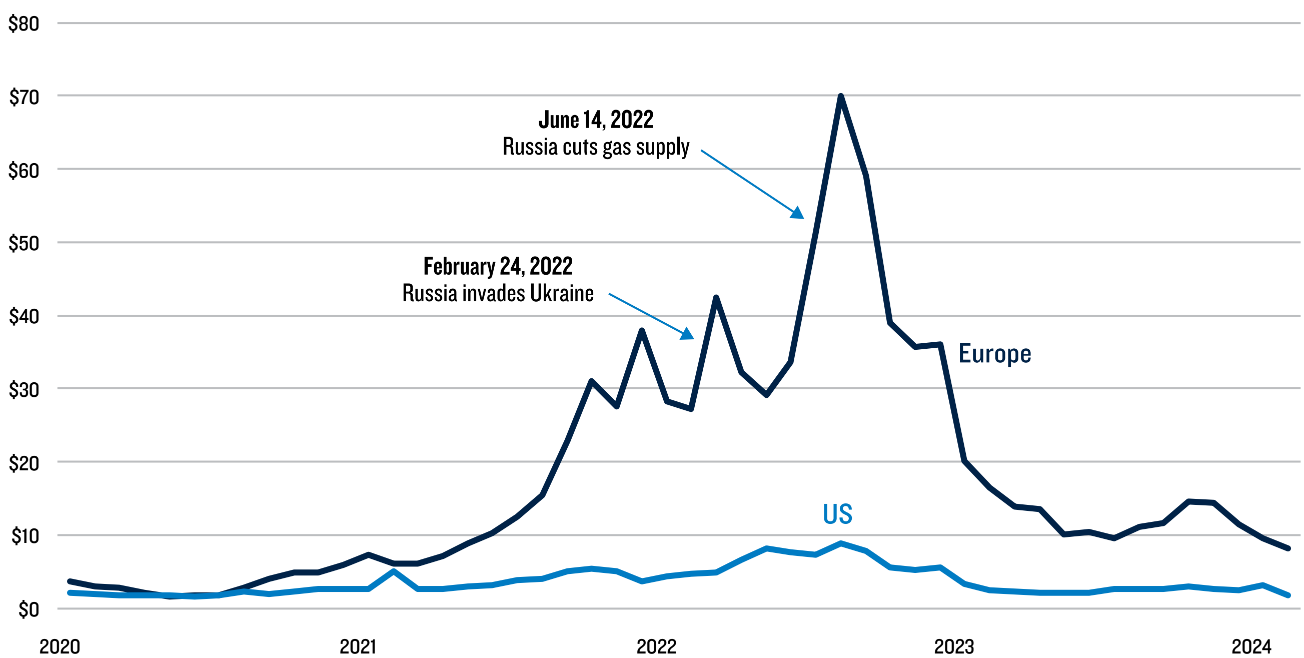
Energy has been the root cause of geopolitical tensions and wars for centuries, and it is difficult to overstate the primacy of ensuring a secure and reliable supply. Dependable energy is not just critical for economic development, it is considered by most countries to be an essential aspect of national security. This is what leads governments – like Japan, China, Germany, the US and India – to maintain strategic reserves of oil or natural gas.[3]

Indeed, when faced with supply shortfalls and the stark prospect of energy rationing, even countries reasonably far along in the transition to zero-carbon sources put their need to meet current energy demand ahead of long-term decarbonization goals. For example, with their gas supply threatened by Russia's invasion of Ukraine, Germany returned to heavy carbon-emitting sources like coal-fired power plants to ensure access to a dependable energy source.[4]

When considering energy security, it is important to note each country faces a unique landscape. At one end, countries with vast reserves of oil or natural gas (and to some degree coal), have reliable access to energy and typically make domestic energy sources the basis of their national energy strategy. Because of their primacy, energy security issues will be a key factor in the pace of energy transition away from fossil fuels. This typically means that countries where fossil fuels are relatively abundant – China, the US, India and the Middle East, for example – will likely have an extended transition to renewables (see Appendix A.1).[5]

Exhibit 3: Natural gas importers face greater price volatility

Natural gas price per one million British thermal units



Note: The cuts to gas supply refers to the first Nordstream pipeline shutoff from Russia to Germany.
Source: World Bank. April 2024.

On the other end of the spectrum, countries not naturally endowed with significant oil or natural gas reserves have two alternatives. Their first option is to rely on importing fossil fuels. An extensive global infrastructure network to store and transport fossil fuels (*e.g.*, pipelines, shipping terminals and storage facilities) built over decades makes this a viable choice. However, countries highly dependent on importing fossil fuels bear more geopolitical and price risk. These risks were brought to the fore when uncertainty rose around the supply of Russian natural gas to Europe as early as the summer of 2021. Germany, Italy and other nations were left scrambling as natural gas prices soared in Europe six months before the invasion of Ukraine in early 2022 (Exhibit 3).

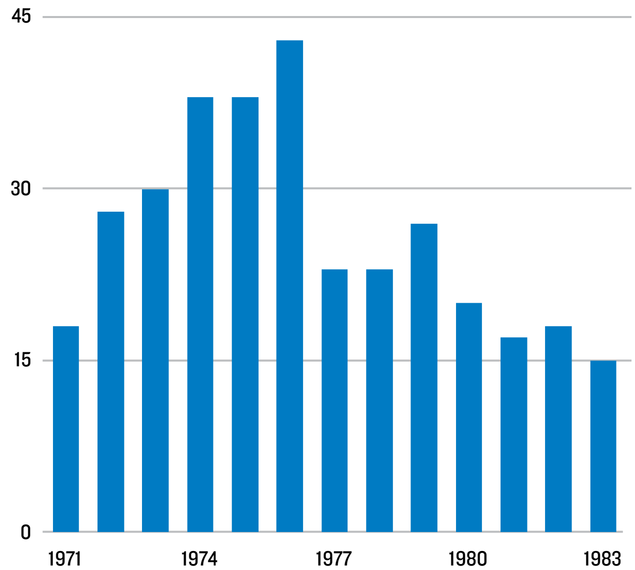
The second option for countries not endowed with sufficient fossil fuel reserves is to seek alternative domestic energy sources. This was an important driver of investments in nuclear energy production: The oil shocks and rationing of the 1970s prompted government-led efforts to build nuclear power plants in France, Sweden and South Korea to boost energy independence (Exhibit 4).[6] Today, nuclear energy still provides a significant amount of energy to many of these countries (see Appendix A.2).

> *Countries not naturally endowed with oil or gas reserves have two alternatives: they can import fossil fuels or seek out alternate energy sources.*

While renewable power generation eliminates vulnerabilities from importing fossil fuels, it also raises new security issues around the supply chains of critical components. For example, China dominates supply chains for lithium batteries controlling more than two-thirds of global processing capacity.[7] Additionally, China accounts for 80% of global manufacturing of solar panels – and has built up sizable technology, efficiency and cost advantages over competitors in other countries.[8]

Exhibit 4: Nuclear power peaked after the 1970s oil shock

Nuclear reactor construction starts between 1971 and 1983



Note: From 1984 to 2022 there were only five occasions with more than ten construction starts.
Source: World Nuclear Association. March 2024.

To counter these vulnerabilities in renewable supply chains, countries are taking measures to ensure a diverse supply of critical metals and manufactured components. Australia, for example, which supplies about half of the world's raw lithium, is expanding its capacity to process and export battery-ready minerals.[9] Other countries – like India and the US – are using subsidies or tariffs to support domestic supply chains and production capacity for solar panels to reduce their dependence on imports.[10, 11]

2. Our reliance on fossil fuels will continue for decades, even amidst the energy transition

Our global economy has evolved over decades with fossil fuels as the primary source of energy. They currently provide 80% of global energy and are likely to remain a significant component of global energy supply for decades (Exhibit 5).

There are multiple economic and political reasons for the continued significance of fossil fuels, but three factors are often underappreciated in discussions on the pace of the energy transition. First, there are many specific industrial uses where renewables may not offer a complete substitute for fossil fuels. Second, the elaborate global infrastructure network for fossil fuels provides a huge incumbency advantage over renewables. Third, permitting issues and NIMBYism contribute to a lack of capital for critical renewable infrastructure.

Fossil fuels directly power industry and transportation

The current stock of capital goods is highly reliant on fossil fuels. For example, the two largest energy consuming sectors – transportation and industrial – account for 72% of all energy use. Notably, this consumption is dominated by direct use of fossil fuels.

Transportation

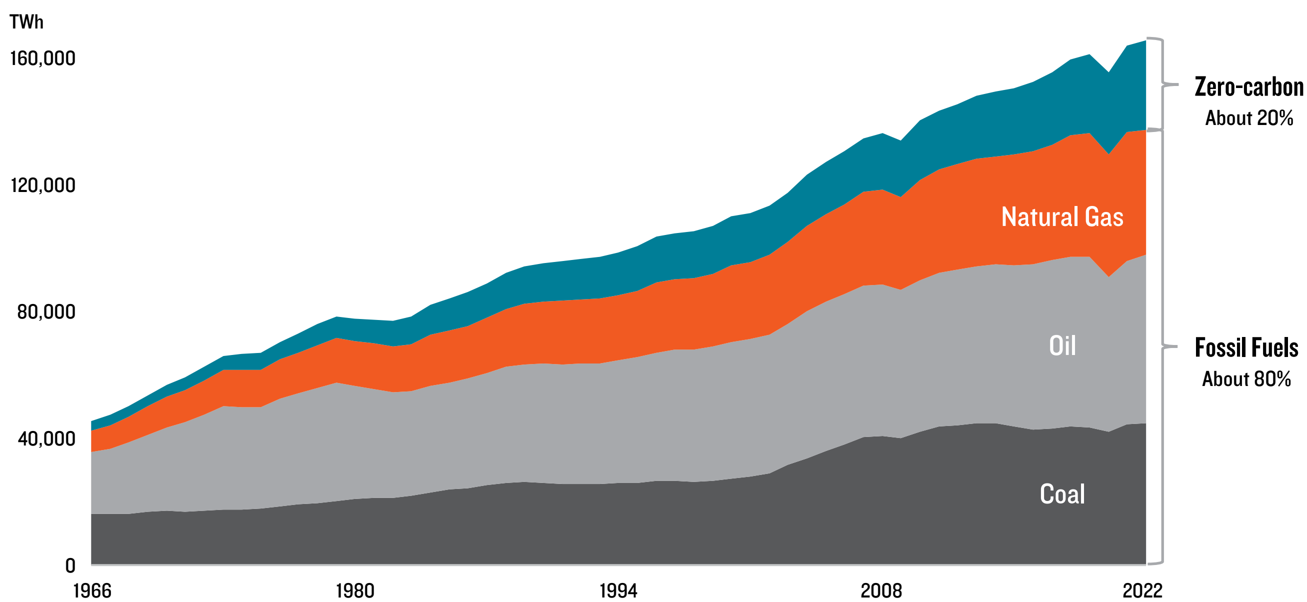
In the transportation sector, gasoline, diesel or other petroleum-based fuels are poured right into the tanks of automobiles, trucks, airplanes, ships and motor-bikes around the world. In fact, fossil fuels provide 98% of the energy used for transport globally.

> *The current stock of capital goods is highly reliant on fossil fuels. For example, the two largest energy consuming sectors – industrial and transportation – account for 72% of all energy use.*

Even in segments of transportation where electrification is already underway – such as automobiles – it is exceedingly slow. There are 1.3 billion internal combustion engine (ICE) automobiles on the road today. Even optimistic forecasts for penetration of electric vehicles (EVs) have well over a billion ICE vehicles remaining through 2050 – roughly twice the

Exhibit 5: Fossil fuels power today's world

Energy consumption by primary source, terawatt hours



Note: Zero-carbon includes solar, wind, biofuels, hydropower and nuclear.
Source: US Energy Information Administration, Global Energy Outlook 2023. March 2024.

number of EVs (Exhibit 6).[12] Furthermore, those forecasts may be increasingly unrealistic as major car manufacturers such as Toyota, Ford and Volkswagen are scaling back their long-term forecasts for EV demand.[13, 14, 15]

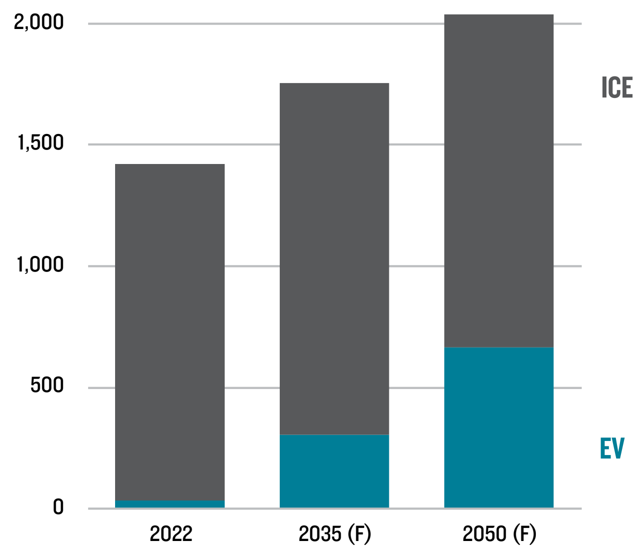
Indeed, fossil fuels have several characteristics that make them exceptionally difficult to displace in the transportation sector. One attribute especially challenging to replicate is their energy density, which is critical for mobility and transportation. That is, on a per-kilogram basis, natural gas, coal, gasoline – and even wood – provide significantly greater energy than electricity stored in a lithium-ion battery (Exhibit 7). The lack of energy density limits the usage of batteries for transport because at scale the weight of the batteries themselves becomes a factor. For example, today's battery technology is often sufficient to power motorbikes, automobiles and buses but is too heavy for long-haul travel by commercial airplanes, cargo ships, trucks or freight trains.

Industrial

The direct use of fossil fuels is ubiquitous and often without any viable substitute in the industrial sector as well. The

Exhibit 6: Global EV adoption is moving slowly

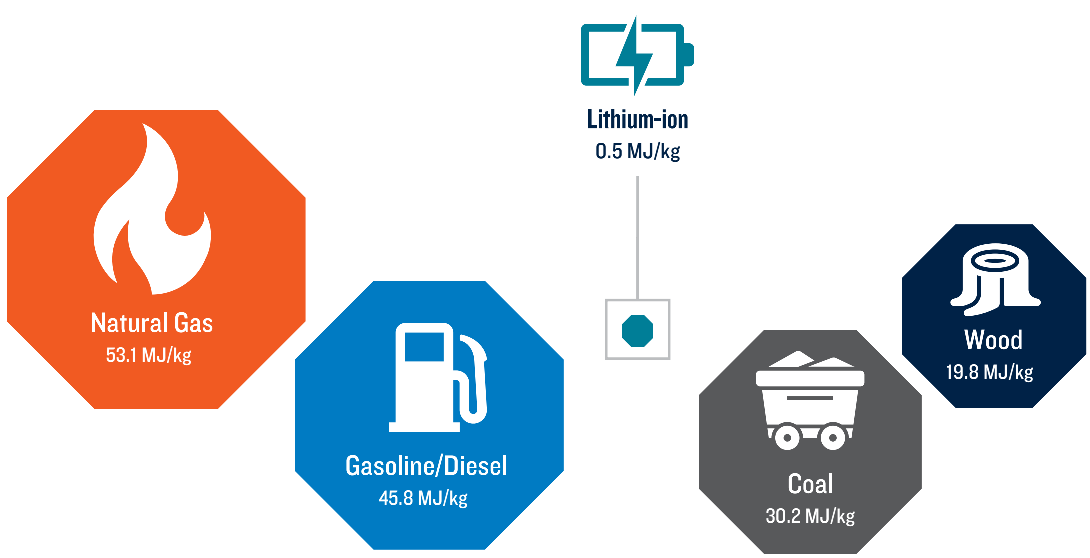
Total vehicles powered by electricity and internal combustion engines, millions



Note: (F) indicates forecast.
Source: US Energy Information Administration, International Energy Outlook 2023.

Exhibit 7: Current batteries cannot compete with fossil fuels on energy density

Energy density in megajoules per kilogram



Source: Adapted from Brookings, "Why are fossil fuels so hard to quit?" March 2024.

role of metallurgical coal in steelmaking provides a useful example of the difficulty in replacing certain attributes of fossil fuels. Combustion of coking coal not only provides the intense heat needed to melt the iron ore, but the carbon released from the coke also very efficiently separates out pure iron from oxidized iron ore by chemically combining with the oxygen.[16] This chemical reaction that purifies iron ore is critical to manufacturing new steel. Electric arc furnaces offer an alternative – though often at higher cost – to many aspects of steel recycling. However, they are rarely used to manufacture new iron.

> *The shortfall in electric grid capacity to support electrification is becoming a material constraint on the global energy transition.*

The global network of transport and storage infrastructure for fossil fuels will not be replicated soon

Another incumbency advantage of fossil fuels is the elaborate infrastructure – namely, in storage and transport – built out over time. With more than 500,000 gas stations globally, gasoline can be accessed in nearly every corner of the world – even where it is not locally produced. The sheer geographical spread of gas stations is a testament to the extensive network that exists to produce, refine, transport and store gasoline. By comparison, electricity is more difficult to store and transport than oil or gasoline. Long-term power storage lacks scale, efficiency and mobility, and an extensive network of infrastructure to store, distribute and transport renewably-generated electricity is a distant prospect.[17]

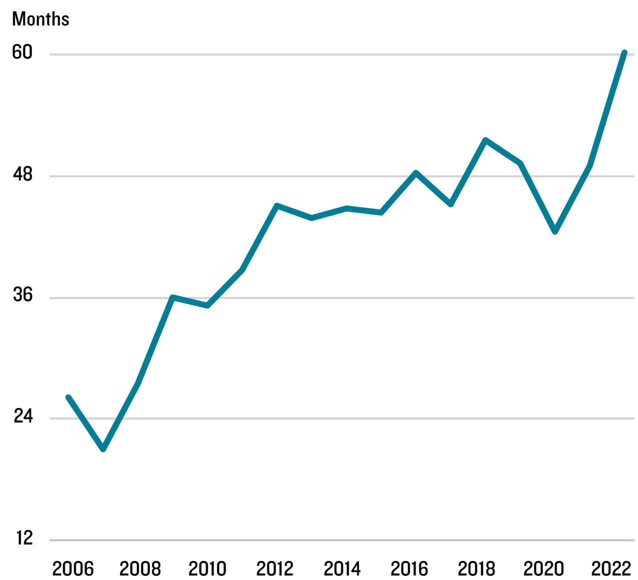
Regulatory and political challenges contribute to a lack of capital for renewable infrastructure

Estimates for the additional energy infrastructure needed for renewables are immense – routinely reaching into the hundreds of trillions of dollars. In 2023, $1.8 trillion was invested in global renewable infrastructure. That annual pace would need to more than double over the next 25 years to meet global net-zero objectives by 2050.[18]

The shortfall in electric grid capacity to support electrification, for instance, is becoming a material constraint on the global energy transition.[19] Delays in connecting new generation projects to the US power grid are growing and now average about five years – more than double the wait time in 2007 (Exhibit 8). This is not merely a US phenomenon either. Tens of billions of dollars in renewable power projects across Asia, Europe and the Americas are being cancelled or delayed due to the lack of new capacity in existing grids.[20, 21, 22]

Exhibit 8: Get in line – longer delays in grid connection

Average time from request for grid connection to operation, US



Source: Lawrence Berkeley National Laboratory. March 2024.

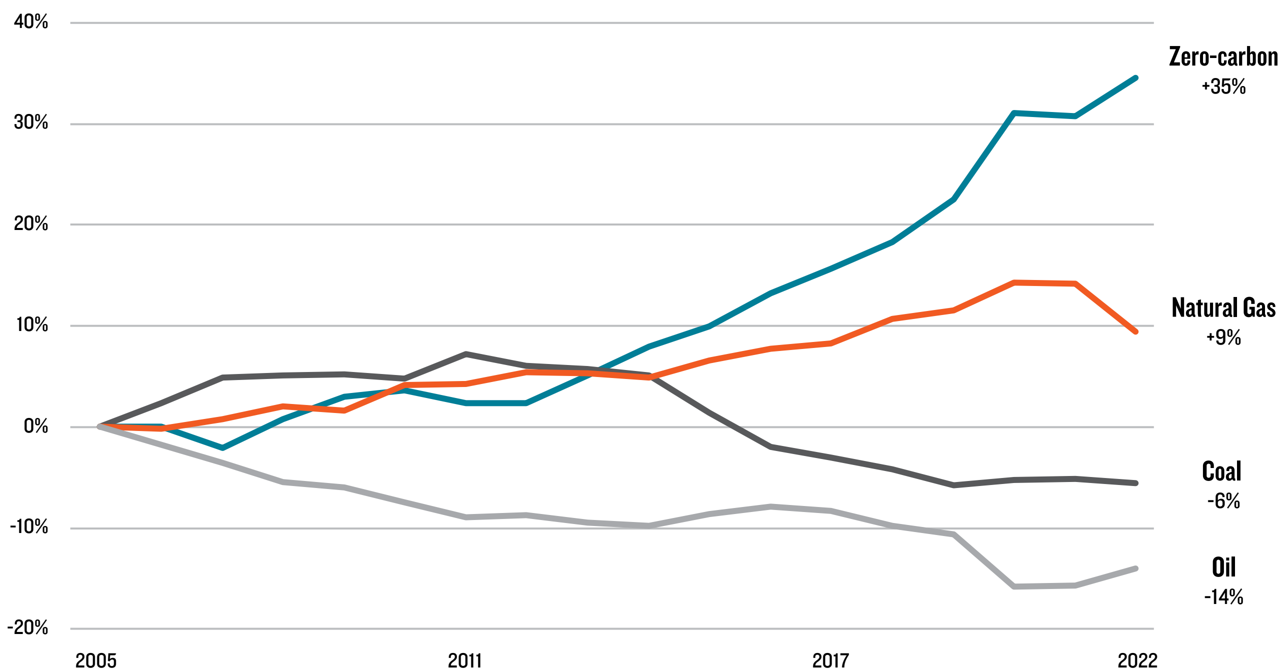
Indeed, transmission is crucial for renewable power generation as the optimal wind and solar farms are usually remote locations far from population centers. The planning and permitting phase for transmission lines in Europe and the United States can routinely take six years or more, often twice as long as the time needed to build the transmission lines.[23] Permitting in most countries is often highly decentralized and fragmented. This leads to opposition from local communities as few welcome wind turbines or high-voltage transmission lines in their neighborhoods. This NIMBYism raises uncertainty around the viability of such projects and has a chilling effect on private capital investment in this space.

3. A major transition is underway – with electrification at the center of it

Despite the notable incumbency advantages of fossil fuels, the global energy system finds itself at a critical inflection point. Previous energy transitions – from wood to coal in the 18th century and from coal to oil in the early 20th century – have unfolded slowly, often over a century or more.[24] A major transition has been underway for two decades from fossil fuels to lower-carbon sources, driven by climate change concerns, government subsidies and regulations, technological innovations, and lower costs of renewable production (Exhibit 9).

Exhibit 9: The current energy transition has been ongoing for two decades

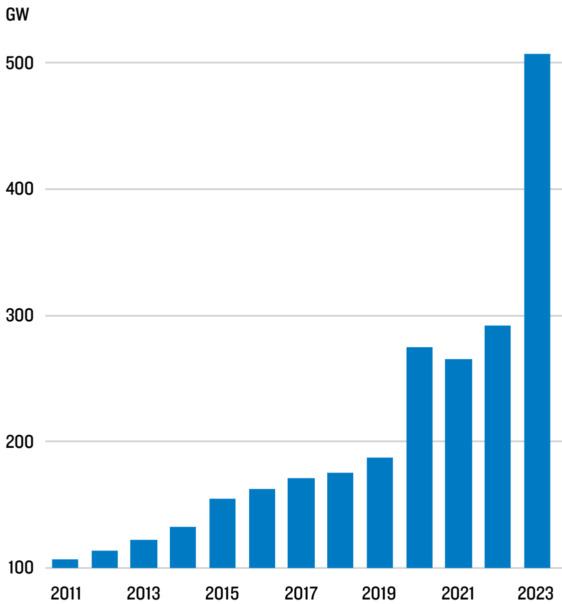
Increase in primary sources' share of global energy consumption



Source: Energy Institute, Statistical Review 2023. March 2024.

Exhibit 10: Renewable power is skyrocketing

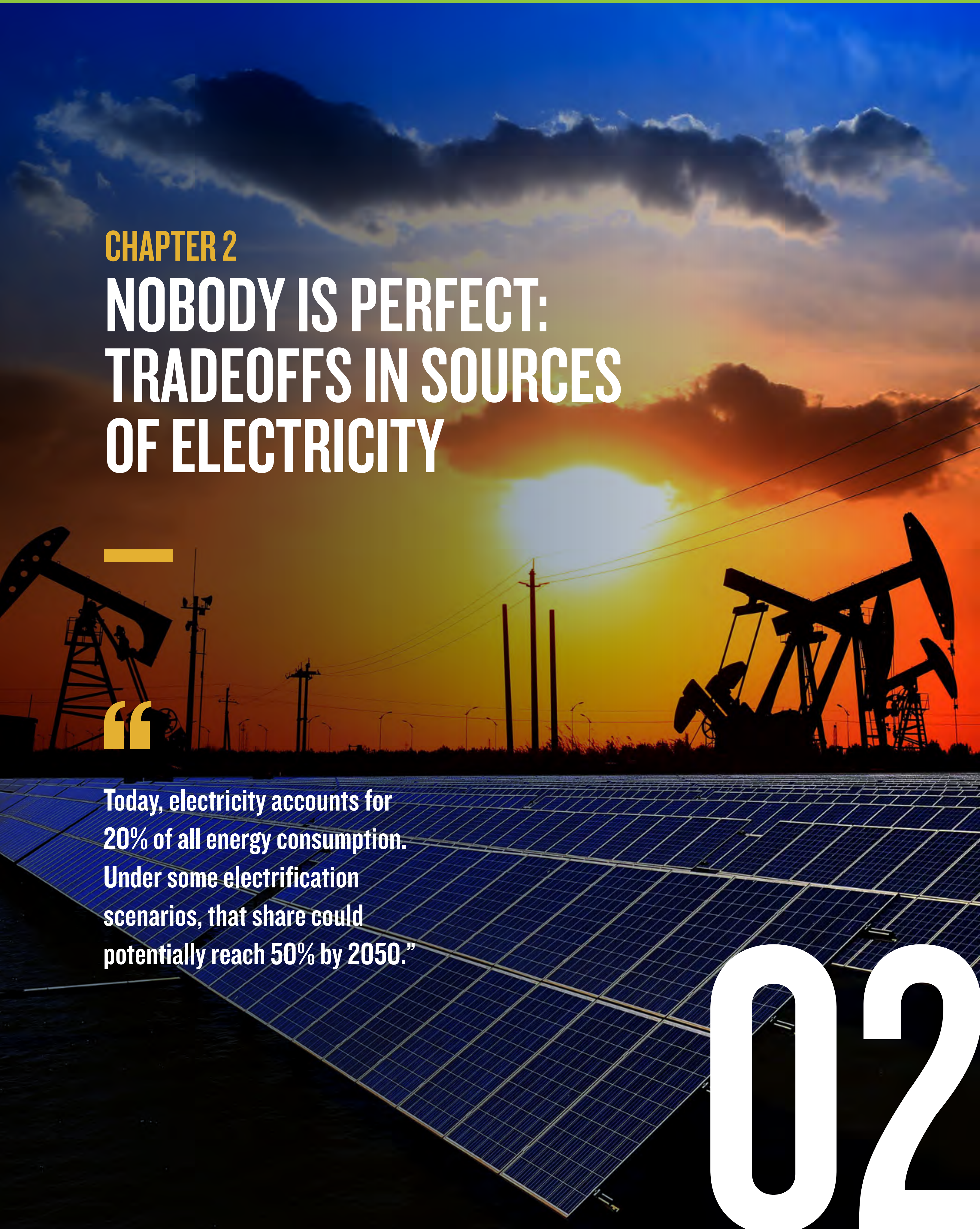
New renewable electricity generation added globally, gigawatts



Source: International Energy Agency and International Renewable Energy Agency. March 2024.

Electrification is a critical component of this decarbonization transition for two reasons. First, it reduces the direct use of fossil fuels – like in automobiles and motorbikes. Second, electricity is the one form of energy that can be affordably produced without significant carbon emissions, most obviously by solar, wind, hydro or nuclear generation.[25] Renewables have increasingly become the first choice for *new* power generation capacity in major energy markets like China, the US, India, the EU and Brazil. In 2023, the world increased its renewable capacity by 50% – and the next five years are expected to see at least the same pace of growth. At this rate the world could more than double its renewable capacity by 2030 (Exhibit 10).[26]

> The tradeoffs in energy sources, while often overlooked, are a critical feature of the energy transition – and the focus of Chapter 2.



CHAPTER 2

NOBODY IS PERFECT: TRADEOFFS IN SOURCES OF ELECTRICITY

"Today, electricity accounts for 20% of all energy consumption. Under some electrification scenarios, that share could potentially reach 50% by 2050."

02

CHAPTER 2

NOBODY IS PERFECT: TRADEOFFS IN SOURCES OF ELECTRICITY

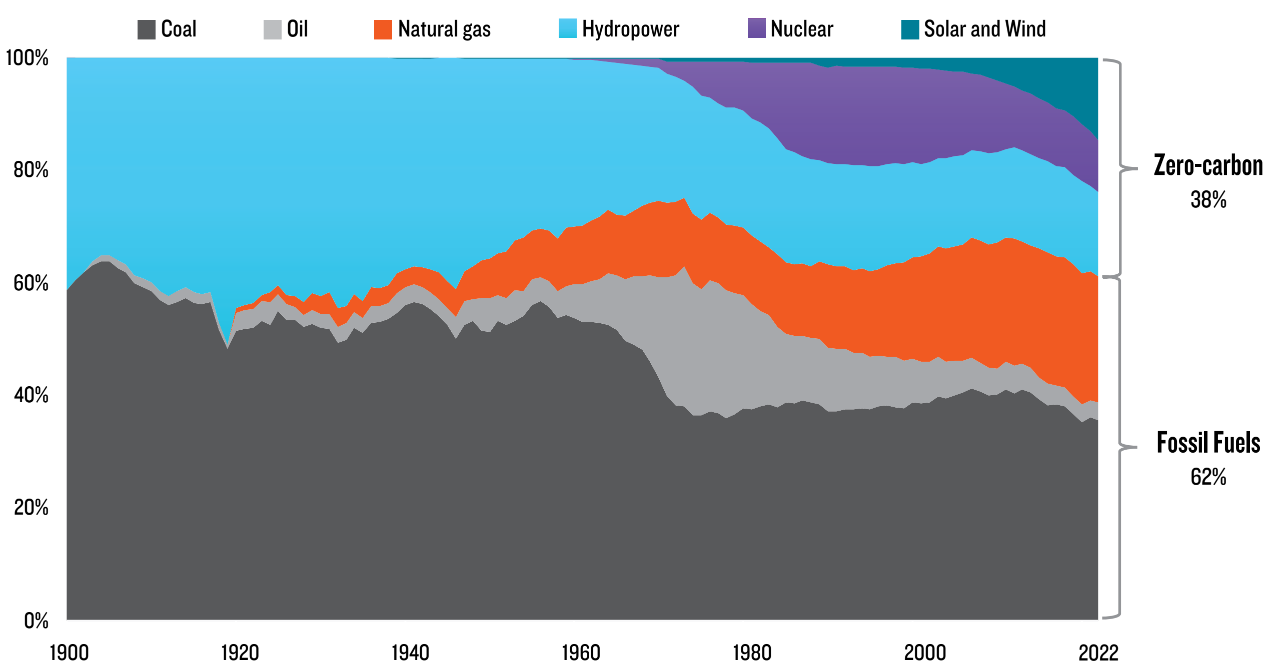
Today, electricity accounts for 20% of all energy consumption. Under some electrification scenarios, that share could potentially reach 50% by 2050.[27] The adoption of digital technology – from mobile phones and cloud computing to artificial intelligence and crypto mining – will only accelerate the immense growth in global electricity demand. This chapter examines the tradeoffs between various sources of electricity and lays out some of the fundamental policy and societal choices around electrification – a critical decarbonization lever as we transition to a lower-carbon energy system.

Given the massive investment poured into renewable power generation globally by governments and private industry, it is striking to note that more than 60% of all electricity is *still* generated from fossil fuels (Exhibit 11).

Of course, this aggregate figure masks the tremendous variation across countries – for example, India generates almost 75% of its electricity from fossil fuels while less than 5% of Norway's power comes from them[28] (Exhibit 12). And one country is very prominent at both ends of the energy transition. China is not only one of the largest consumers of fossil fuels – using enough coal annually to power the entire United States – but also a leader in the transition to renewables – China added more solar and wind capacity in 2023 than the rest of the world combined (see Appendix A.3-6).

Exhibit 11: Electricity generation still relies on fossil fuels

Share of global energy sources in electricity generation



Source: PGIM Thematic Research, Ember and Pinto, et al; 2023. March 2024.

Powering Change: AI's growing role in the energy system

Despite the breathless hype, one crucial aspect of AI is still often underestimated: the exponentially increasing demand for computational capacity to power the training of large language models. This will have profound implications for data centers and may be one of the most overlooked aspects of the energy transition.

Data centers today consume about 2% of global electricity – more than the nation of France.[29, 30]
This is expected to more than double by 2026, equivalent to the electricity consumption of Japan.[31] And, when combining energy needs from training large language models with cloud computing and bitcoin mining, data centers could, by some estimates, be consuming over 20% of the world's electric supply by 2030.[32, 33]

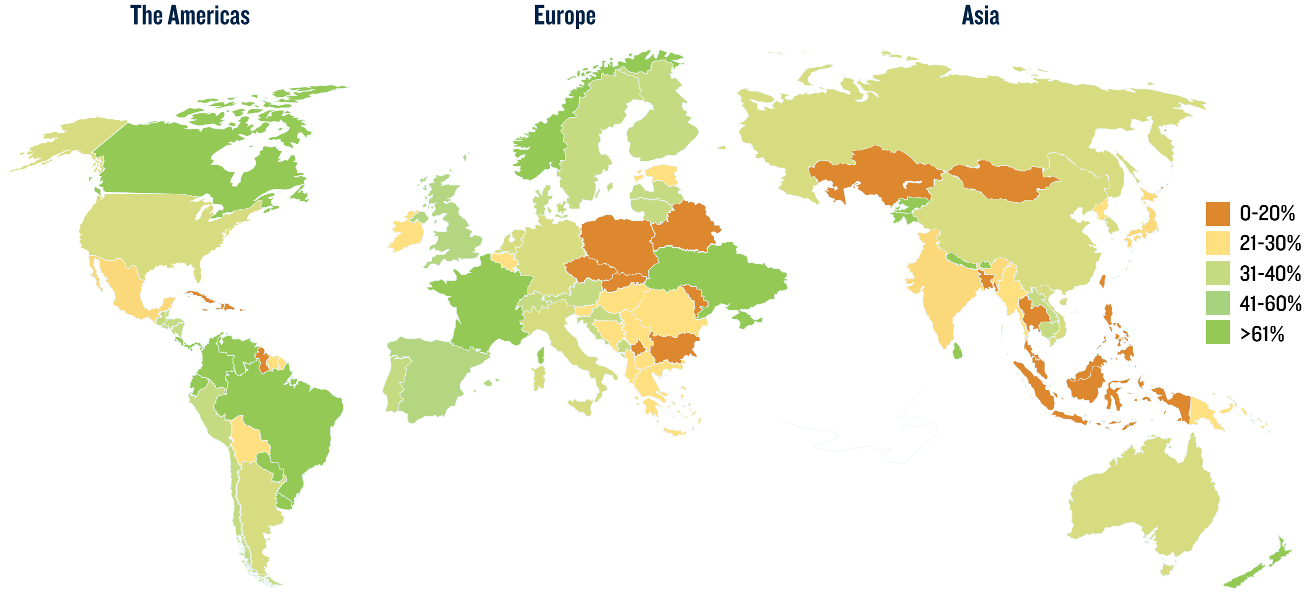
Notably, data centers are driving new demand in developed countries where electricity growth has been sluggish.[34] Electricity demand from data centers in Ireland, for example, is poised to double by 2026 and will make up roughly a third of all electricity demand by then. And the dramatic increase in power needs from data centers is a major reason behind the near doubling of forecasts for US demand growth over the next five years.[35]

Energy to power and cool the servers – the largest operating cost for data centers – is already a constraint on new construction and expansion.[36] For data center operators this means they must not only consider how to scale their business models to accommodate the increased computational intensity and demand for training deep neural networks, but also where to locate new facilities and how to source abundant and cheap power.

Data center operators are responding to this challenge in different ways. Some are actively partnering with zero-carbon energy providers to incorporate a dedicated power source into their data center complexes. Hydrogen power has been part of the solution for several years, and the first off-grid modular data center powered entirely by hydrogen recently opened in the US.[37, 38] And the largest data center operators globally are entering partnerships or joint ventures with renewable energy providers.[39] Amazon, for example, acquired a hyperscale data center campus in Pennsylvania that is adjacent to a nearby nuclear reactor.[40] Other data center operators have also been exploring small modular reactors.[41]

Exhibit 12: Zero-carbon's role in power generation differs widely across the world

Share of total electricity generation from nuclear energy, renewables, and hydroelectric



Source: International Energy Agency and Energy Institute. March 2024.

Nobody is perfect: Tradeoffs from different sources of electricity

An optimal energy system would not only have secure access to primary sources and key components, but it would also provide electricity cheaply when it is most needed and without harming the environment. What is often ignored is that: *no single source of electricity is optimal across these three fronts.* That is, fossil fuels and zero-carbon sources present different tradeoffs.

1. Dispatchability

Dispatchability is technical jargon for the ability to generate power when it is needed, i.e., how easily power production can be turned up or down to meet variations in demand. Typically, electricity is managed around baseload – the minimum level of power demand at any time during the day. In periods when demand increased above the baseload, complementary sources of power could be switched on as needed to meet the rising electricity demand and then shut off as demand declined overnight.[42, 43] Baseload power was typically provided by plants (such as nuclear or coal) with low marginal cost but little ability to adjust output, while complementary power plants (often, natural gas turbines or sometimes hydropower) had a higher marginal cost of production but were dispatchable – that is, their production could easily be dialed up or down to respond to daily fluctuations in demand.[44]

By contrast, most renewables – especially solar and wind – are intermittent. That is, their production is not easily adjusted – and they have considerable variation in production over the course of a typical day. The more renewable power on the grid, the greater the swings between minimum and maximum power production within a day. This has created a new set of infrastructure needs and challenges as intraday supply-demand imbalances need to be actively managed by grid operators.[45]

Current electricity grid and transmission infrastructure is heavily reliant on dispatchable power sources to meet these daily fluctuations in demand. Because of this, simply replacing baseload and complementary fossil fuel sources with more intermittent renewables can lead to significant challenges downstream.

Managing grids with extensive intermittent power sources is feasible – but renewable power generation needs to be paired with complementary infrastructure to enable it. Utility-scale power storage capability, for example, could be used to meet daily fluctuations in demand. In the absence of sufficient storage capacity, easily dispatchable power sources (like some hydroelectric or natural gas) or long-distance transmission lines that can help balance power between multiple grids are needed.

2. Affordability

More than 2 billion people globally – just under a third of the world's population – lack access to clean, affordable energy and still cook their food over open fires or on basic stoves burning wood, charcoal or other biomass.[46] And few developments can trigger universal political backlash quite like rising energy and electricity prices. A surge in energy prices in 2022 generated cost-of-living crises and political protests across the globe – from emerging markets like Pakistan and Ecuador to developed markets like the UK and France.[47, 48] Consequently, governments and politicians have very little incentive to compromise on energy affordability.

> *Solar and wind are amongst the most cost-efficient sources of electricity.*

Over the past decade, government support of wind and solar has attracted private capital which in turn has enabled and accelerated technological advancements that now make solar and wind amongst the most cost-efficient sources of electricity. In fact, several research studies have shown it would be less expensive to build entirely new arrays of solar panels or clusters of wind turbines and connect them to the US grid than it is to keep operating existing coal plants in the US.[49]

Renewable power projects like solar and wind generate electricity today at a relatively low levelized cost of energy (LCOE) – that is, the total cost of power generation over the lifetime of the asset – and have the added feature of zero marginal cost of production (Exhibit 13).

3. Carbon emissions

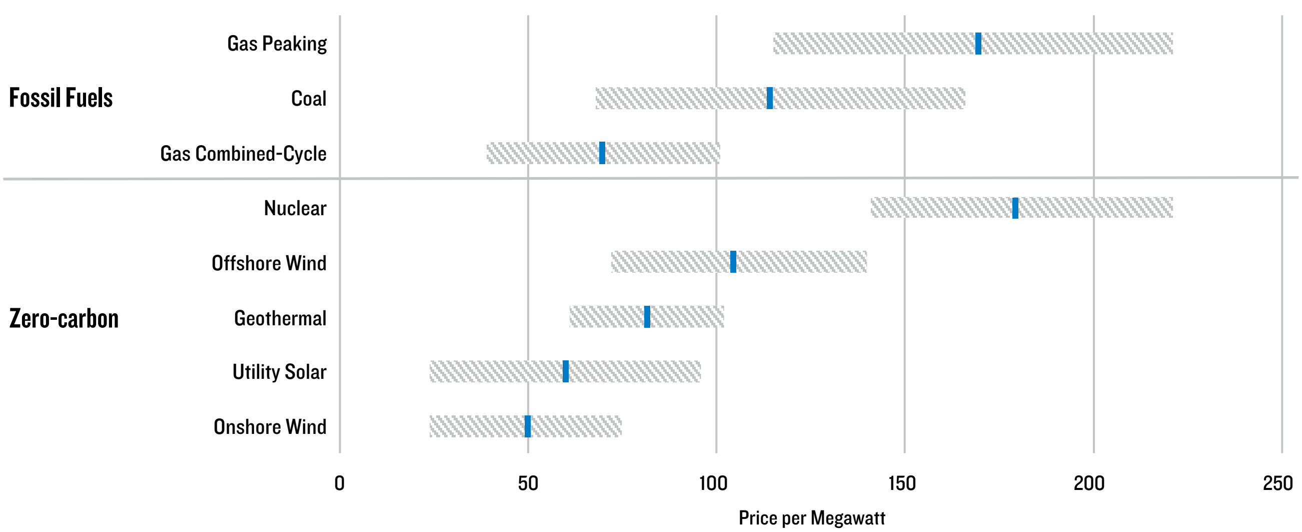
2023 was the warmest year in recorded history – both on land and in the ocean – and the latest example of a persistent increase in global temperatures.[50, 51] Greenhouse gases (GHG) – like carbon dioxide and methane – in the atmosphere are a key factor contributing to warmer temperatures.[52] This persistent global warming is causing ice caps to melt, driving rises in sea levels and generating more frequent extreme weather events – whether they're droughts and floods or more intense storms and wildfires. [53]

Energy – both its production and consumption – accounts for roughly 75% of global GHG emissions.[54] Nearly all of this comes from combustion of fossil fuels. By contrast, renewable sources – once manufactured and in place – can generate electricity with no additional GHG emissions.

A low-carbon energy system – one that features more renewable sources rather than fossil fuels – is critical to reducing global GHG emissions. Regardless of how long

Exhibit 13: Renewables have become the cost-effective way of generating electricity

Unsubsidized levelized cost of energy, price per megawatt (2023)



Note: LCOE has its limitations. For example, it does not account for the additional cost of power storage for intermittent sources to smooth out the fluctuations in their production. But even after adding the cost of firming intermittency – such as the cost of power storage or the need to supplement these renewable sources with dispatchable gas-powered plants – renewable sources remain cost-efficient in most cases – especially compared to nuclear and coal-powered plants.

Source: PGIM Thematic Research, Lazard and International Energy Agency. March 2024.

Exhibit 14: All sources of electricity offer different tradeoffs

Note: Affordability is measured by the levelized cost of energy and carbon-emissions captures emissions per BTU.
Source: PGIM Thematic Research, Lazard, International Energy Agency and US Energy Information Administration. March 2024.

it takes to achieve decarbonization goals, reducing carbon emissions will remain an enduring feature of the energy landscape for decades.

Over 140 countries – including the largest GHG emitters – have made carbon reduction pledges.[55] With so many countries, firms and investors across the globe focused on reducing carbon emissions, it has become a critical and material factor for all energy investors.

As the energy transition continues, fossil fuels will be increasingly displaced by renewables as a source of energy. However, it is important to acknowledge that no single approach to the energy transition will work for all countries at every stage of their development.

The energy system of the future will need a variety of different sources to achieve the best outcomes (Exhibit 14). Given that the dispatchability of fossil fuels complement the intermittence of renewable sources quite well, the energy system of the foreseeable future will likely continue to incorporate both. Furthermore, diversifying energy sources amongst select renewable and fossil fuel sources can provide a much-needed element of resilience and security. More importantly, lower-carbon fossil fuels – like natural gas – can play a significant role and allow for energy security and affordability while the long-term transition is underway.

The tradeoffs around electrification are very real, and the choices governments and societies make will be critical in determining the pace of the energy transition. Long-term investors seeking to navigate the evolving energy landscape will be faced with a range of investment opportunities and challenges, and it is to these we turn in Chapter 3.

CHAPTER 3

INVESTMENT IMPLICATIONS

"It is important to realize there is no silver bullet and multiple energy sources will be needed to meet growing global demand."

03

CHAPTER 3
INVESTMENT IMPLICATIONS

The energy transition is a long, slow, complex process with multiple tradeoffs and challenges along the way. The pace and breadth will vary by country, but this transition remains a critical driver of the global energy system and offers a range of investment opportunities around the world. It is important to realize there is no silver bullet and multiple energy sources will be needed to meet growing global demand. It is also important for investors to recognize the different stages of the transition to find the best opportunities, which we believe are encompassed by three overarching themes.

1. Enabling renewable energy by supporting critical inputs and complementary infrastructure

Renewable power generation has grown significantly and has reached scale in many markets around the world. However, this expansion has not been matched in other areas of renewable infrastructure – like power storage and transmission. This imbalance in renewable infrastructure is reflected in the frequency of episodes of negative prices for electricity, the power lost from curtailing electricity generation and the long delays to get new projects connected to the grid.

> *Electricity from renewable sources is at the core of the energy transition.*

These realities demonstrate complementary infrastructure – namely, power transmission and storage – are lagging and need to be upgraded to handle an energy system with primarily intermittent sources. For investors, the widespread need for expanded and new renewable infrastructure – beyond power generation – is obvious and clear. Additionally, investors should consider key components of the renewable supply chain as well as the vast opportunities in emerging markets where renewable power growth is most rapid.

Debt opportunities in mature markets for renewable power and looking past solar and wind

The energy transition will require more electricity from renewable sources. Government policy and private capital have embraced this aspect of the energy supply chain and global power generation from renewable sources has grown fourfold from 2012 to 2023.[56]

For investors, however, the landscape of power generation becomes more challenging as the market matures. Government subsidies that enable this growth in renewable power generation and rapid technological innovation also drive fierce competition amongst power producers, falling electricity prices and shrinking margins.

Additionally, supply chain bottlenecks, rising costs of equipment and labor, permitting delays as well as higher interest rates all present mounting challenges to new projects compared to just a few years ago.[57] In fact, efforts by the US to ramp up offshore wind power generation are either not drawing interest from project developers or terms are being renegotiated because the economics of power generation have shifted so rapidly.[58, 59] Similar challenges are also plaguing projects in Europe and causing extensive delays or outright cancellations.[60]

So how should investors consider participating in this highly dynamic landscape of renewable power generation in Europe and the US? First, there may be better opportunities in debt rather than equity. Debt financing tends to be less plentiful than equity in this space. Specifically, senior debt offers attractive opportunities. And given higher interest rates globally, some opportunities may emerge in mezzanine and structured debt as well – especially in projects where offtake agreements are in place, permitting of new projects is not wide open, grid connections have already been established and projects are located relatively close to end customers. Additionally, providing debt at the parent or holding company level – rather than at the individual project level – allows for some diversification of idiosyncratic project risk and a more resilient cash flow.

> *Power transmission and storage need to be upgraded to handle an energy system with primarily intermittent sources.*

Second, investors should look past wind and solar power generation and explore hydro and geothermal projects – these energy sources can be dispatchable, also have zero marginal cost and can take advantage of higher prices when wind and solar are not producing. Given how few areas can be considered for these kinds of projects and the difficulty in building new ones, these projects also typically face less competition and obsolescence risk than wind and solar projects, and their debt can be very attractive. Specifically, recapitalization of hydro projects in Europe – Scandinavia and Italy – as well as rebuilding of legacy infrastructure in Chile, Peru, Brazil and other parts of Latin America. Geothermal power projects are more of a niche market with some projects arising in the western United States and parts of Iceland.

EM investors should consider well-positioned renewable power generators in India

With both energy demand and renewable supply surging, India provides an intriguing opportunity for investors. It is already the world's fourth-largest electricity consumer as well as the third-largest renewable power producer. Today renewable sources make up 20% of India's power generation and their share is rapidly growing. India reached an inflection point in 2022 adding more power generation from renewables than fossil fuel sources.

In this landscape of incredible growth, companies with a track record of execution on large-scale projects and established relationships with government and regulatory officials can be attractive. Companies like Greenko and ReNew Energy Global are major players in solar and wind power generation today. The cash flows from existing production can also help to support their ambitious capital-intensive efforts to expand power generation capacity.

In addition to providing attractive opportunities, emerging markets typically provide some unusual risks for investors as well. Renewable power generation is no exception. Electricity theft presents a notable risk in many developing countries in Latin America, Asia and Africa with theft rates estimated as high as 20%-30% in some countries and the global price tag for this approaching $100 billion annually.[61, 62]

Key components of the renewable supply chain: wind turbines and minerals

Another way to invest in the wind sector without getting caught up in the imbalanced infrastructure or the highly volatile price of electricity is to consider investments in the makers of wind turbines. They offer a different risk-reward proposition than the individual projects and can be an attractive investment. Vestas, Nordex and Siemens Gamesa are market leaders in the European and North American markets for land-based and offshore wind turbines.

Metals and minerals are also critical components of the future energy system. While critical minerals like lithium and cobalt get much attention given their scarce availability or concentration of processing, their demand is highly linked to current power storage technology and EV sales. By contrast, because of its extraordinary conductivity, resiliency and malleability, copper is essential to all aspects of electrification – from power generation to transmission and even in equipment like EVs. Because of its unique properties, it is difficult to engineer copper completely out of electric systems – unlike, say, cobalt. In fact, the need for copper across all aspects of electrification may sometimes be overlooked by markets. As electrification advances, the global demand for copper is set to more than double by 2050 (Exhibit 15).[63]

As for the supply of copper, it is usually found in remote locations, and mining is very capital and time intensive.[64] Additionally, approvals and permitting for new mines are becoming more challenging due to environmental concerns. As a result, building new capacity can take years and cost billions – new primary copper mines that started production between 2019 and 2022, for example, had an average lead time of more than 20 years.[65] In fact, with declines of up to 25% in the average quality of copper ore being mined, some copper producers will have to spend more just to maintain their current levels of production.[66, 67]

> *Permitting for new copper mines is becoming more challenging due to environmental concerns. As a result, building new capacity can take decades and cost billions.*

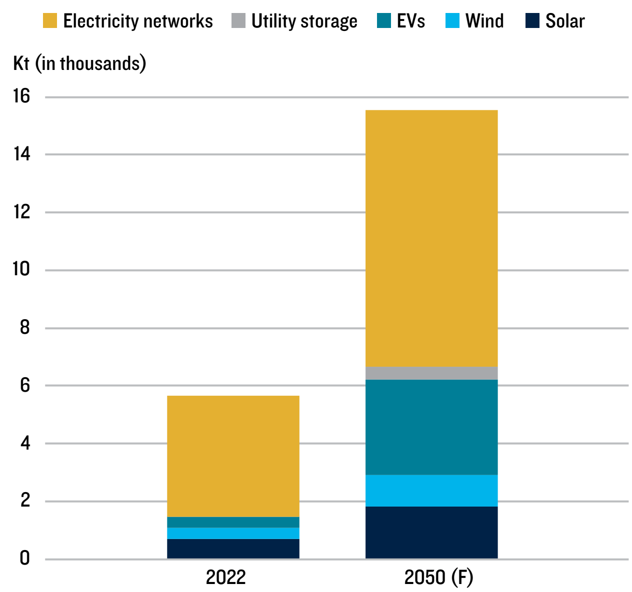
For investors, this creates very attractive long-term supply-demand dynamics.[68] Two pure-play copper miners – Ivanhoe Mines and Ero Copper – may offer solid growth prospects for equity investors. Not only do they produce copper efficiently now, but they also have capacity to expand production soon to meet rising demand. Additionally, for debt investors, Southern Copper and Freeport-McMoRan are large producers with economies of scale, robust cash flows from ongoing business and strong balance sheets.

Expanding and modernizing the grid

The near-universal need for larger and smarter grids presents providers of key grid components and construction services with a powerful macro tailwind. The International Energy Agency estimates that to power itself primarily with renewable energy, the world needs to add or replace nearly 50 million miles of transmission lines by 2040.[69] Companies like Eaton in the US and Schneider Electric in France provide key components including inverters, transistors and substations for transmission lines. Their central role in the energy transition over coming years may not be fully appreciated by the market today.

Exhibit 15: Copper is essential to electrification

Kilotons of copper needed to meet energy transition goals



Note: Shows IEA's assumption under the announced-pledges scenario. (F) indicates forecast.
Source: International Energy Agency. March 2024.

In India, transmission cable makers operate in a somewhat protected market and – given the compelling demand to expand the transmission network – could make for attractive investments. Polycab and Apar Industries are leading players in this growing market.

Engineering and construction of grids and transmission lines is another area where investors can find opportunities in emerging markets. For investors, companies like ISA and Celeo Redes, which engineer and build transmission lines in South America, offer senior secured debt exposure to a portfolio of transmission assets in a liquid, amortizing bond with compensation indexed to inflation and currency rates. Furthermore, they are large operators in their regions and have longstanding relationships with regulators and other government authorities. Having a seat at the table with their respective government officials positions these companies well to navigate permitting challenges and execute on these massive infrastructure projects.

Large-scale and long-duration power storage

Industrial-scale power storage is another vital part of the energy transition that investors should consider. To meet energy transition goals, close to 1,000 GWh of grid-scale and other forms of energy storage will be needed globally by 2030 – roughly 35 times the size of the market today (Exhibit 16).[70] Leading industrial power storage players include Korea's Samsung SDI and LG, China's BYD and Japan's Panasonic.

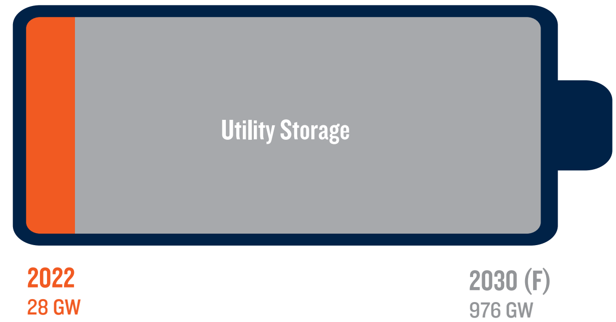
> *Industrial scale power storage is a vital part of the energy transition that investors should consider.*

Long-duration energy storage is a key component of resolving longer-term intermittency and seasonal variability in renewable energy sources. These mechanisms differ substantially from the lithium-based batteries used to power cars and cell phones for hours at a time.[71] They provide the ability to store power for days, weeks or even months to provide an energy system with greater flexibility by absorbing excess power during peak production periods and deploying it as needed to meet seasonal fluctuations in demand and supply.[72] Sufficient and cost-effective long-duration energy storage not only improves the resilience of local and regional electric grids, but it also reduces the need for fossil fuels – such as baseload coal or dispatchable natural gas – to meet energy demand or smooth intermittent renewable power generation.[73]

The most widespread and mature technology used is pumped-storage hydropower, and by some estimates it accounts for 90% or more of bulk electrical energy storage today.[74] It is especially attractive because it can provide an easily dispatchable source of power, but it has specific geographical requirements and there may not be much room to expand. Furthermore, construction of new capacity is very limited because permitting may be difficult to resolve given the displacement of entire towns and villages often involved in these projects. Iberdrola, a European utility, is a current leader in this area. They recently built and opened a new 40 GWh pumped hydro storage facility in northern Portugal that stores excess power and makes it dispatchable for a later date. This brings their current capacity of pumped-storage hydropower stations in Spain and Portugal to over 100 GWh with another 170 GWh under construction or in the pipeline.[75, 76]

Exhibit 16: Growing need for utility storage

Current storage capacity vs. needed storage capacity



Note: Needed storage capacity refers to the net-zero emissions scenario. (F) indicates forecast.
Source: International Energy Agency. March 2024.

Vertically integrated energy providers

Energy providers with power generation and distribution capabilities can be an intriguing area for investors as well. Specifically, dominant players in sizable markets who have a long record of building and maintaining their infrastructure can be very attractive. While these utility firms are often highly regulated, competition is limited in their region, and some may have the ability to pass-through higher costs to end users to protect their margins as well.

In Europe, Iberdrola is a multinational electric utility company and the world's leading producer of wind power with significant expertise and economies of scale. Iberdrola serves around 30 million customers globally and has significant operations across the UK, continental Europe and the Americas. In North America, NextEra Energy is the largest renewable power generator in the US delivering electricity across 49 US states and Canada. They provide electricity from a diversified pool of energy sources that includes wind, solar, nuclear energy and natural gas.

Debt investors may be missing opportunities if they are solely focused on bonds of the holding company. In the case of major power producers like Iberdrola and NextEra, there may be opportunities at the project level as well. These energy producers often finance a portfolio of power projects separately via private credit markets, and this kind of debt can offer investors access to a portfolio of power generation assets.

Energo-Pro is a leading producer of hydropower and an electricity distributor in Eastern Europe and also has exposure to Turkey and Spain. They operate under a regulated rate of return in their distribution business, allowing them to pass through costs to maintain their margins. Given their expertise in acquiring and operating hydropower plants, they also make hydro power equipment and offer consulting services to others.

Large and growing markets provide an excellent backdrop for investors. CenterPoint Energy is a dominant electricity and natural gas distributor in Texas. The state has a growing population, and energy demand is poised to rise with it. Furthermore, Texas is a very large wind and solar generation hub and Centerpoint's grid is a critical component of getting that growing supply to where it is needed.

2. Leaning into lower-carbon fossil fuels while avoiding obsolescence risk

While many aspects of the energy transition remain unsettled and unclear, one thing about the transition is certain – it will take decades, and fossil fuels are not likely to be displaced altogether. In other words, fossil fuels and the immense global network of infrastructure that support their use will contribute to meeting global energy needs for much of the 21st century. For investors, this segment of the energy complex offers opportunities to invest in elements that are quite stable, generate durable cash flows and can bridge the transition to a low-carbon world.

Natural gas is displacing higher-carbon emitting fossil fuels

Natural gas is a key element to a low-carbon future by displacing higher-carbon emitting coal – especially in electricity production. In this capacity it can be valuable as a "transitionary" fuel source while renewable power generation, storage and transmission infrastructure get built up. Indeed, global demand for liquified natural gas is expected to grow by over 50% by 2040 as the coal-to-gas transition expands in China and South Asia.[77]

The surge in natural gas production between 2006 and 2023 globally was driven primarily by the US shale revolution. Hydraulic fracking and horizontal drilling techniques enabled tapping vast new reserves of natural gas in the US, and this development launched a boom around liquified natural gas.[78] US production of LNG has nearly doubled, and the US is now the world's largest exporter (Exhibit 17). Furthermore, Russia's invasion of Ukraine accelerated the LNG infrastructure boom in Europe and other regions. The ability to transport LNG more efficiently has ushered in a more globalized market and improves resiliency as suppliers can respond more quickly to global shocks.[79]

> *For investors, low-carbon fossil fuels offer opportunities to invest in stable, durable cash flows.*

Companies across the natural gas supply chain – from producers to processing to liquifying and transport – can provide attractive opportunities for investors. Small US gas producers like EQT and Antero have efficient operations relative to their peers and offer potential for growth.

Pipelines are another way to invest in natural gas globally. Often these firms have long-term purchase agreements in place. The "toll collecting" from pipelines offers investors a different risk-return proposition in the natural gas space: exposure to booming demand with less exposure to short-term price volatility. In the United States, major pipeline players like Enbridge, Williams and Kinder-Morgan can be attractive for debt investors.

In Latin America, natural gas players like Esentia Energy Systems and GNL Quintero offer distinctive exposure to natural gas transportation and storage as well as LNG regasification. Mexican private power producers like Tierra Mojada and Valia Energia offer investment exposure to baseload, natural gas-fed power plants downstream of pipeline plays.

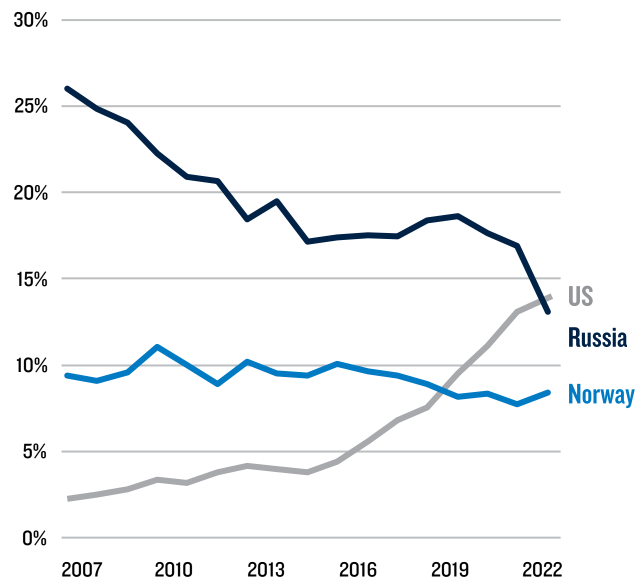
Furthermore, as natural gas producers are pushed to curtail their carbon emissions during extraction, they increasingly turn to drilling service providers like Baker Hughes and SLB. With 50 major oil and gas companies signing pledges at COP28 in late 2023 to substantially curb methane by 2030, the services of these firms will continue to be in demand to detect pipeline leaks and eliminate methane flaring.[80]

For investors seeking to participate in the booming LNG export market without taking on additional commodity risk, Cheniere Energy is an example of a company with a differentiated business proposition. They provide infrastructure to process natural gas into LNG as well as terminals for shipping. With tremendous demand for their services, Cheniere is already a market leader and, given their size and operational efficiency, are achieving economies of scale. There is also room to grow the business with more facilities and additional services. Qatar is another major exporter of LNG, and Gulf International Services is a major drilling contractor in the region with a close relationship to major state-owned producers.

> *Companies across the natural gas supply chain can offer exposure to booming demand with less exposure to short-term price volatility.*

Exhibit 17: The shale revolution has transformed the US into a global natural gas powerhouse

Share of some of the largest exporters of natural gas



Source: Organization of the Petroleum Exporting Countries. March 2024.

Debt opportunities amid mid-size producers

Though some banks have ceased lending to the oil and gas industry altogether, financing is still available for large producers – especially those able to issue in corporate bond markets.[81, 82] However, the pullback in bank lending may be more acute for energy producers too small to tap public credit markets. For direct lenders, this middle-market segment of the energy complex in North America may offer intriguing opportunities as capital can be scarce and lenders have some leverage over pricing and terms.

Early stages of oil and gas exploration and production are often financed with equity. However, once this exploratory work has been completed and optimal areas for drilling wells have been verified, energy players often turn to debt markets for the lower-risk, capital-intensive next stage.[83] This kind of mid-stage development offers reliable cash flows and tangible collateral – making for solid credit fundamentals. Debt that is conservatively underwritten – low leverage, simple capital structures and lending only on the value of known reserves – can be appealing to investors. Additionally, mezzanine or structured debt can come with attractive coupons based on the proven cash flows as well as added upside exposure in the form of asset royalties or warrants – which can provide reliable inflation protection for investors as well.

Is there a role for Big Oil in a new energy system?

Fossil fuels will almost certainly continue to be a component of the energy system of the future – albeit a smaller one and probably more in the form of natural gas than coal and petroleum. This new energy system promises to divide today's Big Oil majors into winners and losers. Some global oil majors will rely on the extended sunset of fossil fuels and focus their investments solely on continuing to provide fuels of the past – namely, petroleum. These firms run the risk of being rendered obsolete by efficiency gains and better infrastructure in renewables. They may ultimately be defined by the magnitude of their stranded carbon assets that are no longer economically viable.

However, there will also be a set of oil majors that will emerge as winners in the new energy landscape. They are more forward-looking, will lean into the energy transition and find ways to remain energy providers regardless of what the primary energy sources might be. Specifically, there are two ways for today's energy majors to remain winners in the energy system of the future:

> *Fossil fuels will almost certainly continue to be a component of the energy system of the future – albeit a smaller one*

1. **Transform their energy production to meet the needs of a new energy system**
   Oil majors that are dynamic enough to shift their energy production to fuel sources of the future will likely remain prominent. Some are incorporating electricity into their current business models. For example, global oil majors BP and Shell are converting their vast network of gas stations into EV charging facilities in the UK and Europe.[84] Others are leveraging their deep insight across the global energy landscape in trading "molecules and electrons" – that is, oil and gas as well as electricity.[85]

   Natural gas and LNG are examples of transitionary fuels that will have a place in the future as a needed complement to renewable sources. TotalEnergies and Shell are two leading producers and transporters of LNG.[86] These companies are well-positioned as gas and LNG make up a significant share of their overall revenues and profits.[87, 88] However, markets may not appreciate this approach as European oil majors like Shell and BP have been trading at a discount to US peers like Exxon Mobil.[89, 90]

2. **Leverage their technical expertise to operationalize green innovations**
   Much innovation in green technology comes from the research labs of oil and gas majors – and there is some evidence to suggest they do it better than energy tech startups. On paper, oil and gas majors not only have robust cash flows to commit significant amounts of capital to fund research, but they also have expertise in extraction, refining and other petrochemical processes to operationalize their findings. Furthermore, these firms have a track record of executing large and complex projects. For example, oil majors with elaborate refining operations can leverage those skills to advance and operationalize biofuels and sustainable aviation.

   Recent research analyzed the landscape of green innovation through the quality and quantity of green tech patents. This research identified oil and gas majors as key innovators around green technology and specifically found both the quantity and quality of green tech patents to be higher for traditional energy firms.[91] The research also indicates the patents from energy firms resulted overwhelmingly from in-house research (rather than acquisitions of startups) and more frequently led to real products that reduced carbon emissions and generated revenue. Shell, BP and Exxon Mobil were among the leaders in green tech patents in areas like biofuels, carbon capture and hydrogen production.[92]

3. Avoiding the hype: Monitoring innovation around renewable energy sources and green tech

Some speculative innovations – like hydrogen – can garner considerable media attention, and firms can be characterized as plucky upstarts challenging large energy incumbents. However, few of the startups behind these speculative technologies are likely to operationalize and scale their businesses sufficiently on their own to displace global energy players. In fact, global energy players will probably be amongst the biggest suppliers and customers for innovative technologies – and many startups in this space may choose to partner with large energy incumbents to leverage their expertise in operations, refining and transport.

For investors, the risk-reward propositions some of these early-stage innovations offer may not be attractive. While these innovations are at different stages of maturity – some closer to the laboratory than the real world – they all have two things in common: first, they each have the potential – when fully mature and operationalized – to profoundly alter the energy landscape. Second, they each face immense challenges before they can be applied in the real world at scale.

Hydrogen fuel cells as an alternate, clean energy source

Hydrogen has gained much attention as a promising alternate fuel source and has some compelling attributes: it is relatively abundant globally, has two and a half times the energy density of gasoline or diesel and burns clean with no carbon emissions. [93]

However, hydrogen faces numerous challenges in transport and storage before it can be used widely. One of the main challenges to wider adoption of hydrogen fuel cells is the specialized infrastructure (and immense cost) needed to produce, transport and store hydrogen. Hydrogen is a gas under typical conditions but is not easily compatible with current pipeline infrastructure. Hydrogen often requires either extreme high pressure (5,000–10,000 psi) or low temperatures (-250 degrees C) to transform it into a liquid state where it is more easily transported or stored.[94] Furthermore, every stage of hydrogen conversion (*e.g.*, gas to liquid and then back to gas) requires energy and only increases the cost to transport and consume hydrogen. Multiple startups are working on resolving the challenges around production, storage and transport of hydrogen. However, they remain far from providing an efficient and viable solution.

> *Research suggests that oil majors are key innovators and among the leaders in green tech patents in areas like biofuels, carbon capture and hydrogen production.*

Nuclear energy: fission to fusion

Nuclear fusion is the process that powers the sun and other stars. It offers the promise of limitless, carbon-free energy.[95] Though fusion reactions have been achieved in government-funded research labs recently, the prospects of commercially operationalizing these reactions to generate power remains decades away.[96, 97] The challenge is nuclear fusion requires such extreme conditions of temperature and pressure – over 100 million degrees Celsius – that creating these conditions safely and efficiently outside of a laboratory is simply not feasible today.

While nuclear fusion moonshots get much media attention, other nuclear technologies have been playing a part of the energy landscape for decades. Nuclear power plays an important role today, with fission-based plants operating in more than 30 countries – more than 60% of France and Slovakia's total electricity come from this kind of nuclear reaction. And many power plants have been running for three decades or more.[98]

With today's focus on energy security and carbon-free energy sources, however, fission-based nuclear power is drawing renewed attention as a key part of the future energy system. Nuclear offers some appealing characteristics: it is locally-based and is a zero-carbon source of baseload power. This also makes it useful for intensive industrial uses like petroleum refining and data centers.

The development of fission-based nuclear energy has been slow since the 1970s due to two main challenges: permitting and cost. Even in cases where the permitting challenges have been met, the estimated cost of power production is not often competitive with other energy sources. Multi-year delays and significant cost overruns in nuclear projects are common. For example, recent new-build nuclear projects in the UK, France and Finland have each seen delays of 10 years or more and actual costs more than double original estimates.[99, 100, 101]

The latest fission innovations are around small-scale reactors. Known as small modular reactors (SMRs) these new designs come with advanced safety features – like automatic shutoffs – and may have lower costs because they can be mass-produced at a factory and shipped in pieces to a site for assembly.[102] They offer the promise of decarbonizing some industrial processes. SMRs are being considered on the sites of retiring coal-fired power plants that have much of the needed infrastructure already in place.[103] In some ways the technology has already been proven as SMRs power hundreds of submarines and ships today and land-based designs have been approved by some national regulators.[104, 105, 106] However, China is the only country to have a land-based SMR currently in operation.[107, 108] While many new SMR projects are announced, few make it to the end because of supply chain challenges as well as cost overruns and delays that make the projects no longer economical.[109, 110]

Innovations in grid-level energy storage

Energy storage mechanisms like batteries can be used to address many challenges facing power sectors growing more reliant on intermittent sources – including improving economic dispatch and transmission system balancing. Furthermore, they can also contribute to resiliency and emergency preparedness.

Lithium-based batteries are dominant, and adoption is growing because advancements in production, efficiency and economies of scale have caused their cost to decline over 80% from 2013 to 2023.[111] Despite these steep price declines, current lithium mechanisms for industrial power storage face several challenges.

Most importantly, lithium batteries are not easy to scale and not always environmentally sustainable. As a result, alternative chemistries that go beyond lithium are emerging. For example, sodium is more abundant than lithium, is cheaper to access and has similar chemical properties.[112] Given their long discharge times, efficiency and improving technology around their density, sodium batteries have tremendous potential for use on the grid.[113, 114]

However, sodium battery technology faces some challenges in the near term. The energy density of sodium-ion batteries is currently below that of lithium-based batteries.[115] Though the chemical components are cheaper and more accessible, the sodium battery industry has not reached economies of scale and has not seen production efficiency gains. In theory, a fully-scaled sodium battery industry should, over time, be able to produce batteries that can be cost-competitive and perform similarly to lithium.[116]

Carbon capture and storage

Carbon capture and storage (CCS) is another potentially transformative technology that faces many real near-term challenges. The process essentially allows for capturing CO_2 emissions from industry sources – such as ethanol manufacturing or coal-fired power plants – and stores the gas in ways that prevent it from ever entering the atmosphere. The promise of CCS is that it enables the world to meet current and future demand – especially in industrial areas that are especially difficult to decarbonize – while still reducing carbon emissions. Indeed, CCS plays a significant role in many zero-carbon scenarios.[117] The challenges of CCS are straightforward. First, there are locational challenges – the sites where carbon is emitted are not often near where carbon can be easily and reliably sequestered. Transporting the captured CO_2 to the sequestration site can be logistically challenging and costly. In the Unites States, there are some efforts underway to build out pipeline infrastructure across the ethanol-producing parts of the Midwest.[118, 119] Companies like Summit Carbon Solutions are involved in building out a "carbon highway" to transport CO_2 from ethanol plants to sequestration and storage sites in other states but face opposition from farmers and landowners around safety and environmental concerns.[120]

> *With today's focus on energy security and carbon-free energy sources, fission-based nuclear power is drawing renewed attention as a key part of the future energy system.*

A second challenge for CCS is how to monetize the operation. In the US, government legislation provides for direct pay incentives, but the uncertainty around the future of the program impedes the long-term infrastructure needed to operationalize it. In countries that have an active carbon market, the sequestration has some value. However, the costs of operation – capturing and filtering the CO_2, transporting it to a different location and sequestering the gas – must be below the value of the incentives for it to be commercially viable.

Chapter 3 examined the hidden risks and opportunities for investors across individual securities and asset classes. However, the evolving and dynamic landscape of the global energy system also has implications that cut across and impact investment portfolios. Chapter 4 turns to these implications and proposes a portfolio-wide action plan for CIOs.

CHAPTER 4

PORTFOLIO IMPLICATIONS

"Government action and ESG objectives each raise important considerations for investors and can impact a range of investment decisions."

04

CHAPTER 4

PORTFOLIO IMPLICATIONS

Government action and ESG objectives each present tradeoffs for investors that impact a range of investment decisions. Here we highlight cross-portfolio implications arising from the changing dynamics across the global energy system and provide an action plan for CIOs.

1. Establish clear positions around global decarbonization, investment objectives and time horizons to inform energy investing

Climate change, decarbonization and energy investing are deeply entangled and highly interconnected. This can leave CIOs, especially those with more climate-focused stakeholders, at times facing conflicting demands and expectations. For example: portfolio decarbonization imperatives from boards – or in some markets regulators; inflation-aligned payouts from pensioners; and enabling a resilient clean energy system from future beneficiaries. The range of cross-purpose demands can be challenging for CIOs wishing to establish a clear and coherent approach to investing in the energy sector. Definitive answers to deceptively simple questions can help inform CIOs thinking around energy investing:

- Are you seeking to purely maximize returns while remaining agnostic as to the environmental credentials of the sources of energy you invest in?
- Are you looking to reduce exposure to climate-related risks over time?
- Are you seeking to play a more proactive and positive role in the decarbonization of our economy?
- Or are you seeking a combination of all three over different time horizons?

Climate change, decarbonization and energy investing are deeply entangled and highly interconnected.

The most effective tools, metrics and approaches to energy investing may differ depending on which objective prevails. Given the layers of complexity around energy investing, it is imperative CIOs have clarity and philosophical agreement with their key stakeholders on these questions first to inform their approach to energy sector investing and establish clear timeframes to guide their decisions.

Clarify objectives around climate change and decarbonization

Having a clear understanding of investment objectives and their multiple impacts across a portfolio is essential. Investors primarily focused on risk-return optimization, for example, face a complex landscape. On the one hand, the shift to electrification and renewables poses transition risks to the fossil fuel realm including producers, equipment makers, utilities, etc. It also raises the prospect of stranded assets – both above ground and below. Electrification can also provide opportunities in other sectors, even energy-intensive ones. For example, as more energy is provided by renewables, power grid prices become more volatile. This volatility can provide arbitrage opportunities for energy-intensive industries to flex their demand for power to coincide with times when renewables are generating lower-cost power.

While embracing the new energy landscape may be a sound long-term strategy as the economy decarbonizes, the costs may be unpalatable in the short term. For example, companies seeking to limit transition risk – such as oil producers – can also struggle to maintain profit margins as they tilt their operations away from fossil fuels. The key question for long-term investors unrestricted by portfolio decarbonization mandates is how to identify companies and assets in critical carbon-intensive segments of today's economy (like steel-making) that are positioning themselves well for transition to the low-carbon economy of the future.

> *Forward-looking carbon-reduction imperatives, for example, may not always align with more near-term goals around economic development and energy poverty.*

Conversely, investors who prioritize portfolio decarbonization or enabling the energy transition, face a different set of challenges. With global energy consumption poised to increase 50% or more by 2050, sustainability-minded investors face the challenge of how to decarbonize in the face of persistent rising global energy demand. Neither divestment from fossil fuels nor investing in the latest climate tech provide a complete answer. A decarbonized global energy supply of the future will rely upon a combination of significant investments in complementary renewable infrastructure, major developments in green tech like hydrogen and carbon capture as well as efficiency gains across multiple sectors and residual fossil fuels including oil and gas. Investors will need to understand where along this spectrum to participate to determine their optimal opportunity set.

Investment time horizon

Regardless of investors' priorities, the risk-return profile of investments in energy is highly dependent on time horizon. For all the focus on long-term risks, it is important to realize many actively managed strategies take advantage of short-term relative value shifts and trading opportunities. Indeed, an active manager with no decarbonization constraints could have anticipated rising oil and gas prices in 2021 and invested in oil producers to take advantage of the short-term price action – even if they believe the long-term prospects for many producers may not be rosy.

The array of tradeoffs within the energy transition over different timeframes makes it essential for investors to be clear about their time horizon – especially since the energy transition will play out over decades and its effect on the energy sector will evolve over that time. For example, the near-term durable cash flows of oil and gas pipelines and their current carbon impact have a different appeal for a pension that is in its runoff phase – paying out all its income and drawing down assets – than they do for a pension that is accumulating assets with its peak payout period decades into the future. A different time horizon can also impact choices around whether to minimize the current carbon footprint of the portfolio today or to lean into investments that enable and maximize avoided emissions in the future.

2. Investors with decarbonization mandates need to consider multiple approaches

For investors with decarbonization mandates, today's energy system presents numerous complexities and challenges. Forward-looking carbon-reduction imperatives, for example, may not always align with near-term goals around economic development and energy poverty. Indeed, multiple approaches for decarbonization have evolved – each making a different tradeoff. Some approaches rely on hard data and focus on current and past Scope 1 and 2 emissions. Others are more forward-looking and lean on estimates of emissions that may be avoided in the future.

Some approaches minimize a portfolio's current carbon footprint

Many net-zero and "Paris-aligned" approaches look to minimize a portfolio's current weighted average carbon intensity (WACI) – a measure of the carbon emissions per revenue by portfolio allocation. The appeal of such an approach is that an investor is supporting those parts of the economy that are not heavy carbon emitters today and can say they are doing their part to not add to carbon emissions.

Typically, this has meant filtering out firms from heavy-emitting sectors, creating challenges when executing this approach across a scaled portfolio. For example, rotating out of high-intensity sectors – like utilities – and leaning into sectors with the lowest WACI today – such as tech firms – can lead to tracking errors unless this is controlled for. Investors should consider a more active portfolio-wide approach that seeks out the most "improving" firms across *all* sectors. This approach can lead to substantial carbon emission reductions across a portfolio (and credible emissions reductions in the real economy) while also minimizing tracking error.

> *Some "off the shelf" temperature alignment models can have a sanguine bias in their ratings.*

Another limitation of a WACI-based approach is that it is a backward-looking measure that focuses on the Scope 1 and 2 emissions of the firm and may not be indicative of the trajectory of future carbon emissions. As a result, investors may be overlooking positive changes made by potential portfolio companies to *reduce* emissions today and in the future. Furthermore, while this approach can create a one-time improvement in the carbon profile of a portfolio, it may be challenging to demonstrate ongoing improvement in WACI year after year.

To account for these limitations, savvy investors need to consider forward-looking projections and evaluate the carbon emissions momentum of a firm. That is, they need to consider the recent trajectory of carbon emissions and evaluate the forward-looking reduction strategies of firms. Additionally, investors will need to actively monitor and reassess each name in their portfolio periodically to ensure they are still reducing carbon today and finding positive carbon momentum for tomorrow – all while minimizing tracking error.

A more forward-looking approach to decarbonization

Increasingly, investors are recognizing that minimizing carbon emissions in their portfolios now may be counterproductive to their ultimate objectives of accelerating a low-carbon economy of the future. Instead, these investors seek to take a longer-term perspective by leaning into technologies that have a high potential to reduce carbon emissions in the future. Because they are looking to maximize *net reduction* of carbon emissions in the future, investors with this approach seek out those firms that have the greatest potential for carbon abatement or displacing high-carbon activities. This approach requires an active strategy and a granular analytical approach that evaluates the credibility and progress of a firm's decarbonization commitments by, for example, evaluating the trajectory of a firm's WACI over the last few years or examining both the quality and volume of their investments in displacing high-carbon activities. Often in these assessments, high-quality, timely data are not available. In executing such strategies, some asset managers employ a mix of qualitative and quantitative analysis.

For investors seeking a forward-looking approach, a temperature-aligned model can also be intriguing. This approach focuses on a firm's forward emissions vs. a benchmark derived from science-based models of an optimal pathway for that sector. For example, a 2 degrees Celsius warming world comes with a maximum global carbon emission over time. That global total for allowable emissions is allocated to sectors and then subdivided for each firm within a sector – creating a rough benchmark for each individual firm. The trajectory of a firm's expected carbon emissions is then compared to the benchmark to determine whether they are over or under their "allowable emissions." This is another methodology for investors to identify those firms that are performing better than their peers at reducing the trajectory of their carbon emissions. This approach has the benefit of identifying more organic emission reductions by not shying away from brown industries and supporting those firms that are actively avoiding emissions at the fastest rate.

> *Carbon neutral pledges made by countries and states can impact the investment decisions of energy producers and distributors.*

Of course, investors will need to recognize some of the shortcomings of this approach and the models commonly used. For example, "off the shelf" temperature alignment models do not ensure that companies' disclosures and plans align with their actual outcomes or results and therefore can have a sanguine bias in their ratings. Some of these models identify nearly half of all firms in their temperature alignment model as being on the path to achieving long-term goals. Investors should look to hold individual firms more accountable by independently verifying their disclosures and plans. This may mean ensuring there are interim targets and incorporating additional metrics to gauge the credibility of their decarbonization commitments. Incorporating rules to capture real-world progress vs. emissions targets is a critical way of validating the results of a temperature-alignment strategy, and CIOs also need to ensure their asset managers are doing this kind of active validation.

3. Closely monitor the current landscape of government "carrots and sticks" – as well as its trajectory

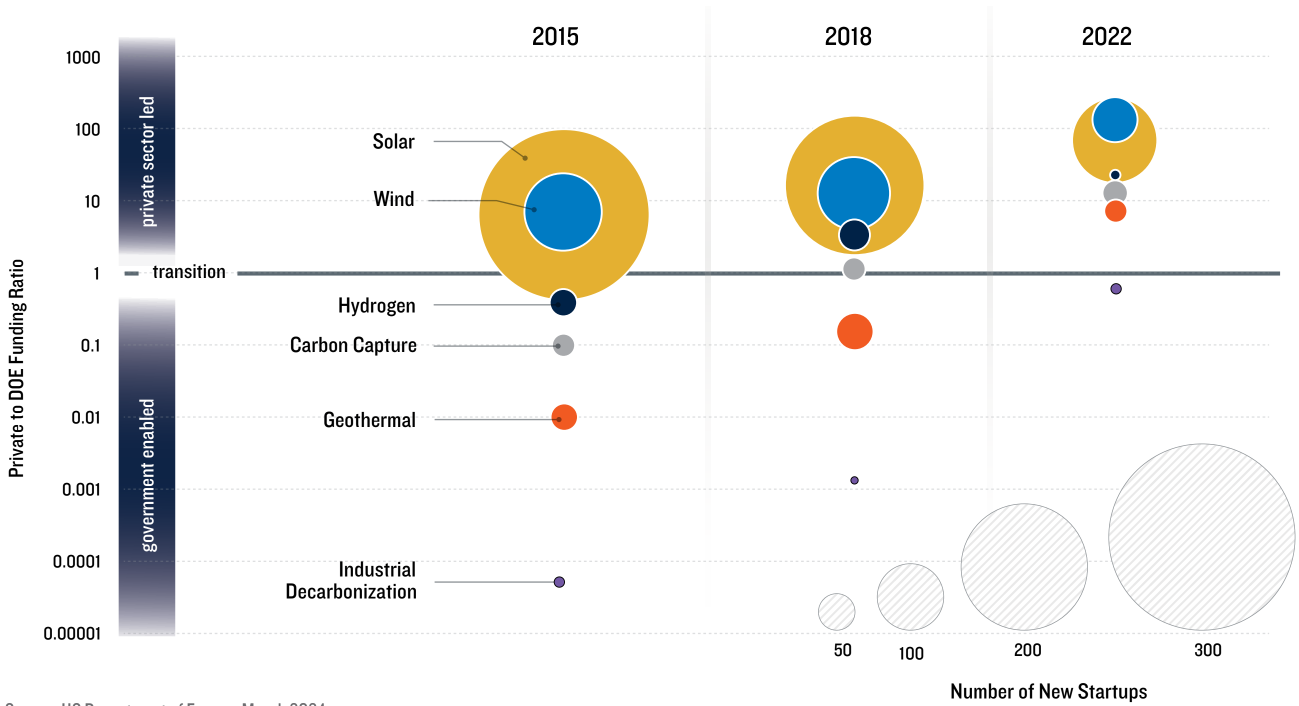
Because of its national security importance, governments play a significant role across the dynamic energy landscape. Given how intertwined government and energy are, investors need to not just be aware of the current state of the policy landscape but also monitor geopolitical and economic developments which influence where it may be headed. Indeed, government involvement is a feature across nearly every region and impacts the risk-reward propositions of energy investments at almost every stage.

For example, governments often fund early-stage basic research around alternative energy sources – like nuclear power – which lead to breakthroughs that find their way into the market.[121] Even at later stages of development, government subsidies and import restrictions can boost critical industries by supporting domestic supply chains for critical energy components – like solar panel manufacturing.[122, 123] While these subsidies and tariffs can support critical energy industries and attract early investors, they are often not permanent and businesses can grow dependent on them. The lingering uncertainty around the future trajectory of supportive policies can be detrimental for investors in the long term.

Attracting private capital to next-generation technology

Investors may find it attractive to invest alongside governments at various stages of innovation. For example, blended finance and public-private partnerships are prominent in emerging markets like India where they can de-risk renewable energy projects, for example, and draw private funding.[124] This is especially true in areas where risk-reward tradeoffs may not otherwise be attractive for private investors.

Exhibit 18: Government involvement in innovative energy technologies can attract private investment



Source: US Department of Energy. March 2024.

In developed markets, government involvement in early-stage funding of innovative technologies can also attract private capital. A study examining investment by the US Department of Energy in cleantech innovations suggests that government funding during early stages of carbon capture and hydrogen production did indeed lead to greater private capital flows in subsequent years (Exhibit 18).

Another key stage where government policy can attract private capital is after a technology has been established and production needs to build scale to gain efficiencies. For example, there are currently government-led initiatives underway in Asia and the Americas to build scale and infrastructure around hydrogen production. The Australian government is executing a National Hydrogen Strategy that includes funding projects directly, as well as revenue support programs to help projects build to scale quickly.[125] Some of the plans are very ambitious. A consortium of energy companies led by BP, for example, plans to build as many as 1,700 wind turbines and 10 million solar panels to produce 26 GW of energy – equivalent to a third of Australia's current grid requirements – in support of green hydrogen production.[126]

Already one of the largest global producers of renewable energy in the world, the state of Texas launched Hydrogen City – an integrated green hydrogen production, storage and transport hub located in South Texas. With additional support from the federal level, the state is attracting interest for green hydrogen projects from global industrial giants.[127, 128]

The focus on hydrogen as a next-generation fuel source is not limited to the most developed economies either. Chile, for example, has launched an ambitious National Green Hydrogen Strategy seeking to promote domestic use amongst its mining and heavy industry sectors. Additionally, the World Bank-supported strategy aims for Chile to be a major exporter of green ammonia products and green hydrogen as well. [129, 130]

Government policy raises several unique risks for energy investors

The shifting landscape of government "carrots and sticks" can alter the economics of large-scale infrastructure projects and add to the uncertainty around estimates of long-term demand and supply. For investors, it is critical to be mindful of this additional layer of uncertainty – and especially so for long-duration debt and infrastructure owners. Specifically, there are several points around policy investors may be overlooking.

First, carbon neutral pledges made by countries and states can impact the investment decisions of energy producers and distributors. For example, Duke Energy is the leading provider and distributor in the state of North Carolina. They have a legal obligation to act on and adhere to the carbon-reduction pledges made by the state legislature.[131] This is influencing their decisions around new energy sources and additional power production.[132]

Second, the life of renewable assets may be longer than current policy is in place for. That is, over the life of their infrastructure asset, government policy can change sharply. These changes may alter the economics of their project and significantly change the value of any debt or equity associated with it.

Third, difficulties in permitting new power plants or transmission lines can serve as a moat for energy providers or distributors. However, as permitting reform becomes more widespread, the size of the moat may shrink and new infrastructure with new technology may render legacy projects obsolete and economically uncompetitive. These kinds of changes around permitting and supply can also radically alter valuations of debt and equity for legacy infrastructure.

At their worst, misplaced government production incentives or tax credits can exacerbate price distortions such as negative pricing during peak demand and supply periods.[133] Or in emerging markets like Mexico, governments protect the interests of state-owned energy firms by impeding private capital investment in renewable power generation.[134] Investors need to examine the role of government policy in each market and assess whether it provides support for their investment thesis or a headwind.

Last, for large-scale consumers of energy, the shifting policy landscape can add another dimension of cost variability to their business models. The swings in energy prices that can arise from even subtle shifts in energy policy serve as an additional source of volatility around cost of goods.

Conclusion

Energy markets have reached a critical inflection point, shifting to renewable energy sources while simultaneously relying on fossil fuels for years to come. This transition will offer many opportunities – from renewable infrastructure to LNG projects – but also a multitude of risks as investors will have to be wary of stranded assets amidst an uncertain path to a lower-carbon future.

While the energy transition will unfold at different paces in different places, what is clear is that it is already underway with significant implications for every investor. At PGIM, we believe it is critical for all investors to consider the many implications of the future energy system on their portfolio and stakeholders (Exhibit 19).

Exhibit 19: Summary of Investment Implications

Enabling renewables and balancing out their infrastructure	
1. Renewable debt opportunities beyond wind and solar power generation	• Debt financing tends to be less plentiful than equity in Europe and the US. This may offer attractive investment opportunities – especially senior debt in mature projects with offtake agreements and grid connections in place. • Investors should consider looking beyond wind and solar power generation projects in Europe and the US and consider hydro and geothermal projects where they are possible.
2. India's renewable power generators offer intriguing opportunity	• India's incredible demand growth provides a strong macro tailwind for renewable power generation companies. • Companies with an established track record of executing on projects and cash flow from existing production may be especially attractive.
3. Wind turbines offer a different risk-reward proposition	• Wind turbines offer a way to invest in renewables with limited exposure to individual power projects and the price volatility of electricity. • Technology leaders in Europe and North America can be particularly attractive.
4. Banking on grid modernization and expansion	• Manufacturers of key grid components – including inverters and substations – offer exposure to a rapidly growing segment of the market. • In South America, transmission companies offer exposure to a portfolio of transmission lines with cost pass-thru capabilities and attractive debt structures.
5. The need for long duration storage	• Utility-scale power storage can mitigate the issues of intermittency and is a vital part of the energy transition. • Pumped-storage hydropower is attractive given its scale, technological maturity and dispatch capacity. While new projects are very limited, investors should consider global players with room to expand their capacity.
6. Vertically integrated energy providers	• Given their long track record of building and maintaining infrastructure and their ability to pass-thru higher costs, regional utilities with power generation and distribution capabilities offer an intriguing investment area. • Some large energy providers finance segments of their power generating assets in private credit markets. Debt investors can find opportunities to get exposure to portfolios of mature projects.

Meeting current demand with fossil fuels while reducing carbon emissions	
1. Natural gas is displacing higher carbon-emitting fuels	• Natural gas can play a critical role in the energy transition by displacing thermal coal. • In the US, small gas producers and large LNG players offer growth potential as global demand soars. • The debt of regional pipeline operators offers investors a different risk-reward proposition.
2. Debt opportunities in the mid-market	• As banks have receded, debt financing for energy producers in the middle-market has become scarcer – creating private credit opportunities. • Investors should look for projects that have passed the exploratory phase as they offer reliable cash flows and tangible collateral.
3. Big Oil and the future role of incumbents	• Though fossil fuels will have an extended sunset, investors need to periodically consider the obsolescence risk in their exposure to Big Oil companies. • Big Oil firms that lean into lower-carbon and renewable sources may face less obsolescence risk – though these firms have not seen higher valuations from markets. • Global oil incumbents are also major players in research around green tech and clean energy. They are among the leaders in patents in areas like biofuels and carbon capture. Some may be winners in the new energy landscape.

Portfolio-wide implications	
1. Establish clear positions on decarbonization, investment objectives and time horizon	• For CIOs it is imperative to clarify their decarbonization objectives with key stakeholders and align their investment timeframe with the energy transition. • Definitive answers to a few simple questions can be clarifying.
2. Investors need to consider multiple approaches to decarbonization	• Minimizing a portfolio's current carbon footprint offers the benefit of supporting current companies with low-carbon emission today, but requires evaluation of future emissions as well. • Investors that take a longer-term perspective should consider firms that have the potential to reduce their own emissions as well as technologies with high potential to avoid carbon emissions in the future.
3. Closely monitor the current landscape and future trajectory of government policy	• Investors need to be aware of the shifting policy landscape because it alters the outlook for investment in every region. • Government policy can impact the risk-reward proposition of energy investments at every stage of development – from basic research all the way on through to large-scale projects.

APPENDIX

A.1: World's largest fossil fuel producers and consumers

Share of the five largest producers and consumers of fossil fuels worldwide (2022)

Oil – Top 5

Production		
	Country	Percent
1	US	18.9%
2	Saudi Arabia	12.9%
3	Russian Federation	11.9%
4	Canada	5.9%
5	Iraq	4.8%

Consumption		
	Country	Percent
1	US	19.7%
2	China	14.7%
3	India	5.3%
4	Saudi Arabia	4.0%
5	Russian Federation	3.7%

Gas – Top 5

Production		
	Country	Percent
1	US	29.8%
2	Russian Federation	15.3%
3	Iran	6.4%
4	China	5.5%
5	Canada	4.6%

Consumption		
	Country	Percent
1	US	22.4%
2	Russian Federation	10.4%
3	Iran	9.5%
4	China	5.8%
5	Canada	3.1%

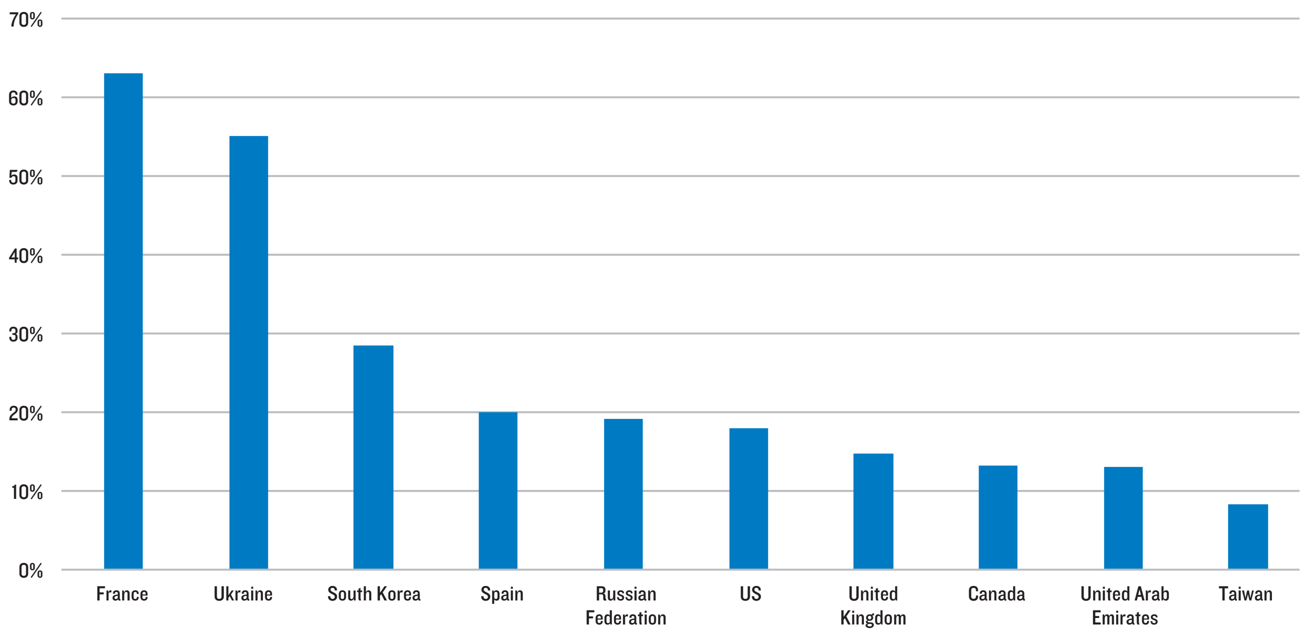
Coal – Top 5

Production		
	Country	Percent
1	China	52.8%
2	India	8.6%
3	Indonesia	8.0%
4	US	6.9%
5	Australia	6.6%

Consumption		
	Country	Percent
1	China	54.8%
2	India	12.4%
3	Indonesia	6.1%
4	US	3.0%
5	Australia	2.7%

A.2: Share of total electricity from nuclear energy

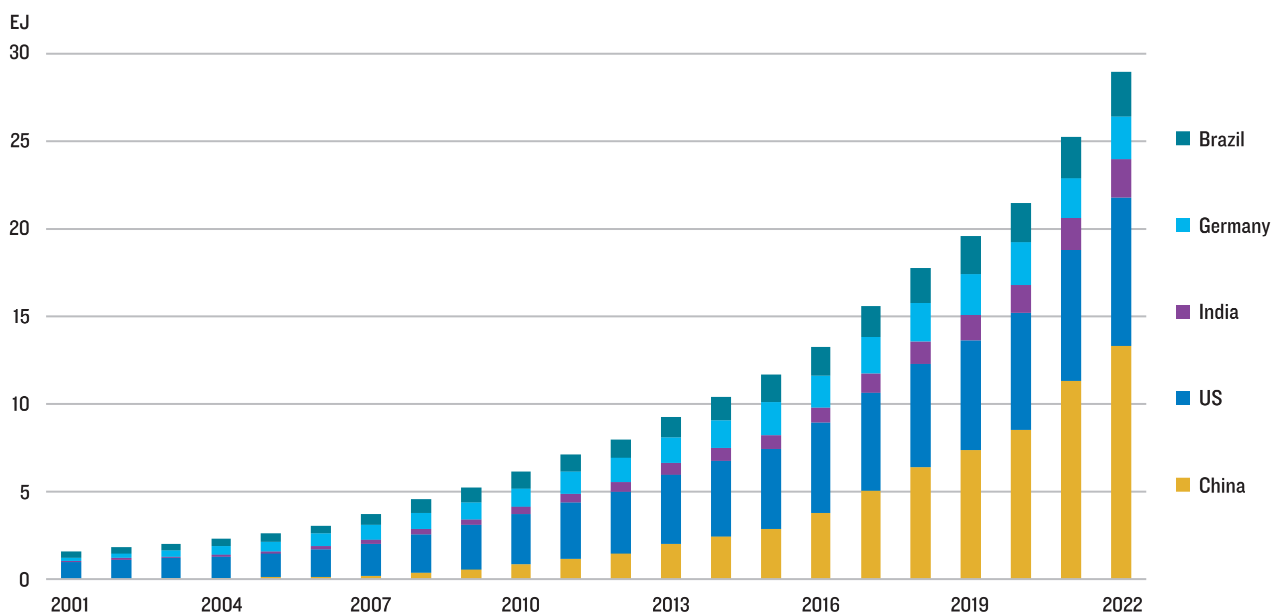
Ten countries with the largest share in 2022



Source: Energy Institute Statistical Review 2023.

A.3: Global energy consumption from renewables

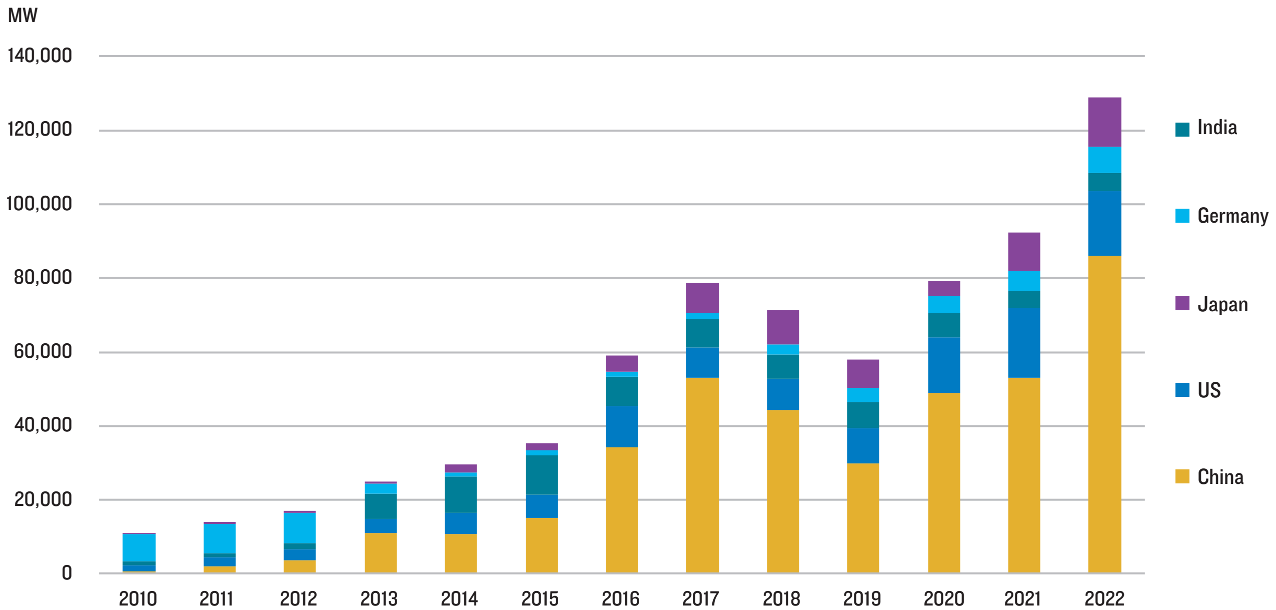
Five largest consumers of renewable energy in 2022, Exajoules



Source: Energy Institute Statistical Review 2023.

A.4: Annual addition of solar capacities

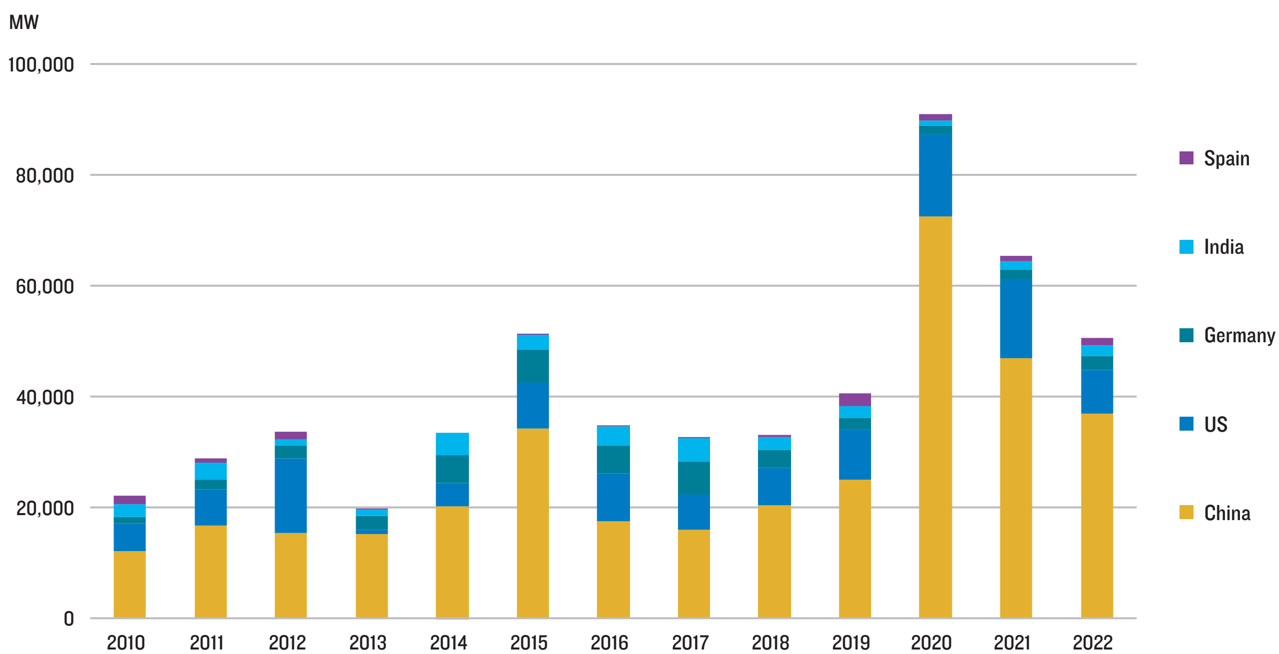
Five countries with the largest new additions in 2022, Megawatt



Source: Energy Institute Statistical Review 2023.

A.5: Annual addition of wind capacities

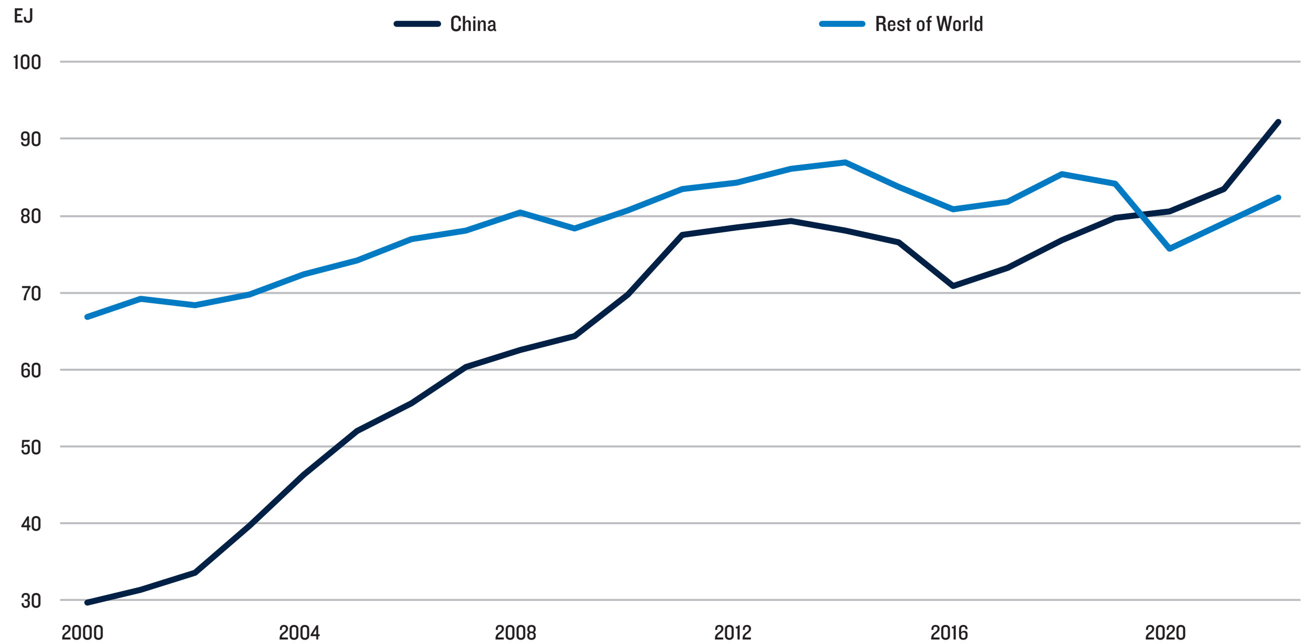
Five countries with the largest new additions in 2022, Megawatt



Source: Energy Institute Statistical Review 2023.

A.6: Annual coal production

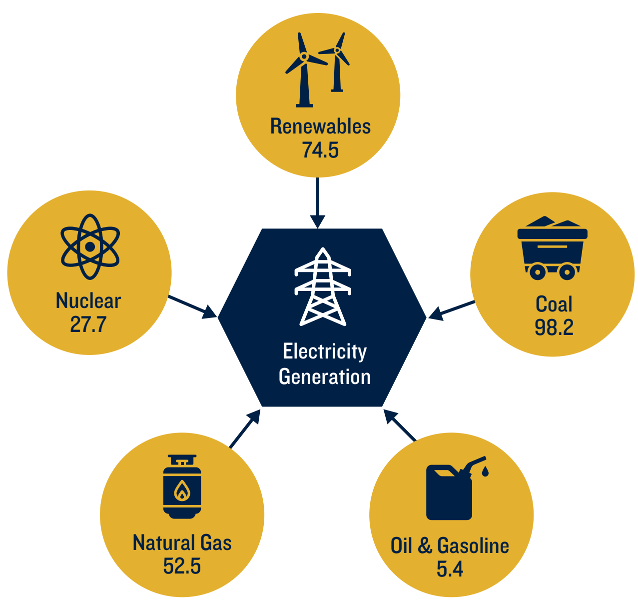
Total coal production of the five largest producers and rest of the world, Exajoules



Source: Energy Institute Statistical Review 2023.

A.7: Electric power generation

Primary energy sources used for Electricity, quadrillion British thermal units (2022)



ACKNOWLEDGMENTS

PGIM gratefully acknowledges the contributions of the following individuals:

Dr. Vanessa Chan, Chief Commercialization Officer, US Department of Energy

Ryan Dalton, Partner, Warburg Pincus

Eric Danzinger, Managing Director, Energy Transition, Riverband Energy Group

Samantha Gross, Director, Energy Security and Climate Initiative, Brookings Institution

Stephen Hendrickson, Director, Office of Technology Transitions, US Department of Energy

Jeff Luse, Partner, Warburg Pincus

Tony Morriss, Senior Manager, Thematic Strategy, Australian Super

Bruce Sassi, President and CEO, Nuclear Energy Insurance Ltd

Katheryn Scott, Engineer, Office of Technology Transitions, U.S. Department of Energy

Travis Skelly, Partner, PruVen

Dr. Scott Tinker, Director, Bureau of Economic Geology, Jackson School of Geosciences, University of Texas

PGIM Contributors

Dr. Raimondo Amabile, PGIM Real Estate

Alyssa Braun, PGIM Fixed Income

Matt Baker, PGIM Private Capital

Neil Brown, Jennison Associates

Wendy Carlson, PGIM Private Capital

Armelle DeVienne, PGIM Fixed Income

Omari Douglas-Hall, PGIM Fixed Income

Bobby Edemeka, Jennison Associates

Jim Footh, PGIM Real Estate

Elizabeth Gunning, PGIM Fixed Income

Callie Hamilton, PGIM Private Capital

Dr. Peter Hayes, PGIM Real Estate

Deb Hemsey, PGIM Private Capital

Matthew Huen, PGIM Real Estate

Eugenia Jackson, PGIM

Darren Ku, PGIM Fixed Income

David Klausner, PGIM Fixed Income

Albert Kwok, Jennison Associates

James Malone, PGIM Fixed Income

Sara Moreno, Jennison Associates

Mark Negus, PGIM Real Estate

Michael Pettit, PGIM Fixed Income

John Ploeg, PGIM Fixed Income

Tom Porcelli, PGIM Fixed Income

Jay Saunders, Jennison Associates

Dr. Gavin Smith, PQS

Naqash Tahir, PGIM Real Estate

Brian Thomas, PGIM Private Capital

Dr. Noah Weisberger, IAS

David Winans, PGIM Fixed Income

Principal Authors

Shehriyar Antia, PGIM Thematic Research

Dr. Taimur Hyat, PGIM

Jakob Wilhelmus, PGIM Thematic Research

ENDNOTES

1 Rhodes, Richard, “Energy: A Human History,” May 29, 2018. https://www.simonandschuster.com/books/Energy/Richard-Rhodes/9781501105364

2 Guénette, Justin-Damien and Jeetendra, Khadan, “The energy shock could sap global growth for years,” June 22, 2022. https://blogs.worldbank.org/developmenttalk/energy-shock-could-sap-global-growth-years

3 Chow, Emily and Yuka, Obayashi, “Wary of 2022 crisis, Asian buyers to build strategic gas reserves,” Reuters, July 20, 2023. https://www.reuters.com/business/energy/wary-2022-crisis-asian-buyers-build-strategic-gas-reserves-2023-07-20/

4 Eckert, Vera and Sims, Tom, “energy crisis fuels coal comeback in Germany,” December 16, 2022. https://www.reuters.com/markets/commodities/energy-crisis-fuels-coal-comeback-germany-2022-12-16/

5 Jacob, Charmaine, “Coal free by 2070? India’s push toward renewables won’t stop coal reliance for the next two decades,” November 2, 2023. https://www.cnbc.com/2023/11/03/india-push-toward-renewables-will-not-stop-coal-reliance-for-20-years.html

6 Palfreman, Jon, “Why the French Like Nuclear Energy,” Accessed March 27, 2024. https://www.pbs.org/wgbh/pages/frontline/shows/reaction/readings/french.html

7 Katwala, Amit, “The World Can’t Wean Itself Off Chinese Lithium,” June 20, 2022. https://www.wired.com/story/china-lithium-mining-production/

8 Wood Mackenzie, “China to hold over 80% of global solar manufacturing capacity from 2023-26,” November 7, 2023. https://www.woodmac.com/press-releases/china-dominance-on-global-solar-supply-chain/

9 Frost, Natasha, “Australia Tries to Break Its Dependence on China for Lithium Mining,” NY Times, May 23, 2023. https://www.nytimes.com/2023/05/23/business/australia-lithium-refining.html

10 Katwala, Amit, “The World Can’t Wean Itself Off Chinese Lithium,” June 20, 2022. https://www.wired.com/story/china-lithium-mining-production/

11 Singh, Rajesh, “India to Resume Curbs on SOlar Imports to Boost Local Producers,” Bloomberg, March 30, 2024. https://www.bloomberg.com/news/articles/2024-03-30/india-brings-back-curbs-on-solar-panel-imports-to-boost-locals

12 Lu, Marcus, “Ranked: Electric Vehicle Sales by Model in 2024,” December 1, 2023. https://www.visualcapitalist.com/electric-vehicle-sales-by-model-2023/

13 Alvarez, Simon, “Volkswagen cites “strong customer reluctance” amid low EV sales,” July 4, 2023. https://www.teslarati.com/volkswagen-strong-customer-reluctance-low-ev-sales

14 Trudell, Craig, “GM, Ford and Tesla Contribute to Setback in EV Sales Growth,” December 15, 2023. https://www.bloomberg.com/news/newsletters/2023-12-15/electric-vehicle-sales-outlook-2024-less-bright-due-to-gm-ford-tesla

15 Takahashi, Nicholas, “Toyota Chairman Predicts Battery Electric Cars Will Only Reach 30% Share,” January 23, 2024. https://www.bloomberg.com/news/articles/2024-01-23/toyota-chairman-predicts-battery-electric-cars-will-only-reach-30-share

16 Crownhart, Casey, “How green steel made with electricity could clean up a dirty industry,” June 28, 2022. https://www.technologyreview.com/2022/06/28/1055027/green-steel-electricity-boston-metal/

17 US Department of Energy, “The Pathway To: Long Duration Energy Storage Commercial Liftoff,” Accessed March 27, 2024. https://liftoff.energy.gov/long-duration-energy-storage/

18 Truby, Johannes Dr. et al, “Financing the green energy transition,” Accessed March 27, 2024. https://www.deloitte.com/global/en/issues/climate/financing-the-green-energy-transition.html

19 Abnett, Kate, “Europe’s grids become green power growth bottleneck, industry warns,” November 16, 2023. https://www.reuters.com/business/energy/europes-grids-become-green-power-growth-bottleneck-industry-warns-2023-11-16/

20 Park, Han-Shin, “Korea rejects BlackRock’s $7.5 bn wind farm project,” January 30, 2024. https://www.kedglobal.com/energy/newsView/ked202401300014

21 Plumer, Brad, “The US Has Billions for Wind and Solar Projects. Good Luck Plugging Them In,” New York Times, Feb. 23, 2023. https://www.nytimes.com/2023/02/23/climate/renewable-energy-us-electrical-grid.html

22 Stallard, Esme and Rowlatt, Justin, “Renewable Energy Projects Worth Billions Stuck on Hold,” BBC, May 10, 2023. https://www.bbc.com/news/science-environment-65500339

23 “Average Lead Times to Build New Electricity Grid Assets in Europe and the United States, 2010-21,” IEA, Jan. 12, 2023. https://www.iea.org/data-and-statistics/charts/average-lead-times-to-build-new-electricity-grid-assets-in-europe-and-the-united-states-2010-2021

24 Despite a Growing Global Consensus, Obstacles to Reducing Net Carbon Emissions to Zero Are Stark,” IMF, accessed March 27, 2024. https://www.imf.org/en/Publications/fandd/issues/2022/12/bumps-in-the-energy-transition-yergin

25 “Global Energy Transformation: A Roadmap to 2050,” IRENA, 2019 edition, accessed March 27, 2024. https://www.irena.org/apps/DigitalArticles/-/media/652AE07BBAAC407ABD1D45F6BBA8494B.ashx

26 “Massive Expansion of Renewable Power Opens Door to Achieving Global Tripling Goal Set at COP28,” IEA, Jan. 11, 2024. https://www.iea.org/news/massive-expansion-of-renewable-power-opens-door-to-achieving-global-tripling-goal-set-at-cop28

27 "Net Zero by 2050: A Roadmap for the Global Energy Sector," US Department of Energy, accessed March 27, 2024. https://www.energy.gov/sites/default/files/2021-12/IEA%2C%20Net%20Zero%20by%202050.pdf

28 International Trade Administration, "Renewable Energy," January 12, 2024. https://www.trade.gov/country-commercial-guides/india-renewable-energy

29 "Electricity 2024 – Analysis and Forecast to 2026," IEA. https://iea.blob.core.windows.net/assets/6b2fd954-2017-408e-bf08-952fdd62118a/Electricity2024-Analysisandforecastto2026.pdf

30 "Electricity Consumption Worldwide in 2022, by Leading Country," Statista, Feb. 19, 2024. https://www.statista.com/statistics/267081/electricity-consumption-in-selected-countries-worldwide//

31 "Electricity 2024 – Analysis and Forecast to 2026," IEA. https://iea.blob.core.windows.net/assets/6b2fd954-2017-408e-bf08-952fdd62118a/Electricity2024-Analysisandforecastto2026.pdf

32 Foy, Kylie, "AI models are devouring energy. Tools to reduce consumption are here, if data centers will adopt," MIT Lincoln Laboratory, September 22, 2023. https://www.ll.mit.edu/news/ai-models-are-devouring-energy-tools-reduce-consumption-are-here-if-data-centers-will-adopt.

33 Jones, Nicola, "How to stop data centres from gobbling up the world's electricity," Nature, September 12, 2018. https://www.nature.com/articles/d41586-018-06610-y

34 St. John, Jeff, "Suddenly, US Electricity Demand Is Spiking. Can the Grid Keep Up?" Canary Media, Dec. 20, 2023. https://www.canarymedia.com/articles/transmission/suddenly-us-electricity-demand-is-spiking-can-the-grid-keep-up

35 Wilson, John D. and Zimmerman, Zack, "The Era of Flat Power Demand Is Over," Grid Strategies, December 2023. https://gridstrategiesllc.com/wp-content/uploads/2023/12/National-Load-Growth-Report-2023.pdf

36 Loten, Angus, "Rising Data Center Costs Linked to AI Demands," July 13, 2023. https://www.wsj.com/articles/rising-data-center-costs-linked-to-ai-demands-fc6adc0e

37 "Equinix to Install Largest Deployment of Fuel Cells for the Colocation Data Center Industry," Bloom Energy, August 16, 2017. https://www.bloomenergy.com/news/equinix-to-install-largest-deployment-of-fuel-cells-for-the-colocation-data-center-industry/

38 "ECL Introduces World's First Fully-Green, Hydrogen-Powered, Off-Grid Data Center-as-a-Service with 99.9999 Percent Uptime at Significantly Lower Cost Than Traditional Colocation Data Centers," Business Wire, Jan. 24, 2023. https://www.businesswire.com/news/home/20230124005492/en/ECL-Introduces-World%E2%80%99s-First-Fully-Green-Hydrogen-Powered-Off-Grid-Data-Center-as-a-Service-with-99.9999-Percent-Uptime-at-Significantly-Lower-Cost-Than-Traditional-Colocation-Data-Centers

39 "Singapore Data Center to Expand Capacity with Bloom Energy Fuel Cells," Bloom Energy. September 6, 2023. https://newsroom.bloomenergy.com/blog/singapore-data-center-to-expand-capacity-with-bloom-energy-fuel-cells

40 Swinhoe, Dan, "AWS Acquires Talen's Nuclear Data Center Campus in Pennsylvania," Data Centre Dynamics, March 4, 2024. https://www.datacenterdynamics.com/en/news/aws-acquires-talens-nuclear-data-center-campus-in-pennsylvania/

41 Proctor, Darrell, "Hydrogen Production, SMRs Touted for Virginia Data Center Hub," August 20, 2023. https://www.powermag.com/hydrogen-production-smrs-touted-for-virginia-data-center-hub

42 "Glossary of Terms Used in NERC Reliability Standards," NERC, updated Dec. 1, 2023. https://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf

43 Milligan, Michael et al, "Marginal Cost Pricing in a World without Perfect Competition: Implications for Electricity Markets with High Shares of Low Marginal Cost Resources," Technical Report, December 2017. https://www.nrel.gov/docs/fy18osti/69076.pdf

44 "Maintaining Reliability in the Modern Power System," US Department of Energy, December 2016. https://www.energy.gov/sites/prod/files/2017/01/f34/Maintaining%20Reliability%20in%20the%20Modern%20Power%20System.pdf

45 Borenstien, Severin & Kellogg, Ryan, "Challenges of a Clean Energy Transition and Implications for Energy Infrastructure Policy," December 2021. https://www.economicstrategygroup.org/wp-content/uploads/2021/11/7-Borenstein-Kellogg.pdf

46 "Our Work Areas Energy Access," UN Development Programme. https://www.undp.org/energy/our-work-areas/energy-access

47 Ebrahim, Zofeen T., "Pakistan in uproar as protests over soaring energy prices turn violent," September 2, 2023. https://www.theguardian.com/global-development/2023/sep/05/pakistan-uproar-violent-protests-soaring-fuel-electricity-prices

48 Savage, Susannah, "Protests over food and fuel surged in 2022 — the biggest were in Europe," January 17, 2023. https://www.politico.eu/article/energy-crisis-food-and-fuel-protests-surged-in-2022-the-biggest-were-in-europe/

49 Wanna, Carly, "Replacing US Coal Plants With Solar and Wind Is Cheaper Than Running Them," January 30, 2023. https://www.bloomberg.com/news/articles/2023-01-30/new-us-solar-and-wind-cost-less-than-keeping-coal-power-running

50 Witze, Alexandra, "Earth boiled in 2023 — will it happen again in 2024?," January 12, 2024. https://www.nature.com/articles/d41586-024-00074-z

51 "2023 was the World's Warmest Year on Record, by Far," NOAA, Jan. 12, 2024. https://www.noaa.gov/news/2023-was-worlds-warmest-year-on-record-by-far warmest year on record, by far," January 12, 2024. https://www.noaa.gov/news/2023-was-worlds-warmest-year-on-record-by-far

52 "The Causes of Climate Change," NASA, accessed March 27, 2024. https://climate.nasa.gov/causes/

53 PGIM Megatrends, "Weathering Climate Change: Opportunities and risks in an altered landscape," Accessed March 27, 2024. https://www.pgim.com/pgim-japan/insights/pgim-mega-trend-weathering-climate-change

54 “Weathering Climate Change: Opportunities and Risks in an Altered Landscape,” PGIM Megatrends, accessed March 27, 2024. https://www.pgim.com/pgim-japan/insights/pgim-mega-trend-weathering-climate-change

55 United Nations, “For a liveable climate: Net-zero commitments must be backed by credible action,” Accessed March 27, 2024. Net Zero Coalition | United Nations

56 “Statistical Review of World Energy,” Energy Institute. https://www.energyinst.org/statistical-review

57 Jopson, Barney, “the Problem with Europe’s Ageing Wind Farms,” Financial Times, Feb. 22, 2024. https://www.ft.com/content/7f742d23-673b-47d3-9ce9-64fa5d322abee

58 Parker, Halle, “Few bid after U.S. opens first-ever offshore wind leases in the Gulf of Mexico off Louisiana, Texas coasts,” August 29, 2023. https://www.wwno.org/coastal-desk/2023-08-29/u-s-opens-first-ever-offshore-wind-leases-in-the-gulf-of-mexico-off-louisiana-texas-coasts

59 Wasser, Miriam, “Offshore wind in the U.S. hit headwinds in 2023. Here’s what you need to know,” December 27. 2023. https://www.npr.org/2023/12/27/1221639019/offshore-wind-in-the-u-s-hit-headwinds-in-2023-heres-what-you-need-to-know

60 Novik, Mari, “Wind Industry in Crisis as Problems Mount,” Wall Street Journal, updated Aug. 7, 2023. https://www.wsj.com/articles/wind-industry-hits-rough-seas-as-problems-mount-5490403a

61 Yakubu, Osman, “Electricity theft: Analysis of the underlying contributory factors in Ghana” https://www.sciencedirect.com/science/article/abs/pii/S0301421518306232

62 Iyer, Sairaj, “Technology vs the $16 billion hole,” February 14, 2023. https://www.sify.com/technology/technology-vs-the-16-billion-hole/

63 “Mineral requirements for clean energy transitions,” IEA, Accessed March 15, 2024. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/mineral-requirements-for-clean-energy-transitions

64 Fernyhough, James, “Rio Tinto Digs Deep as Prized $7 Billion Copper Mine Finally Delivers,” Bloomberg, March 12, 2023. https://www.bloomberg.com/news/articles/2023-03-13/rio-tinto-digs-deep-as-7-billion-copper-mine-finally-delivers

65 Li, Ying, “Copper Miners Enjoy High Profits, but Development Capital Expenditure Lag,” S&P Global, April 26, 2023. https://www.spglobal.com/marketintelligence/en/news-insights/research/copper-miners-enjoy-high-profits-but-development-capital-expenditure-lag

66 Skidmore, Zachary, “Fragmentation of the copper supply chain,” May 20, 2022. https://www.mining-technology.com/features/copper-supply-chain-fragmentation/?cf-view

67 Fernyhough, James, “Copper Mine Flashes Warning of ‘Huge Crisis’ for World Supply,” May 2, 2023. https://www.bloomberg.com/news/features/2023-05-02/copper-faces-troubled-future-as-renewable-energy-causes-demand-to-surge

68 Woods, Bob, “Copper is critical to energy transition. The world is falling way behind on producing enough,” September 27, 2023. https://www.cnbc.com/2023/09/27/copper-is-critical-to-climate-the-world-is-way-behind-on-production.html

69 “IEA Warns of Insufficient Transmission Lines Worldwide to Connect Renewables to the Grid,” IER, Oct. 20, 2023. https://www.instituteforenergyresearch.org/international-issues/iea-warns-of-insufficient-transmission-lines-worldwide-to-connect-renewables-to-the-grid/

70 “Global Installed Grid-Scale Battery Storage Capacity in the Net Zero Scenario, 2015-2030,” IEA, July 10, 2023. https://www.iea.org/data-and-statistics/charts/global-installed-grid-scale-battery-storage-capacity-in-the-net-zero-scenario-2015-2030

71 “The Pathway To: Long Duration Energy Storage Commercial Liftoff,” US Department of Energy, accessed March 27, 2024. https://liftoff.energy.gov/long-duration-energy-storage/

72 “Net-Zero Power: Long-Duration Energy Storage for a Renewable Grid,” McKinsey Sustainability https://www.mckinsey.com/capabilities/sustainability/our-insights/net-zero-power-long-duration-energy-storage-for-a-renewable-grid

73 “The Pathway To: Long Duration Energy Storage Commercial Liftoff,” US Department of Energy, accessed March 27, 2024. https://liftoff.energy.gov/long-duration-energy-storage/

74 McWilliams, Mike, “6.08 – Pumped Storage Hydropower,” Volume 6, 2022. https://www.sciencedirect.com/science/article/abs/pii/B9780128197271000790

75 “Pumped-Storage Hydropower Plants: Do You Know What Pumped-Storage Hydropower Stations Are Used For?” Iberdrola, accessed March 27, 2024. https://www.iberdrola.com/sustainability/pumped-storage-hydropower

76 Jopson, Barney, “Can ‘Water Batteries’ Solve the Battery Storage Conundrum?” Financial Times, Jan. 9, 2024. https://www.ft.com/content/5f0c2623-dfd4-4542-8d94-8bf1dfefcec7

77 “LNG Outlook 2024,” Shell, March 2024. https://www.shell.com/what-we-do/oil-and-natural-gas/liquefied-natural-gas-lng/lng-outlook-2024/_jcr_content/root/main/section_125126292/promo_copy_copy_copy/links/item0.stream/1709628426006/3a2c1744d8d21d83a1d4bd4e6102dff7c08045f7/master-lng-outlook-2024-march-final.pdf

78 “Energy Policies of IEA Countries,” IEA, United States 2019 Review, accessed March 27, 2024. https://iea.blob.core.windows.net/assets/7c65c270-ba15-466a-b50d-1c5cd19e359c/United_States_2019_Review.pdf

79 “After Peak in Mature Markets, Global Gas Demand Is Set for Slower Growth in Coming Years,” IEA, Oct. 10, 2023. https://www.iea.org/news/after-peak-in-mature-markets-global-gas-demand-is-set-for-slower-growth-in-coming-years

80 Gupte, Eklavya et al., “COP28: Fifty oil and gas companies sign net-zero, methane pledges,” S&P Global, Dec. 2, 2023. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/120223-cop28-fifty-oil-and-gas-companies-sign-net-zero-methane-pledges

81 “BNP Paribas: Will No Longer Finance Development of New Oil and Gas Fields,” Reuters, May 11, 2023. https://www.reuters.com/business/sustainable-business/bnp-paribas-will-no-longer-provide-financing-development-new-oil-gas-fields-2023-05-11/

82 Johnston, Ian, “Oil and Gas Firms Face Virtually No Extra Borrowing Costs, S&P Finds,” Financial Times, Nov. 17, 2023 https://www.ft.com/content/830e3ae6-0c3c-4da9-87e7-4ff72aa3e249

83 Halbout, Jérôme, “Financing of Energy Investment,” Palgrave Handbook of International Energy Economics, May 28, 2022. https://link.springer.com/chapter/10.1007/978-3-030-86884-0_17

84 Bindman, Polly, “How oil majors penetrated the EV charging market,” Energy Monitor, November 8, 2023. https://www.energymonitor.ai/tech/networks-grids/how-oil-majors-penetrated-the-ev-charging-market/

85 Bousso, Ron, “Energy giants’ LNG trading results reveal diverging regional bets,” Reuters, November 6, 2023. https://www.reuters.com/business/energy/energy-giants-lng-trading-results-reveal-diverging-regional-bets-2023-11-03/

86 Soudani, Amine, “TotalEnergies, the Leading Exporter of U.S. LNG,” Accessed March 27, 2024. https://corporate.totalenergies.us/totalenergies-largest-exporter-us-lng

87 Bousso, Ron, “Shell’s LNG Trading Makes $2.4B in Final 2023 Quarter, Sources Say,” Reuters, Feb. 23, 2024. https://www.reuters.com/business/energy/shells-lng-trading-makes-24-bln-final-2023-quarter-sources-say-2024-02-23/

88 Ibid.

89 Swint, Brian, “BP and Shell Are Worth Less Than Exxon and Chevron. Here’s Why,” Barron’s, Feb. 23, 2024. https://www.barrons.com/articles/bp-shell-valuations-8545e2b2

90 Swint, Brian, “BP and Shell vs. Exxon and Chevron: The Mystery of Big Oil’s P/E Gap,” Barron’s, Jan. 6, 2023. https://www.barrons.com/articles/bp-and-shell-vs-exxon-and-chevron-the-mystery-of-big-oils-p-e-gap-51673052237

91 Cohen, Lauren et al, “The ES-Innovation Disconnect: Evidence from Green Patenting”, February, 2024. https://www.nber.org/system/files/working_papers/w27990/w27990.pdf

92 Hulbert, Mark, “ESG Investing: Surprising Companies at the Forefront of Green Innovation,” Investor’s Business Daily, Oct. 27, 2023. https://www.investors.com/news/esg-investing-surprising-companies-at-forefront-of-green-tech-innovation/

93 Molloy, Patrick, “Run on Less with Hydrogen Fuel Cells,” ACT News, Sept. 25, 2019. https://www.act-news.com/news/fcevs-run-on-less/

94 “Hydrogen Benefits and Considerations,” US Department of Energy, accessed March 27, 2024. https://afdc.energy.gov/fuels/hydrogen_benefits.html

95 Barbarino, Matteo, “What Is Nuclear Fusion?” IAEA, Aug. 3, 2023. https://www.iaea.org/newscenter/news/what-is-nuclear-fusion

96 “Press Conference: Secretary Granholm & DOE leaders Announced Fusion Breakthrough by DOE National Lab,” US Department of Energy, Dec. 13, 2022. https://www.youtube.com/watch?v=K2ktAL4rGuY

97 Ball, Philip, “What Is the Future of Fusion Energy?” Scientific American, June 1, 2023. https://www.scientificamerican.com/article/what-is-the-future-of-fusion-energy/

98 Novak, Stanislav and Podest, Milan, “Nuclear Power Plant Ageing and Life Extension: Safety Aspects,” IAEA, April 1987. https://www.iaea.org/sites/default/files/29402043133.pdf

99 “EDF Eyes Flamanville EPR Nuclear Reactor Fuel Loading in March,” Reuters, Dec. 21, 2023. https://www.reuters.com/business/energy/edf-eyes-flamanville-epr-nuclear-reactor-fuel-loading-march-2023-12-21/

100 “Finland’s New Nuclear Reactor: What Does It Mean for Climate Goals and Energy Security?” Euronews Green with AP, April 17, 2023. https://www.euronews.com/green/2023/04/17/finlands-new-nuclear-reactor-what-does-it-mean-for-climate-goals-and-energy-security

101 Crellin, Forrest et al., “EDF’s UK Hinkley Point Nuclear Plant Start Date Delayed Again, Costs Mount,” Reuters, Jan. 25, 2024. https://www.reuters.com/business/energy/edfs-nuclear-project-britain-pushed-back-2029-may-cost-up-34-bln-2024-01-23 /

102 Cho, Adrian, “Deal to build pint-size nuclear reactors canceled,” November 10, 2023. https://www.science.org/content/article/deal-build-pint-size-nuclear-reactors-canceled

103 Siegler, Kirk, “Why a Town on the Front Line of America’s Energy Transition Isn’t Letting Go of Coal,” NPR, March 28, 2024. https://www.npr.org/2024/03/28/1240708556/why-a-town-on-the-front-line-of-americas-energy-transition-isnt-letting-go-of-co

104 Dewan, Angela et al, “New-wave reactor technology could kick-start a nuclear renaissance — and the US is banking on it,” February 1, 2024. https://www.cnn.com/2024/02/01/climate/nuclear-small-modular-reactors-us-russia-china-climate-solution-intl/index.html

105 “NRC Certifies First US Small Modular Reactor Design,” Office of Nuclear Energy, Jan. 20, 2023. https://www.energy.gov/ne/articles/nrc-certifies-first-us-small-modular-reactor-design

106 World Nuclear News, “Preparatory work stepped up for Russia’s first land-based SMR,” February 9, 2024. https://world-nuclear-news.org/Articles/Preparatory-work-stepped-up-for-Russia-s-first-lan.

107 Ibid.

108 Peng, Dannie, “Small Modular Nuclear Reactors: How China and the US Are Poles Apart in Energy Ambitions,” South China Morning Post, Dec. 9, 2023. https://www.scmp.com/news/china/science/article/3244234/small-modular-nuclear-reactors-how-china-and-us-are-poles-apart-energy-ambitions

109 "Global Nuclear SMR Project Pipeline Expands to 22 GW, Increasing More Than 65% Since 2021," Wood Mackenzie, March 7, 2024. https://www.woodmac.com/press-releases/2024-press-releases/global-nuclear-smr-project-pipeline-expands-to-22-gw-increasing-more-than-65-since-2021/

110 Bright, Zach, "NuScale cancels first-of-a-kind nuclear project as costs surge," November 9, 2023. https://www.eenews.net/articles/nuscale-cancels-first-of-a-kind-nuclear-project-as-costs-surge/

111 BloombergNEF, "Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh," November 26, 2023. https://about.bnef.com/blog/lithium-ion-battery-pack-prices-hit-record-low-of-139-kwh/

112 Spano, Christina, "Sodium batteries offer an alternative to tricky lithium," October, 26, 2023. https://www.economist.com/leaders/2023/10/26/sodium-batteries-offer-an-alternative-to-tricky-lithium

113 Breakthrough Energy, "Advancing the Landscape of Clean Energy Innovation," February, 2019. https://breakthroughenergy.org/wp-content/uploads/2022/10/Report_AdvancingtheLandscapeofCleanEnergyInnovation_2019.pdf

114 Crownhart, Casey, "How sodium could change the game for batteries," May 11, 2023. https://www.technologyreview.com/2023/05/11/1072865/how-sodium-could-change-the-game-for-batteries/

115 Ibid.

116 Spano, Christina, "Sodium batteries offer an alternative to tricky lithium," October, 26, 2023. https://www.economist.com/leaders/2023/10/26/sodium-batteries-offer-an-alternative-to-tricky-lithium

117 McKinsey & Company, "Scaling the CCUS industry to achieve net-zero emissions," October 28, 2022. https://www.mckinsey.com/industries/oil-and-gas/our-insights/scaling-the-ccus-industry-to-achieve-net-zero-emissions

118 Douglas, Leah, "POET's US Midwest ethanol plants to join Summit Carbon pipeline project," January 29, 2024. https://www.reuters.com/sustainability/climate-energy/poets-us-midwest-ethanol-plants-join-summit-carbon-pipeline-project-2024-01-29/

119 Dunker, Chris, "Carbon pipeline says it has secured easements for half of Nebraska route," December 6, 2022. https://journalstar.com/news/state-and-regional/govt-and-politics/carbon-pipeline-says-it-has-secured-easements-for-half-of-nebraska-route/article_4daa603f-38fd-5d71-9461-ad0b5314a871.html

120 Douglas, Leah, "US carbon capture pipeline setbacks reflect challenges in climate fight," September 28, 2023. https://www.reuters.com/sustainability/us-carbon-capture-pipeline-setbacks-reflect-challenges-climate-fight-2023-09-28/

121 "The History of Nuclear Energy," US Department of Energy, accessed March 27, 2024. https://www.energy.gov/ne/articles/history-nuclear-energy

122 Dvorak, Phred, "America Wanted a Homegrown Solar Industry. China Is Building a Lot of It," Wall Street Journal, Feb. 6, 2024. https://www.wsj.com/business/america-wanted-a-homegrown-solar-industry-china-is-building-a-lot-of-it-a782f959

123 Robinson, Quillan, "The True Cost of Chinese Solar Panels," Time, Jan. 18, 2024. https://time.com/6564184/chinese-solar-panels-cost

124 Ivory, Robin, "How Is Blended Finance Deployed in South Asia?" Convergence, March 14, 2024. https://www.convergence.finance/news-and-events/news/7dygNJASNYPPfN9AHRhvLc/view

125 "Hydrogen Energy," Australian Renewable Energy Agency, accessed March 27, 2024. https://arena.gov.au/renewable-energy/hydrogen/

126 Bearak, Max, "Inside the Global Race to Turn Water into Fuel," New York Times, March 11, 2023. https://www.nytimes.com/2023/03/11/climate/green-hydrogen-energy.html

127 "Australia's Fortescue FFI Sees Texas Potential Among 5 Key Projects," Reuters, Feb. 14, 2023. https://www.reuters.com/business/sustainable-business/australias-fortescue-ffi-sees-texas-potential-among-5-key-projects-2023-02-15/

128 "Linde to Invest $1.8B to Supply Clean Hydrogen to OCI's World-Scale Blue Ammonia Project in the US Gulf Coast," Linde, Feb. 6, 2023. https://www.linde.com/news-media/press-releases/2023/linde-to-invest-1-8-billion-to-supply-clean-hydrogen-to-oci-s-world-scale-blue-ammonia-project-in-the-u-s-gulf-coast

129 "National Green Hydrogen Strategy: Chile, a Clean Energy Provider for a Carbon Neutral Planet," Ministry of Energy, Government of Chile, November 2020. https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf

130 "Chile to Accelerate Its Green Hydrogen Industry with World Back Support," The World Bank, June 29, 2023. https://www.worldbank.org/en/news/press-release/2023/06/29/chile-to-accelerate-its-green-hydrogen-industry-with-world-bank-support

131 Gavin, Cassie, "Response to Duke Energy's Proposed Combined Carbon Plan and Integrated Resources Plan (CPIRP)," NC Sustainable Energy Association, Dec. 5, 2023. https://energync.org/response-to-dukes-proposed-combined-cprip-blog/

132 "Duke Energy Files Updated Carbon Plan to Serve the Growing Energy Needs of a Thriving North Carolina," Duke Energy, Aug. 17, 2023. https://news.duke-energy.com/releases/duke-energy-files-updated-carbon-plan-to-serve-the-growing-energy-needs-of-a-thriving-north-carolina

133 Seel, Joachim et al., "Plentiful electricity turns wholesale prices negative," Lawrence Berkeley National Laboratory, November 2021. https://emp.lbl.gov/publications/plentiful-electricity-turns-wholesale

134 Graham, Dave, "Mexico's Sheinbaum Spurs Hope of More Private Investment in Energy After Lopez Obrador," Reuters, Dec. 21, 2023. https://www.reuters.com/world/americas/mexicos-sheinbaum-spurs-hope-more-private-investment-energy-after-lopez-obrador-2023-12-21/

IMPORTANT INFORMATION

Professional Investor Use Only. All investments involve risks, including possible loss of principal. Past performance is not indicative of future results.

The information contained herein is provided by PGIM, Inc., the principal asset management business of Prudential Financial, Inc. (PFI), and a trading name of PGIM, Inc. and its global subsidiaries. PGIM, Inc. is an investment adviser registered with the U.S. Securities and Exchange Commission (SEC). Registration with the SEC does not imply a certain level of skill or training.

In the United Kingdom, information is issued by PGIM Limited with registered office: Grand Buildings, 1-3 Strand, Trafalgar Square, London, WC2N 5HR. PGIM Limited is authorised and regulated by the Financial Conduct Authority ("FCA") of the United Kingdom (Firm Reference Number 193418). In the European Economic Area ("EEA"), information is issued by PGIM Netherlands B.V. with registered office: Gustav Mahlerlaan 1212, 1081 LA Amsterdam, The Netherlands. PGIM Netherlands B.V. is, authorised by the Autoriteit Financiële Markten ("AFM") in the Netherlands (Registration number 15003620) and operating on the basis of a European passport. In certain EEA countries, information is, where permitted, presented by PGIM Limited in reliance of provisions, exemptions or licenses available to PGIM Limited under temporary permission arrangements following the exit of the United Kingdom from the European Union. These materials are issued by PGIM Limited and/or PGIM Netherlands B.V. to persons who are professional clients as defined under the rules of the FCA and/or to persons who are professional clients as defined in the relevant local implementation of Directive 2014/65/EU (MiFID II). In Italy, information is provided by PGIM Limited authorized to operate in Italy by Commissione Nazionale per le Società e la Borsa (CONSOB). In Japan, information is provided by PGIM Japan Co., Ltd. ("PGIM Japan") and/or PGIM Real Estate (Japan) Ltd. ("PGIMREJ"). PGIM Japan, a registered Financial Instruments Business Operator with the Financial Services Agency of Japan offers various investment management services in Japan. PGIMREJ is a Japanese real estate asset manager that is registered with the Kanto Local Finance Bureau of Japan. In Hong Kong, information is provided by PGIM (Hong Kong) Limited, a regulated entity with the Securities & Futures Commission in Hong Kong to professional investors as defined in Section 1 of Part 1 of Schedule 1 of the Securities and Futures Ordinance (Cap. 571). In Singapore, information is issued by PGIM (Singapore) Pte. Ltd. ("PGIM Singapore"), a regulated entity with the Monetary Authority of Singapore under a Capital Markets Services License to conduct fund management and an exempt financial adviser. This material is issued by PGIM Singapore for the general information of "institutional investors" pursuant to Section 304 of the Securities and Futures Act 2001 of Singapore (the "SFA") and "accredited investors" and other relevant persons in accordance with the conditions specified in Section 305 of the SFA. In South Korea, information is issued by PGIM, Inc., which is licensed to provide discretionary investment management services directly to South Korean qualified institutional investors on a cross-border basis.

These materials are for informational or educational purposes only. The information is not intended as investment advice and is not a recommendation about managing or investing assets or an offer or solicitation in respect of any products or services to any persons who are prohibited from receiving such information under the laws applicable to their place of citizenship, domicile or residence. In providing these materials, PGIM is not acting as your fiduciary. These materials represent the views, opinions and recommendations of the author(s) regarding the economic conditions, asset classes, securities, issuers or financial instruments referenced herein. Distribution of this information to any person other than the person to whom it was originally delivered and to such person's advisers is unauthorized, and any reproduction of these materials, in whole or in part, or the divulgence of any of the contents hereof, without prior consent of PGIM is prohibited. Certain information contained herein has been obtained from sources that PGIM believes to be reliable as of the date presented; however, PGIM cannot guarantee the accuracy of such information, assure its completeness, or warrant such information will not be changed. The information contained herein is current as of the date of issuance (or such earlier date as referenced herein) and is subject to change without notice. PGIM has no obligation to update any or all of such information; nor do we make any express or implied warranties or representations as to the completeness or accuracy or accept responsibility for errors. These materials are not intended as an offer or solicitation with respect to the purchase or sale of any security or other financial instrument or any investment management services and should not be used as the basis for any investment decision. No risk management technique can guarantee the mitigation or elimination of risk in any market environment. Past performance is not a guarantee or a reliable indicator of future results and an investment could lose value. No liability whatsoever is accepted for any loss (whether direct, indirect, or consequential) that may arise from any use of the information contained in or derived from this report. PGIM and its affiliates may make investment decisions that are inconsistent with the recommendations or views expressed herein, including for proprietary accounts of PGIM or its affiliates. Any projections or forecasts presented herein are as of the date of this presentation and are subject to change without notice. Actual data will vary and may not be reflected here. Projections and forecasts are subject to high levels of uncertainty. Accordingly, any projections or forecasts should be viewed as merely representative of a broad range of possible outcomes. Projections or forecasts are estimated, based on assumptions, and are subject to significant revision and may change materially as economic and market conditions change. PGIM has no obligation to provide updates or changes to any projections or forecasts.

PGIM and its affiliates may develop and publish research that is independent of, and different than, the recommendations contained herein. PGIM's personnel other than the author(s), such as sales, marketing and trading personnel, may provide oral or written market commentary or ideas to PGIM's clients or prospects or proprietary investment ideas that differ from the views expressed herein.

Prudential Financial, Inc. of the United States is not affiliated in any manner with Prudential plc, incorporated in the United Kingdom or with Prudential Assurance Company, a subsidiary of M&G plc, incorporated in the United Kingdom.

PGIM'S MEGATREND SERIES

How today's shifting global landscape will affect the investments of tomorrow

The Transformation of Labor Markets

Among its many tragic human and economic consequences, the COVID-19 pandemic left labor markets in turmoil. While these issues get much media attention – and some may prove to have an enduring impact – they often obscure the profound structural changes to labor markets that were already underway prior to COVID and that will ultimately have a much greater impact on reshaping the global workforce..

Learn more at pgim.com/labor

Food For Thought

Whether seeking opportunities or mitigating hidden risks, understanding the rapidly transforming food system is crucial for institutional investors.

Learn more at pgim.com/food

The New Dynamics of Private Markets

Private markets have provided entrepreneurs, corporate tycoons and property developers with access to capital for centuries. But the current scale, growth and complexity of private capital is truly unprecedented – and is radically altering the investment opportunities and challenges facing institutional investors.

Learn more at pgim.com/private-markets

Cryptocurrency Investing

Exploring why direct investments in bitcoin and its peers are currently unattractive for an institutional portfolio – underscored by recent gyrations in the crypto market. Still, the technologies that cryptocurrencies helped spawn present new opportunities for savvy long-term investors.

Learn more at pgim.com/crypto

Reshaping Services

Technological disruption has finally reached the shores of the service economy. It's a development that will represent a major shift for investors and the global economy as services represent more than two-thirds of global GDP, three-quarters of the workforce in developed markets, and nearly half of the workforce in advanced emerging markets.

Learn more at pgim.com/reshaping

Weathering Climate Change

Climate change is no longer a hypothetical risk. It is already transforming the global economy, reshaping markets and altering the investment landscape. In this paper, we propose an actionable climate change agenda that addresses both hidden portfolio vulnerabilities and potential opportunities in the transition to a lower-carbon world.

Learn more at pgim.com/climate

After the Great Lockdown

The pandemic has forced businesses to adapt in ways that will lead to lasting changes in consumer behavior and corporate business models. Now is the time to focus on the massive disruption that lies ahead so we're best positioned for when the Great Lockdown has passed.

Learn more at pgim.com/lockdown

The Future Means Business

Disruptive forces have led to the emergence of three new business models that are radically changing the investment calculus for institutional investors. Here we explore the investment implications of these transformative new corporate models.

Learn more at pgim.com/futurefirm

The Technology Frontier

We are living in an era of unprecedented technological change. At PGIM, we believe the implications for investors will be profound, radically transforming investment opportunities across asset classes and geographies.

Learn more at pgim.com/tech

The End of Sovereignty?

Never before in history have people, information and capital moved across borders at the speed, frequency and volume we see today. In this white paper, we take a closer look at the escalating tussle between globalization and nationalism, the implications this could have for global financial markets, and how long-term investors may best position themselves to navigate these uncertain times.

Emerging Markets at the Crossroads

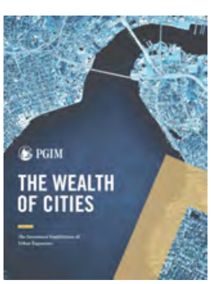
A radical shift in the forces shaping emerging market growth will require investors to take a different investment approach from what may have worked in the past. Increasingly, discovering investment opportunities will be rooted in the ability to capture alpha from the new growth drivers, rather than in chasing the beta of the broad universe.

A Silver Lining

The unprecedented aging of the global population creates increased opportunities in senior housing, multifamily condos, biotech, and the emerging silvertech industry. Institutional investors should consider how this megatrend could affect their portfolios, given the trend's evolving impact on consumer spending and far-reaching effects on emerging nations, home to two-thirds of the world's elderly.

Longevity and Liabilities

The rise in global life expectancy has implications for pension plan liabilities that are not fully appreciated. As new mortality tables demonstrate, longevity risk to pension liabilities could increase dramatically over the next two to three decades. This report examines the challenge and the available risk mitigation strategies.



The Wealth of Cities

Never in history has the pace of urbanization been so rapid: 60 to 70 million people moving to cities every year for the next few decades. To help institutional investors benefit from this "prime time" of urbanization, we identified a range of specific investment ideas across the major investable themes of this opportune megatrend.

PGIM

THE PURSUIT OF OUTPERFORMANCE™

留意事項

※本資料は米国SECの登録投資顧問会社であるPGIMインクが作成したものです。

※本資料は情報提供を目的としたものであり、特定の金融商品の勧誘又は販売を目的としたものではありません。また、本資料に記載された内容等については今後変更されることもあります。

※記載されている市場動向等は現時点での見解であり、これらは今後変更することもあります。また、その結果の確実性を表明するものではなく、将来の市場環境の変動等を保証するものでもありません。

※本資料で取り上げられた資産クラス、個別セクター等はあくまで例示を目的としたものであり、推奨ならびにこれらに係る将来性を明示・暗示的に示唆するものではありません。

※本資料で言及されている個別銘柄は例示のみを目的とするものであり、特定の個別銘柄への投資を推奨するものではありません。

※本資料に記載されている市場関連データ及び情報等は信頼できると判断した各種情報源から入手したものですが、その情報の正確性、確実性について当社が保証するものではありません。

※本資料に掲載された各インデックスに関する知的財産権及びその他の一切の権利は、各インデックスの開発、算出、公表を行う各社に帰属します。

※過去の運用実績は必ずしも将来の運用成果等を保証するものではありません。

※本資料は法務、会計、税務上のアドバイスあるいは投資推奨等を行うために作成されたものではありません。

※PGIMジャパン株式会社は、世界最大級の金融サービス機関プルデンシャル・ファイナンシャルの一員であり、英国プルーデンシャル社とはなんら関係がありません。

PGIMジャパン株式会社
金融商品取引業者 関東財務局長（金商）第392号
加入協会：一般社団法人日本投資顧問業協会、 一般社団法人投資信託協会、一般社団法人第二種金融商品取引業協会
PGIMJ108612