QUANTUM CAPITAL GROUP

Advancing the Global Energy Ecosystem

2025 Stakeholder Report

Contents

Letter to Stakeholders

Dear Stakeholders,

This year, as Quantum Capital Group enters its 27th year, we remain grounded in the same core principle that has guided us from the beginning: striving to deliver strong, risk-adjusted returns to our limited partners by partnering with exceptional entrepreneurs to build great businesses across the energy sector. Over nearly three decades, we have navigated commodity cycles, policy shifts, and market disruptions – always with a long-term view of energy's essential role in human progress. It's that steady perspective that allows us to invest with discipline, adapt with purpose, and support the businesses shaping the future of global energy. I'm pleased to share highlights from the past year as we continue building on that foundation.

Global Shift Toward Energy Pragmatism

Globally, there has been a notable shift toward balancing ambitious climate objectives with the fundamental necessity of energy affordability, reliability, and security. After a period of aggressive decarbonization targets and significant investments in renewables, a combination of recent geopolitical events, energy security concerns, rising energy demand forecasts, and economic realities have prompted a recalibration of energy policies and priorities. Governments and industries alike are recognizing that energy availability and economic stability cannot be compromised by an overly accelerated and costly transition away from traditional energy sources.

This evolution reflects a growing recognition that a sustainable energy future must be underpinned by solutions that are secure, economically viable, and resilient. The path forward requires not just ambition, but coordination – between public and private sectors, across regions, and over time. We believe real progress depends on policy stability, realistic timelines, and investment strategies that acknowledge the full complexity of global energy systems.

All of the Above Energy Strategy

Quantum remains aligned with this pragmatic perspective. We have consistently advocated for an "all-of-the-above" energy strategy, acknowledging the essential roles played by hydrocarbons, renewables, and emerging lower-carbon technologies capable of delivering decarbonization while addressing global energy needs effectively and realistically. Our investment philosophy is rooted in the belief that no single energy source can meet the complex demands of today's global economy. Energy systems must be diversified, cost effective, and scalable – capable of supporting both economic growth and decarbonization.

Global energy demand is expected to continue growing for the foreseeable future, driven by population growth and economic development – the two largest determinants of energy consumption. By 2050, the world's population is projected to grow by roughly 1.5 billion people, with the majority of that growth occurring in developing regions. As these economies expand and living standards improve, per capita energy use will increase significantly. At the same time, energy poverty – defined by a lack of access to affordable, reliable energy – remains a major challenge, limiting health outcomes and economic opportunity for billions. Today, nearly 7 billion people are actively moving up the economic ladder, which will only intensify global energy demand.

We continue to maintain, as we have consistently emphasized, that fossil fuels remain essential to meet this growing demand for energy. Despite strong momentum in renewables, hydrocarbons continue to dominate the global energy mix, supplying 77% of total energy today. Despite trillions of dollars invested in wind and solar over the past decade, fossil fuel consumption has grown nearly twice as fast as renewables in absolute terms. Even under the most aggressive transition scenarios, hydrocarbons will supply more than half the world's energy for decades.

A truly responsible approach to meeting growing global energy demand while reducing emissions requires a fact-based, economically grounded view of what's possible and what's needed. We believe the path forward lies in understanding that energy addition and decarbonization must happen together; that climate and energy security goals must be pursued simultaneously and in coordination with each other; that emissions reductions must be global, not just regional; and that the economics and efficiency of solutions cannot be ignored. Full-cycle cost analysis, regional energy realities, and the influence of human behavior all play a role in shaping viable solutions. By grounding action in these principles, we believe it is possible to chart a path that is both sustainable and scalable – one that addresses climate risk without compromising the energy access and security that billions of people depend on.

Commitment to our Stakeholders

At Quantum, we've long understood that the path to energy security and a lower-carbon future is complex, non-linear, and shaped by evolving global priorities. Our commitment to integrating appropriate and balanced environmental, social, and governance ("ESG") factors remains. We do not see ESG as a standalone initiative or shifting trend. We see it as a core part of disciplined investing, which we believe strengthens risk management, improves decision-making, and supports long-term value creation. Even as regulatory landscapes shift and public debate continues to evolve, our focus remains steady: to invest in companies that generate strong risk-adjusted returns – and do so in a way that responsibly and appropriately considers factors important and relevant to our various stakeholders.

Looking Ahead

Looking ahead, we expect the energy landscape to remain shaped by competing forces: the need for reliability, the drive toward lower emissions, and the global push for greater energy security. These dynamics are not mutually exclusive – but managing them requires nuance, capital discipline, and a deep understanding of regional energy systems.

As technology evolves and policies shift, investors and operators alike must navigate uncertainty while remaining anchored in fundamental realities. The challenge is clear: how to deliver energy that is affordable, abundant, reliable, and clean – not just in theory, but in practice, and not just for the next few years, but for decades to come.

> "At Quantum, we seek to play a role in responsibly providing the energy that makes human progress possible, while aiming to achieve superior risk-adjusted returns for our investors."

At Quantum, we seek to continue to bring a pragmatic, forward-looking mindset to this work. Our experience across the energy value chain can allow us to identify opportunities that are not only financially sound, but operationally viable and aligned with real-world needs. We remain focused on strategies that balance innovation with discipline, growth with resilience, and ambition with realism – because we believe delivering energy solutions that are durable, scalable, and cost-effective is essential to meeting the long-term demands of the global economy.

To our investors – thank you for your continued trust and partnership. Managing your capital is both a huge responsibility and privilege. To our portfolio companies – thank you for your tireless drive, outstanding creativity, and continued commitment to shape the future of energy. We are proud to support your work. And to the Quantum team – thank you for your unwavering commitment to excellence, thoughtful insights, and unassailable integrity. You are the foundation of everything we do.

As we move forward, we remain committed to what has always guided us: delivering strong, risk-adjusted returns for our investors. The world's energy needs are changing, but the core principles that drive value creation remain constant: sound judgment, disciplined execution, and a deep understanding of global energy markets. As we look ahead, we'll continue to make decisions with focus and precision – backed by a team that understands the complexity of this sector and knows how to navigate it.

We appreciate your continued confidence in Quantum Capital Group.

Sincerely,

Wil VanLoh
FOUNDER AND CEO

Quantum's Purpose, Vision & Values

At Quantum Capital Group, our purpose, vision, and values are the guiding principles that define our commitment to success and sustainable growth. We believe that by aligning our investments with our core principles, we can create long-term value for our stakeholders and achieve strong financial performance.

PURPOSE

Quantum's purpose is to advance today's energy ecosystem for tomorrow's sustainable world while delivering superior risk-adjusted returns to our investors.

VISION

Use our capital, expertise, and influence to lead the world in addressing energy security and climate change to improve the lives of current and future generations.

VALUES

Integrity

We do the right thing, remaining true to ourselves and our word even when the choice is not easy.

Excellence

We are a high-energy organization that is committed to being the best in whatever we do, always striving for exceptional performance results.

Collaboration

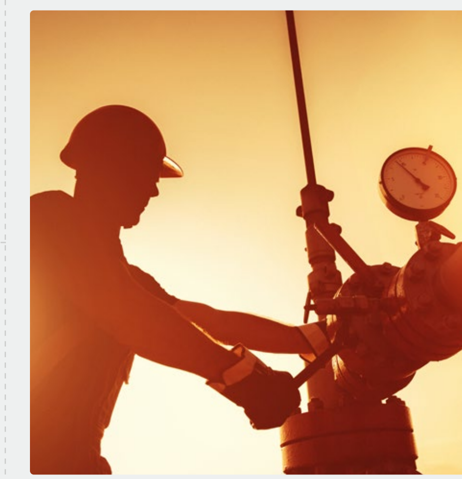
We effectively work together as a team, delivering outcomes that incorporate the best from everyone. We seek solutions that address the needs of all stakeholders.

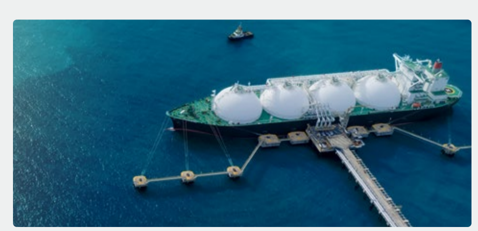
Discipline

We are thorough and thoughtful in our work and decisions, remaining intensely focused on achieving our firm's goals and strategies.

Humility

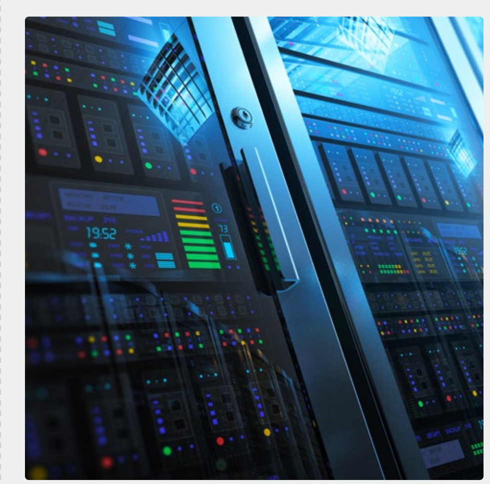
We understand our place in the world, respecting others and appreciating the value that diversity brings. We willingly acknowledge our mistakes and limitations.





Ownership

We are accountable for our individual results as well as those of our team. We take the initiative to make positive things happen, not waiting for others to act.



Entrepreneurial

We are creative, competitive, flexible, and nimble; willing to risk failure in order to pursue innovative solutions that have exceptional results.

About Quantum Capital Group

Founded in 1998, Quantum Capital Group is a leading investment firm specializing in the global energy ecosystem, including production, energy transition, and decarbonization. Our team has deep experience investing across the energy value chain, allowing us to meet today's biggest energy challenges with discipline and agility.

With decades of industry experience, we seek to leverage our technical proficiency, value-driven investment strategies, and expertise in diverse capital structures to consistently deliver strong, risk-adjusted returns. We are entrepreneurs first, with a long-term vision and a collaborative mindset. Through our high-tech and data-driven approach, commitment to ESG, and vast industry expertise, we believe that we are setting the standard for energy excellence.

14.5%
Current Exposure
Current exposure to wells drilled in the lower 48 across all Quantum funds

>$3.5 Bn
Drilling CAPEX
Average annual CAPEX spent across all Quantum funds over the past 3 years

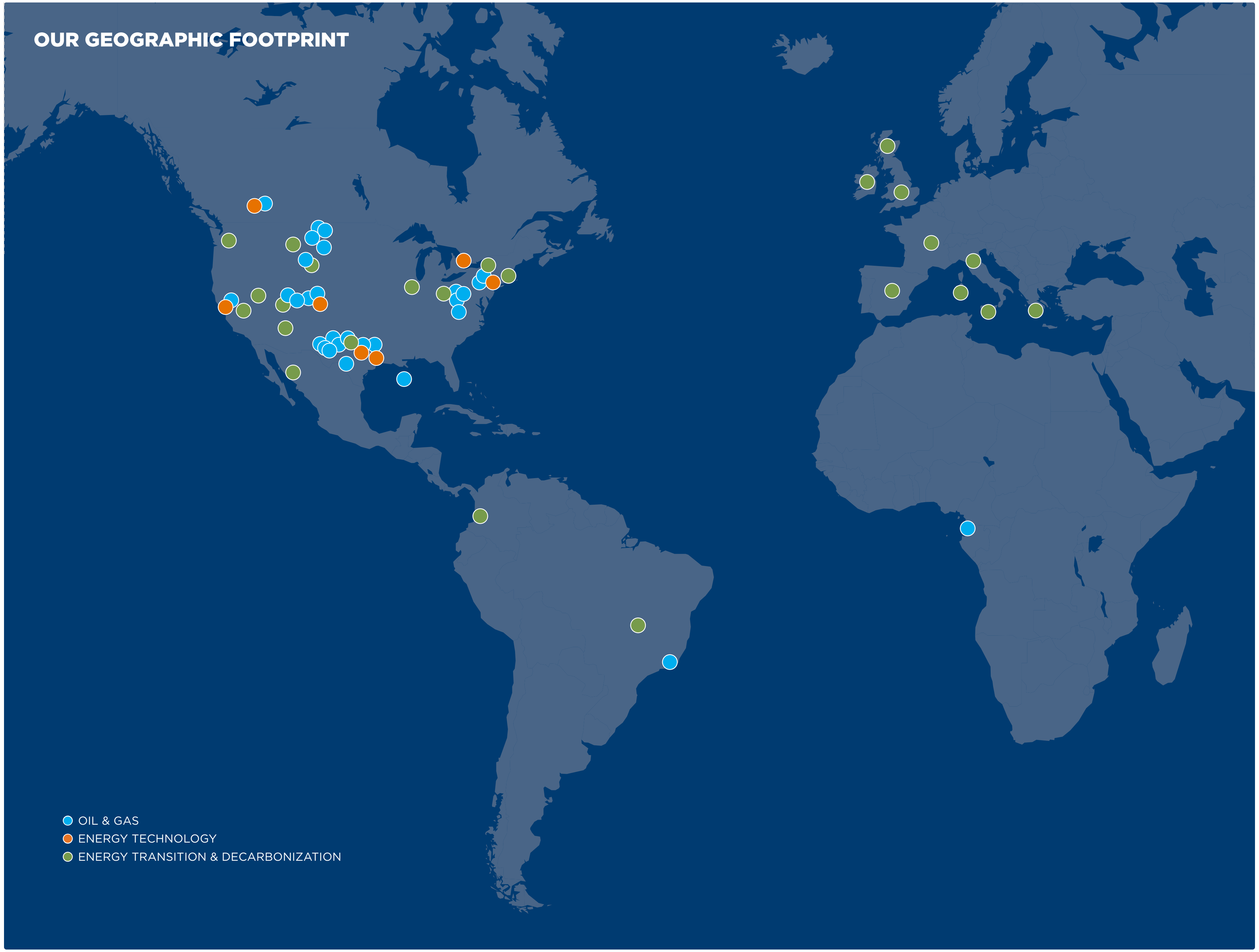
5,000
Wells
Number of wells in which Quantum has had exposure since 2020, across all funds

6 GW
Renewable Energy Under Construction
Renewable energy under construction and in various stages of development in Europe

~600,000 Boe/d
Upstream Production
2024 average oil & gas gross operated production across all Quantum funds

~250,000 Boe/d
Midstream Throughput
2024 average midstream throughput across all Quantum funds

22 TWh
Electricity Generated
Amount of electricity generated by Cogentrix in 2024, enough to power ~2 million U.S. households[(1)]

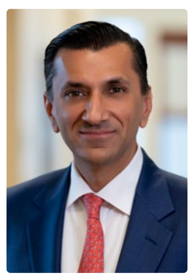


[(1)] Reflects International Energy Agency (IEA) estimate of 10,791 kwh/year for an average U.S. residential utility customer.

Our Investment Platforms & Types

About Quantum Capital Group continued

Quantum has developed a suite of investment strategies to seek to take advantage of the wide variety of opportunities within the global energy ecosystem. We believe our knowledge of the energy value chain and our capability to invest across the capital structure provide us with differentiated competitive advantages.



"At Quantum Capital Group, our investment strategy is defined by a commitment to disciplined analysis and strategic adaptability. We focus on identifying and capitalizing on opportunities that align with our long-term vision. By maintaining a rigorous approach and being responsive to market conditions, we strive to consistently deliver strong, risk-adjusted returns to our investors. Our overarching strategy is to drive sustained growth and value creation while navigating the complexities of an evolving financial landscape."

Ajay Khurana
CO-PRESIDENT, QUANTUM CAPITAL GROUP

Quantum Energy Partners
PRIVATE EQUITY

Quantum's private equity strategy aims to generate competitive, risk-adjusted returns across the global energy ecosystem. Our selective approach enables us to dedicate substantial time and attention to each of our portfolio companies. By leveraging our agility, deep industry knowledge, technical expertise, and robust business acumen, we seek to empower entrepreneurs to break through barriers and rapidly advance their businesses.

Quantum Capital Solutions
STRUCTURED CAPITAL

Through our structured capital solutions strategy, we seek to provide tailored financing solutions that enable companies in the global energy ecosystem to fund growth projects, build cashflow, and generate shareholder value. Within Quantum Capital Solutions, we focus primarily on investing in public companies via asset-level financing, preferred equity, and structured debt.

Quantum Credit Opportunities
OIL AND GAS DIRECT LENDING

Within Quantum Credit Opportunities, we focus primarily on providing senior credit to companies in the oil and gas space. We believe our deep technical and operational expertise, structuring experience, and industry relationships make us the partner of choice for companies seeking to optimize their business plans.

Quantum Innovation Fund
ENERGY TRANSITION AND DECARBONIZATION VENTURE CAPITAL

Through our Quantum Innovation Fund, we seek to invest in transformative technology-based businesses focused on the energy and sustainability sectors. We provide early-stage companies with differentiated strategic insights and access to industry resources. We have significant experience coaching and mentoring founders to "cross the chasm" and build businesses of significant scale. Each venture investment we make receives the same hands on support and dedication that have characterized all our investments since our founding.

SELECT QUANTUM PORTFOLIO COMPANIES*

547 Energy
HG Energy
Trace Midstream
BeZero
Heirloom
Recurve
Impact Exploration and Production
Trident Energy
Bison Oil & Gas IV
Carbon Direct
Orennia
Risilience
Koda
White Rock Oil & Gas
FireBird Energy II LLC
Premium Oilfield Technologies
Power Factors
HEQ Deepwater
Sentinel Peak Resources
Project Canary
Haventus
Cogentrix Energy

* Company logos displayed include majority owned and operated companies that submitted ESG data for the 2024 reporting year and does not include a complete list of Quantum's investments.

Our Team

About Quantum Capital Group continued

At Quantum, our people are the foundation of everything we do. We are proud to have built a team of experienced, forward-thinking professionals who bring deep industry knowledge, analytical rigor, and a shared commitment to our clients.

Across all levels of the firm, our team collaborates closely with an aim to identify opportunities, manage risk, and drive long-term value creation for our stakeholders – while seeking to help to advance the broader energy ecosystem.

153 total employees*

18 firm partners*

11 member investment committee for Quantum Energy Partners Fund*

Multi-Disciplinary Team

We have fully integrated our investment, technical, and strategic shared services teams, which we believe allows us to identify, analyze, price, and manage risk, and create long-term value for our stakeholders.

INVESTMENT TEAM

Our investment team is made up of investment professionals, technical experts, and senior advisors who are involved in all aspects of origination, diligence, structuring, portfolio monitoring, and exits.

TECHNICAL TEAM

Our technical team is made up of industry experts that leverage their extensive experience to provide differentiated insights to Quantum's portfolio companies.

STRATEGIC SHARED SERVICES

Our strategic shared services team is focused on digital, ESG, procurement, and marketing and hedging.

FUND ADMINISTRATION AND CLIENT SOLUTIONS

Our fund administration and client solutions team works with other business groups to support compliance, human capital management, and timely reporting to Quantum's limited partners.

* As of May 5, 2025

Please see the Disclaimers at the end of this report for important additional information regarding AI considerations in our investment practices.

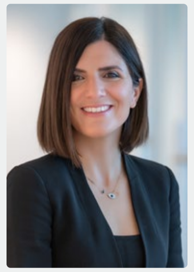
SPOTLIGHT

Our Technical Advantage

We believe Quantum's technical edge is rooted in the depth of our team, the quality of our data, and the rigor of our approach. With 18 dedicated technical professionals – we believe significantly more than peers – our multi-disciplinary team plays a critical role in business development, technical underwriting, and active portfolio stewardship. Our technical team brings decades of experience at leading operators and leverages proprietary digital tools that improve the speed, accuracy, and consistency of our evaluations.

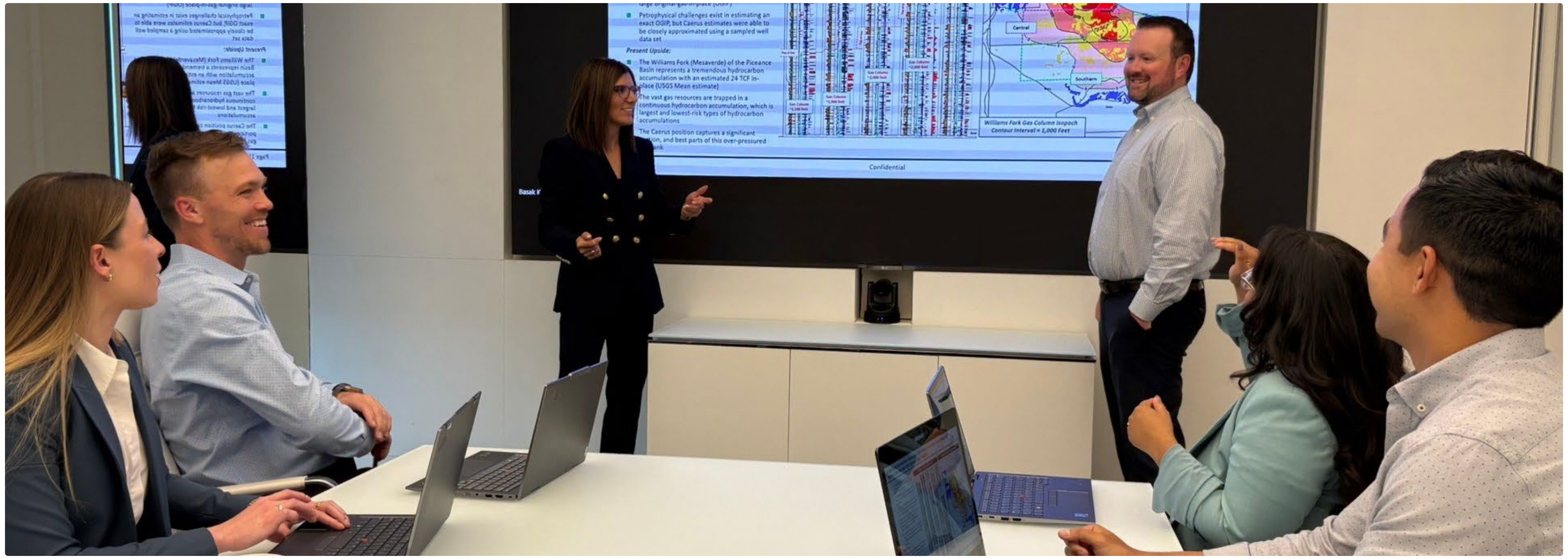
These tools form the foundation of our technical platform, which aims to enable faster, more precise evaluations of assets, teams, and opportunities. The platform supports objective, data-driven decision-making, helps identify high-performing acreage and assets, and provides our portfolio companies with access to advanced AI tools they might not have the scale or resources to develop independently.

Through ongoing engagement with each portfolio company – from acquisition through divestiture – our team supports performance, shares best practices, and aims to deliver consistent value. Combined, we believe these capabilities give Quantum a repeatable, competitive advantage in identifying, underwriting, and enhancing energy investments.



"At Quantum, technical excellence and risk management is embedded in every stage of the investment process – from sourcing and evaluation to execution and portfolio optimization. Our team combines deep operational experience with advanced digital tools to drive faster, more informed decisions and deliver superior risk-adjusted returns for our investors, positioning Quantum as a leader in the evolving energy investment landscape."

Basak Kurtoglu
MANAGING DIRECTOR & HEAD OF TECHNICAL



Global Energy Perspective

Inside this section:

The following discussion represents Quantum's beliefs, opinions and assessments with respect to the topics discussed herein, including potential future trends. There can be no assurance that any historical trends will continue.

Dual Energy & Climate Challenge

Expanding energy access while reducing greenhouse gas emissions

Access to reliable, affordable energy is fundamental to economic growth, public health, and overall quality of life – yet billions of people still lack it. At the same time, climate change – driven largely by emissions from energy use – is also an issue. By adopting new solutions, removing barriers, and taking meaningful and practical actions, we believe we can make significant progress in addressing energy poverty, energy security, and climate change concurrently by 2050. In this report, we examine the key issues, expand on why the current approaches are not working, explore the economics of climate change, highlight proposed solutions, and discuss how to implement them effectively.

The world has an insatiable appetite for more energy. Today, only about 1 billion people experience the benefits of an energy-rich, advanced society, while the other 7 billion – and counting – are working to access more energy and move up the economic ladder. As of 2020, approximately 750 million people still lacked electricity, and 2.4 billion relied on traditional biofuels – such as wood, dung, and charcoal – for heating and cooking. In addition, almost 6 billion people live on less than $10 per day, largely due to limited economic opportunities tied to energy access – a challenge highlighted by Swedish public health doctor Hans Rosling in his book *Factfulness*.

Energy consumption is strongly correlated with increased emissions and rising global temperatures, which have increased 1.5°C above pre-industrial levels, leading to climate change and potential adverse effects, including extreme weather, rising sea levels, economic displacement, and food and water scarcity. The greater the temperature rise, the more significant the adverse effects could be. To provide context, during the last ice age, when glaciers covered approximately 25% of the Earth's land, global temperatures were just 6°C cooler than today. Conversely, during the Jurassic Period, when crocodiles lived above the Arctic Circle, the planet was around 4°C warmer. This demonstrates that even relatively small changes in the Earth's average temperature can have significant effects on its climate.

The Dual Energy and Climate Challenge refers to the need to meet the world's growing demand for affordable, reliable energy while simultaneously reducing greenhouse gas (GHG) emissions to address climate change. In our last Quantum report, we introduced a new framework with seven key principles to address the Dual Challenge, given that previous efforts are not working. Since our last report, there has been a notable shift in government policies, reflecting a growing recognition of the need to address energy poverty and climate change simultaneously. This report uses our proposed framework as a foundation to examine specific actions that address both issues.

The Dual Energy and Climate Challenge is one that transcends temporary leaders or any single administration, demanding long-term commitment and thoughtful action. Success requires education, vision, and strong leadership – along with practical, economically viable strategies.

SEVEN KEY PRINCIPLES TO ADDRESS THE DUAL CHALLENGE

1. Reframe "energy transition" to "energy addition and decarbonization," understanding that there have been no energy transitions in the past – only additions, and no fuel type has been fully replaced.

2. Address both energy needs and climate goals concurrently, recognizing that both are critical to human progress, prosperity, and protection. By considering both, we can unite different groups and work together to find more effective solutions. Our end goal should be abundant, clean energy.

3. Consider the global impact of carbon reduction strategies. Emissions reduction solutions should be capital efficient, enhance energy availability, and avoid shifting emissions to regions with lower environmental standards. This lays the groundwork for actions that contribute positively on a global scale.

4. Focus on efficient, scalable carbon abatement strategies, recognizing that resources are limited. Consider the most economical approaches to reduce emissions and meet energy demand.

5. Utilize full-cycle economics to guide investment decisions, weighing both costs and benefits. The analysis should account for the cost of lifecycle emissions, energy availability and reliability, and both local and global impacts to ensure sound, informed decisions.

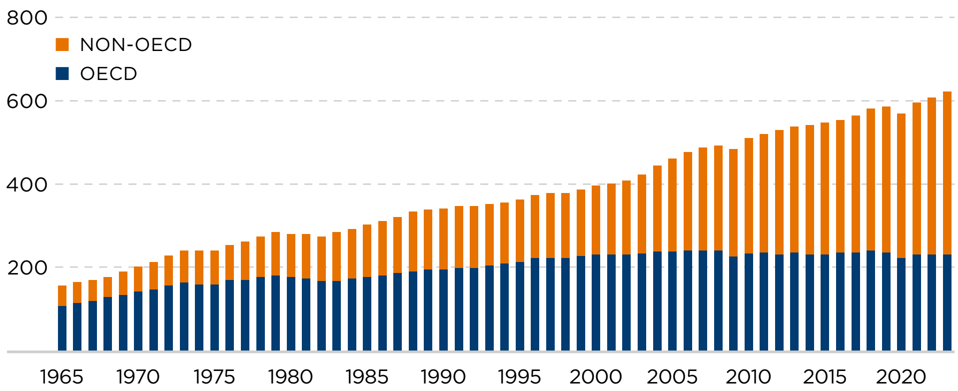
6. Tailor solutions to regional needs and challenges, including energy security, existing infrastructure, social acceptance, and affordability. Understanding these drivers and addressing them will increase the likelihood of identifying and implementing effective solutions.

7. Prioritize education and leadership to drive a timely and effective approach, recognizing energy and climate change solutions are complex and evolving topics requiring strong leadership and a deep, fact-based understanding of technology economics and behavioral sciences, as well as regular updates and course corrections as needed.

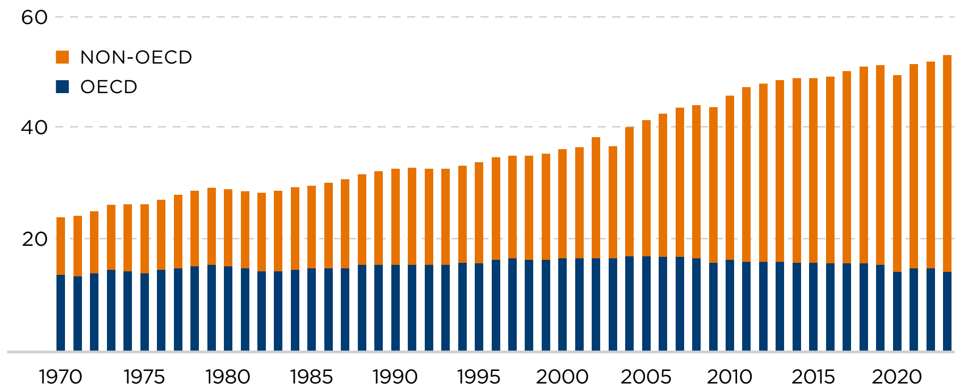
"We are encouraged by the rise of energy pragmatism, as more people recognize that relying solely on renewables without integrating other forms of energy is failing to deliver a reliable, affordable, and energy-secure future. However, abandoning efforts to curb emissions and combat climate change would be an equally dangerous shift of the pendulum. This report emphasizes the need to address both challenges, expands on why current approaches aren't working, and outlines practical and affordable solutions that can. We hope you enjoy it."

Garry Tanner
PARTNER, QUANTUM CAPITAL GROUP

ENERGY CONSUMPTION OF OECD VS NON-OECD COUNTRIES[1]



ANNUAL GLOBAL CO_2 EMISSIONS[2]



(1) "Statistical Review of World Energy," Energy Institute (2024).
(2) "EDGAR (Emissions Database for Global Atmospheric Research) Community GHG Database," European Commission, Joint Research Centre (JRC) (2024).

Energy Pragmatism on the Rise

Global focus shifts to energy security, affordability, and meeting growing demand over clean energy

We are seeing a global shift toward energy pragmatism, with both countries and companies adopting a more balanced approach to meeting the world's energy needs while addressing climate goals.

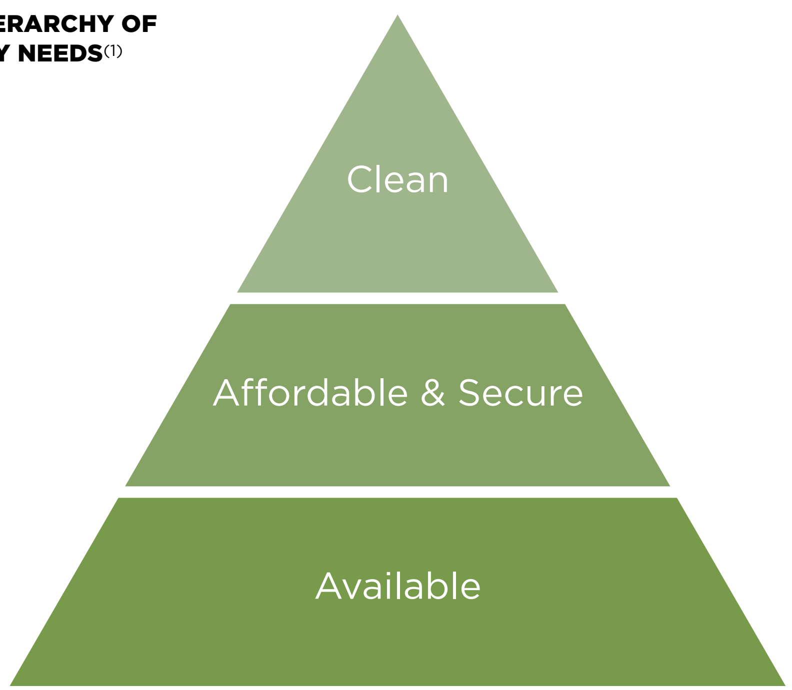
The Hierarchy of Energy Needs

A strong global push toward decarbonization and renewable energy adoption in the mid-2020's led to a perceived prioritization of energy cleanliness over energy availability, affordability, and security. This period was marked by ambitious climate targets, significant investments in renewables, and, in some cases, a premature deemphasis on traditional energy sources.

Geopolitical tensions and rising concerns around energy security and affordability have led many governments and companies to reconsider policies that focus heavily on rapid renewable adoption while disincentivizing other energy sources. Instead, countries and companies are pivoting toward pragmatic policies and strategies that balance climate action with energy security and economic stability, with a more gradual shift to renewables. In times of crisis, such as winter heating shortages, economic collapse, or foreign threats, climate change becomes a secondary concern to basic survival.

While decarbonization remains important, it must be balanced with the fundamental need for reliable, affordable, and secure energy for all.

THE HIERARCHY OF ENERGY NEEDS[1]



U.S.

Under the Biden administration, the U.S. rejoined the Paris Agreement and set ambitious emissions reduction targets, while passing the Inflation Reduction Act to encourage investments in renewable energy. The administration also implemented the most stringent methane regulations in U.S. history. In contrast, during his first months in office, President Trump has prioritized the expansion of domestic energy production. His administration is focused on removing regulatory obstacles that hinder energy production by reopening federal lands and waters for drilling, streamlining permitting processes, and promoting LNG exports. Additionally, a core element of the Trump administration's strategy involves rolling back environmental regulations introduced under President Biden, including the Waste Emissions Charge (WEC), which penalizes oil and gas companies that exceed sector-specific methane emission thresholds.

European Union

The European Union (EU) has long been a leader in climate action, particularly following the announcement of the 2019 European Green Deal. While the EU to remain committed to its long-term climate goals, energy supply disruptions and rising prices following the Russian invasion of Ukraine have caused many EU countries to reconsider their approach.

Released in February 2025, the Action Plan for Affordable Energy reflects a key lesson learned from the crisis: energy policy must balance climate ambition with economic and social realities. The new plan emphasizes affordability, security, and faster execution. It includes measures such as immediate electricity bill relief, tariff adjustments, increased gas supply diversification, and expanded domestic renewable and nuclear capacity to improve energy security and reduce reliance on single suppliers. The plan also calls for enhanced cost competitiveness, a just transition, and faster project implementation through streamlined permitting.

The EU is also emphasizing member state dynamics and showing support for national strategies, with some individual countries shifting toward more pragmatic energy approaches. For example, Germany has extended the life of its coal plants, and LNG continues to play a significant role across the region. Although the EU remains committed to achieving carbon neutrality by 2050, the ongoing reliance on coal and gas – particularly in parts of Central and Eastern Europe – will likely slow the pace of the broader energy transition.[1]

Canada

Canada has taken an aggressive approach to addressing climate change through a multi-faceted emissions reduction strategy, which includes a goal to reduce emissions by 40–45% from 2005 levels through a combination of carbon pricing, investments in renewable energy and clean technology, energy efficiency measures, and international collaboration. However, newly appointed Prime Minister Mark Carney made an immediate motion to defer Canada's federal consumer carbon tax, also known as the "fuel charge," marking a major departure from previous policy. While the consumer tax is gone, the carbon pricing system for large industrial emitters remains in place, signaling a pivot toward placing a greater responsibility on industries to reduce their emissions. Carney has also expressed a desire to position Canada as an "energy superpower" in both clean and conventional energy, which suggests a complex approach to the energy transition.[2]

Shifts in India, Indonesia & Mexico

Other countries experiencing rapid energy demand growth are also shifting their energy strategies. In India, the Prime Minister's coalition is focused on economic growth, energy security, and lower-carbon innovation. The government has set an ambitious goal of 500 GW of renewable energy capacity by 2030, but progress is complicated by inflation, unemployment, and continued reliance on fossil fuels. At the same time, efforts to create green jobs remains a political priority. In Indonesia, the new leadership has committed to increasing both fossil fuel production and investments in renewables, while slowing coal plant retirements to strengthen energy independence. Mexico recently elected climate scientist Claudia Sheinbaum as president. Her administration is taking a pragmatic approach, with a National Energy Plan that calls for investments in electricity generation, expansion of grid infrastructure, increased renewables development, and an expansion of domestic oil refinery capacity.[3]

Corporations

Some corporations are also revising – or even scaling back – their climate goals and strategic direction. In the early 2020s, companies like British Petroleum (BP) and Shell diverted significant resources away from their core hydrocarbon business in pursuit of aggressive decarbonization targets. However, these shifts often led to weaker financial performance compared to peers like ExxonMobil. More recently, BP has softened its climate commitments by reducing planned cuts to oil and gas production,[4] while Shell has softened its 2030 intensity goal, eliminated its 2035 target all together, and announced plans to increase natural gas output.[5] ExxonMobil, which has long prioritized energy security and profitability, continues to signal a "lean in" strategy on oil and gas – even as it scales back some renewable R&D efforts, such as algae-based biofuels.[6]

Similarly, several high-profile financial institutions are taking steps back from their original climate goals. In February, Wells Fargo abandoned their goal of achieving net-zero financed emissions by 2050, explaining the goal was unachievable. Additionally, Wells Fargo, Barclays, Citigroup, Bank of America, and Goldman Sachs have all withdrawn from the Net-Zero Banking Alliance (NZBA). While these banks maintain individual climate commitments, their departure from the alliance suggests a shift away from collaborative, public target-setting toward more independent – and potentially less transparent – approaches.

(1) Adapted from Veriten.
(2) 2024 Global Elections: Redefining the Shape and Focus of the Energy Transition, February 2024.
(3) What's Next for the Energy Transition?, Boston Consulting Group, February 2025.
(4) "BP Makes Record Profit in 2022, Slows Shift from Oil," Reuters.
(5) "Shell Weakens Climate Targets and Vows More Gas," Bloomberg.
(6) "ExxonMobil Leaning on Oil and Gas Even as It Touts Carbon Capture," Reuters.

Energy Powers Human Development

Energy abundance, affordability, reliability, security, and cleanliness all matter

Energy powers the modern world, driving human progress, economic growth, and an improved quality of life. Since the Industrial Revolution, access to abundant and reliable energy has dramatically increased life expectancy, supported prosperity, and transformed societies. From early reliance on biomass and animal labor to the development of coal, oil, and natural gas – collectively known as hydrocarbons or fossil fuels – energy sources have evolved over time to meet the ever-growing demands of a rapidly advancing world. AI and data centers are the latest example of the world's growing and rapidly evolving energy demands.

Global energy demand is expected to continue growing for the foreseeable future, driven by population growth and economic development – the two largest determinants of energy consumption. Projections estimate that by 2050, the world's population will increase by approximately 1.5 billion people, with most of that growth concentrated in developing regions. As these areas become more prosperous, per capita energy use is expected to grow from less than five barrels of oil equivalent per year in low-income regions to closer to more than the 30 barrels per year in high-income regions. Energy poverty – the lack of access to affordable and reliable energy – remains a significant challenge, negatively impacting quality of life and life expectancy. Nearly seven billion people (and growing) are actively climbing the economic ladder, further increasing global energy demand.

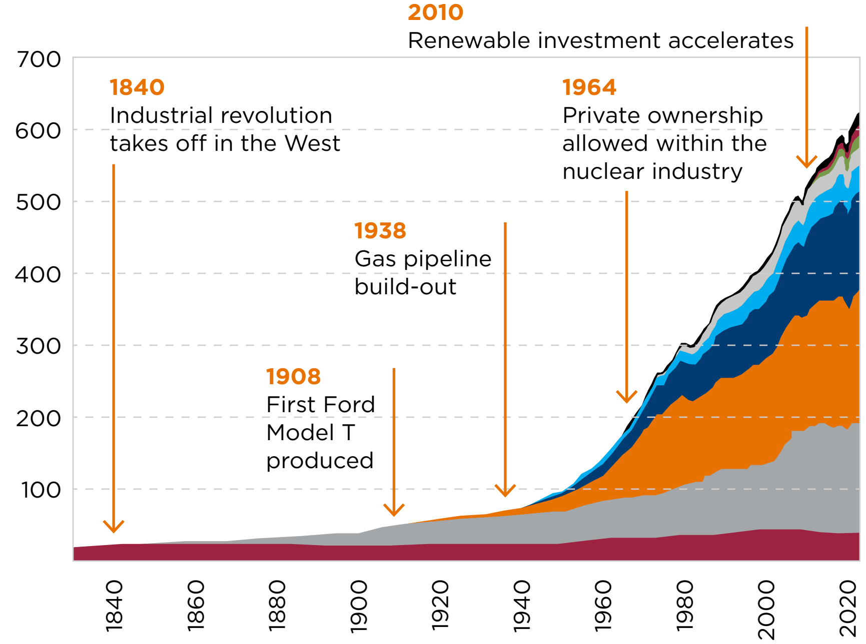
Today, hydrocarbons dominate the global energy mix, accounting for 77% of total useful energy consumption. Renewable sources like wind and solar, while expanding rapidly, still represent a relatively small fraction of total energy use. In fact, despite trillions of dollars spent on renewables since 2010, fossil fuel consumption in absolute terms has grown almost twice as much as renewable energy consumption. Global reliance on hydrocarbons is unlikely to change in the foreseeable future. Historically, energy transitions – or more accurately, energy additions – take decades to reach widespread adoption, supplementing – rather than replacing – existing energy sources.

Energy security is a critical national priority for every country around the world. The U.S. shale boom reshaped the global energy landscape over the last 15 years, with the U.S. providing approximately 90% of global liquids growth and becoming the largest LNG exporter. The recent Russian invasion of Ukraine underscored vulnerabilities in global supply chains and reinforced the importance of reliable, secure energy sources. When evaluating renewable energy, we believe it is important to recognize that key supply chains, processing, and refining capacities are highly concentrated in China, Russia, and other Eastern Bloc countries, adding significant risk to these energy sources. Understanding this element of energy is essential when considering long-term government policies, related actions, and optimal energy solutions.

We support the U.S. Department of Energy's (DOE) priorities on energy, particularly its focus on advancing the U.S. energy addition, promoting innovation, and building and accelerating resilient energy infrastructure. However, we believe that to fully address the challenges ahead, we should also include emissions in our decision matrix, along with energy security, reliability, and affordability. This approach would align with the DOE's goals while ensuring a more sustainable and comprehensive energy future. By incorporating lower carbon energy solutions along with traditional energy sources, we believe we can achieve the optimal solution to the Dual Challenge of enhancing energy security and affordability while addressing environmental sustainability. For further insights related to the importance of energy, refer to our 2024 Quantum Stakeholder Report, pages 20–25.

GLOBAL PRIMARY ENERGY CONSUMPTION BY SOURCE 1800–2020[1]

QBtu



	Market Share (QBTU) 2010	Market Share (QBTU) 2023	Change (QBTU) 2010–2023
Other Renewables	4.0	8.3	4.3
Solar	0.3	14.6	14.2
Wind	3.3	20.6	17.3
Nuclear	25.2	23.3	(1.9)
Hydropower	32.5	37.6	5.1
Gas	107.8	136.8	29.0
Oil	164.0	186.2	22.2
Coal	143.3	155.5	12.2
Biomass	39.8	37.9	(1.9)
Renewable	**264.3**	**293.9**	**29.6**
Traditional	**415.1**	**478.5**	**63.4**

	1840	1860	1880	1900	1920	1940	1960	1980	2000	2020
Population (B)	1.2	1.3	1.4	1.6	1.9	2.3	3.0	4.4	6.1	7.8
Life Expectancy (yrs)	29.0	29.3	29.7	32.0	34.5	42.0	50.1	61.2	66.3	72.6

U.S. ENERGY DEPARTMENT – KEY FOCUS AREAS

Increase investment in oil & natural gas
- Represents an abundant, affordable, and reliable source of energy which will support the U.S. for decades to come
- Fast tracking the buildout of pipelines and LNG infrastructure will further enhance the longevity of U.S. natural gas

Promote innovation
- Continue to drive R&D to advance basic science, reduce costs, strengthen reliability, bolster manufacturing, and improve supply chain security.

Upgrade and expand the grid while supporting development of gas, wind and solar power
- Investment in grid and battery infrastructure is critical to support growing load growth and new generation
- Actively develop gas fired power (with carbon capture and storage when possible), as well as wind/solar/batteries, based on fundamentals, not ideals

Accelerate permitting processes
- Accelerate the permitting process to enable energy infrastructure development, ensuring energy remains affordable, reliable, and secure

Expand the role nuclear plays in the U.S. energy mix
- Nuclear is the only clean, base-load source of 24/7 power, and is a much simpler supply chain than wind/solar/batteries
- Fast track Nuclear Regulatory Commission (NRC) approval for next generation reactor designs and provide government funding to jumpstart construction

[1] Vaclav Smil (2017), Energy Transitions: Global and National Perspectives, BP Statistical Review of World Energy via Our World in Data.

SPOTLIGHT

The Versatility of Petroleum

A closer look into petroleum products

Oil and gas are often only associated with fueling vehicles and powering industry. However, these resources play a far more extensive role in our everyday lives. From the materials in our homes to the products we use daily, oil and gas are foundational to modern living. This spotlight highlights the pervasive presence of petroleum and its byproducts across various industries, highlighting their critical contributions to infrastructure, healthcare, technology, and everyday products.

Transportation

Perhaps the most obvious use of oil and gas is in transportation. Gasoline and diesel, derived from crude oil, power approximately 1.4 billion cars, buses, trucks, and motorcycles worldwide.(1) Additionally, global aviation remains highly dependent on fossil fuels, with jet fuel consumption reaching around 18 million barrels per day in 2022.(2)

Energy & Heating

Natural gas is a primary source of electricity generation and heating in many homes and businesses. Gas-fired power plants convert natural gas into electricity, while residential and commercial heating systems utilize natural gas to maintain comfortable indoor temperatures. Moreover, liquefied petroleum gas (LPG) is used in rural and remote areas where natural gas pipelines might not reach, providing essential energy for cooking and heating.

Medicine & Healthcare

Petroleum products are widely used throughout the healthcare industry, from the operating room to items that support healthy living in our modern society. That includes important lifesaving products and equipment such as pacemakers, MRI machines, IV bags and tubes, surgical instruments, monitors, and stethoscopes. It also includes products that can be essential to daily life such as prosthetics, hearing aids, glasses, and contact lenses. Chemicals derived from petroleum also help make soaps, antiseptics, aspirin, and lifesaving pharmaceuticals.

Household Products

Oil and gas are fundamental to manufacturing everyday household products. Plastics, synthetic resins, and petrochemical-based adhesives are used in everything from food packaging and kitchen utensils to furniture and home insulation. Household detergents, paints, dyes, and even synthetic fragrances are all derived from petrochemical processes. Without oil and gas, many of the conveniences of modern home life would be significantly altered.

Technology & Electronics

The technology industry heavily relies on oil and gas for creating hardware components. Plastics and other petrochemical-based substances form the casings, circuitry, and screens of devices like smartphones, computers, and televisions. In addition, the production processes themselves, from semiconductor fabrication to assembly, often depend on oil and gas derivatives.

Agriculture

Farming equipment typically runs on diesel or gasoline, and fertilizers and pesticides are often derived from natural gas and petroleum. These inputs are crucial for modern large-scale agriculture, directly linking oil and gas to the food supply chain. Additionally, plastic products are used extensively in agricultural settings for packaging, storage, and even irrigation systems. It takes 0.1 units of hydrocarbon energy to make each 1 unit of food energy, in the modern agricultural system.

Clothing & Textiles

Many synthetic fibers, such as polyester, nylon, and acrylic, are derived from petrochemicals. These fibers are prevalent in everyday clothing, sportswear, carpets, and upholstery. Moreover, dyes and finishing agents used in textiles are frequently sourced from petroleum products.

PETROLEUM PRODUCTS MADE FROM ONE BARREL OF CRUDE OIL

There are more than 6,000 everyday products refined from an/or manufactured with natural gas liquids and crude oil, including electronics, paint, cosmetics, synthetic fabrics and medicines. (3) According to the U.S. Energy Information Administration (EIA), a 42-gallon barrel of crude oil is typically used to make ~19 gallons of gasoline, ~11 gallons of diesel fuel, ~4 gallons of jet fuel, and ~4 gallons of gas liquids, heating oil, and residual fuel. The other ~6 gallons are used to make petrochemical feedstocks, waxes, lubricating oils, and asphalt, and a plethora of other everyday materials in a range of areas as highlighted herein.

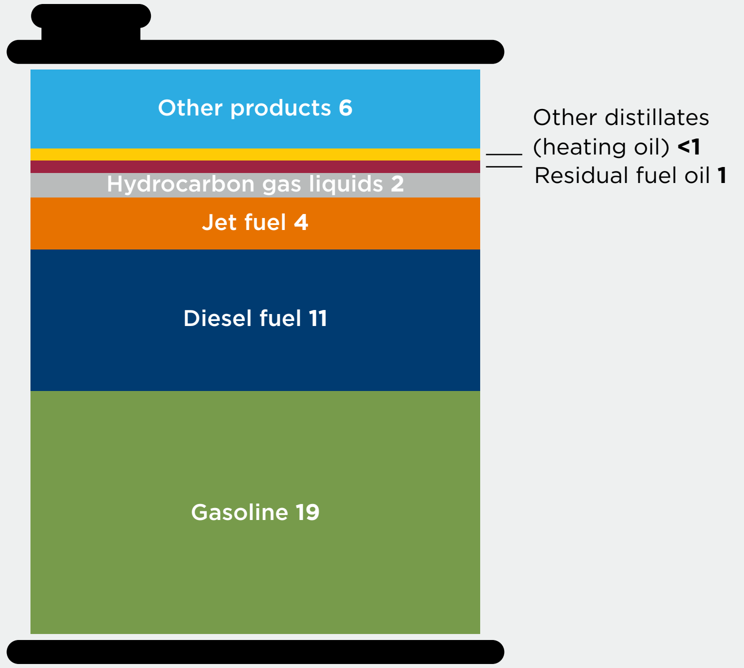
One barrel will produce these “other” products:

- Four pounds of charcoal briquettes
- Wax for 170 birthday candles or 27 crayons
- One gallon of asphalt for roads or roofs
- One quart of motor oil
- One quart of paint thinner or dry-cleaning solvents
- Medicinal oils
- Road oil
- Plant condensates

One barrel of oil provides enough petrochemicals to be the base for *one* of the following:

- 39 polyester shirts
- 750 pocket combs
- 540 toothbrushes
- 65 plastic dustpans
- 23 hula hoops
- 65 plastic drinking cups
- 195 one-cup measuring cups
- 11 plastic telephone housings
- 135 four-inch rubber balls

Other notable crude oil-based products: N95 masks, cell phones, computers, tires



Source: EIA; Chevron

(1) “Global Transportation Report 2023,” Energy Information Administration.
(2) “BP Statistical Review of World Energy 2023,” BP plc.
(3) “Petroleum Products,” – Illinois Petroleum Resources Board.

Climate Change Matters

Understanding the challenge and the path forward

Climate change, driven by rising GHG emissions concentrations in the atmosphere, is a key challenge facing the world today. The Earth's temperature has already increased by 1.5°C above pre-industrial levels, with projections indicating further warming if emissions remain unchecked.[1] Greenhouse gases originate from both natural and human-made sources. Natural emissions result from natural processes such as biological activity, oceanic exchanges, wildfires, and volcanic eruptions. In contrast, human-made emissions stem from human activities such as industrial processes, fossil fuel combustion, deforestation, and methane emissions from agriculture. While both contribute to atmospheric GHG levels, human-made emissions are responsible for the majority of long-term atmospheric accumulation of greenhouse gases and are the primary driver of climate change.

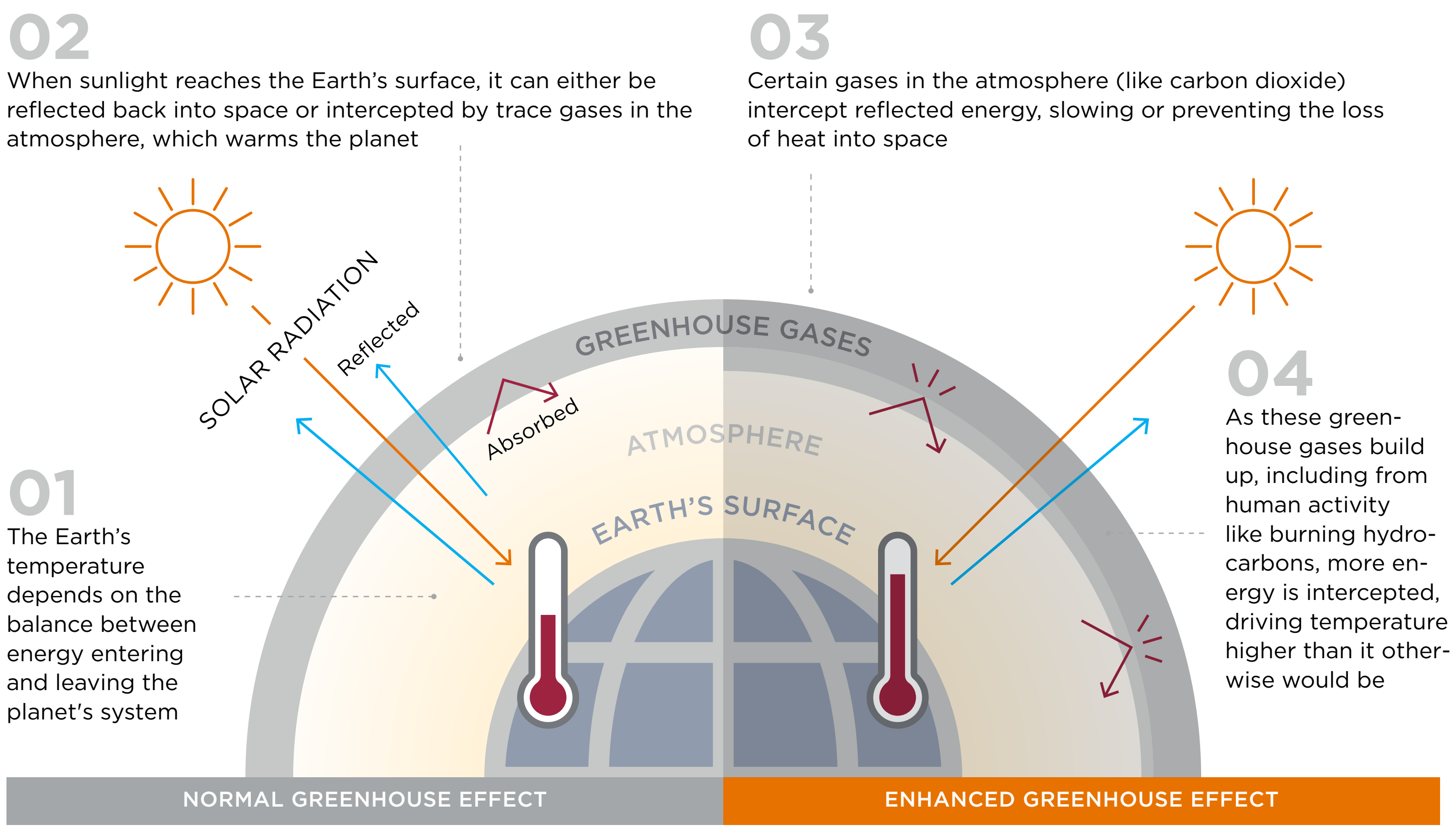
The composition of greenhouse gases varies by volume, with carbon dioxide (CO_2) accounting for 74%, methane (CH_4) 17%, nitrous oxide (N_2O) 6%, and fluorinated gases 2%. However, their impact on global warming differs significantly. For example, methane is 25 to 80 times more potent than CO_2 over a 20– to 100–year period, making its contribution to climate change disproportionately high despite being released in smaller quantities. Similarly, nitrous oxide and fluorinated gases have varying levels of potency and atmospheric longevity, further intensifying the greenhouse effect. Importantly, CO_2 remains in the atmosphere for centuries, requiring long-term removal strategies. In contrast, potent non-CO_2 gases are relatively short-lived in the atmosphere, especially methane (>12 year life), meaning that reducing these emissions today can deliver both cost-effective and high-impact climate benefits.

Energy production, which underpins nearly every aspect of modern life, remains the dominant source of emissions. However, not all hydrocarbons contribute equally. Coal produces nearly twice as much CO_2 as natural gas and about 15–20% more than oil for the same energy output. Additionally, natural gas combustion, unlike coal or wood, does not generate particulate matter, a major air pollutant linked to serious health risks, particularly for those relying on solid fuels for cooking. In *How to Avoid a Climate Disaster*, Bill Gates highlights five sectors – manufacturing (including cement and steel), electricity generation, transportation, agriculture, and heating and cooling (HVAC) – as the "pillars of civilization" responsible for most emissions. While many climate efforts focus primarily on electricity, this sector accounts for only 28% of total global emissions. Addressing all five pillars is essential for meaningful decarbonization.

The continued rise in GHG emissions is increasing the likelihood of climate-related impacts, which are already emerging in extreme weather events, rising sea levels, ecosystem disruptions, and risks to human health and economies. Additionally, exceeding critical climate tipping points could trigger irreversible shifts in Earth's systems, further compounding these challenges. Significant scientific evidence suggests we may be rapidly approaching key tipping points, including Amazon rainforest carbon flux, Arctic ocean circulation, and Arctic sea ice cover. As climate change accelerates, it is reshaping both our environment and way of life, from altered weather patterns to biodiversity loss. Without decisive action, these impacts could escalate, posing increasing challenges to global adaptation and stability.

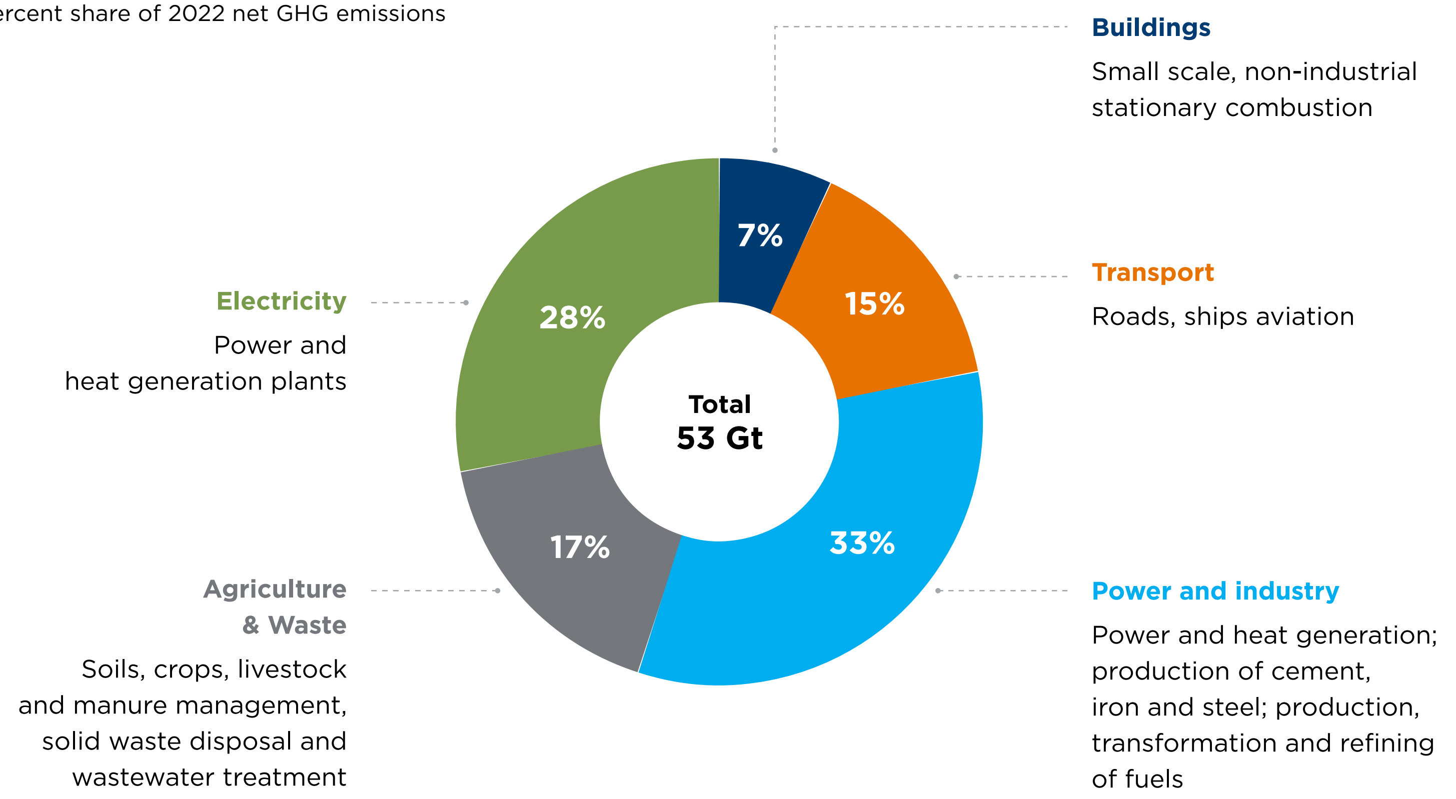
Although global temperature changes are often discussed in terms of averages, they will not be felt equally around the world. Temperature increases will likely be more pronounced in some regions rather than others and mostly felt in developing countries. These areas, already facing economic and infrastructural challenges, will likely experience stronger and more immediate effects, leading to a disproportionate human toll on vulnerable populations in these areas.

GREENHOUSE EFFECT LINKS ANTHROPOGENIC GHG EMISSIONS TO WARMING[2]



GLOBAL EMISSIONS BY SECTOR[3]

Percent share of 2022 net GHG emissions



[1] "WMO Confirms 2024 Warmest Year on Record at About 1.5°C Above Pre-Industrial Level," World Meteorological Organization.
[2] "Overview on the Dual Challenge: Energy and Climate (2023)," OpenMinds.
[3] "Science for Policy Report: GHG Emissions of All World Countries (2023)," Joint Research Centre.

SPOTLIGHT

Human and Economic Impact of Climate Risks and Potential Mitigants:

An analysis of current trends and the mitigation potential

Climate change is impacting global weather patterns, but adaptation efforts can meaningfully limit these impacts. Severe weather events are often making the news, with storms, floods, droughts, wildfires, and heatwaves on the rise. Conversely, mortality rates associated with climate-related natural disasters have declined significantly highlighting the success in weather tracking and response efforts. Ongoing tracking of these events and the associated economic and mortality impacts remains important as we gauge the severity of climate change impacts and the effectiveness of mitigation strategies and response efforts over time.

Historical Trends in Climate-Related Deaths and Economic Costs

Historically, climate-related disasters have caused significant loss of life. The Total Deaths Per Decade chart, sourced from the Emergency Events Database (EM-DAT), illustrates this trend, showing that global deaths from weather-related disasters peaked in the 1920s but decreased by 96% by the 2010s[1] – largely due to improvements in forecasting, early warning systems, emergency response, and infrastructure.[2]

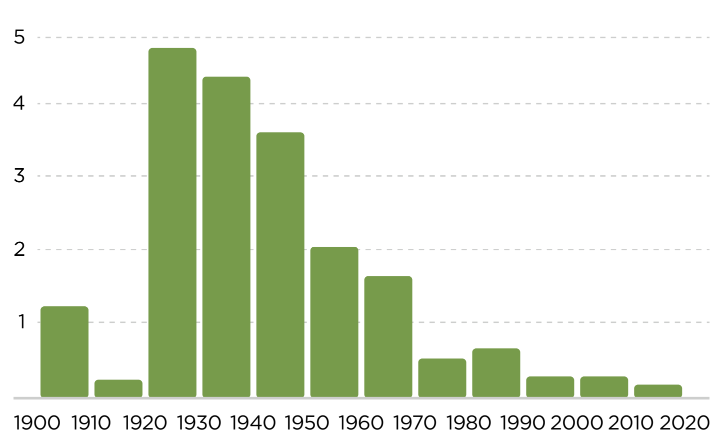
However, it is essential to recognize that while fatalities have decreased, the number, intensity, and economic cost of climate-related disasters have increased.[3] For example, the frequency of extreme weather events has risen fivefold since the 1950s, driven by both climate change and improved reporting.[4] Furthermore, according to the World Meteorological Organization (WMO), weather, climate, and water-related disasters have caused a total of $4.3 trillion in economic losses over the past 50 years – with recent years averaging around $200 billion annually and showing an upward trend.[5] Climate change also contributes to long-term health issues, including heat-related illnesses, food insecurity, and the spread of infectious diseases.

Future Projections Forecast Increasing Mortality Rates

Looking ahead, climate-related disasters are expected to become more severe as global temperatures rise. The IPCC reports that heat extremes are increasing in frequency, duration, and intensity, with some regions likely to experience temperatures exceeding 50°C more frequently.[6] Projections suggest that by 2050, extreme heat events could occur four times more often than in the past century, placing millions at risk. Data from the World Health Organization (WHO) indicates that climate change is projected to cause approximately 250,000 additional deaths per year between 2030 and 2050 due to malnutrition, malaria, diarrhea, and heat stress, which would meaningfully increase the current death-related toll.[7]

TOTAL DEATHS PER DECADE (1900–2020)[8]

Deaths (million)



[1] "2022 Disasters in Numbers," EM-DAT Report.
[2] "Fact Check: Drop in Climate-Related Disaster Deaths Not Evidence Against Climate 'Emergency,'" Reuters.
[3] "The Economic Costs of Extreme Weather Are Soaring, but Number of Deaths Is Falling Fast. Here's Why," World Economic Forum.
[4] "2022 Global Assessment Report on Disaster Risk Reduction," UNDRR.
[5] "The Economic Costs of Extreme Weather Are Soaring, but Number of Deaths Is Falling Fast. Here's Why," World Economic Forum.
[6] *Ibid.*
[7] EM-DAT, CRED/UCLouvain (2024).
[8] "2022 Disasters in Numbers," EM-DAT Report.
[9] NOAA.

Mitigation Efforts Can Make a Significant Difference to Human Health

Beyond increased mortality, heatwaves are expected to lead to widespread infrastructure failures, reduced agricultural yields, health issues, decreased worker productivity, and severe economic losses, disproportionately affecting urban areas with inadequate cooling infrastructure. However, continued advancements in disaster preparedness, adaptation strategies, and infrastructure development could help mitigate climate-related mortality and other negative effects – though such investments alone will not lessen the risks to ecosystems or biodiversity, including coral reefs, tropical forests, or Arctic tundra.

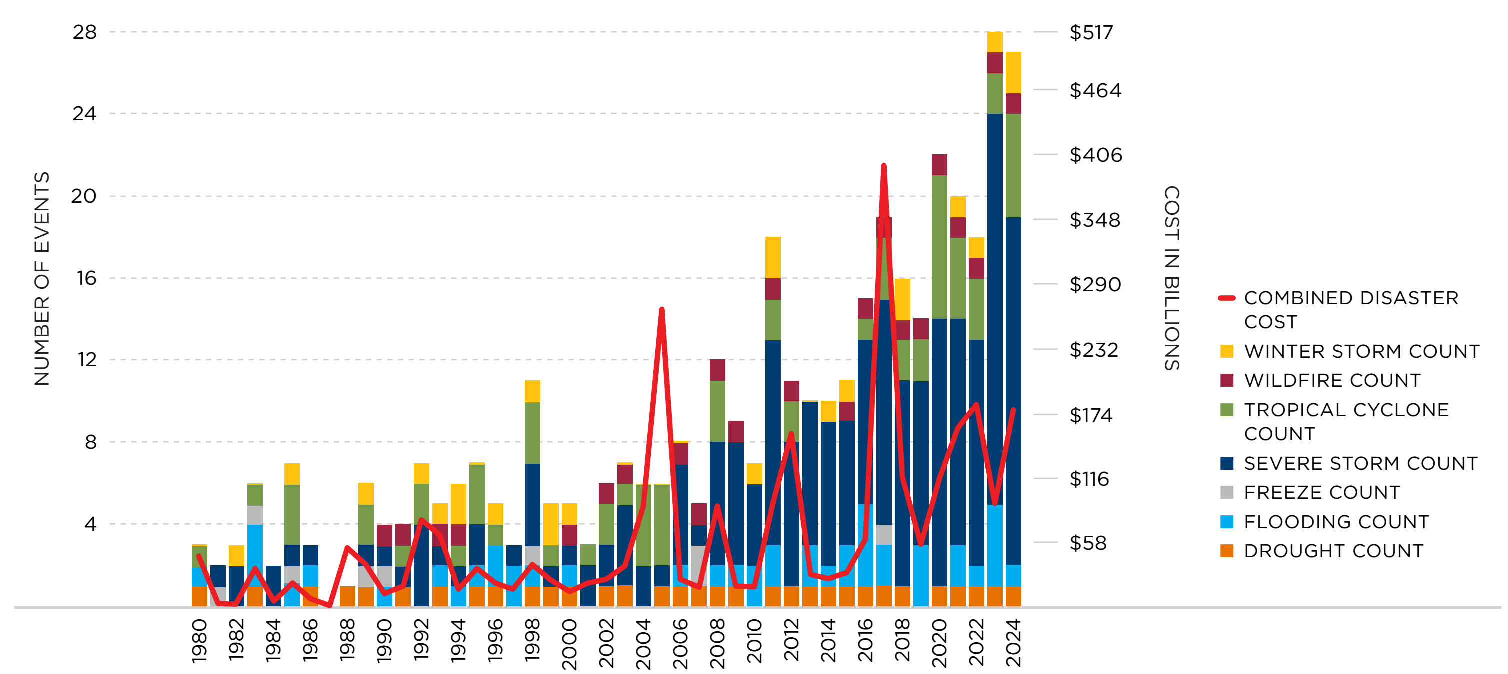
Investing in climate-resilient infrastructure, early warning systems, and sustainable urban planning will be crucial in determining future outcomes. Additionally, expanding access to reliable and affordable energy sources will be essential for powering cooling systems, reinforcing infrastructure, and improving emergency response capabilities in vulnerable regions. Studies indicate that increasing energy access in developing nations could reduce heat-related mortality by up to 40% through widespread adoption of air conditioning and improved building insulation. Furthermore, resilient energy grids can support emergency services by providing faster disaster response and recovery efforts.[8]

A Balanced Perspective

The decline in climate-related deaths is a testament to human progress in disaster preparedness and response. However, the increasing frequency and economic impact of climate-related disasters underscore the need for continued action. While mortality figures and the measured economic impact alone do not reflect the full scope of climate change's effects, they highlight the importance of resilience-building measures. We believe a balanced approach – acknowledging both the successes in disaster risk management and the escalating threats posed by climate change – is essential for crafting effective policies.

UNITED STATES BILLION-DOLLAR DISASTER EVENTS 1980–2024[9]

CPI-Adjusted



Why High Levels of Energy Transition Spending are not Working

Why do current emissions continue to increase despite massive and increasing energy transition investments?

The global energy transition has seen unprecedented and increasing levels of investment – totaling $11.9 trillion over the last 20 years, including almost $4 trillion in the past two years alone, as seen in the chart below. Yet despite this massive financial investment, global emissions continue to increase at roughly the same pace. Why hasn't energy transition spending translated into meaningful progress in emissions reductions?

While we acknowledge that economic growth and population increases are key drivers of rising energy demand and higher emissions, the data shows a steady increase in emissions despite escalating levels of energy transition spending. As illustrated in the chart comparing cumulative energy transition spending and cumulative emissions, progress has not kept pace with investment. We attribute this gap to four key factors:

1. Inefficient allocation of capital that fails to prioritize the most cost-effective carbon reduction strategies on a cost-per-ton basis.
2. Localized projects that reduce emissions in one region but, in some cases, inadvertently increase global emissions, typically by shifting manufacturing to countries with higher carbon intensity per unit of production.
3. Overreliance on less durable solutions that require continuous reinvestment, rather than focusing on durable carbon reduction strategies that provide long-term benefits with lower lifetime costs.
4. Significant investment in early-stage infrastructure and R&D, which – while potentially valuable over time – has yet to deliver meaningful emission reductions relative to the capital invested.

Inefficient Allocation of Capital

The cost of carbon abatement varies widely, from almost zero up to $1,000 per ton. To date, a significant portion of capital has been directed toward high-cost or ineffective carbon abatement strategies, including inefficient applications of renewable energy, inefficient applications of electrified transport, battery storage, biogas landfill taxes, and biomass power generation – despite the availability of lower-cost alternatives. Many of these projects have been politically motivated rather than driven by cost-efficiency, leading to suboptimal outcomes. By focusing on higher cost solutions, the dollars spent have a much smaller impact on the carbon abated.

Carbon Leakage

Additionally, local solutions have been prioritized over global ones, leading to capital investments that essentially relocate manufacturing to regions with higher carbon footprints per unit of energy without fundamentally changing demand, inadvertently increasing global emissions. In some cases, this results in an infinite cost of abatement, as emissions reductions in one location are completely offset – or even exceeded – by increased emissions elsewhere. This has been particularly evident in the shift of manufacturing from North America and Europe to China, where a higher share of coal in the energy mix leads to greater emissions per unit of production.

Less Durable Solutions

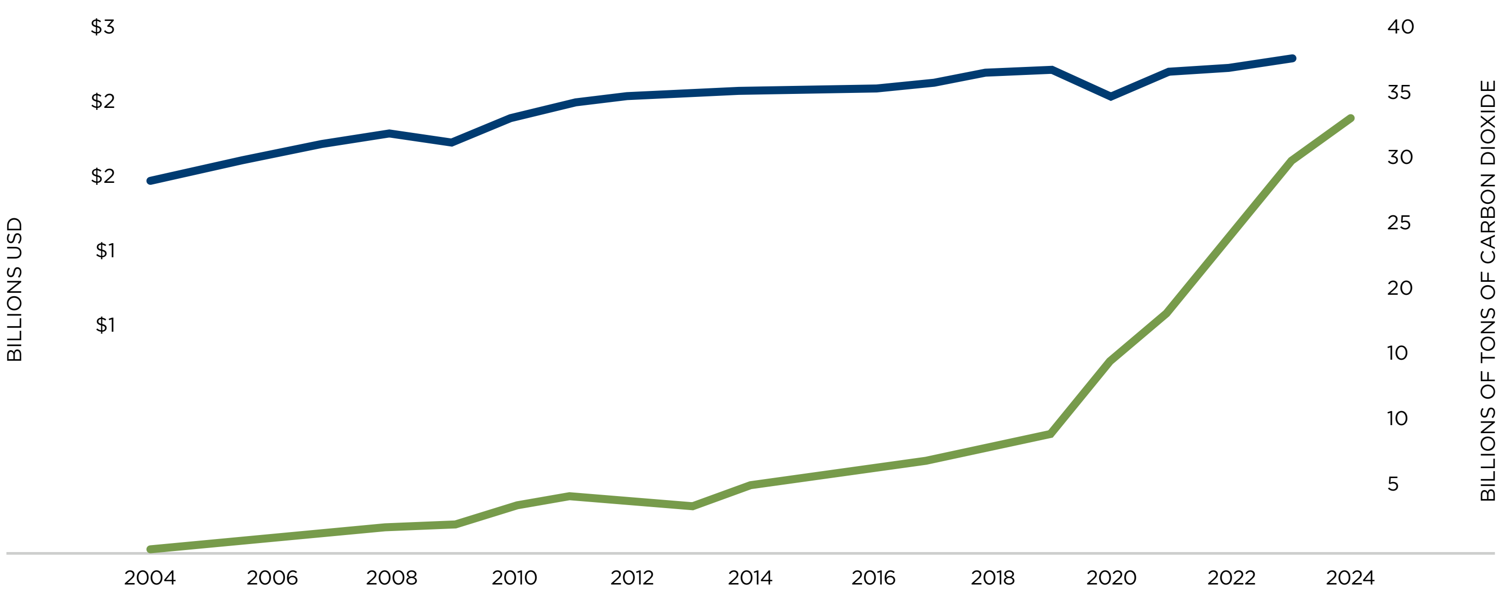
Another challenge is overreliance on less durable solutions, which require significant ongoing annual investments to maintain emissions reductions, driving up lifetime abatement costs. By contrast, durable solutions – though typically more capital-intensive upfront – provide long-term reductions and lower maintenance costs. While we view this as a relatively minor factor compared to the other primary drivers, it remains a challenge.

Investments in Early Stage Infrastructure and RD&D

Early-stage investments in infrastructure – and to a lesser extent, RD&D – may also be a factor, as the benefits of these expenditures often take years and additional capital to fully materialize. Permitting delays, regulatory hurdles, and supply chain constraints can slow infrastructure buildouts and deployment timelines. In terms of Research, development, and demonstration (RD&D), emerging technologies account for only a small portion of the total energy transition spending. In fact, investments in technologies such as electrified heat, hydrogen, carbon capture and storage (CCS), nuclear, and clean industry declined 23% year-over-year to $155 billion in 2024, highlighting the challenges in scaling innovation quickly enough to achieve near-term climate goals.

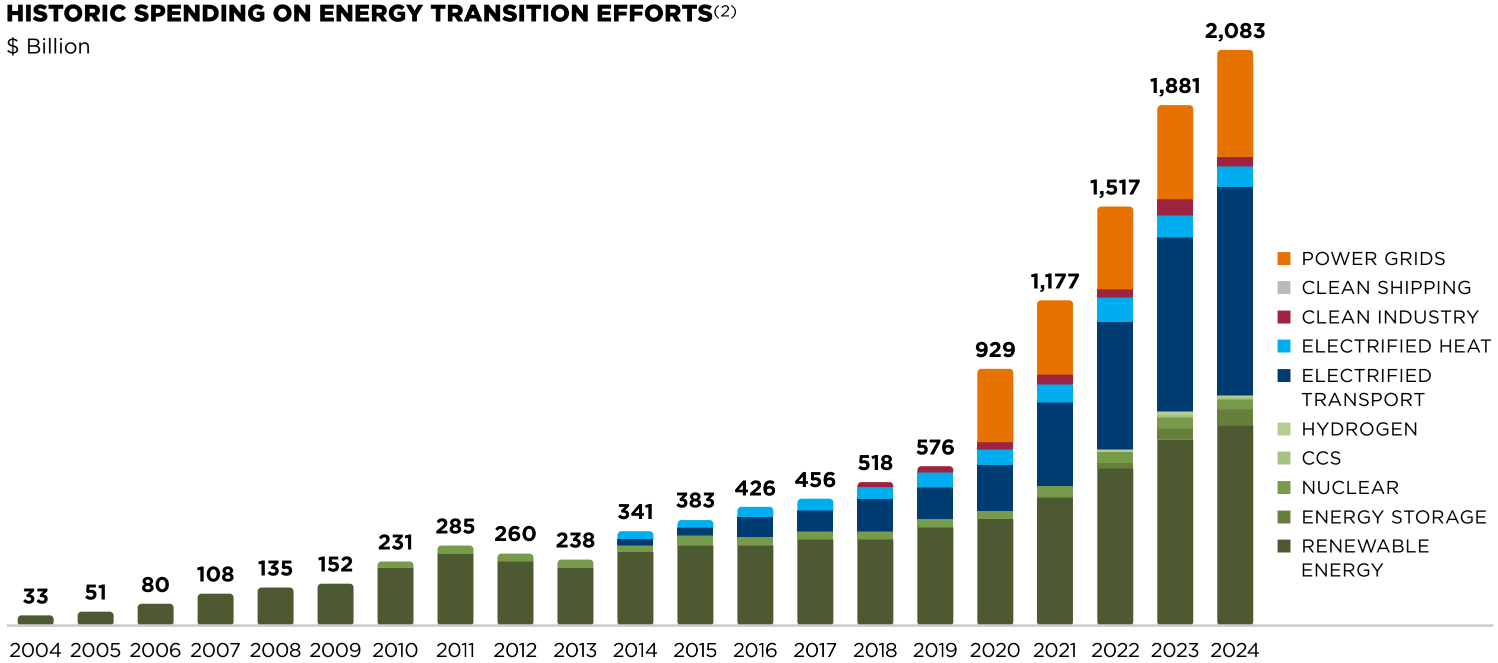
According to ThunderSaid Energy, as cited in our 2024 Quantum Stakeholder Report and further reviewed in this report, many viable abatement solutions exist at costs below $40 per ton, with net-zero pathways achievable for under $100 per ton. In this report, we examine the key drivers behind the lack of progress to date, before highlighting solutions that could drive meaningful progress at reasonable and achievable costs. Had capital been consistently directed toward strategies with abatement costs under $100 per ton, we believe the approximately $2 trillion spent annually could have been far more effective in accelerating global decarbonization.

ANNUAL GLOBAL ENERGY TRANSITION SPEND VS ANNUAL GLOBAL CARBON DIOXIDE EMISSIONS (2004–2024)[1]



HISTORIC SPENDING ON ENERGY TRANSITION EFFORTS[2]

$ Billion



[1] "CO_2 Emissions Data," Our World in Data (2024); "Energy Transition Spending Data," Bloomberg New Energy Finance (2024).
[2] "Chart Data," Bloomberg New Energy Finance (BNEF) (2024).

The Efficiency & Timing of Carbon Abatement Matters

The law of large numbers and why the cost-per-ton of carbon abatement matters

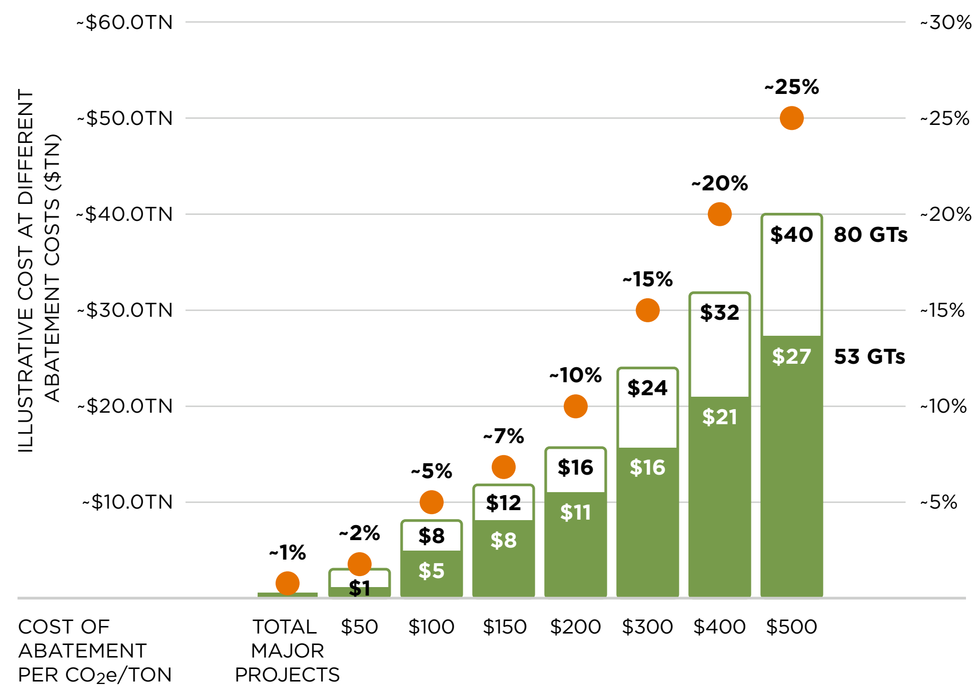
The cost estimates for carbon abatement vary widely, but consensus suggests that the overall expense is massive – driven by high per-ton costs, the magnitude of current emissions, ongoing increases in emissions related to GDP and population growth, and the speed in which we address the problem. These costs could be significantly reduced if we lower the cost-per-ton of abatement and pursue effective solutions sooner rather than later.

Efficiency of Carbon Abatement

The cost estimates for the energy transition vary widely due to significant differences in the expected cost of CO_2 abatement and the timing and types of abatement strategies employed. To illustrate the scale of the challenge, we have estimated the cost of abating each ton of current annual emissions (~53 Gtons of CO_2e per year) and projected emissions by 2050 (~80 Gtons, based on IPCC's trajectory) using a range of cost assumptions. The actual cost of achieving meaningful reductions depends on the effectiveness and efficiency of global strategies, making the cost-per-ton of abatement critical in addressing the Dual Challenge. As costs escalate, climate change efforts begin to consume untenable amounts of global GDP–highlighting the urgent need to prioritize low-cost solutions that deliver faster and more affordable GHG reductions globally. The difference is striking: spending $50 per ton versus $150 or $300 per ton results in dramatically different total costs – especially when multiplied across 53 to 80 gigatons of emissions annually.

When considered as a percentage of global GDP, the scale of projected climate spending becomes even more striking compared to past major infrastructure projects. Monumental initiatives such as the Apollo program and the International Space Station required only a fraction of the investment now being discussed for climate mitigation. It is understandable, then, that some question the wisdom and feasibility of these expenditures, underscoring the urgent need to lower the cost per Gton of CO_2 abatement and focus on more durable solutions.

ILLUSTRATIVE COST PER TON[1]
(2023A: ~53 GT CO_2e BASELINE/2050E: ~80 GT CO_2e BASELINE)



GLOBAL CO_2 ABATEMENT COST ESTIMATES UNDER DIFFERENT PRICE ASSUMPTIONS[1]

CO_2e $/TON COST ASSUMPTION	ABATEMENT ESTIMATE	% OF 2023 GLOBAL GDP
$50	~$2.7tn	~2%
$100	~$5.3tn	~5%
$150	~$8.0tn	~7%
$200	~$10.6tn	~10%
$300	~$15.9tn	~15%
$400	~$21.2tn	~20%
$500	~$26.5tn	~25%

Timing of Carbon Abatement

Timing plays a critical role in the cost and feasibility of climate solutions. Because CO_2 concentration is directly correlated with temperature change, delaying emissions reductions increases the likelihood that we will need to address both future and past emissions to reach a desired atmospheric concentration.

Since the industrial era, we have created about 2,200 Gtons of emissions. Without significant intervention, we are on track to emit another ~1,600 Gtons by 2050. The sooner we act, the lower the cumulative emissions – and the cost – will be. Delaying action allows CO_2 concentrations in the atmosphere to rise further, increasing the likelihood that reducing future emissions alone will no longer be sufficient, and that removing historical emissions will become necessary.

Direct Air Capture (DAC) – one of the few methods that can address historical emissions by removing CO_2 already in the atmosphere – is currently prohibitively expensive, costing ~$1,000 per ton. Although efforts are underway to lower the cost to $300 to $500 per ton, even the low end of that range is significantly more costly than many currently available solutions for avoiding future emissions. In short, the longer we delay meaningful action, the more expensive and difficult it becomes to stabilize global temperatures, as we will be forced to tackle both future and historical emissions simultaneously.

HISTORICAL BENCHMARK: INFLATION-ADJUSTED COSTS OF MAJOR INFRASTRUCTURE PROJECTS[2]

SELECT MAJOR INFRASTRUCTURE PROJECTS	INFLATION ADJUSTED COST (2025 $USD)	PERCENT OF 2023 GLOBAL GDP
Interstate Highway System	~$650bn	~0.6%
Apollo Program	~$200bn	~0.2%
International Space Station	~$150bn	~0.1%
Panama Canal	~$15bn	~0.0%
Total Major Projects	**~$1.0tn**	**~1.0%**

(1) Quantum calculations.
(2) "Infrastructure Spend Table," USA Today, NASA, U.S. Senate Committee on Commerce, World Bank, Our World in Data (2024).

The Cost of CO2 Abatement in Renewables is Highly Variable

Not all renewable projects are created equal and project specifics matter

The cost-effectiveness of renewable energy for CO_2 abatement varies significantly depending on several key factors, with some projects delivering far greater emissions reductions per dollar spent than others.

The cost-effectiveness of renewable energy for CO_2 abatement can vary significantly depending on scale, location, existing infrastructure, and other factors. According to research by Thunder Said Energy, wind and solar can supply ~40% of global grid capacity while maintaining an average abatement cost of ~$60 per ton, depending on coal and gas pricing scenarios. However, increasing renewables beyond this share often leads to higher marginal abatement costs, as projects expand into less favorable locations and incur higher infrastructure and integration costs.

Efficient Investments in Low-Carbon Energy

When optimally selected and deployed in favorable locations, some renewable projects have delivered strong economic and environmental outcomes, achieving efficient carbon abatement at relatively low cost:

ROSCOE WIND FARM (TEXAS, U.S.) – Roscoe Wind Farm is one of the world's largest wind farms, with an estimated lifetime abatement cost of ~$35 per ton. The project benefits from favorable wind conditions (~18 mph annual average) and robust transmission infrastructure.[1]

GEMINI SOLAR + STORAGE PROJECT (NEVADA, U.S.) – The Gemini Solar + Storage Project in Nevada is a 690 MW solar photovoltaic (PV) installation with battery storage, designed to address peak energy demand surges. With a 25-year Power Purchase Agreement (PPA) and optimal land conditions, the project is expected to deliver a lifetime abatement cost of ~$30 per ton.[2]

GRAND COULEE DAM (WASHINGTON, U.S.) – The Grand Coulee Dam is a long-standing example of cost-effective hydropower that displaces 18 million tons of CO_2 annually while maintaining an abatement cost below $10 per ton, despite ~$6 billion in expansions.[4]

Lessons from Less Effective Investments

Not all renewable energy investments have delivered cost-effective emissions reductions. Some projects have failed to cut CO_2 as expected or have significantly exceeded cost projections, resulting in high abatement costs with limited climate benefits. Poor site selection, technology underperformance, misaligned solutions to geographies, and policy-driven incentives that overlook project economics have contributed to inefficiencies. In many cases, these challenges stem from market distortions or infrastructure limitations that drive carbon abatement costs above economically viable levels.

RENEWABLE PORTFOLIO STANDARDS (RPS) – In the U.S., states that implement RPS – policies that require a specific percentage of electricity generation to come from renewable sources, regardless of local conditions or economic efficiency – often experience significantly higher costs compared to market-driven approaches. According to a study by the University of Chicago, the cost of abating carbon emissions through RPS policies can vary between $130–$460 per ton of CO_2, largely due to the added costs of intermittency, geographic challenges, and transmission infrastructure needed to meet mandated targets.[5]

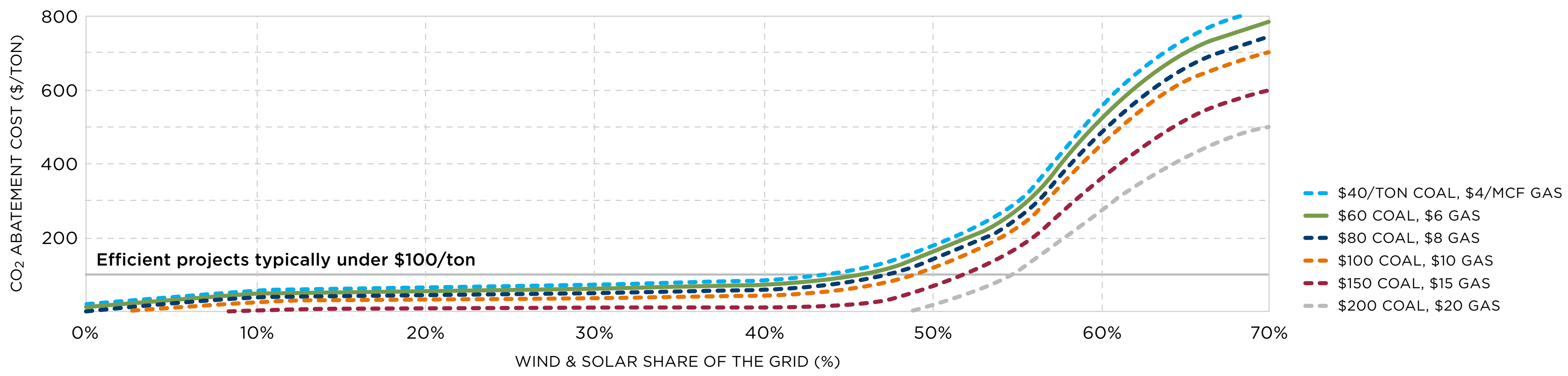
CAPE WIND PROJECT – The Cape Wind Project was a proposed offshore wind farm intended to replace fossil fuel generation on Cape Cod. Despite early momentum, the project became a cautionary example of high-cost renewable development. Elevated PPA prices, prolonged delays, and cost overruns ultimately led to its cancellation in 2017. An MIT analysis estimated the project's implied carbon abatement cost at approximately $300 per ton. A 2008 EPA study also flagged the project's unfavorable economics, attributing some of the challenges to the rigid structure of RPS mandates.[6]

IVANPAH SOLAR POWER FACILITY – Located in California's Mojave Desert, the Ivanpah Solar Power Facility came online in 2014 with high expectations but has significantly underperformed. Originally projected to generate 1 million MWh annually, it has averaged just 0.7 million MWh between 2015 and 2023. The project cost approximately $2.2 billion, supported by $1.6 billion in federal loan guarantees and a $535 million U.S. Treasury grant, along with additional incentives such as investment tax credits and accelerated depreciation. Despite these subsidies and RPS-driven purchasing mandates, abatement costs remain high – estimated at $140–$150 per ton. Recently, PG&E exercised its right to terminate the contract, and Southern California Edison is reportedly reevaluating its position.[7]

NACOGDOCHES BIOMASS PLANT – Commissioned in 2009 and operational by 2012, the Nacogdoches Biomass Plant in Texas was developed under the assumption that rising carbon prices would make renewable generation more competitive than gas-fired alternatives. The plant cost between $400–$500 million to build and was expected to offset 150,000 tons of CO_2 annually compared to natural gas. However, sustained low gas prices rendered the plant economically unviable, and it operated only intermittently. Despite being mostly idle, Austin Energy was required to pay $4 million per month under the contract, ultimately purchasing the plant outright for $460 million to reduce ongoing financial exposure. Based on operational performance, the plant's estimated abatement cost is well over $100 per ton.[8]

These examples highlight that while renewables are essential to decarbonization, their cost-effectiveness varies widely. Strategic project selection and location matter. To achieve climate goals efficiently, we believe investments must focus on abatement cost per ton – not just technology type.

EFFICIENT INVESTMENTS IN LOW-CARBON ENERGY[3]



[1] "E.ON Completes World's Largest Wind Farm in Texas," Reuters.
[2] "BLM and DOI Issue Final Record of Decision for Milestone 690MW Gemini Solar and Battery Storage in Nevada," Business Wire.
[3] ThunderSaid Energy, Wind and solar: what CO_2 abatement costs of renewables?
[4] "Grand Coulee Damn FAQ," Bureau of Reclamation.
[5] "Renewable Energy Mandates Reduce Carbon Dioxide Emissions – But at a Cost," University of Chicago News.
[6] "Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies," MIT Analysis. EPA Notes.
[7] "The Ivanpah Solar Power Monstrosity Bites the Taxpayers. Again," American Enterprise Institute – AEI.
[8] "Austin Buys Troubled Power Plant, Biomass Plant in Nacogdoches Costs $4M a Month," Spectrum Local News.

Carbon Leakage & the Geography of Emissions

Why shifting emissions across borders is undermining global progress

Carbon leakage refers to the phenomenon where actions taken to reduce GHG emissions in one jurisdiction – such as implementing stricter regulations or carbon pricing – ultimately lead to unchanged or even increased global emissions. This occurs when emissions-intensive activities shift to other regions with higher emissions per unit of output, often due to weaker regulations or a more carbon-intensive energy mix. In these cases, emissions are not eliminated – they are simply relocated, or even potentially increased, undermining the overall effectiveness of global reduction efforts.

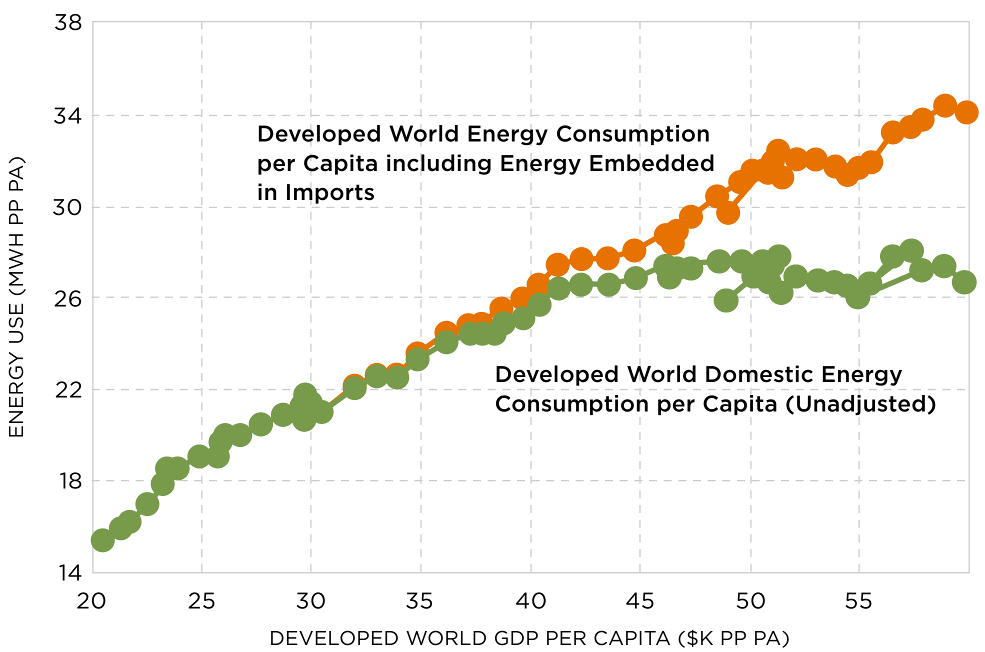
One of the most visible outcomes of carbon leakage has been the migration of manufacturing from developed economies to regions where fossil fuels – particularly coal – dominate the energy supply. As a result, national emissions in countries like the U.S. and those in the EU may appear to decline, even as global emissions rise due to increased production in more carbon-intensive regions. If developed nations accounted for the emissions embedded in imported goods, their energy-related emissions would more closely mirror economic growth.

China offers a striking case study. Since 1990, the country has contributed roughly 9 of the 14 Gtons in additional annual global CO_2 emissions, fueled by rapid population growth, industrialization, and a rising share of global manufacturing – from 9% in 2005 to 30% in 2023. While this growth has helped lower the cost of goods globally, it has also significantly increased global emissions.[2]

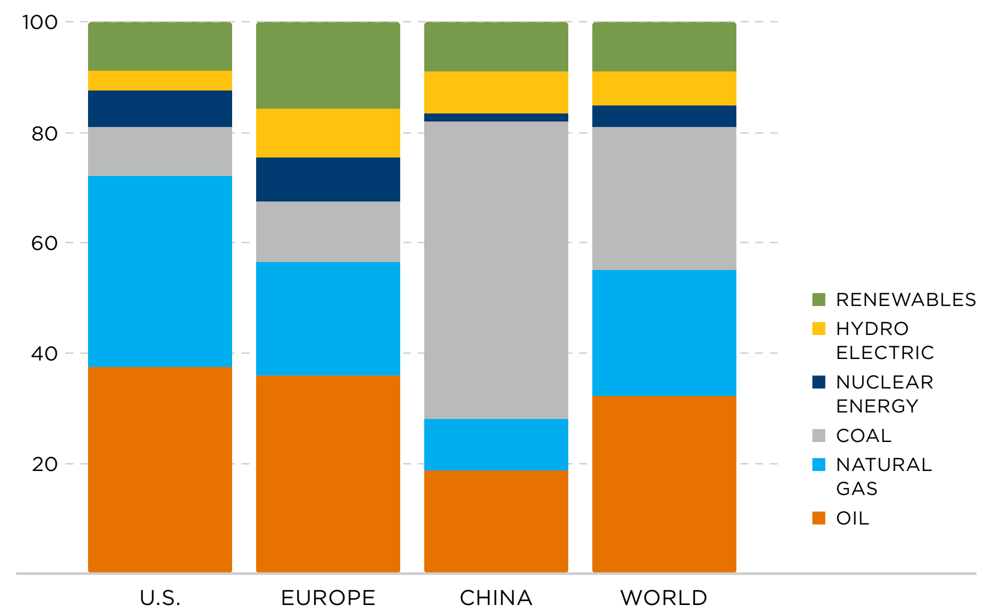
Although China has expanded its renewable energy capacity, its total consumption of traditional fuels – especially coal and oil – has grown more than twice as fast as renewables since 2010. This trend has been largely driven by energy security priorities, with a focus on domestic energy sources and economics. As a result, China's overall energy mix remains two to five times more carbon-intensive than that of most Western economies. This global shift in manufacturing to China and other carbon-intensive regions has played a major role in the rise of global emissions, despite declining emissions in the U.S. and EU.

As discussed in our 2024 Quantum Stakeholder Report, countries such as Germany and Canada have struggled to balance ambitious climate goals with economic competitiveness. The broader shift of industrial production from West to East illustrates the dual consequences of such efforts – environmentally, leakage can increase global emissions, and economically, aggressive domestic reductions can erode industrial competitiveness. As the global conversation increasingly emphasizes energy security and affordability, climate strategies must evolve to reflect the full carbon footprint of global supply chains – not just emissions within national borders. Many groups have advocated for a "dematerialization" strategy – making and using fewer goods – as a means of reducing leakage affects. For example, the EU expects 30–40% of its industrial emissions reduction to come from dematerialization. However, to date, there is no evidence that this approach works or can succeed.[2]

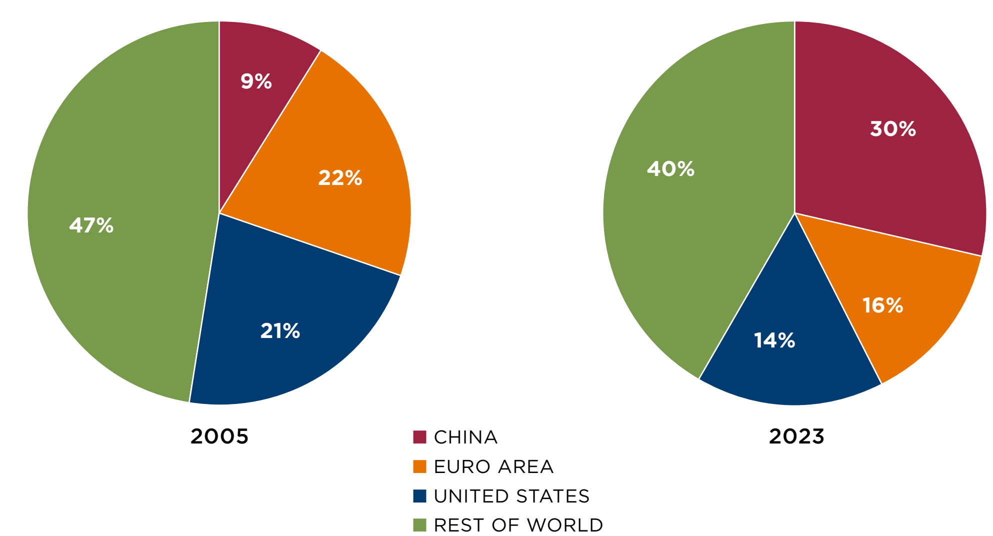
THE IMPACT OF IMPORTED GOODS ON DEVELOPED WORLD ENERGY USE (1965–2023)[1]



2023 ENERGY MIX BY REGION[3]
Stacked percentage share



SHARE OF GLOBAL MANUFACTURING VALUE ADDED OVER TIME[5]
Percent



[1] ThunderSaid Energy.
[2] "Grand Coulee Dam FAQ," U.S. Bureau of Reclamation.
[3] "Statistical Review of World Energy," Energy Institute (2024).
[4] "Effort Sharing: Member States' Emission Targets," European Commission – Climate Action.
[5] World Bank.

There can be no assurances that any historical trends will continue.

Durable Carbon Abatement Investments Matter

Solutions with low long-term maintenance costs provide more durable and efficient emissions reductions

Durable carbon abatement solutions typically involve higher upfront capital but can deliver sustained carbon emission reductions for decades with minimal ongoing costs. We believe these solutions tend to be more cost effective over time because they do not require significant recurring annual investments. By contrast, many emissions reduction projects rely on less permanent solutions that require continuous reinvestment, making them less economical. Increasing the share of durable solutions will be critical to achieving meaningful and affordable carbon abatement.

Examples*

SOLUTION CATEGORY	DURABLE SOLUTIONS	LESS DURABLE SOLUTIONS	ECONOMIC CONSIDERATIONS
Firm and variable low-carbon electricity	Wind Farms, Solar PV, Hydroelectric Dams, Geothermal, Nuclear	Renewable Energy Tax Credits and Feed-in Tariffs	Once installed, renewables continuously reduce emissions with minimal ongoing costs. Nuclear requires large upfront costs but offer very low ongoing emissions and stable long-term generation.
Coal to Gas Switching	Coal-to-Gas Fuel Switching	–	Once the infrastructure is converted from coal to gas, it permanently avoids coal-related emissions – natural gas combustion inherently emits approximately 50% less CO_2 per unit of energy than coal. Thus, the emissions reduction is locked in over the lifetime of the plant, representing a durable reduction from the baseline (coal). However, this solution requires methane leaks from natural gas production and transport to remain low.
Efficiency Gains	Energy-efficient Retrofits, Heating Electrification	–	Insulation, windows, and lighting significantly reduce long-term energy usage. These are permanent reductions through lasting infrastructure improvements with minimal ongoing costs.
Demand Shifts	Sustainable Behavioral Changes, Hybrid EVs	EV Adoption Incentives and Subsidies Recycling and Waste Management Biofuels (Ethanol, Biodiesel, Biogas) Adoption	• Sustainable behavioral changes that reduce emissions are some of the lowest cost emissions reduction options. • Hybrid vehicles provide ongoing benefits with limited carbon abatement costs as fuel savings offset upfront costs, while other EV adoption incentives depend on continuous subsidies. • Ongoing collection, sorting, and recycling facilities require sustained financial investment. If funding stops, waste typically returns to landfill disposal, increasing emissions.
Decarbonize Supplies	Replacement of Methane Leaking Equipment CCUS	Hydrogen	• Substituting pneumatic valves and other oil and gas equipment for no-gas bleeding options permanently eliminates methane and its emissions. • Hydrogen (of all colors) depends on ongoing government subsidies, incentives, carbon pricing, or market support to be competitive against fossil fuels. If subsidies or market incentives are withdrawn or reduced, hydrogen projects can lose economic viability. • CCUS projects typically depend heavily on ongoing subsidies, market support, or R&D investments.
CO_2 Removals, Nature-based and Engineered	Afforestation/Reforestation Direct Air Capture (DAC)	Reduced Emissions from Deforestation and Degradation (REDD+) Carbon Sequestration via Agricultural Practices Payments for Ecosystem Services (PES) Carbon Offset Purchases (Credits)	• Afforestation/reforestation can offer long-term benefits that grow with forest maturity and require limited ongoing management costs. • DAC systems with geological storage permanently remove CO_2 from the atmosphere and store it underground. This investment yields permanent climate benefits; however, operational expenses (energy and maintenance) are ongoing and significant. • Payments for ecosystem services, REDD+ programs, and carbon offset purchases all require ongoing annual payments.

* Not an exhaustive list

Clarifying Economic Durability vs. Carbon Permanence in Carbon Credits

It is important to distinguish the concept of "economic durability," as discussed above, from "carbon permanence," which typically applies to carbon credits. Economic durability refers to the financial effectiveness and long-term economic sustainability of abatement solutions – essentially, how efficiently and continuously a solution reduces emissions from an investment perspective. On the other hand, carbon permanence relates specifically to the stability and long-term security of carbon storage or sequestration, indicating how permanently captured or sequestered carbon is prevented from re-entering the atmosphere. Both concepts are vital but distinct, with economic durability influencing investment strategies and cost-effectiveness, and carbon permanence addressing environmental integrity and effectiveness in carbon markets.

The Energy Transition May Be Cheaper Than You Think

Estimated costs vary meaningfully depending on the methodology and assumptions used

Many experts estimate the cost to achieve net-zero emissions by 2050 would require unprecedented spending – over $100 trillion dollars worldwide over the next 25 years. Climate models and cost projections are inherently challenging to predict, and assumptions about the cost-per-ton of abatement and the speed of decarbonization significantly influence these estimates. However, a critical difference in how we approach the methodology for estimating energy transition costs reveals a fundamentally different – and much more affordable – path to carbon abatement.

The scale of the challenge to reduce emissions appears immense. In 2022, BloombergNEF estimated that achieving net-zero emissions by 2050 would require between $5 to $8 trillion in annual investment over the next 25 years, equal to about 4–8% of global GDP and totaling between $125 and $200 trillion. Other leading institutions provide similar projections. The IEA, in its Net Zero by 2050 report, estimates the need for $4 trillion in annual investments, approximately 4% of global GDP, and $100 trillion over the next 25 years. McKinsey's Global Energy Perspective 2022 outlines an even higher scenario, forecasting cumulative capital expenditures on physical assets at $275 trillion, averaging approximately $9.2 trillion per year or 7–8% of global GDP.

The true cost of the energy transition, however, may be significantly lower than commonly believed – for several key reasons. As outlined in a November 16, 2024, article in The Economist, four main factors suggest that current cost estimates may be overstated. The first three relate to critical assumptions in model construction, while the fourth – and most significant – difference lies in the methodology used to calculate those costs.

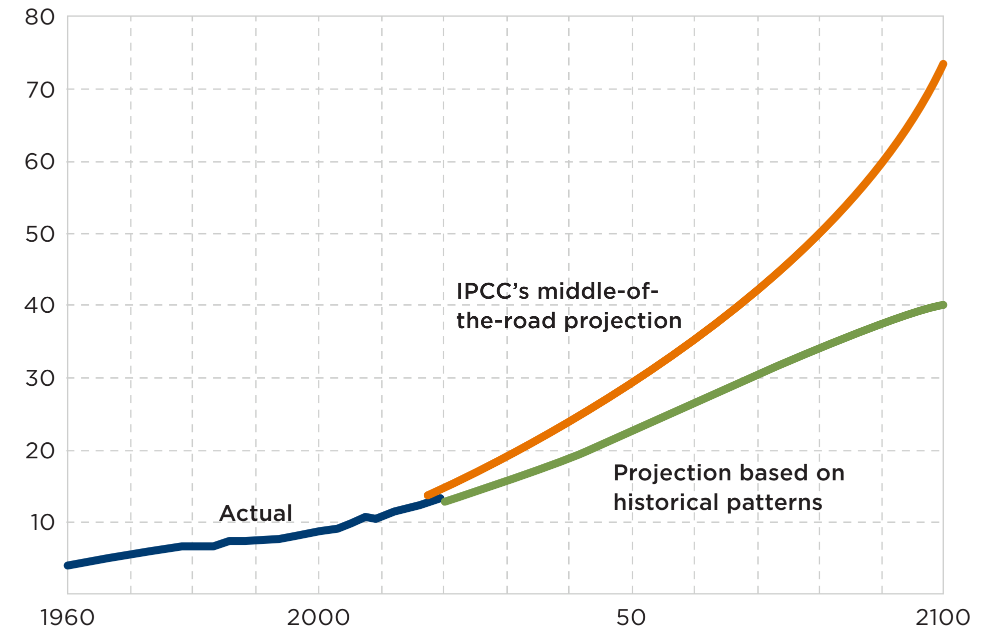
1. **Extremely rapid implementation that increases costs.** Trying to limit global warming at or below 1.5°C – when we are already nearing that threshold – requires significant investments and high-cost emissions removal after emissions have already entered the atmosphere, versus trying to eliminate them as they are produced. Modifying the global warming target to 2.0°C could provide a more achievable path, enabling a more timely and cost-effective solution. However, the potential economic consequences of warming between 1.5°C and 2°C are significant, and since we are on track to overshoot, aiming for a lower target will also involve the added costs of additional CO_2 removals.
2. **Aggressive population and economic growth assumptions that amplify projected energy consumption.** For example, the IPCC's middle case (SSP2) assumes significantly higher economic growth compared to historical trends, which inflates associated projected costs.
3. **Underestimation of how quickly low-carbon technologies can reduce costs.** Technology advancement has played a major role in new carbon abatement solutions and their respective costs, as we and many others have highlighted. For example, solar costs have decreased dramatically with broader adoption, and other technologies may follow similar trajectories. Rupert Way of the University of Cambridge and others have modeled an energy system where the costs of solar power, wind power, lithium batteries, and hydrogen electrolysers decline according to Wright's Law, which states that unit costs fall by a fixed percentage as production scales. In these scenarios, emissions would decrease at a much lower cost.[1]
4. **A fundamental difference in methodology: measuring total energy costs versus incremental clean energy costs.** The most significant difference lies in methodology. Most models calculate the total cost of expanding energy systems, rather than focusing on the incremental cost of adding clean energy compared to continuing with higher-emissions alternatives. A more accurate view of the energy transition compares the additional cost of cleaner energy sources to the cost of maintaining a fossil fuel-dependent energy future.

David McCollum, a climate scientist, and others addressed this in their 2018 paper *Global Energy Transition in the Context of the Sustainable Development Goals*, estimating the incremental cost of decarbonizing the energy system to meet a 2.0°C goal at under $500 billion per year in today's dollars. The UN Environmental Program (UNEP) estimates the cost to meet a 1.5°C target at $7–12T per year – but when adjusted to exclude investments that would happen anyway, that figure falls significantly to between $1–2 trillion annually.

Energy transition cost estimates could be consistently exaggerated because both climate skeptics and climate activists have incentives to overstate them. For skeptics, these large numbers serve as justification for inaction and support the idea that scarce economic resources are better spent elsewhere. For climate activists, inflated figures can help them advocate for increased public spending. In both cases, exaggerated cost estimates risk preventing stakeholders and policymakers from making informed, effective decisions about capital allocation and optimal energy solutions.

Key assumptions can meaningfully impact model outputs

WORLD, GDP PER PERSON[2]
$'000, 2005 prices



WIDE RANGE OF ESTIMATED CARBON ABATEMENT COSTS[3]
Annual Estimated Costs of Net Zero by 2050 (Trillions)

(1) "Way et al.," Joule 6, 2057–2082, September 21, 2022, Published by Elsevier Inc.
(2) "The Energy Transition Will Be Much Cheaper Than You Think," The Economist (2023).
(3) *Ibid.*

Solutions to Provide Affordable, Reliable, Secure & Clean Energy

Practical pathways for cost-effective emissions reductions

ThunderSaid Energy, an independent energy research firm we highlighted in last year's report, offers a practical and efficient roadmap for addressing the Dual Challenge. While their proposed solutions are not without limitations and will require further study and complex implementation, they represent a thoughtful starting point and a valuable contribution to the ongoing discussion.

ThunderSaid Energy estimates that ~1,660 gigatons of emissions must be abated over the next 25 years. This estimate is based on 50 $GtCO_2e$ of emissions in 2019, an expected rise to 80 $GtCO_2e$, and a projected 20% increase in global population by 2050. It assumes that today's energy mix of 30% coal, 30% gas, 25% oil, and 20% renewables continues to scale at current fractional shares.[1] This projection aligns closely with estimates from the IPCC under its Sixth Assessment Report and with other models based on current policies.

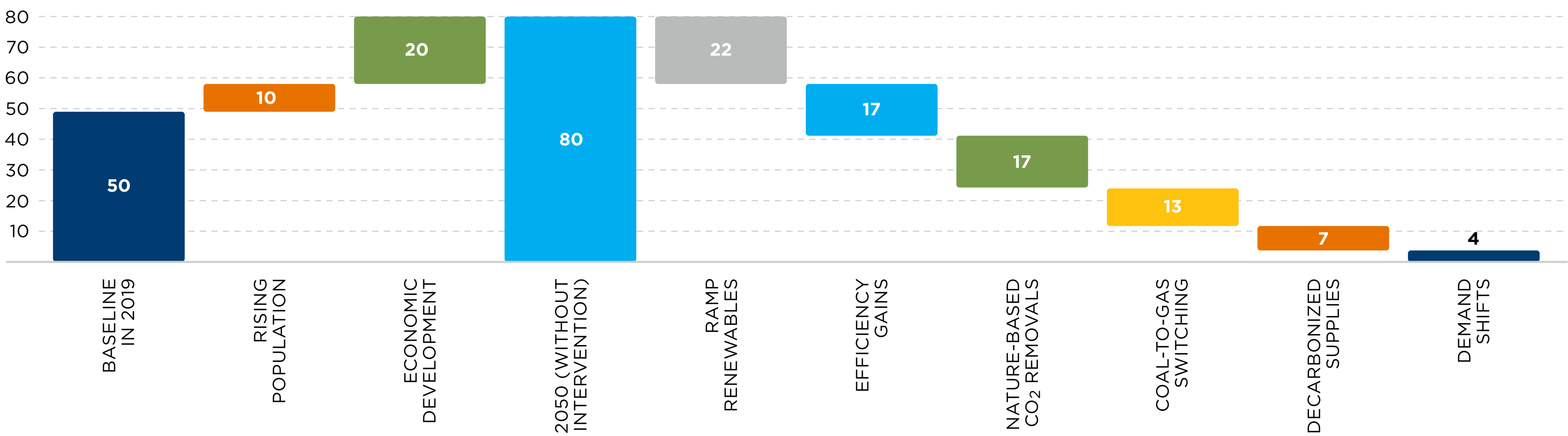
To meet this challenge, Thunder Said Energy outlines a roadmap that prioritizes the six most cost-effective and scalable solutions, which were included in our 2024 Quantum ESG report and are expected to cost under $100 per ton of carbon abatement. Their framework identifies a mix of renewable energy expansion, efficiency improvements, nature-based solutions, coal-to-gas switching, decarbonization, and demand shifts as the most viable pathways.

We find this assessment and proposed roadmap to be a reasonable starting point for understanding both the scale of the challenge and the most practical pathways for addressing it. However, we believe implementing these solutions at scale comes with significant challenges and those challenges vary depending on the solution and the region in which they are implemented. For some solutions, power grid expansion and modernization will be critical to supporting increased renewable energy capacity, but integrating intermittent energy sources into the existing grid remains a technical and economic hurdle. In other solutions, NIMBYism (Not In My Backyard) creates social and political resistance to critical infrastructure projects, further delaying progress. Permitting and regulatory constraints also add complexity, slowing the deployment of new energy projects and transmission infrastructure. Energy security and regional availability of various energy sources also have a significant impact on possible solutions.

Our goal in this section is to evaluate how these six solutions can be implemented in real-world scenarios while navigating these obstacles. We will assess the balance between energy and climate needs, consider economic viability alongside technological feasibility, and explore potential solutions to overcome regulatory and social barriers. By taking a pragmatic approach, we aim to identify strategies that not only drive emissions reductions but also support global economic and social development.

THUNDERSAID ENERGY'S ROADMAP TO NET ZERO, DISAGGREGATED CATEGORY-TO-CATEGORY

Annual CO_2e Emissions (GTpa)



SIX ECONOMIC SOLUTIONS TO SOLVING NET-ZERO

1 RAMPING RENEWABLES
Increasing the global share of renewables – solar, wind, energy storage, hydroelectric, nuclear and biomass – to supply 30% of the world's total energy in 2050 could reduce emissions by 22 gigatons per annum (GTpa), according to ThunderSaid's model.

2 ENERGY EFFICIENCY
Energy efficiency – delivering the same or better performance while using the same or less energy – could reduce emissions by 17 GTpa, according to ThunderSaid Energy. Electric vehicles, additive manufacturing, recycling, and improved building technologies and insulation will all help reduce emissions through enhanced efficiency.

3 NATURE-BASED CO_2 REMOVALS
Nature-based solutions like reforestation, improved forest management, and limiting deforestation can help store and absorb carbon and could reduce emissions by 17 GTpa, according to ThunderSaid's model.

4 COAL-TO-GAS SWITCHING
Coal-to-gas switching is proven and readily available technology that can be implemented relatively quickly to reduce emissions with limited impact on energy costs, accessibility, and energy security. Global fuel swaps from coal to clean-burning natural gas can reduce emissions by 13 GTpa by 2050.

5 DECARBONIZED SUPPLIES
Decarbonized supplies refer to energy sources and technologies that produce little to no GHG emissions. Shifting away from fossil fuels to cleaner alternatives and using technologies that capture or eliminate carbon emissions can reduce emissions by 7 GTpa. Examples include low-carbon hydrogen and derived fuels, cleaner hydrocarbon streams, carbon-neutral or low-carbon feedstocks, and biomass or biofuels with sequestration.

6 DEMAND SHIFTS
Demand shifts refer to structural or behavioral changes in how consumers and businesses use energy. Measures such as increased adoption of remote work, shifting from personal cars to public transportation, and changing consumer habits can reduce emissions by 4 GTpa.

[1] "Decarbonizing Global Energy: The Route to Net Zero?," ThunderSaid Energy.
[2] *Ibid.*

Ramping Renewables

Practical pathways for cost-effective emission reductions

What Is The Solution?

Ramping renewables is the continued growth of clean energy sources – solar, wind, energy storage, hydroelectric, nuclear and biomass – to provide incremental, lower-emission energy. Together, these sources currently account for ~23% of global energy supply, with wind and solar responsible for nearly all of the growth in this category over the last 15 years. This trend is expected to continue and we believe it will play a significant role in expanding global energy capacity in the decades ahead. However, renewables alone cannot meet the world's growing energy demand, as shown in the International Renewable Energy Agency (IRENA) projections below.

How Can The Solution Help Achieve Net-Zero Emissions?

According to ThunderSaid Energy, ramping up renewable energy could reduce global carbon emissions by 22 GTpa, making it the most impactful of the proposed decarbonization solutions. However, achieving this scale of deployment would require significant capital investment and unprecedented coordination among policymakers, industries, and investors. ThunderSaid Energy estimates the average cost of CO_2 abatement from scaling solar and wind at approximately $60 per ton, making it a relatively cost-effective strategy compared to many other decarbonization pathways, when implemented effectively.[1]

The bulk of 22 GTpa reduction would come from a tenfold increase in wind and solar capacity, resulting in 34,000 TWh of generation annually by 2050. This would supply 50% of all global electricity and 30% of total energy demand. This represents a significant increase from previous estimates, as ThunderSaid Energy has revised its solar projections sharply upward while making modest downward adjustments to wind and next-generation renewables. ThunderSaid Energy expects solar to lead this transition, benefiting from rapid efficiency gains, falling costs, and scalability, while wind is expected to remain a key contributor despite economic and technological challenges.

What Is The Impact On Energy Costs, Accessibility & Energy Poverty?

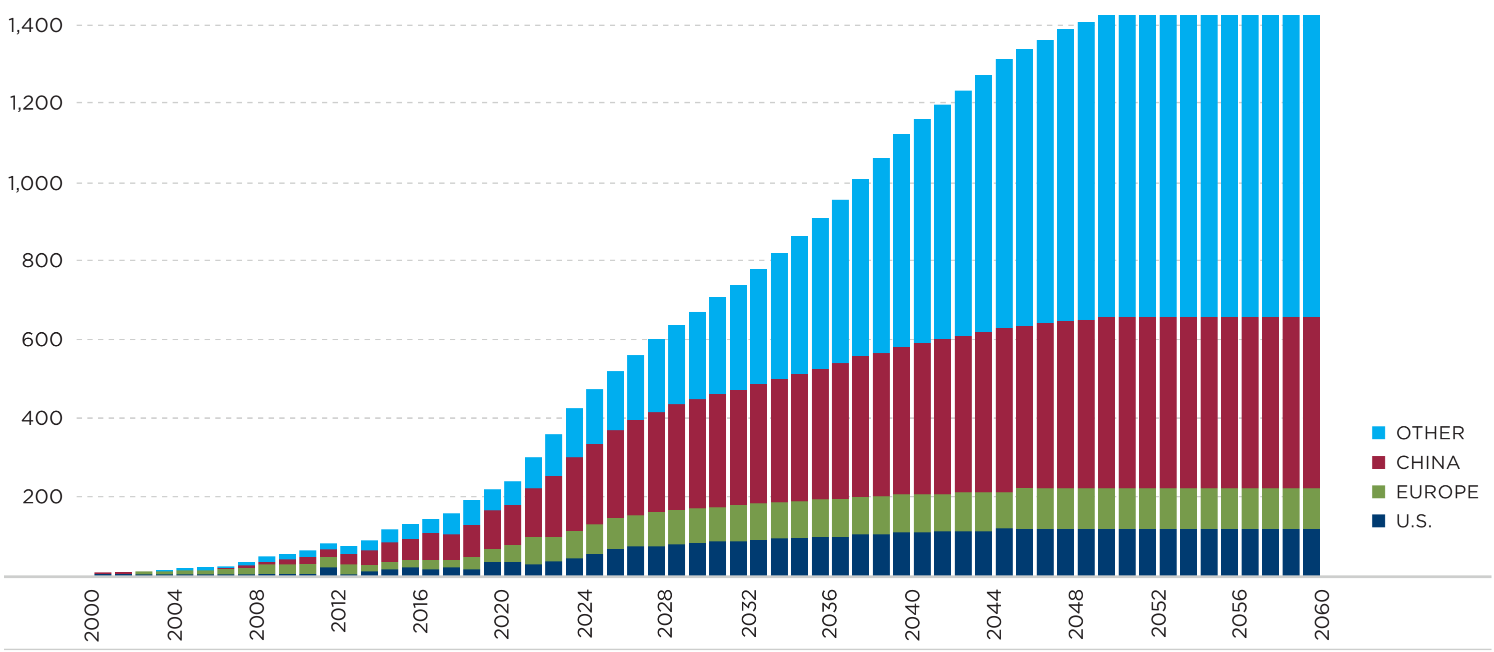
ENERGY COSTS: The cost of solar and wind power generation has dropped dramatically in recent years, with some studies showing a decline of over 80% since 2010, making them cheaper than fossil fuel alternatives and among the most cost-effective sources of new generation in most countries.[2] However, exceptions to this low cost trend can occur if energy systems have low capacity factors, low gas prices, and/or insufficient redundancy and storage, both of which are essential for managing the inherent variability of renewable sources, especially in regions lacking optimal wind and solar conditions. For example, Germany experienced a 270% increase in industrial electricity prices and 139% increase in residential electricity prices from 2000 to 2021 – a staggering increase attributed to low capacity factors and continued dependence on traditional energy sources for reliability, even before the Russian invasion of Ukraine.[3]

ENERGY ACCESSIBILITY: Increased reliance on renewable energy can enhance energy security by reducing dependence on imported fossil fuels, which also has the potential to mitigate price spikes caused by geopolitical events and supply shocks. After the Russian invasion of Ukraine – which triggered disruptions in energy availability and sharp price increases – countries throughout the world, particularly in the EU, have accelerated efforts to reduce reliance on energy imports by investing in renewables and increasing system redundancy. However, as renewable energy systems scale, potential energy security and supply chain challenges could also emerge.

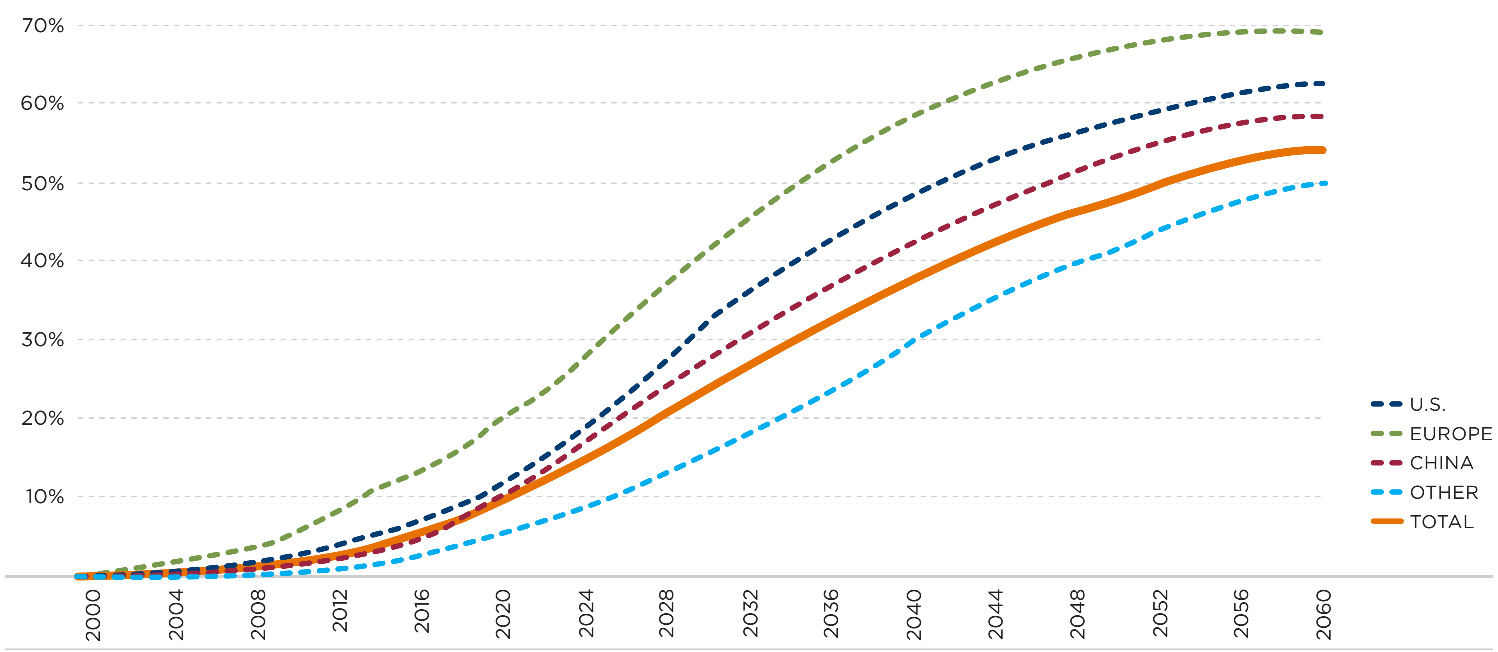
ENERGY POVERTY: Renewable energy buildout can help alleviate energy poverty, particularly through the use of distributed systems that provide reliable energy access to remote communities often excluded from traditional grid infrastructure. Like many large-scale infrastructure projects, renewable deployment also has the potential to create jobs and stimulate local economies. However, if energy prices are negatively affected, this expansion of renewables could unintentionally increase energy poverty by reducing overall energy affordability.

ThunderSaid's projections show wind and solar expanding to supply around 50% of the global electricity grid by 2050, with capacity additions increasing fivefold to 1,400 GW per year

RENEWABLES ADDITIONS[4]
GW



WIND AND SOLAR, PERCENT OF GRID[5]
Percent



(1) ThunderSaid Energy.
(2) "Solar and Wind: What Decarbonization Costs?," ThunderSaid Energy.
(3) International Renewable Energy Agency (IRENA); Bloomberg New Energy Finance (BNEF).
(4) ThunderSaid Energy.
(5) Wind Europe; Fachagentur Windenergie an Land (Agency for Onshore Wind Energy).

Ramping Renewables
continued

How Long Does The Solution Take To Implement and What Are The Estimated Costs?

According to ThunderSaid Energy, to achieve the reduction of 22 GTpa requires increasing renewables generation to 50,000 TWh by 2050. Achieving this goal will require a five-fold increase in power grid investment – rising to $1.5 trillion annually – and a three-fold increase in power electronics investment, reaching $1 trillion annually.[(6)]

Global renewables curtailment rates increased from 3% in 2016, to 5% in 2020, to 8% in 2024. And this is evidence that grids are not being expanded fast enough. Across the globe, the permitting process for renewable energy projects is often prolonged, with timelines that can stretch over several years. Accelerating this process will be essential to achieving net-zero renewable capacity targets. Transmissions projects – which are critical for enabling increased renewable penetration and meeting increasing power demand – represent the most significant long-lead-time challenges in achieving renewable capacity buildout. However, permitting timelines vary widely by country, depending on regulatory frameworks and infrastructure readiness.

What Are The Obstacles & Impediments to Implementation?

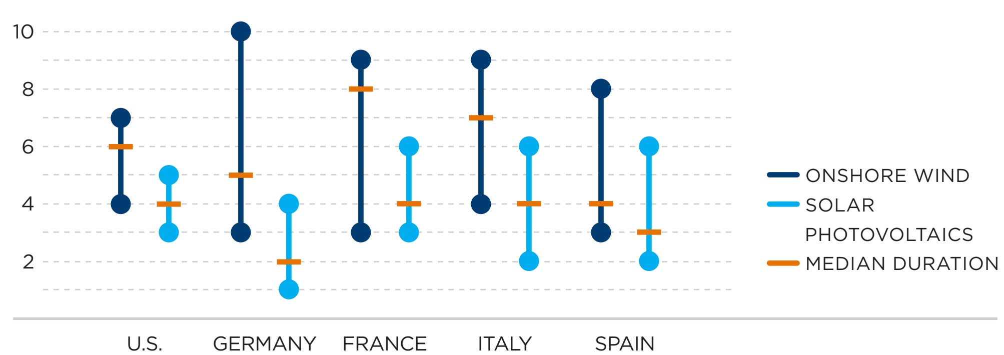
To support the growth of renewables, we believe several challenges must be addressed:

- Permitting and transmission infrastructure need to be streamlined to accelerate deployment and prevent bottlenecks.
- Supply chain management and financing mechanisms will play a crucial role in sustaining large-scale expansion, particularly as renewable penetration increases.
- Enhancing energy storage capacity is vital for balancing supply and demand, ensuring grid reliability and maximizing renewable output.
- Energy security – given the concentration of critical raw materials and processing in specific regions – will be essential to sustaining long-term renewable energy development.
- Access to capital remains a key challenge, particularly given limited returns and other project complexities.

Of the obstacles listed above, inefficient permitting processes and transmission constraints pose some of the most immediate and significant risks to renewable capacity buildout. These issues threaten the development of projects – even when interconnection queues suggest sufficient momentum to meet net-zero capacity targets. BNEF estimates that nearly 600 GW of renewable energy projects were in the connection queues of five key European countries at the end of 2022 – enough to double their existing capacity. In the U.S., projects already in grid queues could triple renewable capacity by 2030. However, the lack of grid infrastructure is leading to extremely long queues for grid connection.[(7)] Across the U.S., power imbalances and insufficient transmission infrastructure are major constraints, limiting the pace and scope of future renewable development.

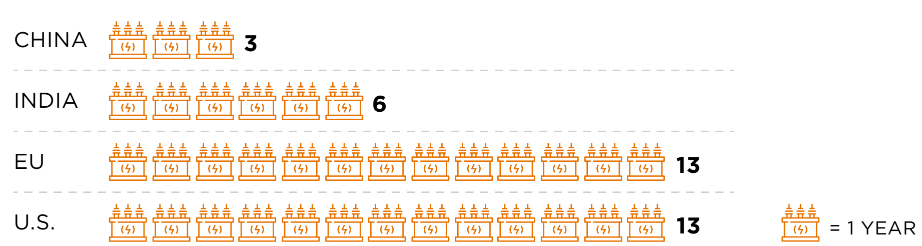
The permitting process (from project start to granted permit) for renewables can take years, with onshore wind taking longer than the process for solar projects.

PERMITTING PROCESS DURATION[(8)]



Transmission lead times have become a major bottleneck for adding new power

TIMELINE FOR PERMITTING A HIGH-VOLTAGE LINE[(9)]



[(6)] ThunderSaid Energy.
[(7)] "Energy Transition Investment," Bloomberg New Energy Finance (BNEF) (2024).
[(8)] "Renewable Energy Development in a Net-Zero World: Land, Permits, and Grids," McKinsey & Company (2024).
[(9)] "Average Lead Times to Build New Electricity Grid Assets in Europe and the United States (2010–2021)," IEA (2022).

Energy Efficiency

Practical pathways for cost-effective emission reductions

What is the Solution?

We believe energy efficiency – delivering the same or better performance while using the same or less energy – has played and will continue to play a vital role in mitigating climate change by reducing energy use, cutting costs, and lowering emissions.

Energy efficiency improvements have been a major factor in reducing energy consumption and emissions in the U.S. and worldwide over the past several decades. According to the American Council for an Energy-Efficient Economy (ACEEE), energy efficiency gains since 1980 have reduced U.S. energy use by approximately 60%.[1] Without the energy efficiency investments made since 1980, energy consumption and emissions worldwide would have been 77% higher, according to the IEA.[2]

Government-driven policies and standards have been key drivers of this progress, with examples including the Corporate Average Fuel Economy (CAFÉ) standards, smart grids, and energy efficient air conditioning and appliances – alongside continued advancements across multiple sectors. While energy efficiency has improved globally in recent years, significant opportunities remain through technological innovation and broader adoption. Many low-cost solutions can deliver additional emissions reductions, making energy efficiency an essential solution on the path to net-zero.

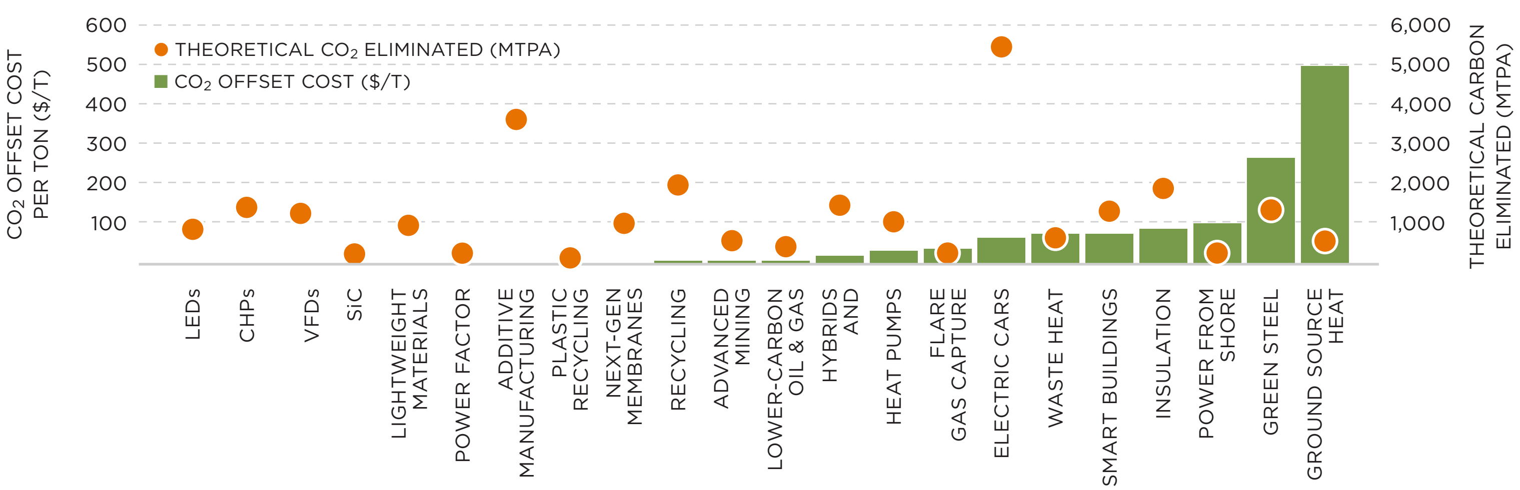
How Can the Solution Help Achieve Net-Zero Emissions?

In ThunderSaid Energy's Roadmap to Net Zero,[2] energy efficiency could contribute 17 GTpa toward the total annual emission reductions needed to reach net-zero. The chart below shows the expected carbon abatement by category and the corresponding cost per MTpa, with most of these approaches delivering carbon abatement at under $100 per ton.

Among these measures, electric vehicles (EVs) and/or hybrids are projected to have the largest impact, delivering 4 GTpa of CO_2 reductions at an average abatement cost of $50-$70 per ton, according to ThunderSaid Energy. While EVs account for a large portion of potential carbon abatement through energy efficiency gains, they also present a complex picture – largely due to cost variability based on vehicle make and model, as well as the carbon intensity of the local power grid.

ENERGY EFFICIENT TECHNOLOGIES[3]

MTPA vs. $/Ton



SPOTLIGHT

Comparing the Carbon Abatement Costs of Electric to Internal Combustion Engine Vehicles

The EV revolution is gaining momentum, but questions remain about how much emissions EVs reduce compared to internal combustion engine (ICE) vehicles – and at what cost. The chart below compares the carbon abatement cost of various 2024 vehicle models relative to a Toyota Camry LE, using emissions based on the average U.S. grid (0.41 kg CO_2 / mile) and a 10-year vehicle lifespan. The Toyota Camry has an ICE, while the hybrids combine a small battery with an ICE, which typically reduces fuel usage by ~30%. The analysis shows that lower cost hybrids and EVs can deliver abatement under $100 per ton, while higher cost models may exceed $1,000 per ton due to limited emission savings relative to added cost.

Another important factor is the carbon intensity of the electricity used to charge EVs. For example, if a Tesla Model 3 were charged entirely with a gasoline-powered generator, the emissions per mile would exceed those of the Toyota Camry, resulting in an abatement cost increase of approximately $1,289 per ton. This illustrates how the emissions-reduction potential of EVs depends on the emissions profile of the electricity source. The higher the carbon intensity of the grid, the smaller the emissions savings – and the higher the cost per ton abated.

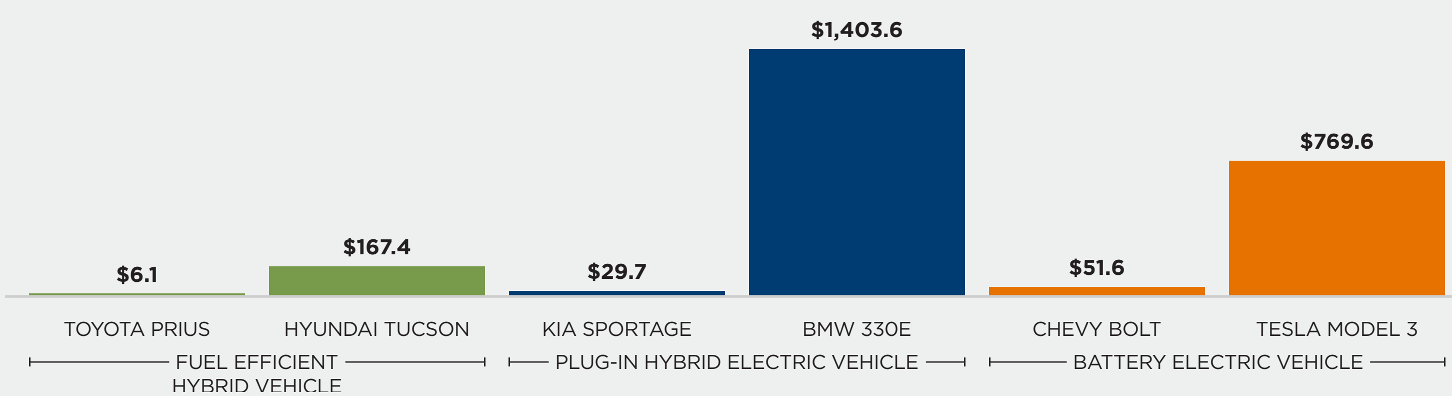
That said, EV investments are helping to scale production and infrastructure, which is expected to lower costs over time.[4] As battery prices decline and manufacturing becomes more efficient, the cost per ton of CO_2 abated is projected to improve. By the late 2020s, EVs are expected to reach purchase-price parity with gasoline vehicles, improving their emissions economics. However, electricity source and vehicle cost will remain key drivers of abatement efficiency.

More cost-effective options already exist within the transportation sector. Improving ICE efficiency – through better engines, transmissions, lighter materials, or hybridization – can reduce CO_2 emissions at a lower cost and sometimes deliver net fuel savings. For example, tightening CAFE standards has achieved reductions at ~$86 per ton (based on credit trading prices), which is lower than some EVs.[5]

Importantly, motivations for EV deployment go beyond carbon economics. In China, energy security is a key driver. The country imports ~6 million barrels of oil per day, so electrification reduces this reliance and improves national energy independence. Public health is another factor, as EVs eliminate tailpipe emissions that contribute to urban air pollution. While EV adoption is growing in China and the EU, the U.S. lags behind, with EVs accounting for ~8% of new vehicle sales.[6]

RELATIVE ABATEMENT COST COMPARED TO A TOYOTA CAMRY LE[7]

Abatement cost ($/ton CO_2)



(1) "The Greatest Story You've Never Heard," ACEEE.
(2) "Decarbonizing Global Energy: The Route to Net Zero?," ThunderSaid Energy.
(3) "Top Technology Database," ThunderSaid Energy.
(4) "Electric Vehicle Outlook 2024," BloombergNEF (BNEF).
(5) National Highway Traffic Safety Administration (NHTSA). CAFE Public Information Center.
(6) "Electric Vehicle Sales Jump Higher in Q4, Pushing U.S. Sales to a Record 1.3 Million," Cox Automotive Inc.
(7) "Electric Vehicles: Total Cost of Ownership?," ThunderSaid Energy.

Energy Efficiency
continued

What is the Impact on Energy Costs, Accessibility & Energy Poverty?

Energy efficiency plays a critical role in reducing energy costs, improving accessibility, and alleviating energy poverty. By lowering overall energy consumption, efficiency measures reduce the need for costly new power generation and transmission infrastructure, easing pressure on energy markets and leading to lower energy prices across multiple sectors. According to the IEA, this leads to more affordable power for both businesses and households.

ACEEE highlights that efficiency improvements since 1980 have saved U.S. consumers nearly $800 billion annually and reduced household energy consumption by 16% per home.[6] Globally, if cost-effective energy efficiency opportunities were fully implemented, households could save an estimated $201 billion in avoided electricity and gas costs and an another $365 billion on transport fuels by 2040.[7]

In regions with limited energy access, declining technology costs and more efficient end-use appliances are expanding the range of affordable options. Super-efficient appliances paired with off-grid energy systems can help supply power to remote, sparsely populated areas where grid access is limited and energy costs are high – helping reduce energy poverty and drive local economic growth.

How Long Does the Solution Take to Implement & What Are the Estimated Costs?

While many efficiency technologies are available, timing of adoption remains uncertain. High-income households and developed economies are more likely to have the awareness, access, and infrastructure needed to adopt energy-efficient technologies quickly. In contrast, low-income households in non-OECD nations may not have the awareness that energy efficient technology is available and may not have the credit to cover the upfront costs.

What Are The Obstacles & Impediments to Implementation?

While many energy efficiency technologies and initiatives are already in progress, several challenges hinder greater adoption and impact including:

HEAVY INDUSTRY CHALLENGES: Heavy industry presents a distinct challenge, as improvements in industrial energy intensity have historically lagged behind those in transportation and buildings. Since 2000, industrial energy intensity has improved at a rate of only ~1% per year, highlighting the need for greater coordination and targeted policies to accelerate progress.

REGULATORY BARRIERS: Regulatory barriers remain significant. Adoption and enforcement of energy efficiency regulations vary widely across countries, and in some regions, such policies are lacking altogether. One major issue is the lack of mandatory building energy codes and appliance standards. Even where such standards exist, they may be weak or poorly enforced, limiting their effectiveness. According to the IEA, over 30% of appliances sold globally fail to meet the highest energy efficiency standards, reducing the potential energy savings from improved technology.

SIGNIFICANT UPFRONT COSTS: High upfront costs can also be a deterrent, despite long-term savings. This challenge is particularly pronounced in developing countries, where affordability remains a key factor in decision-making. Additionally, unfavorable market conditions, such as limited competition among suppliers or lack of availability of energy-efficient technology, can restrict consumer access to these solutions and keep prices high.

REBOUND EFFECT: Another challenge is the rebound effect, where increased efficiency lowers the cost of energy consumption, leading to greater overall energy use. Additionally, global trends – such as the growing number and size of buildings and devices, as well as increasing vehicle miles traveled – could offset energy efficiency gains if not addressed.

We believe overcoming these obstacles requires policy support, financial incentives, improved enforcement of regulations, and increased consumer awareness to ensure that energy efficiency measures reach their full potential in reducing energy consumption and emissions.

Energy Efficiency Technology Cost and CO_2 Abatement Summary[8]

COST OF ABATEMENT ($/MT)	THEORETICAL CO_2 ELIMINATED (MTPA)	% OF THEORETICAL CO_2 ABATED	TECHNOLOGIES AT PRICE POINT
<$0	10,030	36%	LEDs, CHPs, VFDs, SiC, Light-Weight Materials, Power Factor, Additive Manufacturing, Plastic Recycling, Next-Gen Membranes
$1–$50	5,919	21%	Recycling, Advanced Mining, Lower Carbon Oil & Gas, Hybrids, Heat Pumps, Flare Gas Capture
$50–$100	9,474	34%	Electric Cars, Waste Heat Recapture, Smart Buildings, Insulation
$100–$200	245	1%	Power From Shore
$200–$300	1,344	5%	Green Steel
>$300	551	2%	Ground Source Heat

[6] "Multiple Benefits of Energy Efficiency," IEA (2019).
[7] "Energy Efficiency Impact Report," ACEEE (2023).
[8] "Top Technology Database," ThunderSaid Energy.

Nature-Based CO2 Removals

Practical pathways for cost-effective emission reductions

What is the Solution?

Nature-based solutions have the potential to play a significant role in achieving net-zero emissions by removing large amounts of carbon dioxide from the atmosphere. These approaches – including reforestation, improved forest management, and limiting deforestation – are low-cost, technically viable, and offer immediate climate and ecological benefits.

Reforestation involves replanting trees in areas where forests have been cleared or degraded. As trees grow, they absorb carbon dioxide from the atmosphere through photosynthesis, effectively acting as a carbon sink and storing it in their trunks, roots, and soil. Reforestation supports both carbon removal and ecosystem restoration, making it one of the most accessible and impactful nature-based climate solutions.

Improved forest management can help maintain and expand the ability of forests to absorb and store carbon. Strategies such as delaying timber harvests, planting additional trees, selectively thinning to promote healthier growth, managing wildfires, and enhancing soil nutrients all play a role in strengthening forest resilience and maximizing their long-term environmental benefits.

Limiting deforestation is equally critical. The clearing of forests – primarily for agriculture, infrastructure, and urban expansion – releases large amounts of stored carbon into the atmosphere and disrupts ecosystems. Preventing further forest loss, especially in highly forested regions such as Brazil, Russia, Canada, the Democratic Republic of Congo, Indonesia, and the U.S., helps preserve existing carbon storage, reduce emissions from land-use changes, and protect biodiversity.

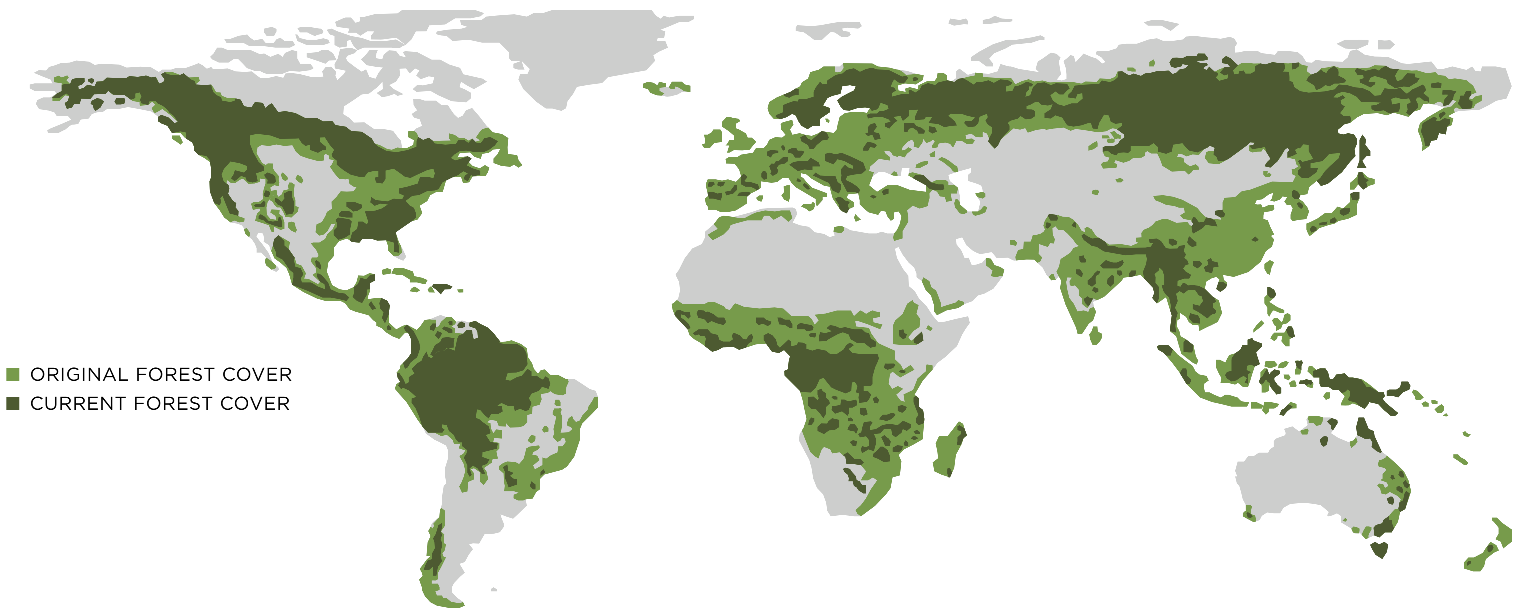
According to the Forest Declaration Assessment, the world lost ~16 million acres of forest cover in 2022 alone, which produced roughly 2.7 Gtons of CO_2 emissions.[1] Forests once covered around 50% of the Earth's land area, but today only 30% of land is forested.[2]

How Can the Solution Help Achieve Net-Zero Emissions?

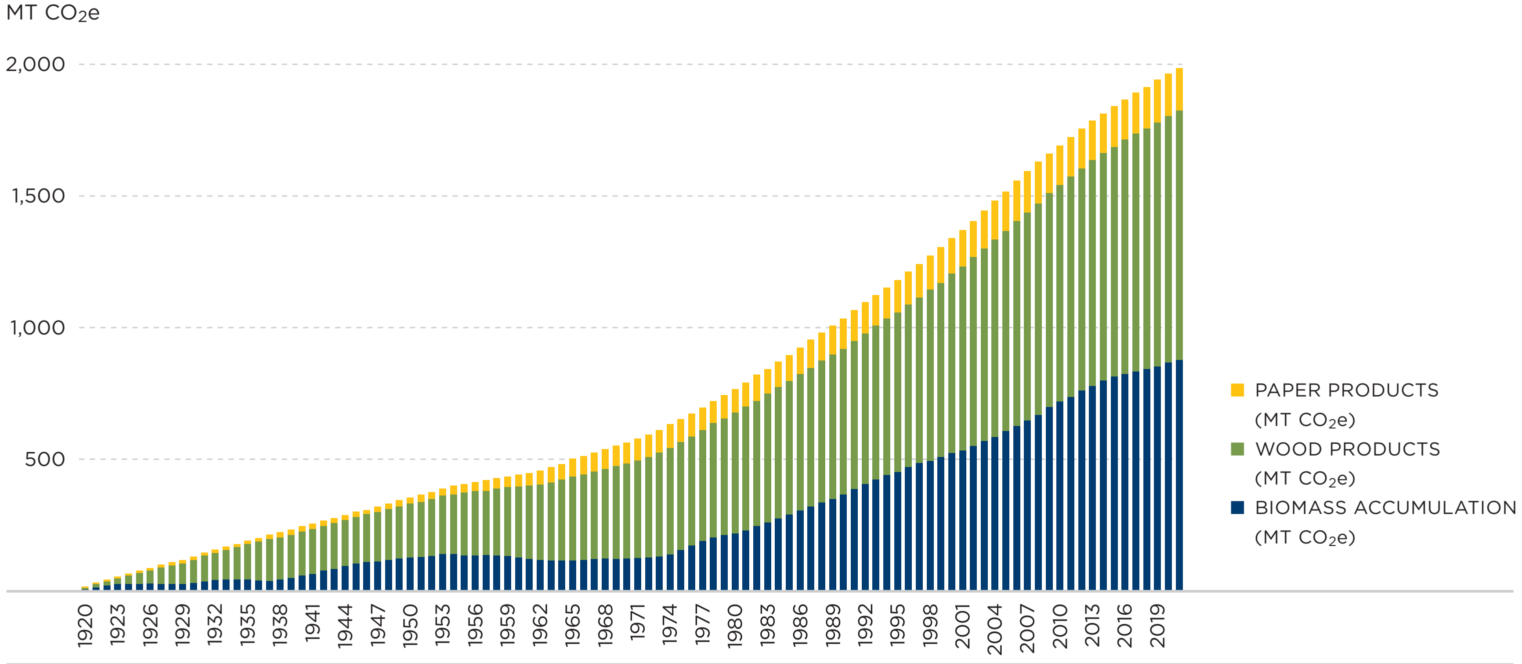
ThunderSaid Energy estimates that nature-based solutions worldwide could remove as much as 15 gigatons of CO_2 per year. However, this estimate is much higher than other studies. Historically, around 5 billion acres of forests have been lost, contributing to over 1 trillion tons of CO_2 emissions since prehistoric times. Given that photosynthesis already fixes approximately 700 GTons of CO_2 annually – compared to human-caused emissions of 53 Gtons per year – even small adjustments in global forest cover could have a significant impact on atmospheric carbon levels.[3]

A compelling example of effective forest management comes from Finland, where pine and spruce forests cover 70% of the country, supporting 60,000 jobs and contributing 4% of GDP. Over time, Finland has increased its standing forest biomass by more than 1 billion cubic meters, capturing nearly 1 Gton of CO_2 in forests and an additional 1 Gton in long-lasting wood products.[5] Notably, over 100 countries covering 5 billion acres have environmental conditions more favorable for forest growth than Finland – raising the question of why nations with vast forest potential, such as Brazil, are not seeing similar success. Expanding reforestation efforts in these regions could drive significant progress toward global carbon neutrality.

DEFORESTATION THROUGH HISTORY[4]



CUMULATIVE CARBON REMOVALS IN FINLAND[5]



[1] Forest Declaration Assessment, coordinated by Climate Focus, with contributions from WWF and partners.
[2] Food and Agriculture Organization of the United Nations (FAO), "Global Forest Resources Assessment 2020."
[3] ThunderSaid Energy, "Nature-Based Solutions for Climate Change."
[4] *Ibid.*
[5] ThunderSaid Energy, "Finnish Forests: A Two Billion Ton CO_2 Case Study."

Nature-Based CO_2 Removals
continued

What is the Impact on Energy Costs, Accessibility & Energy Poverty?

Nature-based solutions, such as reforestation and improved forest management, do not directly increase energy costs, limit energy accessibility, or contribute to energy poverty, as they focus on carbon absorption rather than restricting energy sources.

In many developing countries, however, the conversion of forest land to agriculture, infrastructure, and other higher-value economic uses plays a significant role in national GDP. Striking a balance between economic growth and large-scale reforestation will be particularly important for developing nations that prioritize economic development over climate initiatives. Achieving this balance requires policies that integrate both environmental sustainability and economic opportunity, ensuring that nature-based solutions contribute to long-term resilience without undermining essential economic drivers.

How Long Does the Solution Take to Implement & What Are the Estimated Costs?

Limiting additional deforestation can have immediate impacts. Enhanced forest management and reforestation are long-term processes, as it typically takes around 50 years for trees to fully grow and absorb significant amounts of carbon dioxide. The cost of reforestation varies based on land acquisition, planting, and maintenance, but ThunderSaid Energy estimates that removing CO_2 through forest projects costs about $50 per ton of carbon captured. Over time, the value of the timber and the land itself can increase, helping to offset some of the costs.[6]

Recent research published in Nature Climate Change indicates that natural regeneration – allowing forests to regrow without active planting – can be a more cost-effective approach in nearly half of all viable locations, offering 10.3 times more carbon abatement potential below $20 per ton of CO_2 and 2.8 times more below $50 per ton of CO_2 than previously estimated by the IPCC.[7] This suggests that reforestation can be a highly economic climate mitigation strategy, with substantial opportunities for low-cost carbon removal. Additionally, the value of restored forests – including potential timber resources and improved land productivity – can help offset some of the initial investment, further enhancing the financial viability of reforestation projects.

[6] "Reforestation: Costs of CO_2 Removals?," ThunderSaid Energy.
[7] "Cost-Effectiveness of Natural Forest Regeneration and Plantations for Climate Mitigation," Busch, J., Engelmann, J., Cook-Patton, S. C., Griscom, B. W., Kroeger, T., Possingham, H., & Shyamsundar, P., Nature Climate Change (2024).
[8] "Fiscal Policy to Mitigate Climate Change: A Guide for Policymakers," Chapter 5, p. 90.
[9] "Forest Restoration in Brazil: Essential Factors for Promoting Restoration at Scale," Climate Policy Initiative.

What Are The Obstacles & Impediments to Implementation?

Despite its potential as a climate solution, reforestation faces several obstacles that hinder large-scale implementation and fuel skepticism about its long-term effectiveness and credibility. Additionally, deforestation continues to outpace replanting efforts, and newly planted trees take decades to reach the carbon storage capacity of mature forests. For reforestation to gain widespread support, projects must be perceived as real, measurable, and trustworthy.

ADMINISTRATIVE COMPLEXITY: One of the biggest challenges is the administrative complexity involved in reforestation projects. Reforestation projects often involve fragmented land ownership, competing land-use priorities, and overlapping claims, making it difficult to coordinate large-scale efforts. Finding suitable land without displacing agriculture or other critical uses remains a persistent barrier.

LACK OF TRUST: Some projects have been criticized for overstating carbon savings – such as claiming credits for forests that were never at risk of deforestation – which has undermined trust in the integrity of reforestation efforts. Others argue that the priority should be cutting emissions at the source rather than relying on carbon offsets. Additionally, the use of fast-growing non-native tree species in some projects has raised ecological concerns about disrupting local biodiversity rather than restoring it.

LAND ISSUES: Ownership, land rights, and land availability present another major hurdle. Finding suitable land for reforestation without competing with agriculture or other uses remains difficult. In many regions, forest ownership is fragmented, with multiple stakeholders holding legitimate claims over different aspects of the same land. This creates conflicts over land use, making it difficult to implement large-scale reforestation efforts.[8]

LONGEVITY CONCERNS: Longevity is another concern, as trees are vulnerable to wildfires, disease, and extreme weather events, which can release stored carbon back into the atmosphere.

LACK OF FINANCING: Financing remains a challenge. Given the skepticism and implementation hurdles to date, carbon credits tied to reforestation tend to trade at relatively low prices, making it harder to attract private capital.

Addressing these challenges will require stronger oversight, improved carbon credit verification, and integrated policies that align reforestation with both climate and economic goals. Brazil's experience, for example, highlights how legal, financial, and logistical barriers can significantly delay or derail restoration initiatives – even in countries with strong stated commitments to forest recovery.[9]

Coal-to-Gas Switching

Practical pathways for cost-effective emission reductions

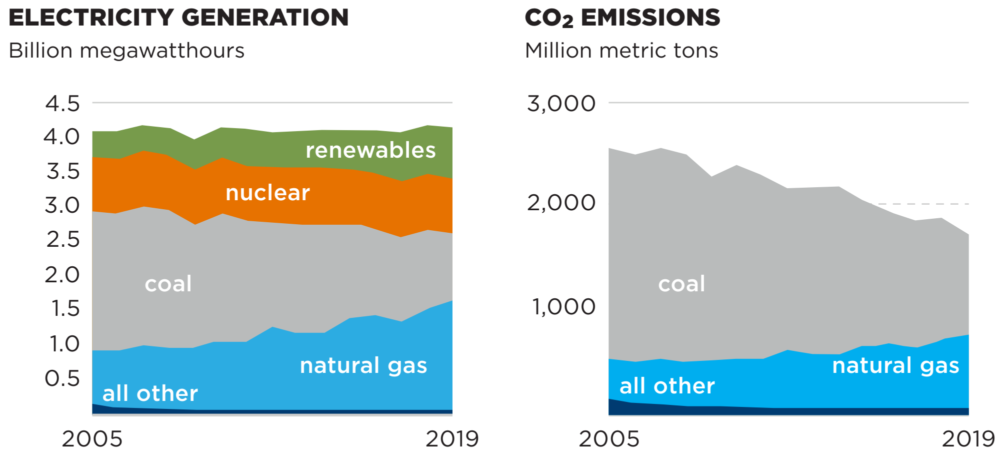
What is the Solution?

Coal-to-gas switching is a proven and readily available technology that can be implemented relatively quickly to reduce emissions with limited impact on energy costs, accessibility, or energy security, depending on a regions' access to natural gas. Coal-to-gas switching also has the potential to improve air quality and public health outcomes, as natural gas burns cleaner than coal, producing fewer airborne pollutants such as particulate matter and sulfur dioxide. This shift could help reduce respiratory diseases in areas with heavy coal use.[1]

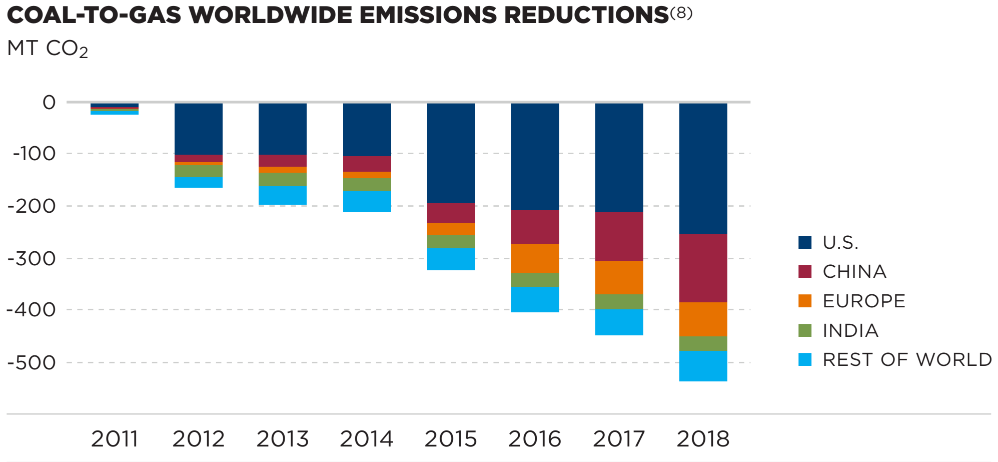
Coal-to-gas switching is the process of replacing coal with natural gas for power generation, either by converting existing coal-fired power plants to burn natural gas or by retiring coal plants and constructing new, high-efficiency natural gas facilities. This transition aims to significantly reduce carbon emissions, as natural gas-fired power plants emit roughly half the CO_2 of coal-fired plants for the same amount of electricity produced. For instance, in the U.S., in 2019, coal-fired plants emitted approximately 2,257 pounds of CO_2 per MWh of electricity, whereas natural gas-fired plants emitted only 976 pounds per MWh.[2] On a fuel basis, coal emits around 209 pounds of CO_2 per million British thermal units (MMBtu) burned, compared to just 117 pounds for natural gas – a reduction of 50–60% in emissions, demonstrating the substantial carbon savings of fuel switching.[3]

Coal-to-gas switching can be achieved through different methods. One approach is retiring older coal plants and replacing them with modern combined-cycle natural gas plants, which are highly efficient at converting fuel into electricity. Another method involves retrofitting existing coal plants by modifying their boilers or furnaces to burn natural gas. While retrofitting is often faster and less expensive upfront, new combined-cycle gas plants typically achieve higher efficiency. Between 2011 and 2019, the EIA reported that 121 coal-fired power units in the U.S. were converted to other fuels, with 103 switching to or being replaced by natural gas-fired plants.[4] This shift has been driven by multiple factors, including stricter emissions regulations, the increasing availability of low-cost natural gas, and technological advancements that have improved the efficiency of natural gas turbines.

U.S. electric power sector electricity generation and CO_2 emissions by source (2005–2019)[5]



CO_2 savings from coal-to-gas switching in selected regions compared with 2010



How Can the Solution Help Achieve Net-Zero Emissions?

ThunderSaid Energy estimates that by 2050, global coal demand could decrease by over 90%, falling from 7.7 GTons per year to just 0.4 GTons. Under a fully realized net-zero scenario, coal-to-gas switching alone could eliminate approximately 13 gigatons of CO_2 per year, accounting for roughly one-sixth of the total 80 GTons per year of emissions that would otherwise be released into the atmosphere.

In fact, the impact of coal-to-gas switching on emissions has already been significant. In the U.S., the shift from coal to natural gas in the electricity mix was the single largest factor in reducing power-sector CO_2 emissions over the last 15 years.[6] Globally, according to the IEA, fuel switching from coal to natural gas between 2010 and 2018 prevented approximately 500 million tons of CO_2 emissions that would have otherwise been emitted. This cumulative emissions savings is equivalent to the effect of adding 200 million EVs powered by zero-carbon electricity to the roads during the same period.[7]

What is the Impact on Energy Costs, Accessibility & Energy Poverty?

The economic feasibility of coal-to-gas switching depends largely on regional gas availability and pricing, as well as existing infrastructure. In the U.S., which has an extensive gas pipeline network, the shale gas boom over the past decade led to low natural gas prices, making coal-to-gas switching primarily market-driven. Many utilities found that they could generate electricity at a lower levelized cost using new gas-fired plants rather than continuing to operate aging coal plants, especially when factoring in environmental compliance costs for coal.[9]

Coal has historically been a widely distributed and locally sourced energy supply in many developing regions, making it a secure and reliable fuel option. In contrast, natural gas requires an extensive infrastructure network, including pipelines, LNG terminals, and storage facilities, which many nations currently lack. In regions where natural gas is not domestically available, accessing gas can be significantly more expensive – given the import and related infrastructure costs – than relying on indigenous coal reserves. For these nations, switching to gas also means depending on imported fuel, which can be costly and subject to market volatility.

Globally, outside of the U.S., natural gas and nuclear power often have higher costs than coal-fired electricity generation.[10] Without policy support or financial assistance, replacing cheap domestic coal with expensive imported gas could drive up electricity prices, making the transition financially burdensome for many countries. The World Bank describes this challenge as a "triple penalty" in the clean energy transition: developing nations face higher electricity costs when shifting away from coal, struggle to access capital for clean energy projects, and risk becoming locked into long-term fossil fuel dependency if financial and infrastructure barriers prevent investment in cleaner alternatives.[11]

(1) "The Role of Gas in Today's Energy Transitions, World Energy Outlook Special Report," IEA.
(2) "Electric Power Sector CO2 Emissions Drop as Generation Mix Shifts from Coal to Natural Gas," Today in Energy, EIA.
(3) *Ibid.*
(4) "More Than 100 Coal-Fired Plants Have Been Replaced or Converted to Natural Gas Since 2011," Today in Energy, EIA.
(5) "Electric Power Sector CO2 Emissions Drop as Generation Mix Shifts from Coal to Natural Gas," Today in Energy, EIA.
(6) *Ibid.*
(7) "The Role of Gas in Today's Energy Transitions, World Energy Outlook Special Report," IEA.
(8) *Ibid.*
(9) "More Than 100 Coal-Fired Plants Have Been Replaced or Converted to Natural Gas Since 2011," Today in Energy, EIA.
(10) *Ibid.*
(11) "Breaking Down Barriers to Clean Energy Transition," World Bank Group.

Coal-to-Gas Switching

continued

How Long Does the Solution Take to Implement & What Are the Estimated Costs?

The time required to implement coal-to-gas switching can be relatively quick depending on whether a new natural gas plant is being built or an existing coal plant is being converted. In our experience, new-build natural gas plants generally take around two to three years to complete after securing permits and financing. Many jurisdictions have streamlined the approval process for gas-fired plants since their environmental footprint is lower than coal, which can accelerate implementation timelines. Conversions of existing coal units can be even faster; if a coal boiler is retrofitted to burn natural gas, the transition can be completed within one to two years, making it a relatively quick method of reducing emissions compared to other large-scale solutions. Related infrastructure and permit timing will also be a factor.

The cost of implementation varies based on regional conditions and fuel prices. According to ThunderSaid Energy, the average cost of CO_2 abatement across all mitigation strategies is estimated at $40 per ton, with coal-to-gas switching falling near this level. However, the infrastructure investment required to scale up natural gas remains a significant factor. While upfront capital costs for building gas pipelines, LNG terminals, and power plants are substantial, the overall system-wide cost remains competitive.

ILLUSTRATIVE CARBON ABATEMENT COSTS

Infrastructure Costs – Natural Gas	
Coal Annual Generation (MWh)	8,850,000,000
Cost per MW of Gas Generation Build-Out ($/MW)	$722,000
Total Gas Generation Build-Out Cost ($Bn)	**$1,279**
Power Plant Useful Life	20
Cost per Year ($Bn)	**$64**
Fuel Costs	
Fuel Cost ($/MMBtu) – Coal	$2.40
Fuel Cost ($/MMBtu) – Natural Gas	$6.00
Fuel Cost ($/MWh) – Coal	$20.47
Fuel Cost ($/MWh) – Natural Gas	$34.12
Total Annual Fuel Cost – Only Coal ($Bn)	$181
Total Annual Fuel Cost – Only Natural Gas ($Bn)	$302
Delta	**$121**
Fuel Costs	
Total Gas Only CO_2 Emitted (Tonnes)	3,540,000,000
Total Coal Only CO_2 Emitted (Tonnes)	8,186,250,000
Delta	**4,646,250,000**
Summary	
Build-Out Annualized Costs ($MM Delta)	$64
Annual Fuel Costs ($Bn Delta)	$121
Total Annual Cost Additions ($Bn)	$185
CO_2 Abatement Cost ($/Tonne)	**$39.76**

Source: Compiled by Quantum with data from the IEA, EIA, and ThunderSaid Energy.

What Are The Obstacles & Impediments to Implementation?

INFRASTRUCTURE AND SUPPLY CONSTRAINTS: One of the biggest obstacles to coal-to-gas switching is the lack of natural gas infrastructure in regions that have historically relied on coal. As previously discussed, many coal-dependent countries do not have the necessary pipeline networks, LNG import terminals, or gas distribution systems to transport and deliver natural gas to power plants and consumers. Building this infrastructure requires significant investment, time, and coordination. Until pipelines or LNG import capacity reach a coal plant, that plant cannot switch to gas. Inland populations will be especially challenged by limited infrastructure, but coastal population centers could more easily be connected via LNG import and related facilities and pipelines.

It should be noted that natural gas plants can also serve as on-demand backup power for intermittent renewables, enhancing grid reliability and making them a cost-effective component of a broader clean energy strategy, but these costs should be included in the cost of renewables to the extent there are needed for reliability.

ECONOMIC, PRICE, AND ENERGY SECURITY RISKS: Another major barrier is economic and price volatility. Unlike coal, which is often domestically sourced, price-regulated, or government-subsidized, natural gas prices are linked to global markets, making them more susceptible to fluctuations and supply disruptions. While coal prices tend to be more stable, gas prices can vary significantly due to global demand, production constraints, or geopolitical tensions. Energy security is another concern, as many nations prefer the reliability of domestic coal over dependence on imported gas. The risks associated with this reliance have been highlighted in recent geopolitical events, such as Europe's energy crisis following Russia's invasion of Ukraine, which underscored vulnerabilities in relying on external gas supplies.

POLICY AND REGULATORY BARRIERS: Government policies can either encourage or discourage coal-to-gas switching. A lack of carbon pricing or weak environmental regulations may allow coal to remain more profitable, as utilities face no penalties for emitting CO_2 and air pollutants. At the same time, long-term climate policies may deter investment in new gas infrastructure. For example, in the U.S., the EPA's proposed 2023 regulations would require new gas-fired power plants to install carbon capture or hydrogen blending by the 2030s to significantly cut emissions. While designed to align with decarbonization goals, such policies create uncertainty for utilities, making them hesitant to invest in new gas plants if they may later face expensive regulatory requirements.

ENVIRONMENTAL CONCERNS (METHANE & CARBON LOCK-IN): To fully realize the climate benefits of coal-to-gas switching, it is essential to minimize methane emissions from natural gas production and distribution. The IEA stresses that controlling methane leakage is critical to ensuring that natural gas remains a cleaner alternative to coal.[10] Methane, the primary component of natural gas, has a global warming potential dozens of times higher than CO_2, meaning even small leaks can significantly undermine the emissions reductions gained from fuel switching. Leaks from pipelines, wells, and LNG infrastructure pose a major challenge, but they can be cost-effectively reduced through improved maintenance, advanced monitoring systems, and cutting-edge leak detection technologies.

Additionally, carbon lock-in is a potential concern. Once built, gas power plants and pipelines are expected to operate for decades, meaning continued CO_2 emissions at a time when the world is aiming for full decarbonization. The IEA has cautioned that the environmental case for building new gas infrastructure is complex, as coal-to-gas switching may provide emissions reductions but could also delay a more fulsome transition to renewable energy. This argument becomes less convincing when viewed through an energy addition rather than energy transition lens.

(10) "The Role of Gas in Today's Energy Transitions, World Energy Special Report," IEA (2024).
(11) Institute for Energy Research, Construction Costs for Gas-fired Power Remains Well Below Those for Solar and Wind.
(12) "The Role of Gas in Today's Energy Transitions," IEA, World Energy Outlook Special Report.

Decarbonized Supplies

Practical pathways for cost-effective emission reductions

What is the Solution?

Decarbonized supply refers to energy sources and technologies that produce little to no GHG emissions, helping to decarbonize the energy supply. This involves shifting away from fossil fuels to cleaner alternatives and/or using technologies that capture or eliminate carbon emissions associated with fossil fuels. Major categories of decarbonized supply technologies include:

CLEANER HYDROCARBON STREAMS: Conventional oil or gas usage can be decarbonized if the resultant CO_2 is captured and stored, or if emissions are offset via credible nature-based solutions, significantly reducing the net carbon intensity.

LOW-CARBON HYDROGEN AND DERIVED FUELS: Hydrogen produced from natural gas using CCS ("blue hydrogen") or via electrolysis powered by renewables ("green hydrogen") can replace high-emission fuels in refining, chemicals, steel, and other sectors.

CARBON-NEUTRAL OR LOW-CARBON FEEDSTOCKS: Fossil-based inputs such as naphtha, methanol, and ammonia can be produced via processes that capture and store CO_2 byproducts or offset emissions through verified CO_2 removal methods.

BIOMASS OR BIOFUELS WITH SEQUESTRATION: Bioenergy systems that integrate combustion or gasification with CCS can achieve a net-negative emissions profile, provided the feedstock is sustainably managed.

How Can the Solution Help Achieve Net-Zero Emissions?

In Thunder Said Energy's model, decarbonized supplies are projected to contribute approximately 7 Gtons of annual CO_2 abatement by 2050, accounting for ~9% of the total reductions. Key contributors include:

- Carbon capture retrofits on gas- or oil-fired facilities, such as oil refineries, petrochemical plants, and gas processing sites, where next-generation CCS technology can be installed, capturing up to 90% of emitted CO_2.
- Blue hydrogen and ammonia, produced by capturing CO_2 from steam methane reforming, can reduced net emissions by 85–90% compared to conventional methods.
- Low-carbon hydrogen and ammonia, once produced, can be utilized in hard-to-abate industries such as steel, fertilizer, and shipping.

Heavy industries such as steel, cement, and advanced polymers rely on concentrated thermal energy or specific chemical feedstocks that are difficult to replace with electrification alone. Decarbonized supplies provide a viable solution, enabling these industries to maintain operations with minimal process changes while significantly reducing net emissions. By integrating low-carbon alternatives like blue hydrogen, ammonia, and CCS, industrial producers can reduce their carbon footprint without sacrificing productivity or competitiveness. However, widespread deployment remains limited, as most of these technologies are still in early stages of commercial application.

What is the Impact on Energy Costs, Accessibility & Energy Poverty?

Decarbonized supply technologies generally come with a cost premium, resulting in higher per-unit energy prices compared to conventional fossil fuels. This can significantly impact affordability and accessibility, particularly in regions already facing energy poverty.

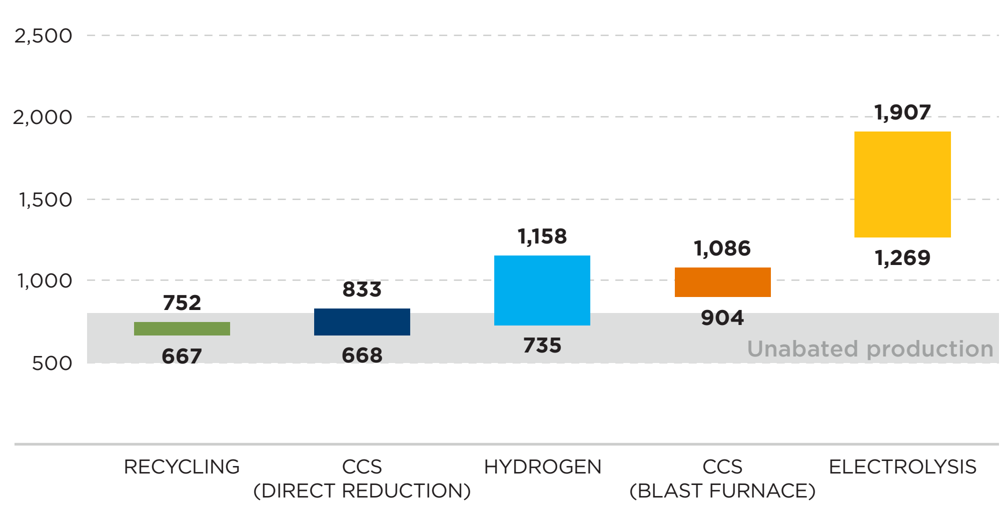
For example, in the steel sector, steel made in the U.S. typically costs ~$600 per metric ton. The chart below highlights the relative cost competitiveness of different net-zero pathways. Recycling remains the most cost-effective method, while hydrogen, CCS using blast furnace, and electrolysis are currently more expensive. However, as these technologies develop further, costs may decline, potentially making net-zero steel more accessible to large buyers in manufacturing, construction, automotive, and other sectors.

How Long Does the Solution Take to Implement & What Are the Estimated Costs?

The rollout of decarbonized supplies is expected to progress alongside rising global energy demand. Thunder Said Energy projects that total energy investment will increase from $1.5 trillion per year today to $4.5 trillion per year by 2050 for core energy systems. While significant capital investment is required, the pace of implementation varies by technology and infrastructure readiness.

Carbon capture retrofits for large industrial facilities typically take two to five years to permit, build, and commission. If financing is secured, we believe deployment could scale significantly over the next decade, particularly in regions with suitable geology for CO_2 storage. The success of these projects depends on policy support, carbon pricing mechanisms, and advancements in capture efficiency and cost reduction.

LEVELIZED COST OF NET-ZERO STEEL PRODUCTION (2024)[1]
$ per metric ton of crude steel



Blue hydrogen projects generally require three to five years from final investment decision (FID) to startup. Several large-scale projects are already progressing, particularly in the U.S. Gulf Coast, where tax incentives have accelerated investment. As infrastructure for hydrogen transport and storage expands, adoption rates are expected to increase, though challenges remain in scaling production and achieving cost parity with traditional fuels.

Decarbonized supplies generally fall within a mid-range cost bracket of $40 to $100 per ton of CO_2 abatement, as they focus on capturing or offsetting emissions from conventional hydrocarbon use rather than completely replacing fossil fuels. Certain pathways, such as turquoise hydrogen, can achieve abatement costs below $40 per ton, making them more competitive with lower-cost renewable energy solutions. However, CCUS and emerging oxy-combustion technologies can range higher, up to $100 or even $150 per ton, depending on factors such as facility retrofitting complexity, capture efficiency, and storage infrastructure.[2][3]

What Are The Obstacles & Impediments to Implementation?

LOGISTICS AND FINANCIAL CONSTRAINTS: Not all decarbonized supply technologies come with the same cost or challenges. Some approaches – such as material recycling and methane abatement – are relatively low-cost and readily available. However, many of the solutions with the greatest potential for CO_2 abatement rely on newer technologies that face significant financial and logistical hurdles, especially in a high-interest-rate environment, where financing large-scale projects becomes more expensive.

PHYSICAL INFRASTRUCTURE LIMITATIONS: Even when capital is available, physical infrastructure limitations remain a major barrier. CO_2 transport networks and large-scale geological storage sites are underdeveloped in many regions, restricting the feasibility of widespread CCS deployment. Additionally, the construction of necessary infrastructure – such as hydrogen production and transport facilities – places pressure on mineral and materials supply chains, leading to potential delays and cost overruns. Bottlenecks in pipeline construction and storage site development could significantly slow progress in decarbonizing industrial emissions.

POLICY UNCERTAINTY AND PUBLIC OPPOSITION: Policy uncertainty and public opposition further complicate implementation. Carbon pricing mechanisms, tax credits, and contracts-for-difference play a crucial role in providing market confidence, but sudden policy reversals can deter industry from committing billions to long-term infrastructure projects. Despite the technical feasibility of large CO_2 storage sites, hydrogen pipelines, and blue ammonia hubs, these projects often face public resistance and local opposition. Concerns about land use, environmental risks, and industrialization can lead to lengthy permitting processes, delaying deployment.

While many decarbonization technologies are at or near commercial readiness, several key technical challenges remain. In order to require further advancements to enhance efficiency, scalability, and cost-effectiveness.

(1) "Steelwall Model," Bloomberg New Energy Finance (BNEF) (2024).
(2) "The IEA Busts 10 Myths About the Energy Transition," IEA (2024).
(3) "Net Zero by 2050: A Roadmap for the Global Energy Sector," IEA (2024).

Demand Shifts

Practical pathways for cost-effective emission reductions

What is the Solution?

Demand shifts refer to changes in how, when, and how much energy is used. Rather than relying on technological upgrades or new infrastructure, these strategies focus on adjusting human behavior, consumption habits, and system-level operations to reduce energy demand and associated emissions.

Common demand-shifting strategies include remote work adoption, increased use of public transportation, smarter thermostat settings, energy-efficient appliances, off-peak industrial operations, reduced single-use materials, and lowering food waste. Unlike traditional efficiency upgrades that depend on equipment, demand shifts focus on changing patterns of energy use across households, businesses, and industries.

Demand shifts are often among the most cost-effective and immediately actionable decarbonization strategies, especially when supported by strong public awareness campaigns and policy incentives. However, their success depends on widespread participation, cultural acceptance, and sustained behavioral change – which can be challenging to achieve at scale.

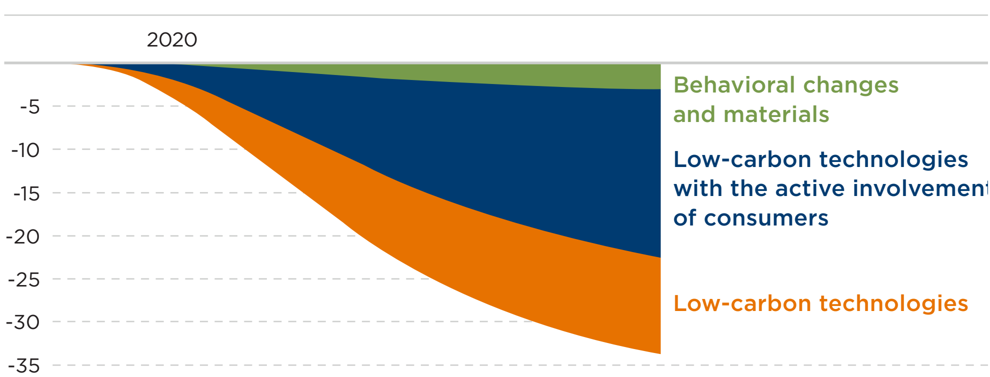
How Can the Solution Help Achieve Net-Zero Emissions?

Thunder Said Energy estimates that combined demand shifts and efficiency improvements could deliver up to 21 gigatons of annual CO_2 abatement by 2050, with behavioral and structural changes alone contributing 4 gigatons per year – roughly 5% of the 80 gigatons per year needed for global net-zero. These demand-side measures reduce overall energy consumption, lower reliance on carbon-intensive supply chains, and help decouple economic growth from emissions.

Around 4–8% of emissions reductions stem from behavioral changes and materials efficiency

ROLE OF TECHNOLOGY AND BEHAVIORAL CHANGE IN EMISSIONS REDUCTIONS IN THE NZE IN 2020[1]

Gt CO_2

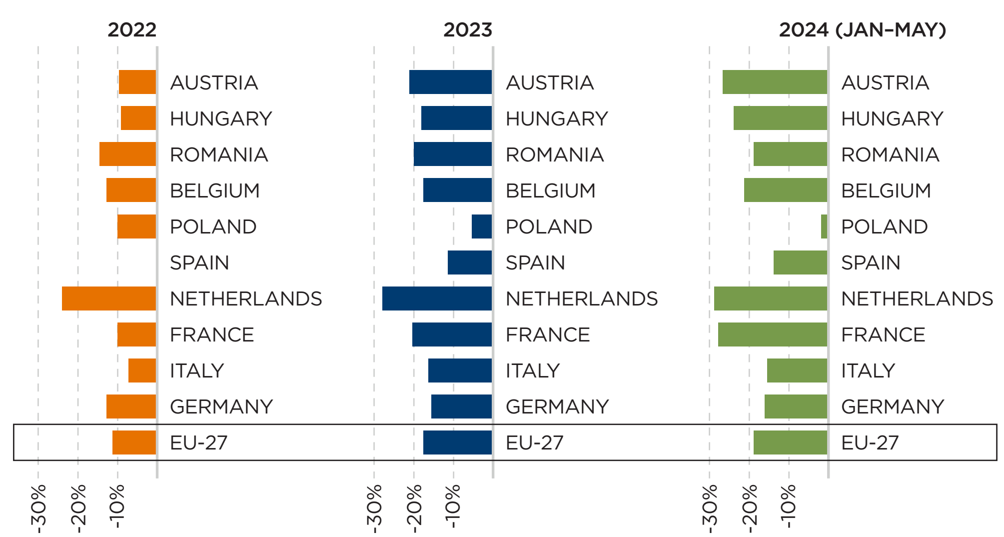


By reducing peak loads and shifting consumption patterns, demand-side management also supports greater use of intermittent renewables while minimizing the need for carbon-intensive backup generation. Behavioral changes such as telecommuting, shared mobility, and thermostat adjustments provide direct emissions reductions, while broader shifts toward durable goods and low-waste consumption reduce upstream energy demand across manufacturing and transport.

Europe offers a compelling case study. Beginning in mid-2022, conservation efforts and policy shifts reduced natural gas demand by approximately 5 billion cubic feet per day. In 2023, consumption was 18% below average and remained 19% lower in 2024. These behavioral and policy-driven reductions – combined with increased renewable generation and mild weather – helped offset an 89% drop in Russian pipeline imports, boosting energy security and leading to record gas storage levels.

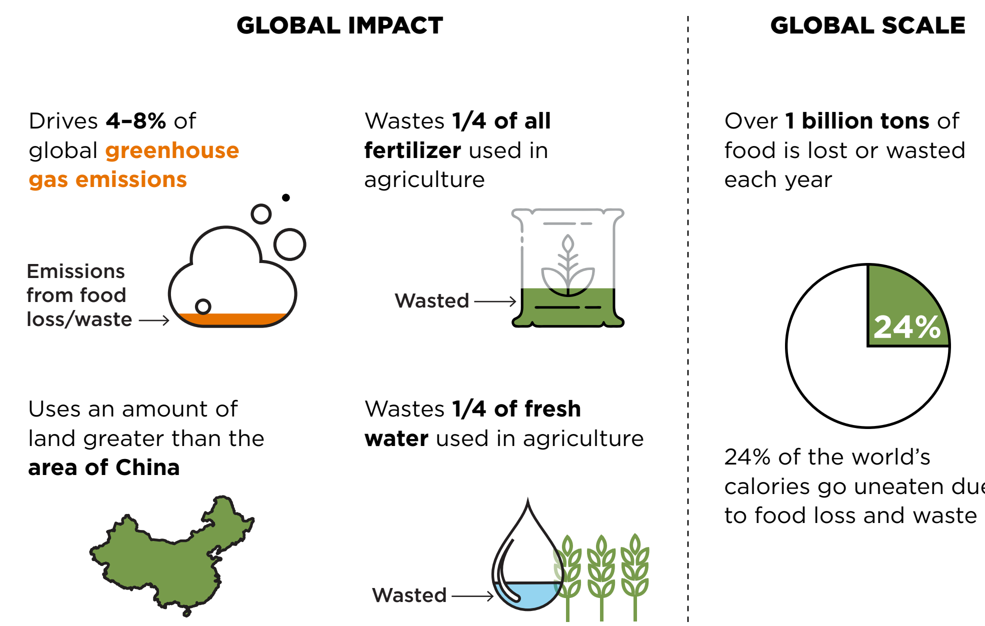
CHANGE IN CONSUMPTION IN EU-27'S TOP 10 NATURAL GAS-CONSUMING COUNTRIES (2022–2024 VS. THE FIVE YEAR (2017–2021) AVERAGE)[2]

Percentage



Avoiding food waste is another high-impact opportunity. The IPCC estimates that 8–10% of global GHG emissions – or roughly 4.4 gigatons of CO_2-equivalent annually – are linked to the production, transportation, and decomposition of uneaten food. Targeted interventions in the food system, both at the consumer and supply-chain levels, can significantly reduce these emissions with minimal capital investment.

GLOBAL FOOD WASTE[3]



What is the Impact on Energy Costs, Accessibility & Energy Poverty?

Useful energy demand is expected to grow from 75,000 TWh in 2019 to 120,000 TWh by 2050. Even with decarbonized energy sources like gas, renewables, and nuclear, demand shifts reduce the infrastructure needed to support this growth. However, while demand shifts reduce energy use in developed countries, their implementation must support development in emerging economies. The IPCC notes that low-income populations require more energy, not less. Demand strategies should focus on cleaner, more efficient delivery – such as electric cookstoves instead of biomass or low-cost solar lighting for off-grid households. These solutions also enhance air quality and reduce health risks from indoor pollution.

From a cost perspective, demand shifts offer some of the most affordable pathways to decarbonization. Based on a baseline of $40 per ton of CO_2 abated and a potential abatement of 4 gigatons, the global annual cost is approximately $160 billion. Yet many demand-side strategies – such as telecommuting, off-peak EV charging, and energy conservation behaviors – are cost-neutral or even cost-saving, with abatement costs often below $20 per ton.

(1) "Role of Technology and Behavioural Change in Emissions Reductions in the NZE," IEA, Net Zero by 2050 report, Figure 2.14.
(2) "Supply, Transformation and Consumption of Gas," Eurostat.
(3) "Driven to Waste: Global Food Loss on Farms," WWF and Tesco (2021).

Demand Shifts

continued

How Long Does the Solution Take to Implement & What Are the Estimated Costs?

Behavioral changes – such as remote work, time-of-use (TOU) pricing, and energy conservation – can typically be implemented within 2 to 5 years with regulatory support and public engagement. Structural changes, including public transit expansion, building retrofits, and industrial scheduling shifts, generally require 5 to 15 years due to infrastructure development, funding constraints, and adoption timelines.

Demand shifts are among the most affordable climate solutions available. Pilot programs have demonstrated abatement costs below $20 per ton of CO_2, making these strategies significantly cheaper than many technology-driven approaches such as carbon capture or green hydrogen.

What Are The Obstacles & Impediments to Implementation?

BEHAVIORAL RESISTANCE: We believe implementing demand shifts faces several interrelated obstacles. One of the most significant is behavioral resistance, as lifestyle changes – such as adjusting work schedules, commuting habits, or electricity use – can be perceived as inconvenient, particularly when the benefits are not immediately tangible. Overcoming this resistance requires sustained public education, targeted incentives, and well-designed policy tools that align individual actions with broader system-wide efficiency gains.

POLICY GAPS: Policy gaps also pose a major challenge. Instruments like time-of-use electricity pricing, carbon pricing, and incentives for teleworking or fleet optimization are essential to guide behavior. However, inconsistent regulatory frameworks, short-term policy cycles, or lack of enforcement can undermine progress and discourage both individual and corporate participation in demand-side programs.

INFRASTRUCTURE LIMITATIONS: Infrastructure limitations further constrain the effectiveness of demand shifts. These strategies often depend on the availability of reliable public transportation, safe cycling networks, or advanced electricity grids – components that remain underdeveloped in many rapidly urbanizing regions and even in some high-income countries. Without such infrastructure, the feasibility of large-scale behavioral transitions is significantly reduced.

MARKET FRICTION: Market friction impedes progress in industrial and commercial sectors. Businesses need clear, real-time price signals and transparent data to optimize their operations for energy efficiency. Yet supply chain complexity, rigid contracts, and opaque pricing structures often prevent companies from responding effectively. To overcome these barriers, we believe expanded use of smart meters, dynamic pricing models, and open data-sharing platforms will be essential.






Technology Updates & Progress

Technology landscape at a glance

Technological advances have played and we believe will continue to play a critical role in providing both abundant and reliable energy and reducing emissions. These advances are continuing and could lead to even more efficient and affordable climate abatement over time. In our 2024 Stakeholder Report, we discussed a variety of new technologies at various stages of maturity. In this section, we expand upon the technologies highlighted last year with key updates and have included additional technologies that have been topics of recent discussions in the industry.

RENEWABLE ENERGY IN SOLAR & WIND

Renewable energy continues to grow at a significant pace, but many of the challenges we highlighted last year have now materialized, prompting a more measured approach. The effective cost of abatement from renewables is highly variable, as discussed on page 17, with outcomes dependent on project specifics. Capital has decreased in many regions, with the U.S. Clean Energy Index down ~65% since its peak in 2021 and numerous high-profile bankruptcies across the sector. Supply chain constraints, land use limitations, and transmission challenges persist. The energy security of renewables remains a concern given that many critical minerals and the associated processing is concentrated in the East. China and other nations continue to drive adoption, but the pace and scale of deployment will be region specific.

ENERGY STORAGE

The global energy storage market is on track for record growth in installations, but the two largest markets – China and the U.S. – may face challenges next year. In China, expansion may slow as national targets have already been met, while in the U.S., policy uncertainty under the new Trump administration could impact momentum. However, overall deployment is expected to rise each year over the next decade as other markets rapidly scale up. BloombergNEF expects the energy storage market to be 10 times larger by 2035, reaching 228 GW (965 GWh) of cumulative capacity.[1] In 2023, the global battery energy storage system (BESS) market doubled, adding over 90 GWh of capacity and bringing the total global volume of battery storage to over 190 GWh.[2] Despite this growth, BESS capacity still represents less than 1% of global electricity.[3]

GRID INTEGRATION

To support the energy transition, substantial investments and grid expansions will be needed worldwide through 2050. Over the past four years, the average annual global grid investment has reached ~$300 billion. Looking ahead, annual investment needs are projected to rise to between $450 billion and $800 billion by 2030, depending on the forecast scenario.[4]

ELECTRIC VEHICLES (EVs)

Demand for EVs has continued to grow. Global sales of fully electric and plug-in hybrid vehicles rose by a quarter last year to over 17 million cars, and future forecasts expect continued growth.[5] While EV demand is expected to remain strong, there is increasing uncertainty in the U.S. market due to the potential policy changes from the Trump administration. The U.S. EV market currently benefits from tax incentives which are at risk of being eliminated as the Trump administration deprioritizes climate goals. Additionally, proposed tariffs on China, Mexico, and Canada are likely to impact sales of both domestic and foreign EVs.[6] Overall, EVs represent 2% of all cars.

ENERGY EFFICIENCY IN BUILDING & INDUSTRIAL PROCESS TECHNOLOGIES

At the end of 2023, almost 200 countries committed to a landmark agreement to collectively double the global average annual rate of energy efficiency improvements by 2030. However, a year later, progress remains slow, with a significant boost in policy implementation still needed. In 2024, global energy efficiency – measured by the change in primary energy intensity – improved by only about 1%, the same modest rate as in 2023 and roughly half the average pace seen in between 2010 and 2019. Accelerating energy efficiency efforts is crucial, as it could account for over a third of the CO_2 emissions reductions needed by 2030 under a net-zero emissions by 2050 scenario.[7]

CARBON CAPTURE, UTILIZATION, & STORAGE (CCUS)

The IEA estimates that 6,000 megatons of CO_2 need to be captured and stored annually by 2050, representing ~16% of current global emissions. Currently, the U.S. and Europe have CCUS capacity of 25 megatons, highlighting the significant gap between current capabilities and long-term targets. The U.S. is expected to remain the market leader, with CCUS capacity potentially increasing fourfold by 2030,[8] primarily concentrated within the oil and gas industry, driven by enhanced oil and gas recovery projects. Momentum for further market growth is driven by the desire to find solutions for hard-to-abate industries, and CCUS, if successful, provides a clear solution for emissions removal. However, U.S. and European regulatory shifts under new administrations could impact project timelines and limit growth in a nascent market that is challenged with permitting delays, supply chain issues, and a heavy dependence on government incentives for commercial viability.

DIRECT AIR CAPTURE (DAC)

DAC technologies extract CO_2 directly from the atmosphere at any location, unlike other forms of carbon capture, which are generally carried out at the point of emissions, such as a steel plant. DAC provides a unique opportunity to remove existing emissions from the atmosphere, which could have significant implications for achieving emissions reduction goals. The DAC market remains in its early stages, with a global capacity currently around 59 kilotons of CO_2 removal annually and only a few commercial-scale facilities in operation.[9] Like other CCUS pathways, DAC faces major challenges – particularly on the cost side. Current removal costs range from $600 to $1,000 per ton, but recent technological advancements could bring costs down to $300 per ton. Such a decline would have major growth implications, potentially triggering a step-change in the market's ability to scale and contribute meaningfully to long-term emissions reduction goals.

CLEAN FUELS (HYDROGEN)

Hydrogen's versatility and potential for zero-emission energy make it a promising solution for industries ranging from transportation to manufacturing. However, the cost of hydrogen production remains a significant barrier. Similar to the political challenges facing the CCUS market, hydrogen is also vulnerable to regulatory shifts under new administrations in the U.S. and across Europe.

Recent outlooks show continued global momentum in 2025. In the U.S., at least three large-scale blue hydrogen projects are expected to reach final investment decision (FID) in 2025, while globally, investment in giga-scale green hydrogen projects has reached FID. As of the end of 2024, around 16 GW of green hydrogen capacity has reached FID, including major projects like Neom Helios in Saudi Arabia and the Kakinada project in India. However, the path to operations for these giga-scale projects is not guaranteed. Key factors – including regulatory favorability, access to low-cost renewable energy, capital costs, and project timelines – will ultimately determine the pace and scale of hydrogen deployment.[10]

CLEAN FUELS (AMMONIA)

There have not been major updates to the ammonia market since the publication of our 2024 Stakeholder Report. However, the Chinese ammonia market continues to show strong potential for growth. China is both the world's largest producer and consumer of ammonia. While renewable ammonia production remains in its early stages, China's ammonia output is still almost entirely fossil fuel-based. In June 2024, the country announced a new Ammonia Industry Special Action Plan, targeting a 13 Mt reduction in CO_2 emissions by 2025, primarily through the retirement and retrofit of inefficient facilities. The plan also proposes the co-firing of renewable ammonia with coal in power plants as a strategy to reduce carbon emissions – an approach that could significantly increase future demand for renewable ammonia.[11]

(1) "Global Investment in Low-Carbon Energy Transition Hit $755 Billion in 2021," Bloomberg New Energy Finance (BNEF) (2024).
(2) "Electronic Design & Software Development Services," Integra Sources (2024).
(3) "Batteries and Secure Energy Transitions," IEA (2024).
(4) "Global Low-Carbon Energy Technology Investment Surges Past $1 Trillion for the First Time," Bloomberg New Energy Finance (BNEF) (2024).
(5) "Digging to Zero? Inside the Race to Decarbonise Mining," Reuters (2024).
(6) "Trump Funding Cuts Force Layoffs at U.S. Renewable Energy Research Lab," Reuters (2024).
(7) "Batteries and Secure Energy Transitions," IEA (2024).
(8) "ING Takes Next Steps on Energy Financing After COP28," ING (2024).
(9) "The Home of Carbon Market Data," AlliedOffsets (2024).
(10) "Energy Transition Outlook," Wood Mackenzie (2024).
(11) "Just Energy Transitions & Fossil Fuel Phaseout," Columbia Center on Sustainable Investment (CCSI) (2024).

Key Developments in Renewable Energy: Offshore Wind

Description

Offshore wind uses the same fundamental technology as onshore wind – turbines that generate electricity by harnessing wind energy – but is installed in bodies of water, typically at sea. Offshore turbines benefit from stronger and more consistent wind speeds and face fewer land-use issues (e.g. NIMBYism), allowing for larger turbine designs. There are two main offshore wind structures: fixed-bottom and floating. Fixed-bottom turbines are anchored directly to the seabed and are most suitable for shallow waters, typically up to 60 meters deep. Floating turbines, designed for deep waters beyond 60 meters, can be installed in areas where the seabed drops off sharply, such as much of the continental shelf. While floating wind holds long-term potential, fixed-bottom systems are currently more economically viable and remain the most widely deployed form of offshore wind.

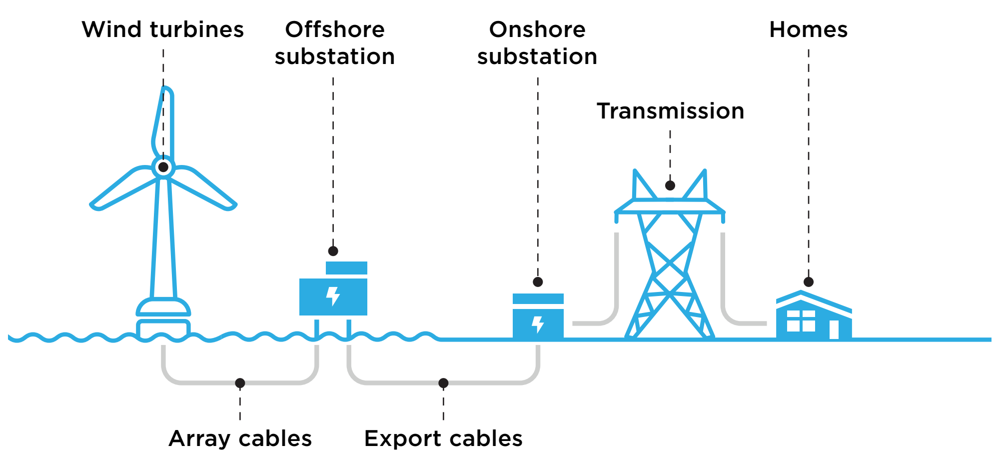
Current State & Recent Progress

GROWTH: The global commissioned capacity of offshore wind increased from 3 GW in 2010 to ~68 GW[1] in 2023. Over the same period, the cost of offshore wind generation decreased by ~60%.[2] This progress was driven by increased competition, low interest rates, technological advancements, and industrialization. Today, the offshore wind market has 81 GW of commissioned capacity.[3]

The offshore wind market could grow dramatically, with global potential estimated at 20,000 GW for fixed-bottom offshore wind and 50,000 GW for floating offshore wind. However, recent macroeconomic headwinds, including rising raw commodity prices, high interest rates, and supply chain constraints, have strained the market and threatened profitability of offshore wind projects, resulting in a reduced outlook for offshore wind growth issued for the first time in 2023.[4] The market, which currently stands at 68 GW, is expected to continue experiencing slower growth in new capacity additions – as the industry navigates persistent headwinds.

PROJECT ADVANCEMENTS: Of the 81 GW of global offshore wind capacity, the majority is in China, followed by U.K. and Germany. The global offshore wind industry is gearing up for growth in 2025, with capacity additions expected to reach 19 GW, 65% of which will be in China.[5] Project delays in 2024 had a significant impact on final investment decisions (FID) for new projects. However, some projects continued to move forward, including Red Rock Power and ESB's 1.1-GW development in the U.K., Iberdrola's 315-MW Windanker in Germany, and RWE and TotalEnergies' 795-MW OranjeWind in the Netherlands. In 2025, the U.K., Poland, and Germany are expected to drive a surge in European FIDs, reaching 9.5 GW, with several projects in these countries on track for final approval.[6]

In the U.S., after several pilot projects, commercial-scale offshore wind deployment is now underway. The federal government has approved 19 GW of offshore wind projects off the coasts of Maine, New York, and the Gulf of Mexico.[7] The first commercial-scale offshore wind power plant in the U.S. – the 806-MW Vineyard Wind 1 project – achieved first power in January 2024 with the installation of several operating turbines.



Current Limitations/Challenges

ECONOMICS: The offshore wind industry has been significantly impacted by rising interest rates, inflation, and global supply chain issues. Offshore wind has been 10–20% more exposed to cost-side shocks than other forms of renewable energy, leading to growing concerns about its economic viability. Many stakeholders have questioned the industry's outlook following a wave of project cancellations tied to cost increases of 40% to 60%.[8] In particular, numerous projects operate under Contracts for Difference (CfDs) that are not indexed to inflation, making them unprofitable under current market conditions.

Notably, 2023 was a difficult year for U.S. and UK offshore wind, with nearly half the pipeline canceled due to cost overruns and billions of dollars in write-downs by major developers. In January 2025, Shell withdrew from its joint venture with EDF on the 2.8 GW Atlantic Shores project off the coast of New Jersey after the company announced it was deemphasizing its renewable activities. In July 2023, Swedish developer Vattenfall cancelled its 1.4 GW Norfolk Boreas project in the U.K., citing rising costs and supply chain vulnerability.[9] In both markets, political and regulatory uncertainty has added to the challenges. In the U.S., the Trump administration's recent opposition to offshore wind has created additional headwinds for the sector.[10]

SUPPLY CHAIN CHALLENGES: There sheer size of offshore wind turbines – some blades exceed 15 meters – has posed significant challenges for transportation, assembly, and installation. These logistical hurdles have increased the urgency for domestic manufacturing capabilities in countries with ambitious offshore wind targets. In the U.S., a particular concern is the limited availability of wind turbine installation vessels, which forces developers to rely on international fleets and exposes them to global capacity constraints.[11]

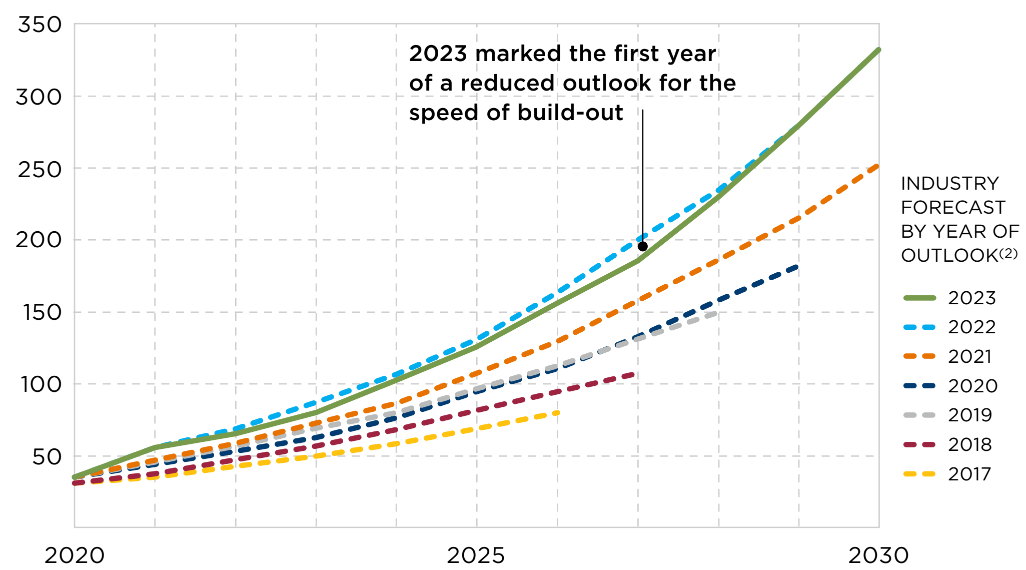
Future Impact if Successful

Offshore wind has the potential to transform the global energy landscape. According to the IEA, the world's offshore wind resources could meet current global electricity demand 18 times over. Despite this vast potential, the projected global offshore wind capacity is expected to reach only 250 GW by 2030 under COP28 commitments – far below IRENA's recommended 500 GW by 2030 to stay on track with net-zero targets.[12]

For the U.S., in particular, offshore wind represents a major opportunity: it could unlock a vast supply of clean, domestic energy, significantly reduce carbon emissions, support the creation of thousands of jobs, and help catalyze a new domestic manufacturing industry around turbines, vessels, and supporting infrastructure.

Expected capacity growth has steadily increased until 2030, which marked the first year of down-adjusted expectations

PROJECTED GLOBAL INSTALLED CAPACITY[13]
Gigawatt



(1) "Offshore Wind Overview," National Renewable Energy Laboratory (NREL) (2024).
(2) "Offshore Wind: Strategies for Uncertain Times," McKinsey & Company (2024).
(3) "UK Wind and Global Offshore Wind 2024 in Review," EnergyPulse (2024).
(4) "Offshore Wind: Strategies for Uncertain Times," McKinsey & Company (2024).
(5) "Global Offshore Wind Landmark: 19GW," Rystad Energy (2024).
(6) *Ibid.*
(7) "Biden-Harris Administration Approves Eleventh Offshore Wind Project in U.S. History," U.S. Department of the Interior (DOI) (2024).
(8) "Offshore Wind: Strategies for Uncertain Times," McKinsey & Company (2024).
(9) "Vattenfall Halts Project, Warns UK Offshore Wind Targets in Doubt," Reuters (2024).
(10) "Why U.S. Offshore Wind Power Is Struggling," WIRED (2024).
(11) "Wind Turbine Makers Halt Race for Size, Focus on Cost and Delivery," Reuters (2024).
(12) "COP28 Global Offshore Wind Update Report," ERM (2024).
(13) "Offshore Wind Overview," National Renewable Energy Laboratory (NREL) (2024).

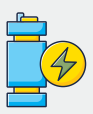
Key Developments in Nuclear Energy

Description

For additional background and information regarding nuclear energy, see our 2024 Quantum ESG report.

Nuclear energy generates electricity through controlled nuclear reactions, typically fission, in which atoms are split to release heat. This heat is used to produce steam that drives turbines, generating electricity. Nuclear power offers a stable, dispatchable source of low-carbon electricity and is widely considered to be a critical component in meeting rising global baseload demand, especially as global electrification accelerates.

While traditional nuclear reactors are large-scale and centralized facilities requiring significant capital investment and long construction timelines, technological advancements have led to the development of Small Modular Reactors (SMRs). SMRs are compact, factory-fabricated nuclear reactors designed to be more cost-effective, scalable, and flexible that conventional plants. They can be deployed in remote locations or smaller grids. However, SMRs remain in early development, with the first commercial deployments expected toward the end of the decade. Technological maturity and regulatory approval processes remain key barriers to broad adoption.

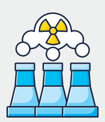


SMALL MODULAR REACTOR (SMR)[1]

Electrical Output
300MWe

Energy Production
7.2 million kWh
of electricity generated per day

Land Size
34 acres
for a 12-module, 924 MWe NuScale SMR plant



NUCLEAR POWER PLANT[1]

Electrical Output
1,000MWe

Energy Production
24 million kWh
of electricity generated per day

Land Size
640 acres
for a typical 1,000mW Nuclear Facility

Current State & Recent Progress

GROWTH: Nuclear generation is on track to reach new heights in 2025. More than 60 nuclear reactors are currently under construction around the world, representing more than 70 GW of capacity – one of the highest levels of construction seen since 1990.[2]

China is leading the market in growth and is expected to surpass the U.S. and EU in total capacity by the end of the decade. This momentum is driven by the need to meet baseload power demand, which has and will continue to increase due to data center needs. Japan is also undergoing a major policy shift regarding nuclear energy. After more than a decade of scaling back nuclear following the Fukushima disaster, the Japanese government reversed course in early 2025, calling to maximize nuclear energy due to growing demand from power-hungry sectors like AI and semiconductors.[3]

In Europe, energy security concerns following Russia's invasion of Ukraine have renewed interest in nuclear energy. As detailed in our 2024 Stakeholder Report, nuclear is increasingly viewed as a pathway to reduce dependency on foreign energy sources. In 2024, nuclear accounted for 24% of the EU's electricity generation, and the EU Nuclear Alliance – comprising 11 member states – has urged the inclusion of nuclear power in the EU's new Affordable Energy Action Plan.[4]

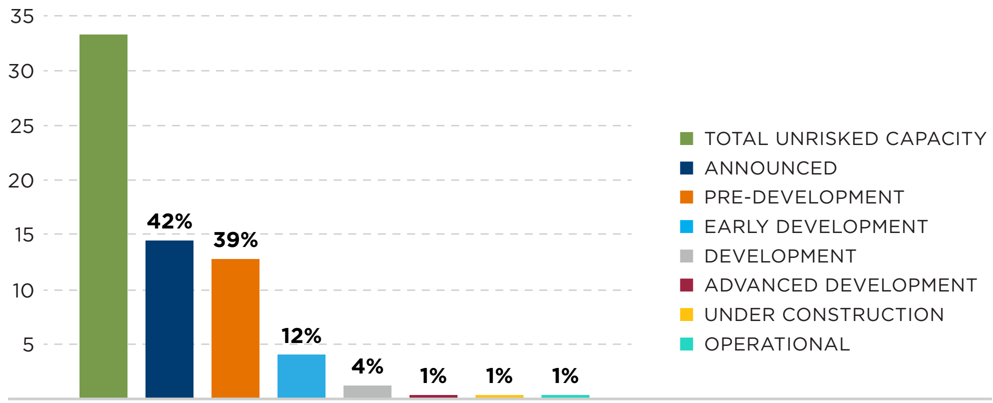
There is a similar trend in the U.S., with nuclear power gaining traction due to soaring power demand from AI and data centers. In September 2024, Constellation Energy announced plans to restart operations at Three Mile Island Unit 1 after entering into a power purchase agreement with Microsoft to power its data centers. The project is currently underway and ahead of schedule for its target restart in 2028.[5]

By the end of 2024, the global SMR project pipeline had reached 33 GW, representing a 48% increase from the beginning of 2024 and a 148% increase since 2021. This rapid growth reflects strong global interest in SMRs as a clean, dispatchable solution to meet rising electricity demand. However, the technology remains in early stages of deployment. Only six SMR projects worldwide are currently operational or under construction, and all except Russia's offshore KLT-40S are demonstration or prototype facilities. Of the total 33 GW pipeline, 42% of projects are still in the announced phase, and just 7% have progressed beyond early development.[6]

PROJECT ADVANCEMENTS: The EU and the U.S. together account for approximately 40% of the global SMR pipeline. The EU represents the largest regional market, while the U.S. remains a key player with an unrisked pipeline of 12.6 GW. However, neither region has operational SMR projects at this time. The only projects currently in operation are located in China and Russia.

Several notable SMR developments are underway globally. In Canada, Ontario Power Generation plans to begin construction in 2025, with the first unit targeted for completion by 2028. In Poland, ORLEN Synthos Green Energy (OSGE) is planning a fleet of reactors, with the first expected to be operational by the end of the decade. Russia is advancing a project in Seversk, which marks a significant step forward in Generation IV reactor technology. NuScale is pursuing projects in Romania and Poland, each at different stages of development. In South Korea, a collaborative project with Saudi Arabia received design approval in September 2024, underscoring continued international momentum in SMR deployment.[8]

TOTAL NUCLEAR UNRISKED SMR PIPELINE BY STATUS WITH PERCENTAGE OF PIPELINE, NAMEPLATE POWER GENERATION CAPACITY[7]



Current Limitations/Challenges

ECONOMICS: Large-scale nuclear projects have historically faced cost overruns and significant delays. Costs remain a major obstacle to SMR deployment as well. Despite their smaller size, SMRs must contend with the loss of economies of scale that benefit larger nuclear plants. Additionally, the reduced scale of SMRs does not necessarily guarantee simplified regulatory procedures, as existing frameworks were designed for large conventional reactors, leading to potential construction delays and subsequent cost overruns.

TECHNOLOGY CONSTRAINTS: There are over 80 diverse SMR designs currently in various stages of development across the globe. A lack of design standardization, in conjunction with the fractured regulatory framework discussed above, poses a challenge to the rapid build-out of SMRs. Given the newness of the technology and untested nature of many innovations introduced in SMR designs, technology risks unidentifiable today will arise as the first projects come online.

Future Impact if Successful

We believe nuclear power could play a pivotal role in decarbonizing baseload electricity generation. It offers stable, carbon-free energy that complements intermittent renewables. If SMRs and next-generation reactors prove successful, they could make nuclear energy more scalable, flexible, and economically viable, especially in regions with limited space or grid infrastructure.

China is expected to dominate short-term growth, but we believe Europe, the U.S., and Japan may reclaim technology leadership through successful deployment of SMRs and next-generation designs. The rise of AI and digital infrastructure, with its large energy footprint, further boosts nuclear energy's long-term relevance.

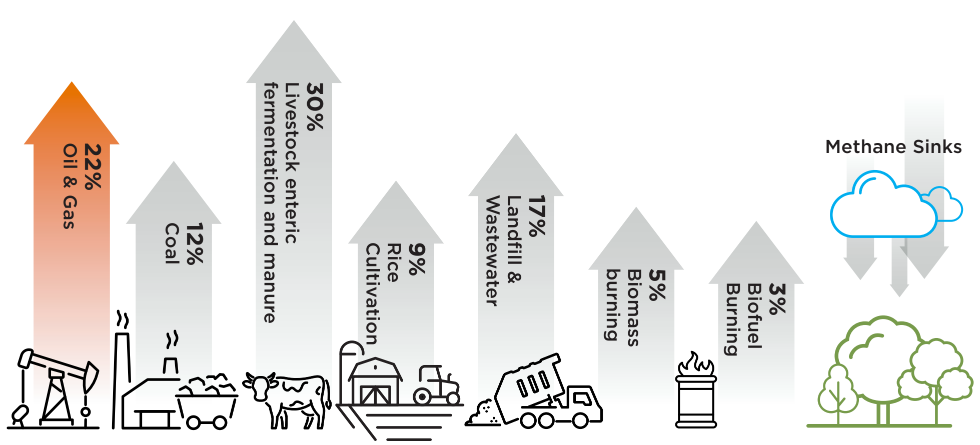
[1] "Small Modular Reactors vs. Nuclear Power Plants: Technical Comparison," European Commission, NuScale Power, and U.S. Department of Energy (2024).
[2] "The Path to a New Era for Nuclear Energy: Executive Summary," IEA (2024).
[3] "How Nuclear Energy Is Reshaping the Energy Debate," BBC (2024).
[4] "Call to Include Nuclear in Europe's Affordable Energy Plan," World Nuclear News (WNN) (2024).
[5] "Three Mile Island Owner Says Reopening of Nuclear Station Is on Schedule," PennLive (2024).
[6] "SMR Nuclear Market Update: Q4 2024," Wood Mackenzie (2024).
[7] *Ibid.*
[8] *Ibid.*

Key Developments in Methane Abatement

Description

Methane abatement refers to the strategies and actions aimed at reducing methane emissions into the atmosphere. As a greenhouse gas, methane has a global warming potential 80-87 higher than carbon dioxide over a 20-year period, or 25-36 over 100-years period, and is responsible for roughly 30% of the global temperature increase since the Industrial Revolution. The energy sector – including oil, natural gas, coal, and bioenergy – accounts for over a third of human-caused methane emissions.[1] Other major sources include agriculture, landfills, and wastewater treatment. Solutions span across sectors and include leak detection and repair in oil and gas systems, optimized flaring, methane capture in mining operations, and improved livestock manure management. Emerging technologies such as methane reactors and concentrators are also being explored. For the oil and gas industry in particular, methane abatement offers one of the most cost-effective and impactful opportunities for immediate emissions reduction.[2]

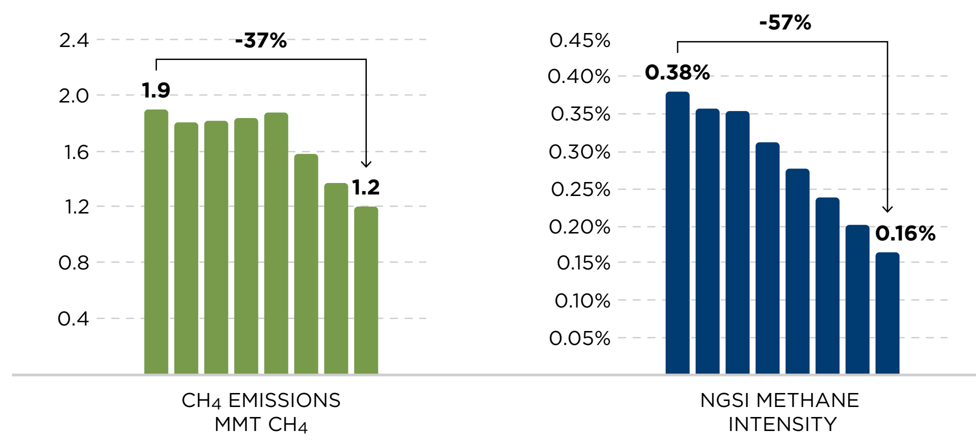
HUMAN-MADE METHANE SOURCES[3]



Current State & Recent Progress

GROWTH: The Global Methane Pledge (GMP), launched in 2021, is an agreement led by the U.S. and EU to reduce methane emissions by 30% by 2030. Since its launch, numerous oil & gas companies have committed to cutting methane emissions. Regulatory, corporate, and social pressures have added

U.S. OIL & GAS GHG EMISSIONS TRENDS (2015–2022)[4]



additional pressure to further reduce methane emissions. At COP28 in December 2023, organizations representing up to 50% of global oil production signed the Oil & Gas Decarbonization Charter (OGDC), pledging to achieve "near-zero methane emissions" and "zero routine flaring" by 2030.[5]

The industry has made strides toward the goal of reducing emissions. In the U.S., between 2015 and 2022, methane and GHG intensity declined by 57% and 39% respectively, as reported to the EPA. These reductions have come from a variety of initiatives and demonstrate how environmental responsibility, and economic efficiency can go hand-in-hand:

MINIMIZING METHANE LOSSES: Advanced technologies and real-time monitoring are crucial for rapid detection and mitigation of methane leaks. By quickly identifying and addressing leaks and venting, operators capture valuable natural gas that would otherwise be lost, directly increasing sales revenue. Replacing older, high-emission equipment, like pneumatic controllers that routinely vent methane, with zero-emission alternatives powered by instrument air, significantly lowers methane emissions.

REDUCING FLARING: While flaring is a common practice for managing excess gas, the industry is making significant strides in minimizing it. Technological advancements and a focus on waste reduction have resulted in an 11% decrease in U.S. flaring-related emissions since 2015.

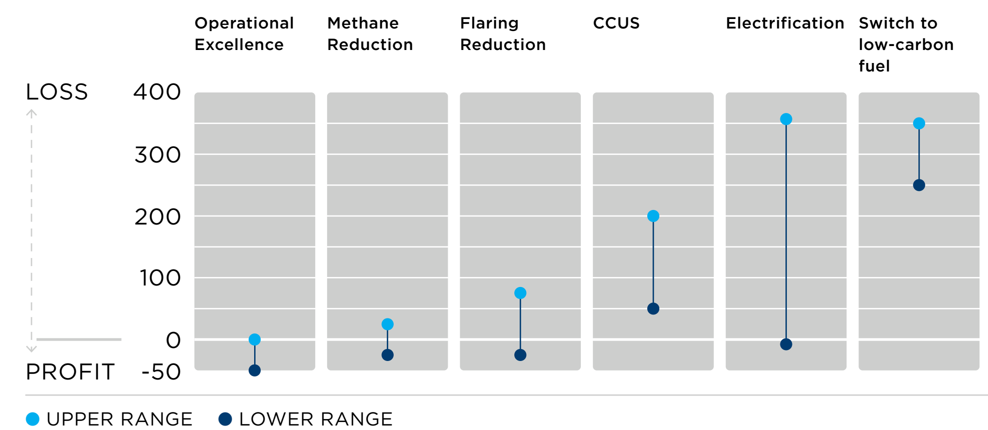
TRANSITIONING TO LOWER-EMISSION OPERATIONS: Many companies are actively replacing traditional fuels and equipment with cleaner alternatives. Electrification of compressors, fracturing fleets, and drilling rigs is reducing CO_2 emissions and lowering operational expenses by shifting away from diesel.

Current Limitations/Challenges

ECONOMICS: Annual investment of around $15 billion would be required to mobilize all methane abatement measures in the oil and gas subsectors.

METHANE & CARBON ABATEMENT COST RANGE[6]

$ per ton of CO_2 equivalent



Based on average natural gas prices in 2023, this investment is roughly equal to the market value of the captured methane – meaning that up to 75% of methane emissions from oil and gas could be reduced at nearly no net cost to the industry. However, while these economics are favorable for most companies, small independent operators with low-producing wells may find it difficult to justify the capital expenditures required for methane-reducing upgrades.

POLICY UNCERTAINTY: While the Biden administration introduced a suite of methane regulations – along with a methane fee to incentivize emissions cuts by U.S. operators – this was one of the first environmental rules targeted for rollback by the Trump administration. As a result, the regulatory environment in the U.S. remains highly volatile and dependent on the political administration in power. Though certain EPA rules under OOOO still regulate methane, much of the industry's abatement activity is now voluntary.

Globally, significant gaps also remain. Countries including Algeria, India, Iran, Russia, Syria, Thailand, and Venezuela – which collectively account for roughly 30% of global methane emissions from fossil fuels – have not made government-led commitments to reduce those emissions. Additionally, several large oil and gas companies, such as Pemex, Sinopec, and Canadian Natural Resources, have yet to make public commitments on methane reduction. These regulatory inconsistencies and lack of global alignment limit the effectiveness and pace of methane abatement progress.

Future Impact if Successful

We believe the global upstream oil and gas sector could reduce up to 7% of global GHG emissions by eliminating methane emissions entirely. The agriculture sector could contribute an additional 8.5% reduction by addressing its methane footprint.

(1) "Global Methane Tracker 2024," IEA.
(2) "Cutting Emissions in Geothermal Power: Global Best Practices," ThinkGeoEnergy.
(3) "Managing Methane in the Waste Sector," Rocky Mountain Institute (RMI).
(4) Oil and Gas Benchmarking Report 2024," ERM (2024).
(5) "Oil & Gas Decarbonization Charter Launched to Accelerate Climate Action," COP28 UAE.
(6) "Coal Mine Methane: An Overview for Investors," Environmental Defense Fund (EDF).

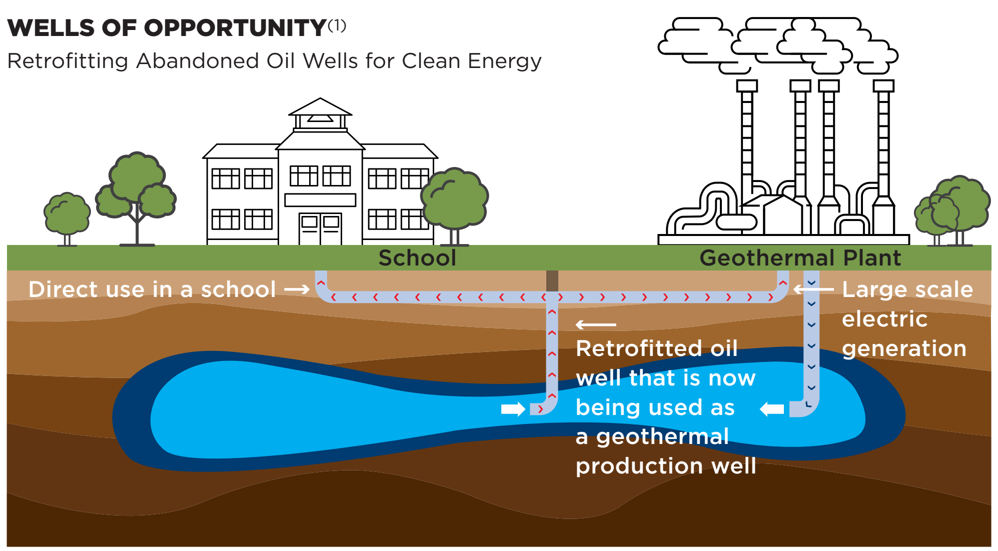
Key Developments in Geothermal

Description

Geothermal energy utilizes the internal heat from the Earth to generate electricity and thermal energy, typically accessed by drilling wells into underground reservoirs of hot water or steam. Electricity is produced at geothermal power plants, which use the heat to create steam that drives turbines. There are also direct-use applications, where naturally heated water from underground reservoirs is used for heating buildings, industrial processes, and other needs. While geothermal heat exists beneath the Earth's surface everywhere, traditional geothermal systems can only tap into this heat in specific places with naturally occurring reservoirs of hot water or steam. So, while the source of heat is widespread, the ability to use it with current technology is limited to certain geologically active areas. We believe unlocking geothermal energy more broadly will require next-generation technologies that can access heat in areas without these ideal natural conditions.

WELLS OF OPPORTUNITY[1]

Retrofitting Abandoned Oil Wells for Clean Energy

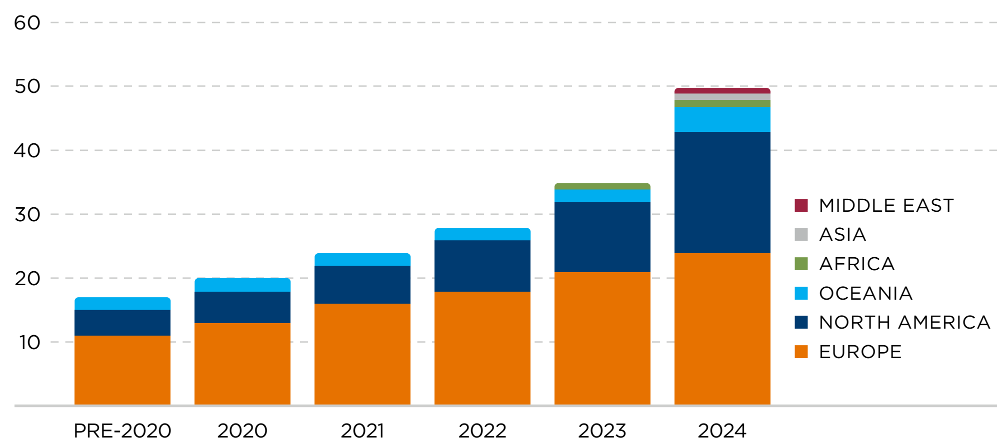


Current State & Recent Progress

GROWTH: Global geothermal power generation capacity reached 16,873 MW by the end of 2024. During the year, 389 MW of new capacity was added,[2] including 14 next-generation geothermal projects – three commercial-scale projects and 11 pilot facilities.[4] Notably, next-generation geothermal began expanding into new regions, including the Middle East and Asia Pacific, signaling growing interest in tapping into geothermal energy beyond traditionally viable locations.

NEXT GENERATION GEOTHERMAL PROJECT TRACKER[3]

Total project count



TECHNOLOGICAL ADVANCEMENTS: Innovation in next generation geothermal technologies promises significant expansion potential beyond 2025. While most projects today remain in the pilot stage, commercial-scale viability is increasingly within reach, with several promising pathways emerging, including:

Enhanced Geothermal Systems (EGS): EGS utilizes multi-stage hydraulic fracturing and horizontal drilling, adapted from oil and gas operations, to create or enhance fracture networks in impermeable hot rock. This enables heat extraction in regions lacking natural permeability or fluid. Fervo Energy's projects in the U.S. have already demonstrated commercial viability, with plans to deliver clean power by 2026.

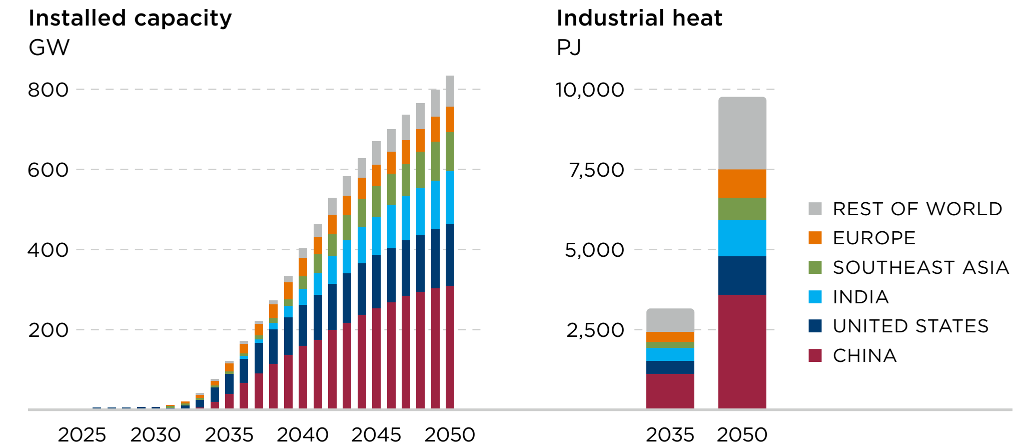
Closed-Loop Geothermal Systems (CLG): CLG circulates fluid through sealed wellbores without requiring reservoir stimulation, eliminating risks of induced seismicity and reducing water consumption. Eavor Technologies' project in Germany aims to produce 8 MW from four deep boreholes by 2027.

Superhot Rock Geothermal (SHR): SHR targets ultra-high-temperature reservoirs exceeding 400°C and could generate five to ten times more energy per well than conventional systems. Projects like the Newberry Volcano project in the U.S. are pioneering tools and materials for extreme conditions.

Current Limitations/Challenges

ECONOMICS: Next-generation geothermal technologies face economic and technical challenges that currently limit their widespread adoption. These systems require significant upfront capital, with costs in 2022 reaching $8.7 million per MW, nearly eight times that of solar. High initial investments, coupled with exploration risks and the potential for dry wells, drives the weighted average cost of capital to a steep 15% in pre-drilling stages. Exploration and drilling account for 40–60% of project expenses, with financing costs elevated due to resource uncertainty.[6] Despite these challenges, the IEA estimates that next-generation geothermal costs could fall by 80% by 2035, and the U.S. Department of Energy has a goal to reduce costs by 90% over the same time period.

MARKET POTENTIAL FOR NEXT-GENERATION GEOTHERMAL POWER CAPACITY AND INDUSTRIAL HEAT BY REGION, 2025–2050[5]



TECHNICAL RISKS: Technologically, advancing next generation geothermal challenges the limits of current drilling techniques and material science. However, up to 80% of the investment required for a geothermal project involves capacity and skills that are already well established in the oil and gas industry. Cross-industry partnerships between oil and gas and geothermal could benefit both industries by advancing the geothermal market while providing diversification opportunities for traditional oil and gas players.[7]

Future Impact if Successful

Next generation geothermal offers the potential for clean, baseload, and dispatchable power – key attributes for a reliable and decarbonized energy grid. If successfully scaled, we believe it could become a major contributor to global energy needs. According to the Massachusetts Institute of Technology, geothermal energy has the potential to meet global energy demand twice over. In the U.S., the Department of Energy estimates that next-generation geothermal energy could provide up to 120 gigawatts of firm capacity – power that can be delivered consistently on demand – by 2050.

(1) "Going Back to the Well Again: Harnessing Geothermal Energy's Potential," U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2024).
(2) "Top 10 Geothermal Countries 2024," ThinkGeoEnergy (2024).
(3) "Geothermal: 2024 in Review," Wood Mackenzie (2024).
(4) *Ibid.*
(5) "The Future of Geothermal," IEA (2024).
(6) "Next-Generation Geothermal Technologies Are Heating Up," BloombergNEF (BNEF) (2024).
(7) "The Future of Geothermal," IEA (2024)

Energy Pragmatism Education & Perspective

Understanding the drivers behind the pillars of the new framework will support meaningful action

Energy pragmatism means taking a balanced view to the Dual Challenge based on facts and economics. We are encouraged by the progress we are seeing in spots across the globe towards this renewed energy pragmatism. To effectuate a global solution, we believe adopting a revised decision framework is a key step. Each of the 7 pillars in our proposed framework are summarized below and each highlights a critical concept that must be well understood and incorporated in solving this complex and global problem. Within this framework, we believe Dual Challenge solutions do exist that acknowledge the priority of energy security, reliability, and affordability but also incorporate cleanliness at levels that protect our environment and are affordable. We hope this report has been useful and helps educate and inspire efforts to solve the Dual Challenge in an efficient and sustainable way.

Solving the Dual Challenge

Energy Addition & Decarbonization

Fossil fuels make up 77% of all energy use and the absolute usage has more than doubled the increase in renewables the last 15 years. No other historical energy sources have been eliminated as new sources are found given the incredible need for more energy as the population and world economy continue to grow.

Address Energy & Climate Goals Concurrently

While many focus on one or the other, both energy and climate goals are important and should be addressed concurrently to make real progress regardless of changing administrations and political winds.

Effective Solutions Must Consider the Global Impacts

We have one atmosphere. Reducing emissions in one region only to have the emissions (or more) appear in another region does nothing to reduce climate change and may make things worse.

Economics & Efficiency Matter

The cost of climate abatement and the impact on energy costs should be considered. Lower cost carbon abatement options should be prioritized to mitigate costs. Actions which meaningfully increase energy costs should be avoided. Timely solutions matter as delays to limit emissions allow current emissions to continue and may drive higher cost solutions in the future.

Full-cycle Economics Should Guide Investment Decisions

Understanding the nuances and actual full-cycle costs of options matters as all "solutions" are not created equally.

Regional Needs/Energy Security Impact Local Decisions

The hierarchy of energy needs will drive behaviors as energy availability, security, and affordability will take precedent over cleanliness. Understanding this human long-term behavior will help drive more pragmatic and practical solutions.

Education & Leadership

Without fundamental understand and effective leadership, practical solutions and real progress are unlikely to occur. Learning from the mistakes of the past and employing "best practices" that work more broadly will provide the needed energy and measurable reductions in emissions

Integrated ESG Program

Inside this section:

Integrating Material Environmental, Social, and Governance Factors to Unlock & Retain Value Creation

A Letter from Keila Diamond, Head of ESG

In navigating the evolving landscape of global energy, we recognize that incorporating financially material Environmental, Social, and Governance (ESG) factors is integral to achieving long-term business value and competitive advantage. Rather than a source of additional burden, integrating ESG considerations directly enhances operational efficiencies, strengthens compliance and risk management, and positions businesses to succeed in an increasingly competitive market.

The past decade saw a strong global push toward decarbonization at any cost, prioritizing energy cleanliness at the expense of availability, affordability, and security. Ambitious climate targets and large-scale investments in renewables, while well-intentioned, in some cases led to the premature deemphasis of traditional energy sources. More recently, geopolitical tensions and energy crises have driven a shift toward energy pragmatism. Many governments and companies are reevaluating policies that disincentivize traditional energy, adopting more balanced strategies that consider both climate action and economic stability. In times of crisis – be it winter heating shortages or foreign threats – basic energy needs inevitably take precedence. Yet, while ensuring secure and affordable energy is essential, we must not lose sight of the imperative to reduce emissions.

This evolving global context underscores the importance of balance – between near-term reliability and long-term sustainability. At Quantum, we approach this challenge with a pragmatic, all-of-the-above investment philosophy. We acknowledge that global energy demand will continue rising for decades, and that no single source can meet this need. Our strategy embraces hydrocarbons, renewables and low carbon infrastructure. We believe that energy addition and decarbonization must go hand in hand.

Importantly, ESG is not just about “doing good.” It’s about future-proofing our portfolio companies and seizing competitive advantage by:

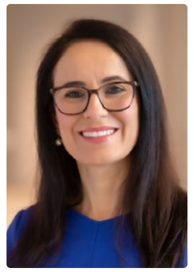
- Unlocking hidden efficiencies while reducing environmental impact and operational costs
- Building resilience against climate risks, safeguarding operations and ensuring long-term success
- Reducing costs through energy and resource efficiency
- Mitigating compliance risks by staying ahead of regulatory change
- Enhancing employee productivity and safety
- Preserving license to operate amid rising stakeholder scrutiny
- Increasing exit multiples by appealing to a broader pool of future buyers

As capital flows shift and stakeholders demand greater transparency and risk management, material ESG integration positions our portfolio companies to thrive. It sharpens operational discipline, supports capital efficiency, and ensures that portfolio companies remain aligned with the expectations of investors, buyers, regulators, and communities. And it is not all about compliance – it is about operational excellence. By embedding ESG where it matters most, we enhance our ability to build enduring, high-performing platforms in the energy space.

Our portfolio companies exemplify how strategic ESG integration can tangibly enhance business outcomes:

- **KODA Resources,** effectively reduced emissions intensity and operational costs by investing in advanced leak detection and repair technology, driving both environmental improvements and operational savings.
- **Bison Oil & Gas,** by taking early action to refine emissions data, prioritize reduction opportunities, and maintain an open dialogue with regulators, the company has been able to endure new compliance obligations effectively, while positioning itself for long-term operational success in a more tightly regulated environment.
- **FireBird Energy,** upgraded its system, and simultaneously reduced NOx emissions, emissions from diesel fuels, and captured $5.5 million in redirected gas to secondary markets.

These examples demonstrate that integrating ESG considerations isn’t merely a goodwill – it fundamentally drives value creation. By proactively addressing emissions, resource use, and operational safety, our companies have strengthened their resilience and enhanced their market positioning, particularly as strategic buyers’ preference favor business that can easily bolt-on to their own operations and business models.



> ESG is not just about “doing good.” It’s about future-proofing our portfolio companies and seizing competitive advantage.”
>
> **Keila Diamond**
> HEAD OF ESG, QUANTUM CAPITAL GROUP

As fiduciaries, we remain focused on scalable strategies that protect and grow enterprise value. Material ESG integration – centered on emissions, safety, water stewardship, compliance, and community relations – has contributed to the improvement of quality, resilience, and investability of Quantum’s energy assets. It is through this pragmatic, data-backed approach that we believe ESG becomes a tool of value.

We invite you to consider ESG not as an obligation, but as an opportunity – a strategic tool to strengthen your investment and position it successfully for the future. Quantum remains committed to supporting our portfolio companies in capturing these opportunities, aligning economic growth with responsible environmental and social stewardship and long term financial success.

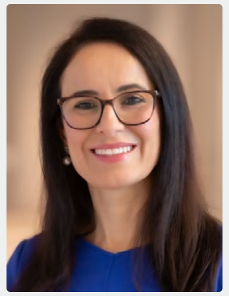
ESG Governance

Quantum Capital Group has developed a robust ESG governance framework that aligns with our core values.

This structure aims to ensure that ESG considerations are embedded in decision-making, fostering transparency, accountability, and long-term value creation. Our ESG Policy serves as the foundation for how we integrate environmental, social, and governance principles across all aspects of our business. It outlines the expectations and standards for responsible investment, operational sustainability, and ethical conduct, seeking to ensure that our actions align with our commitment to creating long-term value. This policy guides both Quantum and our portfolio companies in making informed decisions that reflect our dedication to transparency, risk management, and sustainable growth.

ESG STEERING COMMITTEE

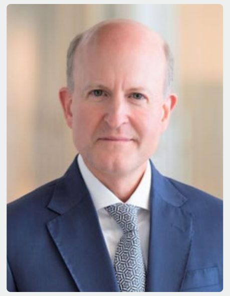
The Quantum ESG Steering Committee provides strategic oversight, seeks to ensure alignment with our company values, oversees the integration of ESG principles into investment strategies and operations, seeks to ensure that ESG risks and opportunities are identified and managed, and strives to create long-term value creation.



Keila Diamond
MANAGING DIRECTOR & HEAD OF ESG

Wil VanLoh
FOUNDER & CEO

Ajay Khurana
PRESIDENT



Charles Baillie
CHIEF OPERATING OFFICER

Garry Tanner
PARTNER

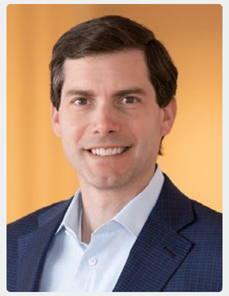
Jim Baird
PARTNER & GENERAL COUNSEL EMERITUS

Roman Bejger
PARTNER & GENERAL COUNSEL

Michael Dalton
MANAGING DIRECTOR, CLIENT SOLUTIONS

Tom Field
PARTNER

Alan Smith
OPERATING PARTNER



Blake Webster
PARTNER

ESG GOVERNANCE STRUCTURE

Program Sponsorship

RESPONSIBLE TEAM: Executive Team

The Executive Team is responsible for providing overall sponsorship of the ESG program, seeking to ensure that it aligns with the company's core values and strategic goals. Their leadership helps drive the integration of ESG across all areas of the business.

Oversight, Strategic Guidance & Representation

RESPONSIBLE TEAMS: ESG Steering Committee and Quantum Representatives on the Boards of Portfolio Companies

The ESG Steering Committee and Quantum representatives on portfolio company boards provide oversight and strategic guidance to Quantum and our portfolio companies, seeking to ensure that ESG initiatives are aligned with business objectives and regulatory requirements. They monitor progress and advocate for the integration of ESG principles at the highest levels of governance.

Strategy Development & Implementation Support

RESPONSIBLE TEAMS: ESG Team, Transaction Team, Technical Team, Client Solutions Team, and Digital Team

These teams collaborate to develop and support the implementation of ESG strategies across the portfolio. Each team brings its expertise to help ensure that ESG considerations are deeply embedded in all aspects of investment, technical operations, client engagement, and digital transformation.

Implementation

RESPONSIBLE TEAMS: ESG Team and Portfolio Companies

The ESG Team works directly with portfolio companies to implement ESG strategies, with an aim to drive tangible actions and results. This includes working closely with company leadership to embed ESG best practices into daily operations and long-term planning.

Please see the Disclaimers at the end of this report for important information regarding ESG considerations in our investment practices.

ESG Factors

To ensure our ESG efforts are strategically focused, we conducted a comprehensive materiality assessment to identify the most critical issues for Quantum and our portfolio companies.

This assessment allowed us to prioritize key areas that align with investor objectives and the long-term sustainability of our investments. As part of this process, we benchmarked our ESG priorities against leading global frameworks, including the Sustainability Accounting Standards Board (SASB), the Task Force on Climate-related Financial Disclosures (TCFD), the Global Reporting Initiative (GRI), and the Institutional Limited Partners Association (ILPA). We also incorporated input from Quantum leadership, portfolio company representatives, and external stakeholders to ensure a well-rounded and informed approach.

We equip our portfolio companies with the tools and guidance needed to actively manage these ESG considerations, directing resources toward high-priority areas where we believe we can deliver the greatest value. By integrating ESG factors into every phase of the deal life cycle, we seek to enhance risk management and identify opportunities that contribute to long-term value creation.

OUR MATERIAL ESG FACTORS*

Environmental

CLIMATE CHANGE

Minimizing our emissions and mitigating potential impacts to the climate

- GHG (Scopes 1 & 2): Methane, Flaring, Combustion
- GHG (Scope 3)
- Climate Resilience

NATURAL RESOURCES & RELEASES

Operating responsibly and being good stewards of the resources we operate

- Biodiversity & habitat
- Air emissions
- Water consumption
- Wastewater
- Waste
- Spill prevention
- Well closure & site decommissioning

Social

HUMAN CAPITAL

Keeping employees safe and prioritizing their well-being

- Health & safety
- Labor standards & human rights
- Asset integrity & process safety
- Human capital management

COMMUNITY RELATIONS

Supporting our stakeholders, including the communities where we operate

- Community engagement
- Indigenous People & First Nation rights
- Land acquisition, use & resettlement

Governance

CORPORATE ETHICS & GOVERNANCE

Increasing accountability and transparency, and upholding our ethical standards

- ESG performance monitoring, evaluation & reporting
- Stakeholder engagement
- Business ethics and code of conduct
- Cybersecurity

* There can be no assurance that the list of ESG topics is exhaustive, and additional topics may be identified as material on a case-by-case basis for each investment. There is no guarantee that any of the steps taken by Quantum and/or third parties to mitigate, prevent, or otherwise address material ESG topics will be successful in preventing or mitigating impacts on returns, completed as expected or at all, or will apply to or continue to be implemented in the future. Please see disclosures for important information regarding ESG considerations in our investment practices.

ESG Integration Strategy

At Quantum, we view ESG as an important component of our investment strategy, embedding it throughout the investment lifecycle to maximize value and minimize risk. By proactively addressing material ESG factors, we aim to strengthen operational resilience, enhance efficiency, and create long-term financial stability. We believe integrating ESG not only helps safeguard our investments but also positions our portfolio companies for stronger market differentiation and more favorable exit opportunities.

ESG INTEGRATION IN THE INVESTMENT LIFE CYCLE[(1)(2)]

	Pre-Investment Thorough analysis, review & approval			Post-Investment Active ownership, engagement & realization	
Deal Lifecycle	Deal Sourcing	Due Diligence	Investment Decision	Ownership & Stewardship	Exit
ESG Objectives	Minimize exposures that conflict with Quantum's risk-adjusted return expectations	Identify material ESG risks and opportunities	Invest and integrate material ESG analysis	Steward active investments	Influence through results and engagement
ESG Integration	Assess new opportunities for alignment with Quantum and investors criteria	Evaluate material liabilities, risks, and opportunities through the lens of Quantum's material ESG factors	Consider the valuation of ESG performance when making the final investment decision	Work with portfolio companies to implement key initiatives and continuously seek to mitigate regulatory risks	Communicate value added and potential future upside to potential buyers

(1) Although Quantum considers our ESG strategy to be an opportunity to improve performance and avoid risk for our investments, Quantum cannot guarantee that our strategy will positively impact financial or climate performance of any individual portfolio company. Please see the Disclaimers at the end of this report for important information regarding ESG considerations in our investment practices.
(2) As Quantum deems feasible and appropriate. Quantum's investment professionals will integrate material ESG factors into the investment process by implementing some or all of the above example practices.

ESG Integration Strategy

DEAL SOURCING, DUE DILIGENCE, & DECISION MAKING

Quantum integrates ESG early in the investment process, beginning with due diligence.

Integrating ESG into Quantum's investments begins at the earliest stages – during due diligence and the pre-investment decision-making process. Our ESG and investment teams work side-by-side to evaluate material ESG risks and opportunities from the outset, helping inform investment decisions and identify areas for potential value creation.

However, the extent to which we can apply ESG considerations varies depending on the investment structure and our level of influence. In situations where Quantum has limited influence – such as minority or limited-access positions – we adjust our ESG application to what is practical and feasible under the circumstances. In these cases, we may analyze public data, perform benchmark analyses, and engage directly with leadership teams to assess their approach to ESG and determine whether their values align with Quantum's investment philosophy.

Where Quantum has operational control, we undertake a more detailed ESG review. This includes an in-depth review of ESG risks, including document analysis, data review, and site visits, where appropriate. We also partner with external experts to support due diligence and develop action plans when needed.

Due Diligence Goals and Key Steps

Understand Commitment Level

- Engage management teams to assess their oversight of ESG risks.
- Evaluate ESG teams to understand their capacity for managing sustainability challenges and delivering on ESG priorities.

Analyze Historical ESG Performance

- Review key ESG documents, policies, permits, and historical data to assess the company's performance over time.
- Engage third-party consultants, where appropriate, to provide expert analysis and validate internal reporting.
- Conduct site visits, where appropriate, to gain direct insight into operational practices and associated risks.

Assess ESG Factors and Seek to Reduce Risk/Create Value

- Identify and quantify material ESG risks.
- Map material ESG risks and opportunities to action plans designed to mitigate downside exposure and enhance long-term value.
- Summarize key findings and present action plans to Quantum's Investment Committee.

Execute on ESG Opportunities

- Partner with deal teams and portfolio companies to implement identified action plans.
- Leverage ESG data to uncover and drive additional value-creation projects.

OWNERSHIP & STEWARDSHIP

During the investment period, we work side by side with our portfolio companies to advance key ESG initiatives that help manage risks and unlock value.

From the outset of each partnership, we serve as a hands-on resource, equipping management teams with ESG tools, best practices, and operational guidance. Our standardized internal processes and reporting frameworks offer companies a solid starting point to strengthen their ESG practices under Quantum's ownership. By engaging early – during deal screening and due diligence – we help identify material ESG issues and opportunities, laying the groundwork for focused, collaborative action. We then tailor our support to fit each company's specific context, working closely with management to enhance operational performance, improve resilience, and position the business for stronger long-term outcomes, including the potential for value premiums at exit.

Engagement Goals During Ownership & Stewardship Phase

Onboarding

- Conduct strategic planning sessions with portfolio leadership to address issues identified during due diligence, develop clear ESG action plans, and align priorities for implementation.

Quarterly Working Group Meetings

- Convene quarterly cross-portfolio meetings to share ESG insights, discuss challenges, exchange best practices, and foster a collaborative learning environment.

Resources and Reporting

- Provide a robust suite of ESG tools, resources, and templates – including quarterly ESG surveys and Board reporting materials – to help companies monitor progress and drive continuous improvement.

Regulatory Information Sessions

- Engage legal, environmental, and regulatory experts to deliver targeted briefings, keeping portfolio companies informed on evolving regulations and emerging ESG risks.

Check-ins

- Conduct regular one-on-one meetings with designated ESG coordinators from each portfolio company to review progress, address roadblocks, and offer tailored strategic and operational support.

Strategic Partnerships

- Help portfolio companies identify and connect with leading third-party experts in areas such as monitoring, emissions reductions, and ESG data services to accelerate key initiatives and strengthen outcomes.

Though Quantum strives to complete all due diligence and ownership activities listed, these activities are conducted on an investment-by-investment basis and, due to the nature of certain investments, may not encompass all actions outlined. Examples of such cases include portfolio companies without operating assets, those where Quantum is a minority investor or lender, or instances where Quantum lacks operational control and has limited access to management or non-public ESG information. There can be no assurance that any strategy described herein is not modified (perhaps materially) in the future or will lead to successful outcomes or improved portfolio company performance. Please see the Disclaimers at the end of this report for important information regarding ESG considerations in our investment practices.

ESG Integration Strategy

MONITORING, EVALUATION & REPORTING

To effectively deliver on our ESG program, we collect a comprehensive range of data across our portfolio through a rigorous monitoring and reporting process.

Our data collection efforts are a foundational element of how we engage with portfolio companies and form a core part of our collaborative approach. By analyzing these data points, we are able to spot emerging trends, evaluate risks and opportunities, and design targeted action plans to help address key issues. We report ESG performance proactively and transparently across multiple channels to help ensure our disclosures are clear, comparable, and meaningful to stakeholders. In addition, we maintain regular dialogue with investors and other stakeholders to gather input and help ensure our reporting continues to meet evolving expectations and informational needs.

Portfolio Company Reporting Process

For majority owned and operated companies, our standard reporting framework includes several key components:

Quarterly Surveys

- Used to identify trends, highlight key risks or issues, and align with Quantum's ESG policies and expectations.

Annual Surveys

- Used to capture detailed, year-over-year data, providing a comprehensive view of progress and challenges.

Quarterly Board Reports

- Portfolio companies use a standardized Quantum reporting template to brief their Boards on ESG progress, key initiatives, and long-term performance trends.

Unplanned Events

- Portfolio companies must promptly report material incidents or events, and Quantum supports mitigation efforts.

ESG Data Metrics

Each year, Quantum collects a comprehensive set of key performance indicators (KPIs) across multiple categories, giving us a holistic view of our portfolio's ESG performance and progress.

CATEGORY	TYPES OF METRICS MONITORED
Energy Consumption	Electricity consumption / Fuel consumption
GHG Emissions	Scope 1 / Scope 2 / Gas flaring
Methane	Methane intensity and LDAR / Methane reduction
Air Emissions	Number of Title V facilities / Criteria pollutants
Water	Total fresh / Non-freshwater sourced / Recycled water
Spills	Oil spills / Water spills / Chemical spills
Safety, Contractor, Vehicle	Work hours / TRIR / LTIR / PVIR / Lost time incidents
Regulatory Compliance	Notice of Violations (NOVs) and associated fines
Anonymous Reporting	Presence of systems in place
Community Relations	Number and type of complaints
Human Capital Management	Employee turnover and demographics

Reporting processes apply to select companies with relevant data available. Not all Quantum companies, including partially owned companies, or non-traditional oil and gas companies are required to report on all metrics.

SUPPORTING EXIT VALUES

We believe that portfolio companies with a strong ESG track record are more attractive to buyers, offering enhanced resilience, reduced risk, and improved long-term value.

By integrating ESG considerations throughout the ownership phase, we believe we help position our companies not only for operational success but also for a more compelling, higher-value exit. As part of the exit process, we work closely with our operated, majority-owned portfolio companies to prepare credible and comprehensive ESG materials – ensuring they meet listing requirements and provide prospective buyers with the ESG information they increasingly expect. We assist in responding to potential investors' questions by compiling clear, verifiable ESG data that highlights business improvements, risk mitigation efforts, and sustainability achievements under Quantum's ownership. Additionally, we focus on strengthening each company's ESG management system, so it is self-sustaining and robust, which we believe helps safeguard against reputational or operational risks after exit and ensuring the company remains well-positioned for long-term success under new ownership.

Engagement During Exit Phase

Identify High-Impact Projects for Potential Buyers

We collaborate with companies to identify what we believe are high-impact ESG initiatives that appeal to potential like-minded buyers, with the intent to make the company more attractive at exit.

Highlight ESG Progress and Compile Relevant Data

We help our portfolio companies gather and present ESG data that showcases the positive business improvements achieved over time. This information gives prospective buyers insights into the company's ability to deliver value through its ESG initiatives.

Seek to Ensure Self-Sustaining ESG Systems Post-Exit

To ensure a smooth transition post-exit, we aim to help companies develop self-sustaining ESG management systems that can operate independently.

Portfolio Company ESG Performance

Inside this section:

Operational Greenhouse Gas Emissions

As part of our commitment to responsible investing, we work to consistently measure, manage, and reduce greenhouse gas emissions within our portfolio. We believe maintaining a strong focus on environmental stewardship allows us to better manage risks, align with stakeholder expectations, and create long-term value for our investors.

Carbon dioxide and methane are the most material sources of operational emissions across our portfolio and remain the primary focus of our tracking and reduction efforts. In addition, we collect data on other greenhouse gases, such as nitrous oxide (N_2O), and require reporting on emissions from company-owned vehicles. While these additional sources represent a smaller share of total emissions and offer fewer reduction opportunities, we encourage companies to pursue lower-emission alternatives where practical. Quantum tracks year-over-year GHG metrics to monitor progress, identify risks and opportunities, and support continuous improvement.

In 2024, our total Scope 1 portfolio emissions increased compared to 2023, largely due to asset acquisitions, increased drilling and completions, and higher overall production. Additionally, the EPA introduced several changes to reporting methodologies and calculations, increasing the Global Warming Potentials for methane and nitrous oxide and updating emission factors for several point sources. These changes make year-over-year aggregated greenhouse gas data difficult to compare. Additionally, given the nature of our business, fluctuations in aggregated emissions and intensity metrics are expected as companies enter and exit the portfolio. Rather than focusing on fund-wide metrics, Quantum prioritizes tracking year-over-year trends at the individual portfolio company level and works closely with each company to identify opportunities for improvement. Our focus is on identifying and advancing projects that not only mitigate environmental risks but also deliver strong economic value. By aligning emissions reduction efforts with both risk management and financial performance, we believe we help our companies build more resilient, efficient, and sustainable operations.

2024 TOTAL EMISSIONS[1]

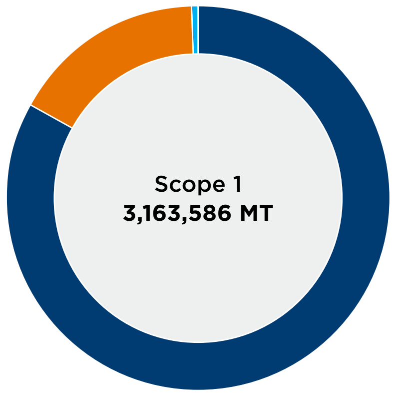
MT CO_2e

Carbon Dioxide (CO_2) Emissions from combustion operations and flaring	**2,582,949 MT**
Methane (CH_4) Emissions from venting or leaking natural gas	**569,860 MT**
Nitrous Oxide (N_2O) Another type of emissions resulting from combustion operations	**2,640 MT**
Vehicle Emissions Another type of emissions resulting from combustion operations	**8,136 MT**
Scope 1 Operational emissions from upstream and midstream companies, including vehicle emissions	**3,163,586 MT**

2024 SCOPE 1 PORTFOLIO EMISSIONS

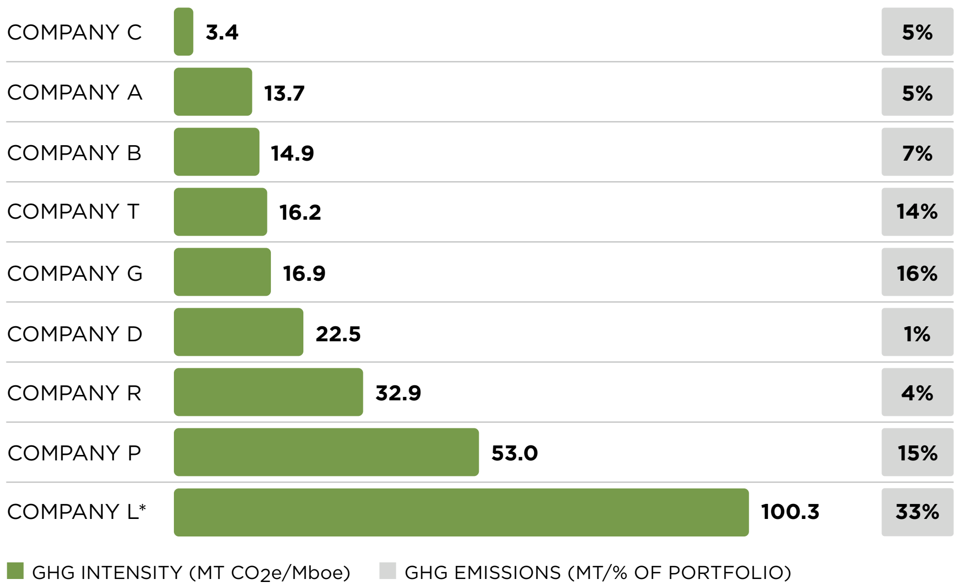
Percent

- **81.6%** CARBON DIOXIDE
- **18.0%** METHANE
- **0.3%** VEHICLE



SCOPE 1 GHG EMISSIONS INTENSITY[2]

MT CO_2e/Mboe



* Company L, which makes up 33% of portfolio GHG emissions, has a large amount of CO_2 emissions and high GHG intensity due to the combustion required for steam flood operations.

Flaring

Quantum is committed to minimizing routine flaring across our oil and gas portfolio as part of our broader strategy to drive operational efficiency and maximize resource value. We help our portfolio companies reduce flaring through infrastructure improvements and operational enhancements, ultimately improving asset profitability and long-term investment returns.

Flaring – the burning of excess natural gas – often stems from limited takeaway infrastructure or operational safety needs, which are challenges in certain basins where Quantum operates as well as in our offshore investments. By working closely with portfolio companies to address these barriers, we help reduce flaring, which not only strengthens environmental performance but also improves financial outcomes by increasing gas capture rates, reducing waste, and enhancing revenue opportunities.

For U.S. operators, flaring calculations have changed with EPA's updated calculation methodology, making it difficult to assess year-over-year trends. However, we work closely with individual operators – particularly oil companies that face takeaway constraints – to identify critical projects that will reduce flaring. Our priority areas include key basins such as the Permian, Williston, and Powder River, as well as offshore operations. Notably, Quantum's offshore operator, Trident Energy, accounts for the majority of flared volumes in the portfolio and is a major focus of our efforts. Notably, Trident has launched a dedicated "Flare Hunting Program" that incentivizes operators to systematically identify, repair, and replace equipment and valves before they malfunction and trigger emergency shutdowns that result in flaring. For more on Trident's flaring reduction strategy, see their 2024 ESG report.

[1] To calculate CO_2e, Global Warming Potential (GWP) of 25 and 298 were used for methane and nitrous oxide emissions respectively in conjunction with EPA reporting.
[2] Quantum's total portfolio company GHG intensity is estimated using aggregated data provided by portfolio companies. Portfolio company data has not been verified by Quantum or any third party. Data may exclude portfolio companies who did not report data.

Methane

Managing methane emissions is a critical priority for Quantum because methane is a highly potent greenhouse gas with a far greater short-term warming impact than carbon dioxide. We believe proactively addressing methane emissions not only strengthens the environmental performance of our oil and gas portfolio companies but also supports financial performance by minimizing regulatory risks, improving operational efficiency, and protecting asset value.

We believe that effective methane management is essential to reducing exposure to future compliance costs, safeguarding our license to operate, and enhancing long-term investment returns. Each year, we collect methane data from our portfolio companies and conduct in-depth analyses to identify reduction opportunities, benchmarking our companies against an intensity level of 0.2% – a widely used industry reference recommended by NGOs and the former threshold of the proposed Waste Emissions Charge (WEC). In 2024, methane accounted for 18% of operational emissions from our oil and gas portfolio companies, and our portfolio continued to outperform our 0.2% methane intensity goal. While fluctuations in portfolio-wide methane intensity may occur as companies enter or exit the portfolio or adjust operations, we remain focused on strengthening methane management practices to enhance operational efficiency, reduce costs, and protect the financial performance of our portfolio companies.

Our approach to supporting methane management focuses on proactively designing new facilities to eliminate emission sources where possible, retrofitting and upgrading existing equipment to minimize methane leaks or venting due to volume constraints, and implementing active leak detection and repair (LDAR) programs.

Proactive Planning

When developing new production, our companies carefully consider how to design facilities that minimize methane emissions. This can include electrifying operations from the outset to avoid using field gas for power, securing ample gas takeaway capacity to support future expansions, and applying the latest technologies to avoid venting gas into the atmosphere. For example, HG Energy in Appalachia installed instrument air packages on all new facilities beginning in 2022. This immediately curtailed emissions and was a contributing factor in HG's low methane intensity of 0.01%. In an annual Oil and Gas Benchmarking study performed by ERM and Ceres, HG had the second lowest methane intensity out of the top 100 producers in the country.

Retrofits and Upgrades

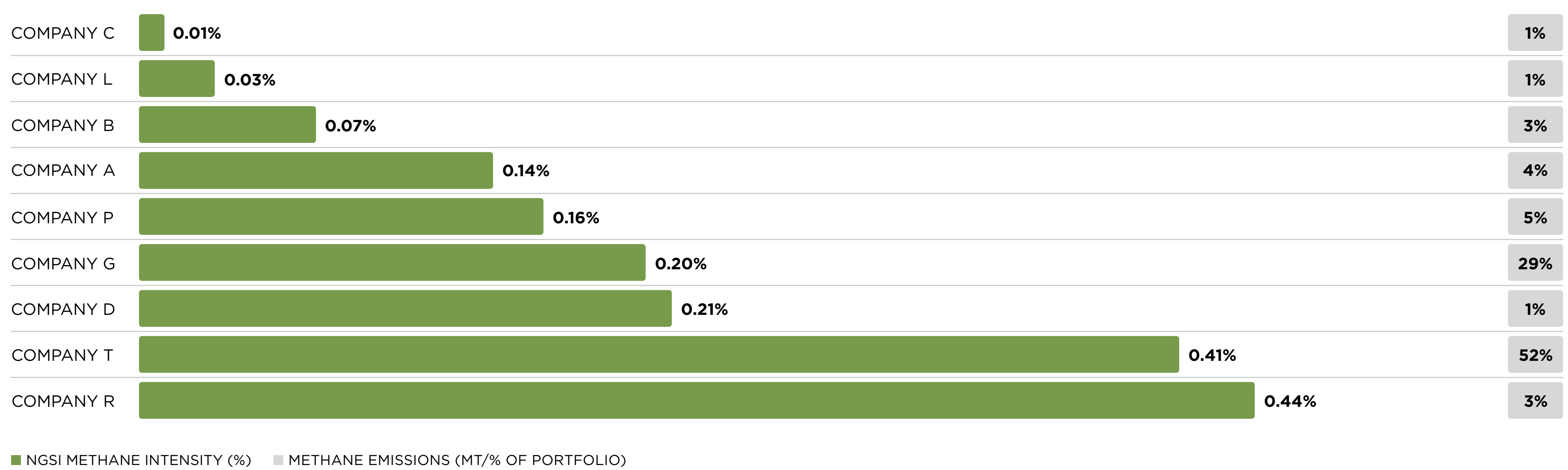
Oftentimes, during an acquisition, companies inherit older operations equipment that requires upgrades to reduce methane emissions. Quantum portfolio companies have a demonstrated track record of improving infrastructure and onsite equipment to achieve meaningful methane reductions. From expanding pipelines and gas takeaway capacity to replacing natural gas-powered pneumatics with nitrogen-powered control devices, we believe Quantum companies have identified practical solutions to cut methane emissions from existing sources. For more details, see the case studies on pages 52, 53, and 54, where we highlight projects from KODA, Bison, and FireBird.

Leak Detection and Repair

Keeping natural gas in our pipelines is good business – we believe that active, multi-layered programs enable our companies to find and fix leaks quickly, keeping our product where it belongs, in the pipeline. Quantum companies use a variety of strategies for Leak Detection (LDAR), including Optical Gas Imaging (OGI) cameras, continuous monitoring, and aerial flyovers. Each approach offers distinct advantages, and combining them reinforces overall LDAR efforts while improving operational efficiency by identifying malfunctioning equipment.

OGI cameras, for example, precisely pinpoint emission sources and meet regulatory standards. Continuous monitors provide 24/7 leak alerts and apply data analytics to identify trends in leak patterns. Piloted aircraft can scan hundreds of sites per day and are highly useful in detecting pipeline leaks or releases in remote areas. Quantum companies are encouraged to use all three of these methods in a combination that works best for their unique asset.

METHANE INTENSITY
Percent



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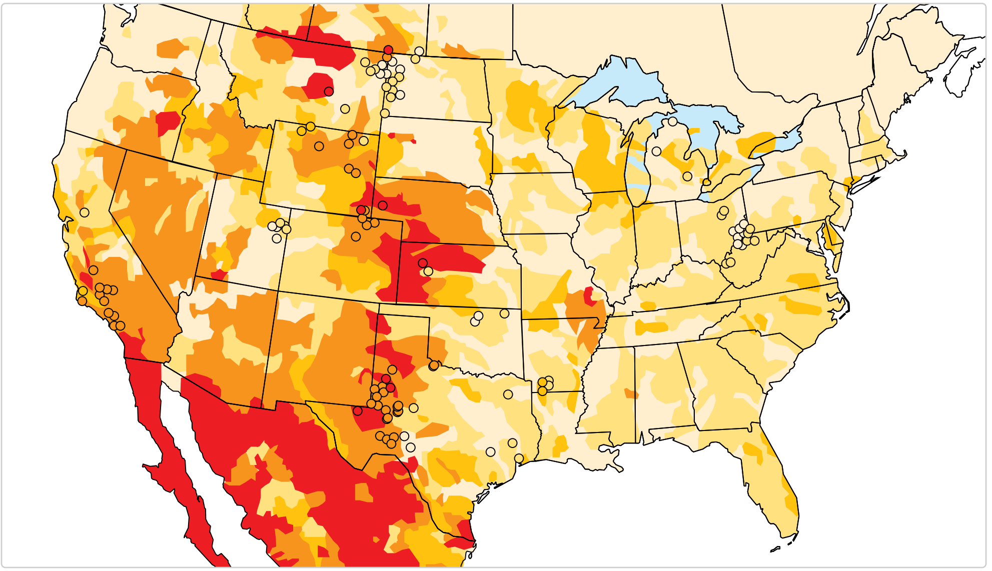
Water

Reducing freshwater consumption is a key part of our strategy to manage operational costs, mitigate resource risks, and strengthen portfolio resilience. By prioritizing the use of alternative water sources and mapping regional scarcity risks, we believe we help our companies operate more efficiently and maintain a strong license to operate.

Water is vital to Quantum portfolio company operations. We remain focused on reducing freshwater consumption across our portfolio companies, recognizing that effective water management can drive significant cost savings in procurement and disposal while reducing exposure to water scarcity risks. We believe responsible water use also strengthens our companies' social license to operate and enhances their position in an increasingly resource-conscious market. In 2024, nearly 72% of the water sourced by our portfolio companies came from non-freshwater sources.

Identifying Water Stressed Assets

To better understand our footprint, and manage our water usage, Quantum maps regional water scarcity risks using the World Resources Institute (WRI) Aqueduct tool to pinpoint any operations that may be in water-stressed areas. We intend to perform this exercise annually to ensure our analysis is up to date. While the majority of Quantum's current operations lie outside of areas of extreme scarcity, companies are still taking measures to mitigate their water use for environmental and business purposes.



Overall Water Risk
Low, Low/Medium, Medium/High, High, Extremely High

Quantum Wells Risk
Low, Low/Medium, Medium/High, High, Extremely High

Portfolio Company Water Usage

Quantum operators use water for a variety of reasons, but portfolio water usage is primarily driven by hydraulic fracturing operations at companies expanding production and drilling and completions programs, as well as steam flood operations operating in California. In hydraulic fracturing, or fracking, large volumes of water mixed with sand and chemicals are injected at high pressure to create fractures in low-permeability rock, allowing oil and gas to flow from the reservoir. A single well can use anywhere from 1.5 to 16 million gallons of water for fracking. These large volumes create opportunities for companies to develop water recycling programs, which can yield significant cost savings on both water sourcing and disposal.

2024 TOTAL FRESHWATER CONSUMPTION
Percent

	FRESHWATER SOURCED	FRESHWATER (MBBL)
COMPANY L	3%	5,025
COMPANY T	10%	1,299
COMPANY B	31%	9,514
COMPANY P	54%	106
COMPANY C	67%	11,712
COMPANY G	80%	12,070
COMPANY D	89%	1,457
COMPANY A	98%	25,698
COMPANY R	100%	1,858

YEAR-OVER-YEAR PORTFOLIO FRESHWATER USAGE
Percent, Total Bbbl

	Percent	Total Bbbl
2022	27%	89,513
2023	21%	55,793
2024	28%	68,739

SPOTLIGHT

Sentinel Peak Resources' Conservation of Precious Water Resources

Sentinel Peak Resource (SPR), a California operator that utilizes a steam flooding to extract oil, is Quantum's largest contributor to total water sourced in the portfolio. However, due to their commitment to excellent water stewardship, the company recycles nearly 97% of the water it sources and is on its way to becoming a net supplier of water to the State of California. Through a comprehensive program combining recycling, conservation, and reverse osmosis technology, Sentinel Peak continually works to minimize its impact on freshwater sources.

Since acquiring the asset in 2017, SPR has reduced freshwater purchases by 50%, preserving over 400 million gallons of freshwater annually, and has increased the reuse of recycled water by 20% compared to its predecessor. To further advance beneficial reuse, SPR not only uses recycled water in its own operations but also treats a portion of its produced water with reverse osmosis and ultrafiltration, adding it into a local stream to support aquatic life and habitats.

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Human Capital Management

Our goal is to foster strong human capital management practices across our portfolio companies to build a workforce that is safe, engaged, and highly productive. We believe that a strong human capital foundation not only drives operational efficiency but also strengthens competitiveness and supports long-term organizational success.

Safety

We work closely with portfolio companies to promote a culture that prioritizes the well-being of every employee, aiming to ensure workers return home safely each day. By focusing on safety, we believe we minimize the risks and costs associated with workplace incidents, including regulatory fines, higher insurance premiums, and productivity losses. A strong safety culture also supports workforce morale and overall operational performance. In 2024, Quantum portfolio companies and their contractors collectively worked over 7 million hours, achieving a Total Recordable Incident Rate (TRIR) of 0.94.

This includes majority-owned companies where Quantum maintains operational control, with a particular focus on upstream and oilfield services businesses, where operational risks have been identified as highest.

Asset Integrity and Process Safety

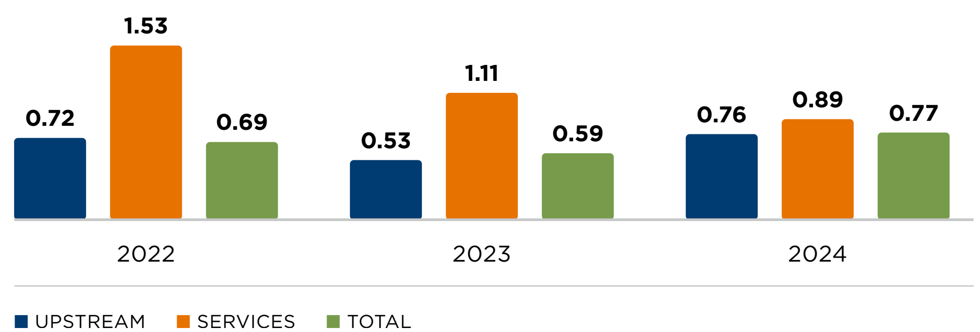
In our oil and gas portfolio, we emphasize operational efficiency and risk reduction through robust asset integrity and process safety practices. This includes a lifecycle approach to asset management – spanning design, maintenance, and replacement – while balancing operational costs. Proactively managing asset conditions helps protect personnel, avoid environmental incidents, and maintain reliable, uninterrupted operations.

Gathering Human Capital Data Across Investment Types

We work closely with our portfolio companies and management teams to foster cultures designed to encourage innovation, improve how decisions are made, increase employee satisfaction and loyalty, and support lasting growth. As of April 2025, we collected human capital data for 24 portfolio companies across our climate technology, private equity, and renewables investments, covering over 4,700 unique employees. We believe this data helps us fully understand the composition of our workforce, recognizing that it can differ significantly across industries.

TOTAL RECORDABLE INCIDENT RATE (TRIR) PORTFOLIO TREND OVER TIME[1]

Rate

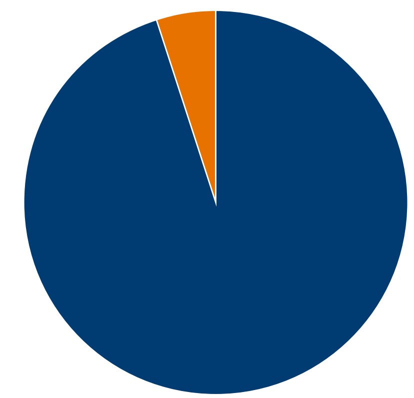


2024 HOURS WORKED[1]

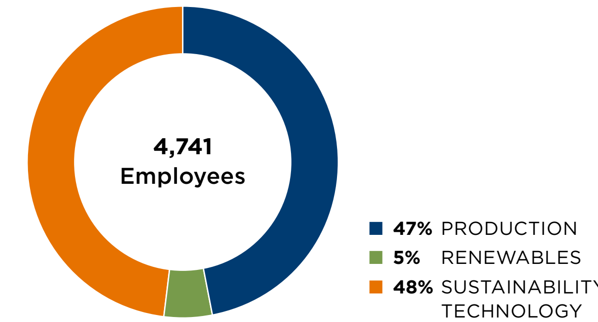
Percent

95% UPSTREAM
5% SERVICES

Quantum companies and their contractors worked over 16 million hours in 2024.

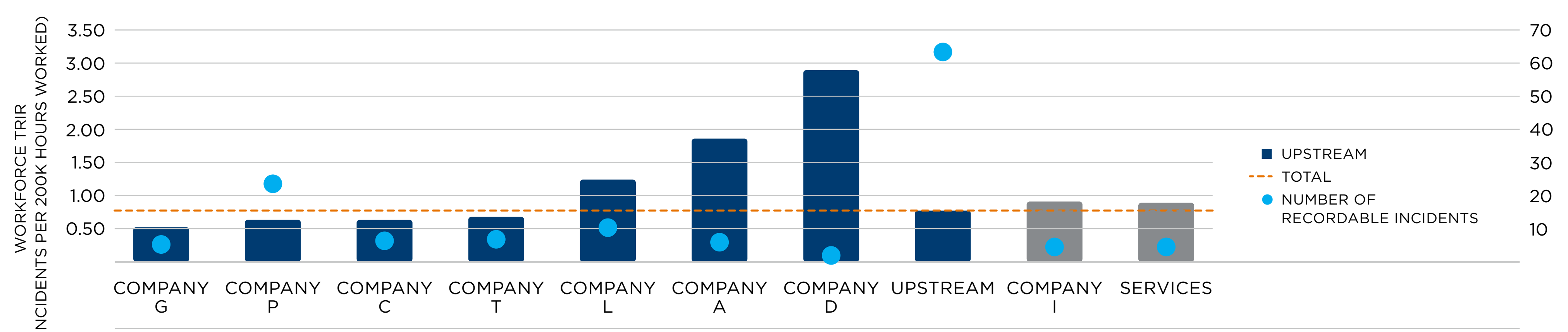


PORTFOLIO COMPANY HEADCOUNT BY INVESTMENT TYPE



Sustainability Technology	Renewables	Oil & Gas Production
10 Companies	**4** Companies	**10** Companies
2,284 Employees	**289** Employees	**2,215** Employees
228 Average Number of Employees	**61** Average Number of Employees	**228** Average Number of Employees

2023 WORKFORCE TRIR BY PORTFOLIO COMPANY AND INDUSTRY VERTICAL[2]



(1) Human capital management data as of December 31, 2024, and does not include Quantum Capital Solutions or companies that did not track human capital management data.
(2) Quantum aggregate metrics do not include Company B, who did not track contractor hours but reported two contractor incidents.

Portfolio Company Case Studies

Inside this section:

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CASE STUDY

KODA: ESG Leadership Drives Value in Caerus Oil & Gas Acquisition

KODA

PRIMARY OFFICE
Denver, Colorado

YEAR OF QUANTUM INVESTMENT
2018

KODA Resources, LLC is focused on the acquisition and development of oil and gas properties in the Rocky Mountain Region. They are actively operating in the Williston and Uinta Basins.

In August 2024, as part of Quantum's larger acquisition of Caerus Oil and Gas, KODA acquired 160,000 acres of upstream and midstream facilities in Utah's Uinta Basin. These assets offered significant production potential but also came with inherited environmental challenges, particularly around methane emissions. During due diligence, Quantum's teams worked with Caerus and external experts to assess methane risks and reduction opportunities. Following the acquisition, KODA identified and prioritized the major ESG projects needed to address inherited emissions and improve operational performance.

Drawing on its proven history of executing high-value ESG initiatives and recognizing the need for rapid improvement, KODA prioritized a targeted methane reduction strategy for its newly acquired operations. KODA quickly identified pneumatics as the largest emissions driver and developed a two-pronged plan to address emissions at the source:

Pneumatic Device Inventory Project

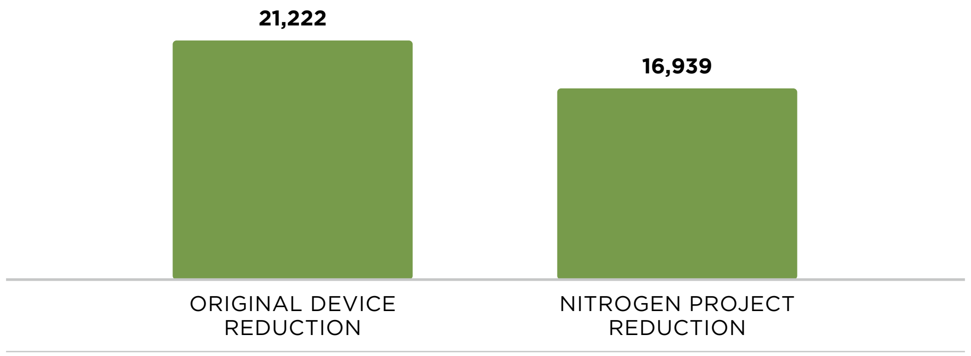
KODA engaged an expert consultant to conduct a detailed onsite inventory of the new equipment inherited during the acquisition. This effort involved training personnel, assigning specific individuals to the project and having them meticulously collect manufacturing data, which was entered into KODA's centralized management system. This work allowed the team to establish a reliable inventory and reduce previously inflated equipment counts. The project was completed ahead of schedule and under budget, delivering both environmental and operational benefits.

Centralized Air Compressor Project

In parallel, KODA implemented a centralized air compressor project at a 182-well legacy site. As part of the initiative, KODA converted the site's natural gas pneumatics to nitrogen and air-driven systems by installing 2-inch surface polypipe throughout the facility. The project aims to effectively eliminate methane emissions from the upgraded infrastructure, including pneumatic components such as heat trace systems, methanol pumps, and chemical pumps. To support the sitewide conversion, KODA installed three air compressors – creating a scalable model for future emissions reductions across its operations. This effort will not only lower emissions and improve operational efficiency, but also can strengthen KODA's regulatory positioning by proactively addressing emissions ahead of potential compliance requirements.

By drawing on its established ESG expertise, KODA was able to integrate the Caerus assets efficiently, improve their environmental profile, and strengthen long-term operational value.

PNEUMATIC DEVICE COUNTS IN THE GREATER NATURAL BUTTES (GNB) FIELD
Number of pneumatic devices



KODA'S STRONG ESG TRACK RECORD

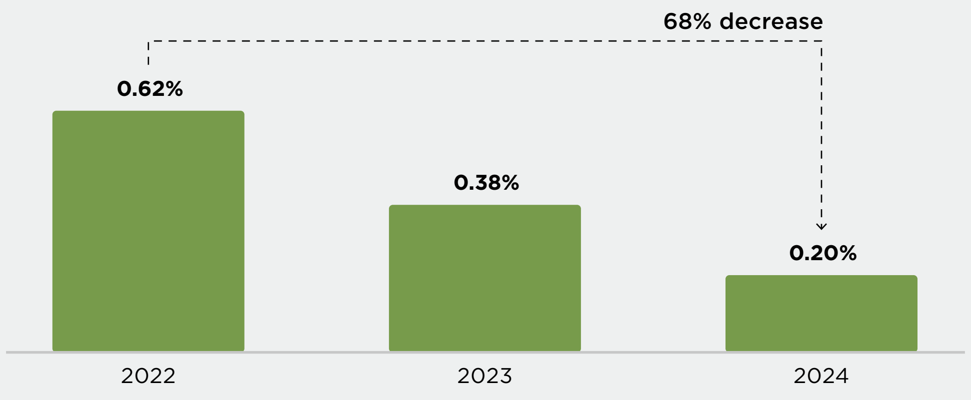
KODA's ability to deliver immediate ESG improvements at the Caerus assets reflects a broader history of disciplined execution across emissions management, water stewardship, and workforce safety. Since 2022, the company has steadily reduced its methane intensity, achieving a 68% decrease between 2022 and 2024, even while expanding production, adding new facilities, and carrying out rigorous drilling programs. This strong methane management foundation positioned KODA to act decisively on inherited emissions challenges at the newly acquired Caerus operations. Notably, KODA also eliminated flowback emissions through a two-year improvement effort, earning the 2022 Utah Petroleum Association Environmental Award.

Water stewardship remains a central pillar of KODA's ESG approach. In 2024, nearly 80% of the water sourced for operations came from non-freshwater sources, reducing pressure on scarce freshwater supplies. In Utah, KODA achieved a nearly 35% water recycling rate during fracking operations, creating a scalable model for future water conservation efforts. The company also piloted recycling programs in North Dakota, laying the groundwork for expansion in 2025 and beyond. By proactively mapping regional water scarcity risks, KODA aimed to ensure that its operations avoid the most sensitive areas, helping to manage long-term resource challenges.

Maintaining a strong safety culture is equally critical to KODA's performance. In 2024, across more than 1.85 million hours worked, the company recorded just seven recordable incidents and one lost-time injury, achieving a total recordable incident rate (TRIR) of 0.75. Through improved contractor engagement, robust safety training, and focused incident prevention initiatives, KODA reinforces its operational excellence while protecting its workforce.

These achievements highlight how KODA's ESG performance directly supports its operational and financial success. By reducing risk, strengthening asset resilience, and improving efficiency, we believe KODA has built a strong foundation that enables the company to capture growth opportunities and deliver long-term value for stakeholders.

KODA'S YEAR-OVER-YEAR METHANE INTENSITY
NGSI Methane Intensity (%)



CASE STUDY

Bison: Reducing Emissions to Meet State Regulatory Requirements

BISON OIL & GAS IV

PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Denver, Colorado	2022

Bison Oil & Gas operates in the DJ Basin of Colorado and Wyoming. Bison has operated in the DJ since 2015 and currently operates over 220,000 net acres, 500 wells, and 50,000 barrels of oil equivalent (BOE) of production per day – making it one of the largest private companies in the DJ Basin.

Beginning with 2024 reported emissions, Colorado is enforcing updates to Regulation 7 that establish annual intensity-based targets for both GHG and NOx emissions reported by oil and gas operators. These targets are tied to production volumes and scale more aggressively for "Majority Operators" – defined as those with over 50,000 kBOE of production for NOx intensity and greater than 10,000 kBOE for GHG intensity.

Through April 2024, Bison IV was classified as a Minority Operator for both NOx and GHG intensity, with a total production volume of just under 9,000 kBOE. Its estimated GHG intensity at the time was approximately 5.2 metric tons of CO_2e per kBOE (mtCO2e/kBOE), well below the applicable target of 34.39.

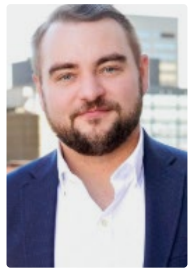
In May and September 2024, Bison IV acquired producing assets from Upland Exploration, Civitas, and CCRP. These bolt-on deals helped push Bison IV's production footprint above 10,000 kBOE, reclassifying the company as a Majority Operator for GHG intensity purposes. While it remained a Minority Operator for NOx intensity – exceeding its 2024 target by 42% – the reclassification required Bison IV to meet a significantly more aggressive GHG target of 10.94 mtCO2e/kBOE beginning with its 2025 calendar year emissions.

Given their remote locations and lack of access to utility power, the emissions intensity of the acquired assets posed a challenge. On average, these new assets operated at an intensity of roughly 93.8 $mtCO_2e$/kBOE – nearly nine times Bison IV's pre-acquisition profile.

Bison has a team of air specialists with deep expertise in identifying ways to reduce emissions. In early 2025, the Bison team began working through a detailed review of its proposed development schedule, facility design and emissions assumptions, and operating data. Key inputs, such as heater run-time, engine load, and equipment efficiency, were reassessed using vendor data and metered field readings to improve reporting accuracy and eliminate any inflated variables from the calculations.

At the same time, the company kicked-off several emission reduction initiatives, including: working with utility power companies on infrastructure expansion; outsourcing compression to midstream partners; implementing more top-down monitoring; developing a more measurement-informed emission inventory; shutting in marginal wells with high emissions, low production, and poor economics; and completing bulk separation upgrades. Each initiative was thoroughly evaluated for feasibility, cost-effectiveness, and projected impact on the company's overall intensity profile through 2030.

By taking early action to refine emissions data, prioritize reduction opportunities, and fine-tune the pace and timing of its development schedule, Bison IV's projected GHG intensity for 2025 is now below the 10.94 $mtCO_2e$/kBOE target. Moving forward, Bison IV plans to leverage its emissions management software Validere to monitor and manage its current and projected intensity.



"Our team has been part of every major rulemaking in Colorado over the past decade, and we strive to strike the appropriate balance that allows Colorado to excel in the most responsible oil and gas production in the world and allows bison to excel in Colorado."

Austin Akers
CEO OF BISON OIL & GAS

CASE STUDY

FireBird Energy: Reducing Flaring in the Permian Basin

FireBird Energy II LLC

PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Fort Worth, Texas	2023

FireBird Energy LLC is a Fort Worth, Texas-based upstream oil and gas company focused on the acquisition and responsible development of assets in the Midland Basin. With a strong long-term commitment from its ownership and an innovative and experienced management team in both its Fort Worth and Midland offices, FireBird is well positioned to pursue strategic acquisition opportunities and to develop its properties in a fiscally and socially responsible manner for the benefit of all stakeholders.

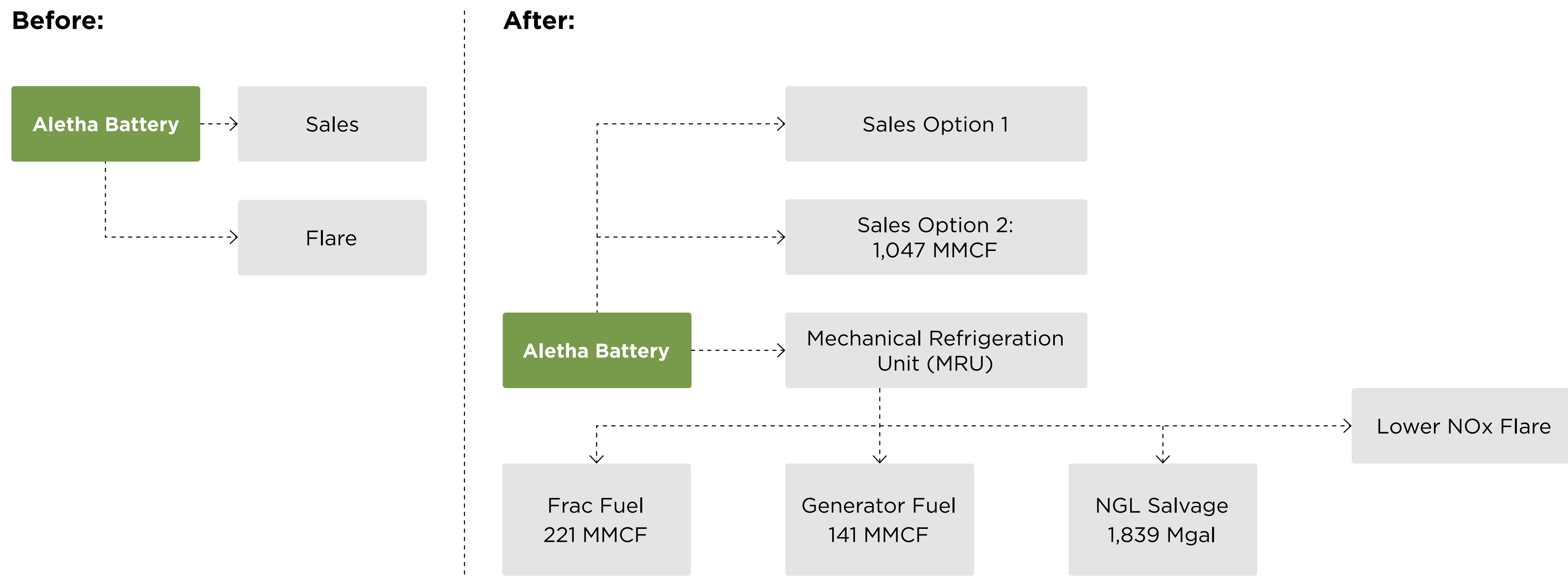
In November 2023, FireBird Energy acquired a sizable asset from Summit Petroleum, adding 16 new wells that were coming online just as FireBird was assuming operational control. However, gas and electrical infrastructure were undersized for the load demands and gas volumes associated with the new wells, creating an immediate challenge: how to meet production needs while reducing flaring.

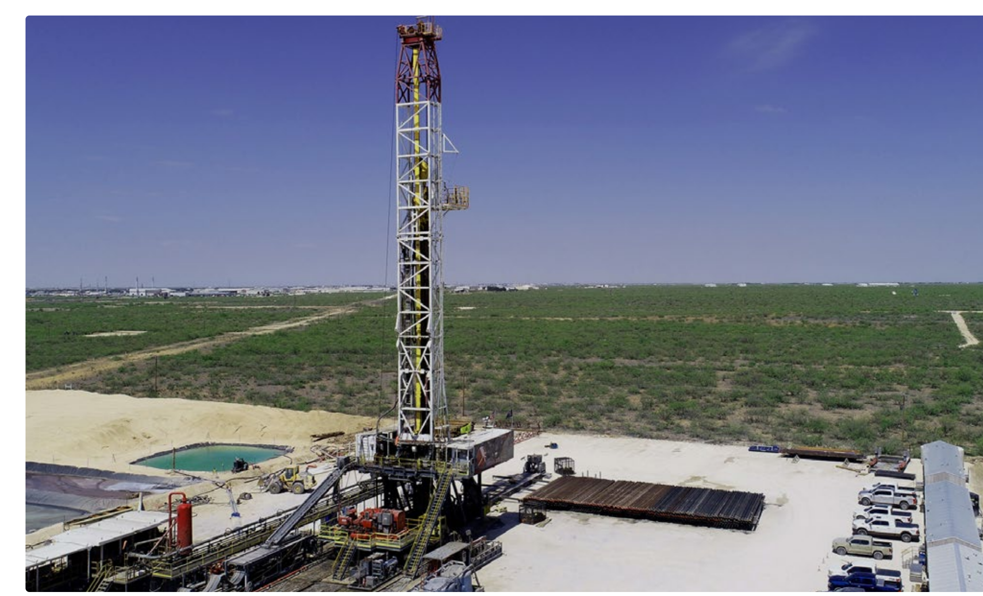
To address this, FireBird implemented a multi-pronged infrastructure upgrade. The team constructed overflow pipelines to secondary gas gatherers, deployed mechanical refrigeration units (MRUs) to strip natural gas liquids (NGLs) from the gas stream for use in reciprocating engines powering the grid and frac fleets, and captured gas that would have otherwise been flared – reducing the NOx emissions and making the Natural Gas Liquids (NGLs) commercially viable.

These efforts delivered both environmental and financial benefits. Flaring volumes were reduced by repurposing and rerouting gas, while infrastructure improvements enabled FireBird to utilize previously stranded gas as a local energy source. With the conditioned field gas, fewer thousands of cubic feet (MCF) were needed to displace the same amount of diesel in contrast to CNG and also eliminated the need for CNG trucking, further reducing emissions. Over $5.5 million in value was realized through redirected gas, access to secondary markets, reduced diesel and trucked CNG usage, and recovered NGLs.

Importantly, these upgrades enhanced FireBird's regulatory position in the Permian Basin, a region under increasing scrutiny for flaring rates and aerial monitoring by non-governmental organizations (NGOs) and the U.S. Environmental Protection Agency (EPA). By addressing both environmental impacts and operational efficiency, FireBird not only improved asset performance but also reinforced its long-term license to operate in a closely monitored, highly regulated region.

FireBird's upgraded system reduces NOx emissions, captures value from NGL sales, displaces diesel use, and enables the utilization of onsite field gas.





CASE STUDY

Quantum Acquires Cogentrix

PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Charlotte, North Carolina	2025

Cogentrix is a U.S.-based independent power producer (IPP) with end-to-end capabilities, managing 5.3 gigawatts (net) of gas-fired capacity. The company operates a diverse and well-maintained portfolio of 11 natural gas-fired power plants across the Mid-Atlantic PJM Interconnection, Electric Reliability Council of Texas (ERCOT), and ISO New England (ISO-NE) power markets.

In January 2025, an investor group led by Quantum Energy Partners acquired Cogentrix Energy for $3 billion. Cogentrix is a leading U.S. power generation company with a portfolio of 11 natural gas-fired plants located across three major power markets: PJM (Mid-Atlantic), ERCOT (Texas), and ISO-NE (New England). These regions represent some of the most active and important energy markets in the country. Together, these plants generated 22 terawatt-hours of electricity in 2024 – enough to power roughly 2 million U.S. households.[1]

A Diverse and Valuable Asset Base

Cogentrix's portfolio is structured to balance reliability and flexibility across a dynamic grid. Its assets fall into three key categories:

- Foundational Assets – Plants such as Liberty, Patriot, Altura, and Cedar Bayou 4 operate nearly year-round, providing steady baseload power and serving as the operational backbone of the portfolio.
- Dispatchable Assets – Facilities like Bridgeport and Newington are designed to ramp up during peak demand periods or when market conditions are favorable, delivering essential flexibility.
- Upside Assets – Sites including Lakewood and Rock Springs, while smaller or less efficient, offer valuable peaking capacity that supports grid stability when it is needed most.

This strategic mix enables Cogentrix to deliver consistent, reliable power while maintaining the optionality to adapt to evolving grid requirements, market shifts, and technological advances in the years ahead.

[1] Reflects IEA estimate of 10,791kWh/year for an average U.S. residential utility customer

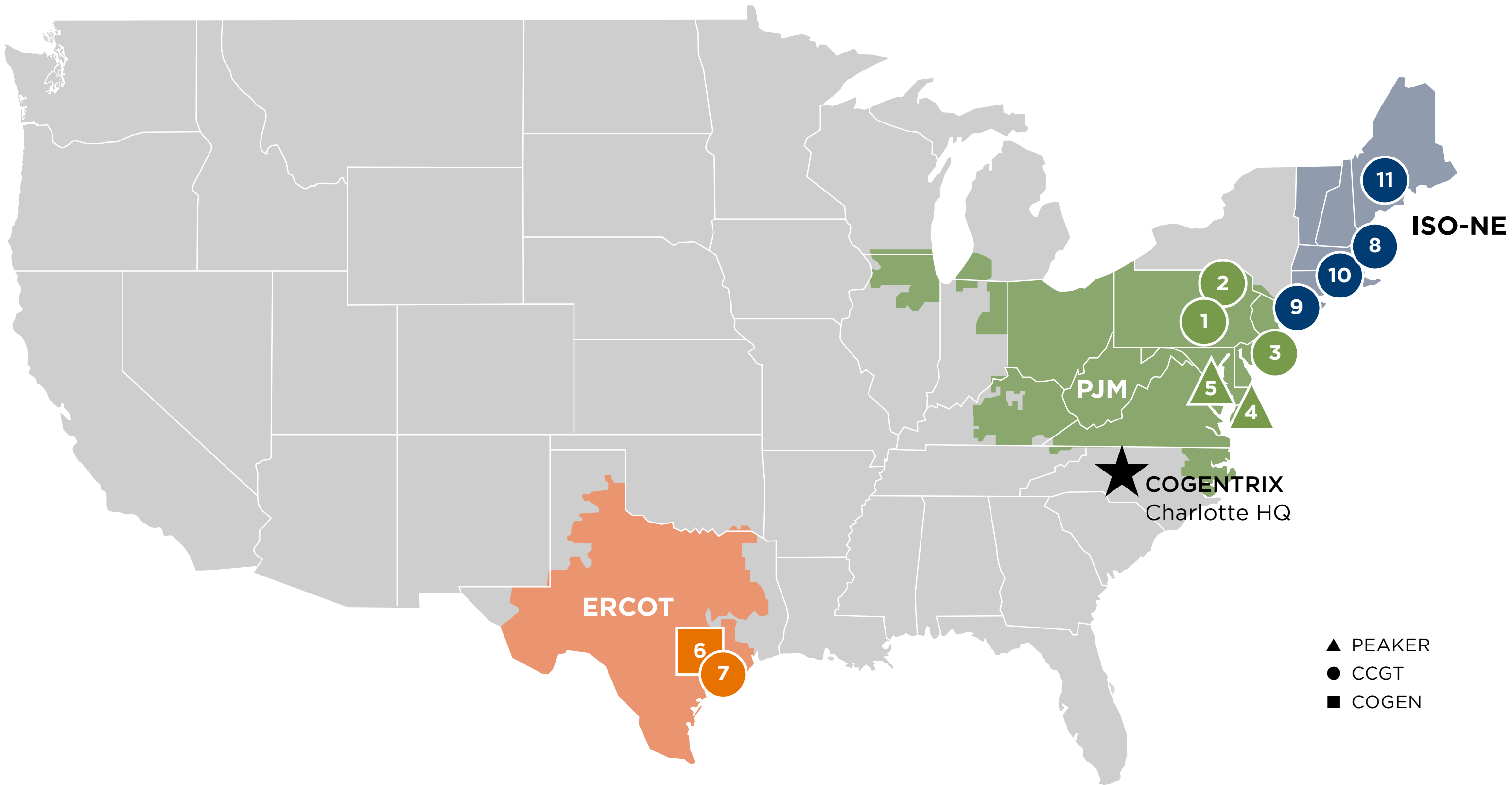
Why It Matters

Electricity demand in the U.S. is rising sharply, driven by the rapid expansion of data centers, the reshoring of domestic manufacturing, and the accelerating electrification of vehicles, homes, and businesses. Meanwhile, the challenges of developing new power infrastructure – from complex permitting processes to persistent supply chain bottlenecks – have made the value of existing, dispatch-ready generation capacity even more critical. In this constrained environment, Cogentrix's established fleet is uniquely positioned to help provide grid reliability, particularly during high-demand periods, while providing the scale and responsiveness needed to support the country's evolving energy needs.

Strategic Fit

Quantum views Cogentrix as a long-term growth platform that aligns squarely with its broader power sector strategy. With a combination of operational scale, geographic diversity, and a strong performance track record, Cogentrix offers multiple pathways for value creation – from upgrading and optimizing existing facilities to pursuing new development projects and expanding services for large-scale energy customers, including hyperscale data centers. This acquisition reinforces Quantum's commitment to building a robust, flexible, and resilient energy portfolio capable of meeting the demands of a fast-changing power landscape.

Cogentrix has 11 power plants across the mid-Atlantic, Texas, and New England



CASE STUDY

NetOn Power

neton POWER

PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Madrid, Spain	2022

NetOn Power focuses on self-consumption solar photovoltaic (PV) energy projects for commercial and industrial customers across southern Europe. The company currently serves a broad range of industries in Spain and Italy, including chemicals, pharmaceuticals, automotive, food processing, packaging, fashion, and plastics.

Industrial companies today face increasing pressure to manage energy costs, secure reliable power supply, and address regulatory and market risks in an increasingly volatile environment. NetOn Power provides practical, photovoltaic (PV)-based solutions to these challenges, delivering onsite clean energy through flexible, pay-as-you-go models anchored by Power Purchase Agreements (PPAs).

NetOn Power helps commercial and industrial clients generate renewable energy directly at their facilities, reducing dependence on external utilities and protecting against energy price volatility. By lowering energy procurement costs and minimizing exposure to regulatory shifts, self-consumption projects deliver immediate financial benefits. These onsite solutions also support companies' emissions reduction goals, creating direct value across both operational and strategic objectives.

NetOn's integrated PV-based offerings include:

- Ground-mounted and rooftop self-consumption solar PV systems
- PV-powered process electrification and industrial decarbonization
- Behind-the-meter battery storage to optimize energy use
- Onsite solar EV charging infrastructure
- Onsite hydrogen production capabilities

By combining leading clean energy technologies with simple, client-driven service models, NetOn Power aims to enable industrial companies to lower costs, manage risk, and build stronger, more future-ready operations.

How does NetOn Help Commercial & Industrial Clients?

1. **Analyze electricity consumption profile and design optimal PV solution**
   NetOn Power analyzes the client's consumption curve and energy needs. Its team of energy experts and engineers works with the client to design the most appropriate PV-based energy solution (plant size, surplus export, battery storage options, etc.).
2. **Identify and secure close-by land plots to develop dedicated PV solutions**
   NetOn begins by assessing the client's available surfaces, including rooftops and owned land. If existing space is insufficient, the company identifies adjacent suitable land plots and conducts a thorough analysis of their technical, regulatory, and economic feasibility. This is followed by negotiation and the securing of land rights.
3. **Develop, build and operate dedicated PV assets under local PPA**
   NetOn Power manages all subsequent phases of the project, including detailed engineering, permitting, construction, commissioning, asset management, and operations and maintenance (O&M) services. NetOn funds all necessary investments and bills the client based on actual energy consumption through an onsite PPA ranging from 10 to 28 years.

NetOn's clients include:

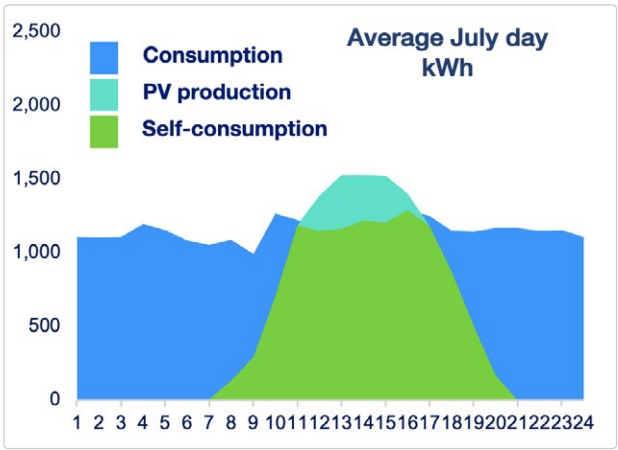
Attindas HYGIENE PARTNERS, MONBAKE, Acideka, trezeta, LECHE Pascual

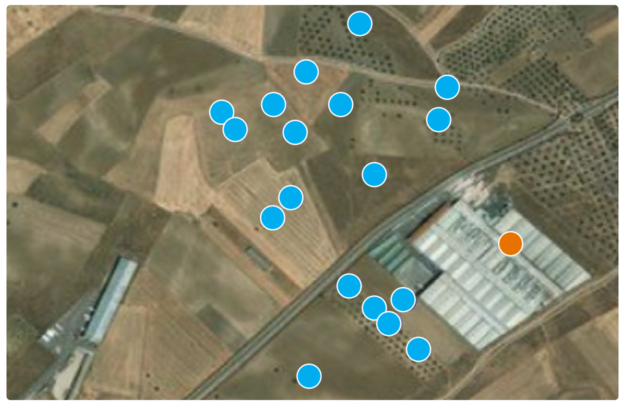
"NetOn's PV self-consumption solutions provide immediate and very significant cost savings to industrial companies, coupled with a substantial improvement of their sustainability performance. For many of our clients they represent a very relevant long-term competitive advantage in the markets where they operate."

Alberto Martin
CEO, NETON POWER

>1GW Projects pipeline	**90**MW Confirmed PPAs
>1,800 Ha Land reserved	**10**MW Plants operating or under construction
>400MW PPAs under negotiation	

As of the end of 2024.





SOLAR PANELS MANUFACTURING PLANT

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