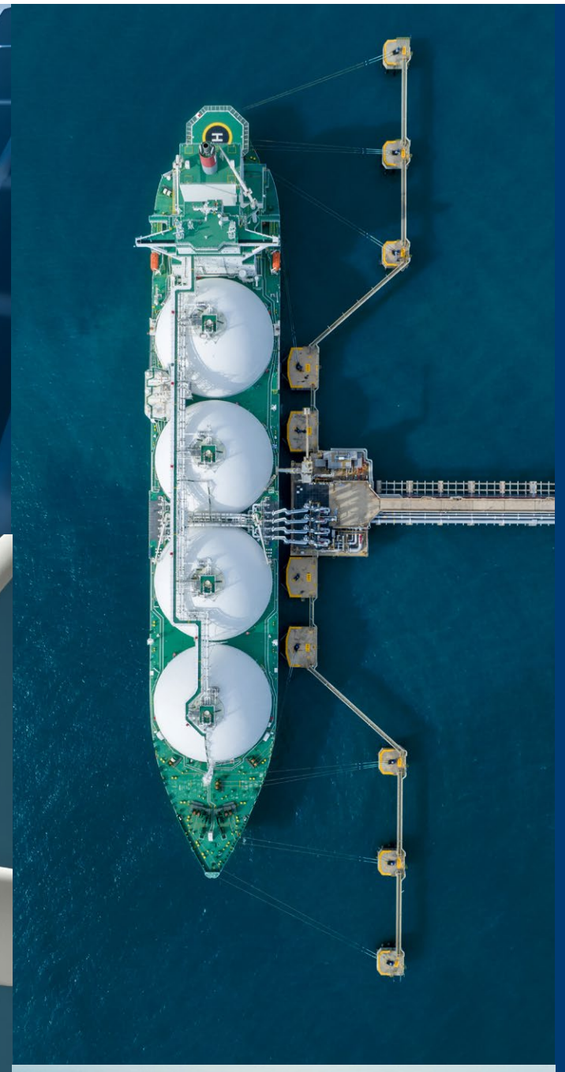


QUANTUM CAPITAL GROUP

Advancing the Global Energy Ecosystem

2024 Environmental, Social & Governance Report

Contents

Letter to Stakeholders

Dear Stakeholders,

As we reflect on another transformative year at Quantum Capital Group, our commitment to advancing the global energy ecosystem and delivering superior risk-adjusted returns remains unwavering. The global energy landscape continues to evolve at an unprecedented pace, driven by the world's incessant growth in energy demand, coupled with the need to provide energy that is affordable, reliable, abundant, and clean. In response, we have proactively adapted our strategies to not only align with these shifts but also to capitalize on the emerging opportunities they present. I am pleased to share the strides we have made in strengthening our position as a trusted financial partner in this dynamic industry, while striving to make a positive impact on the world around us.

Our focus on sustainability and the environment has been at the core of our business since our inception more than 26 years ago. Our investment philosophy remains anchored in the belief that integrating ESG considerations into our decision-making helps increase operational efficiencies and reduce costs, unlock new revenue streams, secure more attractive and flexible financing, mitigate regulatory risks, achieve higher valuations, and facilitate more successful exits. Ultimately, we believe integration not only drives value but solidifies our competitive advantage in the marketplace.

Evolving Dynamics of the Global Energy Landscape

The energy industry has long served as a catalyst for human progress. Affordable and reliable energy has driven advancements in healthcare, education, and infrastructure, improving quality of life and fostering socioeconomic progress. Yet, billions of people around the world still lack access to affordable, reliable energy, severely affecting their daily lives and economic opportunities.

Today, the energy industry stands at a critical juncture. The demand for affordable, reliable energy will continue to increase, driven by population growth, economic development, and the imperative to confront the global challenge of energy poverty. Simultaneously, we face the urgent need to reduce our environmental impact. Further exacerbating this complex challenge is the critical issue of American energy independence – recent geopolitical events have underscored its importance for strengthening national security, improving economic resilience, and mitigating the risks associated with global market volatility.

Therefore, we believe any shifts towards renewable energy must be coupled with efforts to build domestic supply chain capabilities. Historically, the U.S. has offshored key components of the energy transition, such as mining and processing essential minerals like copper, lithium, cobalt, and rare earths, necessary for producing wind turbines, solar panels, and lithium-ion batteries. China is the predominant beneficiary and today, it controls a substantial portion of the global market share in these sectors – thus China's influence in the energy transition industry far surpasses Saudi Arabia's influence in the oil industry.

For the U.S., Europe, and our allies to achieve energy security in a scenario where renewable energy dominates the energy mix, we must control our own supply chains. However, developing the necessary domestic capabilities will take decades, trillions of dollars, and a streamlined regulatory environment. This represents a significant opportunity to bring high-paying jobs back to the U.S., but it also poses a major economic and national security risk if not carefully planned on a bipartisan basis and then painstakingly executed with a long-term commitment to maintain the course by both Washington and the American people.

The Essential Role of Diverse Energy Sources

We maintain, as we have consistently emphasized, that hydrocarbons will continue to play a crucial role in the global energy landscape for decades to come. Currently, hydrocarbons provide about 77% of the world's energy, and even the most optimistic forecasts for renewable energy penetration suggest that hydrocarbons will continue to dominate the global energy mix through 2050. To put this in perspective, the highest market share achieved by any new energy source within its first fifty years of usage was coal, at 35%, and that was in the 1800's when global energy usage was very small compared to today. Meanwhile, wind and solar, despite significant investments, currently represent only about 4% of global market share after almost 15 years of installations at scale. In addition, when considering alternatives for decarbonizing energy, we all must recognize that every energy source has advantages and disadvantages that affect its affordability, sustainability, availability, scalability, and reliability.

These complex realities make it clear that any meaningful transition away from hydrocarbons will take decades and achieving a low-carbon economy is going to require all forms of energy, including hydrocarbons, renewable energy, and nuclear energy. That is why we are focused on highly attractive market opportunities across the entire energy value chain that have the potential for significant disruption, profitable growth, and the ability to deliver a meaningful reduction in greenhouse gases while enhancing the overall resiliency of our energy ecosystem. We believe we must continue to produce hydrocarbons in a way that is environmentally responsible and protects people and communities, while simultaneously investing in decarbonization, low-carbon energy sources, and technologies that can transform the energy landscape.

Quantum's Evolution and Looking Ahead

Looking ahead, we will seek to continue leveraging our competitive advantages and more than 26-year track record to provide the world with affordable, reliable, abundant, and cleaner energy, while aiming to generate strong returns for our investors. We are proud to have evolved from a firm focused solely on oil and gas to a diverse company focused on the entire energy value chain with four different investment strategies, including private equity, structured capital, direct lending, and venture capital. We believe this comprehensive approach to energy investing provides Quantum with a sustainable competitive advantage because of our differentiated insights and proprietary information. It also enables us to be a solutions provider, not just a source of capital, making us more relevant to all prospective clients with which we interact.

"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."

We believe the energy sector represents an exceptionally attractive investment opportunity, with our investment thesis for oil and natural gas more promising now than at any time since Quantum's inception. While we recognize the significant opportunities in the energy transition space, we also acknowledge the challenges, including supply chain disruptions, inflation, high interest rates, policy uncertainties, and substantial capital requirements. After a comprehensive assessment of various energy transition and decarbonization opportunities – including renewables, natural gas infrastructure, carbon capture and storage, hydrogen, distributed generation, and equipment and services – we have chosen to concentrate on clean energy infrastructure, technology, and decarbonization within this evolving sector.

We are proud to have expanded our presence in 2024 with the opening of a new Quantum office in New York. This strategic expansion increases our ability to hire talented professionals; provides us with better access to a larger network of potential clients, partners, and investors; enhances our ability to identify, evaluate, and secure more investment opportunities; and allows us to interact more frequently in person with our limited partners.

I am truly thankful for the opportunity to work with such a passionate and driven team every day. To everyone at Quantum and our portfolio companies, your dedication and creativity are unmatched. Your commitment to excellence, willingness to go above and beyond, and ability to constantly innovate have pushed our company forward and set new standards within the industry.

We are inspired by the trust that our investors – teachers, first responders, public servants, hospitals, institutions of higher learning, and many others – place in us. It is a profound responsibility to manage their capital, knowing that these resources are meant for their future income security and advancing the missions of their organizations. We remain committed to enhancing our contributions to the global energy ecosystem, striving to not only meet the current energy demands but do so in a way that is beneficial for all our stakeholders.

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.

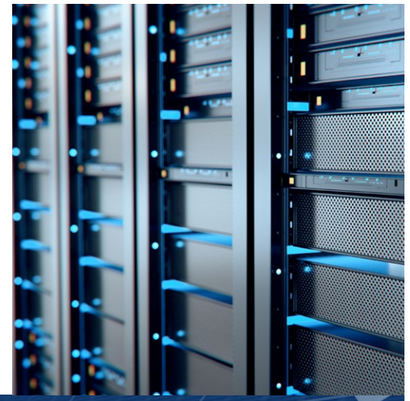
Values

Integrity

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

Humility

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

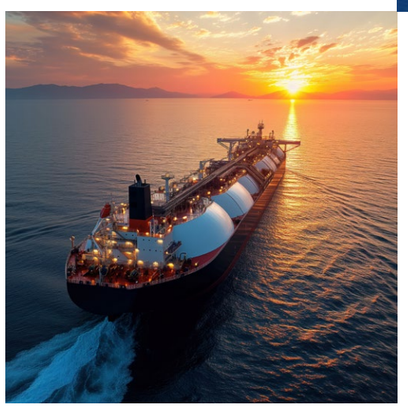


Excellence

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.

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 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 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.

Quantum Capital Group Opens Office in New York City

In 2024, we proudly expanded our presence by opening a new Quantum office in New York staffed with 13 full-time employees as of December 31, 2023. This strategic move boosts our capacity to recruit talented professionals and provides greater access to a broader network of potential clients, partners, and investors. It also enhances our ability to identify, evaluate, and secure more investment opportunities, while enabling more frequent in-person interactions with our limited partners.

$29B
Assets under management[1]

8
Flagship funds raised since 1998[1]

>150
Investments made

>700,000 Boe/d
Upstream production across all Quantum exploration and production portfolio companies[2][3]

~35 GW
Operating and development portfolio gigawatts of solar, wind, and battery storage[1]

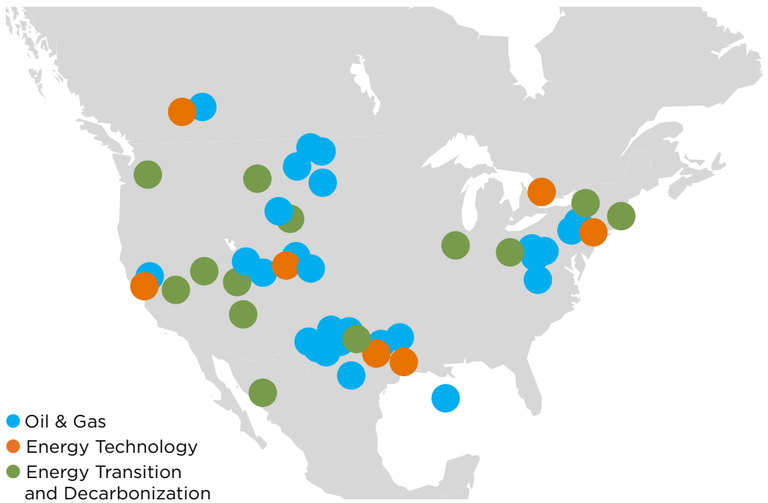
>1,000 wells
Drilling exposure per year

>10%
Quantum's exposure to total U.S. horizontal rig count[4]

[1] As of November 2024
[2] 2023 average oil and gas production over all Quantum funds
[3] As of December 31, 2023
[4] 2024 stats include rigs funded by both operated and non-operated equity and credit investments.

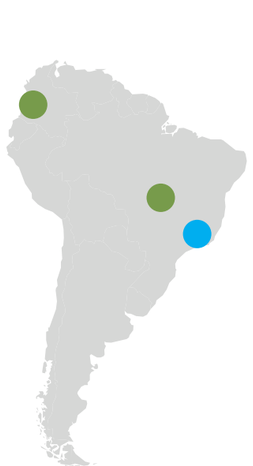
Our Geographic Footprint

North America



Europe

South America



Africa

Our Investment Strategies & Types

About Quantum Capital Group *continued*

Quantum has developed a suite of investment strategies 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 · Rio Oil and Gas II, LLC · KODA · White Rock Oil & Gas · seismos · FireBird Energy II LLC · Premium Oilfield Technologies · Dragos · Power Factors · Welligence Energy Analytics · HEQ Deepwater · Sentinel Peak Resources · Mexico Pacific · Project Canary · workrise

* Company logos displayed include majority owned and operated companies that submitted ESG data for the 2023 reporting year and does not include a complete list of Quantum's investments.

The E's of ESG: More Than Just Environment

About Quantum Capital Group *continued*

At Quantum, we believe that considering ESG metrics strengthens our ability to steward our investors' capital. Broadly, ESG refers to environmental, social, and governance risk factors and value creation opportunities. While attention is often focused on the "environmental" aspect, which we agree is crucial, we take a broader approach by focusing on what we call The Six E's.

The Six E's are a concise set of guiding principles drawn from Quantum's material ESG factors. For the complete list of these factors and details on how we apply them throughout each phase of the deal lifecycle, see the Integrated ESG Program section of this report.

"ESG is not only the right thing to do, but when done thoughtfully and practically, it improves business performance and value creation across the portfolio."

Garry Tanner, Partner, Quantum Capital Group

The Six E's

Quantum places The Six E's at the forefront of our firm and investments

Environment

We are focused on decarbonizing our operations, minimizing air pollutants, and being good stewards of the environment in which we operate.

Exceptional Governance

Governance is underpinned by our fiduciary responsibilities and strong emphasis on risk management, control, and transparency with our stakeholders.

Employees

Success in our investments depends on having the best people on our teams. A well-designed ESG program fosters collaboration, strengthens connectivity, and boosts employee morale and performance.

External Engagement

We engage in external collaborations to drive thought leadership, shape industry standards, and stay ahead of emerging trends, while fostering community involvement across all stakeholders we serve.

Economics

ESG initiatives can help portfolio companies reduce costs and create additional revenue opportunities.

Exits

Buyers are increasingly placing a focus on ESG and will prioritize assets which meet or enhance their ESG objectives.

Principles in Action

KODA and White Rock decreased methane emissions through pneumatic replacements.

Strong ESG oversight, thorough risk assessment, and active mitigation strategies provide high confidence in our due diligence and decision-making processes. This approach enables us to remain competitive, as demonstrated by the 2024 Caerus Oil and Gas acquisition.

At the firm level, we established Quantum Serves, a program that brings our employees together to serve the community.

Quantum's senior leadership has participated in over 20 events this year, made TV appearances, and been featured in prominent books and articles. Quantum also maintains a meaningful presence in the communities where we operate.

HG's electric frac fleet saved over $7.5M in diesel costs and reduced emissions by more than 8,500 metric tons.

Recent exits from Rockcliff, Tug Hill, XcL, and Tanos demonstrate that a strong ESG track record enables Quantum to achieve successful exits while capturing premium value.

Governance at Quantum

About Quantum Capital Group *continued*

At Quantum, our commitment to governance is rooted in a profound respect for the fiduciary responsibilities we carry. We recognize that our role as custodians of capital is not merely a duty but a privilege that demands diligence and integrity. Our governance practices are underpinned by a strong emphasis on risk management and control, and we strive to foster a culture of transparency.

Committees

Each committee at Quantum plays a critical role in our governance and operational framework. It is important to note that the list of committees below does not imply an order of importance or hierarchy; every committee contributes uniquely to the success and integrity of our organization.

COMMITTEES	RESPONSIBILITIES
Executive Committee	Oversees the organization, manages urgent matters, and shapes Quantum's policies and strategic direction.
Investment Committees One for each investment strategy	Establishes investment and risk management guidelines, makes investment decisions and monitors progress, advises and approves certain investment activities, and aligns decisions with each fund's strategic goals.
Valuation Committee	Reviews and approves the valuation of fund investments, including the inputs/variables used in determining the fair value of investments.
Audit Committee	Oversees financial reporting, ensures the integrity of financial statements, and monitors internal controls and compliance with regulatory standards.
Operating Committee	Manages and mitigates operational risks, ensuring that business processes, systems, and controls are effective, resilient, and aligned with Quantum's strategic objectives.
Conflicts and Investment Allocation Committee	Identifies and manages potential conflicts of interest and oversees the fair and transparent allocation of investment opportunities across Quantum.
Expense Allocation Committee	Oversees the proper distribution of expenses, ensuring that costs are fairly and transparently allocated in alignment with financial policies and objectives.
ESG Committee	Oversees the integration of ESG principles into investment strategies and operations. For additional information about our ESG Committee, see page 61.
Artificial Intelligence (AI) Committee	Guides the strategic implementation of AI technologies across operations and investments. Evaluates AI-driven investment opportunities, assesses risks associated with AI applications, and seeks to ensure that AI tools are used ethically and effectively to enhance decision-making and operational efficiency.

Key Policies, Guidelines, and Procedures

Our guiding policies and procedures support our commitment to operating with integrity and transparency. Key policies not included below are Quantum's Incident Response Plan, Disaster Recovery and Business Continuity Plan, and Third-Party Management Plan.

Employment Handbook
Annual review and compliance certification

- Purpose, vision, values
- Equal Employment Opportunity
- Non-Harassment (zero tolerance)
- Employee assistance program and benefits
- Open door policy (access to executives and senior management)

Compliance Policies and Procedures Manual
Annual compliance certification

- Code of Ethics
- Conflicts of interest, personal securities, insider trading, gifts and entertainment, outside business activities, political contributions
- Anti-money laundering, Foreign Corrupt Practices Act
- Portfolio management and allocation, proxy voting, valuations, safeguarding clients' assets, marketing, books, records

ESG Policy
Reviewed annually

- Engagement with portfolio companies on ESG matters
- ESG guiding principles for investments and operations
- Integration of ESG factors into investment decision-making processes

Reporting and Grievance Mechanisms
Reviewed annually

- Anonymous hotlink to report complaints and violations via third-party compliance system
- Defined process for investigating complaints, including escalation procedures

Our Differentiated Team

About Quantum Capital Group *continued*

Every member of our team is passionate about the global energy ecosystem and working with the entrepreneurs that drive its progress. We believe that it takes a true partnership mentality to build great companies, and we live that belief every day. As of July 2024, Quantum had:

128
total employees

11
senior advisors and operating partners

12
member investment committee for Quantum Energy Partners Fund

Multi-Disciplinary Team

We have fully integrated our investment, technical, and strategic shared services teams, allowing 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 ensure compliance, human capital management, and timely reporting to Quantum's limited partners

Quantum's Technical, Operating, Digital, and ESG DNA

Multidisciplinary investment, technical, and strategic shared services teams

In-house industry experts with operational capabilities

Culture of discipline, patience, and risk management

Enhanced decision making with machine learning and AI tools

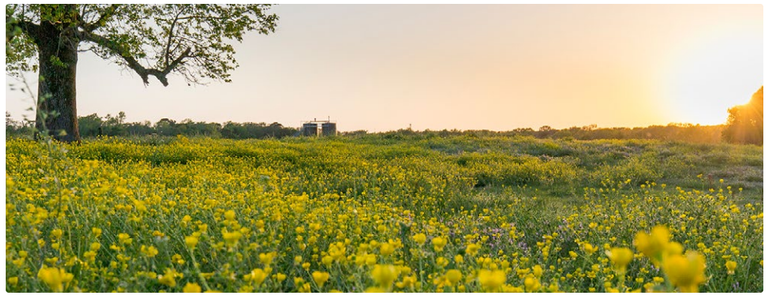
Commitment to ESG stewardship

New Quantum Operating Partner

Interview with Alan Smith, Quantum Operating Partner and Former CEO of Rockcliff Energy

Through these kinds of (ESG) initiatives at Rockcliff, it became clear that a strong ESG framework is not just about compliance – it is about creating value."

Alan Smith, Operating Partner,
Quantum Capital Group



About Alan Smith

Alan Smith recently rejoined Quantum as an Operating Partner, bringing a wealth of experience from his extensive career in the energy industry building and growing successful companies. He co-founded and led Rockcliff Energy, a Quantum portfolio company that was successfully sold to TG Natural Resources at the end of 2023. Before Rockcliff, Alan was the CEO of Quantum Resources Management and QR Energy. He also co-founded and served on the Board of Directors of Trace Midstream's Haynesville company and was the Chairman of Mesa Minerals.

Before that, Alan was a Managing Director at Quantum Energy Partners, where he worked closely with portfolio companies on strategy, operations, and growth. Earlier in his career, he founded and led Chalker Energy Partners.

You recently rejoined Quantum, bringing extensive experience as an operator and entrepreneur. Throughout your time creating, managing, and operating various energy companies, you have seen the role of ESG evolve. How do you perceive the role of ESG in creating value for companies in the energy sector?

In my experience at Rockcliff, ESG creates significant value when it is built on a strong culture of stewardship. At Rockcliff, we embedded ESG principles into the core of our operations, not just as a means of compliance but as a fundamental part of how we approached our responsibilities. We viewed ourselves as stewards of the assets we managed, with a duty to excel – not just for our investors, but for all stakeholders, including our employees and surrounding communities.

The core tenets we built our company on – safety, accountability, and integrity – were essential to our success. We prioritized transparency, encouraging our teams to report every incident, not just those required by regulation, so we could learn and improve continuously. We believe this proactive approach helped us manage risks effectively, enhance operational efficiency, and ultimately add value.

From an environmental perspective, Rockcliff significantly reduced emissions by adopting bi-fuel engines for drilling and completions activities, installing instrument air packages to power pneumatics, and constructing pipelines for flowback water. To tackle fugitive emissions, we implemented Project Canary to detect leaks, allowing us to capture and sell more gas. And once we achieved Project Canary TrustWell's highest level of certification, we attracted buyers willing to pay a differentiated price for our gas, which increased our revenue and more than paid for those investments.

Through these kinds of initiatives at Rockcliff, it became clear that a strong ESG framework is not just about compliance – it is about creating value. By prioritizing environmental responsibility and operational integrity, we were able to reduce costs, increase revenue, and build a reputation that resonated with both the market and our stakeholders. This approach showed that ESG can be a key element in driving growth and maximizing the potential of our assets.

In what ways can the insights gained from your experience at Rockcliff be applied to enhance Quantum's portfolio companies, particularly in integrating ESG principles throughout every stage of an investment?

The lessons we learned at Rockcliff can be incredibly valuable when applied to Quantum's portfolio companies. One of the key takeaways is the importance of embedding ESG principles from the very beginning of an investment. When you integrate environmental stewardship, social responsibility, and strong governance into the core strategy from day one, you set a solid foundation for long-term success.

Throughout the lifecycle of an investment, from inception to operation and eventually to exit, I believe ESG can drive significant value. Early on, it helps in identifying and mitigating risks, which can lead to smoother operations and fewer regulatory challenges. As the company grows, focusing on ESG can improve operational efficiency, reduce costs, and enhance the company's reputation. Finally, at the exit stage, a strong ESG track record can make the company more attractive to like-minded buyers and increase the company's market value, as more investors are looking for businesses that are profitable and operate responsibly.

Quantum Serves

About Quantum Capital Group *continued*

In 2023, we proudly launched Quantum Serves, an initiative aimed at fostering firm-wide collaboration and community engagement. Our community service days are designed to give back to our local communities while integrating our growing team. This year, 110 Quantum employees participated in three impactful days of service in partnership with local organizations. Through Quantum Serves, we strive to strengthen our bonds within the firm and make a meaningful difference in the communities we serve.

"Quantum Serves is dedicated to community engagement, which plays a vital role in building our team culture. By partnering with local organizations and volunteering, we not only give back but also foster stronger bonds among our team members. It is inspiring to see our employees come together for such meaningful causes, and I am proud of the positive impact we are making both within our organization and in the community."

Nichole Jaggers, Head of Human Capital Administration and HR, Quantum Capital Group

Urban Harvest

Urban Harvest is dedicated to building food security and resilience in our community. Forty of our employees participated in replanting garden beds for the children at MacGregor Elementary School, contributing to a healthier and more sustainable future for the next generation.

Houston Food Bank

The Houston Food Bank, the largest food bank in terms of distribution, leads hunger relief efforts across 18 southeast Texas counties. Thirty-one Quantum employees sorted and boxed 6,000 pounds of food, providing 5,000 meals to the community.

Trees for Houston

Trees for Houston is dedicated to growing, planting, and maintaining thousands of trees across the greater Houston region. Forty Quantum employees contributed to this mission by planting trees to provide shade for the playground and track at Fleming Middle School.

External Engagement & Thought Leadership

About Quantum Capital Group *continued*

At Quantum Capital Group, our CEO and other senior leaders actively engage in external collaborations to promote thought leadership. By participating in key industry conferences, leading panels on energy innovation, and working with global sustainability organizations, we share our expertise and drive forward-thinking solutions. These engagements also allow us to influence industry standards, foster partnerships, and stay ahead of emerging trends, reinforcing our commitment to sustainable energy practices and leadership in the sector.

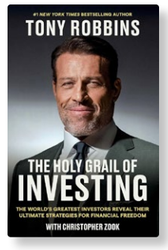
Open Minds

Established in 2018, OpenMinds brings together diverse experts to discuss and develop solutions to society's biggest challenges. Today, their mission is to accelerate progress against the Dual Climate and Energy Challenge. Initial objectives include decarbonizing power generation, expanding energy infrastructure, and enabling future leaders.

Through its NextGen program, Open Minds' is enabling future leaders by identifying, equipping, and connecting them with the expertise and resources they need to succeed. The 2024 NextGen cohort is composed of top graduate level and PhD university students with extensive prior experience and expertise across a wide variety of climate and energy topics. These individuals are working with sponsor companies on real-world projects, addressing key aspects of the Dual Challenge.

Keila Diamond, Quantum's Managing Director and Head of ESG, is sponsoring a NextGen project focused on methane abatement. The students are exploring the potential for small and mid-sized U.S. oil and gas operators to accelerate progress on reducing methane emissions over the next 5–10 years.

The Holy Grail of Investing



Wil VanLoh, CEO and founder of Quantum Capital Group, is featured in Tony Robbins' latest book, *The Holy Grail of Investing*. In the book, Wil shares insights into Quantum's distinct investment strategies and offers perspectives on the firm's success. He also discusses energy trends and provides personal anecdotes about his entrepreneurial journey.

Bloomberg Surveillance

Bloomberg Surveillance is a flagship financial news and analysis program broadcasted on Bloomberg Television and Bloomberg Radio. Hosted by experienced financial journalists, such as Tom Keene, Jonathan Ferro, and Lisa Abramowicz, the show features interviews and discussions with top economists, market strategists, policymakers, and industry leaders. In September 2024, Quantum CEO Wil VanLoh joined the panelists to discuss energy policy issues, including the challenges facing U.S. LNG, the shale revolution, and the broader implications for global energy markets. He also talked about ESG and renewable energy, highlighting the need for a balanced approach to the energy transition that blends conventional energy with advancements in renewables.

Carbon and ESG Strategies Conference, Hart Energy

At the August 2023 Hart Energy Carbon and ESG Strategies Conference, three leaders from Quantum Capital Group took the stage to share their expertise on navigating the energy transition and implementing carbon management strategies. The event covered critical topics such as carbon capture and storage (CCS), ESG initiatives, and emerging technologies in the energy sector. Quantum's participation included:

Rob Meister,
Managing Director

Discussed "Technology and Venture Capital," focusing on creating financial value and achieving superior performance during the energy transition.

Keila Diamond,
Managing Director & Head of ESG

Spoke on "The ESG Roadmap," outlining strategies for managing sustainability risks and capitalizing on opportunities.

Basak Kurtoglu,
Managing Director & Head of Technical

Shared lessons learned from early CCS projects and their applications in the energy industry.

Other Notable External Speaking Engagements

Throughout 2023 and 2024, Quantum personnel actively engaged with the investment community, with representatives from the Finance, Technical, Digital, and ESG teams speaking at events across the country. Since our previous report was published, Quantum employees have spoken at many conferences, including:

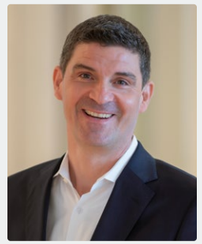
- Women's Private Equity Summit
- 24th WPC Conference
- Financing U.S. Power Conference
- U.S. Power, Renewables & Energy Transition Finance
- Houston Energy Leadership Series
- Evolve Conference
- REEF Wall Street Conference
- Carbon Tracking and Reporting Conference
- 12th Private Equity New York Forum
- Kayo Women's Infrastructure Summit
- Energy Capital Assembly
- WEN Conference
- Super Dug
- Petroleum Alliance Annual Meeting

SPOTLIGHT

Engaging with the Quantum Community on AI

We believe that, when executed effectively, digital transformations can systemically improve decision-making and elevate a company to the forefront of algorithmic innovation."

Sebastian Gass, Chief Technology Officer, Quantum Capital Group



Digital technologies provide competitive advantages for energy companies

Over the past five years, many of today's leading energy and investment companies have prioritized digital transformation as a key corporate initiative. At Quantum, we believe that technology-driven transformation creates a significant performance divide, establishing a competitive advantage for those who embrace digital innovation.

We believe that, when executed effectively, digital transformations can systematically improve decision-making and elevate a company to the forefront of algorithmic innovation. Algorithmic decision-making emphasizes system thinking with a focus on asking the right questions, utilizing comprehensive data sets, and analyzing data through multiple models for more informed outcomes. Studies have shown that this approach has the potential to transition enterprises from relying on point estimations to solving problems through uncertainty ranges.

This shift can result in significant business benefits, including:

Operational Cost Savings: McKinsey[1] estimates that data science has the potential to reduce operational costs by 10–30% in unconventional oil and gas operations, based on a study of assets that came online between 2010 and 2019.

Increased Return on Investment: We believe successful data science projects focused on drilling, completion, production optimization, and sub-surface intelligence have the potential to deliver returns that are several multiples higher.

Enhanced Transaction Frequency and Returns: In 2020, SourceScrub and Pitchbook analyzed 389 firms and found that digitally mature firms engage in transactions 3.5 times more frequently and generate internal rates of return that are 8.8 percentage points higher than less digitally advanced firms.[2]

The transformative power of AI and data at Quantum

At Quantum, leveraging data for informed decision-making has long been part of our core philosophy. Over the past four years, we have advanced this commitment through a comprehensive digital transformation aimed at enhancing our decision-making and risk analysis processes. By focusing on four key areas, we have identified opportunities to significantly elevate our business performance.

Enhanced Contextual Understanding

By transitioning from Excel-based analysis to algorithmic and AI-based models, we have significantly improved our ability to analyze complex energy systems. This shift helps us manage hundreds of thousands of variables in AI models, compared to thousands in Excel.

Cost-Effective Questioning through Automation

At Quantum, we believe that those who ask the most questions often find the best answers. However, questioning can be time-consuming and costly. By automating our back-office operations and integrating systems across the firm, we have significantly reduced the time associates spend answering questions. Immediate insights are now accessible through automated dashboards and analytics engines.

Minimized Bias through Comprehensive Private Data Sets

We have integrated third-party, internal, and private data into a unified industrial data set, securely accessible across the organization through data catalog technology. Through this approach, we aim to democratize data access and ensure that the most up-to-date and unbiased data is consistently used for analysis across the firm.

Multi-Model Paradigm for Interdisciplinary Expertise and Diverse Perspectives

We strive to leverage multiple models, often from different methodologies or perspectives, to solve problems or make predictions. This allows us to enhance collective intelligence, reduce potential biases, and increase the accuracy of our decision-making processes.

References:

[1] August 2020: McKinsey & Company Digital transformation in energy: Achieving escape velocity
[2] SourceScrub, 2021: Why 78% of digital transformation initiatives fail and what to do about it

Any estimates, expectations, or projections are provided for informational purposes only and are not necessarily indicative, or a guarantee, of future results. Please see the Disclaimers at the end of this report for important additional information regarding AI considerations in our investment practices.

SPOTLIGHT

Engaging with the Quantum Community on AI *continued*

Quantum's digital capabilities

As part of our digital transformation initiative, we developed a robust, cloud-based digital platform to automate the infrastructure of both Quantum and our portfolio companies. This platform, known as the Quantum Energy Cloud (QEC), was created in collaboration with Microsoft and Databricks. It aims to establish foundational cyber resiliency, build a world-class private data estate, automate business processes, and deploy systemic AI capabilities across the entire portfolio.

The QEC acts as our central nervous system by integrating Quantum's curated data lake, which consolidates and structures external, private, and derived data for in-depth analysis. Covering 10% of public and private wells in the U.S. and 99% of public wells in the U.S. as of May 2024, this comprehensive data set enables business development, portfolio management, back-office operations, and investor relations to work from a unified, high-quality foundation.

The QEC enhances our ability to consume and interpret data, while continuously ingesting new industry and private data. We believe our AI-driven tools, built on top of this data set, enable us to process and analyze critical industry information at an unprecedented scale. Quantum's investment models leverage this toolset to improve speed, accuracy, insights, conviction, and overall probability of success. With these capabilities, we hope to identify opportunities and deals before they hit the market, accelerate deal screening, and effectively manage existing investments through various economic cycles.

Digital solutions for our portfolio companies

As of May 2024, approximately 70% of Quantum's investments were already leveraging the QEC, creating standardized cybersecurity controls, data architectures, and AI accelerators across the Quantum portfolio. This seamless integration enables us and our portfolio companies to share data, applications, and AI models efficiently, creating a cost-effective shared services model. Many portfolio companies have adopted one or more of over 100 available AI accelerators in their cloud environments, delivering tangible business value. Additionally, Quantum has introduced a private Generative AI tool called Quantum IQ, which allows us and our portfolio companies to interact with both public and private data sets, democratizing access to our private data set. An AI working group has been established to facilitate mutual learning, push the boundaries of AI usage in energy, and implement best-in-class models.

Educational initiatives and community engagement

Many case studies are detailed in Quantum's Data Science Handbook, which serves as a guide for introducing data science capabilities to traditional and energy transition enterprises. Quantum also provides educational services to our limited partners. For example, in January 2024, Quantum hosted a workshop with Caz Investment at Houston's Minute Maid Park to educate investors on the power of Generative AI. By sharing AI advancements with the broader community, Quantum aims to promote responsibly-sourced production.

Looking ahead

Quantum is highly optimistic about the future and remains dedicated to continually advancing the use of our private data set. Looking back on our 26-year history, we have seen multiple iterations of a virtuous cycle, where each round improves our contextual understanding, increases automation, expands our data sets, and enhances our ability to solve problems with diverse models. This, in turn, elevates the quality of our decisions and strengthens our risk assessment processes.

Navigating these cycles is challenging, but Quantum has built the framework and expertise to make data-driven analysis second nature to our operations. We believe that this organizational resilience, combined with the transformative potential of AI, will continue to set us apart in the decade ahead.

Case Studies

KODA

One of Quantum's portfolio companies, Koda, develops and operates oil and natural gas assets in the U.S., supplying natural gas to West Coast markets. The company faced challenges expanding its drilling due to manual data collection processes that hindered the analytics needed to optimize performance. To address this, Quantum collaborated with Koda to integrate data from private wells and public sources, creating an automated, modern data foundation. This integration enabled advanced drilling analytics and improved applications, resulting in better performance and significant cost savings.

BISON OIL & GAS IV

Another Quantum portfolio company, Bison, needed a detailed analysis of completion designs for analog wells, incorporating completion variables, historical production data, and forecasts. Quantum collaborated with Bison to create a data pipeline that integrated multiple data sources and developed an automated data visualization workflow. This enabled Bison to identify optimal completion designs and create a production analytics dashboard. Quantum also established workflows to automate daily production performance reports for management. As a result, Bison improved production outcomes, reduced costs, and streamlined data management processes.

Global Energy Perspective

Inside this section:

This Global Energy Perspectives section reflects Quantum's beliefs, opinions, and assessments with respect to the topics discussed herein, unless otherwise cited.

PART 1

The Dual Challenge

The Dual Energy & Climate Challenge

We must adopt a new framework

Despite massive global attention over the last 25 years, efforts to solve the Dual Challenge – providing affordable, reliable energy to meet rising energy demand while simultaneously reducing emissions that contribute to climate change – have fallen short. To date, we have neither eliminated energy poverty nor reduced annual emissions.

Today, there is a polarized debate with some calling for an urgent "energy transition" away from hydrocarbons in favor of renewable energy to reduce emissions and combat climate change, while others stress only the benefits of energy access for human development and the growing demand for energy, which can only be supplied by an energy mix that includes a significant amount of hydrocarbons. At Quantum, we believe both emission reduction and access to energy are critical and must be achieved simultaneously.

Energy powers our modern world and access to it has improved the human condition measurably over the last 100 years. However, approximately 77% of the energy used today comes from hydrocarbons, which produce greenhouse gas emissions, a contributing factor to climate change. Unchecked, climate change could have negative impacts on our world and way of life.

This is called the Dual Energy and Climate Challenge (Dual Challenge): how to meet the increasing demand for energy while simultaneously reducing emissions and mitigating climate change.

Current efforts to solve the Dual Challenge are not working. To limit warming to 1.5–2.0°C, the Intergovernmental Panel on Climate Change (IPCC) calls for a reduction of over 90% of current emissions by 2050. Yet, since the Kyoto Protocol was introduced in 1997, global annual emissions have risen by 29%,[1] with developing countries significantly increasing their emissions and offsetting modest reductions by many developed economies. Also during this period, despite world energy supply increasing by 55%, billions of people remain in energy poverty without access to reliable, affordable energy. This has occurred despite trillions of dollars invested in renewable energy, government incentives, and significant political attention worldwide.

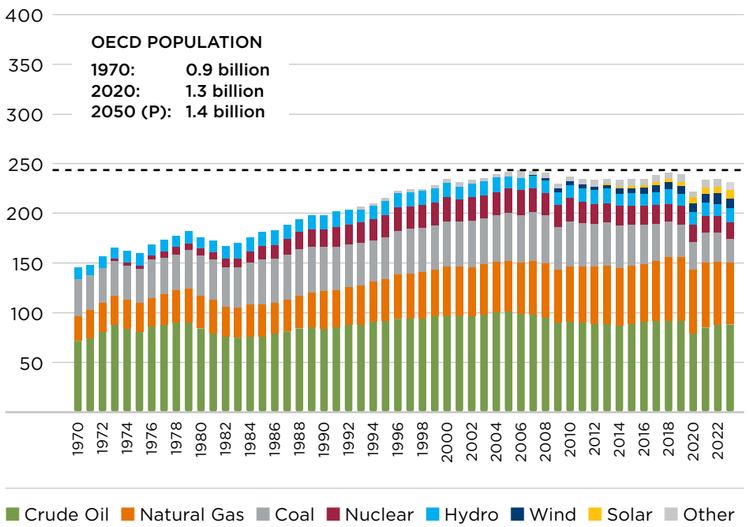
Today, approximately 1 billion people, primarily in Organization for Economic Co-operation and Development (OECD) countries, enjoy the privileges of affordable, abundant, and reliable energy. These countries have relatively stable populations, robust and efficient economies, and levelized energy consumption. In addition, they have invested in reducing emissions and have been modestly successfully in doing so over the last 25 years. In contrast, non-OECD countries, which represent the other approximately 7 billion people in the world, have expanding populations, are striving to improve their living standards, and are experiencing an increasing demand for energy, which is accompanied by a notable rise in emissions.

"The current approach to solving the Dual Energy and Climate Challenge is not working. Solutions exist today that can materially decrease emissions and reduce energy poverty. By globally adopting a new framework focused on energy addition and decarbonization, we can meet these goals. We are committed to leading and advancing this new paradigm."

Garry Tanner, Partner, Quantum Capital Group

Energy demand of OECD population[1]

EJ



Energy demand of non-OECD population[1]

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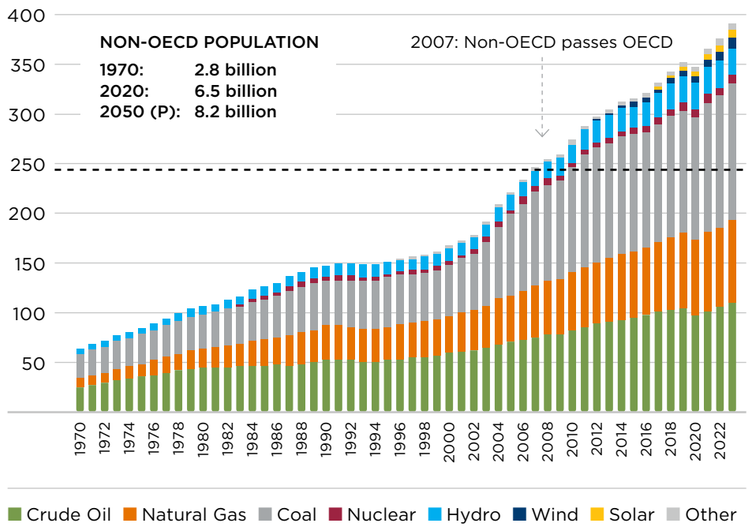
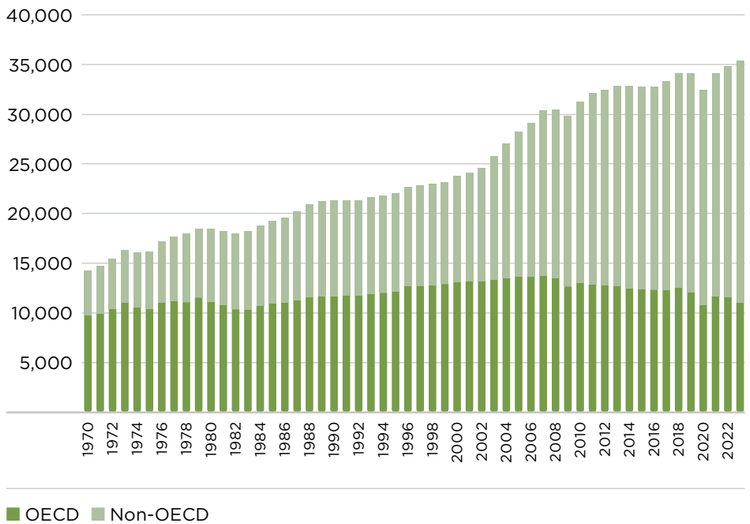


Annual anthropogenic global CO_2e emissions[2]

Million tonnes CO_2



References:

[1] Medlock, Kenneth, III, PhD. Exploring Energy Value Chains. Keynote presentation, Annual Energy Summit, Baker Institute, October 1, 2024. Data compiled from the EI Statistical Review of World Energy, 2024.

[2] The carbon emissions above reflect only those through consumption of oil, gas, and coal for combustion-related activities, and are based on 'Default CO_2 Emissions Factors for Combustion' listed by the IPCC in its Guidelines for National Greenhouse Gas Inventories (2006). This does not include any carbon that is sequestered, other sources of carbon emissions, or emissions of other greenhouse gases.

The Dual Energy & Climate Challenge

A new framework is needed to help solve the Dual Challenge

The lack of progress in solving the Dual Challenge appears to stem from several key misconceptions that have resulted in costly, ineffective solutions, which fail to address the root causes despite decades of effort and trillions of dollars spent. A new framework is needed to enable better decision-making and drive meaningful progress in solving the Dual Challenge.

In this report, we highlight key considerations around both energy and climate change. Addressing both challenges concurrently is key, yet many stakeholders are focused on one without fully addressing the other. In this report, we will look at examples of successful and unsuccessful approaches to help underscore the perspectives driving some seemingly ineffective "solutions."

Additionally, we will explore evolving technologies aimed at addressing the Dual Challenge and consider a realistic timeline for energy additions and new technologies, emphasizing practical solutions that can make an impact in the near term while other "solutions" advance over a longer timeframe. We will also examine how focusing on local solutions can sometimes limit understanding of the broader global impacts. Often, solutions that seem effective locally may exacerbate the Dual Challenge on a global scale. With only one atmosphere, exporting emissions to another region does not allow us to achieve a net reduction in global emissions.

When considering Dual Challenge solutions, we identify seven key perspectives outlined below that could reframe priorities and capital allocations, and ultimately lead to meaningful progress in supplying the world the energy it needs in a way that reduces emissions and mitigates the effects of climate change.

Quantum has been investing in energy for over 26 years and brings a balanced perspective as an energy expert across all energy verticals. We recognize the need to reduce emissions and mitigate climate change, while ensuring the world's energy needs are met. By fully understanding energy, climate change, historical failures and successes, and the realities of science, economics, execution, and politics, we believe a new framework can help overcome biases and lead to more effective global solutions, both today and in the future.

Through this new framework, we hope the public, governments, and decision-makers worldwide will gain deeper insights into the complexities of energy and climate change, better understand the interrelationship between these two critical challenges, and be inspired to support more practical and effective solutions to the Dual Challenge than those currently being pursued. This Global Energy Perspectives section reflects Quantum's beliefs, opinions, and assessments with respect to the topics discussed herein, unless otherwise cited.

Old framework for solving the Dual Challenge

Expect a rapid energy transition that quickly replaces existing energy sources without appreciating the historically long timelines – often measured in decades – required for prior energy additions, and the inability to phase out existing energy sources.
Prioritize either climate goals or energy needs in isolation, focusing on one at the expense of the other, rather than balancing both aspects of the Dual Challenge.
Focus on local actions to reduce emissions without considering capital efficiency or the broader, global implications and unintended consequences of these actions.
Frame climate change as a challenge that justifies limitless spending, calling for immediate, high-cost interventions without evaluating cost-effectiveness.
Use narrow or misleading measures of energy efficiency (such as Levelized Cost of Energy) that do not account for the full lifecycle cost of energy, like on-stream time, backup power for interruptible sources, disposal, and other factors that can lead to incorrect conclusions.
Adopt a "one size fits all" approach that ignores the need for customized solutions tailored to the specific needs of individual regions and localities.
Expect meaningful solutions without fundamental education and understanding. Significant misinformation exists and arguments on both sides have been politicized.

New framework for solving the Dual Challenge

Reframe "energy transition" to "energy addition and decarbonization," understanding that energy transitions historically take time and do not fully replace existing forms of energy.
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.
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 ground work for actions that contribute positively on a global scale.
Focus on efficient, scalable carbon abatement strategies, recognizing that resources are limited. Consider the most economical approaches to reduce emissions and meet energy demand.
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.
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.
Prioritize education and leadership to drive a timely and effective approach, recognizing energy and climate change solutions are complex topics requiring strong leadership and a deep, fact-based understanding of technology, economics, and behavioral science.

PART 2

Why Energy Matters

Energy Drives the Modern World & Human Prosperity

There is a measurable link between energy access and prosperity

Energy is the essential ingredient that drives our modern world. It is the industry that drives every other industry, creating a measurable link between energy access and human development. Since the dawn of the industrial revolution, access to more abundant and reliable energy sources has created a golden era of human progress and prosperity, leading to increased life expectancy, greater quality of life, and unprecedented economic growth.

Energy is the ability to do work. It drives all human activity and can be categorized into five basic functions: making things (cement, steel, plastics), powering things (electricity), growing things (plants and animals), transportation (planes, trucks, cargo ships), and heating, cooling, and refrigeration. Energy can be measured in a variety of ways but the most common are watt hours or British thermal units (BTUs). A watt is a unit of power per second. A BTU is a measure of heat, which is a form of energy. The world uses approximately 175,000 terawatt hours of power per year, or roughly 620,000 trillion BTUs. These are enormous numbers that are difficult to comprehend.

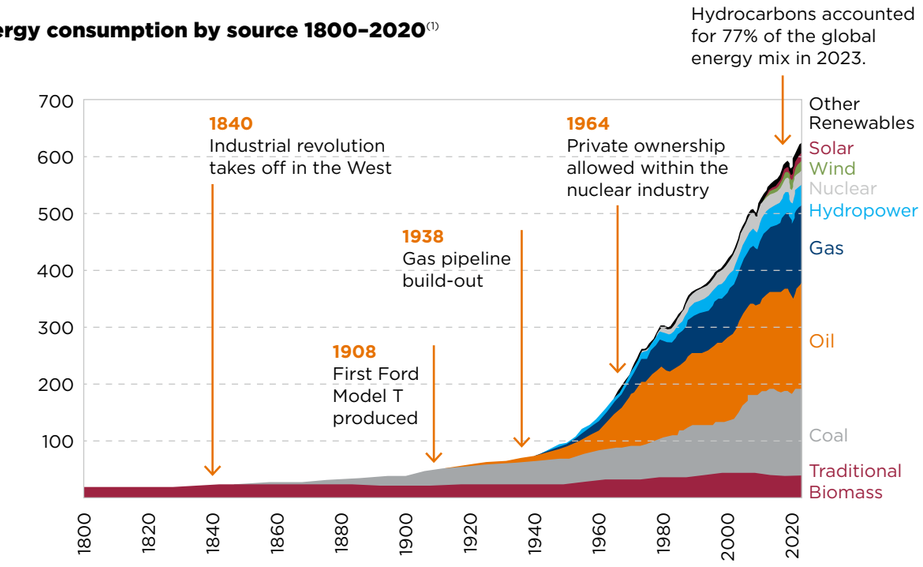
Energy comes in many forms, and over the years, new forms of energy have been developed. Prior to the industrial revolution, energy primarily came from biomass and animal and human labor. The industrial revolution was ushered in by the development of coal, followed by oil and natural gas, collectively known as hydrocarbons. This was later supplemented by nuclear energy and renewable sources like solar, wind, and hydropower.

Today, producing electricity accounts for approximately 47% of total global energy use. While wind and solar have grown over the last 20 years, they still represent a small proportion of the total energy mix, accounting for 3.5% and 2.5%, respectively. Hydrocarbons remain dominant, comprising 62% of power generation, 98.5% of all non-electric energy, and nearly 80% of total global energy use.

With the increase in energy sources and usage, the world's population, prosperity, and overall human condition have flourished. Since the development of hydrocarbons in the 19th century, the global population has quadrupled from 1.6 billion to almost 8 billion people, global life expectancy has more than doubled from 32 years to over 72 years, and global gross domestic product (GDP) has skyrocketed from negligible levels to over $80 trillion dollars on an inflation-adjusted amount. The United Nations Human Development Index (HDI), which is a proxy for the human condition, combines life expectancy at birth, years of education, and per capita gross national production. There is a strong correlation between energy consumption and the HDI scores: countries in the developed world generally have higher HDI scores and higher energy use, while those in the developing world tend to have lower HDI scores and lower energy usage.

Global primary energy consumption by source 1800–2020[1]

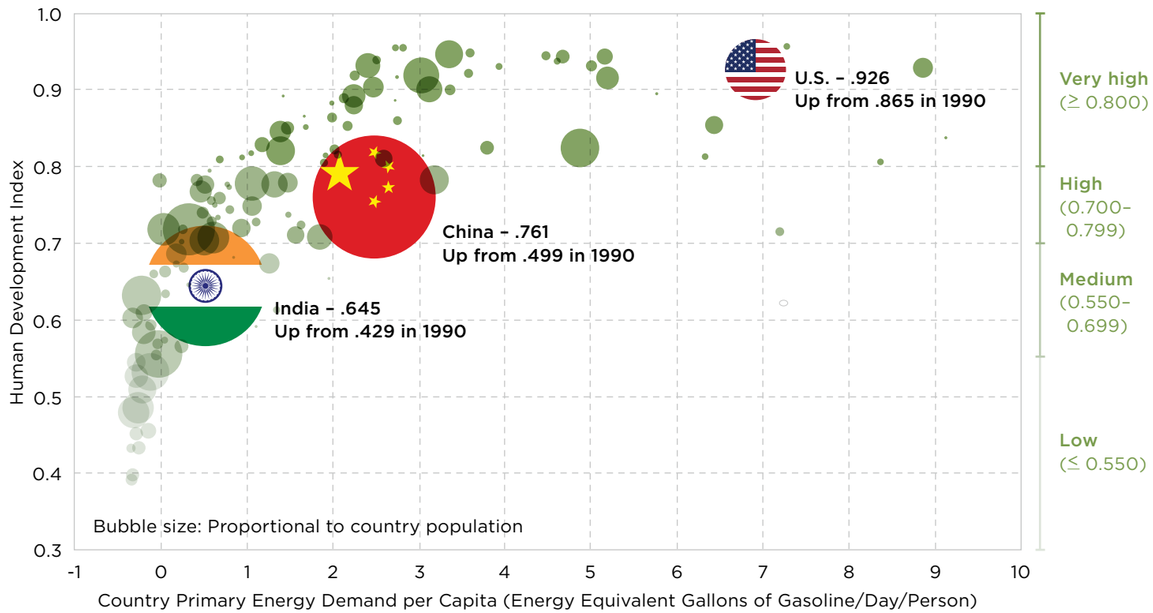
QBtu



Before 1800
Prior to the industrial revolution, humans mainly relied on biomass for heat and muscles for kinetic energy, and life expectancy was relatively short and not improving.

	1800	1820	1840	1860	1880	1900	1920	1940	1960	1980	2000	2020
Population (billion)	1.0	1.1	1.2	1.3	1.4	1.6	1.9	2.3	3.0	4.4	6.1	7.8
Life Expectancy (years)	28.5	29.0	29.0	29.3	29.7	32.0	34.5	42.0	50.1	61.2	66.3	72.6

Access to affordable energy is essential for human development improvement[2]



References:

[1] Vaclav Smil (2017), BP Statistical Review of World Energy via Our World in Data
[2] U.S. Energy Information Administration (EIA) International Energy Outlook (2021)

Energy Poverty Results from a Lack of Energy Access

It is a critical problem that needs to be solved

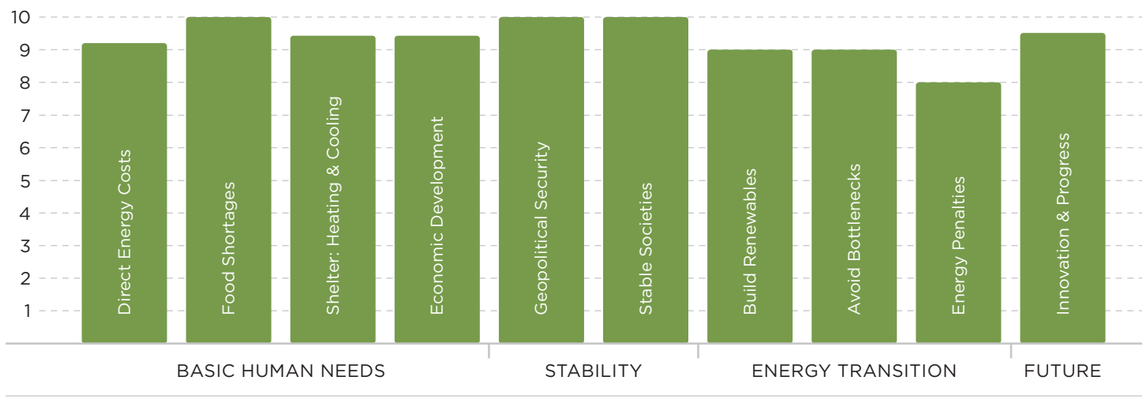
Energy poverty is the lack of access to affordable and reliable energy. Without access to energy, quality of life and life expectancy decreases. Energy poverty is a critical issue today, contributing to millions of premature deaths each year. Energy shortages drive higher energy costs, affecting basic human needs like food, shelter, and economic development; threaten geopolitical stability; hinder the development of new forms of energy; and stifle future innovation as resources are consumed by higher energy costs.

Only about 1 billion people in the world enjoy the benefits of an energy rich, advanced society, while the other 7 billion people are working to move up the economic ladder. As of 2020, approximately 750 million people still lacked access to electricity, and 2.4 billion people relied on traditional biofuels, such as wood, dung, and charcoal, for heating and cooking. The World Health Organization (WHO) estimates that over three million premature deaths occur each year due to the indoor use of these traditional biofuels. A lack of energy access also affects water and food supplies, transportation, and economic development. Almost 6 billion people in the world live on under $10 per day due to a lack of economic development, which is linked to energy access, as highlighted by the Swedish public health doctor Hans Rosling in his book *Factfulness*.

According to a recent study by Thunder Said Energy, an energy-focused research institute, there are 10 reasons to prioritize an energy surplus. These include meeting basic human needs, maintaining societal stability, funding the energy transition, and supporting future innovation and progress.

Basic needs, such as food, shelter, cooking, and economic development, are directly impacted by energy costs. Managing and reducing these costs is essential for improving quality of life. Low-income societies use about 4.5 barrels of oil equivalent per person per year, while high-income societies use 35 barrels – almost eight times as much. Economic prosperity is impossible without access to energy.

Ten reasons for prioritizing global energy surplus[1]
Importance (out of 10)

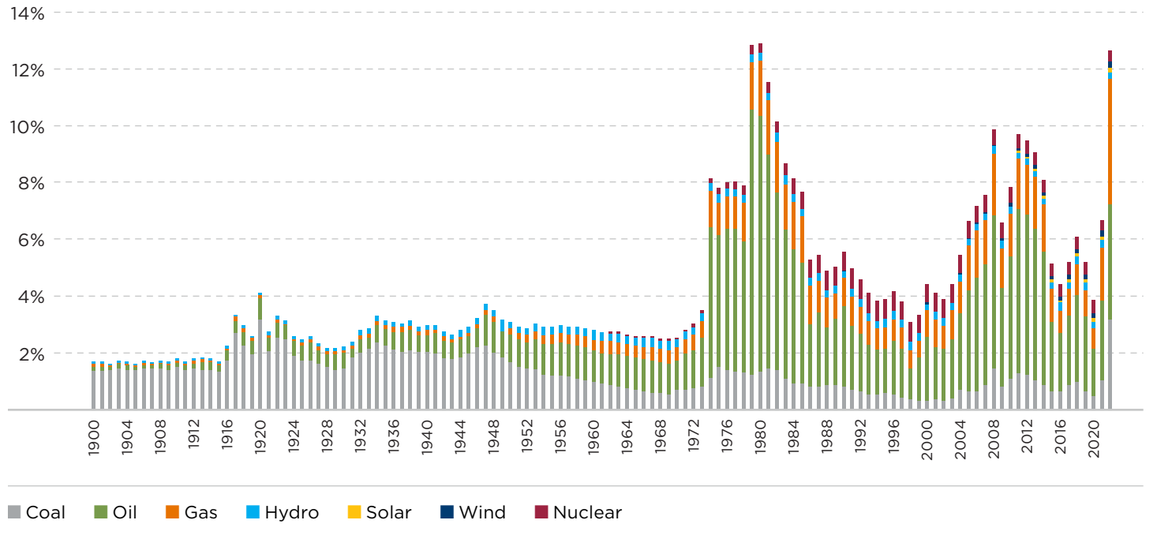


History has also shown that energy shortages can lead to geopolitical instability, revolutions, and wars. The pain and suffering associated with high energy prices can trigger these negative events. For example, the Arab oil embargoes of the early and late 1970s caused major disruptions, as a significant portion of global GDP was allocated to primary energy costs.

How will we finance the massive capital required to drive the development of new energy sources if our basic energy costs continue to increase? Developing wind, solar, and the infrastructure to transport and maintain these energy sources represents one of the largest capital mobilization efforts in history. This is in addition to developing other new forms of energy, CCS, biofuels, hydrogen, and next generation nuclear.

We are currently underinvesting in global energy supplies due to reduced investment in traditional oil, natural gas, and coal, while spending significantly on the energy addition. Thunder Said Energy estimates that global energy was undersupplied by around 2% in 2022, with the shortfall expected to escalate to about 10% by 2030. Historically, at the start of the industrial revolution in 1900, primary energy costs absorbed 4% of global GDP, while in 2022, energy costs accounted for 13% of global GDP. As energy shortages grow, global energy costs could increase to more than 14% of global GDP, leaving less to invest in other needs. With an average abatement cost of $40 per ton of CO_2, offsetting the average American's annual carbon footprint of 20 tons would cost approximately $800 per person. This expense will be increasingly difficult to finance if the average American is already spending incremental funds to pay for their energy needs.

Primary energy costs could continue rising[1]
As percent of GDP



Reference:

[1] Thunder Said Energy

Energy Demand Likely to Continue Growing for Foreseeable Future

Driven by population growth and economic development

Energy demand is expected to continue growing for the foreseeable future, driven by population growth and economic development. While stable populations and increasing energy efficiency have limited energy demand growth in the developed world, the developing world is experiencing both population growth and economic expansion, driving a significant increase in energy demand.

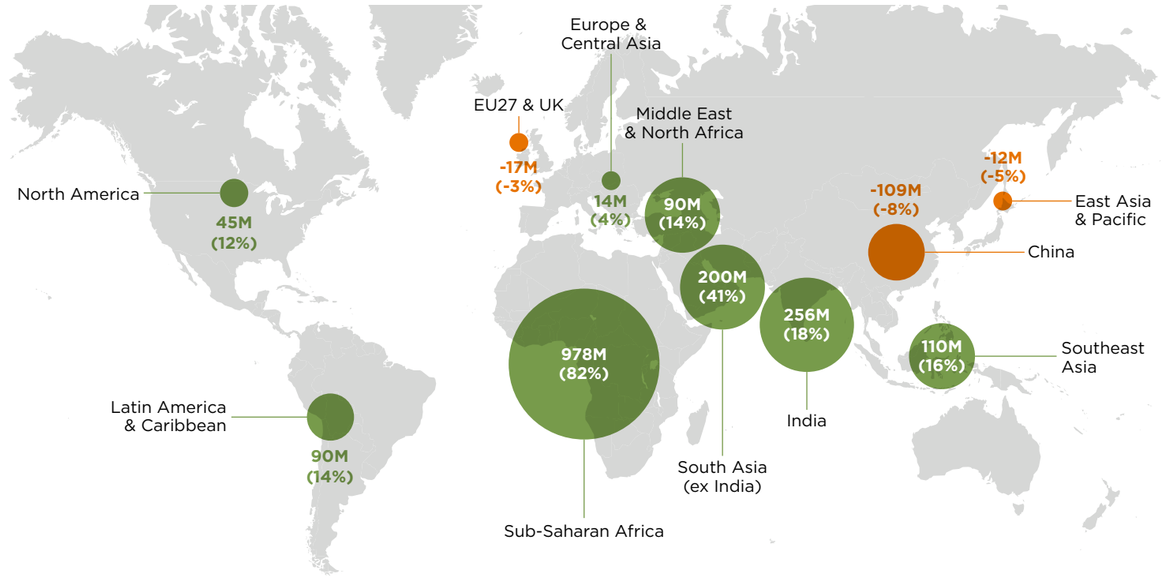
In most developed countries, population growth has stabilized and improvements in energy efficiency have reduced per capita energy consumption. However, developing nations are experiencing both population growth and substantial increases in energy demand. The United Nations estimates that the global population will increase to nearly 10 billion by 2050, with much of this growth occurring in regions like sub-Saharan Africa. These same developing regions with growing populations are also experiencing the most economic growth, which leads to higher energy consumption per capita, as previously discussed.

As economic development progresses in these regions, billions of people currently with limited energy access are expected to improve their living standards and gain access to more reliable energy sources. For example, the EIA estimates that by 2050, more than 1.1 billion people will transition from low-income to middle-income status, leading to a projected 135% increase in energy consumption. Additionally, when people move from middle-income to high-income status, their energy consumption is expected to increase by another 225%. While advancements in energy efficiency will help mitigate some of this energy demand, these improvements are unlikely to fully offset the rising energy consumption in the developing world.

Although energy demand forecasts vary, given historical growth trajectories, expected population and economic growth forecasts, and the strong correlation between these factors and energy demand, it is difficult to envision a future where energy demand does not continue to increase significantly. The EIA and the International Energy Agency (IEA) currently have several energy demand forecasts, all of which indicate increasing energy demand over time. Recently, energy demand forecasts have increased further as advancements in AI and the rapid growth in data centers are expected to add exponentially to future energy needs. However, the full extent of this increase is difficult to predict, as this macrotrend is still in its early stages.

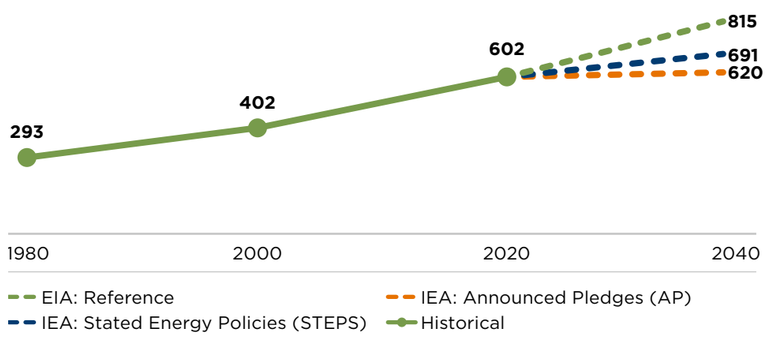
Projected population growth by region[1]

Population growth will be overwhelmingly concentrated in regions with lower energy consumption today



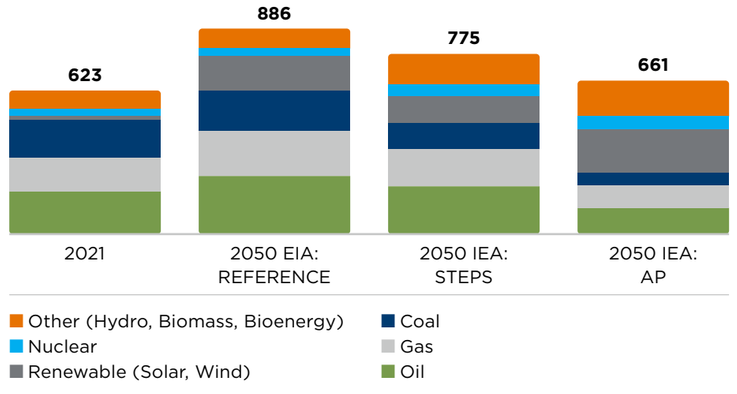
Global energy consumption forecast[2]

QBtu



Global energy consumption mix forecast[2]

QBtu



References:

[1] UN, World Population Prospects 2022 (medium fertility variant), BP Statistical Review of World Energy, 2022; World Bank; EIA; Bain & Company analysis
[2] EIA International Energy Outlook 2021, IEA 2022 Stated Policies Scenario (STEPS), IEA 2022 Announced Pledges Scenario (AP), Resources For the Future

Energy Sources & Optimal Energy Selection

Many critical factors shape the selected energy solutions

Energy comes in many different forms, each with unique attributes that determine its suitability to meet a region's specific energy needs. Several critical factors shape local decisions about which energy source to prioritize, including overall energy needs, economic conditions, access to technology, energy security, and political and economic stability, among others. Ultimately, the optimal energy mix for each region is determined by its unique characteristics and circumstances.

Key energy attributes include availability, cost-effectiveness, reliability, energy density, social acceptance, and emissions intensity. These factors guide local decisions about which energy sources to develop and utilize. These decisions vary across different markets. For example, solar and wind energy are renewable, affordable, and socially accepted, but they are intermittent and cannot be easily transported over long distances. As a result, they are most effective in regions where lower emissions are a priority, production is reliable, and energy demand is concentrated near the source, such as in the U.S., Europe, and China.

On the other hand, hydrocarbons such as oil and natural gas, which are dense, reliable, and easily transported, are prioritized in regions where energy demand is high, infrastructure is well-established, and renewables are less reliable or available, such as in many other parts of the world. Hydropower is most effective in areas with large river systems and many of the world's major rivers have already been dammed to capture this energy potential and convert it into power. Geothermal energy thrives in geologically active regions like Iceland but is relatively limited elsewhere. Coal is pervasive, with significant use in China and India, where reserves are vast.

Energy selection criteria and the various regional perspectives must also be considered when working to solve the Dual Challenge. By acknowledging and integrating these diverse factors, we can develop tailored strategies by region that address both energy needs and climate goals effectively.

Energy source attributes[1]

SOURCE	ABUNDANT?	AFFORDABLE?	RELIABLE?	ENERGY DENSITY?	TRANSPORTABILITY?	SOCIAL ACCEPTANCE?	EMISSIONS INTENSITY?
Why is this important?	The world needs a lot of energy. Abundant, readily available sources are key to meeting growing demands.	Affordability ensures people have access to energy regardless of their economic status.	Reliable sources can be trusted to continue providing energy despite weather conditions.	Because the world needs more energy, density – the amount of energy that can be contained in a given space – is important. More energy in smaller volumes is ideal.	Energy needs to be easily available to people who need it – whether in rural places, or big cities.	People want to understand where their energy comes from, and feel safe and confident consuming it without negative consequences.	To combat climate change, the world must decrease emissions. Energy sources with lower emissions intensities are ideal.
Solar/Wind	🟢	🟠	🔴	🔴	🔴	🟢	🟢
Hydropower	🔴	🟠	🟢	🟠	🔴	🟢	🟢
Biomass	🔴	🟠	🟠	🔴	🔴	🟢	🔴
Nuclear	🟠	🟠	🟢	🟢	🟠	🔴	🟢
Gas	🟢	🟢	🟢	🟢	🟢	🟠	🟠
Oil	🟢	🟢	🟢	🟢	🟢	🔴	🔴
Coal	🟢	🟢	🟢	🟢	🟢	🔴	🔴

Reference:

[1] Quantum internal analysis

Energy Security Matters

It drives bespoke solutions as countries seek to control their own energy futures

Energy security refers to a country's ability to control its own energy resources, which are vital to national security and economic prosperity. Any effective solution to the Dual Challenge must consider each region's energy security needs to gain acceptance, especially in the current world of rising global tensions and regional conflicts. Traditionally, countries rely on the energy sources most abundant within their borders and supplement them with secure energy imports from abroad. We expect this approach to continue in the future.

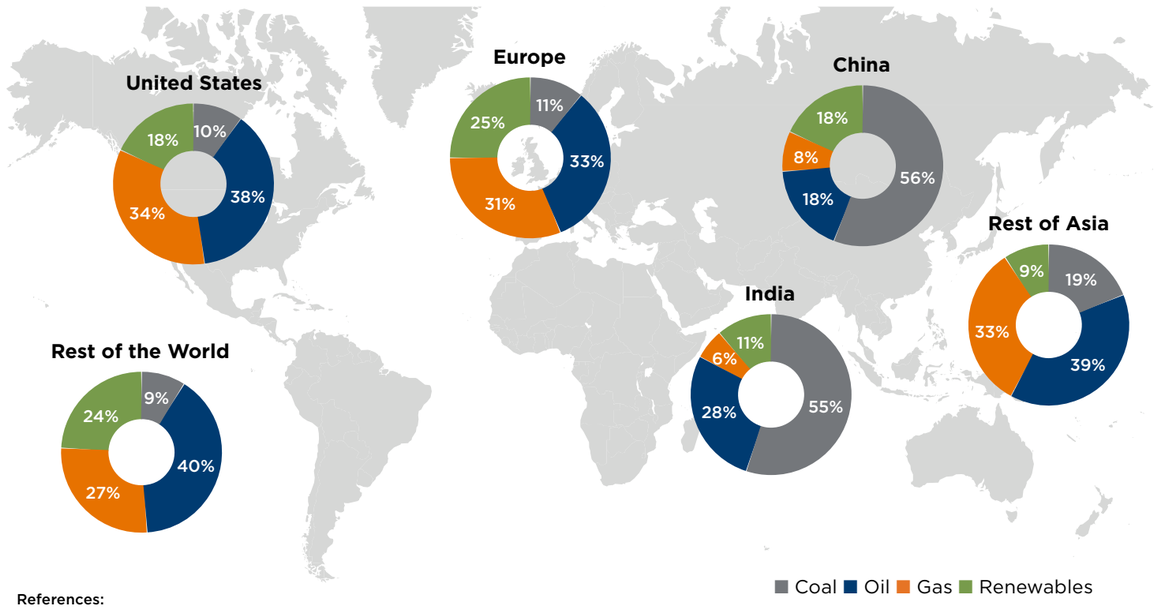
The issue of energy security was brought to the forefront during the Russian invasion of Ukraine and the subsequent embargo on Russian natural gas, which caused energy prices to spike in Europe and around the world. These events heightened concerns about energy security, leading many nations, particularly in Europe, to prioritize diversification efforts over addressing global emissions and other issues. Without the benefits of the U.S. shale boom over the last 15 years, solutions to global energy issues and the negotiating power of energy producers would have significantly impacted global geopolitics.

The U.S. shale boom started in 2007 with natural gas and expanded to oil around 2010. Since then, U.S. natural gas production has more than doubled, from about 50 billion cubic feet (Bcf) per day to over 100 Bcf per day, while oil production has grown from about 5 million barrels per day to approximately 13 million barrels per day – making the U.S. the world's largest oil and gas producer, surpassing Saudi Arabia and Russia. This surge in U.S. production has helped meet global energy needs, with the U.S. producing some of the cleanest and most socially responsible hydrocarbons in the world.

Today, numerous geopolitical hotspots pose risks to global energy security, including the Russian invasion of Ukraine; escalating tensions in the Middle East; growing issues between China, Taiwan, and the Philippines; and potential instability in Africa and South America. Approximately 23% of global oil supply is produced in regions with ongoing or high-potential conflicts, and around 18% of global oil supply transits through two strategic straits bordered by countries directly or indirectly associated with terrorism. Energy security remains a critical factor that must be considered when solving the Dual Challenge.

Globally, countries primarily rely on domestic or regional energy resources. For example, China and India, with their vast coal reserves, depend on coal for about 55% of their growing energy needs, contributing significantly to regional emissions. The U.S. and Europe, on the other hand, draw over 50% of their energy from oil and natural gas, supported by substantial natural gas reserves and access to LNG. In much of the rest of the world, oil constitutes about 40% of the energy mix, favored for its ease of transport and global availability. These factors are also essential when considering solutions for the Dual Challenge.

Percent of 2022 energy consumption by source[1]



Global hotspots drive supply uncertainties and price volatility[2]

1: RUSSIA/UKRAINE	
Production (Mbpd)	10,620
Percent of Global Supply	10.4%
Consumption (Mbpd)	3,782

2: RED SEA	
Trade Flows (Mbpd)	~3,300
Percent of Global Supply	3.2%

3: IRAN	
Production (Mbpd)	3,250
Percent of Global Supply	3.2%
Consumption (Mbpd)	1,912

STRAIGHT OF HORMUZ	
Production (Mbpd)	~15,200
Percent of Global Supply	14.9%

4: VENEZUELA/GUYANA	
Trade Flows (Mbpd)	1,440
Percent of Global Supply	1.4%
Consumption (Mbpd)	268

5: WEST AFRICA	
Production (Mbpd)[1]	3,800
Percent of Global Supply	3.7%
Consumption (Mbpd)	1,114

6: CHINA/TAIWAN	
Trade Flows (Mbpd)	5,290
Percent of Global Supply	5.2%
Consumption (Mbpd)	15,498

References:

(1) Our World in Data, Primary energy consumption by source (2022); Energy Institute Statistical Review of World Energy (2023)
(2) Current production and estimated trade volumes per EIA and Goldman Sachs; consumption as of 2022 per the Energy Institute. OPEC country production statistics excludes condensate production. Includes production from the countries highlighted orange as well as OPEC member nations in West Africa

Energy Transitions/Additions Take Decades, Not Years

No transition/addition has resulted in the elimination or reduction of prior forms of energy

Since the beginning of the industrial revolution, the world has undergone a continual process of energy transitions – or energy additions, as we like to call them – since no transition has eliminated or even reduced prior forms of energy. Additionally, it takes decades for new forms of energy to gain market acceptance and for the necessary infrastructure to be developed to support widespread adoption.

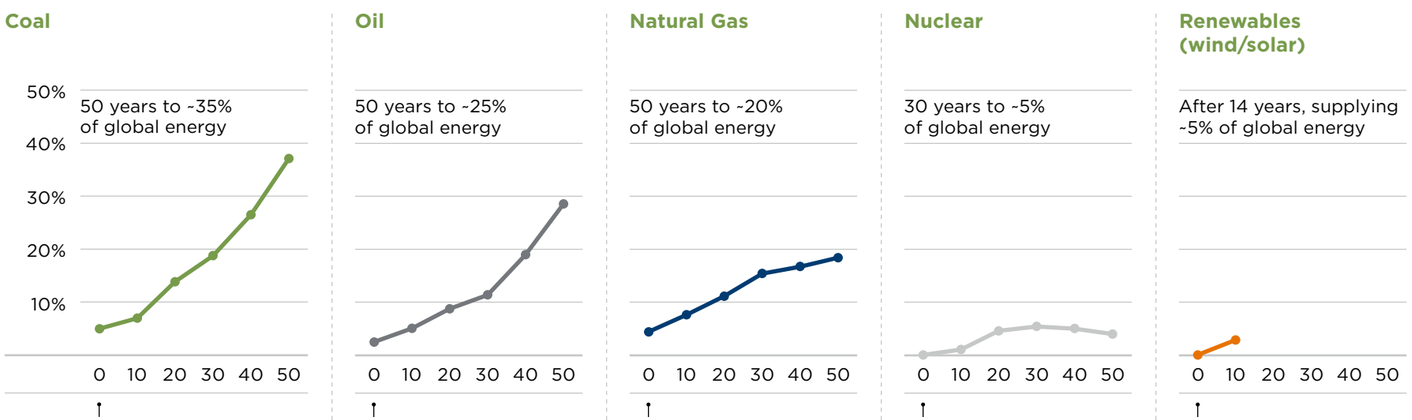
In 2023, traditional energy – coal, oil, and natural gas – accounted for 77% of the world's energy mix, down just 2% from the 79% they represented in 2010. However, in absolute terms, traditional energy use has grown nearly twice as much as renewable energy over that timeframe, with an increase of 59.3 quadrillion BTUs compared to 32.5 quadrillion BTUs for renewables. This reflects an energy addition, rather than an energy transition.

Since the industrial revolution, energy sources have continually evolved, with people seeking innovation and efficient energy sources to enhance their quality of life. As previously mentioned, coal powered the industrial revolution in the mid-1800s, oil growth supported the mass adoption of automobiles, and natural gas emerged in the 1930s as an important energy source for heating and industrial processes. Nuclear energy emerged in the 1960s but never achieved widespread acceptance due to safety concerns. Most recently, renewables – specifically wind and solar – have grown significantly with government support and a declining cost structure, and today they represent approximately 5% of the global energy mix after more than a decade of investment.

Each major energy source has developed over decades, gradually capturing market share at different rates but all requiring substantial time to drive meaningful impact. This extended development period is partly due to the need to build out the necessary infrastructure and achieve market acceptance. The current fossil fuel infrastructure, with an estimated value in the trillions of dollars, includes a global supply chain, distribution network, and installed base of vehicles and related facilities around the world. Building equivalent infrastructure – or converting existing infrastructure – to support new energy sources requires tremendous investment and time, inherently limiting the speed of execution. Looking ahead, given the modest pace of renewable energy market penetration to date, it seems likely that achieving substantial market share will take decades.

We believe traditional energy sources will continue to play a meaningful role in the decades to come. Even in the IEA's Stated Energy Policies and Announced Pledges scenarios – which would be challenging to achieve because energy demand growth would need to moderate meaningfully from historical trends – fossil fuel use remains significant in 2050. Calls to end fossil fuel use over the next few years or decade appear unrealistic when considering previous energy additions and current energy demand trends.

Share of global energy supply by energy source since initial adoption[1] (percent)



1840
Industrial revolution takes off in the West

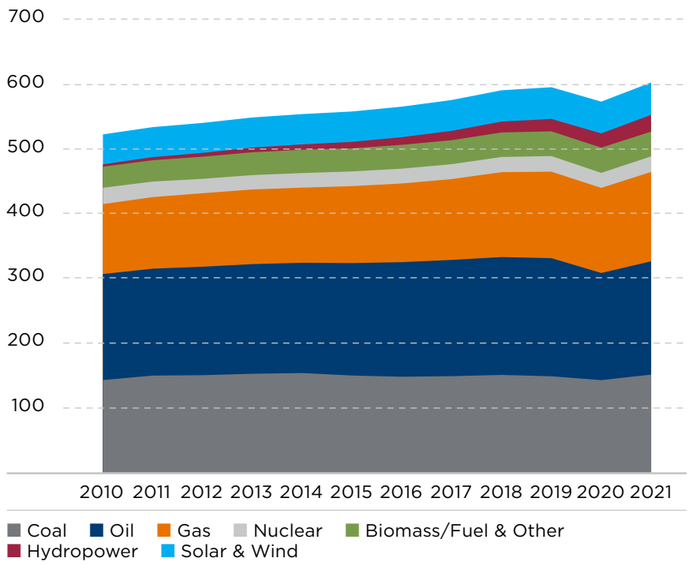
1908
Ford Model T is first produced

1938
Gas pipeline build-out

1964
Private ownership allowed within nuclear industry

2010
Adoption of EU Renewable Energy Directive and U.S. Renewable Energy and Energy Efficiency Export Initiative (RE4I)

Global energy demand by type[2] (QBtu)



ENERGY SOURCE	MARKET SHARE		CHANGE (QBTU)
	2010A	2022A	2010-2022
Solar & Wind	1%	5%	28.1
Hydro	6%	6%	6.6
Biomass/Fuel & Other	9%	8%	4.6
Nuclear	5%	4%	(2.2)
Natural Gas	21%	22%	28.7
Oil	31%	30%	19.1
Coal	27%	25%	11.5

References:

[1] Vaclav Smil, Energy Transitions: History, Requirements, Prospects
[2] IEA

PART 3

Climate Change & the Energy Addition

Climate Change is Real & Needs to be Addressed

It is driven by increased greenhouse gas emissions

Climate change is real and driven by increased greenhouse gas emissions, including carbon dioxide (CO_2), methane (CH_4), and other gases, from human activities. These emissions are contributing to the warming of the Earth, driving climate change with potentially serious impacts on the environment and human well-being. If left unchecked, the consequences could be real.[4]

The world is now 1.2 degrees warmer than pre-industrial temperatures due to global emissions, leading to climate change and potentially adverse effects such as extreme weather, rising sea levels, economic displacement, and food and water scarcity. The greater the temperature rise, the more significant the impact and potential adverse effects could be. To provide context, the Earth was 6 degrees cooler during the last ice age, with glaciers covering approximately 25% of the land area, and around 4 degrees warmer during the Jurassic Period, when crocodiles could be found above the Arctic Circle. Relatively small changes in the Earth's average temperature can have effects on its climate.

While the Earth's temperature and CO_2 concentrations have varied naturally over eons, these changes have typically occurred over long geologic timescales measured in millions of years. The rapid rise in atmospheric CO_2 concentrations and temperature increases over the last 175 years – since the beginning of the industrial revolution – is unprecedented.

According to the IPCC Sixth Assessment Report, addressing climate change requires significantly reducing emissions from the current level of approximately 53 gigatons (Gt) per year by 2050. Under various scenarios outlined by the IPCC, we could see the following temperature changes unfold:

- **Current emissions trajectory (SSP3–7.0):** If emissions continue to rise at the current pace, they could reach approximately 80 Gt of CO_2 per year by 2050, likely resulting in a temperature increase of 3.3°C to over 5.7°C above pre-industrial levels.
- **Stabilized emissions (SSP2-4.5):** If global emissions stay around current levels – 53 Gt of CO_2 per year – global temperatures could increase about 3.5° by 2050.
- **Emissions reduction to near zero emissions (SSP1-2.6):** To limit global warming to between 1.5°C and 2.0°C, emissions would need to be drastically reduced to below 10 Gt of CO_2 per year by 2050, in line with the Paris Agreement targets.
- **Deep cuts to zero emissions (SSP1-1.9):** Limiting global warming to 1.5°C would require reducing global emissions to net-zero by 2050, a goal that appears unachievable given historical trends.

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.[4]

Modest temperature changes can have dramatic impacts

6°C
degrees **lower** than today

Last ice age
when ~25% of Earth's land area was covered in glaciers

4°C
degrees **higher** than today

Age of the dinosaurs
when crocodiles could be found above the Arctic Circle

References:

(1) OpenMinds, Overview on the Dual Challenge: Energy and Climate (2023)
(2) Bill Gates, How to Avoid a Climate Disaster (2021)
(3) U.S. Geological Survey (USGS)
(4) IPCC Sixth Assessment Report

The Science of Climate Change

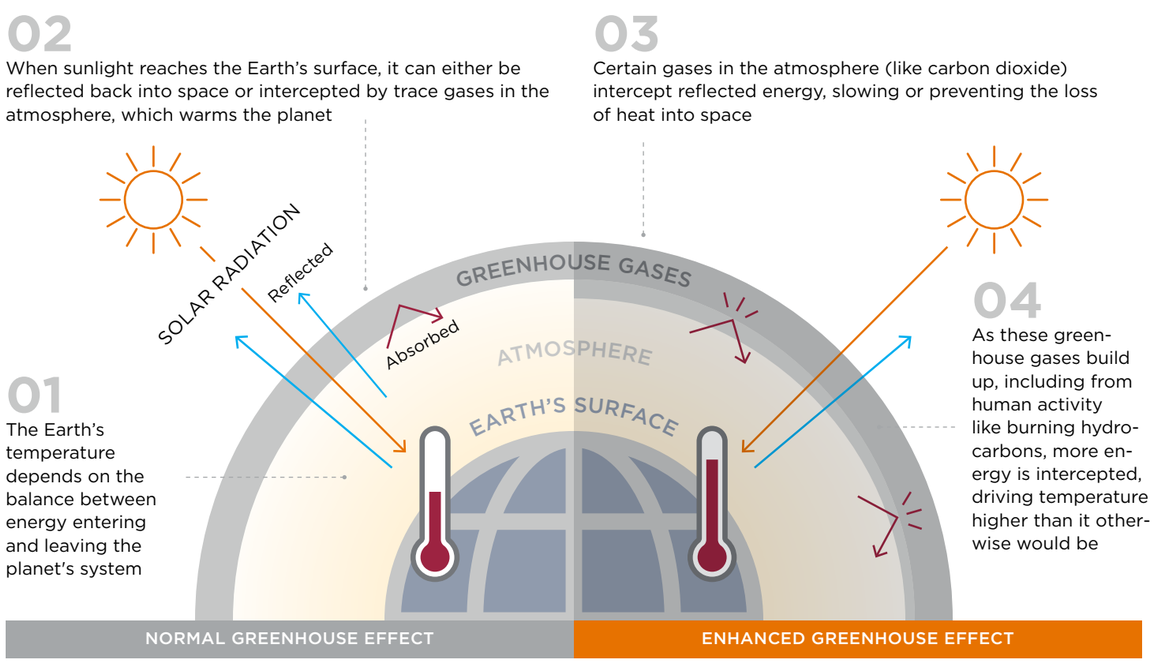
Human activity has contributed significantly to global emissions

Human activity and the use of energy, principally hydrocarbons, have contributed to global emissions, increased concentrations of greenhouse gases in the atmosphere, climate change, and its adverse effects worldwide.

Emissions come from a variety of sources, categorized into biogenic and non-biogenic or anthropogenic origins. Biogenic emissions result from natural processes such as biological processes, oceanic processes, wildfires, and volcanic eruptions. Non-biogenic, or anthropogenic, emissions are human-made and result from activities such as industrial processes, hydrocarbons combustion, deforestation, and methane emissions from livestock and farming. These anthropogenic emissions are responsible for the majority of long-term atmospheric accumulation of greenhouse gases and are the primary drivers of climate change. Today, we emit approximately 53 Gt of total emissions per year.

These gases are emitted into the atmosphere and absorbed by the ocean and plants. As they are emitted into the atmosphere, they increase the concentration of greenhouse gases, which increases the greenhouse gas effect, raises the Earth's temperature, and causes climate change. Increased CO_2 levels are also raising the concentration of carbon dioxide in the oceans, making them more acidic. On land, the extra CO_2 promotes more plant growth, contributing to the "greening" of the planet.

Greenhouse effect links anthropogenic GHG emissions to warming[1]



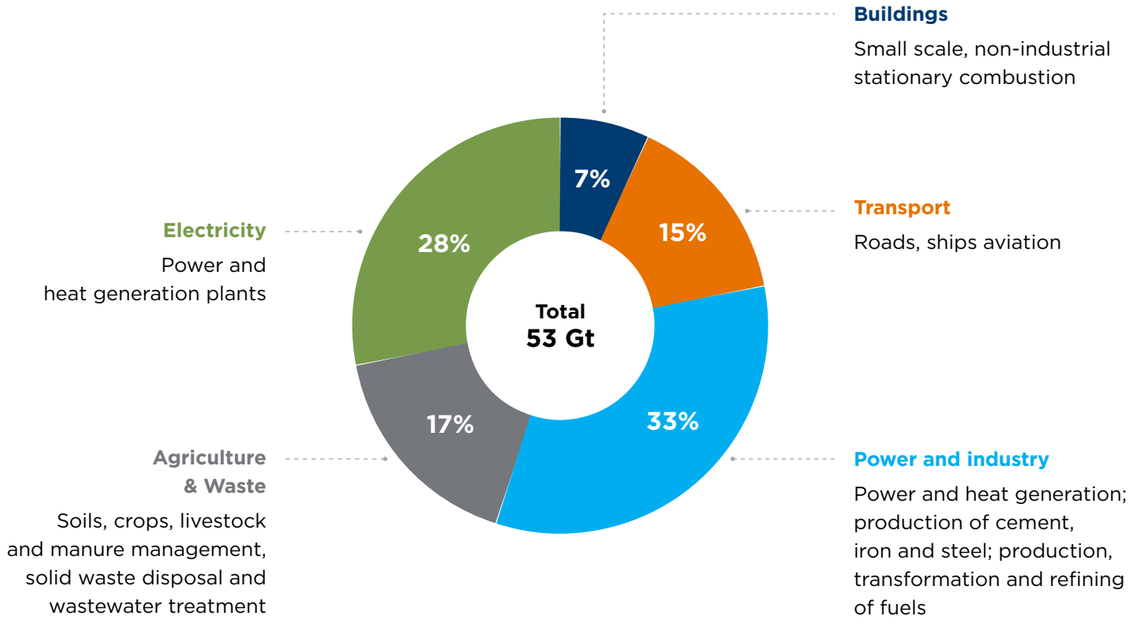
The primary greenhouse gases by volume are carbon dioxide (CO_2) at 74%, methane (CH_4) at 17%, nitrous oxide (N_2O) at 6%, and fluorinated gases at 2%. However, not all greenhouse gases have the same impact. For example, methane, which is emitted from sources like natural gas extraction and livestock, is 25 to 80 times more potent than CO_2 over a 20- to 100-year period as it decays, making its contribution to global warming significantly greater despite being released in smaller quantities. Other gases, such as nitrous oxide and fluorinated gases, also play a role in intensifying the greenhouse effect, with varying degrees of potency and longevity in the atmosphere.

Everything we do relies on energy, primarily from hydrocarbons, which creates emissions. However, not all hydrocarbons produce the same emissions. Coal generates about twice as much CO_2 as natural gas, and about 15–20% more CO_2 than oil for the same amount of energy produced. Additionally, unlike coal or wood, natural gas combustion does not produce particulate matter, which contributes to air pollution and can lead to serious health issues – especially for people who burn wood or coal indoors for cooking.

In his book, *How to Avoid a Climate Disaster*, Bill Gates identifies the key drivers of today's emissions, which he calls the "pillars of civilization" – manufacturing (including construction materials like cement and steel), electricity generation, transportation, agriculture, and heating and cooling (HVAC). To meaningfully reduce emissions, all five sectors must be addressed, yet many climate efforts focus only on electricity, which represents just 28% of global emissions.

Global emissions by sector[2]

Percent share of 2022 net GHG emissions



References:

[1] OpenMinds, Overview on the Dual Challenge: Energy and Climate (2023)
[2] Joint Research Center, Science for Policy Report, GHG emissions of all world countries, 2023

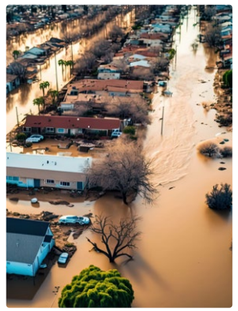
Climate Change and its Potential Impacts Must be Taken Seriously

Consequences could be significant and multifaceted

The continued increase in greenhouse gas emissions is potentially driving global warming impacts, which we may already be witnessing in the form of extreme weather, rising sea levels, ecosystem disruptions, human health risks, and economic and social impacts. Additionally, crossing critical tipping points have the potential to trigger shifts in Earth's systems. Climate change and its potential impacts should be considered.

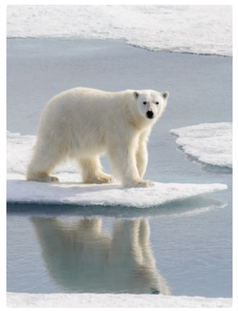
Potential Consequences of Global Warming[1]

The effects of global warming may already be reshaping our environment and way of life. From shifting weather patterns to stressed ecosystems, these changes may be widespread and accelerating, with potential implications for future stability. Without decisive action, these impacts could intensify, challenging our ability to adapt.



Extreme Weather Events:

The frequency and severity of heatwaves, hurricanes, floods, and droughts have increased, disrupting lives, agriculture, and infrastructure.



Rising Sea Levels and Ocean Warming:

Melting glaciers and warming oceans could be raising sea levels, threatening coastal communities, and altering marine ecosystems.

Impact on Ecosystems:

Many plants and animals could be struggling to adapt to shifting temperatures, leading to biodiversity loss and weakened ecosystems.

Human Health Risks:

Climate change could be linked to heat-related illnesses, vector-borne diseases, and food and water insecurity, potentially posing a direct risk to human well-being.

Economic and Social Impacts:

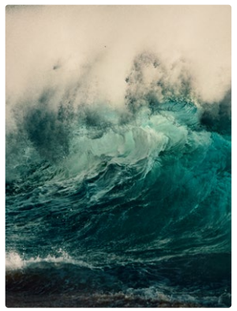
Agriculture, fisheries, and tourism could be affected by changing conditions, while increased displacement and migration could be placing pressure on communities and resources.

Tipping Points: Potential Irreversible Climate Shifts[1]

As greenhouse gas emissions continue to rise, the likelihood of crossing critical climate tipping points could increase. These tipping points are thresholds in Earth's climate system that, if exceeded, could trigger rapid and often irreversible changes. Such shifts could not only intensify existing impacts – such as extreme weather, sea level rise, and ecosystem disruption – but could also lead to new, destabilizing effects on a global scale.

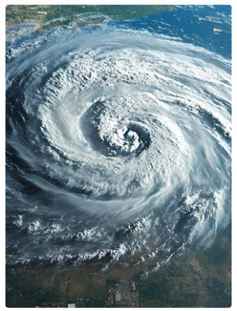
Collapse of Large Ice Sheets:

Rapid melting or potential collapse of major ice sheets, such as those in Greenland and West Antarctica, could cause significant sea-level rise, potentially posing serious risks to coastal communities worldwide.



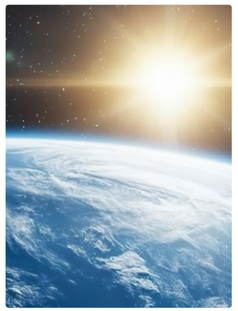
Disruptions in Ocean Currents:

Disruptions in ocean currents, particularly the Atlantic thermohaline circulation (Gulf Stream), could alter global climate patterns and destabilize regional climates.



Feedback Processes:

Self-reinforcing feedback loops, where warming leads to further warming, can accelerate climate change. For instance, melting ice decreases Earth's albedo (reflectivity), potentially causing greater solar absorption and intensifying warming.



Enhanced Long-Term Warming:

Persistent, intensified warming over time could trigger irreversible shifts in the climate system, including potential runaway greenhouse effects and other lasting climatic changes.

Reference:

[1] IPCC Sixth Assessment Report

Worldwide Emissions Continue to Increase

Largely driven by developing countries

Over the last 25 years since the Kyoto Protocol in 1997, despite worldwide focus, over $8 trillion in energy addition spending, and significant public and governmental support, global emissions continue to increase every year as we approach 2050.

Since 1990, the U.S., Europe, and other OECD countries have modestly reduced emissions by approximately 0.3 Gt per year. Meanwhile, China, India, and other non-OECD countries have increased their emissions by 14.2 Gt per year over the same timeframe. Achieving worldwide emission reductions will require a commitment from both OECD and non-OECD countries.

From the industrial revolution to the introduction of the Kyoto Protocol in 1997, approximately 1.6 trillion tons of emissions were released into the atmosphere, primarily by Europe and the U.S. accounting for approximately 70% of all post-industrial emissions. Since 1997, another 900 Gt have been emitted, primarily by developing countries, bringing total global emissions to approximately 2.59 trillion tons since 1900.

Despite ambitious net-zero goals, global emissions continue to increase each year, albeit at a reduced rate of growth, driven largely by developing countries that are prioritizing energy access, economic growth, and population expansion – all factors that increase energy demand and emissions.

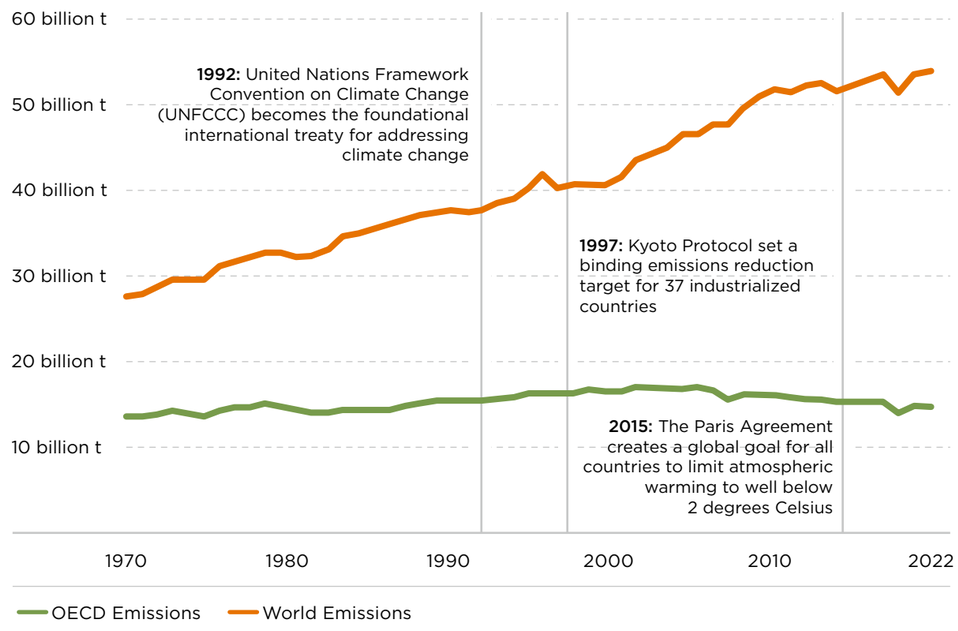
Since 1990, most of the emissions growth – 14 out of 15 Gt – has come from energy-related CO_2, which now accounts for approximately 37 Gt per year. The remaining 1 Gt of growth is attributed to methane (~11 Gt/year), nitrous oxide (~2 Gt/year), and fluorinated gases (~1 Gt/year).

Given the historic emissions from developed countries, the challenges developing nations face in balancing emission reductions with other priorities, and the limited progress on the Dual Challenge, it is evident that a broader global perspective and a redefined approach are necessary to achieve meaningful progress.

Energy CO_2 emissions trends and growth by region[1]
Gt of CO_2

	1990		2022		CHANGE OVER TIME	
REGION	EMISSIONS	PERCENT OF TOTAL	EMISSIONS	PERCENT OF TOTAL	SHARE OF GROWTH	DELTA
United States	5.1	20%	5.1	12%	0%	(0.1)
EU–27	3.9	13%	2.6	6%	-8%	(1.1)
Other OECD	3.1	13%	4.6	11%	6%	0.9
Total OECD	**12.0**	**46%**	**12.3**	**30%**	**-2%**	**(0.3)**
China	2.5	14%	11.8	29%	62%	8.9
India	0.6	3%	2.8	7%	16%	2.3
Other non-OECD	7.1	37%	14.2	34%	21%	3.0
Total non-OECD	**10.2**	**54%**	**28.7**	**70%**	**98%**	**14.2**
International Trade/Travel	**0.5**	**2%**	**1.0**	**3%**	**3%**	**0.5**
World	**22.8**	**100%**	**37.1**	**100%**	**100%**	**14.4**

Total global greenhouse gas emissions[2]
Billion tonnes CO_2e



References:

[1] Emissions are production-based and include emissions from energy and land-use change, measured in gigatons of CO_2. Bain & Company analysis; Our World in Data; Global Carbon Project
[2] Emissions measured in tons of CO_2-equivalent and include carbon dioxide, methane, nitrous oxide, and f-gases. Joint Research Centre (JRC), the European Commission's science and knowledge service (2023)

Energy Addition Challenges Moving to Scale

Renewable energy sources are key but face many constraints

Renewable energy sources, primarily wind and solar, are critical components of the energy addition, addressing climate change, and solving the Dual Challenge. As these energy sources move to scale, however, they face supply chain constraints, permitting and transmission hurdles, high capital requirements, and energy security concerns. Given these challenges, the practical reality of achieving the desired shift to renewables alone appears impractical.

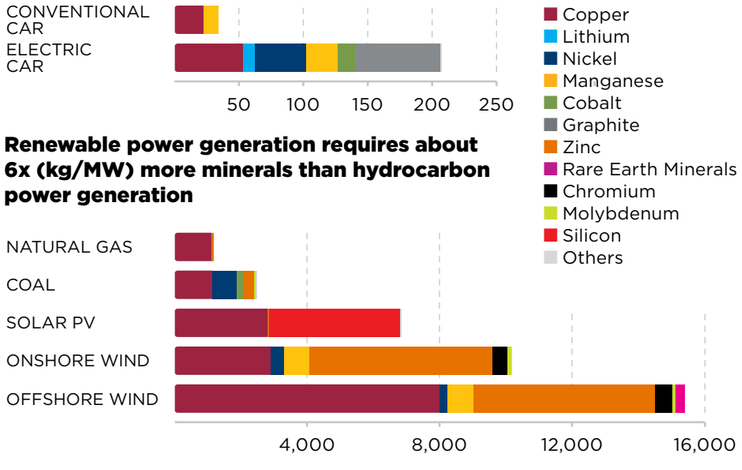
To meet energy addition goals for renewables, supply chains would need to grow at an unprecedented pace to meet demand. Renewable power plants require approximately six times more minerals and metals per kilowatt than hydrocarbon-based power generation. When accounting for the intermittency of renewables, this ratio could escalate to between 12 and 18 times more for the same effective energy output. Similarly, electric vehicles require about five times more minerals and metals than internal combustion engines. Meeting emission reduction targets would also mean scaling up wind and solar technologies by 6 to 14 times, creating an unprecedented demand surge for these critical materials. However, the average time needed to bring a new mine online is approximately 17 years, according to the IEA, which creates a major impediment to growth.

Permitting and transmission requirements present additional challenges to scaling renewables. In the U.S., permitting renewable projects has become increasingly more difficult as 'Not In My Backyard' (NIMBY) sentiments grow in response to the land use requirements of wind and solar power. Compared to oil and gas operations, which benefit from existing infrastructure and higher energy density, wind and solar require significantly more land to generate equivalent power.

Expanding wind and solar also requires expanding the electrical grid to transmit power from production sites to areas of demand. However, existing infrastructure and energy systems are closely tied to traditional energy, complicating the shift toward renewables, which require significant infrastructure upgrades to integrate into national grids. Global grid capacity would need to grow by 2.5 times its current size and incorporate enhanced storage capabilities to support intermittent sources like solar and wind.[3] These infrastructure upgrades are not only costly but also face bureaucratic roadblocks and lengthy permitting processes. For example, the average permitting time for a high-voltage transmission line is 13 years in the U.S. and the EU – more than 4 times longer than in China and more than twice as long as in India.

Electric vehicles require about 5x (kg/vehicle) more minerals than internal combustion engines[1]

Mineral requirements for green technologies[1]

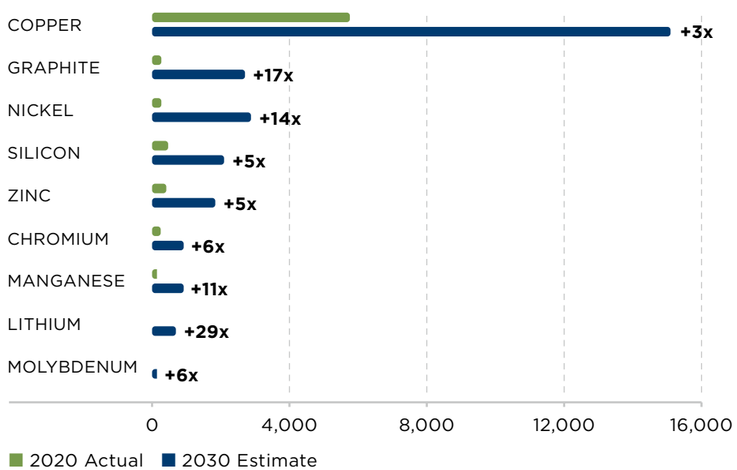


Renewable power generation requires about 6x (kg/MW) more minerals than hydrocarbon power generation

Growing adoption of green technologies will increase demand for these critical minerals[1]

Actual vs. future demand from clean energy uses[1]

Thousands of tons

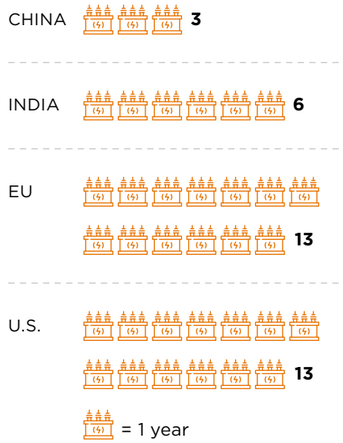


Number of homes served by one acre of land use[4]

Land requirement

Transmission lead times have become a major bottleneck for adding new power[2]

Timeline for permitting a high-voltage line



References:

[1] IEA Critical Minerals Outlook. Based on IEA World Energy Outlook estimates for the Net-zero Emissions by 2050 Scenario
[2] IEA
[3] DNV, DNV New Power Systems report: Global grid infrastructure to double by 2050 to meet surging electricity demand, June 2024
[4] Vaclav Smil, Power Density Primer: Understanding the Spatial Dimension of the Unfolding Transition to Renewable Electricity Generation; Liberty Energy, Bettering Human Lives, 2024

Energy Security Within the Energy Addition

How foreign control of key supply chains increases risk

Key supply chains for mining, processing, and manufacturing of renewable technologies are primarily controlled by a small number of countries that are not geopolitically aligned with the West. As these energy sources gain importance, energy security will become an even greater concern, significantly increasing the challenges associated with the energy addition.

Geopolitical factors and energy security concerns are presenting substantial challenges to moving away from traditional energy sources to relying solely on renewables. Conflicts like Russia's invasion of Ukraine have exposed vulnerabilities in energy systems, underscoring Europe's dependence on specific suppliers and intensifying calls to strengthen energy security. For example, disruptions from this conflict raised natural gas and power prices, costing the EU and UK approximately €1 trillion in 2022 alone, reinforcing the urgent need for diversified, stable energy sources.

Additionally, escalating tensions in the Middle East, such as the Israel-Iran conflict, pose further risks to global energy markets. Approximately 30% of global oil production originates from the Middle East, and the Strait of Hormuz – a critical chokepoint – facilitates about 15% of the world's crude supply and 20% of global LNG flows, including half of Europe's LNG supply. Any escalation in this region could result in severe disruptions to oil and gas flows, driving up prices and amplifying the energy security concerns for countries heavily reliant on these imports.

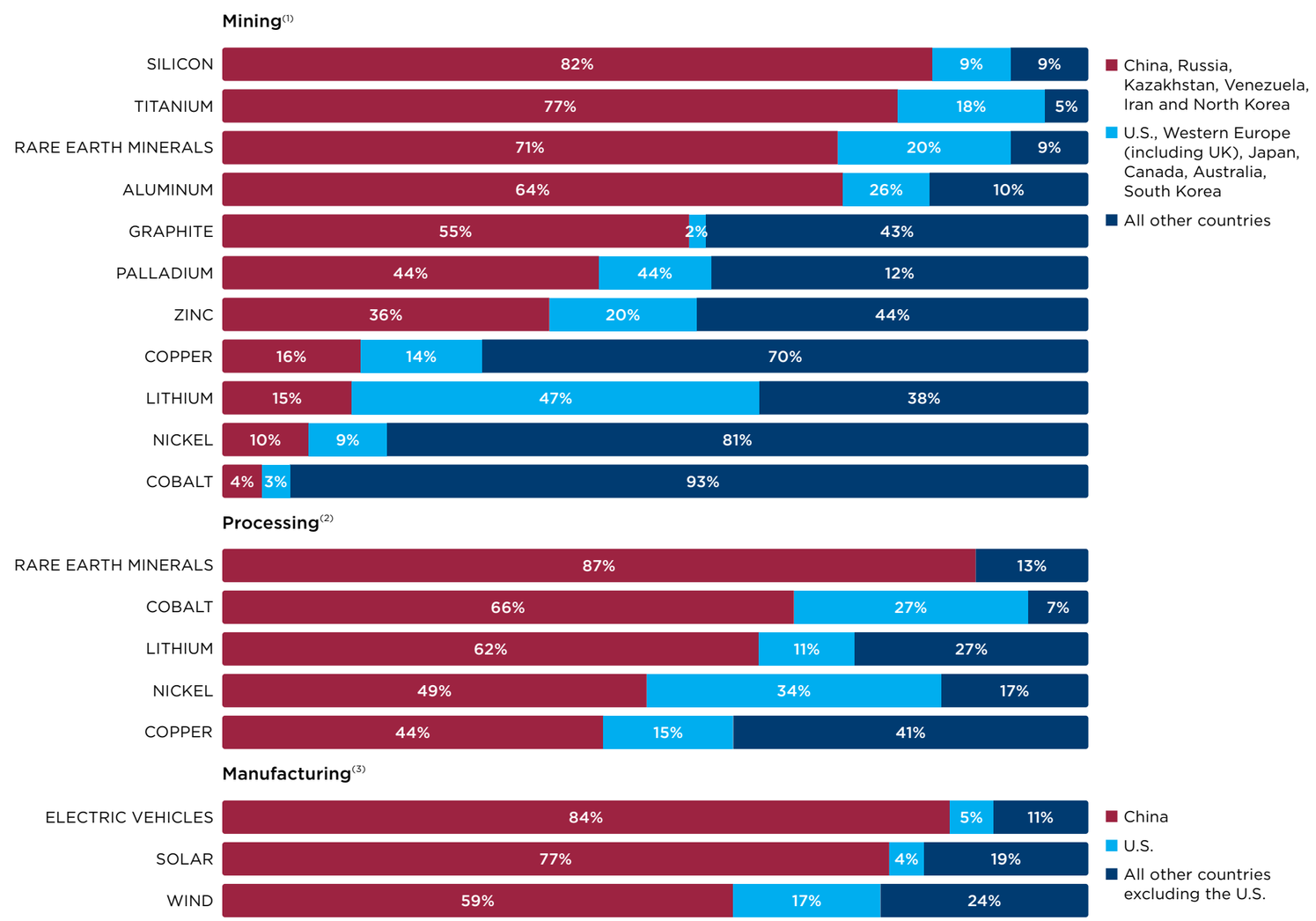
While the shift to renewables aims to reduce dependency on traditional energy sources, it introduces new complexities in energy security. Critical supply chains for renewable technologies are concentrated among a few countries, with China and Russia dominating much of the market. Together, they control over 70% of rare earth mining, more than 50% of mineral processing, and about two-thirds of renewable energy manufacturing. China alone holds the majority share of global refining capacity for essential minerals – 66% of cobalt, 39% of copper, 62% of lithium, 49% of nickel, and 87% of rare earth metals. This concentration introduces a new dependency where political tensions or supply constraints could threaten the stability of the global shift to renewable energy sources.

Meeting the demand for critical minerals will require production to expand dramatically – 3 to 29 times by 2030 to align with projected needs. However, ESG considerations and NIMBYism have limited mining investments in Western democracies, making them more reliant on foreign sources. As China and Russia increase their market dominance, they are also investing in refining and processing facilities for minerals they do not fully control, further consolidating their influence over global supply chains.

Moreover, the world relies on China for renewable technology components – such as wind turbines, solar panels, and lithium-ion batteries. The U.S. must reshore or near-shore these production capabilities for national security purposes, which will take decades and add costs. For instance, reshoring solar manufacturing in the U.S. would involve substantially higher costs and lengthy plant construction times compared to current imports.

Supply chain and trade dynamics, along with energy security concerns, have already constrained access to essential resources and equipment for advancing the energy transition, and this trend is likely to continue.

Mining, production, processing, and manufacturing by region (2023)[1][2][3][4]
Percent



References:

(1) USGS
(2) Bloomberg New Energy Finance, IEA, USGS
(3) Bloomberg New Energy Finance, U.S. Department of Energy, Thunder Said Energy

Energy Addition Mobilizing Unprecedented Levels of Spending

Reaching net-zero would require a scale of investment unmatched in history

Over the last decade, cumulative spending on energy addition activities has surpassed $8 trillion, with nearly $2 trillion invested in 2023 alone – about 1.8% of global GDP. Estimates suggest that reaching net-zero by 2050 could require sustained investments in the range of 4-8% of GDP for decades, a scale of investment unmatched in history.

In 2023, the world invested nearly $1.8 trillion on energy addition activities across a broad range of technologies. According to BloombergNEF, electrified transportation accounted for the largest share at ~$634 billion, followed by renewables at ~$622 billion, and power grids at ~$310 billion. The remaining ~$200BN was divided among electrified heat, clean industry, energy storage, shipping, nuclear, carbon capture, and hydrogen. While the total emissions reductions achieved are challenging to quantify, it is clear that these investments have not yet resulted in an overall decrease in global emissions. However, they have likely slowed the rate of emissions growth worldwide. Additionally, the actual cost of carbon abatement on a per-ton basis remains uncertain, making it difficult to compare against the cost of existing carbon abatement options.

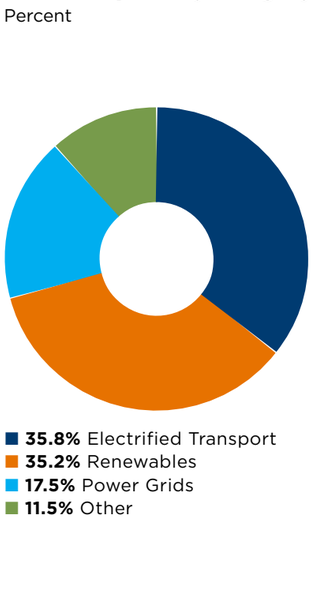
Cost estimates for achieving net-zero emissions by 2050 range from 4–8% of global GDP over the next 25 years – a massive resource commitment. For context, historic U.S. projects like the Manhattan Project and Apollo Program each cost roughly 0.4% of GDP annually for a few years.

While cost estimates vary, all are significantly above current spending levels, which have risen dramatically over the last decade. Examples include:

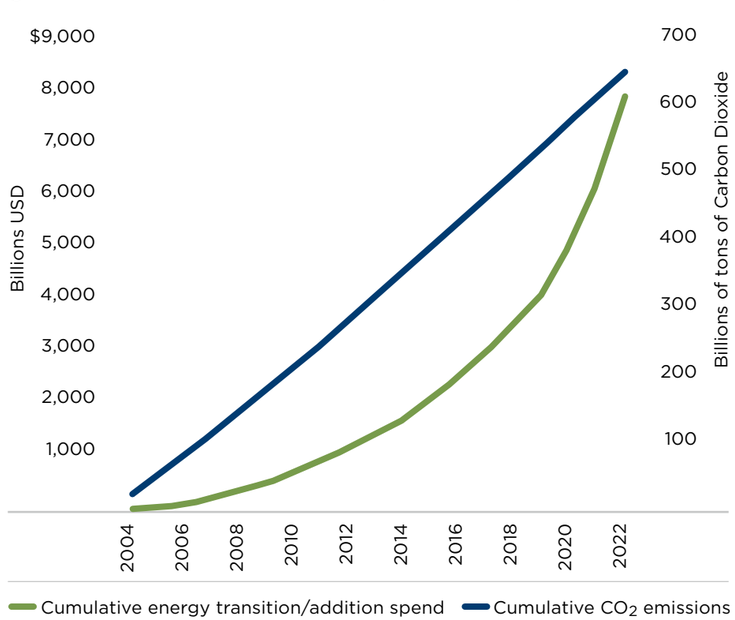
- **IEA:** *Net-zero by 2050* report suggests $4 trillion per year, about 4% of global GDP.
- **BloombergNEF:** Achieving net-zero by 2050 would require $173 trillion total, or $5.8 trillion annually (6% of GDP).
- **McKinsey:** *Global Energy Perspective 2022* estimates that cumulative capital spending on physical assets could reach $275 trillion, averaging $9.2 trillion annually (7–8% of GDP).

Investment levels vary by country based on priorities, resources, and capacity. China currently spends around 4% of its GDP on energy security and transition initiatives, Europe around 2%, and the U.S., benefiting from abundant natural gas, oil, and coal, about 1%.

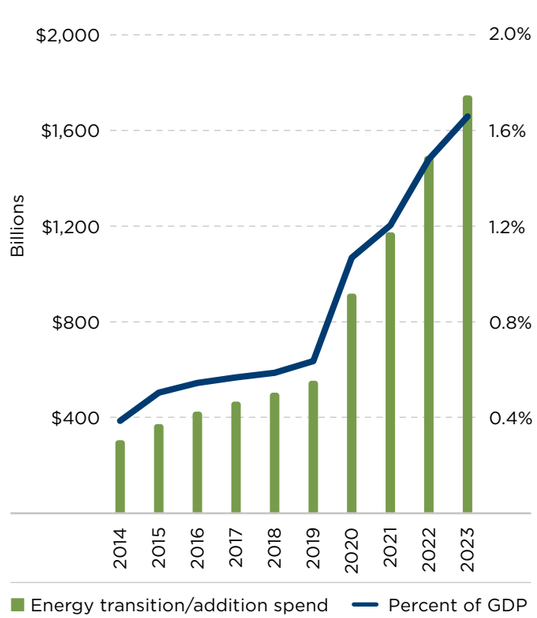
2023 energy transition/addition spend by category[1]



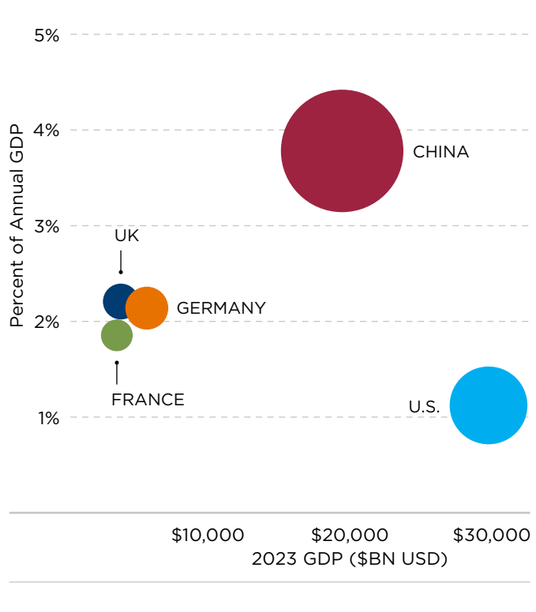
Cumulative global energy transition/addition spend vs global carbon dioxide emissions (2004–2022)



Global energy transition/addition spend and as a percent of global GDP (2014–2023)



Energy transition/addition spending by country as a percent of 2023 GDP



References:

[1] Our World in Data, BloombergNEF
[2] Energy Transition Investment Trends 2024 (BNEF), World Bank

Government Incentives are Reducing Emissions but Inconsistently

Incentive structures are complex and arbitrary

Carbon emissions are a negative externality, yet their costs are not fully included in the activities that produce them. To address this, governments in the U.S., EU, and UK implement taxpayer-funded incentives like tax credits and cap-and-trade systems to reduce emissions and support clean energy. However, these programs can be inconsistent, favoring certain technologies with greater incentives, leading to inefficiencies. A consistent global framework would be more effective.

Carbon emissions are a negative externality, yet their costs are not fully factored into the activities that generate them. Various government incentive structures around the world, primarily in the U.S., EU, and UK, are helping reduce emissions and support the development of new, cleaner energy technologies. These incentives are funded by taxpayers, either directly through higher taxes or indirectly via higher energy costs. However, these incentive structures are often complex and somewhat arbitrary, favoring certain technologies with greater incentives. This approach can lead to inefficiencies. A more consistent, economically-driven, global incentive structure is needed to support the goal of reducing global emissions most efficiently.

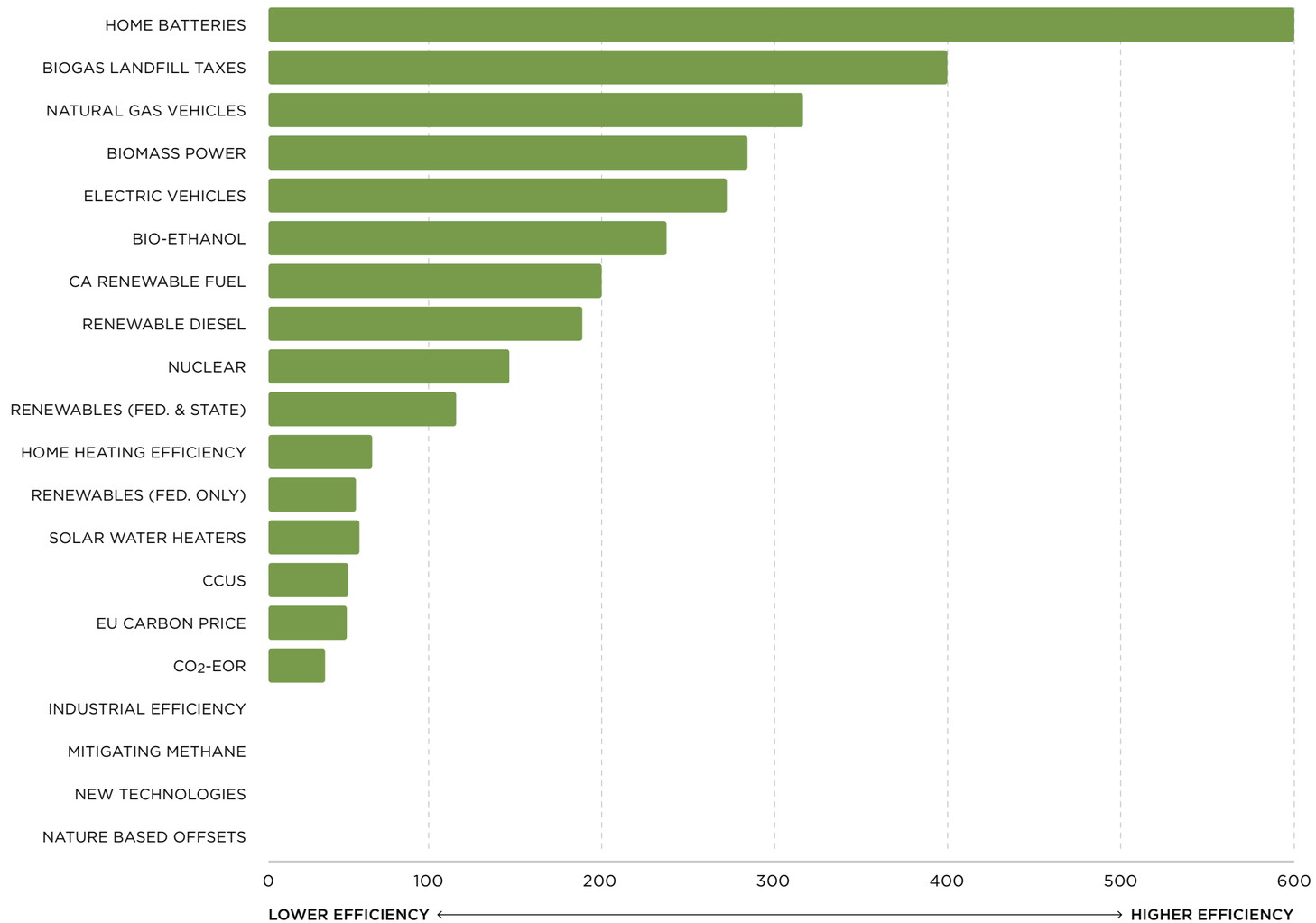
Fiscal incentives are designed to drive behavior that reduces emissions. However, as the cost per ton of abatement increases, the incentive becomes less efficient. Most current incentives are concentrated in the U.S., EU, and UK. These incentives take two primary forms: tax incentives, which are fixed and/or escalate over time to reduce emissions, and "cap-and-trade" (C&T) systems, which set jurisdictional emission limits and allow emission credit trading, establishing a system where emission allowances can be bought and sold. Both tax incentives and C&T systems are typically measured in dollars per ton of emissions ($/ton) but can vary significantly depending on technology, region, and specific legislation.

Countries around the globe use distinct strategies to achieve CO_2 abatement. The U.S. focuses on incentive-based policies, passing the IRA in 2022, which allocated approximately $369 billion in clean energy tax credits, carbon capture incentives, electric vehicle subsidies, clean manufacturing support, and environmental justice initiatives.

In contrast, the EU has adopted a comprehensive regulatory framework with legally binding emissions targets, an emissions trading system (ETS), and environmental taxes like its Biogas Landfill Taxes. As part of the European Green Deal, the EU has strengthened its ETS and introduced the Carbon Border Adjustment Mechanism (CBAM), a tariff on carbon-intensive imports designed to prevent carbon leakage – the shifting of emissions to countries with less stringent regulations. The UK, post-Brexit, launched its own ETS and continues to promote offshore wind and hydrogen through Contracts for Difference.

Fiscal incentive[1] ($/ton of CO_2 abated)

This chart summarizes the current incentives in the U.S., UK, and EU, ranked from highest to lowest support in $/ton under current legislation, along with estimated market trading values to illustrate pricing mechanisms across these jurisdictions.



Reference:

[1] Thunder Said Energy

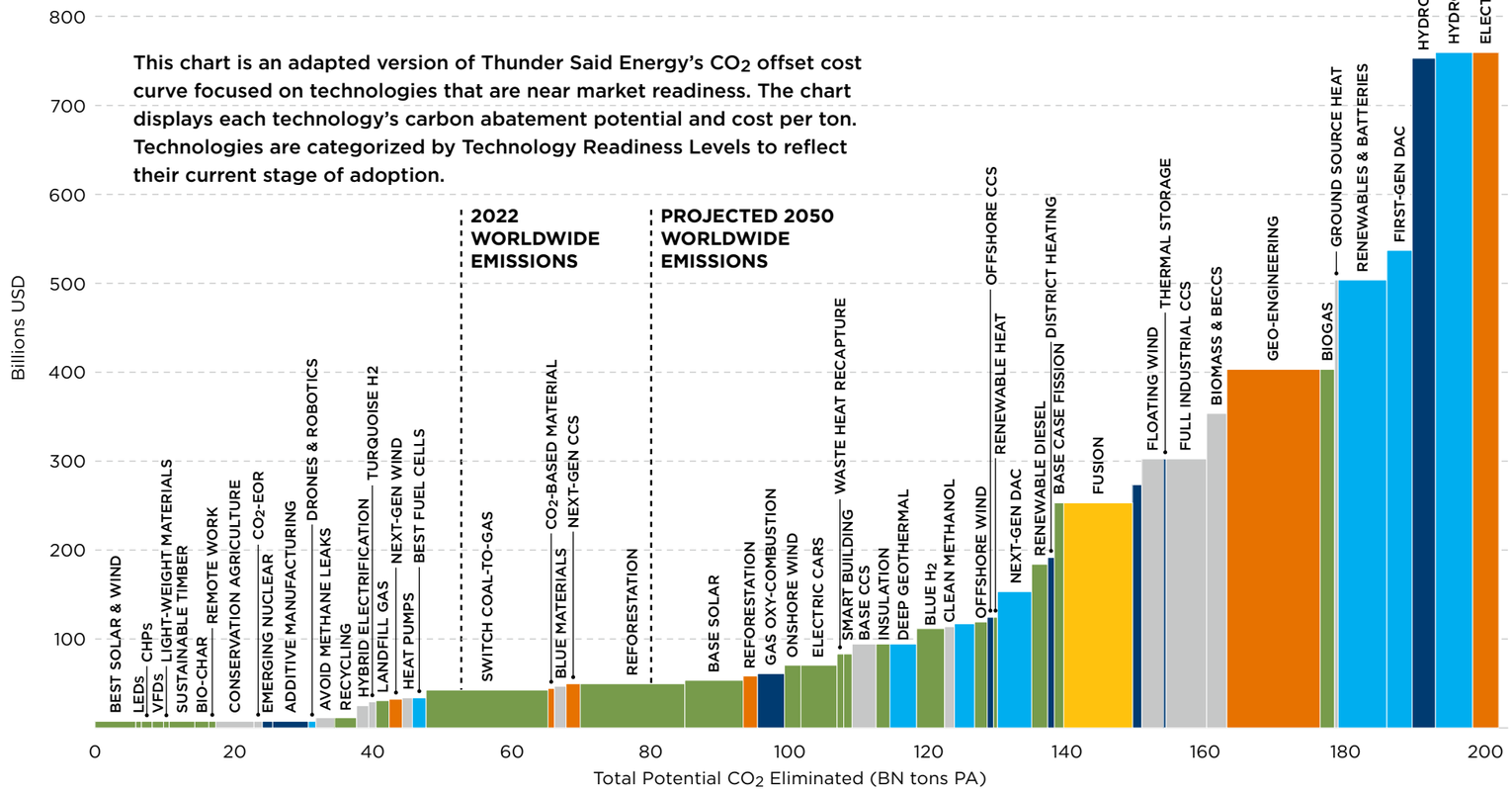
Government Incentives are Reducing Emissions but Inconsistently *continued*

Globally, carbon pricing is expanding. China is scaling up its national ETS, Canada is strengthening its carbon tax, and countries like Japan, South Korea, and Chile are implementing carbon pricing mechanisms. A key challenge is integrating and aligning these varied carbon tax schemes to prevent carbon leakage. This integration would require a global standard and coordination of these diverse government regulations. The EU's CBAM is one approach to addressing carbon leakage that could inspire similar policies worldwide.

Current abatement cost estimates for different technologies vary widely. Thunder Said Energy recently published a summary highlighting some of the most efficient (lower-cost) carbon abatement technologies, many of which are under $40 per ton, with several incurring no incremental abatement cost. These lower-cost technologies should be prioritized, and governments should carefully evaluate the benefits of incentivizing higher-cost abatement strategies.

We must also balance incentivizing carbon reduction efforts today with investing in research and development (R&D) for future advancements in carbon reduction technologies. A key consideration is to evaluate the future impact of R&D funding alongside the net benefit of current incentives by comparing the cost of carbon abatement with the required incentives to drive adoption. By examining a carbon abatement curve and assessing the potential of each technology, we can develop an economically driven approach to optimize carbon reduction incentive structures.

CO_2 abatement cost per technology[1] ($/ton)



TRL	STAGE	SUB-STAGE	KEY TESTS
1	Design	Components	Components have been designed, with lab-scale components tested and ready to integrate.
2	Development	Prototype	A lab-scale prototype is being built. Components are tested and further testing is in process under simulated conditions.
3	Development	Pilot	A more advanced prototype is being built and is being tested under operating conditions.
4	Development	Validation	An advanced prototype is built. It is tested under operating conditions. It is stress-tested to improve robustness.
5	Production	Commercialization	After extensive testing and demonstration, the technology is proven and a final product has been designed.
6	Production	Mature	The technology is in commercial operation, but questions may remain over scalability.

Reference:

[1] Thunder Said Energy

PART 4

Learning from Previous Efforts

What Is Not Working & What Is Working

Case studies highlighting examples of failure and meaningful successes

While current solutions are making an impact, they remain insufficient to fully address the Dual Challenge, as global emissions continue to rise, and billions still face energy poverty and security issues.

In this section, we explore case studies that reveal the limitations of previous efforts and illustrate the potential of a new approach focused on near-term actions to address and solve the Dual Challenge. These examples highlight both meaningful successes in improving energy access and reducing emissions, as well as the reasons why, despite 25 years and $8 trillion invested, the Dual Challenge remains unresolved. With a pragmatic, informed framework dedicated to expanding energy access and security while lowering global emissions, substantial progress is within reach.

FAILURE CASE STUDIES

The premature death of oil and gas.

The actual cost of eliminating the primary global energy source on an accelerated timeline is significant. Most solutions focus on either energy availability or reducing emissions in isolation. Some argue that hydrocarbons are ruining the planet and must be eliminated at all costs, while others emphasize energy availability for economic development and the importance of energy security. This singular focus limits cooperation, compromise, and creative solutions, leading to dogmatic and inflexible positions and policies.

Germany's path to higher energy prices.

Germany's ambitious shift toward renewable energy, combined with a swift departure from traditional sources, has resulted in significant trade-offs. Although emissions have decreased, the rise in energy costs has slowed the economy and adversely impacted the industrial sector, which could cause geopolitical issues in the future.

Why coal?

Coal remains the most carbon-intensive energy source in widespread use, currently providing about 25% of the world's energy. Despite increased awareness of its significant climate impacts, the world is burning more coal today than at any point in history. To understand this continued reliance on coal, one must consider factors such as energy security, social acceptance, and the affordability challenges faced by many countries outside the OECD, where cleaner energy solutions may be financially out of reach.

The Canadian Dual Challenge solution that wasn't.

Canada, a major natural gas producer and respected energy trading partner, had the potential to supply natural gas to Asia and accelerate the coal-to-gas transition. However, by focusing on reducing its relatively minor domestic emissions and limiting natural gas exports, Canada negatively affected its own economy and missed an opportunity to contribute meaningfully to global emission reduction efforts.

SUCCESS CASE STUDIES

Gas market drives change.

The U.S. shift from coal to natural gas has resulted in one of the largest emissions reductions among OECD countries.

These are not the hydrocarbons you think you know.

Responsibly-sourced oil and gas can support decarbonization and help solve the Dual Challenge. Today's producers are embracing a new, more responsible future.

The road less traveled.

France's commitment to nuclear power after the initial Arab oil embargo has provided reliable electricity while safely reducing emissions. Should we give nuclear another look?

Necessity is the mother of invention.

Russia's invasion of Ukraine accelerated Europe's push for energy diversity. Within a year, Europe resolved a major energy crisis through rapid permitting, construction, deployment, and conservation.

The Premature Death of Oil & Gas

How prematurely limiting oil and gas drives energy poverty and hinders the energy transition

Key Metric Summary

Local Climate Impact

Emissions from the oil and natural gas sectors made up 4% of total U.S. GHG emissions in 2022 and would likely increase if production grows.[1]

Global Climate Impact

A theoretical shift of all Russian production to the methane intensity levels of the U.S. and Canada would decrease Russian methane emissions from energy by ~40%. This would decrease global methane emissions by ~4 metric tons annually – representing about 6% of global methane emissions from energy.[2]

Energy Impact

Continued investment in hydrocarbons will increase energy availability around the globe and lower overall energy prices.

Energy Security Impact

Increasing production in the Western-aligned nations would further diversify world production and improve overall world energy security.

Economics without CO_2 Credits

Fossil fuel production economics differ due to market dynamics but are generally viable without subsidies.

Economics with CO_2 Credits

Relative economics would suffer in a fiscal regime that includes carbon taxes or CO_2 tax credits for competing energy sources.

Timeline to Execution

Moderate: North American unconventional onshore has a much quicker cycle time relative to offshore development but would take years to ramp up.

References:

(1) EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2022
(2) IEA 2023 Methane Tracker, EIA World Liquids and Natural Gas Production
(3) Our World in Data
(4) Thunder Said Energy
(5) OPEC 2024 Statistical Review, Bloomberg
(6) EIA, IEA Methane Tracker

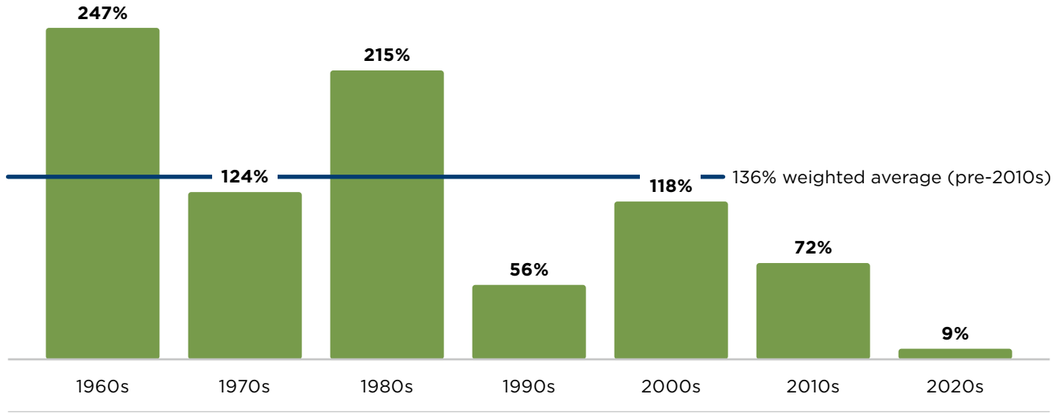
Background and Context

Some governments and non-governmental organizations (NGOs) have called to limit future investments in hydrocarbons, including oil, gas, and related infrastructure. However, traditional energy sources currently supply nearly 80% of the world's energy, with demand continuing to grow.[3] The negative sentiment towards oil and gas has limited investment, leading to a significant decline in global oil and gas reserve replacement rates over the past decade. Since oil and gas are naturally depleting resources, global supplies could decline by around 5-8% per year without ongoing reinvestment. This could drive a major disconnect in future supply and demand dynamics, resulting in increased energy poverty and rising energy costs worldwide.

These higher energy prices could strain global economies and reduce the capital available to fund the energy addition. In 2022, global energy costs consumed around 13% of global GDP, up from about 5% in the late 2010s.[4] Given the significant capital required to fund decarbonization, this incremental energy cost could slow down funding for these efforts. Adopting an "energy addition and decarbonization" approach – utilizing a range of energy sources and focusing on efficient decarbonization – is more practical than an "energy transition" that prioritizes the elimination of hydrocarbons and relies heavily on renewables. An aggressive push towards renewables could overburden renewable supply chains, which will take time to scale, potentially driving energy prices even higher. Ironically, reducing the available hydrocarbon energy mix too quickly may actually slow the world's decarbonization efforts.

The supply picture: Oil and gas are depleting resources that require constant reinvestment

Global oil and natural gas reserve replacement ratio[5]
Reserve additions/production, percent



Assessment

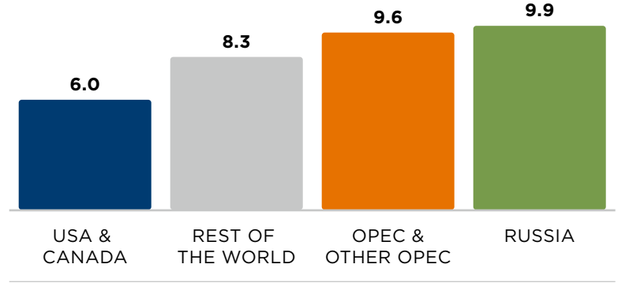
To avoid a potential energy shortfall and continue reducing emissions, the world needs to continue investing in hydrocarbons while pursuing efforts to decarbonize production and advance cleaner energy sources like renewables and nuclear. This approach aims to create a more abundant and cleaner energy mix. Hydrocarbon decarbonization can be achieved through several strategies:

Prioritizing Production in Countries with Strong ESG Standards: Countries like the U.S. and Canada have a carbon footprint per barrel that is approximately 40% lower than many other producing countries.[2] To lower global emissions, North America should increase – not reduce – its hydrocarbon production. By restricting North America production without decreasing global hydrocarbon demand, we inadvertently raise global emissions, as the supply is sourced from regions with higher emission rates.

Responsibly Produced Hydrocarbons: Oil and gas producers can adopt practices that focus on reducing methane emissions, using low carbon fuels, and implementing lower-carbon operating methods.

Carbon Capture, Utilization, and Storage (CCUS): Decarbonizing hydrocarbon production can also be achieved through CCUS. When applied to concentrated hydrocarbon uses, such as power generation, refineries, steel, chemical, and other heavy industries, CCUS can substantially reduce related emissions.

Methane intensity of oil and natural gas[6]
tCH_4/ktoe



Germany's Path to Higher Energy Prices

"Energiewende" is ambitious, but at significant cost to Germany

Key Metric Summary

Local Climate Impact

By the end of 2023, Germany had reduced its GHG emissions by 46% compared to 1990 levels.[1]

Global Climate Impact

Germany was responsible for ~1.8% of global CO_2 emissions from combustible fuels in 2022, the 8th-highest in the world and the highest in Europe.[2]

Energy Impact

43% reduction in energy supply per unit of GDP from 2000–2023, reflecting a marked change from an industrial-heavy to a service-based economy.[2]

Energy Security Impact

Germany is still heavily reliant on foreign imports and losing industrial capabilities may pose additional geopolitical risks in the future.

Economics without CO_2 Credits

Germany's strategy has generated the highest electricity prices in OECD.

Economics with CO_2 Credits

CO_2 intensity is on par with the U.S. but costs are three times higher.

Timeline to Execution

Long: Germany's target is to reduce emissions by 55% by 2030 and to reach net-zero by 2045.[1]

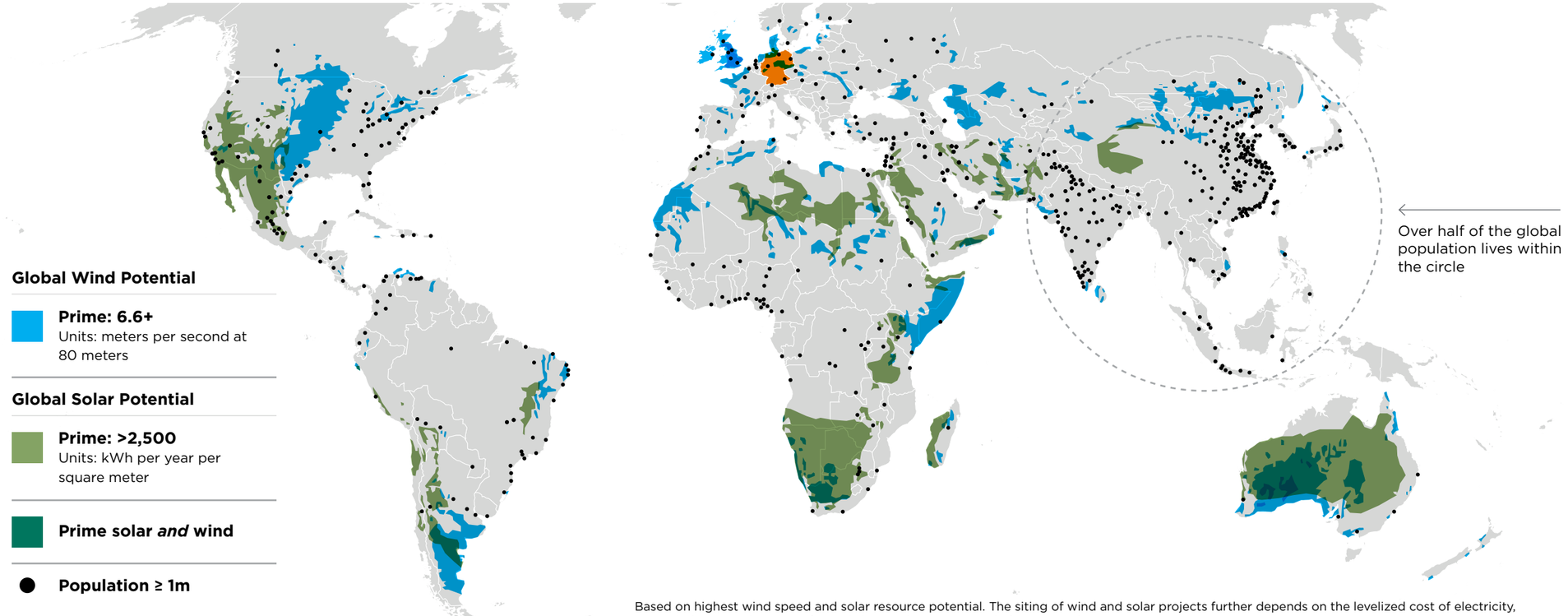
References:

(1) Indicator: Greenhouse ga emissions, Umweitbundesmt
(2) IEA
(3) Reuters
(4) Peter Zeihan, Disunited Nations, 2020.
(5) Bundenetzagentur, Growth in renewable energy in 2023

Background and Context

Germany's Energiewende ("Energy Turnaround") was initiated in the early 2000s due to concerns about fossil fuel dependence and environmental protection. Through a series of legislative acts, Germany set ambitious goals: reducing annual emissions by 55% from the 1990 benchmark of 1.3 billion tons of CO_2 by 2030, achieving net-zero emissions by 2045, sourcing 60% of energy from renewables by 2050, and retiring nuclear and coal plants by 2022 and 2030, respectively. Germany has invested significantly in this strategy, with estimates at over €500 billion allocated to date and an additional €200 billion expected from the government's Special Climate and Transformation Fund (CTF) over the next three years.[3] As of 2023, Germany reported a 46% reduction in GHG emissions since 1990, approximately 577 million tons per year, achieved through a combination of increased renewable energy generation and lower power demand across all sectors.

Prime wind and solar locations based on resource potential[4]
within 1,000 miles of a major city



Based on highest wind speed and solar resource potential. The siting of wind and solar projects further depends on the levelized cost of electricity, transmission capacity, ease of permitting, and access to capital, among others.

Assessment

Germany's focus on renewable energy has helped reduce emissions, but at a staggering cost due to low capacity factors and the continued reliance on traditional energy sources for reliability. Despite installing nearly 170 gigawatts of renewable capacity,[5] Germany faces significant challenges because of its relatively limited geographical generation potential. The country's solar generation is below the global average on a per-square-meter basis, and wind capacity is also below average. This means that solar and wind installations in Germany tend to be utilized less and require more backup traditional energy, which makes energy more expensive than in countries with more favorable conditions.

Germany's Path to Higher Energy Prices *continued*

Given this poor reliability, Germany has delayed retiring fossil fuel power plants and continues to generate nearly 50% of its electricity from these non-renewable sources. As a result, Germany's energy intensity is comparable to that of other developed countries, but its energy costs are substantially higher. Currently, Germany has plans to install more renewable energy to meet their emission reduction targets, potentially making further inefficient investments in suboptimal energy sources.

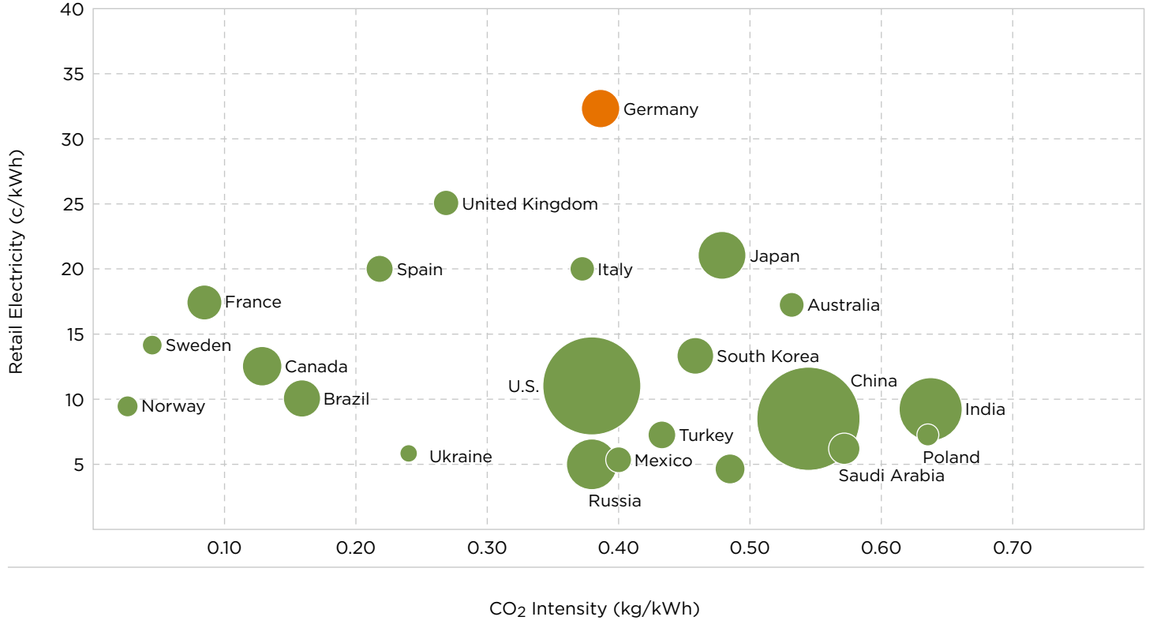
High energy prices have affected Germany's economy and geopolitical influence. In 2023, Germany was the only G7 economy to shrink, with several notable companies, like BASF and Volkswagen,[1][4] announcing plans to relocate production due to increased manufacturing and energy costs. To mitigate these impacts, Germany has focused on retraining its workforce to transition from an industrial-based economy to a lower-emissions, service-based economy.

While this transition could succeed, the loss of core industrial capabilities could have geopolitical ramifications in the future, especially given the ongoing Russian invasion of Ukraine, which has intensified global energy security concerns.

Comparing Germany's top-down, regulatory-driven approach with the U.S. approach – which emphasizes market-driven coal-to-natural gas switching and strategically deploying renewables with higher capacity factors – highlights key differences in energy abundance and emissions reductions. As shown in the Energy Transition Pathway table, Germany leads in renewable energy adoption and overall emissions reductions but lags in emissions per capita, affordability metrics, and energy security.

In 2021, Germany emitted as much CO_2 per unit as the U.S. and European counterparts but had notably higher electricity prices

Global comparison of CO_2 intensity and retail electricity prices by country (2021)[2]



Germany vs U.S. energy policy comparison[3]

		GERMANY	UNITED STATES
Energy Transition Pathway		Deliberate, highly centralized, government-led with targets and mandates	No-target, no-mandate, market-driven
Significantly reduce emissions	Hydrocarbons as share of primary energy supply	**-7 pts** (86% to 79%, 2000–21)	**-6 pts** (88% to 82%, 2000–21
	Renewables as share of electricity production	**+34 pts** (6% to 41%, 2000–21)	**+12 pts** (9% to 21%, 2000–21)
	Total GHG emissions	**-15%** (951M tons of CO_2-e to 812M, 2000–18)	**-10%** (6,594M tons of CO_2-e to 5,030B, 2000–18)
	GHG emissions per capita	**-15%** (11.6t CO_2-e to 9.8, 2000–18)	**-22%** (23.4t CO_2-e to 18.2, 2000–18)
Deliver affordable, reliable, secure energy	Residential electricity price	**+139%** (€0.13/kWh to €0.31/kWh, 2000–21)	**+67%** ($0.08/kWh to $0.14/kWh, 2000–21)
	Industrial electricity price	**+270%** (€0.13/kWh to €0.19/kWh, 2000–21)	**+59%** ($0.05/kWh to $0.07/kWh, 2000–21)
	Energy dependence*	**More dependent** (61% to 70%, 2000–2019)	**Less dependent** (27% to -2%, 2000–19)

Note: *Energy dependence = (energy imports – energy exports)/total primary consumption, measured in millions of tons of oil equivalent (Mtoe)

References:

[1] Reuters, BASF plans more German cuts even as group profit set to rebound
[2] Thunder Said Energy
[3] OpenMinds, Overview on the Dual Challenge Energy and Climate (2023)
[4] World Bank GDP Dataset

Why Coal?

Understanding how energy security, resource availability, and economics shape climate policy

Key Metric Summary

Local Climate Impact

Coal power plants constructed in China since 2015 emit ~1.8 billion tons of CO_2 annually.[1]

Global Climate Impact

Globally, coal power plants constructed since 2015 emit ~3.0 billion tons of CO_2 annually.[1]

Energy Impact

New coal power plants make up ~34% of China's coal generation capacity and produce ~400 megawatts.[1]

Energy Security Impact

Switching away from domestic coal would expose China to significant reliance on foreign fuels.

Economics without CO_2 Credits

Globally, coal is typically the cheapest electricity source based on levelized cost.[6]

Economics with CO_2 Credits

At a carbon price of $80 per ton, China's new coal capacity would incur an annual cost exceeding $140 billion.[1]

Timeline to Execution

Moderate: Expanded North American infrastructure and international arrangements would take years.[3]

References:

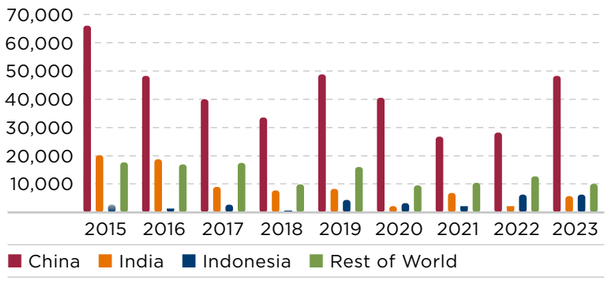
[1] Global Energy Monitor
[2] Our World in Data
[3] Thunder Said Energy "China coal revisions: the most frightening chart in global energy?"
[4] 2024 Energy Institute Statistical Review of World Energy
[5] World Bank

Background and Context

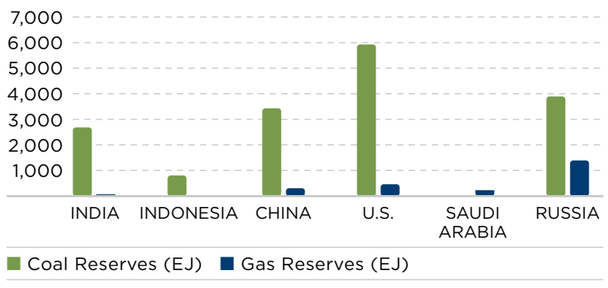
Western nations have largely stopped construction of new coal power plants, and many are actively retiring facilities in favor of lower-emission natural gas and renewable power generation sources. However, many developing economies are not only resisting coal retirements but are actively expanding coal-fired generation infrastructure. Notably, China and India have added nearly 500 gigawatts of coal-fired generation in the last decade.[1] These facilities alone emit more than 2 billion tons of CO_2 annually. For comparison, the entire EU emitted around 2.8 billion tons of CO_2 in 2022 from all sources combined.[2] China alone has an additional 375+ gigawatts of coal-fired power plants approved or planned as of early 2024 – more than 14 times the capacity of the entire UK power grid.[3]

While these nations are aware of coal's emissions and the potential consequences of global climate change, many domestic factors influence them to prioritize near-term needs like energy demand, energy security, and economic growth over climate goals. The principal factors driving continued coal expansion in developing nations is growing energy demand, cost, and availability. Rapidly growing demand pushes countries towards cheap and available sources of energy, and globally, coal remains the most abundant hydrocarbon resource. China and India have vastly larger coal reserves than natural gas.[4] Coal is also, on average, the cheapest source of electricity when measured by levelized cost.[5] When choosing between costly foreign energy sources and affordable, abundant domestic coal, it is unsurprising that these nations continually prioritize economic growth and energy security over long-term climate considerations to meet their growing demands.

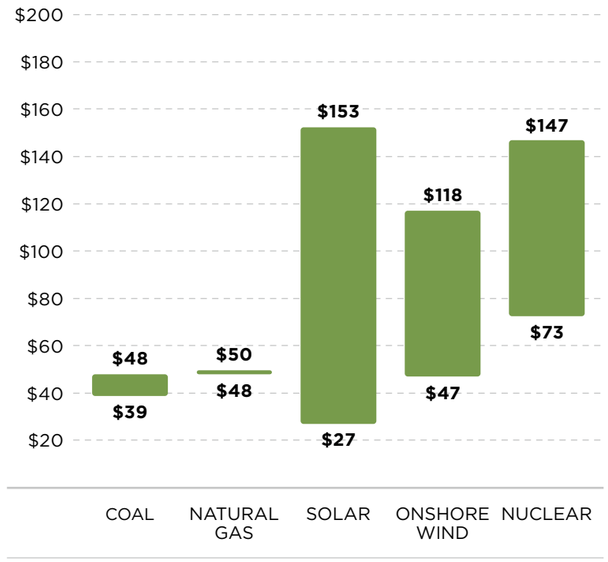
New coal power plants (2015–2023)[1]



Coal and natural gas reserves[4]



Global levelized cost of electricity[5]



Assessment

An ongoing debate about who should pay for the energy addition stems from the fact that developed nations, especially the U.S. and Europe, contributed about half of the approximately 2,000 Gt of global emissions since 1900 and continue to contribute about 25% of annual global emissions. Furthermore, developing nations argue they cannot afford to invest in the energy addition or the needed infrastructure. When evaluating carbon abatement strategies across the globe, supporting developing countries with their own Dual Challenge journey may provide a more effective use of allocated carbon abatement capital than pursuing higher-cost strategies domestically.

The goal is to achieve a cleaner, more abundant energy supply worldwide. Supporting energy additions in countries that cannot afford them could yield more meaningful carbon abatement on a $/$CO_2$ reduction basis. Such investments may also be mutually beneficial for nations providing support. For instance, if Canada and/or the U.S. were to expand LNG export capacity and fund import terminals abroad, they would be serving new markets and displacing higher-emission energy sources with cleaner-burning natural gas. Trusted North American production could also help address energy security concerns while having a meaningful impact on both energy poverty and climate goals.

The Canadian Dual Challenge Solution That Wasn't

How Canada's focus on their emissions missed a greater opportunity to impact global emissions

Key Metric Summary

Local Climate Impact

Canada's efforts have resulted in a reduction of ~44 million metric tons since 2019.[6]

Global Climate Impact

Adopting a timeline similar to U.S. LNG development could have resulted in savings of about 50 million metric tons of CO_2e per year.[1][2]

Energy Impact

Coal-to-gas switching in U.S. markets has reduced energy prices by ~5% since 2015 without affecting reliability.

Energy Security Impact

LNG exports would have increased Canadian annual GDP by ~$6 billion (0.3%).

Economics without CO_2 Credits

Natural gas development projects were and are economic without subsidies.

Economics with CO_2 Credits

Economics would be improved considering global emission reductions.

Timeline to Execution

Relatively fast: Adopting a similar timeline to U.S. LNG development.[2]

Background and Context

Canada is taking an aggressive role in addressing climate change through a multi-faceted emissions reduction approach involving federal, provincial, and territorial governments, alongside private sector and community initiatives. The strategy includes carbon pricing, investments in renewable energy and clean technology, energy efficiency measures, and international collaboration, all aimed at meeting Canada's climate goals of a 40–45% reduction from 2005 emissions levels (761 million tons per annum) by 2030 and net-zero by 2050.

Canada has focused on domestic emissions reductions and provided limited support for its energy industry given the link between hydrocarbons and emissions. Canadian oil and gas production levels have remained relatively flat during the shale revolution over the last 15 years, despite having tremendous oil and natural gas reserves, while the U.S. has nearly tripled domestic oil production and doubled gas production. The U.S. has also become a leading oil and LNG exporter, with projects under construction to double LNG exports again by 2030. Canada, in contrast, is just beginning Phase 1 of its first LNG export facility, with Phase 2 facing significant delays partly due to rigorous permitting requirements and environmental standards.

According to the latest National Inventory Report (NIR) submitted to the United Nations Framework Convention on Climate Change (UNFCCC), Canada's GHG emissions in 2019 were approximately 752 metric tons of CO_2 equivalent,[6] roughly the same as the 2005 levels, although recent efforts are making an impact. Since 2019, Canadian emissions have dropped ~44 million tons per annum, or roughly 6%.[6]

Given Canada's geopolitical standing, long history as an energy exporter, and proximity to Asia, it could have accessed even more LNG markets than the U.S. By focusing primarily on domestic emissions reductions and providing limited support for its domestic energy business and export potential, Canada missed a significant opportunity to make a larger impact on global emissions while also supporting their own economy.

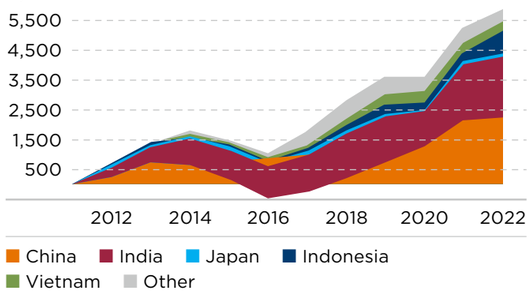
As demonstrated by the U.S., coal-to-gas switching is one of the most impactful near-term actions for reducing global emissions and maintaining or improving energy availability.

Assessment

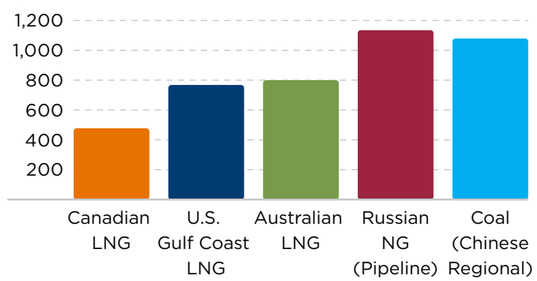
Canada could encourage the development of its relatively low-carbon traditional energy resources and, through associated export infrastructure, link this development to expanded LNG facilities that could displace coal in global markets. Canada, with its vast low-cost natural gas reserves and proximity to Asian markets, has an opportunity to offset substantial amounts of Asian coal demand. Canada has approximately 30 million tons per annum of LNG export capacity currently under evaluation, which, if constructed, could potentially offset more than 50 million tons of Asian CO_2 emissions per year while contributing more than $50 billion in government revenues over the lifespan of these projects.[1]

To capitalize on this opportunity, Canada could: 1) prioritize regulations that recognize emissions are a global rather than a local issue; 2) expand the necessary support infrastructure – such as pipelines, processing facilities, clean power generation, and power transmission; and 3) prioritize marketing to Asian countries to build confidence in Canada's ability to provide reliable energy imports that meet their growing needs.

Increase in coal consumption (2012–2022)[3]
TwH



2023 GHG emissions[4]
kg CO_2e/MWh



References:

(1) Boston Consulting Group, "Canada's Low-Carbon LNG Opportunity"
(2) EIA, QCG internal calculations assuming Canadian LNG has grown at the same rate U.S. relative to total production
(3) DOE National Energy Technology Laboratory 2019 Study
(4) Journal of Cleaner Production, "Greenhouse-gas emissions of Canadian LNG for use in China"
(5) EIA Statistical Review of World Energy
(6) Canadian Center for Energy Information

Gas Market Drives Change

U.S. coal-to-gas switching has driven one of the largest emission reduction success stories worldwide

Key Metric Summary

Local Climate Impact

Coal-to-gas switching in the U.S. saved ~3,351 metric tons of CO_2 emissions between 2005 and 2019, or ~200 metric tons annually.[1]

Global Climate Impact

Coal-to-gas switching provides an opportunity to save ~1.0 Gt in CO_2 emissions globally in 2035.[2]

Energy Impact

U.S. electricity prices have remained low.

Energy Security Impact

The U.S. has developed domestic gas reserves and become one of the world's largest gas exporters.

Economics without CO_2 Credits

Gas development has been financed organically via private investment (although many shale boom investments proved uneconomic).

Economics with CO_2 Credits

Carbon credits could further incentivize the use of natural gas to supplement renewables and further accelerate coal retirements.

Timeline to Execution

Less than a decade: The U.S. was able to embrace emerging technology to rapidly scale gas supply, an approach that is potentially replicable elsewhere.

Background and Context

Coal-fired power generation creates significantly more emissions compared to natural gas power generation. Historically, coal was the largest fuel source for U.S. power generation. Both coal and natural gas power generation can provide reliable, on-demand baseload power without the intermittency challenges faced by renewables. However, prior to 2007, U.S. natural gas production was stagnant, leading to discussions about importing LNG to meet the country's growing natural gas needs.

The shale gas revolution began with the development of horizontal drilling and fracture stimulation, expanding significantly in 2007 and unlocking vast new natural gas reserves in the U.S. The U.S. also initiated an aggressive effort to retire coal plants and replace coal-fired generation with natural gas combined cycle power generation. From 2005 to 2019, the U.S. retired 690 coal-fired plants across the country with a nameplate capacity of over 92,000 megawatts, decreasing active coal generation capacity by approximately 30% and halving the number of active facilities.[3] Over that same period, U.S. CO_2 emissions dropped by approximately 900 million metric tons.[1] Coal-to-gas switching accounted for 61% of the emissions decline. By 2023, natural gas had overtaken coal's market share, supplying 43% of U.S. power compared to coal's 16%,[4] helping further reduce emissions while maintaining lower energy prices.

Assessment

The rapid growth of natural gas generation in the U.S. and the resulting emissions reductions represent a major achievement over a relatively short 12-year period. In fact, U.S. emissions declined by more than the combined reductions of the next three largest emission-reducing countries globally. This coal-to-gas shift marked a significant turning point in the U.S., as emissions growth became decoupled from GDP growth.

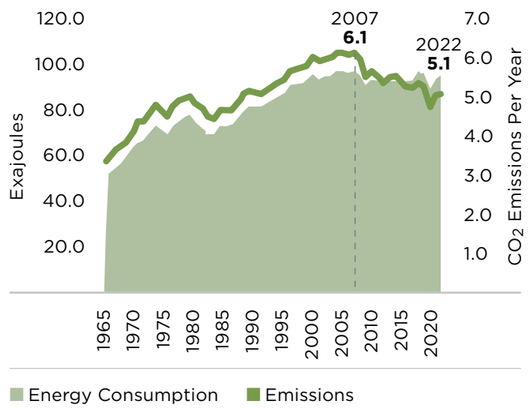
Globally, coal-to-gas switching saved an estimated 500 million metric tons of CO_2 emissions from 2005 to 2019, primarily in the U.S. and China.[4] Today, however, the world still burns 8.5 billion metric tons of coal annually – the highest level in history.[5] According to OpenMinds, replication of this U.S. strategy globally represents a major opportunity and could reduce CO_2 emissions by ~1.0 Gt through 2035, given that natural gas emits ~50% less CO_2 relative to coal when burned.[2] However, a full global shift from coal to gas is impractical: few countries share the U.S.'s natural gas resources and many regions lack the infrastructure to support natural gas at scale. Additionally, coal remains a key economic driver in countries like China and India. Still, this example shows the significant potential to reduce emissions with today's technology, even without new innovations.

References

(1) US Energy Related Carbon Dioxide Emissions, 2019 (EIA)
(2) Confronting the Dual Challenge: Emerging Solutions (OpenMinds)
(3) EIA-860M Survey Form (EIA)
(4) Share of electric generation by power type (EIA)
(5) Coal 2023 (IEA)
(6) 2024 Statistical Review of World Energy (Energy Institute)
(7) Energy Explained (EIA)
(8) U.S. on track to close half of coal capacity by 2026 (Institute for Energy Economics and Financial Analysis)
(9) Average Price: Electricity per Kilowatt-Hour in U.S. City Average (St. Louis Federal Reserve)

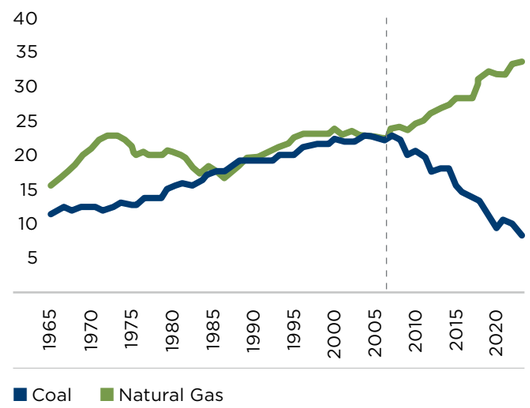
U.S. emissions have decoupled from energy consumption

U.S. energy consumption and CO_2 emissions trends (1965–2022)[6]



...driven largely by growth in gas vs. coal consumption

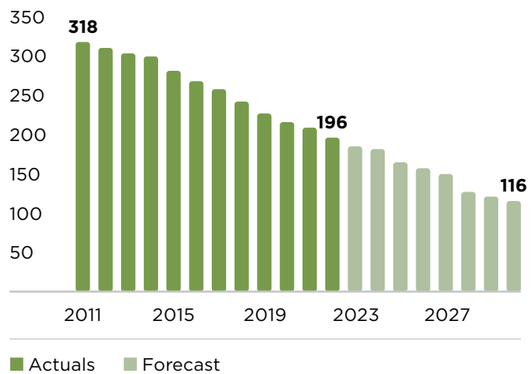
U.S. shift in energy sources: coal vs. natural gas consumption (1965–2022)[7] (QBtu)



...allowing the U.S. to aggressively retire coal plants

U.S. coal generation capacity[8]

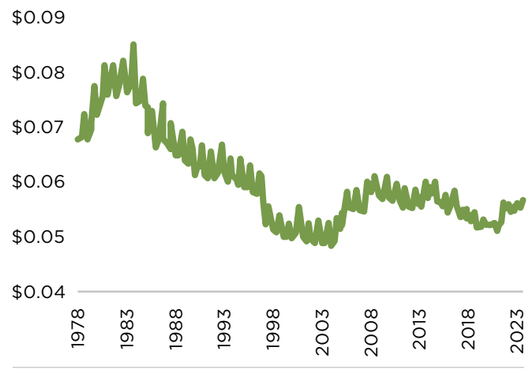
GW



...while household electricity prices have remained low

Historical U.S. household electricity prices (1978–2023)[9]

$/KWh, inflation adjusted



These Are Not The Hydrocarbons You Think You Know

U.S. oil and gas companies focus on reducing emissions as a "license to operate"

Key Metric Summary

Local Climate Impact

Emissions reduction efforts have resulted in a decrease of 60 million metric tons per year in the U.S.[2]

Global Climate Impact

Other nations with oil and gas operations could potentially use similar solutions to the U.S. to decarbonize hydrocarbons.

Energy Impact

The U.S. has maintained robust oil and gas production while advancing efforts to decarbonize operations.

Energy Security Impact

Enhancing operational efficiency and reducing emissions further strengthens the U.S. energy supply, making it more secure and sustainable.

Economics without CO_2 Credits

U.S. producers have realized efficiency gains and improved economics.

Economics with CO_2 Credits

Assuming high quality credits purchased at $80/ton, abatement in the U.S. would total to $4.8 billion per year.[2]

Timeline to Execution

Immediate: Since 2015, U.S. producers reduced GHG intensity by approximately 15% per year.[2]

Background and Context

A significant portion of global emissions result from the burning of hydrocarbons, including coal, oil, and natural gas, which currently account for approximately 80% of the world's energy mix. Approximately 17%[1] of these emissions are methane, a particularly harmful greenhouse gas that is 25 to 80 times[1] more impactful than CO_2 over a 20-year period. Historically, the oil and gas sector had been slow to address climate-related issues, with a primary focus on mitigating water, air pollution, and health and safety concerns. However, growing regulations and increased awareness are now driving energy companies to reduce their operational emissions and produce hydrocarbons with a lower emissions footprint.

Assessment

Today, lower emissions are a requirement to operate in the U.S., and the oil and gas sector is finding ways to reduce emissions while enhancing operational efficiency and profitability. Between 2015 and 2022, methane and GHG intensity declined by 57% and 39%, respectively, as reported to the EPA. For oil and gas operators, emissions reduction efforts focus primarily on improving operational efficiency, with U.S. operators reporting annually to the EPA and implementing both self-driven initiatives and federally regulated methane reduction measures.

Emission reductions are being achieved through various approaches, which oil and gas companies are implementing across the U.S. These examples illustrate efforts that have resulted in both reduced emissions and increased profitability:

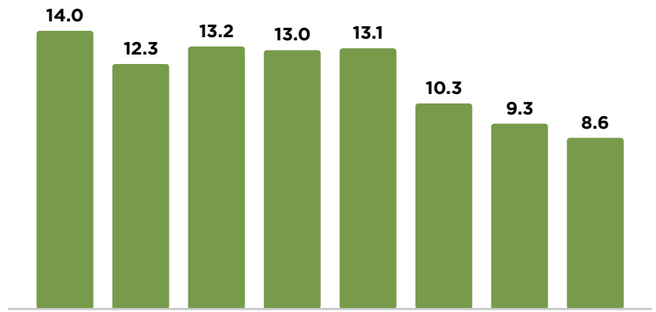
Methane Leak Detection and Mitigation: Readily available technologies, particularly for methane monitoring and reduction, enable operators to minimize leaks and venting, capturing natural gas that would otherwise be wasted and instead making it available for sale. Supervisory Control and Data Acquisition (SCADA) systems and continuous monitoring from companies like Project Canary immediately identify upsets and releases that could otherwise go undetected. Legacy equipment that regularly vents methane is being replaced with zero-emitting options, such as pneumatic controllers powered by instrument air.

Flaring Mitigation: Flaring is commonly used to manage excess gas production on new wells or during operational upsets. However, technological improvements and industry efforts to minimize waste gas have contributed to an 11% reduction in U.S. flaring-related emissions since 2015.

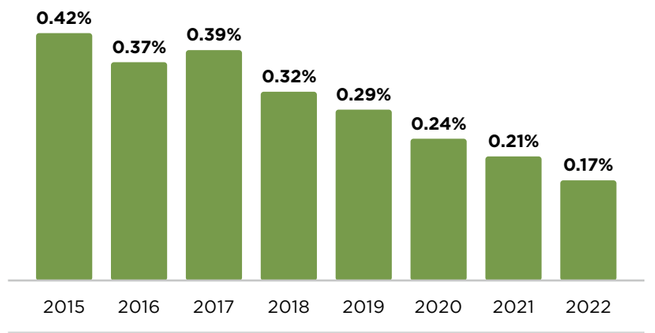
Use of Lower Carbon Fuels and Equipment in Operations: Many standard fuels and equipment are being retrofitted or replaced with lower-emission options, such as electric compressors, frac fleets, and drilling rigs. By replacing diesel fuel with electricity, companies are reducing CO_2 emissions while also lowering operational costs.

Additionally, operators are looking at advancing CCUS, along with other emerging decarbonization technologies, to mitigate emissions from industrial energy use. Given the current reliance on hydrocarbons, their unique attributes, the long timeline for any energy addition – typically measured in decades, not years – it is crucial to advance methods for lowering the emissions footprint of this core energy source. While all forms of decarbonization should be pursued before relying on carbon credits, high-quality carbon credits are available to offset emissions that are challenging to eliminate.

GHG intensity of top 100 U.S. producers (2015–2022)[2]
MT/Mboe



Methane intensity of top 100 U.S. producers (2015–2022)[2]
Percent



References:

[1] Statistical Review of World Energy (2024)
[2] ERM, Annual Oil and Gas Benchmarking Report (2024)

The Road Less Traveled

France's successful strategy of deploying nuclear energy for clean, reliable baseload power

Key Metric Summary

Local Climate Impact

Despite having one of the largest GDPs in Europe, France ranked 30th in CO_2 emissions per capita in 2022.[6]

Global Climate Impact

France is the world's largest net exporter of electricity and generates ~€3 billion annually from these sales.[7]

Energy Impact

France continues to rely on nuclear energy as its primary source of electricity – currently generating 70% – due to its reliable and clean baseload generation.[7]

Energy Security Impact

With a scaled reactor fleet and additional onshore capabilities, including enrichment, France is able to ensure affordable access to clean energy without relying on foreign imports.

Economics without CO_2 Credits

Scaling a domestic nuclear energy program can be extremely costly without subsidies, as several countries – including the U.S. – are experiencing with the expensive process of reviving aging nuclear programs.

Economics with CO_2 Credits

As governments incorporate nuclear energy into their carbon-free futures, several, including the U.S., have realized that production and investment tax credits are critical for managing initial development costs until nuclear energy deployments achieve sufficient momentum.

Timeline to Execution

Moderate: Following the oil embargoes of the 1970s, France began its nuclear program with a steady, well-supported strategy to grow its nuclear fleet, achieving a majority share of its electricity generation – a level of saturation that comparable countries will likely need decades to reach.[1]

Background and Context

The 1973–1974 OPEC oil embargo was a major shock to the global energy supply chain, shifting power to oil-producing nations and revealing the developed world's dependence on Middle Eastern oil imports. The embargo underscored the link between hydrocarbons and the geopolitical interests of their producers, highlighting the critical need for energy security. Countries responded in various ways: while some had readily accessible reserves to maintain energy independence, others, like France, lacked domestic resources and remained reliant on oil imports.[1]

Assessment

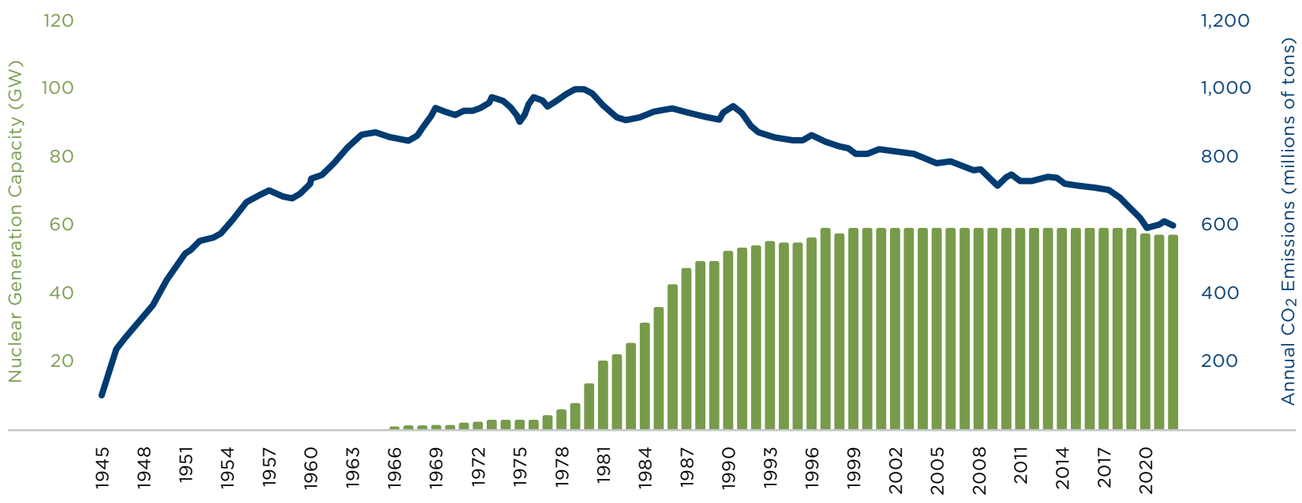
At that time, nuclear energy was an emerging technology, and France chose to strengthen its energy security by focusing on nuclear power as a major source of baseload electric production. This shift helped reduce the country's reliance on the oil-burning plants, which supplied the majority of France's electricity at the time.[2] Between 1975 and 1990, France aggressively expanded its nuclear capacity, building and connecting 52 reactors, with over half completed in the first 10 years.[3] Furthermore, France developed its own uranium enrichment capabilities and became one of the world's largest uranium enrichment providers for nuclear power.[4] Since the mid-1980s, nuclear energy has provided the majority of France's electricity supply, hovering at around 70% of the total energy mix.[1]

France's nuclear buildout, launched in 1975, significantly boosted its energy independence and reduced emissions, giving France one of the lowest emission intensities in the European power sector. This shift has also helped France remain competitive with some of the lowest electricity prices across Europe.[3][5]

However, the nuclear expansion was not without challenges. The Saint-Laurent-des-Eaux nuclear power plant in central France experienced two level 4 nuclear incidents on the International Nuclear and Radiological Event Scale (INES), in 1969 and 1980, both resulting in partial core meltdowns. The reactors were repaired each time, and the plant continued operation until its closure in 1992. Despite these incidents, a 2007 study by Markandya & Wilkinson found that nuclear power has a death rate from accidents and air pollution per terawatt-hour comparable to wind and solar (~0.03), which is over 800 times lower than coal (~25).

France began reducing emissions in the late 1970s because of their nuclear power buildout

France's nuclear generation capacity and CO_2 emissions over time (1945–2020)[5][6]



References:

(1) Nuclear power plants generated 68% of France's electricity in 2021 (EIA)
(2) Why The French Like Nuclear Energy | Nuclear Reaction | FRONTLINE | PBS)
(3) PRIS – Country Details
(4) Uranium Enrichment – World Nuclear Association
(5) CO_2 Intensity of Grids by Country (Our World In Data)
(6) IEA
(7) Nuclear Power in France - World Nuclear Association

Necessity Is the Mother of Invention

European energy security challenge illustrates that timely solutions are possible when faced with adversity

Key Metric Summary

Local Climate Impact

~225 million metric tons of CO_2 abated from 2022–2023 due to a reduction in combustion emissions.[8]

Global Climate Impact

~215 million metric tons of global CO_2 abated from 2022–2023, accounting for local emissions abatement adjustments and a decline in industrial output.[9]

Energy Impact

Europe experienced significant increases in energy costs to meet energy needs.

Energy Security Impact

Europe was able to wean off Russian pipeline gas dependence, though this process led to significant energy price increases, which could have been magnified with harsh weather scenarios.

Economics without CO_2 Credits

Economic impact has been negative, with substantial increases in energy import costs driven by national security needs.

Economics with CO_2 Credits

Carbon credits partially offset declines in industrial output driven by elevated energy costs.

Timeline to Execution

Rapid: Europe was able to cut Russia pipeline gas exports by 70% within a year.[5]

Background and Context

Following the Russian invasion of Ukraine in February 2022, Europe faced extreme energy adversity, as the continent was forced to find alternatives to Russian gas, which had supplied approximately 40% of the EU's total gas demand and 10% of its total gross available energy in 2021.[1][2] Russia's use of its natural gas resources as an economic and political lever meant Europe needed to act quickly to address considerable uncertainty over Russian gas supplies ahead of winter demand.

Assessment

Europe managed to navigate winter 2022 through a combination of LNG imports, conservation, fuel switching, and fortuitous weather – an outcome few had predicted. After an additional year to prepare, the EU exited winter 2023 with gas storage at record levels.[3] Since Russia's invasion of Ukraine, Europe has added approximately 10 Bcf per day of new LNG regasification capacity, enabling a 60% increase in LNG imports from 2021 to 2023. This increase has displaced around 40% of pre-invasion Russian gas supplies.[4][5] Additionally, European consumers reduced natural gas usage by approximately 20% compared to pre-war levels.[6] Together, these efforts have helped Europe maintain sufficient energy supplies to meet their needs, as evidenced by their record gas storage levels in 2023.

The speed of LNG buildout and implementation of conservation measures was remarkable. Shortly after the invasion, Germany announced its intention to develop its own LNG infrastructure, starting with interim floating units and transitioning to permanent land-based facilities over time. The first floating unit was inaugurated in December 2022, only 10 months after the invasion. Europe's existing LNG import and pipeline infrastructure further facilitated the rapid expansion of additional LNG import terminals.

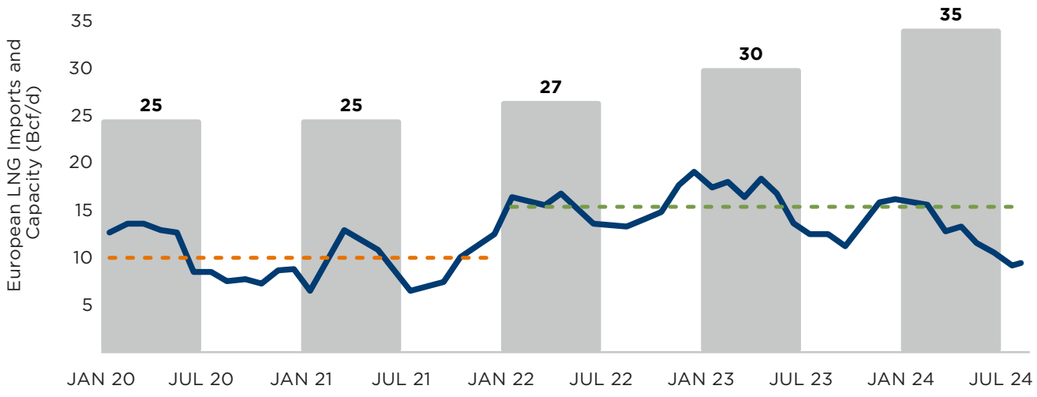
Another positive outcome of this energy security challenge was the reduction in CO_2 emissions associated with the conservation and efficiency efforts. While this rapid behavioral change led to meaningful cost inflation – with the EU's energy import bill increasing by ~270% from 2020 to 2022[7] – the European economy avoided a major recession or disruption, a remarkable feat given the initial magnitude of Russian reliance.

References:

(1) How Europe can cut natural gas imports from Russia significantly within a year (UChicago)
(2) 2021 EU Energy Mix (Eurostat)
(3) EU exits winter with gas storage at record levels (Financial Times)
(4) European LNG Tracker (Institute for Energy Economics and Financial Analysis)
(5) European natural gas demand imports
(6) European natural gas demand tracker)
(7) European energy costs (European Union)
(8) Total CO_2 Emissions From Combustion in the EU (IEA)
(9) Change in Production of Manufactured Goods (Eurostat); World Manufacturing Production (United Nations Industrial Development Organization)
(10) Bloomberg

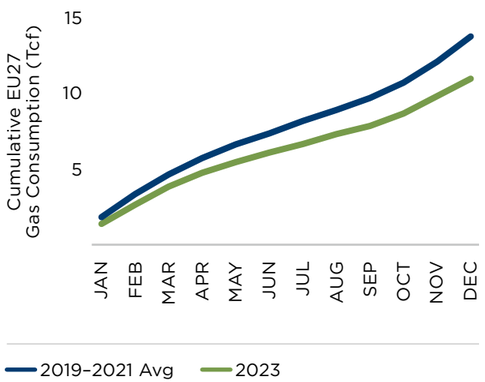
Europe has been able to rapidly deploy LNG import terminals to scale capacity...

Trends in European LNG imports and capacity (2020–2024)[4][10]



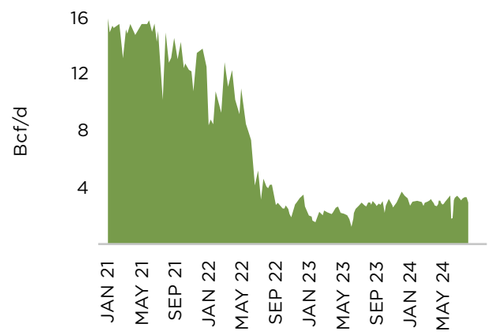
...while reducing natural gas consumption to balance supply constraints

Cumulative EU gas consumption (2023 vs. 2019–2021 average)[6]



...and ultimately decreasing reliance on Russian pipeline gas

EU daily gas consumption trends (2021–2024)[5]



PART 5

Technological Advances & Prospects for the Future

Technology Advancements Supporting the Energy Addition

Technology advances have and will play a meaningful role in the Dual Challenge

Technological advancements have played and will continue to play a crucial role in both providing abundant energy and reducing emissions. Technology enables the deployment of cleaner energy sources, improves energy efficiency, and creates new opportunities for reducing greenhouse gas emissions. Continued investment in research and development, along with supportive policies and market mechanisms, will be critical to accelerating these advancements and achieving global climate goals.

Technological advances help increase energy efficiency, which is a major factor in limiting energy demand growth in advanced economies. In the U.S., energy intensity – or the amount of energy consumed per unit of GDP – decreased about 36% from 2000 to 2020,[2] with recent annual improvements ranging from 1–2% per year.[3] In 2023, the U.S. invested over $390 billion in energy efficiency initiatives, supported by policies like the IRA, which aims to deliver additional efficiencies in the coming years. Both residential and commercial energy intensities are projected to continue to decrease through 2050 as states and localities adopt new building energy codes and existing homes and commercial spaces install energy-efficient technologies. Examples include insulated high-performance windows, heat pumps, LED lighting, solar panels, and energy efficient appliances.

Advancements in technology are also accelerating the adoption of energy addition solutions and reducing costs. These advances are occurring across a broad spectrum of projects and areas, including but not limited to the areas outlined below:

Renewable Energy Technologies in Solar and Wind

- **Efficiency Improvements:** Advances in solar cell technology have significantly increased the efficiency of converting sunlight into electricity.
- **Cost Reductions:** Technological improvements and economies of scale have dramatically reduced the cost of solar panels, making solar energy one of the cheapest sources of electricity in many regions.
- **Turbine Design:** Innovations in turbine design, such as larger blades and taller towers, have increased the capacity and efficiency of wind turbines.
- **Offshore Wind:** Advances in offshore wind technology have opened new areas for wind energy development, providing access to stronger and more consistent wind resources.

Energy Storage via Battery Technology

- **Lithium-Ion Batteries:** Improvements in lithium-ion battery technology have increased energy density, reduced costs, and extended the lifespan of batteries, making them more viable for both grid storage and electric vehicles.
- **Next-Generation Batteries:** Research into solid-state batteries, flow batteries, and other advanced storage technologies promises further improvements in performance and cost.

Grid Integration

- **Smart Grids:** Smart grid technologies enhance renewable energy source integration, grid stability, and efficient energy distribution.
- **Demand Response:** Advanced metering and control technologies enable demand response programs, which can reduce peak demand and improve grid efficiency.

Electric Vehicles (EVs)

- **Battery Improvements:** Advances in battery technology have increased the range and reduced the cost of electric vehicles, making them more competitive with internal combustion engine vehicles.
- **Charging Infrastructure:** Development of fast charging technologies and widespread deployment of charging stations have made EVs more convenient for consumers.
- **Efficiency Gains in Autonomous and Connected Vehicles:** Innovations in autonomous and connected vehicle technology can optimize driving patterns, reduce congestion, and improve fuel efficiency, further reducing emissions.

Energy Efficiency in Building and Industrial Process Technologies

- **Insulation and Windows:** Advances in building materials, such as high-efficiency insulation and windows, have significantly reduced energy consumption for heating and cooling.
- **Smart Thermostats and Controls:** Smart home technologies allow for more precise control of energy use, reducing waste and improving efficiency.
- **Process Optimization:** Advanced sensors, automation, and data analytics enable more efficient industrial processes, reducing energy consumption and emissions.
- **Waste Heat Recovery:** Technologies for capturing and reusing waste heat from industrial processes can significantly improve overall energy efficiency.

Carbon Capture, Utilization, and Storage (CCUS)

- **Post-Combustion Capture:** Advances in chemical solvents and other capture technologies have improved the efficiency and reduced the cost of capturing CO_2 from power plants and industrial sources.
- **Direct Air Capture:** Emerging technologies for capturing CO_2 directly from the atmosphere hold promise for addressing emissions from diffuse sources.
- **Geological Storage:** Improved techniques for injecting and storing CO_2 in geological formations ensure safe and long-term sequestration.
- **Carbon Utilization:** Technologies for converting captured CO_2 into useful products, such as fuels and building materials, provide additional pathways for reducing emissions.

Numerous new and advancing technologies are being developed to help address the Dual Challenge. This section explores some of the most critical areas, examining where these technologies are on the development pathway, the challenges they face, and their expected timeline to commerciality and adoption. We will cover energy storage, electric vehicles, CCUS, nuclear, hydrogen, and ammonia.

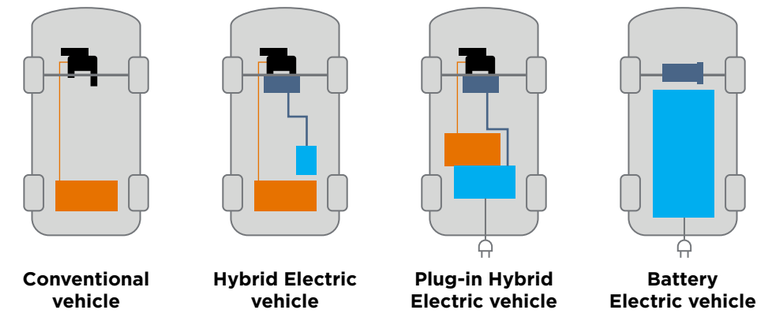
Electric Vehicles (EVs)

EVs have achieved deployment success, and the industry is expected to continue growing, but resource and infrastructure constraints could slow progress.

Description

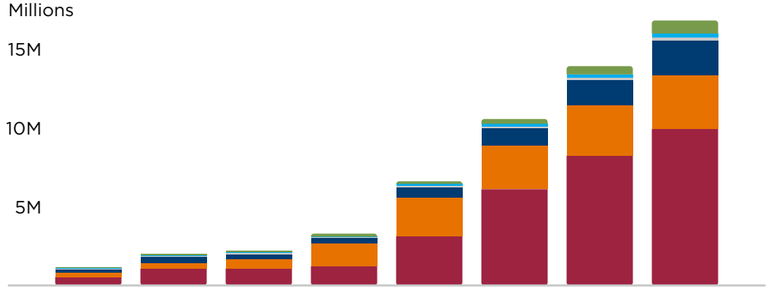
EVs are powered by electricity, using electric motors and batteries to store and provide energy instead of internal combustion engines (ICE). Battery EVs (BEVs) are considered zero tailpipe emission vehicles, as they emit no greenhouse gases while in operation. Other types of EVs include plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and fuel cell electric vehicles (FCEVs), which are less relevant.

Comparison of Vehicle Types[1]

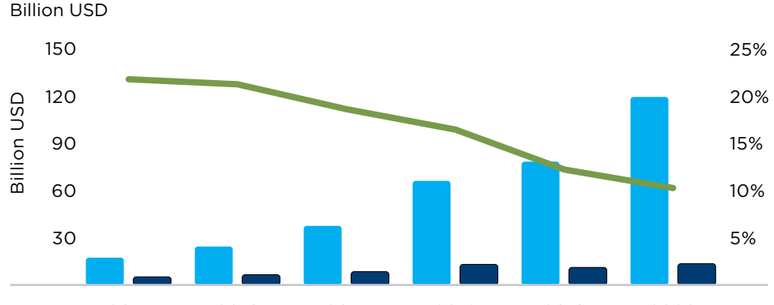


Electric vehicle sales still rising

Sales of passenger EVs (2017–2024)[2]



Consumer & government spending on electric cars (2015–2020)[5]



Current State and Recent Progress

Growth: In 2023, approximately 14 million new electric cars were registered globally, bringing the total number of EVs on the road to 40 million worldwide. BEVs accounted for 70% of the electric car stock in 2023. While EV sales continue to grow globally, the market is materially concentrated. In 2023, around 60% of new EV registrations were in China, 25% in Europe, and 10% in the U.S., accounting for nearly 95% of global electric car sales combined.[3] Despite this growth, EVs still represent less than 4% of approximately 1.1 billion cars in the world.

Investment: Worldwide, reported investment announcements from 2022 and 2023 alone exceeded $275 billion in EVs and $195 billion in EV batteries.[3] This surge in funding is largely driven by government subsidies and incentives. While large-scale government-backed investment in technologies like hydrogen is relatively new, EVs exemplify a technology that has benefitted significantly from public spending and is now reaping the benefits of increased consumer demand. Strict targets have also spurred investment. Currently, 16 countries – including Canada, Japan, and the U.K. – have policies mandating 100% EV sales in 2035 or earlier.[4]

Current Limitations/Challenges

Resource constraints: EVs rely on batteries, which are costly to manufacture and currently depend on battery chemistries that require rare earth metals. These metals are scarce, energy-intensive to mine, and geographically concentrated, impacting the ability to scale EV production quickly and at feasible costs.

Infrastructure requirements: EVs require a robust charging infrastructure network, which does not yet exist at scale. A scenario of net-zero by 2050 would require a stock of 17 million publicly-available charging points by 2030, necessitating an annual increase of around 23% from 2023 levels.[3] Additionally, existing power infrastructure will face increased strain as EV adoption grows due to the added power load. Managing this demand will be crucial to support the complete transition from ICE engines to EVs over the next few decades.

Installed base and cost: Currently there are over 1 billion ICE cars worldwide, which would take decades to replace. Cost also continues to be a concern as the average full electric model has a starting price of $53,048 compared to an average of $35,722 for an ICE compact crossover in the U.S. The cost gap is coming down but remains an impediment to accelerated adoption.[6]

Future Impact If Successful

EVs emit more than five times less emissions compared to ICE vehicles, depending on the energy source used to charge the EV.[7] Increased penetration of EVs can rapidly decarbonize the transportation industry, which accounts for a significant portion of emissions – approximately 30% in the U.S., for example.[8]

EVs have made considerable progress over the past decade. Continued government support, along with expanded infrastructure and strengthened power grids, will be essential to achieve deployment levels needed to support climate goals.

References:

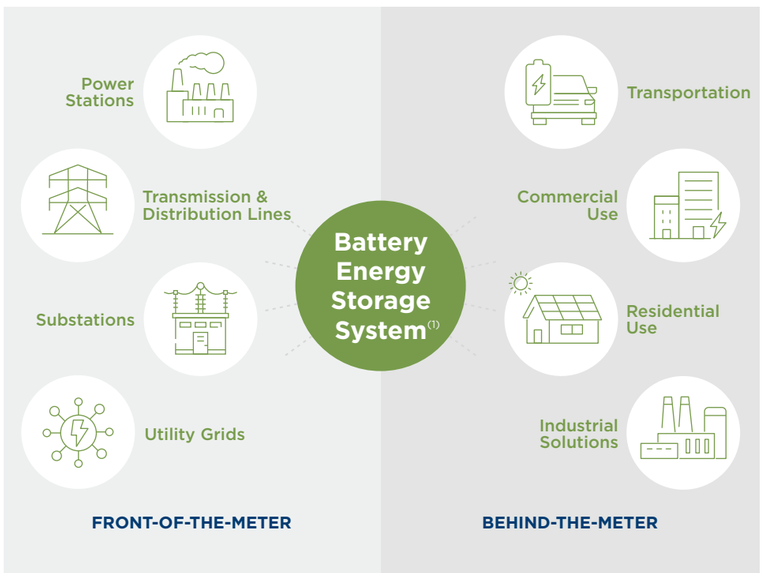
[1] www.linkedin.com/pulse/best-choice-ice-vehicles-vs-evs-hybrid-how-shaping-up-kulkarni/
[2] BNEF, EV Market Growth Jan 2024.
[3] International Energy Agency, Global EV Outlook 2024, April 2024.
[4] World Resources Institute, Countries Adopting Electric Vehicles Fastest, September 2023.
[5] International Energy Agency, Electric Vehicles
[6] Edmunds, Big Gap Remains in Average Price of Electric Car vs. Gas Car
[7] U.S. Department of Energy, Alternative Fuels Data Center, September 2024.
[8] U.S. Environmental Protection Agency, Fast Facts on Transportation, 2023.

Energy Storage

Energy storage is critical to facilitate renewable penetration, but cost and supply chain dynamics limit rapid deployment.

Description

Energy storage, specifically battery energy storage systems (BESS), are batteries that receive electricity from the power grid, directly from a power station, or from renewable energy sources. BESS store this energy and then release it when needed. These systems can be small-scale and behind-the-meter (e.g., residential-level energy storage) or large-scale and front-of-the-meter (e.g., utility-scale battery at a solar farm or power plant). BESS are used to manage energy demand, boost grid resilience, and address intermittency by providing a consistent flow of electricity when renewable sources are unavailable.



Current State and Recent Progress

Growth: In 2023, the global BESS market doubled, adding over 90 gigawatt-hours (GWh) of capacity and bringing the total global volume of battery storage to over 190 GWh.[1] Despite this growth, BESS capacity still represents less than 1% of global electricity demand, which is approximately 27,000 terawatt-hours.[2] Nearly 90% of the newly added capacity came from China, the EU, and the U.S.

Improved economics: The IEA attributes strong BESS growth to declining prices for lithium-ion batteries, which fell from around $800 per kilowatt hour (kWh) in 2013 to under $140 per kWh in 2023. This price drop is due to advances in battery chemistry and manufacturing, complemented by market reforms and declining equipment costs. In the U.S. specifically, the IRA established federal tax credit eligibility for BESS projects. Nonetheless, the IEA asserts that additional cost reductions are essential to scale up batteries globally.

Current Limitations/Challenges

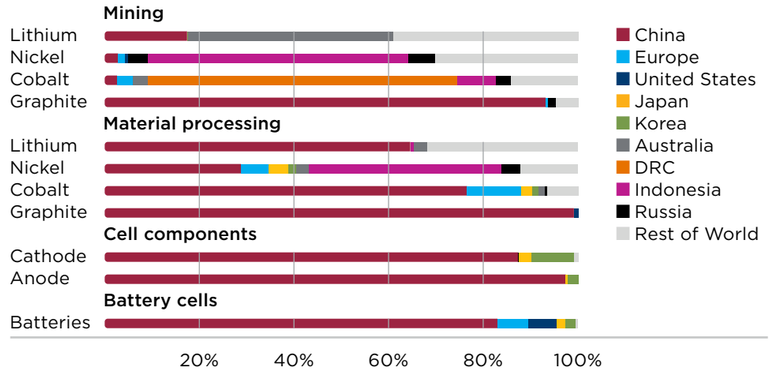
Economics: While battery costs have declined by 90% in less than 15 years and utility-scale batteries paired with solar are already competitive with new coal in some countries such as India,[1] it will likely take a few years for costs to be competitive with new natural gas in the U.S. and new coal in China. In the U.S., government incentives are a key driver of economic feasibility for BESS, with subsidies currently accounting for an estimated 25% reduction in storage costs.[3]

Energy security: The geographic concentration of the entire BESS supply chain makes it vulnerable to geopolitical risks, impacting both cost and supply. Battery manufacturing remains concentrated in only a few countries, as does the extraction and processing of the critical minerals it relies on. Raw material supply and extraction are geographically concentrated in countries like Australia (lithium), Democratic Republic of the Congo (cobalt), and Indonesia (nickel). Over half of global raw material processing for BESS-critical minerals – including lithium, cobalt, and natural graphite – occurs in China, which also holds almost 85% of battery cell manufacturing capacity.

Supply chain: The concentrated manufacturing of BESS creates vulnerabilities to logistical disruptions caused by political tensions, trade policies, tariff structures, or local crises. Additionally, the scarcity of critical minerals for manufacturing strains the supply chain, and surging demand for BESS could lead to shortages or significant price increases.

Geographical distribution of the global battery supply chain[2]

Percent



Future Impact If Successful

Further growth of BESS solutions depends on continued cost reductions, diversification of manufacturing for energy security, and addressing supply chain challenges.

Geographic diversification of battery manufacturing: While China currently produces the most batteries today, the IEA reports that 40% of announced plans for new battery manufacturing facilities are in advanced economies such as the U.S. and EU.

Development and refinement of battery chemistry less reliant on critical earth minerals: Alternatives to lithium-ion batteries, such as sodium-ion batteries, use more abundant raw materials. The expectation is that further innovation in battery chemistries and manufacturing could reduce global average lithium-ion battery costs by another 40% from 2023 to 2030.

BESS deployment will be a key factor in achieving global renewable energy and emissions reduction goals. To triple renewable energy capacity by 2030, as required under COP28 (net-zero by 2050), the IEA projects that around 1,200 gigawatts of energy storage will be required – up from the current 85 gigawatts of installed BESS capacity worldwide.[1]

References:

[1] Integra Sources
[2] International Energy Agency, Batteries and Secure Energy Transitions
[3] Lazard LCOE+ (June 2024)

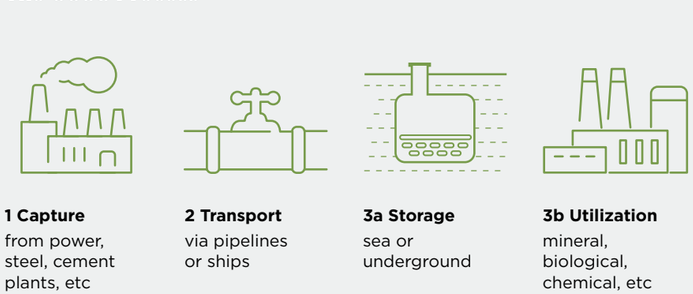
Carbon Capture, Utilization, & Storage (CCUS)

CCUS is poised to be a major player in decarbonizing traditional energy sources and helping achieve net-zero emissions targets, but the sector must overcome challenges related to cost, technological barriers, and public support.

Description

CCUS is a set of technologies designed to reduce carbon emissions by capturing CO_2 from industrial processes, power generation, or directly from the air. The captured carbon can be: (i) utilized by being converted into products (such as enhanced oil recovery (EOR) or materials like concrete), or (ii) stored underground in geological formations to ensure the emissions do not re-enter the atmosphere.

The CCUS Process[1]



1 Capture
from power, steel, cement plants, etc

2 Transport
via pipelines or ships

3a Storage
sea or underground

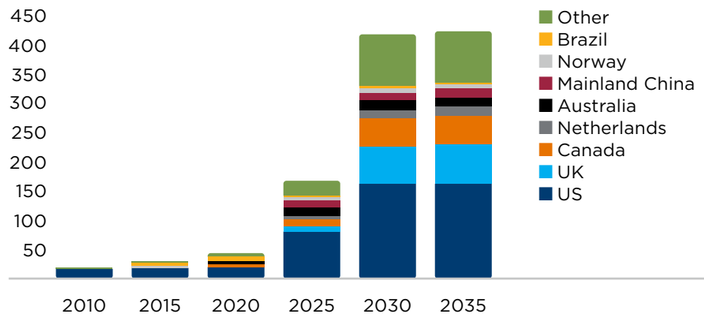
3b Utilization
mineral, biological, chemical, etc

Current State and Recent Progress

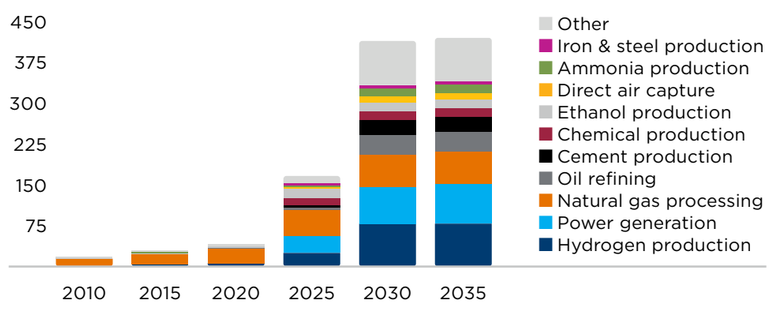
Growth: Global carbon capture reached approximately 53 million tons per annum by the end of 2023, representing a 7% compound annual growth rate (CAGR) since 2010 but representing only about 0.1% of global emissions. Beyond gas processing and ethanol, CCUS is a nascent technology. Initial growth was incentivized by EOR projects, particularly in the U.S., though global net-zero goals have now overtaken EOR as the main driver of CCUS demand. The U.S. is the market leader, with 39% of proposed carbon capture capacity by 2035, followed by the UK with 12%, and the rest of Europe with 16%.[2]

Diverse Project Base: Given the wide range of CCUS applications, multiple pathways exist to achieve carbon capture. Currently, the CCUS market is largely driven by natural gas processing, with EOR serving as a primary utilization method for the captured carbon. However, BloombergNEF forecasts that hydrogen and power generation will gain significant market share by 2030.

Proposed carbon capture capacity by market (2010–2035)[2]
Million metric tons of CO_2 per year



Global carbon capture capacity by point source, historical and announced (2010–2035)[2]
Million metric tons of CO_2 per year, cumulative



Government incentives: Like many other capital-intensive climate solutions, CCUS relies on incentives to achieve economic feasibility. The U.S. IRA increased tax credits for carbon capture projects, and countries such as Norway and Canada are developing large-scale projects, including Norway's Northern Lights CCS project and Canada's Alberta Carbon Trunk Line.

Current Limitations/Challenges

Economics: Costs vary significantly by source. For carbon capture, costs range from $15–$25 per ton of CO_2 for some industrial processes to $40–$120 per ton of CO_2 for more complex processes, such as cement production and power generation. Transport and storage costs also vary based on factors like volume, transport distances, and storage conditions. In the U.S., onshore pipeline transport costs range from $2–$14 per ton of CO_2, while onshore storage costs have a wider spread.[3] Tax credits, like the U.S. 45Q program, provide up to $85 per ton of CO_2 for point source capture and $180 per ton for direct air capture with permanent storage; however, these incentives often fall short of fully covering the costs for many projects.[4]

Efficiency: Efficiency challenges limit CCUS applications. Current carbon capture projects do not capture 100% of emissions; while many are designed to achieve a 90% capture rate, actual rates are often lower. Additionally, the energy required to power capture systems can increase power demand by 13–44%, depending on the application. Similarly, transport and geologic sequestration of carbon also face efficiency risks, primarily associated with CO_2 leakage.[5]

Public support: In many jurisdictions, CCUS is perceived as supporting the continued use of hydrocarbons, which can limit public support. Creating a paradigm that supports reducing emissions and providing abundant energy will be critical to improving support for this technology.

Future Impact If Successful

Currently, CCUS captures approximately 53 million tons of carbon emissions per year. However, to meet long-term climate goals, the IPCC and IEA estimate that around 1 billion tons per year will need to be captured through CCUS by 2030, increasing to several billion tons by 2050. Achieving this scale by 2030 or 2050 is currently considered unrealistic.

CCUS has the potential to significantly reduce emissions from sectors that are otherwise difficult to decarbonize. If successfully scaled, it could mitigate millions of tons of carbon emissions annually. However, the current global CCUS capacity is nowhere near the levels needed to achieve net-zero, and significant upfront investment will be required to reach these targets.

References:

[1] International Association of Oil and Gas Producers
[2] BNEF, CCUS Market Outlook 1H 2024, June 2024.
[3] International Energy Agency, Is Carbon Capture Too Expensive?, February 2021.
[4] International Energy Agency, The Future of Hydrogen, June 2019.
[5] World Economic Forum, 7 Things to Know About CCUS, November 2023.

Nuclear Energy

Nuclear energy could meet the need for zero-emission baseload power, but a few notable accidents, limited public support, and recent cost over-runs pose challenges to increased adoption.

Description

Nuclear energy is released from the nucleus (core) of atoms. It can be released through fission (splitting large atomic nuclei like uranium or plutonium) or fusion (fusing small nuclei like hydrogen). Currently, all nuclear energy is generated through fission. While fusion releases more energy than fission, fusion remains in experimental phases and is unlikely to reach commercial scale for decades, if at all. Nuclear power plants use the heat from fission to turn water into steam, which drives turbines to create electricity.

Current State and Recent Progress

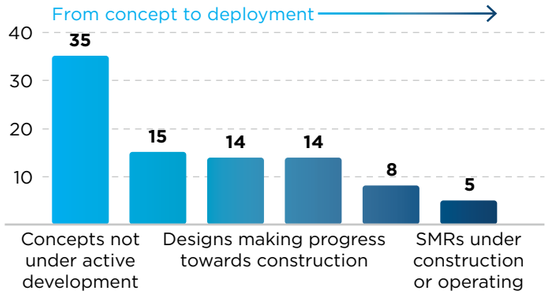
Growth: Nuclear energy currently provides about 9% of the world's electricity from around 440 power reactors. In 2023, nuclear plants supplied 2,602 terawatt-hours of electricity, up from 2,545 terawatt-hours in 2022, a 2% increase.[1] Countries are divided in their approach to nuclear energy: China is rapidly expanding with 30 reactors under construction; France derives around 70% of its electricity from nuclear energy; conversely, Germany completed its nuclear phase out in 2023.

In the U.S., the Department of Energy's Loan Programs Office announced a $1.52 billion commitment in March 2024 to restart the Palisades Nuclear Plant in Michigan. The most recent nuclear power plant built in the U.S. is the Vogtle Unit 3 in Georgia, which became operational in 2023, marking the first new nuclear reactor in the U.S. in over 30 years.[1]

Technological advancements: Innovations in small module reactor (SMR) development have boosted the feasibility of new nuclear power projects. SMRs have smaller physical footprints, reduced capital investment requirements, provisions for incremental power additions, and are designed to offer distinct safeguards, security, and nonproliferation advantages.[2] SMR development is still in early stages, but the pipeline of pre-construction projects is growing.

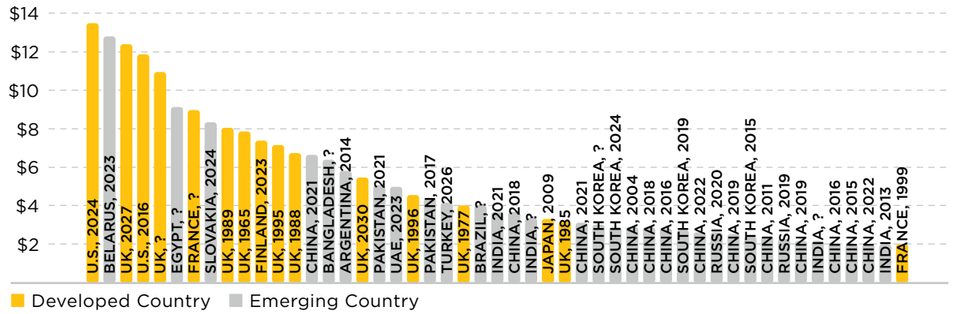
SMR Pipeline: Progress from concept towards first commercial deployment[3]

Number of SMR designs



Nuclear capital costs by country and year of completion[8]

Millions of 2023 US$ per MW



Recent retirement delays and restarts: In the U.S. and EU, retirements for nuclear plants have been delayed to support power demand. The Diablo Canyon plant in California was slated for retirement in 2025, but the state extended operations through 2030 to help prevent rolling blackouts.[4] In the EU, Belgium originally mandated that all nuclear power plants shut down by 2025, but the government has extended operations for its two newest reactors through 2035 to meet electricity demand.[5] In September 2024, Constellation Energy announced plans to restart operations at Three Mile Island Unit 1 in Pennsylvania, aiming to have the reactor operational by 2028. The company plans to invest approximately $1.6 billion in refurbishments to bring the reactor back online. Microsoft agreed to purchase electricity from the plant to support its growing fleet of data centers.

Current Limitations/Challenges

Economics: Over the past decade, both traditional nuclear reactor and SMR development projects have faced significant cost overruns and schedule delays. Two nuclear reactors in Georgia (Vogtle 3&4), which were intended to herald a nuclear power revival in the U.S., were completed seven years behind schedule and $17 billion over budget. Nuclear costs in the U.S. are among the highest in the world, driven by regulatory hurdles and permitting, high labor costs, and lack of design standardization.[6]

New generation nuclear slow to deliver: On the SMR side, deployment costs and schedules for four SMRs operating or under construction in Russia, China, and Argentina have dramatically exceeded original projections, with costs now three to seven times higher than originally estimated.[7]

Nuclear waste: Nuclear energy produces high-level nuclear waste, such as spent nuclear fuel, which remains highly radioactive for thousands of years. Safe disposal of this waste is critical to ensuring the long-term safety of nuclear technology. At the Hanford Nuclear Site in Washington, the cleanup of 56 million gallons of chemical and nuclear waste is a $110 billion project expected to take 50 years.[9]

Public support and safety: A series of rare but devastating nuclear disasters have led to significant public scrutiny of nuclear power: most notably the incidents at Three Mile Island (1979), Chernobyl (1986), and Fukushima (2011). Germany's decision to phase out its nuclear program was spurred after the Fukushima disaster.

National security: Nuclear waste sites pose potential national security risks as targets during wartime. Additionally, diversifying the supply chain is essential for securing nuclear independence worldwide. Russia currently controls nearly 40% of the global uranium enrichment market.[10]

Future Impact If Successful

Nuclear energy produces minimal greenhouse gas emissions during operation, making it one of the cleanest large-scale energy sources. According to the International Atomic Energy Agency (IAEA), nuclear power prevents over 2 gigatons of carbon emissions annually by replacing fossil-fuel power plants.

While nuclear energy plays a crucial role in reducing greenhouse gas emissions and providing reliable power within the existing operating fleet, high costs, waste management challenges, public support and safety concerns, and national security issues have all contributed to limiting its continued growth. Innovations like SMRs and advancements in nuclear waste solutions could address some of these challenges, but there is still a long path ahead before nuclear energy can fully realize its potential as a clean, safe, and economically viable energy source.

References:

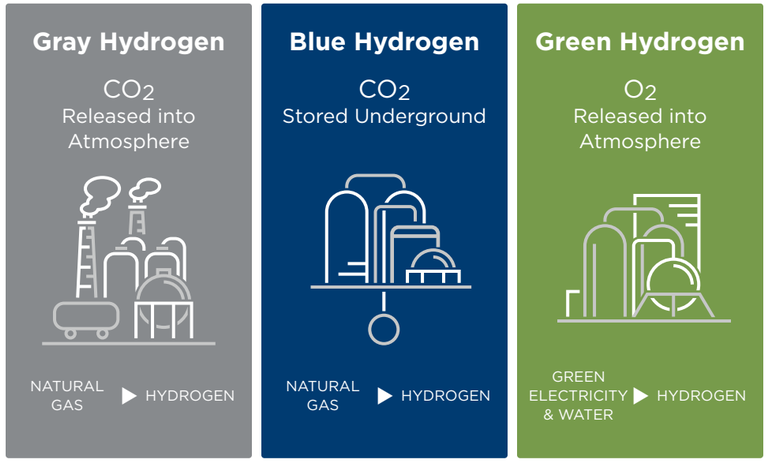
(1) World Nuclear Association, Nuclear Power in the World Today, September 2024.
(2) U.S. Department of Energy, Benefits of SMRs.
(3) Nuclear Energy Agency
(4) *Fortune*
(5) World Nuclear Association
(6) MIT
(7) IEEFA, Small Modular Reactors, Still Too Expensive, Too Slow and Too Risky (May 2024)
(8) JP Morgan, Eye on the Market 14th Annual Energy Paper (March 2024)
(9) NBC News, Welcome to "the Most Toxic Place in America", November 2016.
(10) Columbia SIPA, Reducing Russian Involvement in Western Nuclear Power Markets, May 2022.

Hydrogen

Hydrogen has the potential to address hard-to-decarbonize sectors with robust government support and financial incentives, but the incremental infrastructure needed to support growth is substantial.

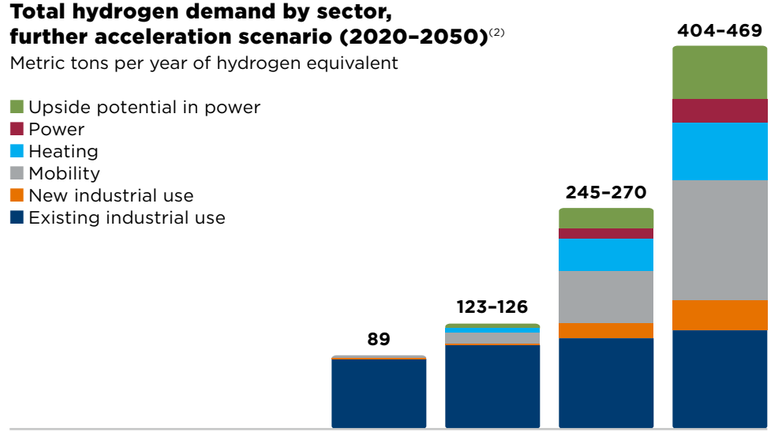
Description

Hydrogen can be used as power or direct fuel. For power generation, hydrogen gas is converted into electricity inside a fuel cell, where a chemical reaction between hydrogen and oxygen produces electricity, with water and heat as byproducts. Hydrogen can also be used as direct fuel in hydrogen-powered vehicles or for industrial applications. It can be produced from various sources like natural gas or water via electrolysis. The three main hydrogen production pathways (often referred to by color) are classified by their feedstock and energy source.



Total hydrogen demand by sector, further acceleration scenario (2020–2050)[2]

Metric tons per year of hydrogen equivalent



	2020	2030	2040	2050
Share of clean hydrogen, %	<1%	~30	~77	~93

Current State and Recent Progress

Growth: Virtually all hydrogen consumed today is gray hydrogen (around 90 million tons per year). However, demand for gray hydrogen is projected to decline as demand for clean hydrogen – both green and blue – rises and the costs of green hydrogen become more competitive. By 2050, clean hydrogen could account for 73–100% (125 to 585 million tons per year) of total hydrogen demand.

Financial and government incentives: In the U.S., the IRA introduced a production tax credit for clean hydrogen production. The EU's Green Deal also promotes clean hydrogen through financial support mechanisms. In additional to financial incentives, countries around the world have established ambitious targets. The EU aims to install 6 gigawatts of electrolysis capacity by 2024, scaling up to 40 by 2030 under the REPowerEU plan.[5] The U.S., under the Bipartisan Infrastructure Law, has set a Department of Energy target of producing 10 million tons per annum of clean hydrogen by 2030. Japan has set a target of producing 12 million tons per annum by 2040[7] and China plans to have 50,000 hydrogen fuel cell vehicles on the road by 2025, increasing its electrolyzer capacity to meet domestic demand.[8]

Current Limitations/Challenges

Economics: Current hydrogen production costs far exceed traditional fuel. For instance, $30 per barrel of oil[9] translates to approximately $0.22 per kilogram, which is over eight times cheaper than the $2.13 per kilogram cost of gray hydrogen. Green hydrogen production is more than three times more costly than gray hydrogen. A substantial reduction in the price of green hydrogen will depend on economies of scale and continued policy support.

Supporting infrastructure: Hydrogen is not easily compatible with existing fuel infrastructure due to its low energy density by volume, meaning it requires high pressures or low temperatures for effective storage and transport. Considering existing government targets, a 2021 estimate projected that global hydrogen spending could exceed $600 billion by 2030, with $200 billion required for infrastructure development to support hydrogen expansion, including fueling stations, storage, and pipelines.[10]

Getting to know the hydrogen color palette

COLOR	DEFINITION	AVERAGE PRODUCTION COST IN 2023
Gray	Produced from natural gas with abatement	$2.13 per kilogram
Blue	Produced from natural gas with carbon capture	3.10
Green	Produced from water electrolysis using renewable electricity	6.40

Future Impact If Successful

Green hydrogen could account for 12–20% of global energy consumption by 2050, with the potential to reduce global carbon emissions by 6 gigatons per year.[1] Hydrogen could be especially helpful in replacing hydrocarbons in hard-to-decarbonize sectors like steel, cement, shipping, and aviation.

There is huge potential for hydrogen as a clean energy source. However, the technology and infrastructure are still developing, and overcoming high production and transportation costs is critical. Furthermore, hydrogen's environmental impact will only be fully realized if green hydrogen production overtakes gray hydrogen as the dominant method of production.

References:

(1) Democrats Abroad
(2) McKinsey, Global Energy Perspective 2023: Hydrogen outlook
(3) BloombergNEF

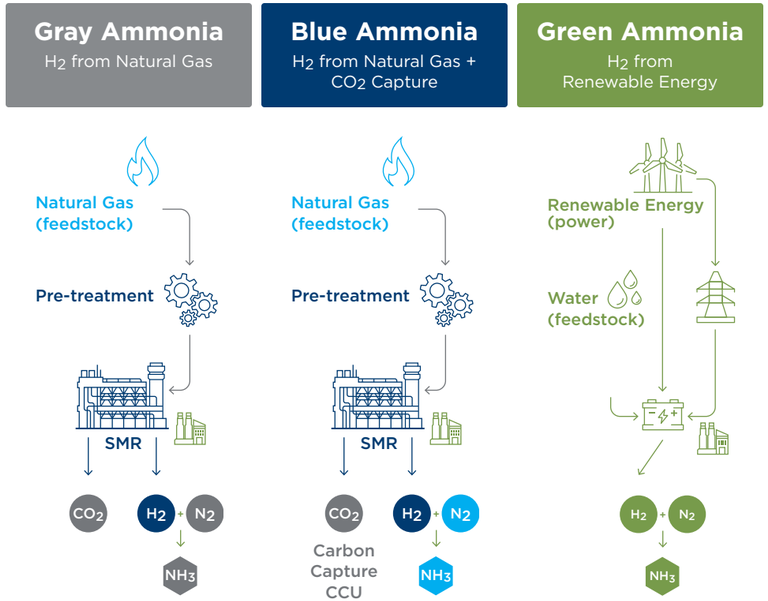
Ammonia

Ammonia is essential for producing fertilizers and is gaining traction as a potential clean fuel source, but costly and emissions-intensive production processes threaten growth.

Description

Ammonia (NH_3) is a chemical composed of nitrogen and hydrogen, traditionally used in fertilizers to boost crop yields and sustain the global food supply. Due to its ability to carry hydrogen, ammonia is now being explored as a fuel for shipping and power generation. There are three primary types of ammonia production: gray ammonia, blue ammonia, and green ammonia. The classification depends on the feedstock and energy source used in the production process.

Ammonia types and uses[1]

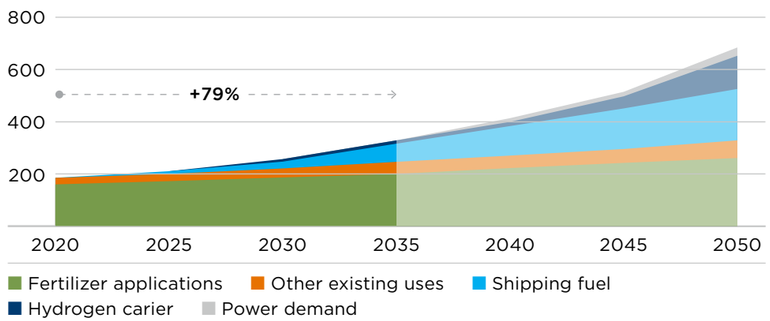


Current State and Recent Progress

Growth: Global ammonia production has remained around 190 million metric tons for the past five years but is expected to almost double by 2035 and triple by 2050. Fertilizer applications and industrial uses are the primary sources of demand and are expected to continue to drive growth as the population grows. China is the largest producer of ammonia, accounting for 30% of global production, with the U.S., EU, India, Russia, and the Middle East each accounting for an additional 8–10%.[2]

Global ammonia demand is expected to nearly double by 2035

Ammonia demand (2020–2050)[5]
Metric tons



Technological advancements: Advances in integrating ammonia production with renewable energy sources have made it easier to produce green ammonia. Similarly, advancements in carbon capture technology have allowed ammonia producers to continue using natural gas with reduced emissions, enabling the production of blue ammonia.

Current Limitations/Challenges

Economics: Current production costs for green ammonia are double that of conventional gray ammonia.[2] Large fertilizer companies, like Nutrien, have even suspended major low-carbon ammonia projects due to these economic challenges.[4] Like most commodity markets, ammonia is vulnerable to price volatility.

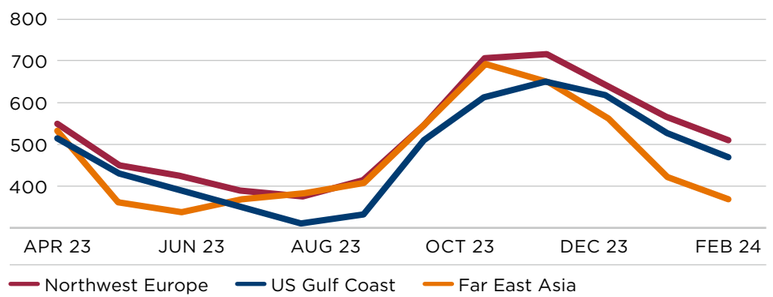
Decarbonization: Ammonia production and consumption are highly carbon-intensive, generating up to 2% of global greenhouse gas emissions, a level roughly equivalent to all commercial aviation worldwide.[5] Decarbonizing production is an essential step for growth of the ammonia market. However, green ammonia production is not yet scalable, with both electrolyzer capacity and the renewable energy sources needed to power it far below the required levels. In 2023, global electrolyzer capacity was approximately 790 megawatts.[6] Producing renewable ammonia at the scale needed to achieve net-zero would require more than 1,000 gigawatts, more than 1,200 times the current capacity.[4]

Future Impact If Successful

If current ammonia production is replaced with green ammonia production, more than 550 metric tons of carbon emissions could be abated.[5] However, the path to critical green ammonia market penetration is long and requires substantial expansion of both electrolyzer and renewables capacity.

Ammonia production needs to become more sustainable. As the industry shifts to green ammonia, there is potential for significant reductions in greenhouse gases. However, achieving these reductions will require overcoming significant economic and technological barriers to scaling up production.

Platts blue ammonia assessments[7]
($/mt) CFR monthly average



References:

[1] Hydrogen Tech World
[2] International Energy Agency, Ammonia Technology Roadmap, October 2021
[3] S&P Global, Analysis: Global ammonia prices fall 50% on year, sparking concerns over future low-carbon market, August 2023
[4] Reuters, Nutrien to pause potash ramp up, ammonia project on falling prices, August 2023
[5] Boston Consulting Group, Short-term solutions for bending the ammonia emissions curve, September 2023
[6] Aurora Energy Research, Global electrolyzer, April 2023
[7] S&P, Blue, green ammonia prices diverge as electrolysis power prices rise, natural gas falls

PART 6

The Path Forward

The Path Forward in Solving the Dual Challenge

A new framework is needed to set the stage for moving forward

To solve any complex problem, we must agree on the primary goal to mobilize and align people. The path forward to solve the Dual Challenge is complex and extremely difficult. We need vast and growing amounts of energy for human prosperity as the world economy and population continue to grow, and we need to reduce global emissions to limit climate change, which could have significant negative impacts on humanity. Unfortunately, increasing energy use correlates with higher emissions. By working together, acknowledging the dual necessity of both energy and climate solutions, and adjusting our paradigm to a new framework, we believe the world can make meaningful progress on both fronts. Our goal must be clear and unwavering: to secure more abundant, cleaner energy.

Recapping the Problem Embedded in the Dual Challenge

To propel the modern world and support human prosperity, estimates are that we may need up to 50% more energy by 2050. Since the dawn of the industrial revolution and access to more abundant energy, the human condition has thrived. Billions of people living in underdeveloped societies are striving for higher levels of prosperity and growing their populations, both of which drive increased energy demand. However, the use of energy drives emissions and climate change. The negative impacts of climate change are significant, with unknown side effects that are hard to predict. To achieve net-zero emissions by 2050, we need to abate as much as 80 gigatons of emissions per year. Despite worldwide attention and massive spending, our efforts are falling short, as emissions continue to increase and energy poverty persists. We need a new approach.

The critical attributes of an effective solution framework include reframing the primary goal, expanding our range of options, prioritizing global solutions, balancing the cost and benefits, maintaining transparency with the data, and ensuring that policymakers and stakeholders understand and support proposed solutions.

Reframe "energy transition" to "energy addition and decarbonization." "Energy transition" implies a rapid shift from traditional energy sources to cleaner alternatives. However, historically, new energy sources have taken decades to gain significant market penetration, have never fully replaced previous sources, and typically do not reduce the absolute usage of those sources. Limiting effective and currently available solutions simply because they involve hydrocarbons is counterproductive. This approach fosters creativity and expands the range of solutions for addressing the Dual Challenge, including pathways to decarbonize traditional energy sources.

Address both energy and climate goals concurrently. While many efforts focus on either increasing energy or significantly reducing emissions, an effective approach must address the dual priorities of tackling energy poverty and mitigating climate change, and work to solve both concurrently. This requires a new paradigm that moves beyond myopic viewpoints and embraces the need to both advance human prosperity with more energy and reduce global emissions to limit climate change. Ultimately, the goal should be to provide abundant, clean energy.

Effective solutions must consider global implications. We share one atmosphere, and no single country or group of countries can address this challenge alone. A unified global framework for carbon pricing is essential to drive meaningful reductions and incentivize solutions with worldwide impact, rather than local actions that may be less effective. Additionally, adopting local solutions that effectively shift emissions to regions with lower environmental standards may seem beneficial locally but can increase global emissions. Similarly, investing in high-cost local solutions may be less impactful than allocating resources to support more effective carbon reduction efforts in other regions.

Focus on efficient, scalable carbon abatement strategies. The costs of addressing the Dual Challenge are immense, and resources are limited. An effective solution must consider economics, prioritizing carbon abatement strategies that offer the best $/ton efficiency without compromising energy availability. Solutions that restrict energy availability risk driving up costs, thereby reducing the capital available for further carbon abatement efforts. In the long term, allocating capital to R&D for technologies with strong potential to enhance carbon abatement efficiency should also be part of the strategy.

Utilize full-cycle economics to guide investment decisions. We must rely on factual, comprehensive assessments that consider full-cycle costs and benefits from a global perspective. This approach ensures that decisions are based on accurate data, as the quality of decisions depends on the reliability of the underlying information. Thoughtful consideration of inputs, as well as the true costs and benefits, is essential when evaluating options for reducing emissions and delivering abundant, clean energy.

Tailor solutions to regional needs and challenges. Local biases, energy infrastructure, security, and financial capacity will drive adoption and must be considered. Understanding and addressing these factors will increase the likelihood of identifying and implementing effective solutions on a global scale. Ignoring these local concerns can lead to misunderstandings, heightened tensions, and delays in implementation, allowing emissions to rise and energy poverty to persist.

Prioritize education and leadership. Both are essential to drive timely and effective solutions, recognizing that energy and climate change are complex topics requiring a deep, fact-based understanding of technology, economics, and behavioral science. Strong leadership is needed to address this immense, global challenge effectively.

Technology Readiness, Impact, & Economics Should Drive Solutions

If we hope to solve the Dual Challenge, we need to start now

The key to reducing emissions is to prioritize technologies that are ready, cost-effective, and capable of making a meaningful impact, aiming to reduce emissions without limiting energy availability. Governments should focus on educating their constituents and enacting policies that remove barriers to the most efficient solutions, not just the most popular ones. A global carbon price is essential to drive the level of investment needed worldwide. Achieving net-zero carbon without sacrificing energy access is possible.

Technology readiness, potential impact, and cost should guide our actions, especially considering the monumental cost of solving the Dual Challenge. By analyzing the potential impact and the cost abatement curve, we can identify the most economical and impactful ways to make a difference. These insights should shape our investment decisions and policies.

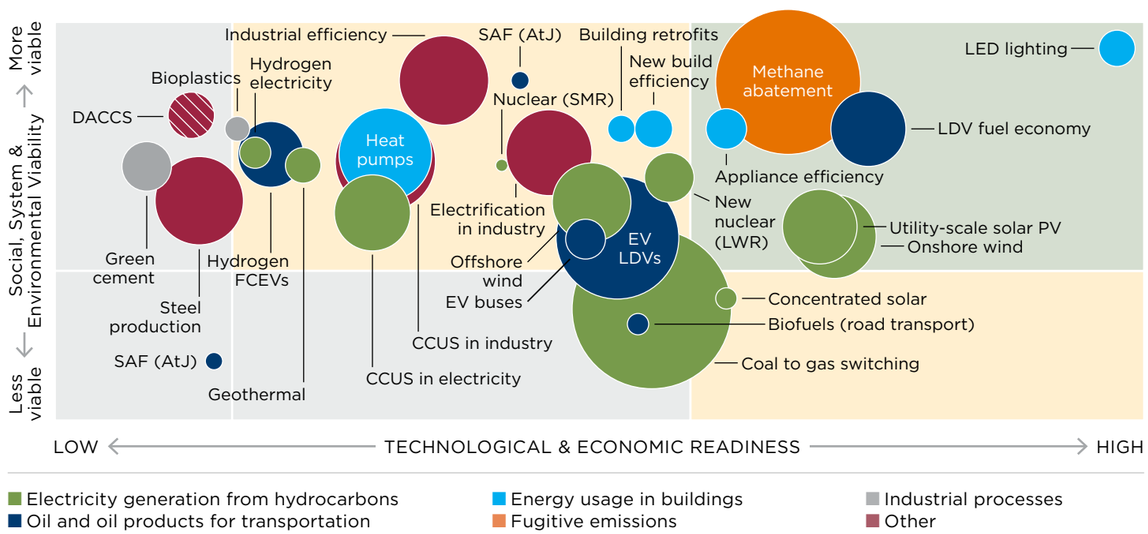
OpenMinds recently published a prioritization of potential solutions, evaluating the social, systemic, and environmental viability of various carbon abatement strategies against their technological and economic readiness and potential impact. This exercise helps identify the top 10 solutions, which include renewables, coal-to-gas switching, CCUS, methane emission reductions from energy, a range of efficiency enhancements, and nuclear. The chart below illustrates these priorities.

In addition, Thunder Said Energy recently published a summary of the costs of various carbon abatement technologies, highlighting the most efficient (lower cost) options that should be prioritized. These include advancing renewables, coal-to-gas switching, decarbonizing oil and gas through enhanced practices and CCUS, efficiency gains and demand management, and nature-based CO_2 removal. Together, these measures could achieve net-zero emissions by 2050, offsetting the approximately 80 gigatons of annual emissions projected if current trends continue. Importantly, these strategies can be implemented promptly, with meaningful progress starting today, as illustrated in Thunder Said Energy's carbon abatement roadmap.

While the exact solution, timing, and overall cost may vary, we believe these priorities are well-chosen, as they consider readiness, costs, and impact. Additionally, they address the need for carbon abatement without exacerbating energy poverty. Examples such as U.S. coal-to-gas fuel switching, hydrocarbons with a lower GHG footprint, and Europe's rapid adjustment to the Russian invasion of Ukraine demonstrate that timely, economic, and impactful solutions to the Dual Challenge are possible. Conversely, we have observed the inefficiencies of agenda-driven solutions that overlook these factors, as seen in cases like Germany and Canada, where economics and a balanced approach to both emissions and energy were not fully considered.

In our view, the question is not whether we can solve the Dual Challenge, but how we will accomplish it and build the global support necessary for these critical actions. Achieving this support will require a new framework for addressing the Dual Challenge, along with education, leadership, and global coordination – including a universal carbon tax. Together, we can create a future of both energy abundance and decarbonization.

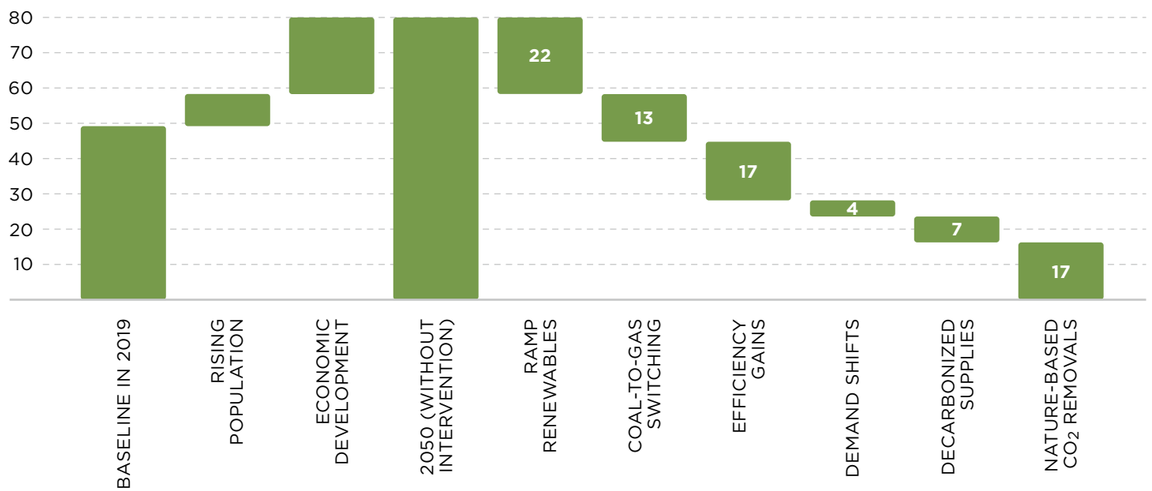
OpenMinds evaluation of potential solutions[1]



Our updated roadmap to net-zero, disaggregated category-to-category

Annual CO_2e emissions[2]

GTpa



References:

(1) OpenMinds, The Dual Challenge: Energy and Climate (2023)
(2) Thunder Said Energy

Education & Leadership are Essential Drivers for a New Approach

Fact-based and economically driven decision making must be a key priority

Education and sponsorship from global leaders – focused on fact-based, cost/benefit-driven analysis and decision-making – is essential in addressing the Dual Challenge. A significant portion of the population lacks a clear understanding of energy and its externalities, such as carbon emissions. This knowledge gap has often led to policy decisions based more on perceptions, politics, and misunderstandings. A better grasp of these energy and climate realities, combined with strong leadership, will lead to more effective policies and outcomes.

A recent IEA study, *Energy Literacy: What Do People Know About Energy?*, assessed public knowledge of energy systems, including understanding of energy sources, consumption patterns, and the environmental impacts of energy use. The study revealed significant gaps in public understanding, especially regarding energy efficiency and the role of various energy sources in climate change. For example, the carbon footprint of an electric vehicle depends on the energy sources used to charge it – if powered by coal rather than renewables, it may produce more emissions than anticipated.

This lack of understanding highlights some of today's perception challenges, for example:

- There is a belief among some that we should quickly replace hydrocarbons – which currently provide 77% of the world's energy – without recognizing the complexity of this transition and the current lack of an available, reliable alternative energy source.
- Many view a shift to wind and solar as a solution to emissions and energy needs, given that these sources are renewable. However, while sun and wind are renewable, their implementation requires vast amounts of minerals, steel, cement, construction, and transmission infrastructure – none of which are renewable.
- Renewable energy is not consistently reliable without significant advancements in battery technology, which are not yet feasible. Thus, traditional energy sources will remain essential for an extended period and may even become more critical as renewables grow in market share, which can drive up overall energy costs.

The key to creating effective solutions for the Dual Challenge lies in a deep understanding of energy and climate dynamics. This includes knowledge of different energy sources, their origins, functionality, advantages, limitations, and full-cycle costs, including associated externalities like carbon emissions. Promoting energy and climate literacy should be a priority for governments and educators globally, particularly in developed nations. Moving beyond entrenched thinking, we must adopt fact-based, cost-benefit-driven decision-making to foster open dialogue and more effective solutions.

Leadership at the highest level can drive national agendas and perspectives. Iconic speeches such as "I Have a Dream" and "Ask not what your country can do for you..." illustrate how paradigm-shifting visions can mobilize a country or even the world. Today's leaders must educate themselves and be bold enough to set forth a new vision for solving the Dual Challenge, moving beyond the current narrative. This begins with education and the ability to articulate a different path for addressing both climate change and energy poverty, which is achievable today if we can redirect resources and gather the political capital to change the narrative.

Effective solutions also require the political will to execute. Currently, significant disagreements appear to have distracted us from the true goal – providing abundant, reliable, and clean energy. We have suboptimized the goals into polarized agendas: "eliminate hydrocarbons" or "ignore climate concerns." We need leadership that can bring both sides to the table in an open, constructive dialogue to identify the best solutions. Once identified, we need leadership to implement these solutions through public education, policy, and funding.

We hope these Global Energy Perspectives help reframe the problem and approach, driving near-term, effective solutions for the Dual Challenge. Much is at stake, and we are proud to contribute to a sustainable energy future, leading the world toward a better tomorrow.

> **Saving our planet, lifting people out of poverty, advancing economic growth... these are one and the same fight. We must connect the dots between climate change, water scarcity, energy shortages, global health, food security, and women's empowerment. Solutions to one problem must be solutions for all."**
>
> **Ban Ki-moon,** 8th Secretary-General of the United Nations

> **However beautiful the strategy, you should occasionally look at the results."**
>
> **Winston Churchill,** former Prime Minister of the UK

> **Facts are stubborn things; and whatever may be our wishes, our inclinations, or the dictates of our passions, they cannot alter the state of facts and evidence."**
>
> **John Adams,** 2nd President of the United States

> **A true leader has the confidence to stand alone, the courage to make tough decisions, and the compassion to listen to the needs of others."**
>
> **Douglas MacArthur,** American military leader and Supreme Commander for the Allied Powers in the Pacific theater

Integrated ESG Program

Inside this section:

Quantum's ESG Approach

Interview with Keila Diamond, Quantum's Managing Director and Head of ESG

"We believe ESG is about applying common sense to protect the environment and stakeholders, ensure good governance, and maintain strict compliance with the law."

Keila Diamond, Managing Director & Head of ESG, Quantum Capital Group

In your view, what is ESG, and what role does it play in the private equity space, particularly at Quantum?

Broadly, ESG refers to environmental, social, and governance risk factors and value creation opportunities – issues that investors often consider, with the goal of enhancing long-term investment performance. ESG is often mistakenly equated with impact investing, which aims to achieve positive financial returns and environmental and social outcomes. The key distinction is that while every company faces ESG risks and opportunities, not every company generates the positive impacts necessary to qualify as an impact investment.

So, what is the purpose of ESG? We believe ESG is about applying common sense to evaluate whether a company complies with laws, keeps employees safe, and minimizes environmental harm. Within private equity, the role of ESG varies widely across asset managers.

At Quantum, ESG is integral to our hands-on approach. We believe that thoroughly analyzing how ESG-related risks and opportunities can impact profitability and operational continuity is essential. For example, companies that comply with environmental regulations avoid harming local ecosystems and the potentially material costs of non-compliance. We aim to actively support our portfolio companies in identifying and assessing emerging risks, pricing them appropriately, and providing resources to help manage them effectively. Over time, we believe that using this approach helps us not only mitigate risks but also capitalize on value creation opportunities as they arise.

Does Quantum continue to see value in integrating ESG in its investment lifecycle? Can you summarize your approach?

Yes, there are various reasons we continue to integrate ESG factors into our investment lifecycle. However, it is important to emphasize that for us, ESG integration is a process, not a product. We currently do not have an impact fund or a fund marketing its ESG characteristics. We invest in companies based on our interpretation of their potential risk-adjusted returns, not because of their ESG commitments. Our focus is on identifying and managing ESG factors to both protect and create value.

Protecting Value: Value protection involves identifying and managing investment risks and opportunities in order to preserve existing value, thereby preventing the risk of value being destroyed through fines or penalties, business interruptions, or reputational damage. For example, over the past year, the U.S. has introduced new regulations aimed at improving measurement, reporting, and mitigation of GHG emissions in the energy sector, including the Waste Emissions Charge (WEC), which essentially acts as a methane fee for excess emissions. To protect the value of our assets, it is crucial for our portfolio companies to comply with the new Environmental Protection Agency (EPA) regulations and reduce emissions to avoid costly fees. At Quantum, we actively engage with our companies and provide resources to help them navigate the evolving regulatory landscape, as detailed on page 77.

Creating Value: Value creation typically involves identifying opportunities that can enhance investment returns through cost reductions, improved efficiencies or productivity, and stronger brand reputation. For example, one of our portfolio companies transitioned to electric frac fleets, which is expected to save over $10 million annually in fuel costs. This initiative not only reduces emissions and potential compliance costs but also increases the company's appeal to a broader set of prospective buyers, thereby creating value.

In summary, we do not shy away from investments where there is room for improvement; instead, we see them as opportunities to apply our skills and resources to protect and create value, make a positive environmental impact, and ultimately increase risk-adjusted returns for our investors.

What are some of the key challenges you face in integrating ESG factors into your investment lifecycle at Quantum?

Arguably, one of the greatest challenges is the lack of a unified framework and standardized metrics to effectively quantify ESG value creation. Although there are comprehensive industry-level key performance indicators, comparing private market participants remains a challenge. Quantum is part of the Institutional Limited Partners Association (ILPA) ESG Data Convergence Initiative (EDCI), which has made significant strides in improving standardized ESG performance disclosures across a diverse range of General Partners. Additionally, EU regulations aimed at creating standardized sustainable investing terminology and disclosure practices have begun influencing global fund labeling standards. However, adhering to these regulations introduces its own set of challenges.

Many investors indicate that collecting data from portfolio companies is overly burdensome, particularly when each LP requires different metrics. From the LPs' perspective, there is a need for metrics that can be consistently applied across portfolios, providing sufficient detail to be meaningful without overwhelming them with excessive, unweighted data points.

If a reader of this report has only 10 minutes, what should they focus on?

Energy Transition Insights
The Global Energy Perspective section offers a compilation of extensive research and in-depth exploration of how the energy transition necessitates balancing energy security, accessibility, affordability, and the reduction or elimination of carbon emissions. See pages 15–55 for additional details.

Portfolio Performance Overview
The majority of our ESG engagement efforts are dedicated to supporting our portfolio companies in managing ESG factors to drive value creation. A summary of their performance can be found on page 87.

Case Studies on Value Creation
For tangible examples of how value creation is achieved, refer to the case studies and spotlights on pages 89, 90, and 91.

ESG Governance

The Quantum Executive Team has developed a comprehensive ESG governance structure that aligns with our core values. This framework aims to ensure that ESG considerations are integrated into decision-making processes, promoting transparency, accountability, and long-term value creation for all stakeholders.

Our cross-functional ESG Steering Committee, chaired by our Head of ESG and composed of nine senior leaders, provides strategic oversight and ensures alignment with our company values. In parallel, our dedicated ESG Team, made up of subject matter experts, is responsible for developing and implementing our ESG strategies to drive meaningful progress across all environmental, social, and governance initiatives.

Within our portfolio companies, Quantum representatives serving on governing boards are responsible for setting policies and overseeing ESG progress. We also seek to provide our deals teams with comprehensive ESG training so they can better understand and integrate ESG factors into the entire investment lifecycle.

Our Transaction, Technical, Client Relations, and Digital teams are responsible for collaborating with the ESG Team to implement and monitor progress and assist our portfolio companies with their ESG efforts, as needed. Our collaborative approach aims to foster regulatory compliance, unlock growth opportunities, and mitigate risks.

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.

Please see disclosures for important information regard ESG considerations in our investment practices.

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 ensure that ESG considerations are deeply embedded in all aspects of investment, technical operations, client engagement, and digital transformation.

Implementation

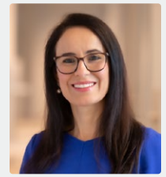
RESPONSIBLE TEAMS: ESG Team and Portfolio Companies

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

ESG Steering Committee

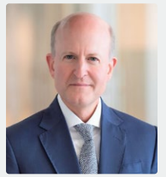
The Quantum ESG Steering Committee provides strategic oversight, ensures alignment with our company values, oversees the integration of ESG principles into investment strategies and operations, seeks to ensure that ESG risks and opportunities are identified and managed, and strives to create long-term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

Committee Chair

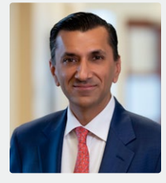


Keila Diamond
Managing Director & Head of ESG

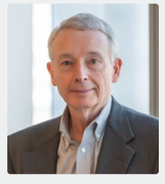
Wil VanLoh
Founder and CEO



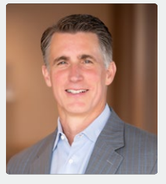
Charles Baillie
Co-President



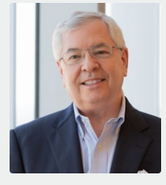
Ajay Khurana
Co-President



Chuck Davidson
Partner

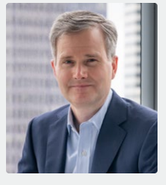


Garry Tanner
Partner



Jim Baird
Partner & General Counsel Emeritus

Roman Bejger
Partner & General Counsel



Michael Dalton
Managing Director, Client Solutions

Our ESG Progress*

Quantum has continuously worked to evolve its ESG initiatives and demonstrate a deep commitment to sustainability, innovation, and responsible investment practices. Over the years, we have strengthened our ESG framework through strategic partnerships, advanced data integration, and industry leadership. Our journey reflects our dedication to creating long-term value while addressing critical global challenges. The following timeline highlights key milestones in our ongoing effort to enhance ESG performance and deliver meaningful impact.

1998 – 2019

Quantum founded with core values established, including integrity and doing the right thing from the perspective of environmental and social responsibility

Partnered with Dutch pension plan to enhance ESG program and reporting

apg

Certain portfolio companies began tracking ESG performance data

Partnered with Environmental Defense Fund (EDF) to reduce methane emissions in the Permian Basin

2020

Hosted inaugural methane solutions summit with EDF

Hired Keila Diamond as first full-time Head of ESG

Signed on to the UN Principles for Responsible Investing

Signatory of:

PRI Principles for Responsible Investment

Rolled out enhanced ESG data gathering for portfolio companies

2021

Launched ESG integration strategy program

Expanded due diligence process to assess for ESG factors and risks

Engaged ERM for emissions inventory, transition and physical risks analysis

First portfolio company began implementing Project Canary continuous monitoring and undergoing TrustWell™ Certification process

Firmwide unconscious bias training with Dr. Mahzarin Banaji

2022

ESG Data Convergence Initiative

Became a participant of ILPCA ESG Data Convergence Initiative

Portfolio companies achieved over 80% of continuously monitored gas production with Project Canary

PROJECT CANARY

Began quarterly data gathering from certain portfolio companies

Published first publicly-available ESG report

Certain portfolio companies begin tying executive compensation to ESG metrics

2023

Tug Hill and XcL sold to EQT, with their strong ESG track record differentiating them from competitors in the basin

Firmwide inclusive recruitment training with Dr. Elizabeth Haines

KODA

Partnered with KODA to reduce methane emissions from low flow wells

Launched “Quantum Serves”

QUANTUM SERVES

Hosted training for portfolio companies on methane regulations

Rockcliff Energy, with its strong ESG program and significant investments in reducing methane emissions, acquired by TG Natural Resources

* Please see disclosures for important information regarding ESG considerations in our investment practices.

Our ESG Integration Strategy

At Quantum, we focus on integrating ESG throughout the entire investment lifecycle, where applicable. By adopting this integrated approach, we aim to reduce risks, enhance operational efficiency, and support the delivery of superior risk-adjusted returns. We believe that strong ESG performance not only drives financial success but also differentiates our portfolio companies in the market, leading to more attractive exits. Our commitment to ESG integration underscores our belief that responsible practices and profitability are mutually reinforcing, contributing to the long-term value and success of our investments.

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	**Avoid exposures that conflict with Quantum's risk-adjusted return expectations**	**Identify ESG risks and opportunities**	**Invest and integrate 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 mitigate regulatory risks	Communicate value added and potential future upside to potential buyers

Please see disclosures for important information regarding ESG considerations in our investment practices.

(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

(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 Factors

To understand where to focus our ESG efforts, we conducted a materiality assessment to identify the most important issues for Quantum and our portfolio companies. This assessment has enabled us to prioritize our efforts and give immediate attention to topics that are important to our investors and the sustainability of our investments.

Our material ESG factors are the lens through which we identify high-probability and high-impact risks and opportunities for our portfolio companies at every phase of the deal life cycle. We empower our portfolio companies to actively manage these ESG factors, and we allocate resources to high priority topics where we can provide the most value to our stakeholders.

Our materiality assessment included a benchmark assessment of critical factors identified by international organizations, including the Sustainability Accounting Standards Board (SASB), the Task Force on Climate-related Financial Disclosures (TCFD), the Global Reporting Initiative (GRI), and ILPA. We also incorporated feedback from a diverse range of internal stakeholders, including Quantum leadership and portfolio company representatives. Additionally, we frequently engage external stakeholders to understand the concerns of our investors and their views on ESG.

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
- Executive incentives tied to ESG performance

* 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.

Deal Sourcing, Due Diligence & Decision Making

Deal Sourcing → Due Diligence → Investment Decision → Ownership & Stewardship → Exit

Integrating ESG into our investments begins with due diligence during the pre-investment decision-making process. During this process, our ESG team works side-by-side with our investment team to consider ESG risks and opportunities from the outset. However, the extent of our influence and control over our portfolio companies depends on the specific investment structure and terms.

In situations where Quantum has limited capacity to conduct thorough due diligence or exert influence over ESG issues, the application of ESG considerations is adjusted to what is practical and feasible under the circumstances. During these types of engagements, Quantum may analyze public data, perform benchmark analyses, and engage with leadership teams to assess their commitment to ESG and whether their values align with Quantum's.

When we have operational control and access to management and ESG data, we seek to review and consider material ESG risks and opportunities from the beginning of the investment process, as deemed feasible and appropriate. This extensive exercise can include a detailed review of key ESG documents, assessing a company's historical data, and where appropriate, visiting facilities to gain further understanding of a company's operations and associated risks. Additionally, Quantum often engages third-party external consultants with sound expertise to assist with site visits, document review, and creating action plans to address any material concerns that may be raised during due diligence.

"We are highly focused on identifying ESG risks during due diligence. In today's rapidly changing regulatory environment, we carefully assess for compliance issues and the financial and environmental risks they could pose to our investments."

Tom Field, Partner, Quantum Capital Group

Due Diligence ESG Goals and Key Steps*

Understand portfolio company culture and management's commitment to our ESG strategies

- Engage management teams to understand oversight of ESG risk
- Connect with operations or ESG teams to understand competency and level of expertise

Analyze historical performance and ESG data for each investment

- Where appropriate, engaged third party consultants to assist with the due diligence process
- Conduct desktop review of key ESG documents, policies, permits, and data
- When appropriate, visit facilities to gain further understanding of operations and associated risks

Assess priority ESG factors and seek to reduce risk/create value for each investment

- Identify and size material ESG risks
- Create action plans that address any material concerns
- Summarize key findings and present action plans to Quantum's Investment Committee

Execute on ESG opportunities post-investment through our portfolio stewardship framework

- Work closely with deal team and portfolio company to complete action plan
- Leverage data gathered through robust reporting program to identify and execute on additional value creation projects

SPOTLIGHT

Due Diligence Highlights for Caerus Oil & Gas

In August 2024, Quantum acquired Caerus Oil and Gas for $1.8 billion from Oaktree Capital Management and other investors. The Caerus assets were divided between two Quantum portfolio companies: QB Energy (QB), which received the Piceance assets comprising around 600,000 acres of upstream gathering and compression midstream assets, and KODA Resources (KODA), which received 160,000 acres of upstream and midstream facilities in the Uinta Basin.

These assets provide access to some of the largest natural gas resources in the western markets, which have experienced repeated, localized energy shortages in recent years. With this acquisition, Quantum recognized a distinct opportunity to invest in substantial natural gas production with significant value creation potential.

During Quantum's initial environmental analysis and benchmarking, we discovered that Caerus reported a methane intensity that exceeded Quantum's targets and would expose QB and KODA to potential WEC penalties. To address this, Quantum's deal team and ESG team worked closely with Caerus management throughout the due diligence process to understand their methane emission sources and explore reduction opportunities. Along with third-party expert Ramboll Environmental, the teams developed a strategy to lower methane intensity, aiming to meet Quantum's targets and avoid costly EPA fees. By establishing this plan during the due diligence phase, QB and KODA were able to immediately being aligning with Quantum's processes to enhance the environmental profile of these newly acquired assets.

Quantum's Due Diligence Process for Caerus

- **Engagement with management and environmental support staff** to understand emissions calculation methodology and current reduction projects
- **Data collection** through detailed internal surveys
- **Site visits** to further understand operations and evaluate facilities
- **Third-party expert assessment** with Ramboll Environmental to complete phase one of the due diligence process
- **Creation of methane reduction plan** including cost analysis of reduction methods

The select investment is provided for illustrative purposes only to demonstrate Quantum's investment approach generally, and not all applicable investments are shown. There is no guarantee that Quantum will be able to identify similar investments in the future. Please see disclosures for important information regarding ESG considerations in our investment practices.

There can be no assurance that any plan described herein is not modified (perhaps materially) in the future or will lead to successful outcomes or improved portfolio company performance.

Please see disclosures for important information regarding ESG considerations in our investment practices.

* Though Quantum strives to complete all due diligence 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.

Ownership & Stewardship

During the investment period, we collaborate closely with our portfolio companies to implement key ESG initiatives aimed at managing risks and capitalizing on ESG opportunities.

From the beginning of our partnerships with new portfolio companies, we act as a valuable resource, offering management teams a suite of ESG tools, best practices, and operational support. Our standardized in-house tools and proven reporting procedures provide a strong foundation for companies to begin their ESG journey with Quantum. By prioritizing early ESG engagement during deal screening and due diligence, we can collaborate closely with companies from the outset to address and prioritize the risks and opportunities identified. We then partner with our portfolio companies to understand their unique needs and tailor our support to enhance their operational efficiency and effectiveness. This customized approach has the potential to boost their profitability and also positions them for potential premium in exits.

The select investment is provided for illustrative purposes only to demonstrate Quantum's investment approach generally, and not all applicable investments are shown. Examples of such cases may include portfolio companies that do not have operating assets, portfolio companies where Quantum is a minority investor or lender, or certain portfolio companies where Quantum has no operational control and little access to management or non-public ESG information.

* Engagement processes vary by investment type, materiality of ESG risks, and relevant data available.

Ownership & Stewardship ESG Goals

Guide or assist portfolio companies to support compliance with applicable regulations and standards, implementation of their ESG action plan, and continuous ESG performance improvements, including value creation

Stay informed and respond to new developments and/or risks relevant to each companies' ESG performance

Build and maintain a collaborative relationship that helps promote and achieve ESG goals

Engagement During Ownership & Stewardship Phase*

Onboarding
Quantum is introduced to management and ESG coordinators and conducts strategic planning sessions to address issues identified during due diligence and develop action plans.

Quarterly Working Group Meetings
Quantum portfolio companies meet quarterly to share insights, discuss challenges, and exchange best practices.

Resources and Reporting
Quantum provides tools and resources to monitor and enhance ESG performance, including quarterly ESG surveys and Board templates.

Regulatory Information Sessions
Quantum engages legal and environmental experts to brief portfolio companies on evolving regulations.

Check-ins
Quantum conducts one-on-one meetings with designated ESG coordinators from each portfolio company to review progress, address challenges, and provide tailored support.

Strategic Partnerships
Quantum helps companies identify third-party experts in monitoring, emissions reductions, and other service providers to support key initiatives.

SPOTLIGHT

Rio Oil & Gas II, LLC: Monitoring and Reducing Emissions

Quantum portfolio company Rio is a Permian Basin operator focused on the Midland and Delaware sub-basins. They are committed to continuously improving their environmental performance. From their active participation in industry groups like the Environmental Partnership to their robust methane monitoring program, Rio believes that understanding and reducing methane emissions is a key part of being a responsible operator.

Like all operators, Rio's goal is to keep methane in the pipe. By employing multiple types of frequent methane monitoring, Rio is able to find and fix methane leaks quickly and leverage the data from these different technologies to understand where operational improvements can be implemented to avoid future leaks. From detailed, bottom-up inspections of equipment using Optimal Gas Imaging (OGI) cameras to comprehensive, top-down aerial flyovers of entire locations, Rio is committed to finding and fixing leaks.

OGI Camera
Leak Detection and Repair (LDAR) surveys occur quarterly, with a lease operator surveying each piece of equipment using a handheld OGI camera.

Facility-Wide Continuous Monitoring
Continuous monitoring gives Rio real-time leak data from their well pads, allowing lease operators to immediately find and fix leaks. Over 80% of Rio's production was covered by continuous monitors, as of December 31, 2023.

Piloted Aircraft
Quarterly flyovers at different monitoring thresholds give Rio leak data from an aerial view and cover all assets, including pipelines and widespread facilities.

Portfolio Monitoring, Evaluation & Reporting

Ownership & Stewardship *continued*

To successfully implement our ESG program, we collect a comprehensive set of data across our portfolio as part of our robust monitoring and reporting process.

This data allows us to consistently measure, monitor, evaluate, and transparently report on the ESG progress and challenges of our majority-owned portfolio companies. By leveraging this data, we strive to identify common trends, assess risks and opportunities, and develop action plans to address challenges. Our data gathering process is a key pillar of our engagement with portfolio companies and is central to our collaboration with them.

We proactively disclose our ESG performance through various formats in a manner informed by globally recognized reporting frameworks such as ILPA EDCI, SASB, Principles for Responsible Investment (PRI), and TCFD. These frameworks provide a standardized approach to reporting and enable stakeholders to assess our performance in a meaningful and comparable manner. Additionally, we engage in regular dialogue with investors and other stakeholders to gather feedback and ensure that our disclosures meet their information needs and expectations.

5
years of annual performance reporting[3]

2
years of quarterly reporting[3]

3
years of EDCI reporting[3]

3
types of annual surveys collected[3]

>5,000
data points collected in 2023[3]

28
reporting companies[3]

Portfolio Company Reporting Process[1]

Throughout the ownership period, we work closely with our portfolio companies and communicate with them frequently on ESG matters. Portfolio companies are asked to report to Quantum through several avenues. Our minimum reporting engagements for wholly owned and operated companies include:

Quarterly Surveys

By evaluating and analyzing quarterly performance reports, we work with portfolio company management teams to identify important trends, develop plans to address issues, drive improvement, and ensure alignment with Quantum's ESG policies.

Annual Surveys

Portfolio companies are asked to submit detailed annual surveys that cover operational data, human capital metrics, and emissions statistics.

Quarterly Board Reports

Utilizing a Quantum-provided template, portfolio companies are encouraged to submit quarterly reports to their Boards, allowing executive teams to provide longer-term oversight of trends and action plan implementation.

Unplanned Events

Portfolio companies are asked to inform our team immediately of any unplanned events, and we work closely with them to understand the circumstances and develop mitigation plans.

About EDCI

ILPA's Data Convergence Initiative is driving conformance of meaningful ESG metrics for the private equity industry. Since 2022, Quantum has provided data to the ILPA. Our General Partners can access Quantum's data via the platform.

ESG Data Convergence Initiative

ESG Data Metrics[1]

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. The high-quality, consistent data we gather enables effective analysis and helps us identify trends, risks, and opportunities across our operated, majority-owned investments. Additionally, the years of data collected from companies across various sectors and basins provide valuable insights for Quantum and inform benchmarking for potential new investments.

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

References:

(1) 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 all metrics
(2) Quarterly surveys apply to nine upstream oil and gas companies only
(3) As of December 31, 2023

ESG Implementation Supports Exit Values

Deal Sourcing → Due Diligence → Investment Decision → Ownership & Stewardship → Exit

We believe that portfolio companies with a strong ESG track record are more attractive to buyers, and our integration and implementation of ESG considerations during the ownership phase helps our companies prepare for a more successful exit.

During the exit process, we help our operated, majority-owned portfolio companies prepare credible ESG materials for exit, including listing requirements or information prospective buyers may seek. We assist in answering questions from potential investors by compiling relevant ESG data that demonstrates business improvements. Additionally, we work to ensure the company's ESG management system is self-sustaining and capable of mitigating post-exit reputational risks.

Engagement During Exit Phase

Identify High-Impact Projects for Potential Buyers
We collaborate with companies to identify high-impact ESG initiatives that appeal to potential like-minded buyers, thereby making 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 help companies develop self-sustaining ESG management systems that can operate independently.

QUANTUM COMPANY ▼ ROCKCLIFF ENERGY

BUYER ▼ TGNR

Rockcliff Energy, a leading natural gas company with a strong ESG program and significant investments in reducing methane emissions, was focused on developing the prolific East Texas Haynesville Shale. In 2023, Rockcliff was acquired by TG Natural Resources, a prominent natural gas exploration and production company backed by Tokyo Gas.

$2.7 Billion Transaction

"With this acquisition, TG Natural Resources (TGNR) is committed to leadership in the Haynesville play, one of the world's most important sources of clean natural gas … Rockcliff has also made large investments in reducing methane emissions from their already very clean operations and we plan to continue to accelerate the drive to lower methane intensity in our combined operations."

Craig Jarchow
CEO, Tokyo Gas Unit TGNR

QUANTUM COMPANY ▼ TUG HILL OPERATING / XCL MIDSTREAM

BUYER ▼ EQT

Tug Hill and XcL, an oil and gas exploration company and its midstream partner in the Appalachian Basin, were acquired by EQT Corporation in 2022. Tug Hill and XcL's commitment to value-enhancing ESG initiatives played a pivotal role in the valuation and acquisition by EQT.

$5.2 Billion Transaction

"Tug Hill's strong environmental performance is fully aligned with EQT's net-zero and other emissions targets. Tug Hill's methane intensity in 2021 was just 0.004%, which is below EQT's at 0.039%, and brings our pro forma business even closer to our 2025 methane intensity target of 0.02%."

Toby Rice
CEO, EQT

QUANTUM COMPANY ▼ Tanos

BUYER ▼ DIVERSIFIED energy

Tanos Energy, a company focused on oil and gas exploration and production in East Texas and North Louisiana, was acquired by Diversified Energy in 2023. Tanos was recognized for its commitment to operational efficiency and sustainability, earning a Gold designation from Project Canary for its environmental performance.

$250 Million Transaction

"We built our business on the premise of being responsible stewards of existing natural gas and oil assets, so we value (Tanos') Project Canary recognition. The 'Gold' designation complements our already strong ESG actions, including the OGMP 2.0 Gold Standard, further highlighting our commitment to transparency and validating the important work we're doing to responsibly produce natural gas."

Rusty Hutson, Jr.
CEO, Diversified Energy

The select investments are provided for illustrative purposes only to demonstrate Quantum's investment approach generally, and not all applicable investments are shown. There is no guarantee that such investments were profitable or that Quantum will be able to identify similar investments in the future. There can be no assurance that any historical trends will continue or projections will materialize.

Continuing to Invest in Strong Teams

Interview with Sean Willis, CEO of Vickery Energy and Former President and COO of Tug Hill Operating

At Tug Hill, we were committed to operational excellence, and consideration of environmental impacts was an innate part of that commitment. We believed that doing things the right way from the start was important to our success."

Sean Willis, CEO of Vickery Energy and Former President and COO of Tug Hill Operating

About Sean Willis

Sean joined Tug Hill Operating, a Quantum portfolio company, in 2014 as VP of Engineering and was named President and COO in 2020. In this role, Sean managed Tug Hill's operational, technical, and commercial activities in Appalachia, and he was instrumental in the company's successful sale to EQT Corporation in 2023. Quantum is excited to continue our successful partnership with Sean and the former Tug Hill team through our investment in Vickery Energy.

Tug Hill had a highly focused and effective ESG program, and you were an early adapter of several advanced initiatives and technologies like air compression and continuous monitoring. Why was it important for Tug Hill to commit to responsible operations from the start?

We were committed to operational excellence, and consideration of environmental impacts was an innate part of that commitment. We believed that doing things the right way from the start was important to our success. Our long-term planning and high level of collaboration with all of our stakeholders helped us align our priorities. When we were building Tug Hill, all of our decisions were underpinned by economics and our goal to protect the environment and communities, advance social progress, and implement effective governance policies. Our ESG accomplishments were the result of many years of project planning, intentional execution, and enhanced monitoring and reporting.

Additionally, Tug Hill had a dedicated staff of talented environmental, health, and safety (EHS) professionals. Our EHS and operational teams collaborated effectively to thoughtfully upgrade our facilities and refine our overall production practices, with a focus on maximizing efficiencies that would result in decreased emissions. This approach and our "one team mentality" helped us achieve the lowest methane intensity among the top 100 U.S. producers in 2022.

What value did you initially see the ESG program bringing to Tug Hill, and how did that manifest during the sale to EQT?

Initially, we viewed a strong ESG program as essential for identifying material risks and opportunities related to our operations. We actively engaged with Quantum, our peers, and industry groups to stay aligned with best practices. As active members of ONE Future and the Environmental Partnership, we were always looking for ways to enhance our ESG program.

Operating in Appalachia, we were fortunate to have grid access for the majority of our assets. This enabled us to electrify well-pads and minimize vented methane. So, in addition to developing new pads with built-in operational efficiencies to reduce emissions, we also enhanced the legacy assets we inherited. As a result of our focus on continuous improvement, we successfully decreased our emissions intensity every year we operated.

Recognizing the potential to further leverage our ESG initiatives, we pursued a Trustwell Responsibly-Sourced Gas (RSG) certification and achieved Platinum status. The premium price we earned for our certified gas more than justified our investment, ultimately transforming ESG from a cost center into a value driver for Tug Hill.

The full value of our ESG efforts became evident during our acquisition by EQT. We understood that any prospective buyer would require a strong ESG performance, but we went beyond that – we positioned ourselves as an industry leader. This was particularly appealing to EQT, which has a stellar track record, and they highlighted our environmental performance as a key factor in the deal.

What ESG practices and principles will you prioritize as Vickery develops?

We remain committed to our core philosophy of doing things the right way from the beginning, seeking to ensure that responsible environmental practices are considered at every stage of development. This approach is now in our DNA.

We are excited to have many of the same talented team members who contributed to Tug Hill's success. Their dedication to continuous improvement and teamwork helped shape an ESG program that set a high standard, and we plan to carry that same spirit forward as we build Vickery. Additionally, we are eager to explore and implement some of the innovative emissions reduction technologies that are now emerging. Our commitment to learning, growing, and adapting remains steadfast, and as we develop Vickery, we intend to apply the same attention to detail and dedication to ESG excellence that we were known for at Tug Hill.

The CEO of Vickery is not receiving compensation for any statements regarding Quantum. However, he does receive general compensation in connection with his employment at Vickery. Additionally, although he is not invested in a Quantum fund, there may be conflicts of interest arising from his current role with Vickery since Vickery is a current portfolio company of a Quantum fund, as such fund holds a majority interest in Vickery.

Risk Management

Inside this section:

Risk Management

Risk management is integral to every phase of the deal lifecycle at Quantum. In addition to financial risks, we aim to identify and mitigate material ESG risks, guided by our established ESG factors. These risks are assessed during the due diligence process and are managed throughout the ownership and stewardship phases to optimize risk-adjusted returns and maximize exit value.

Our multi-disciplinary team is distinctly suited to identify and mitigate potential risks in our investments. Industry experts from our ESG, technical, and digital teams analyze market and regulatory risks, helping to ensure our firm is strategically positioned to address them. Our strategic shared services teams lead firm-level initiatives and assist portfolio companies in executing projects to minimize impacts over a wide range of topics.

Our risk management framework addresses a wide range of focus areas, including but not limited to climate risk, regulatory compliance, and cybersecurity. We believe that by integrating these considerations into our decision-making processes, we protect our investments and position our portfolio companies for long-term success within an evolving regulatory and market landscape. Additionally, we proactively engage with our portfolio companies to enhance their risk resilience, seeking to ensure they are equipped to navigate both current and emerging challenges. We believe this holistic approach allows us to safeguard value creation and sustain growth, while upholding our commitment to responsible investment practices.

Quantum's ESG Risk Analysis Process

Identify
Pinpoint the key variables that can derail an investment

Analyze
Define the probability distributions of potential outcomes

Price
Determine the appropriate value for the level of risk

Manage
Closely monitor and actively engage with management throughout the lifecycle of an investment

Climate-Related Risk Management

At Quantum, we aim to take a balanced and strategic approach to managing material climate-related risks, with the goal of supporting our investments' contribution to global energy needs while mitigating climate impacts.

In the Global Energy Perspectives section of this report, we highlight the need to secure abundant, affordable energy for the growing world population while curbing global emissions. At Quantum, we believe that a shift away from hydrocarbons will take decades and achieving a low-carbon economy will require all forms of energy, which is why we invest across the global energy ecosystem. Using our climate strategy as a framework, we carefully consider how our investments may affect global emissions and climate change.

Our Climate Strategy

At Quantum, we are energy specialists. We invest across the energy value chain, balancing our diverse portfolio with production, renewables, and sustainability technology. We believe this approach enhances our firm's climate resilience. Additionally, we believe our deep expertise across the global energy ecosystem gives us differentiated insights, enabling us to provide solutions that enhance the climate resilience of our portfolio companies as well.

Decarbonize Operations to Responsibly Deliver Oil & Gas

Work closely with our portfolio companies to monitor and report on emissions, while executing projects aimed at lowering their emissions

Invest in Energy Transition and Decarbonization Opportunities

Grow capacity for renewables, clean energy, and decarbonization infrastructure

Build Climate Risk Intelligence and Resilience

Collect data and analyze climate risks and opportunities for our investments

Climate Strategy Management Steps

We have implemented a structured approach to manage climate-related risks and opportunities, helping to ensure our strategy is integrated across all operations. We believe these steps allow us to proactively address both current and emerging climate challenges.

Calculate carbon footprint

Since Quantum does not directly generate significant operational GHG emissions at the firm level, we calculate our annual financed emissions to understand our indirect environmental impact.

Assess risks

We have identified representative transitional risks and opportunities using two climate scenarios and evaluated the physical risks of three portfolio companies that we believe are geographically representative of future investments.

Disclose Results

We disclose our emissions data each year and seek to align our disclosures with the recommendations of the TCFD. See page 95 for additional information.

Create operational targets

We developed goals for oil and gas operators that we believe align with industry best practices to reduce GHG emissions. To learn more, see page 73.

Understanding and Managing Our Material Climate Risks

In 2021, Quantum engaged with globally recognized sustainability consultant Environmental Resources Management (ERM) to expand the scope of our climate strategy and create a system of best practices for continuously managing material climate risks. During this initial assessment, in alignment with the recommendations from the TCFD, we evaluated climate-related transition risks and opportunities for our investments under the IEA U.S. Sustainable Development Scenario (SDS) assumptions. We also evaluated the physical risks of three representative Quantum portfolio companies. Acknowledging that climate change data is dynamic and complex, Quantum revisits this analysis to ensure our understanding of risks and opportunities remains current.

Our Financed Emissions*

Calculated 2023

Scope 1

Operational emissions from upstream and midstream companies and vehicle emissions

2,047,996 MT (5.5%)

Scope 2

Emissions associated with electricity usage including office consumption and electrified operations equipment

176,413 MT (0.5%)

Scope 3

End-product use for all production and throughput

35,267,067 MT (94.1%)

Quantum's Total Financed Emissions **37,491,476 MT (100%)**

* Data boundaries and scope: our emissions analysis includes GHG emissions from majority-owned portfolio companies associated with oil and gas operations as of December 31, 2023. Companies with minimal production were not included. All data has been provided directly by portfolio companies and has not been verified by Quantum or any third party. For more information, please see page 96. Scope 3 emissions calculated by Quantum using GHG Protocol Standard.

Decarbonize Operations to Responsibly Deliver Oil & Gas

Climate-Related Risk Management *continued*

Decarbonize Operations to Responsibly Deliver Oil & Gas → Invest in Energy Transition and Decarbonization Opportunities → Build Climate Risk Intelligence and Resilience

A key component of our climate strategy is decarbonizing operations so we can responsibly produce and deliver oil and gas without compromising energy supply. As part of that effort, we have developed aspirational operational goals for our portfolio companies to help manage and reduce their Scopes 1 and 2 GHG emissions. With these goals serving as a roadmap, our portfolio companies can improve operational efficiency, increase revenue by capturing and monetizing more gas, and proactively prepare for possible future regulatory requirements in furtherance of our objective to enhance their value.

Operational Emissions Goals[1]

Methane Emissions

Quantum recommends the below methane intensity caps to our portfolio companies:

Aim to achieve or maintain a methane intensity below 0.20% for the upstream segment[2]

Aim to achieve or maintain a methane intensity below 0.024% for the midstream segment[2]

Direct Measurement

Direct detection of methane leaks results in more accurate methane emissions data and allows operators to quickly identify problems and implement leak reduction strategies. Hence, Quantum recommends that portfolio companies:

Implement direct detection and measurement of methane emissions using on-the-ground direct measurement and continuous monitoring sensors

Flaring

In line with the World Bank Zero Routine Flaring Initiative adopted by many leading oil and gas companies, Quantum recommends that portfolio companies:

End routine flaring by 2030

Aim to keep flaring intensity below 1%[3]

CO_2 Emissions from Fuel Combustion

Quantum recommends that portfolio companies:

Strive to Scope 1 CO_2 emissions from fuel combustion in operations by 50% by 2030[5]

Scope 2 Emissions

To reduce Scope 2 emissions from electricity used in drilling, completion, and production, where possible, Quantum recommends that portfolio companies:

Strive to procure 100% renewable electricity by 2030

Where renewable electricity is not available, use Renewable Energy Credits (RECs), in alignment with Scope 1 GHG Protocol offsetting guidance

SCOPE 1 | SCOPE 2

Please see disclosures for important information regarding ESG considerations of our investment practices.

(1) Targets are non-binding, and no assurance can be given that targets will be achieved by portfolio companies
(2) Methane intensity is calculated as methane emissions allocated to the natural gas value chain divided by the methane throughput, following the approach established by the Natural Gas Sustainability Initiative (NGSI) Methane Intensity Protocol
(3) Flaring intensity is calculated as the percent of produced gas that is flared
(4) Reductions made compared to company-calculated baseline
(5) New companies coming into the portfolio will aim to reduce fuel consumption according to the baseline calculated in their GHG footprint during acquisition

SPOTLIGHT

Oil & Gas Emissions Explained

Illustration produced by the Houston Museum of Natural Science (HMNS).

1

Drilling Rigs

Drilling operations require large engines to power onsite equipment. Traditional engines are fueled with diesel and emit CO_2 emissions when the fuel is combusted, like a car engine.

Increasing fuel efficiency, powering engines with clean natural gas, and utilizing electric drilling rigs can reduce emissions from engines.

2

Hydraulic Fracturing and Flowback

In post-fracking flowback, a mix of oil, gas, and water is released into tanks or pits. Gas in this mixture can be vented or flared.

Reduced Emissions Completions (REC) have specialized equipment that captures gas during well completions after fracking, delivering it to sales lines instead of venting or flaring.

3

Wellheads

Wellheads do not directly produce emissions, but associated flanges and valves are potential sources of fugitive emissions.

4

Three-Phase Separators

Separators do not directly produce emissions, but associated flanges and valves are potential sources of fugitive emissions.

5

Pneumatic Controllers

Gas-driven pneumatic controllers regulate pressure, and emit when actuating.

Pneumatics can run on electricity, compressed air, or nitrogen, and emissions can be routed to other processes in closed vent systems.

6

Dehydrators

Dehydrators remove water from gas. During the process, they can vent methane vapors and emit volatile organic compounds and hazardous air pollutants.

Zero emission dehydrators use flash tanks to capture and reuse non-condensible vapors, preventing their release to the atmosphere.

7

Vapor Recovery Units (VRUs)

VRUs capture tank emissions, separating liquids and vapors. Liquids return to tanks and vapors go to sales lines, compressors, or fuel gas. This reduces facility emissions effectively.

8

Pneumatic Pumps

Pneumatic pumps use gas pressure to move liquids through pipelines. They emit when functioning properly.

Pneumatic pumps can be powered with compressed air, or emissions from pumps can be routed to another process.

9

Compressors

Compressors emit CO_2 from combustion and can leak methane. Faulty compressors may allow methane to slip through the engine uncombusted.

Regular maintenance keeps compressors running properly. Emissions can be routed to other processes or control devices. Electric compressors can reduce methane and CO_2 emissions.

10

Storage Tanks

Storage tanks contain oil, condensate, or water. They have pressure relief devices called enardo valves. When an enardo valve malfunctions, pressure and vapors are released through thief hatches on top of the tanks.

Pressure monitors alert operators to tank overpressure, enabling quick fixes. Tank vapors can be flared or used to power processes, reducing emissions. Rapidly closing thief hatches also helps reduce emissions.

11

Flares

Flares combust excess vapors, and high vapor tanks are routed to flares in emergencies to prevent direct venting.

While flares primarily produce CO_2 by combusting gas, they can emit methane from uncombusted gas that escapes through the flare stack. Regular monitoring and maintenance are key to efficient flares and lower emissions.

Liquids Process

Gas Process

12

Trucks

Trucks are sometimes used to transport water or oil to and from facilities.

Transporting liquids through pipelines can reduce truck traffic and associated CO_2 emissions.

13

Fugitive Emissions

Fugitive emissions are unintended leaks from equipment, often due to wear, damage, or improper maintenance.

Modern leak detection uses methane sensors, OGI cameras, flyovers and drones, with operators frequently combining methods for quick detection and repair.

For illustrative purposes only. This graphic covers most processes but does not include an exhaustive or complete list of emissions activities. Further sources may apply.

Invest in Energy Transition & Clean Infrastructure Opportunities

Climate-Related Risk Management *continued*

Decarbonize Operations to Responsibly Deliver Oil & Gas → **Invest in Energy Transition and Decarbonization Opportunities** → Build Climate Risk Intelligence and Resilience

As a key component of our climate strategy, Quantum invests in products and infrastructure that are essential to support global electrification and decarbonization. Through our 547 Energy platform, we conduct thorough due diligence on a wide range of opportunities in the energy transition and development space, including renewables, power, and clean energy infrastructure.

Investing in Clean Energy Infrastructure

We believe that energy infrastructure is critical to low or no carbon energy, power generation, and transmission. By focusing on the development and modernization of essential infrastructure, we strive to enable scalable, sustainable solutions for clean energy across industries and geographies.

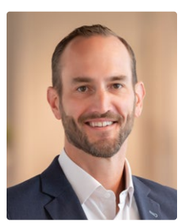
Haventus

Haventus, based in Inverness, Scotland, provides critical infrastructure for the offshore wind industry. The company identifies, redevelops, and manages strategic sites to support large-scale renewable energy development. Its first facility at Ardersier Port on the North Sea coast is expected to be Scotland's largest and will be dedicated to offshore wind deployment and servicing. See page 93 for additional information.

Mexico Pacific

Their anchor project, the Saguaro Energia LNG facility located 200 kilometers from the U.S. border, leverages low-cost natural gas from the nearby Permian Basin and a shorter shipping route that avoids the congested Panama Canal, resulting in cost savings, logistical advantages, and lower GHG emissions.

"Infrastructure is critical to low or no carbon energy generation and transmission. Because of Quantum's experience with traditional energy midstream infrastructure, which is required to support bridge fuels for the energy transition, we believe we are well suited to invest in the power generation and transmission that is necessary to the energy transition."



JB Oldenburg, Managing Director, Quantum Capital Group

547: Quantum's Renewable Energy Platform

547 Energy is a global, multi-technology renewables development platform with 7 gigawatts of wind and solar projects in its development pipeline across multiple geographies in the U.S. and Europe. Guided by an experienced team in the renewable space, 547 is focused on investing in early-stage wind, solar, and energy storage projects, aiming to build a diverse clean energy portfolio that delivers private equity returns.

547 Core Investments

Aer Soléir

Dublin, Ireland-based developer of onshore, utility-scale, wind, solar, and battery storage projects across Europe

BlueFloat ENERGY

Madrid, Spain-based global developer of utility-scale, fixed-bottom and floating offshore wind projects

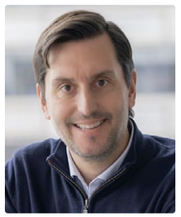
neton POWER

Madrid, Spain-based renewable energy development platform focused on self-consumption energy projects for commercial and industrial customers throughout southern Europe

CleanArc DATA CENTERS

Las Vegas, Nevada-based clean energy powered data center developer

"547's expertise of the global renewable energy landscape allows the company to anticipate how technologies and markets are likely to evolve over time and gives 547 the flexibility to pivot quickly and decisively when market fundamentals change."



Gabriel Alonso, CEO, 547 Energy

SPOTLIGHT

547's ConnectGen sold for ~$1 Billion

ConnectGEN®

ConnectGen is a U.S. utility-scale multi-technology development platform specializing in wind, solar, and battery storage projects. With approximately 70 employees and 24 gigawatts of multi-technology pipeline across 13 U.S. states, the company identifies high-potential sites in grid-intelligent markets, offering offtake optionality and opportunities for value-based electricity pricing. Quantum has fully monetized the ConnectGen platform in three separate transactions, valued at approximately $1 billion, highlighting our ability to deliver strong returns in the energy transition space.

It should not be assumed that the investments described herein were or will ultimately be profitable or that investments made in the future will be profitable or will equal the performance of these investments.

Build Climate Risk Intelligence & Resilience

Climate-Related Risk Management *continued*

Quantum is focused on building intelligence to understand the risks associated with climate change, and how climate change may impact our investments. We performed a benchmark assessment of physical and transition risks in 2021 to gather a baseline assessment of potentially material climate risks to our portfolio.

Examples of physical risks include rising sea levels, hurricanes, flooding, droughts, wildfires, etc. Transition risks include market and technology risks, regulatory and legal liabilities, and reputational risks, which vary by investment type. In addition to the initial study we performed with ERM, we conduct an ongoing analysis of these risks to understand the financial impact climate change may have on our investments. For more information on this analysis, see Quantum's 2022 ESG Report and the TCFD index on page 95.

In seeking to understand the risks to our own investments, Quantum has identified an opportunity to invest in companies that are focused on building climate resilience and intelligence. Quantum has invested in a wide array of services that are complementary to our energy investments, applicable across various industries, and can identify climate risks, ratings, and solutions to build climate intelligence.

Risilience

PRIMARY OFFICE	YEAR OF INVESTMENT
Cambridge, England	2022

Risilience's climate analytics technology aims to drive business transformation toward a low-carbon economy with its award-winning climate-intelligence SaaS platform. Risilience helps businesses understand and navigate climate risks by integrating them into business strategies and quantifying their financial impact. Through their digital twin technology and advanced climate models, Risilience provides insights into the risks of future scenarios, offering granular financial-impact assessments. Additionally, they support reporting requirements and assist companies in navigating increasingly complex regulations. Risilience's solutions empower clients to make informed investment decisions that reduce emissions, capitalize on market opportunities, and support a value-driven, net-zero strategy.

Carbon Direct

PRIMARY OFFICE	YEAR OF INVESTMENT
New York, New York	2022

Carbon Direct is focused on making meaningful and equitable climate action achievable for any organization at any stage in the climate journey with a scientifically-proven approach. They aim to help organizations go from climate goals to climate action by combining technology with deep expertise in climate science, policy, and carbon markets to deliver carbon emission footprints, actionable reduction strategies, and carbon dioxide removal credits that meet our quality criteria. Carbon Direct helps clients set and equitably deliver on their climate commitments, streamline compliance, and manage risks through transparency and scientific credibility.

ORENNIA

PRIMARY OFFICE	YEAR OF INVESTMENT
Calgary, Canada	2021

Orennia is a technology company focused on providing insights and analytics to capital allocators in the renewable and alternative energy sectors. As the world seeks greater investments in renewables to meet global emissions targets, investors have lacked access to a platform with the necessary data and analytics to guide sound investment decisions. Orennia's solution aggregates multiple disparate sources of publicly available data, cleans, normalizes, and organizes it, and then applies value-added analytics and insights developed by industry experts. This streamlined process, delivered through their platform, accelerates innovation and capital deployment by automating key aspects of the investment decision-making process.

Regulatory Risk Management

At Quantum, we prioritize regulatory risk management to ensure compliance and mitigate potential challenges in an evolving legal and regulatory landscape.

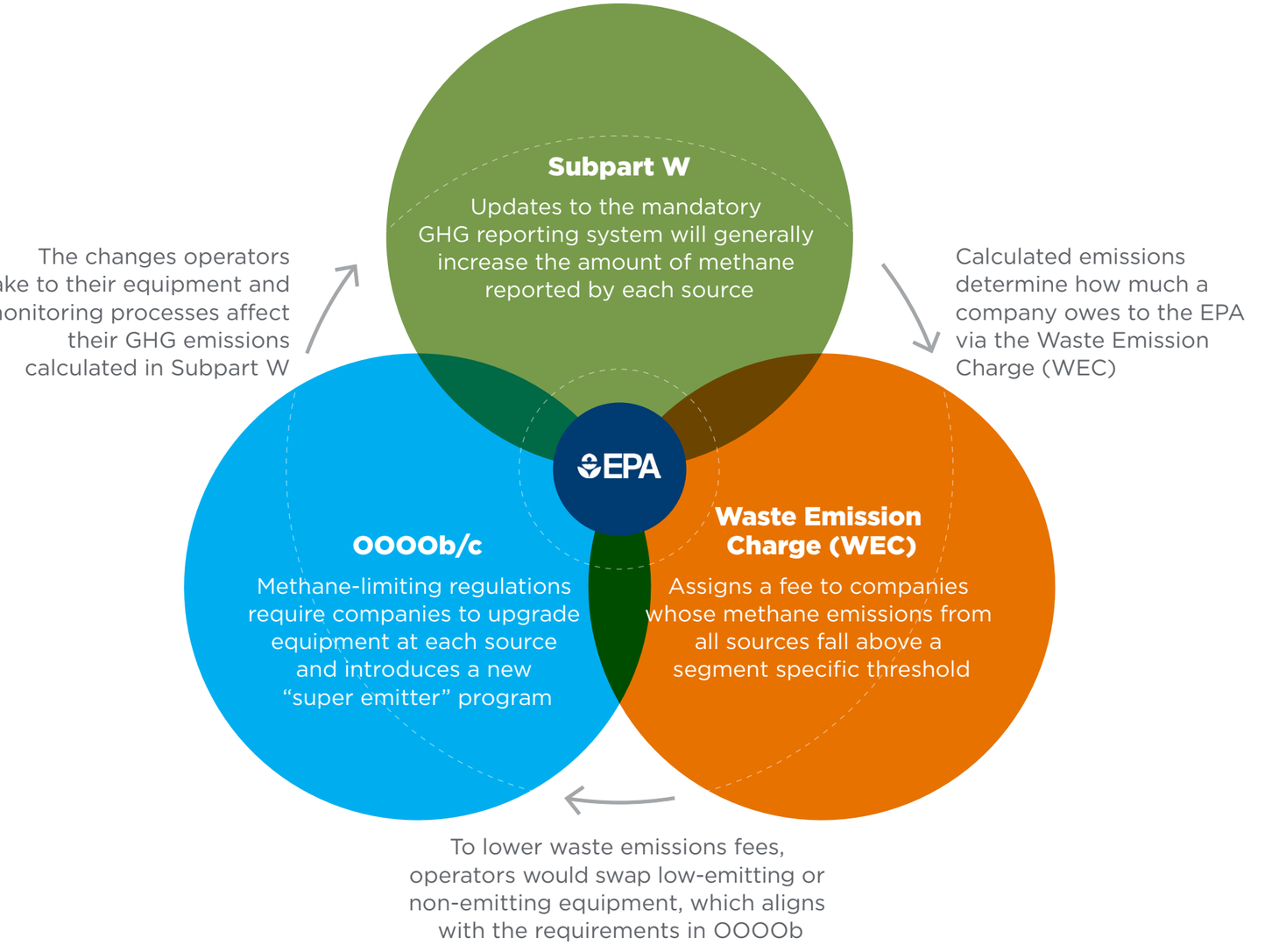
In 2023, the EPA introduced a comprehensive set of regulations and fees specifically aimed at curbing excess methane emissions within the oil and gas sector. These regulations, which include both performance standards and financial penalties, are designed to address methane leaks and emissions at multiple stages of production, making the rules not only overlapping but also interconnected in their application.

At Quantum, we have conducted an assessment of these regulations to understand the potential implications for our portfolio companies. Our analysis has allowed us to identify areas where the new rules could impact operations, costs, and compliance requirements. In response, we are working proactively with our portfolio companies to develop and implement tailored mitigation strategies that address both immediate compliance and long-term sustainability goals.

In addition to mitigation efforts, we are providing ongoing support to help ensure that our portfolio companies remain well-prepared as the regulatory environment continues to evolve. By closely monitoring any updates or changes to these regulations, we can help portfolio companies swiftly adjust their strategies and ensure that compliance measures remain effective. Our commitment to staying ahead of regulatory shifts enables us to minimize risks and enhance operational resilience across the portfolio.

Quantum Engages with Portfolio Companies to Increase Awareness of Regulatory Landscape

- **Providing regulatory updates**
- **Hosting teach-ins from leading environmental experts**
- **Supporting emissions reduction initiatives**
- **Assessing source-level emissions and year-over-year progress**
- **Building strategic partnerships with emissions reduction experts and monitoring companies, such as Project Canary**



Regulatory Risk Management *continued*

EPA New Source Performance Standards (NSPS) Subpart OOOO(b)

OOOOb is the latest update to the EPA's rules aimed at reducing methane emissions from oil and gas facilities. This suite of rules focuses on monitoring, performance testing, and maintenance of onsite equipment to reduce methane emissions. Since the original OOOO rule in 2011, regulations for new equipment have become increasingly stringent as advancements in data and technology improve the industry's ability to address methane emissions. Methane emissions are often considered easier to abate than other GHG emissions because leaks can be quickly and affordably detected and fixed with current technology.

OOOO Rules Compliance Timeline

OOOOb regulates the following equipment:

- **Completions of hydraulically fractured wells**
- **Compressors**
- **Pneumatic controllers and pumps**
- **Tanks**
- **Sweetening units**
- **Associated gas from oil wells and liquids unloading**

OOOOa requires operators to use OGI cameras to survey equipment and address leaks semi-annually. OOOOb enhances these measures by increasing monitoring frequency to quarterly and introducing a Super-Emitter Response Program (SERP). SERP allows third parties to notify the EPA of any large operator leaks over 100 kg/hour. Third parties typically discover these leaks through aerial flyovers or satellite data. This program promotes a "top-down" and "bottom-up" approach to leak detection, combining aerial overviews of facilities with detailed inspections using OGI.

Subpart W: Petroleum and Natural Gas Systems – Greenhouse Gas Reporting Rule (40 CFR Part 98)

The EPA began collecting reports for the Greenhouse Gas Reporting Program (GHGRP) in 2011 to provide accurate data for climate policy decisions. Subpart W of the GHGRP requires oil and gas operators that emit over 25,000 metric tons of carbon dioxide equivalent to report their emissions.

Subpart W outlines calculation methodologies for reporters for each piece of equipment, including the use of EPA-prescribed emissions factors, which can differ significantly from observed field emissions. The goal of the new Subpart W and proposed changes is to shift the focus of reporting to empirical data that more accurately reflects methane emissions.

Similar to OOOOb, the updates to Subpart W are driven by the EPA and operators having a better understanding of methane sources, more accurate emission factors, and improved technology for direct measurement of methane emissions. Reliable data collection is critical for formulating climate policies and has become increasingly important as emissions reported in Subpart W will be the basis for determining the WEC fees.

U.S. Methane Emissions Reduction Program (MERP) Waste Emission Charge (WEC)

The WEC is an element of the MERP that was included in the 2022 IRA to reduce emissions from oil and gas operations. The WEC incentivizes operators to meet segment-specific methane intensity thresholds. Companies that report under Subpart W will be assessed against these thresholds and required to pay a fee for each ton of methane emitted above their sector-specific limit.

In 2025, companies that fail to meet their sector-specific intensity thresholds may be required to pay the WEC, with the fee per excess ton increasing annually for the first three years of reporting.

INDUSTRY SEGMENT	INDUSTRY SEGMENT-SPECIFIC THRESHOLD
Onshore Petroleum and Natural Gas Production	0.20%
Offshore Petroleum and Natural Gas Production	0.20%
Onshore Petroleum and Natural Gas Gathering and Boosting	0.05%

PAYMENT SCHEDULE ($ PER EXCESS TON OF METHANE)		
2025	2026	2027
$900	$1,200	$1,500

Cybersecurity Risk Management

We have developed a robust cybersecurity program that leverages advanced technologies and automation to effectively manage risks and analyze large volumes of data. Our approach prioritizes thorough risk management and targeted information filtering, aiming to provide comprehensive protection against cyber threats. This program extends to both Quantum and our portfolio companies, providing a unified defense strategy.

Our cybersecurity practices are aligned with the National Institute of Standards and Technology (NIST) Cybersecurity Framework 2.0 (CSF) standards, and we strongly encourage all portfolio companies to participate in relevant training and adhere to these guidelines. Additionally, we have introduced a comprehensive 5-star rating system to promote the consistent implementation of key cybersecurity measures across our portfolio.

Quantum Five-Star Rating System

- **Cyber education and training programs**
- **Multi-factor authentication for all critical systems**
- **IT policies including password management guidelines**
- **Managed detection and response services, along with regular vulnerability assessments**

Quantum Core Cybersecurity Recommendations for Portfolio Companies

Identify

- Establish and document cybersecurity policies while maintaining a comprehensive inventory of critical assets.
- Assign a senior leader to oversee and be accountable for the cybersecurity program.
- Implement a Governance, Risk, and Compliance (GRC) framework to guide cybersecurity efforts.
- Perform external GRC evaluations and vulnerability assessments every two years.

Protect

- Enforce secure password practices, establish a documented password policy, and enable multi-factor authentication (MFA) wherever feasible.
- Deploy mobile device management (MDM) software and install antivirus and anti-malware protection.
- Utilize firewalls and VPNs to ensure secure network access.
- Keep off-site backups of all critical data for disaster recovery.
- Conduct ongoing cybersecurity training and phishing awareness programs for employees.
- Secure adequate cyber insurance coverage to mitigate potential risks.

Detect

- Establish procedures to consolidate logs and events from multiple systems and generate actionable alerts.
- Conduct regular reviews of critical alerts across all systems.

Respond

- Develop and document a response plan for addressing potential cybersecurity incidents.
- Conduct annual testing of disaster recovery and business continuity plans.

Recover

- Incorporate recovery strategies into the response plan, such as:
  - Restoring essential data from cloud and off-site backups.
  - Ensuring employees can access critical functions during network disruptions.

SPOTLIGHT

Learning from a Cyberattack

Portfolio Company Overview

In 2023, one of our portfolio companies was targeted by a cyberattack. A malicious actor intercepted and altered communications between two parties, capturing sensitive information from key executives and manipulating data sent to the company's bank and partners. The attackers also attempted to intercept and authorize wire transfers, but were unsuccessful.

Impact on Portfolio Company

The attack prompted the company to suspend operations for two days to address the "man-in-the-middle" threat and restore functionality. The compromised login credentials resulted from a lack of multi-factor authentication and insufficient review of privileged access roles.

Key Takeaways

Key takeaways from the cyberattack include:

- Provide cybersecurity awareness training and phishing simulations to help employees recognize cyber threats.
- Strengthen endpoint security tools.
- Implement multi-factor authentication (MFA) across systems.
- Update security controls and review privileged access for Azure and Microsoft 365.
- Develop and test incident response plans
- Leverage Managed Detection and Response (MDR) services to detect and mitigate threats from malicious actors.

Portfolio Company ESG Performance

Inside this section:

GHG Emissions

As responsible investors, we recognize the importance of diligently monitoring, tracking, and reducing our portfolio company emissions, with a focus on our most significant emissions – carbon dioxide and methane. By doing so, we can gain a comprehensive understanding of our environmental impact and leverage that information to align with market and regulatory requirements. This commitment reflects our dedication to responsible stewardship with the goal of delivering the highest possible risk-adjusted returns for our investors.

In addition to gathering data on carbon dioxide and methane emissions, we collect information from our companies on nitrous oxide (N_2O), another type of greenhouse gas reported to the EPA. We also require reporting on emissions from company-owned vehicles. These emissions make up a small percentage of our total emissions, with fewer options for reduction. However, where feasible, companies explore options for lower-emitting vehicles.

Quantum carefully tracks year-over-year metrics to identify trends in our GHG data. We believe that maintaining a consistent record of our emissions helps us identify areas for improvement and clearly assess the risks and opportunities within our portfolio. However, due to the nature of our business, we experience fluctuations in our aggregated metrics and intensities as companies enter and exit the portfolio.

In 2023, our total Scope 1 portfolio emissions decreased compared to 2022, driven by initiatives implemented by our portfolio companies. However, our GHG and methane intensities, measured as a ratio of emissions over production, increased following the exit of large production values from our portfolio, including Tug Hill, Rockcliff, and Tanos. These companies had relatively low Scope 1 emissions as large producers and were highly influential in our 2021–2022 intensities. We remain focused on helping our portfolio companies reduce emissions for our existing assets, prioritizing projects that reduce risks while offering quick payback or the potential to lower regulatory compliance costs.

Please see disclosures for important information regarding ESG considerations in our investment practices. There can be no assurance that any historical trends will continue.

(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 Scope 1 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
(3) Does not include emissions from vehicles

2023 Portfolio Scope 1 Emissions[1]

Carbon Dioxide (CO_2)
Emissions from combustion operations and flaring
1,790,687 MT CO_2e

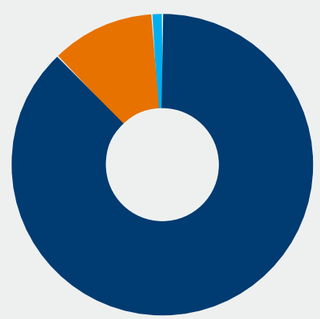
Methane (CH_4)
Emissions from venting or leaking natural gas
226,320 MT CO_2e

Nitrous Oxide (N_2O)
Another type of emissions resulting from combustion operations
1,589 MT CO_2e

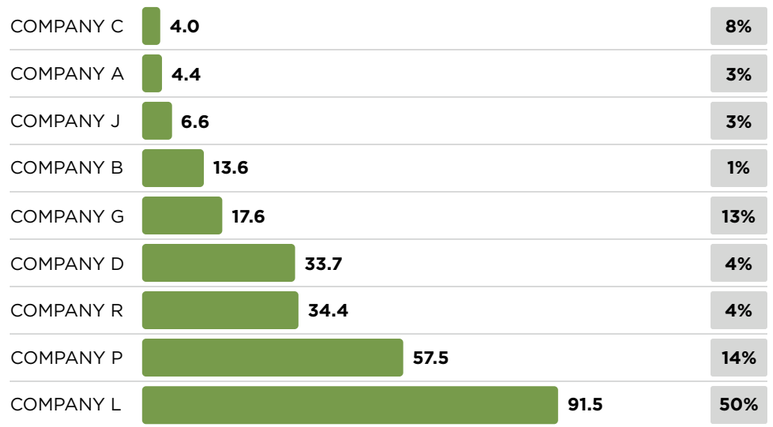
Vehicle Emissions
Emissions from company-owned vehicles
29,399 MT CO_2e

Scope 1
Operational emissions from upstream and midstream companies, including vehicle emissions
2,047,995 MT CO_2e

2023 portfolio Scope 1 operational emissions
Percent



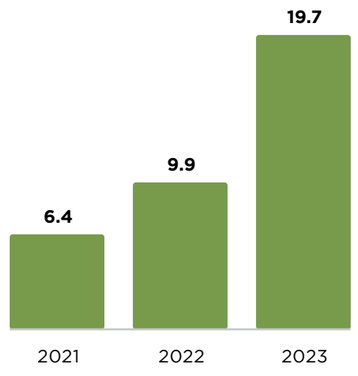
2023 Scope 1 GHG emissions intensity by portfolio company[2]
MT CO_2e/Mboe



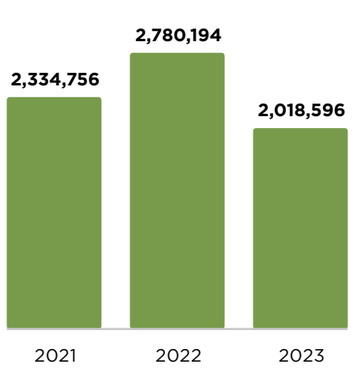
GHG Intensity (MT CO_2e/Mboe) GHG Emissions (MT/% of Portfolio)

* Indicates new portfolio company or newly-acquired asset
** Companies not listed here are not within the scope of reporting for this metric

Year-over-year portfolio Scope 1 GHG intensity
Total greenhouse gas emissions/ total production (MT CO_2e/Mboe)



Year-over-year portfolio Scope 1 GHG emissions[3]
Total greenhouse gas emissions/ total production (MT CO_2e/Mboe)



GHG and methane intensities do not include vehicle emissions, to align with calculation methodology and benchmarks using EPA Subpart W data.

Progress on Operational Emissions Goals

Reducing Methane

We believe addressing methane emissions plays a crucial role in the environmental and financial performance of our oil and gas portfolio companies. We evaluate methane emissions from our portfolio companies by source, as specified by the EPA's Subpart W, and in compliance with the newly instituted OOOOb regulations. We believe this evaluation allows us to pinpoint specific areas for improvement and enables us to allocate efforts and resources more effectively as we assist our portfolio companies in their ongoing efforts to reduce GHG emissions.

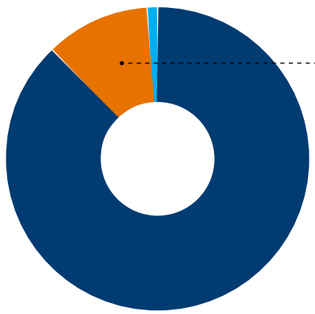
Our approach to supporting methane management centers around deploying advanced direct detection methods to effectively identify and minimize methane leaks, with the goal of maintaining a portfolio methane intensity below 0.2%. Our target is aligned with industry peers and NGOs like the Oil and Gas Methane Partnership (OGMP 2.0). It is also consistent with the prescribed methane emissions thresholds outlined in the IRA.

In 2023, methane comprised 11% of operational emissions from our oil and gas portfolio companies and our portfolio outperformed our 0.2% methane intensity goal. While there may be fluctuations in our portfolio-wide methane intensity as companies enter or exit our portfolio or make operational adjustments, we are committed to consistently monitoring and improving our methane management practices to ensure long-term sustainability and operational excellence for each company.

Our portfolio companies are encouraged to diligently assess their methane emissions and proactively address each identified source. Consistent with previous years, pneumatics remained the primary contributors in 2023. The companies in our portfolio are actively working to reduce leaks by employing a range of technologies, including continuous monitoring through Quantum's portfolio company Project Canary.

2023 portfolio Scope 1 operational emissions[1]

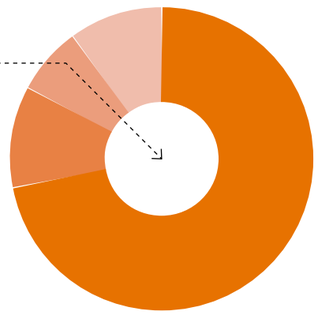
Percent



- **87%** Carbon Dioxide
- **11%** Methane
- **1%** Vehicle Emissions
- **<1%** Nitrous Oxide

2023 portfolio methane emissions by source

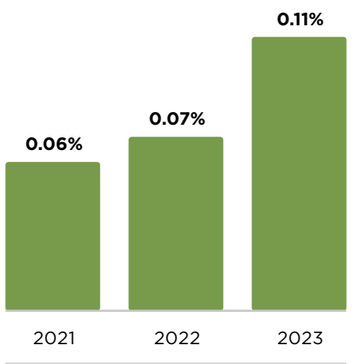
Percent



- **72%** Pneumatic Controllers and Pumps
- **11%** Flaring
- **7%** Leaks
- **10%** Other

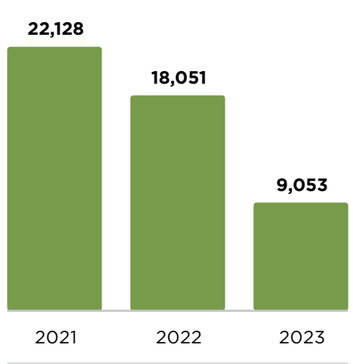
Year-over-year portfolio NGSI methane intensity[2]

Methane emissions from natural gas/ methane content of natural gas throughput (%)



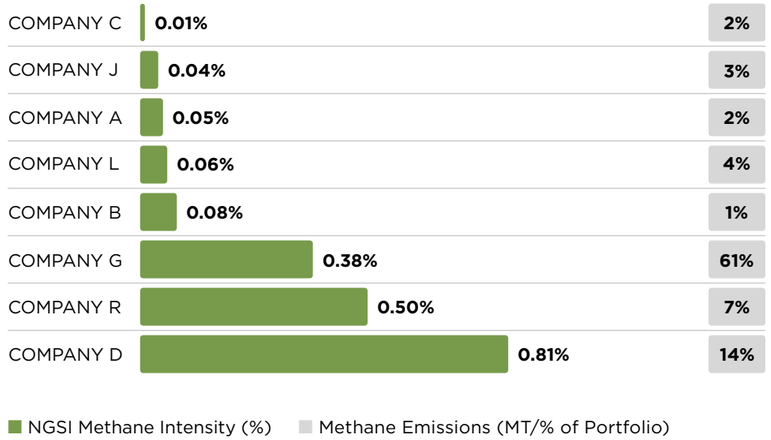
Year-over-year portfolio methane emissions

MT CH_4



2023 methane intensity by portfolio company[3]

Percent



Pneumatics: Quantum companies, including KODA Resources and White Rock Resources, are tackling methane emissions from pneumatic devices

Flaring: See Quantum's flaring performance and how companies are complying with new flaring regulations

Leaks: Quantum companies use different technologies to quickly find and fix leaks – Rio Oil and Gas is an example of how using multiple technologies benefits companies

Please see disclosures for important information regarding ESG considerations in our investment practices. There can be no assurance that any historical trends will continue. Quantum's total (portfolio) methane intensity is estimated using aggregated data provided by portfolio companies. Portfolio company data has not been verified by Quantum or any third party.

(1) Data may exclude portfolio companies who did not report data
(2) Quantum calculates methane intensity in accordance with the Natural Gas Sustainability Initiative (NGSI) protocol. Data may exclude portfolio companies who did not report data
(3) Quantum's total portfolio methane 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

Progress on Operational Emissions Goals *continued*

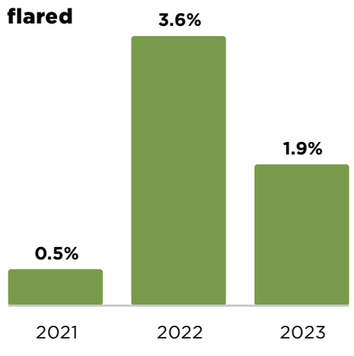
Progress on Flaring

Our goal is to assist our portfolio companies in eliminating routine flaring and setting short-term flaring intensity targets. Flaring, the burning of excess natural gas, typically results from challenges in natural gas takeaway infrastructure or operational safety considerations. This is the case for certain basins Quantum operates in, and for our offshore investment. By collaborating closely with our portfolio companies, we aim to address these issues, reduce flaring, and optimize the utilization of natural gas resources. This not only enhances environmental sustainability but also improves the profitability of our investments.

In 2023, Quantum's aggregated flaring intensity decreased, driven by improvements across several portfolio companies. The most significant progress came from Trident, our offshore investment made in 2022. Like many offshore operators, Trident faces limited gas takeaway infrastructure. Under Quantum's guidance, Trident aimed to reduce flare volumes, achieving a 20% reduction in flaring compared to 2022.

Year-over-year portfolio percent gas flared
Gas flared/gas produced

In 2023, Trident achieved a 20% in flaring reduction with Quantum's support. Trident's is a major driver in Quantum's overall flaring intensity, and greatly contributed to the firm-wide reduction.



SPOTLIGHT

Trident's Efforts to Reduce Gas Flaring

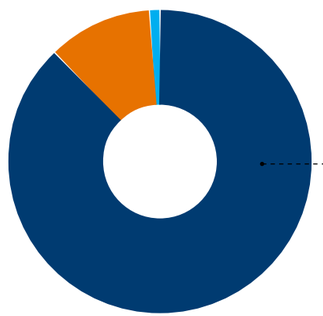
Trident Energy operates three producing assets, including facilities offshore Equatorial Guinea and Brazil. Each of these assets presents a different opportunity to reduce flaring with innovative solutions. As part of their effort to reduce flaring in Brazil, Trident developed a "Flare Hunting Program" to methodically identify, repair, and replace equipment and valves before they malfunction and cause the need for an emergency shutdown, resulting in flaring. In Equatorial Guinea, Trident invested significant capital to upgrade the vapor recovery unit and process piping at their facility, which could reduce flaring by 75%. Additionally, through their gas and power initiative, Trident is developing the capability to divert gas to the national grid or generate electricity for local communities. Together, these two programs are expected to eliminate the need for production flaring on Trident's Equatorial Guinea assets.

Reducing Combustion Emissions

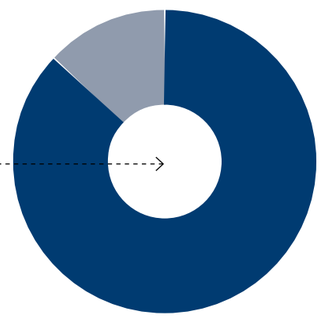
GHG emissions from fuel combustion are primarily generated by equipment such as engines used in steam flooding, drilling operations, well completions, and compression for low-pressure wells. These activities are essential to the oil and gas extraction process, but they also produce significant amounts of combustion-related emissions, which are a major component of our portfolio's Scope 1 emissions.

Recognizing the environmental impact, we are committed to implementing strategies to reduce these emissions. This includes investing in more efficient fuel-fired equipment, adopting advanced technologies that reduce fuel consumption, and enhancing operational practices to minimize unnecessary combustion. Additionally, we are exploring alternative energy sources and innovative solutions to further decrease our reliance on traditional fuel-fired systems.

2023 portfolio Scope 1 operational emissions[2]
Percent



2023 portfolio CO_2 emissions by source[2]
Percent



Please see disclosures for important information regarding ESG considerations in our investment practices. There can be no assurance that any historical trends will continue.

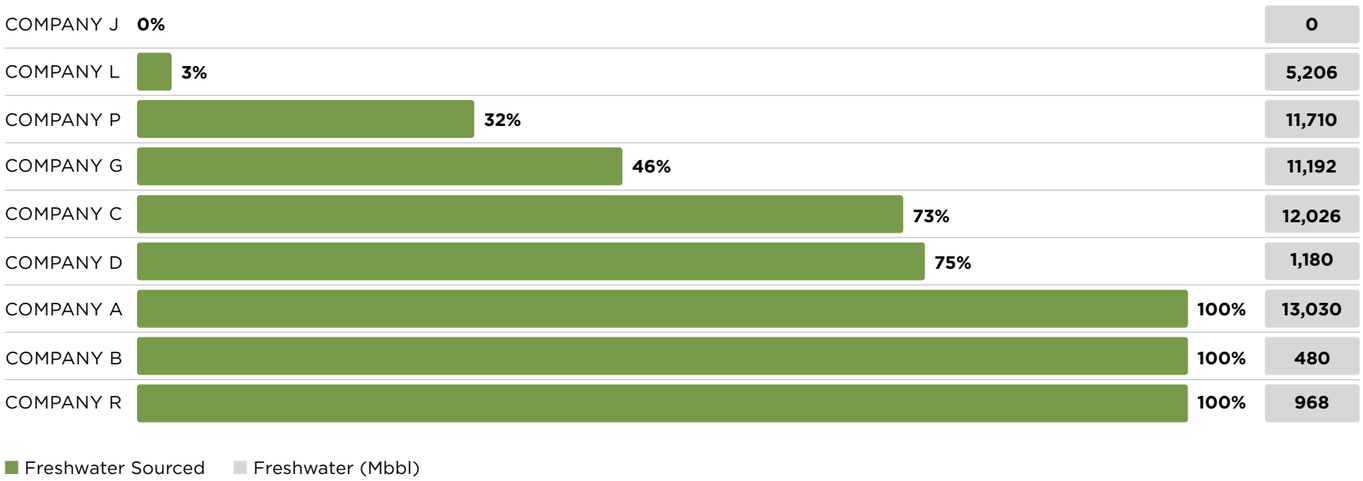
(1) Quantum's total flaring intensity is estimated using aggregated data provided by portfolio companies. Portfolio company data has not been verified by Quantum or any third party
(2) Equipment specific sources as reported to EPA or identified by Quantum portfolio companies. Portfolio company data has not been verified by Quantum or any third party

Water Stewardship

We remain committed to reducing freshwater consumption across our portfolio companies. We believe this effort can lead to substantial cost savings in water procurement and disposal and mitigate impacts and risks associated with water scarcity. Moreover, by responsibly managing water usage, we enhance our companies' social license to operate, which strengthens their competitive position in an increasingly resource-conscious market.

In 2023, nearly 80% of the water sourced by our portfolio companies came from non-freshwater sources. The decrease in freshwater use this year was largely due to the sale of a portfolio company that sourced a large share of water. To better manage water resources, we have mapped out water scarcity in the regions where we operate, confirming that the majority of our portfolio company operations are not located in extremely high scarcity areas.

2023 total freshwater consumption by portfolio company
Percent

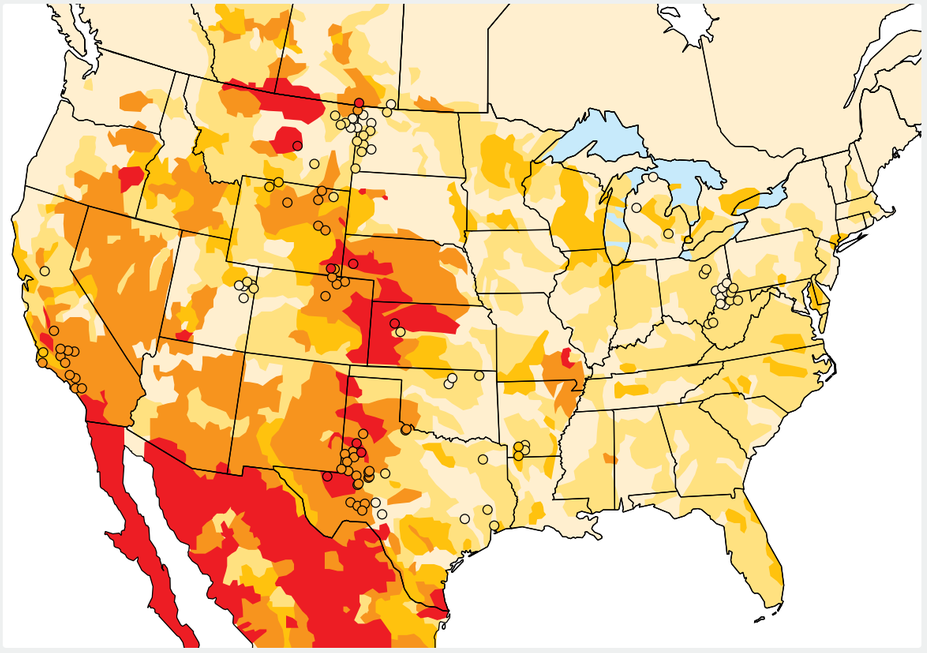


Year-over-year portfolio freshwater usage
Percent, Total Bbbl

SPOTLIGHT

Quantum's Annual Water Risk Assessment

Each year, Quantum's ESG and Technical teams collaborate to assess water scarcity risks across our portfolio using the World Resources Institute (WRI) Aqueduct tool. We evaluate each company by the number of wells they operate in extremely high-risk areas. Overall, only 2% of Quantum's portfolio wells are in these high-risk regions. Our largest contributor to high-risk wells accounts for 78% of this total but actively addresses water scarcity through a robust water recycling system, using the lowest volume of fresh water in the portfolio.



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

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

The select investment is provided for illustrative purposes only to demonstrate Quantum's investment approach generally, and not all applicable investments are shown. There is no guarantee that Quantum will be able to identify similar investments in the future. Please see disclosures for important information regarding ESG considerations in our investment practices. There can be no assurance that any historical trends will continue.

Quantum's total non-freshwater usage is calculated using aggregated data provided by portfolio companies. Portfolio company data has not been verified by Quantum or any third party.

Safety

Our goal is to cultivate strong human capital management practices within our portfolio companies. By doing so, we aim to build a workforce that is safe, highly engaged, and productive. We believe this focus not only boosts operational efficiency but also enhances competitiveness and ensures the long-term success of the organization.

Safety

We partner with our portfolio companies to instill a culture that prioritizes the well-being of every employee, seeking to ensure they return home safely each day. By focusing on safety, we aim to minimize the risks and costs associated with workplace accidents, such as regulatory fines and higher insurance premiums. We believe this commitment to safety also fosters a more productive work environment by maintaining employee health and boosting morale.

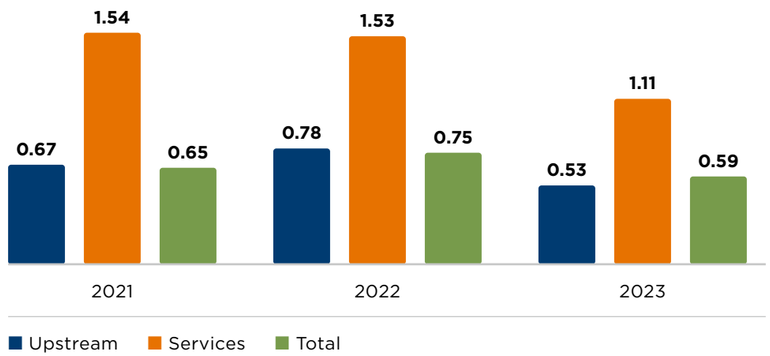
In 2023, our portfolio's Total Recordable Incident Rate (TRIR) was 0.57, reflecting a decrease compared to 2021 and 2022. Throughout the year, Quantum companies and their contractors collectively worked over 14 million hours.

Quantum companies and their contractors worked over 14 million hours in 2023.

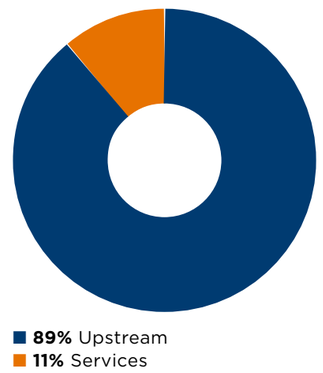
Asset Integrity and Process Safety

Our focus with our oil and gas portfolio companies is on ensuring operational efficiency and reducing risks through strong asset integrity and process safety measures. This involves a lifecycle approach to asset management, including design, maintenance, and replacement, while balancing costs. By actively managing asset wear and tear, we aim to protect personnel, avoid environmental impacts, and ensure seamless operations.

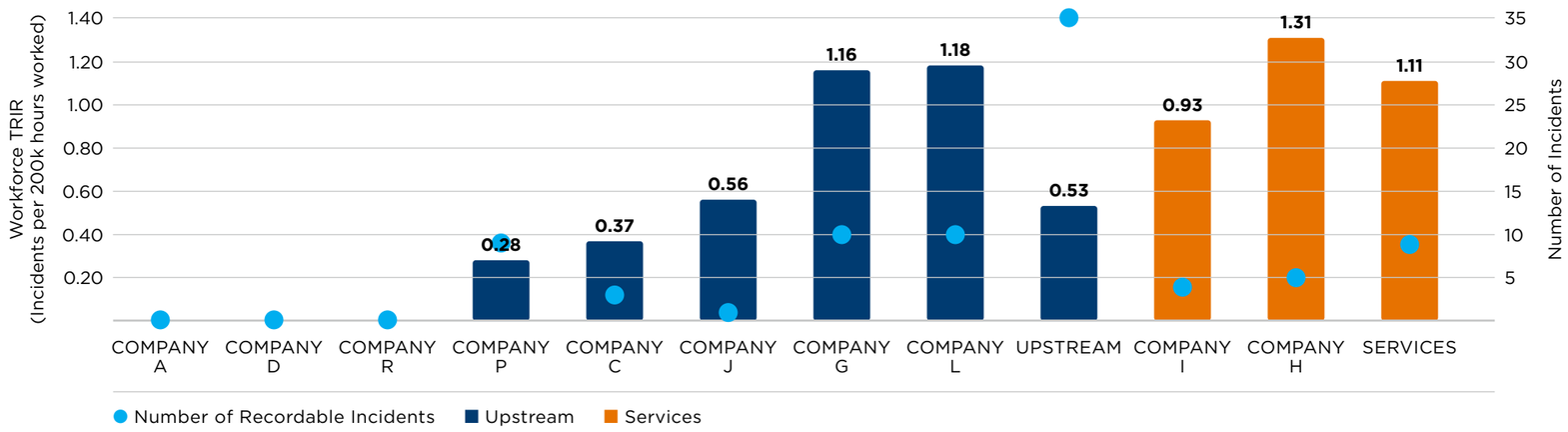
Year-over-year portfolio total recordable incident rate (TRIR)[1]
Rate



2023 portfolio hours worked
Percent



2023 workforce TRIR by portfolio company and vertical*



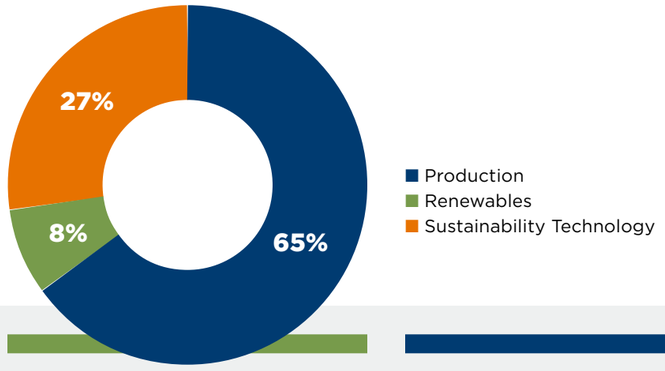
(1) Portfolio company data as of December 31, 2023. Companies that had not yet commenced operations or have minimal production were not included. All data has been provided directly by portfolio companies and has not been verified by Quantum or any third party. There can be no assurances that any historical trends will continue.

*Quantum aggregate metrics do not include Company B, who did not track contractor hours but reported 2 contractor incidents.

Driving Value with Diverse and Highly Qualified Teams in the Portfolio

Our ongoing collaboration with portfolio companies focuses on human capital management policies to stimulate innovation, enhance decision-making, boost employee engagement and retention, and support sustainable long-term growth. As of December 21, 2023, our portfolio companies were made up of over 3,600 unique individuals across investment strategies. We gather human capital data for a holistic understanding of our employee makeup, which varies by industry.

Portfolio company headcount by investment type



Sustainability Technology

7 Companies

995 Employees

142 Average Number of Employees

Renewables

6 Companies

289 Employees

48 Average Number of Employees

Production

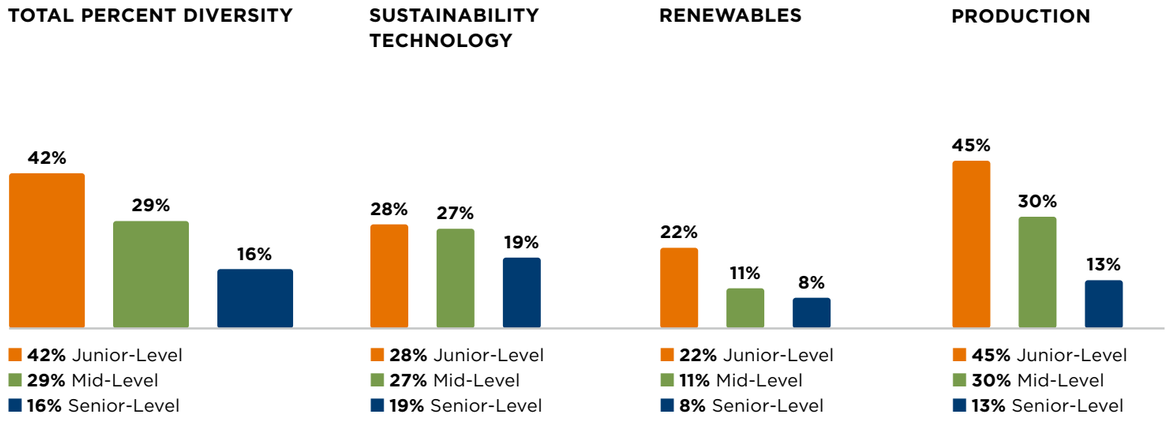
15 Companies

2,340 Employees

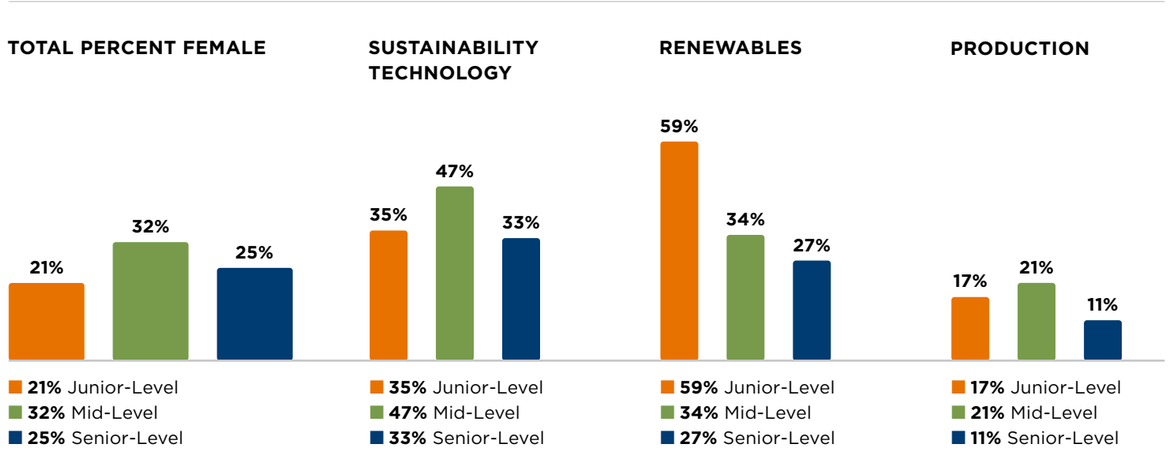
156 Average Number of Employees

Human capital management data as of December 31, 2023 does not include Quantum Capital Solutions or companies that did not track human capital management data.

2023 overall portfolio company racial/ethnic representation
Percent



2023 portfolio company gender representation
Percent



Portfolio Company ESG Performance Disclosure

Quantum carefully monitors portfolio company performance on an annual basis, with certain types of companies tracking certain metrics on a quarterly basis. We believe that actively gathering this data helps us to gauge company performance and actively pursue projects we believe can add value and mitigate risks proactively and frequently.

While we believe in transparently sharing this data with our stakeholders, we recognize that aggregated metrics reflect only a snapshot of the portfolio at a specific point in time. Due to the nature of our business, identifying trends in aggregated data is challenging as companies enter and exit the portfolio. Although we present aggregated year-over-year data on certain pages, our primary focus is on the progress of each individual portfolio company during their time under Quantum's stewardship.

Environmental performance metrics[1]

	2023
Scope 1 GHG Emissions (MT CO_2e)	**2,047,995**
Carbon Dioxide	**1,790,687**
Methane	**226,320**
Nitrous Oxide	**1,589**
Scope 1 Emissions from Fleet	**29,399**
Scope 2 Electricity Emissions[2]	**176,413**
Scope 3 Emissions[2][3]	**34,038,756**
Scope 1 GHG Intensity (MT CO_2e/Mboe)[4]	**19.7**
Methane Emissions Intensity (%)[5]	**0.11%**
Methane Monitoring	
Number of Leaks Detected	**1,752**
Number of Components Surveyed	**526,057**
Flaring Intensity (% of Natural Gas Produced)	**1.9%**
Water Usage	
Freshwater Sourced (Mbbl)	**55,793**
% Freshwater Usage	**27%**
Water Recycled (Mbbl)	**229,882**
Spills above 1 bbl of Liquid Released to the Environment[6]	
Water (bbl)	**24**
Oil (bbl)	**20**
Volume of Spills Released to the Environment	
Water (bbl)	**1,989**
Oil (bbl)	**189**

Safety performance metrics[7]

	2023
Total Recordable Incident Rate (TRIR)	
Employee	**0.79**
Contractor[8]	**1.35**
Workforce	**0.57**
Lost Time Incident Rate (LTIR)	
Employee	**0.36**
Contractor[8]	**0.29**
Workforce	**0.16**
Preventable Vehicle Incident Rate (PVIR)	**0.69**

Social performance metrics[9]

	2023
Total Workforce Headcount	**3,624**
Minorities as a Percentage of Workforce	**32%**
Women as a Percentage of Workforce	**25%**
Minorities as a Percentage of Leadership[10]	**16%**
Women as a Percentage of Leadership[10]	**25%**

Disclaimer: The information in this report is based on portfolio company data across all funds provided to Quantum Capital Group for the 2023 reporting year. Reporting companies include majority owned operators unless otherwise noted.

(1) Emissions metrics include data from Upstream and Midstream portfolio companies for the Production and Gathering and Boosting segments of EPA's Subpart W. Certain companies with emissions below reporting thresholds, or companies that did not have assets for the majority of the reporting year did not disclose emissions to Quantum. Emissions from vehicle fleet, which make up a small portion of total emissions are not included in this estimate

(2) Scope 2 emissions are calculated using Upstream and Midstream portfolio company provided production data in conjunction with EPA fuel and electricity emissions factors. Not all portfolio companies provide this data

(3) Scope 3 emissions do not include production from QEP owned minerals companies, with reductions made based on emissions from QEP companies who produce on these mineral companies to avoid double counting

(4) Greenhouse Gas Intensity calculated as GHG emissions over total hydrocarbon production in barrel of oil equivalent; MT CO_2e/MBoe

(5) Methane Intensity calculated using Edison Electric Institute and American Gas Association Natural Gas Sustainability Initiative (NGSI)

(6) Spill metric was updated in 2021 from reportable spills and associated volumes to spills>1 bbl for comprehensive reporting

(7) Safety metrics include data from Upstream and Service Companies

(8) All companies reported contractor data beginning in 2021

(9) Social metrics include data from 26 majority owned portfolio companies including minerals and alternative energy companies for '21, and 17 companies in 2020

(10) Leadership defined as Senior level VP to Executive level management

Portfolio Company Case Studies

Inside this section:

The select investments are provided for illustrative purposes only to demonstrate Quantum's investment approach generally, and not all applicable investments are shown. There is no guarantee that Quantum will be able to identify similar investments in the future. Please see disclosures for important information regarding ESG considerations in our investment practices. There can be no assurance that any historical trends will continue or projections will materialize.

Strategically Reducing Regulatory Exposure

The *Benchmarking Methane and Other GHG Emissions of Oil & Natural Gas Production in the United States* report, published by ERM in June 2024, highlights that higher methane intensities are generally linked to emissions from pneumatic devices – equipment that must be eliminated in facilities built after 2022 under EPA OOOOb regulations.

In 2022, pneumatic controllers were the largest source of total reported production-segment methane emissions in the U.S., making up 67% of total reported methane emissions.[1]

KODA and White Rock proactively addressing methane emissions from pneumatics

KODA and White Rock have employed similar strategies to mitigate their methane emissions. Both companies conducted comprehensive assessments of their total methane emissions to identify their largest sources and developed compliance maps to address those sources while adhering to new regulations. KODA and White Rock manage legacy assets, which often have incomplete or unavailable equipment inventories. Therefore, a key part of their strategy involved creating comprehensive systems to inventory their equipment. This process included training personnel, assigning specific individuals to the project, and having them meticulously document each component type and subtype to accurately classify their pneumatics. Establishing a reliable inventory was critical to both companies refining and reducing their previously inflated pneumatic device counts.

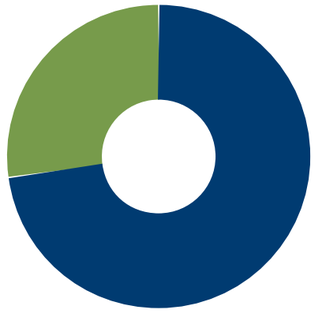
In addition, White Rock and KODA have retrofitted nearly 500 intermittent bleed pneumatic devices with zero emission alternatives. This not only reduces methane emissions and avoids costs associated with the WEC, it keeps valuable gas in the sales pipeline that would otherwise be wastefully vented.

KODA

PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Denver, Colorado	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.

KODA Resources 2023 methane emissions by source[2]
Percent



- **73%** Pneumatics
- **27%** Other

415
Pneumatics retrofitted

$1.2M
Projected methane fee savings

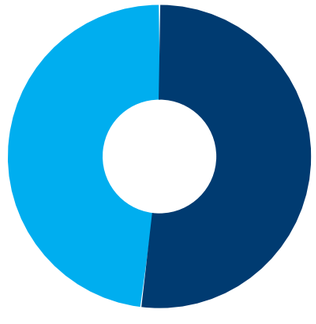
1,316
Tonnes of methane reduced from 2022 baseline

WHITE ROCK OIL & GAS

PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Plano, Texas	2021

Founded in 2012, White Rock invests in and develops onshore oil and gas wells in the U.S. on behalf of their institutional partners.

White Rock 2023 methane emissions by source[2]
Percent



- **52%** Pneumatics
- **48%** Other

79
Pneumatics retrofitted

$315K
Projected methane fee savings

350
Tonnes of methane reduced from 2022 baseline

References:

[1] Benchmarking Methane and Other GHG Emissions of Oil & Natural Gas Production in the United States / June 2024
[2] Numbers and dollars are estimates provided by portfolio companies as of August 31, 2024. All data has been provided directly by portfolio companies and has not been verified by Quantum or any third party

HG ENERGY | INVESTMENT STRATEGY: QUANTUM ENERGY PARTNERS

Using a Multi-Pronged Approach to Reducing Emissions

HG Energy has a longstanding commitment to environmental stewardship and supporting local communities. As part of this commitment, the company collaborates with regulatory agencies in Appalachia to promote a community culture of respect for and protection of the environment. Internally, HG expects active participation from all employees to drive growth and uphold its high operational standards, including strengthening environmental programs that not only improve performance but deliver cost savings.

Taking a multi-pronged approach to reducing methane emissions

The Appalachian Basin is recognized as one of the lowest methane intensity operated basins in the U.S.[1] Over the years, HG has implemented a multi-pronged approach to reducing methane emissions. Leveraging their access to grid power, the company has reduced the use of equipment like pneumatic devices and pumps. Beginning in 2022, HG began installing instrument air packages on new facilities to avoid emissions from these sources and has since retrofitted existing pads as well. These efforts have yielded an estimated 77% decrease in methane emissions from 2021 to 2023. In addition to these operational upgrades, HG maintains a methane leak monitoring program, including quarterly LDAR on 100% of locations, and a robust daily AVO (Audio, Visual, Olfactory) program, where observations are recorded and stored electronically in HG's leak database.

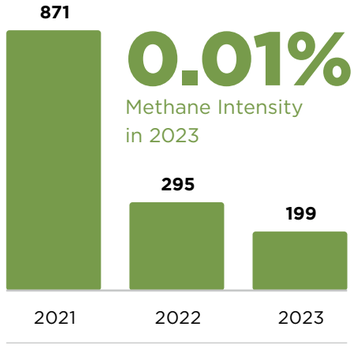
Leveraging new technology to create value and enhance environmental performance

While methane continues to be a focus, HG is also reducing their CO_2 emissions, which make up an estimated 97% of the company's total emissions, by switching from a dual fuel frac fleet powered by a combination of diesel and natural gas to an electric frac fleet powered by natural gas produced by HG. Electric frac fleets are new to the industry, and HG is an early adopter of this technology. By significantly reducing their use of diesel fuel, HG anticipates annual multi-million dollar costs savings each year and CO_2 emission reductions of over 8,000 metric tons per year from the already low-emitting dual fuel fleet.

PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Parkersburg, West Virginia	2016

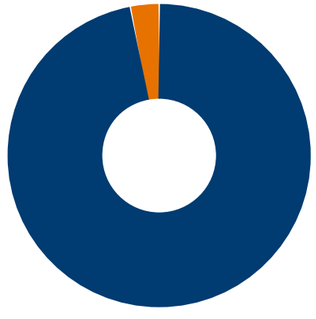
HG Energy, LLC is a leading independent producer of natural gas and oil and proudly supports economic growth and development in the Appalachian Basin.

HG year-over-year methane reductions[2]
MT CH_4



0.01%
Methane Intensity in 2023

HG 2023 methane emissions by source[2]
Percent



HG's electric frac fleet:

$7.5M
Diesel fuel cost savings per year

8,580 MT
Reduction in emissions per year

References:

[1] Benchmarking Methane and Other GHG Emissions of Oil & Natural Gas Production in the United States / June 2024
[2] All data has been provided directly by portfolio companies and has not been verified by Quantum or any third party

Harnessing the Power of AI to Reduce Emissions from Steam Injection

Since its inception, Sentinel Peak has been deeply committed to responsible environmental practices and operational excellence. The company continues to find innovative ways to increase operational efficiency, improve environmental performance, and cut costs – all while pursuing growth through key acquisitions.

Assessing Sentinel Peak's emissions

Steam flooding, a thermal recovery method, involves injecting steam into a reservoir to enhance heavy oil recovery. At Sentinel Peak, steam is generated using gas-powered engines, which contribute approximately 97% of their total emissions. As a California operator under some of the nation's strictest methane regulations, Sentinel Peak has minimal methane emissions – 3% as of the end of 2023 – making CO_2 the primary focus of their reduction efforts.

Utilizing intelligent oilfield tool to reduce emissions and costs

The steam injection process not only accounts for most of Sentinel Peak's emissions but also represented approximately 30% of its operating costs at the end of 2023 due to the expense of purchasing gas. To address this, Sentinel Peak partnered with Quantum's digital team to build an Intelligent Oilfield tool designed to optimize steam usage and reduce costs. This AI-based thermal management system aims to ensure minimum injection rates during the steam flooding process, enhancing efficiency and cost-effectiveness.

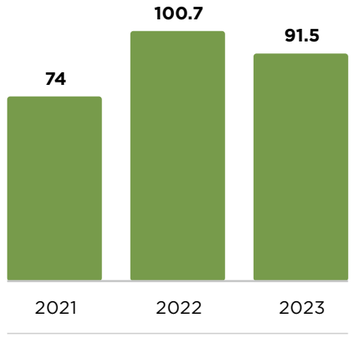
Improving acquired assets with innovative technology

In 2022, Sentinel Peak Resources acquired Seneca Resources, another steam flood operator. As a result of this acquisition, Sentinel Peak's year-over-year emissions initially increased. However, Sentinel Peak successfully leveraged their steam injection tool to improve the efficiency of the acquired asset. Due to their stewardship and enhanced analysis, Sentinel Peak reduced steam injection by more than 3 million barrels and GHG Scope 1 emissions by more than 120,000 metric tons in 2023. The company is currently evaluating advanced methods to further minimize steam for each well without reducing production, potentially reducing their emissions by an additional 10%.

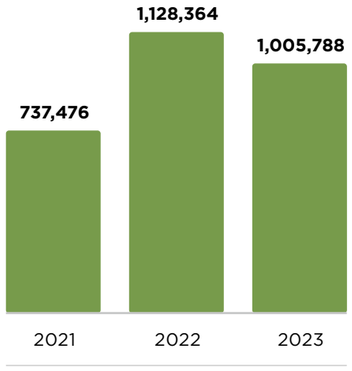
PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Denver, Colorado	2016

Sentinel Peak is focused on acquisition, development, and exploration of oil and gas assets, primarily focusing on heavy oil development in California.

Sentinel Peak year-over-year Scope 1 GHG intensity
MT CO_2e/Mboe



Sentinel Peak year-over-year emissions reductions
MT CO_2e



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Operating Responsibly in Colorado

Bison is a leading operator in the DJ Basin, with extensive experience operating and growing their business in the state of Colorado. Their years of experience operating in the state enable them to comply with Colorado's rapidly evolving regulations, which often set the standard for emissions reduction initiatives nationwide.

Colorado's evolving regulatory landscape

Colorado's Regulation 7 (Reg 7), 'Control of Ozone via Ozone Precursors and Control of Hydrocarbon via Oil and Gas Emissions,' targets emissions during pre-production and early production phases of upstream oil and gas facilities. Reg 7 includes a mandate for drilling operations, with a recently passed provision requiring operators to reduce NOx emissions by 30% by 2025 and 50% by 2030.

Bison addresses ozone precursor, NOx

To meet these requirements, our new portfolio company, Bison Oil and Gas IV, has secured lower-emission Tier IV engines for all hydraulic fracturing operations in 2024, which are expected to reduce NOx emissions by 42% for diesel engines and 82% for dual-fuel engines. Additionally, Bison is piloting an electric drilling rig to further reduce emissions, with the rig projected to eliminate 70 tons of NOx emissions per well and potentially lower costs by reducing diesel fuel use.

Bison eliminates methane from flowback

The Bison team believes operational efficiency can yield both cost savings and emissions reductions. Their recent improvements to the flowback process are a prime example of this principle in action. In 2023, Bison systemically eliminated all flowback equipment, including tanks, separators, iron packages, associated truck traffic, and water hauling. This has resulted in savings of $25,000 per well, an 82% reduction in flowback emissions, and fewer spills during the flowback phase.

BISON OIL & GAS IV

PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Denver, Colorado	2022

Bison Oil & Gas IV is one of the largest private operators in the DJ Basin of Colorado and Wyoming, with over 200,000 net acres, 400 wells, and 30,000 barrels of oil equivalent (BOE) of production per day, as of the end of 2023.

Partnering with academia to better understand fugitive methane emissions

Strategic partnerships play a crucial role in helping Bison achieve their goals of continuously reducing emissions and increasing operational efficiency. Bison is partnering with the Energy Institute at Colorado State University to better understand fugitive methane emissions. As a participant in the Site-Aerial-Basin-Emissions-Reconciliation (SABER) and Colorado Ongoing Basin Emissions (COBE) programs, Bison is working to demonstrate that high frequency sampling can produce accurate emissions inventory estimates for entire basins. This collaboration involves two-way data sharing between the operator and the Energy Institute through aerial overflights – the Institute sponsors the flyovers, while the operator assists with understanding the source and cause of the detected emissions. Traditional emissions inventory estimates have long failed to pinpoint the causes of detected emissions, which has historically led to incorrect assumptions and inaccurate emissions accounting. Bison is proud to help strengthen emissions estimates while enhancing its own leak detection with more frequent flyovers.

All data has been provided directly by portfolio companies and has not been verified by Quantum or any third party.
Any expectations are provided for informational purposes only and are not necessarily indicative, or a guarantee, of future results.

Developing a Leading Energy Transition Facility in Ardersier Port

Haventus was established to address the critical need for port space to support large-scale deployment of offshore wind in Scotland and the rest of the UK. With its extensive coastline, rich marine engineering heritage, and favorable water conditions, we believe Scotland is distinctly positioned to lead in offshore wind expansion, a key element in meeting their climate and energy security objectives.

Unlocking offshore wind potential

The company emerged following the success of the 2022 ScotWind offshore wind leasing round, which resulted in the approval of approximately 28 gigawatts of offshore wind development off Scotland's North Sea coast. Together with the Innovation and Targeted Oil and Gas (INTOG) leasing round, approximately 35 gigawatts of offshore generation capacity is expected to be deployed over the next decade, and support further advancement of the UK's path to net-zero. This ambitious deployment has created an urgent need for significant energy infrastructure in Scotland and the UK.

Ardersier Port offers deployment solutions for offshore wind providers

Currently under development and scheduled to open in the second half of 2025, the first Haventus energy transition facility at Ardersier Port is expected to be Scotland's largest on the North Sea coast, dedicated to deploying and servicing offshore wind installations. The facility is strategically located on the Moray Firth, with first rate access via sea and road to more than 450 acres of working space, including a naturally sheltered harbor.

The site is accessed via an initial >650 meters of quay, with plans for an additional kilometer of quay forming the centerpiece of future expansion. Every aspect of the port's development is designed to meet the specific needs of offshore wind developers and the supply chain. Beyond supporting the transition to net-zero in the UK, Ardersier Port represents one of the largest industrial regeneration projects in the Highlands and will potentially reestablish the port as a major local employer, supporting and creating hundreds of jobs.

All data has been provided directly by portfolio companies and has not been verified by Quantum or any third party. Any expectations are provided for informational purposes only and are not necessarily indicative, or a guarantee, of future results.

Haventus | ARDERSIER PORT

PRIMARY OFFICE	YEAR OF QUANTUM INVESTMENT
Inverness, Scotland	2023

Haventus is an energy transition facilities provider, offering pivotal infrastructure for the offshore wind industry. The company identifies, redevelops, and manages strategic sites to enable the renewable energy sector to develop at scale. Haventus' mission is to serve the global imperative for a net-zero future.

> **Scotland's growing offshore wind capabilities present an era-defining opportunity – not only to achieve a just transition to net-zero, but to harness the skills which lie across our energy sector and wider supply chain to create thousands of green jobs and transform our regional and national economies...The Ardersier Port redevelopment, which is central to the ambitions of the ground-breaking Inverness and Cromarty Firth Green Freeport, exemplifies this opportunity."**
>
> **John Swinney,** First Minister of Scotland

ESG Performance Disclosures

Inside this section:

Appendix A: TCFD

The Task Force on Climate-related Financial Disclosures (TCFD) is an initiative established by the Financial Stability Board (FSB) in 2015. The primary goal of the TCFD is to improve and increase the reporting of climate-related financial information, helping investors, lenders, insurers, and other stakeholders assess and manage risks and opportunities related to climate change. This section summarizes how Quantum Capital Group's climate reporting aligns with the TCFD recommendations.

Governance

Quantum's Executive Team is Quantum's highest decision-making body regarding climate-related issues. The Executive Team is responsible for overseeing the broad implementation of risk management and Quantum's ESG Policy, which includes information on the oversight of climate-related topics. Quantum's Investment Committee (IC) makes final investment decisions. The IC meets as required to consider potential investments, and considers climate-related issues, risks, and opportunities, when applicable, when doing so. Quantum has an ESG Steering Team, comprised of senior leaders and spearheaded by Quantum's head of ESG, which provides oversight of ESG strategies and program management.

Strategy

Quantum's strategy as it relates to identifying and managing material climate-related risks and opportunities is two-fold: (i) firm-wide infrastructure and processes to support the analysis of climate-related risks, and (ii) distributed responsibility to investment professionals to review and manage investment risks, including climate risks, in portfolio companies.

Quantum seeks to monitor existing investments and perform advanced due diligence on potential new investments, to the extent reasonably feasible, using a set of customized ESG factors that evaluate several categories including (but not limited to) climate-related risks. Our ESG due diligence and underwriting process culminates in a Quantum Investment Committee Memorandum (QICM), which documents our understanding of the most material ESG and climate-related risks and opportunities associated with the potential investment. This diligence analysis often includes a historical ESG performance review and considers future potential ESG issues and opportunities that Quantum investment professionals may include in the underwriting, business plan, governance, and compensation strategy for each investment. We define material ESG factors as areas that can significantly influence Quantum's ESG performance or present substantial investment or reputational risks or opportunities linked to ESG considerations.

While the processes for identifying relevant risks and opportunities vary by industry, our climate-related risk and opportunity assessments aim to combine in-house analyses of portfolio company operations with insights from external services, consultants, NGOs and other sources. For instance, our evaluations of resource efficiency, carbon emissions, and climate-related risks and opportunities – considering both absolute levels and annual changes – enable us to prioritize risks and opportunities. These range from the impact on valuations due to emission reduction costs to the potential effects of carbon regulations and taxes.

In addition to incorporating sustainability considerations across our investment analysis, Quantum seeks to integrate climate-related risks and opportunities in the stewardship phase by providing our portfolio companies with tools and resources to measure, monitor, and improve their emissions performance and manage other climate-related risks and opportunities. Quantum representatives serving on the Board of Directors or other governing bodies of our portfolio companies are responsible for advancing the implementation of policies and portfolio company alignment with the ESG priorities set for each portfolio company, which may include reducing GHG emissions.

Risk Management

Transitional Risks and Opportunities

We evaluated the climate-related transitional risks and opportunities of our investments under the IEA's U.S. SDS assumptions, which follows the best practice of aligning scenarios with a company's geographic scope of investments or operations. Our evaluation of risks and opportunities under the SDS assumptions is focused on six types of investments that are part of our current portfolio or potential areas of investment, including upstream oil and gas production, oil and gas midstream, LNG export, electric vehicle charging, wind and solar, and carbon capture.

The risks and opportunities are analyzed through the lens of three main influences:

- **Market and Technology:** This category includes changes in demand and the uncertainty related to the financial viability and adoption of emerging technologies.
- **Regulatory and Legal:** This category covers policies and rules that may both restrict and incentivize specific forms of energy, technologies, and business models.
- **Reputational:** This category relates to potential challenges around attracting investment in specific sectors or types of assets.

Physical Risks

We conducted a pilot physical risk assessment on three geographically representative portfolio companies. Two of these companies are in the U.S. and represent locations where our investments in energy opportunities are likely to grow, and the third is in a location that represents the closest proximity to sea level.

For each of the three assets, we conducted an analysis using data to generate climate-related indicators impacting physical assets. This analysis aligns with the IPCC Sixth Assessment Report (AR6) and considers both an optimistic scenario, where global temperatures are limited to below 2.0°C of warming by 2100, and a pessimistic scenario, where temperatures remain below 4.0°C by 2100.

PHASE 1: Hazard Screening This phase included a calculation of future changes in climate hazards, which accounted for past and projected physical risks across the following hazard categories: extreme heat, cold stress, extreme rainfall, drought stress, water stress, flooding, hurricanes, landslides, and wildfires.

PHASE 2: Asset Exposure This phase consisted of determining climate-related risks for each asset; data from screening was matched with financial and historical information about each site to determine criticality and vulnerability.

PHASE 3: Financial Risk This phase consisted of a calculation of future financial risks from climate events, using both financial and historical data to produce a range of potential estimates for damages, losses, and business interruptions due to climate hazards. We plan to refine and expand this initial assessment to evaluate material physical risks and opportunities for both current and future assets.

Metrics and Targets

Quantum's metrics and targets are outlined on page 73 of this report.

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