Bettering Human Lives

Liberty Energy | 2024

LIBERTY®

Energy Matters

Everyone desires and deserves more energy and the opportunities it unleashes.

Our three cover editions represent the range of living conditions experienced globally.

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Liberty Energy | First printing January, 2024. | www.libertyenergy.com

Key Takeaways

1. Energy is essential to life and the world needs more of it!
2. The modern world today is powered by and made of hydrocarbons.
3. Hydrocarbons are essential to improving the wealth, health, and life opportunities for the less energized seven billion people who aspire to be among the world's lucky one billion.
4. Hydrocarbons supply more than 80% of global energy and thousands of critical materials and products.
5. The American Shale Revolution transformed energy markets, energy security, and geopolitics.
6. Global demand for oil, natural gas, and coal are all at record levels and rising — no energy transition has begun.
7. Modern alternatives, like solar and wind, provide only a part of electricity demand and do not replace the most critical uses of hydrocarbons. Energy-dense, reliable nuclear could be more impactful.
8. Making energy more expensive or unreliable compromises people, national security, and the environment.
9. Climate change is a global challenge but is far from the world's greatest threat to human life.
10. Zero Energy Poverty by 2050 is a superior goal compared to Net Zero 2050.

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INTRODUCTION

A Letter From Our CEO,

Our mission is to better human lives. Human happiness comes through relationships, love, and finding a strong purpose in life. Preconditions for these ultimate ends are food, shelter, health, education, and longevity. None of these are possible without energy, and the quality of each depends on the degree of access to affordable, reliable, and secure energy. This report covers in some detail the profound changes in the human condition — life expectancy, emergence from poverty, nutrition, rising education, and more — brought about by the emergence and spread of hydrocarbon energy. A thriving society must be energized by affordable, reliable, and secure technologies. So far in modern history and for the foreseeable future, hydrocarbons are essential to this goal.

Liberty's mission of bettering human lives begins at home. Our top goal is to improve the lives of everyone in the Liberty family. Liberty's success in our business also positively impacts our communities and the world. We pursue our mission with a straightforward business philosophy: Hire great people and treat them like adults. Play to win and have fun doing it. We have been successful in attracting and retaining exceptional people who together truly shine. Our industry's top market research firm, Kimberlite, has ranked Liberty at the top of the big four frac companies in the five overall quality categories for all seven years that they have conducted their survey! We are committed to constant improvement, aiming to exceed our performance each day, week, month, and year.

The transformation in human lives brought by the modern world has not yet spread fully to all. Perhaps only a billion people today enjoy the full benefits of a highly energized lifestyle. These lucky one billion consume an average of 13 barrels of oil per year, 40% of the global total. The other seven billion people average only three barrels of oil consumption, and every one of them aspires to a higher standard of living. Moving the other seven billion (soon to be eight billion) even halfway to the lifestyles of the lucky one billion requires more than doubling of today's oil production. Roughly five billion people today are wearing hand-washed clothes, as their families do not yet enjoy the time-saving convenience of a washing machine. More than two billion lack access to clean cooking fuels and reliable access to electricity. I could go on, but you get the point.

Yet many people who are already fortunate to be among the highly energized are driving a strong movement, based on genuine concerns about climate change, that threatens to slow the progress of the seven billion striving to achieve the lifestyles of the more fortunate one billion. While the focus on climate change is understandable, the movement fails to address the critical and inevitable tradeoffs involved. This movement would better serve humanity by measuring climate risks against the jeopardy of human deprivation, illness, and death that accompanies a lack of access to affordable, reliable, secure energy. So far, a myopic focus on climate change and climate politics has dominated.

The result has been the rise of a destructive misunderstanding. It goes something like this: “Climate change is the most menacing threat to humanity, and we can reverse this ever-growing crisis by rapidly transitioning our global energy system to cheaper, cleaner, greener energy sources if only nudged by bold government policy incentives.” None of this is accurate. It is based on a combination of climate change exaggerations, a strict focus on CO_2 mitigation instead of climate adaptation, and a failure to appreciate the scale and complexity of the global energy system.

Climate change is a real and global challenge that we should and can address. However, representing it as the most urgent threat to humanity today displaces concerns about more pressing threats of malnutrition, access to clean water, air pollution, endemic diseases, and human rights, among others. This report aims to put climate change in perspective relative to these other threats.

The second half of the destructive misunderstanding involves our energy system. Politicians, policymakers, pundits, and the press talk endlessly about how solar, wind, and batteries can transform our whole energy system and address the climate crisis. The reality is that these politically favored technologies have not, will not, and cannot replace most of the energy services and raw materials provided by hydrocarbons. Today they are deployed almost exclusively in the electricity sector, which delivers only 20% of total primary energy consumption. Manufacturing is the largest user of energy globally, mostly in the form of process heat that cannot effectively be supplied via electricity. Further, the ultra-high-power density required for the likes of aviation, global shipping, long-haul trucking, and mobile mining equipment have no viable replacements in sight. Critical materials from hydrocarbons provide nitrogen fertilizer that is responsible for fully half of global food production. In addition, hydrocarbons supply critical materials to produce plastics and petrochemicals that are essential components of modern lives. They also provide asphalt, paints, lubricants, cosmetics, 60% of global clothing fiber, and thousands of other products. Without hydrocarbons we would have no way to produce the vast quantities of steel and cement that undergird our built world. Even wind turbines, solar panels, and batteries are made of hydrocarbon materials and require huge amounts of energy from hydrocarbons to supply the high-temperature process heat required for their fabrication. Energy sobriety is desperately needed.

I am quite passionate about alternative energies and have been my whole life. Liberty Energy is an investor and partner with companies in next-generation geothermal energy, small modular nuclear reactors, and sodium-ion battery technology. The world needs more energy, better energy. Achieving this requires contributions from all viable energy technologies. Recently the wealthy world has gone beyond over-optimism surrounding the breadth and scalability of a narrow slice of alternative energy and, unfortunately, has rushed head-long into outright obstruction of hydrocarbon infrastructure and production. Obstructing the existing energy system without a reliable substitute is reckless. *Bettering Human Lives* addresses these issues in depth, hoping to inform a more thoughtful dialogue of the inevitable tradeoffs surrounding the nexus of energy, climate, and poverty.

Energy

I once described calculus to my daughter as abstract and tricky, yet critical for understanding our physical world. Energy is far trickier and vastly more important to society and our world. Energy is the essential ingredient that makes everything happen. Everything.

Perhaps this explains why the over 5,000 people at Liberty Energy dedicate our lives to energizing the world. We do this in the face of strident opposition from activists, non-governmental organizations, governments, and an ever-growing list of agencies, regulatory bodies, and media. To thrive in this industry, you must believe in the mission.

And believe we do, with more than 40 frac crews and 30 wireline crews working 24/7, 365 days a year helping produce the oil and gas that supplies nearly 70% of total U.S. primary energy consumption. Liberty's innovative engineers, who helped launch the shale revolution and are now rolling out next-generation natural gas-powered frac fleets, also believe. And so does our supply chain team, which deftly and just-in-time delivers nearly one billion pounds per week of sand from subsurface deposits via our rail and road systems to frac locations across North America. Our distinguished board of directors and everyone else in the Liberty family believe in our mission and relentlessly pursue it as well.

This report will show how the dramatic increase in available energy to humanity brought by hydrocarbons together with the rise of bottom-up social organization — human liberty — transformed the human condition over the last two centuries. Human life expectancy globally has risen from around 30 to over 70 years, just in the last 200 years! Dire poverty, those living on less than $2 per day in today's money, has plummeted from nearly 90% of humanity 200 years ago to less than 10% today. This story is little known and less appreciated, but critical to understanding our world today and where our future might lead. Hydrocarbons vastly expanded the energy available to humanity. They also enabled the creation and rise of industries that never existed before, including modern medicine and communications, high technology, leisure travel, and an endless array of sports and outdoor adventures. Hydrocarbons enabled the creation of machines to harness other sources of energy at scale such as hydropower, modern biofuels, nuclear, geothermal, wind, and solar. These derivative energy sources have very different strengths and weaknesses.

You will read about the transformation of food production in hydrocarbon-energized societies. Throughout human history almost everyone worked in food production, whereas today only 2% of Americans feed our country and the U.S. leads the world in agricultural exports.

History shows that affordable, reliable, secure energy is the agent of change required to live long, healthy lives and realize dreams. Energy enables transformation and pushes back the ultimate constraints on what is possible. A poorly energized society is poor. A highly energized society is prosperous and full of opportunities for its citizens to create and pursue dreams.

It was not until the dawn of the 20th century that coal surpassed wood as the largest global source of energy. Oil surpassed coal a few decades later and natural gas may eventually pass coal globally, as it already has in most wealthy countries. However, the large and rising Asian economies of China, Vietnam, Indonesia, and the Philippines remain dominated by coal and oil and likely will be for some time. Hydrocarbons supply more than 80% of global primary energy, as they have throughout my life.

Hydrocarbons have brought tremendous upsides to humanity via longer opportunity-rich lives, enabling all the modern conveniences of widespread access to clean water, indoor heating and plumbing, modern medicine, plus forest and grassland preservation via reduced need for cropland from huge increases in agricultural productivity. Hydrocarbons also have downsides such as air pollution, climate change, and the geopolitical impacts of uneven resource distribution. Everything involves tradeoffs. There is no such thing as “clean” or “dirty” energy. All energy sources have positive and negative impacts on humans and their environment. Evaluating the tradeoffs in energy systems requires thoughtful analysis in the context of local conditions, values, and needs.

I believe that the American Shale Revolution in which Liberty works has proven upsides that vastly outweigh the downsides. Technology and innovation have more than doubled U.S. oil and gas production over the last two decades while reducing drilling rigs and land required. The abundance of natural gas has displaced coal as the primary source of electricity, reducing U.S. per capita CO_2 emission to levels not seen since 1941. The U.S. has gone from being the world’s largest importer of oil and natural gas to a net exporter of oil and refined products and the world's largest exporter of natural gas! Many benefits have accrued from this surge in supply, first and foremost, the significant reduction in global oil and natural gas prices. Lower energy prices better human lives.

The geopolitical benefits of achieving America's long-sought goal of energy independence are also significant. Figure A shows the transformation of the U.S. energy balance of trade versus China, Europe, and Russia. China has become the world's largest importer of both oil and natural gas. However, coal is China's most important energy source, and it has massive domestic coal resources. China has become the largest producer of energy-intensive manufactured goods, following a century of American leadership in manufacturing. Today the U.S. annually consumes 25 exajoules* of energy across the transportation sector and 25 exajoules in the industrial sector. For China, those numbers are 20 exajoules for transportation and 70 exajoules in manufacturing! China's massive, low-cost coal resources and willingness to deploy them has turned China into the world's heavy industry titan, dominating global production of energy intensive goods such as cement, steel, metals processing, batteries, automobiles, polysilicon, and more. With today's low-priced abundance of natural gas in the United States, the economic benefits of moving energy-intensive manufacturing to China have mostly vanished. We cannot say the same for Europe, which seems destined to continue its deindustrialization.

Figure A

Energy Independence vs. Energy Dependence: Net Exports (Imports) of Oil, Natural Gas & Coal

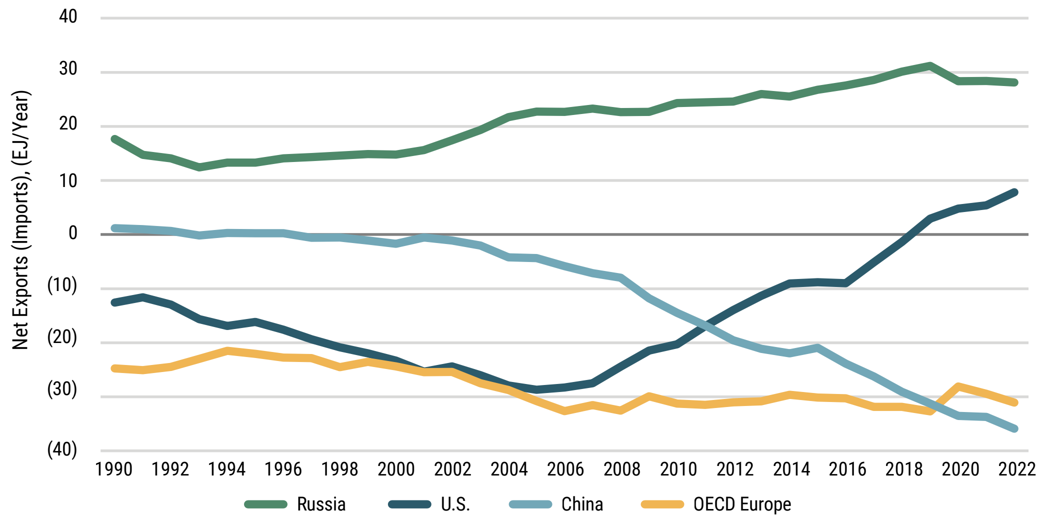


Figure A — Energy Institute - Statistical Review of World Energy (2023), IEA, JP Morgan Annual Energy Paper

Ironically, the wealthy world has outsourced energy intensive manufacturing from modern natural gas-fueled factories in the U.S and Europe to Chinese coal-fueled factories, all in the name of going "green" or reducing greenhouse gas emissions. Every time a large steel plant is closed in Europe or the U.S. due to "climate" policies, the impact is the opposite of a "climate" benefit. Steel, or other energy-intensive manufacturing, is simply being moved from a cleaner manufacturing facility to a higher-emission overseas plant. These "climate" policies grow global emissions, and export well-paying blue-collar jobs. National or state-level greenhouse gas emissions goals have many perverse impacts. Unfortunately, they remain politically popular.

**1 Exajoule (EJ) = 0.95 Quadrillion British Thermal Units (BTUs) = 278 Terawatt-hours (TWh)*

Were there downsides to the shale revolution? Of course. Many communities have seen increased truck traffic, dust, and noise coming with the industrial activity of shale development. Liberty has worked tirelessly to reduce these negative impacts with our Liberty Quiet Fleet®, transitioning to natural gas from diesel for fleet power, and many other technologies detailed in the Liberty sections of this report. All activities have tradeoffs, but the best have upsides that vastly exceed the downsides.

This report describes our mission and seeks to answer the charge that the sooner hydrocarbons are gone, the better the world will be. We answer that charge with an emphatic "No." In fact, quite the contrary. The biggest global energy challenge is that the world desperately needs more energy, not less energy. The world needs more affordable energy, not more expensive energy. The world needs more reliable energy, not less.

How are we doing on the task of adding more global energy, or energy addition, to grow the number of people with highly energized lives like the lucky one billion? In 2010 the world consumed 507 exajoules of energy, which rose to 574 exajoules by 2022. This is progress. Where did this extra 67 exajoules come from? Natural gas, the world's fastest-growing energy source, supplied nearly 40% of the additional energy. Oil supplied 24%, and coal 14%. Hence, hydrocarbons contributed just under 80% of the growth in energy, roughly in line with the little more than 80% of total global energy they have supplied for decades. Wind contributed a little more than 9% and solar a little less than 7%. Hydropower provided 4% and nuclear a net of zero incremental energy, meaning that a roughly equal amount of nuclear capacity was retired as new capacity was built. These numbers illustrate that the term "energy transition" is deceptive and misleads otherwise thoughtful people to support destructive policies that obstruct hydrocarbon production and transportation, driving up energy prices. Hopefully, energy sources outside of hydrocarbons can carry more than 20% of the incremental load in supplying the vital next 226 exajoules to get our world energy system to the 800 exajoules projected for global annual demand by 2050. Nuclear appears to be the most viable option to add sizable new energy resources in the coming decades.

Some retort that we don't need more energy, we just need to use energy more efficiently. The pioneering 19th century English Economist, William Stanley Jevons, addressed this conjecture in his 1865 book *The Coal Question*. He concluded that increases in energy efficiency led to more, not less, coal consumption. Increases

Figure B

Global Primary Energy Demand by Source vs Energy Intensity

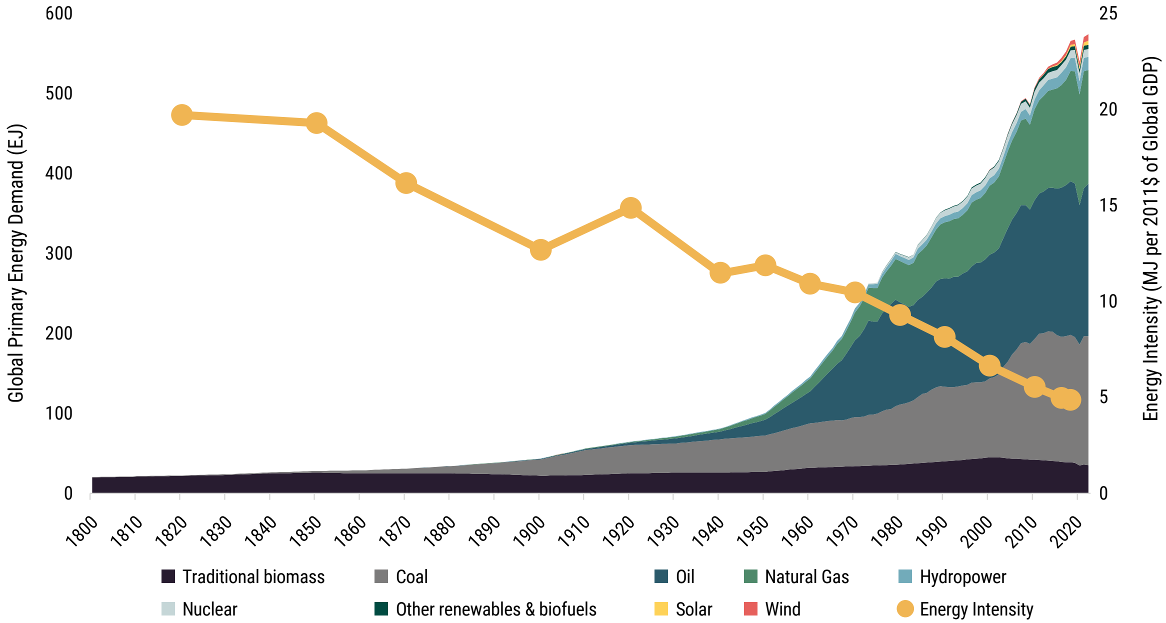
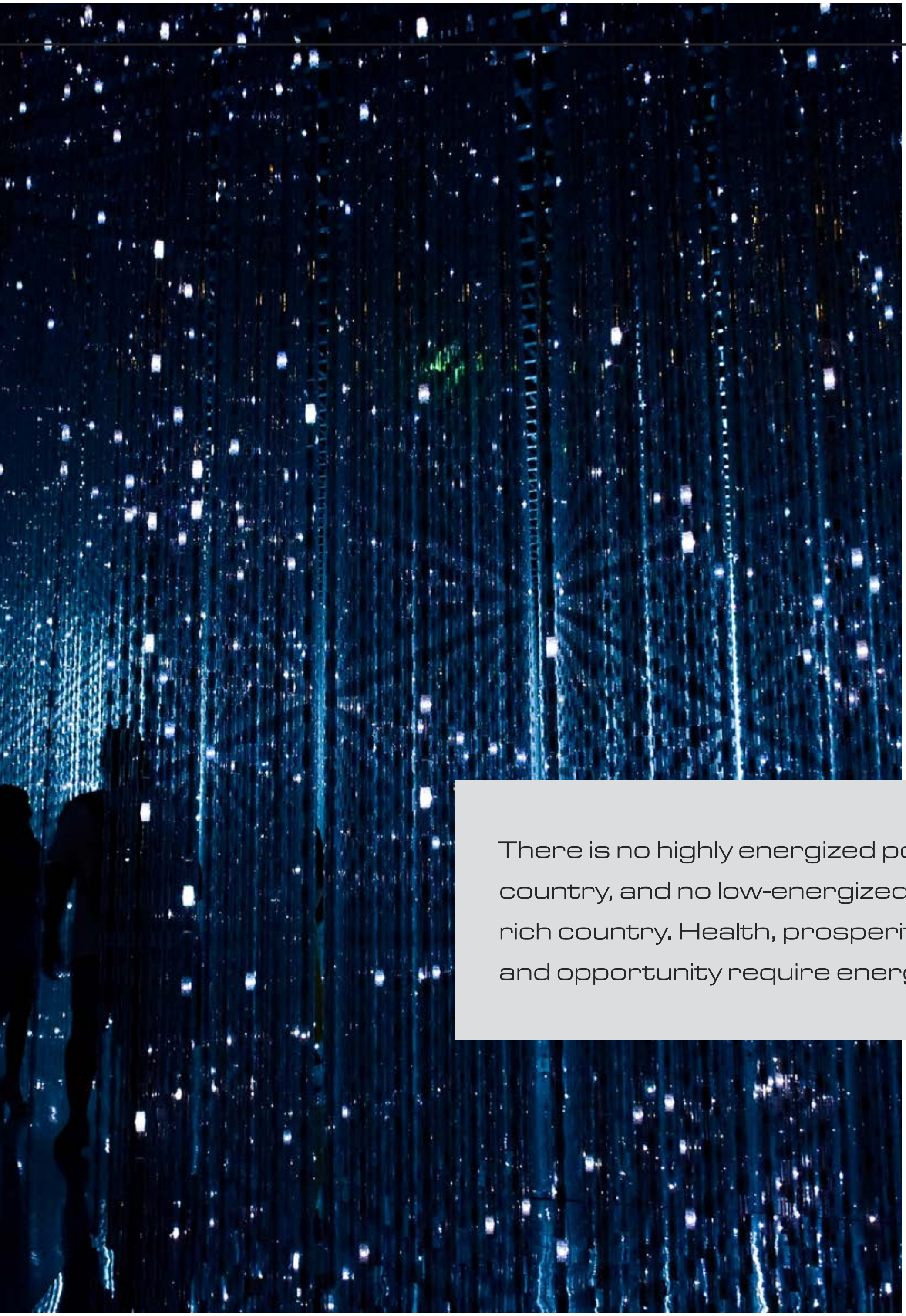


Figure B — Vaclav Smil, 2017, Energy Institute, IEA, Maddison Project, 2020, and Bijou Insights

in engine efficiency make it cheaper to travel, enabling increased travel. Historical trends in U.S. gasoline consumption have been most impacted by price at the pump and economic growth rates. Lower prices and economic growth drive consumption up. High prices and tough economic times reduce demand for all goods. Figure B shows the "Jevons paradox" in action across the entire global energy system over the last two centuries. In it, we can see two centuries of increasing efficiency in energy usage to generate economic value (GDP) combined with two centuries of growing demand for energy. Since 1990, energy efficiency has increased 36% and total energy consumption has increased 63%.



There is no highly energized poor country, and no low-energized rich country. Health, prosperity, and opportunity require energy.

Energy and the Modern World

The world has transformed more dramatically in the last 200 years than during any period in history. Life expectancy has more than doubled and dire poverty has gone from being the normal human condition to a gruesome affliction suffered by less than 10%. Destitution (living on less than $2 per day) remains but is a scourge that we should end by the year 2050. We can do this, but only if we don't stand in the way of increased energy access. No one can rise from poverty without increased energy consumption. Soaring energy availability enabled dramatic improvements in human well-being over the last two centuries, expanding today's life possibilities beyond the wildest imaginations of our ancestors. The enormous increase in energy availability to Americans today is the equivalent to everyone having a hundred human servants working to satisfy their needs, bringing lifestyles that would make Louis XIV envious. Harnessing coal, oil, and natural gas to empower human action, together with the rise of human liberty (bottom-up social organization) have completely transformed the human condition. Economic historian Dierdre McCloskey termed this transformation the Great Enrichment.

There are people in the world today who do not appreciate or understand this transformation. This unawareness is demonstrated by the rapid rise of the ESG (Environment, Social, and Governance) movement in the investment community. A movement often distinguished by its explicit opposition to hydrocarbons and its promotion of a top-down, check (or fill-in) the box definition of social graces. Albeit often well-intentioned, ESG has stood in opposition to the transformative forces that enabled the modern world: hydrocarbons and bottom-up social organization. Perhaps these attitudes can enjoy a moment in the sun among the lucky one billion, but they are unlikely to stand the test of time or enjoy prominence in the developing world.

Liberty Energy and myriad other companies care deeply about the environment, social advancement for all, and good corporate governance. In fact, a vibrant market economy with dynamic companies competing for workers and customers has been the prime driver of the tremendous social and environmental progress of the last several decades. Progress has been most pronounced among societies with free people, free markets, and limited government with low corruption. Segregation on buses in the old American South required governments to first drive private jitney transportation companies out of business. That's because few for-profit ventures are willing to alienate customers. Only when public transportation became a government monopoly could segregation in buses be strictly enforced. Unfortunately, it took Rosa Parks, Martin Luther King Jr., and a strong social movement with legislative and legal enforcement reforms to end legal segregation in the American South. Competition drives businesses to be places of opportunity and empowerment.

Today's global economy as measured by inflation-adjusted global Gross Domestic Product is 100 times larger than it was in 1820! Our world would be unrecognizable to our ancestors and virtually every aspect of it is intimately tied to our complex and massive energy system. Phasing out just one use of natural gas, Haber-Bosch

synthesis of nitrogen fertilizer, would cut global food production in half. Hospitals and virtually all aspects of modern medicine employ an incredible range of custom-designed plastic materials like medical instruments, syringes, masks, gowns, tubing, carrier fluids for vaccines, and more. I had a metallic and synthetic mesh material device implanted 20 years ago to close a flaw in my heart termed Patent Foramen Ovale (PFO). I owe my life to hydrocarbon materials as do countless others. I have yet to mention planes, trains and automobiles, or electricity, telephones, the internet, home heating, lighting, and such. Today's world is built on hydrocarbons. New energy sources such as wind and solar can be components of a diverse energy mix but they are mono-purposed, providing only intermittent electricity at high costs and none of the other human life needs sourced by natural gas and refined products.

Manufacturing of materials and products is the largest and most important usage of energy, because these materials and products make everything else possible. Roughly the same amount of energy (20% of global primary energy) is used to produce just four materials – cement, steel, plastics, and fertilizer – than is delivered by the entire global electricity sector. These four materials are termed the "Four Pillars of Civilization" by our greatest living energy scholar, Vaclav Smil. The modern world rests upon the foundation of these four materials. You will read more about this later in the report.

When I learned that global life expectancy had been stagnant at around 30 years of age for many centuries before the dawn of the modern era, I fell in love with the modern world and the high-quality energy sources that make it possible. Now let's turn to climate change.

Climate Change

Industrial development of the modern world has driven up atmospheric concentration of carbon dioxide by 50%, from a little less than 0.03% to now above 0.04%. This rise has mainly been driven by the combustion of hydrocarbons: coal, oil, and natural gas. Carbon dioxide, methane, and nitrous oxide are the primary greenhouse gases increasing due to human activities. However, naturally occurring water vapor is the most important greenhouse gas. Without water vapor in our atmosphere our planet would be frozen and uninhabitable for humans. Human industrial and agricultural activity increases greenhouse gas concentrations and is contributing significantly to a warming trend that earth has experienced over the past 150 years. Total warming over this period has been about 1.3°C (2.3°F).

A warming planet leads to expansion of seawater and melting of ice caps that drive up sea level. Mean global sea level rose around nine inches in the 20th century and at current rates would add 15 more inches throughout the 21st century.

Another thing that we often hear about climate change is that it leads to a significant increase in extreme weather events with deadly consequences. This claim is false. Extensive reports from the Intergovernmental Panel on Climate Change (IPCC) actually show no increase in the frequency or intensity of hurricanes, tornadoes, floods, or weather-related droughts. Further, deaths from extreme weather have declined significantly for a century as wealthier, more energized societies are much more resilient to extreme weather. Annual deaths from extreme weather events have declined by over 90% even as the global population has quadrupled during the last century. Climate change discourse is unfortunately rife with false claims and alarmist proclamations from all quarters. We seek to address that in this report by giving a brief technical summary of the physical phenomenon and an overview of the empirical data on temperature, sea level, extreme weather, and wildfires. Following the technical sections is a review of climate economics work and the policy implications. A realistic understanding of climate change is important for evaluating tradeoffs around the energy / climate / poverty nexus.

While climate change is a significant problem, it should be considered in the context of the world's other largest afflictions such as malnutrition, endemic diseases, and air pollution. Figure C puts climate change in this context by overlaying comprehensive economic work to quantify the economic damage from the world's most pernicious afflictions as compared to the estimated climate change impacts from Nobel Prize-winning climate economist, William Nordhaus. While the world has made great progress over the last century in reducing the impacts of malnutrition, disease, and air pollution, the impacts today remain quite large in absolute scale, particularly to the world's least fortunate.

Figure C shows clearly that while climate change is significant, it is far less urgent than our other largest afflictions today. Affordable, reliable energy alone will not cure these afflictions, but no cure is possible without it. Prioritizing climate change above these other afflictions threatens to hamper progress on our most urgent issues and losing support for long-term plans to address climate change.

Two things are required for positive progress on climate change: a sober understanding of the issue and the tradeoffs required, and massive improvements in energy technologies that can deliver low-carbon energy that is also low cost, reliable and secure. These are both critical. Despite the grand soirees and proclamations from the annual Conference of the Parties (COP) global climate gatherings, the world's developing nations are simply not going to implement policies that increase energy costs, reduce energy security, and displace energy-intensive manufacturing from their countries. These policies remain fashionable in many wealthy nations today, but it will not and should not happen in middle-to-lower-income nations. In fact, I don't believe that it should happen in wealthy nations either.

Much of the rich world – the lucky one billion – are losing perspective as they push misdirected efforts to achieve the social and political goal of appearing to "take action" against climate change. Overheated rhetoric is epitomized by current U.N. head António Guterres' "code red for humanity" and "global boiling." Political actions that follow from these farcical proclamations pose a growing threat to the economic wellbeing of the populace and to the geopolitical security of many nations. This report has case studies showing the costly failures of "climate" policy in Germany, as well as the EU, UK, and California. Today the hottest "climate" policy seeks to ban natural gas stoves and heating; New York City passed a law to do just this. New York State gets nearly half of its electricity (the replacement for gas used in heating and cooking) from natural gas, 23% from hydropower and 25% from nuclear before it closed the Indian Point nuclear reactor. Wind and Solar combined provide only 5% of New York State's electricity. Yet it was still sold as a "climate" solution to ban natural gas-burning stoves and home heating furnaces to be replaced with far more expensive electricity, which is largely produced from burning natural gas.

Viable paths to reducing greenhouse gas (GHG) emissions can only come from reliable and affordable low-carbon energy technologies, combined with continuing efforts to reduce the GHG emissions from hydrocarbons that have supplied roughly 80% of global primary energy for 70 years. I say this not as a partisan of hydrocarbons – I began my energy journey in nuclear, solar, and geothermal – but as someone committed to the premise that energy realism is a precondition of humanism. Liberty Energy is working today on next-generation geothermal via our partnership with Fervo Energy and next-generation nuclear with Oklo, a small modular nuclear reactor company. We are quite excited about the prospects for both companies, which is why we took an ownership stake and formed partnerships. We support all forms of energy that can better human lives.

Figure C

How Much Richer Would the World Be Had We Solved Different Issues

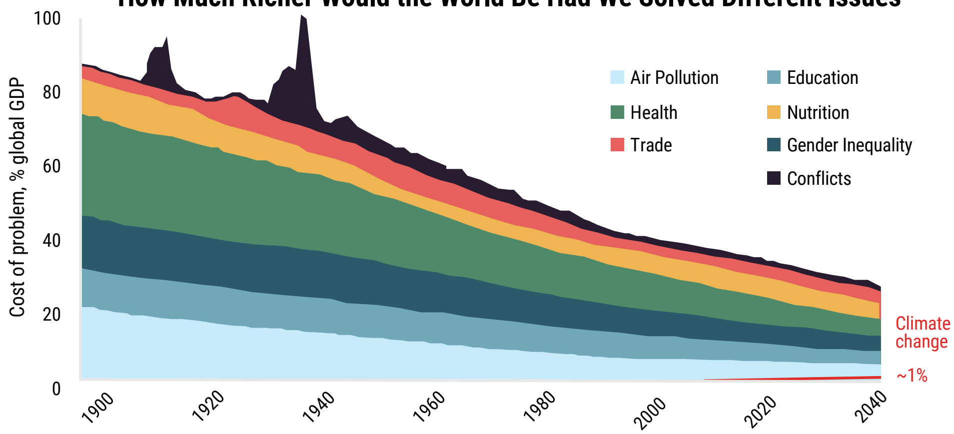


Figure C — Lomborg, Bjorn. "Welfare in the 21st Century: Increasing Development, Reducing Inequality, the Impact of Climate Change, and the Cost of Climate Policies." Technological Forecasting and Social Change, vol. 156, 2020, p. 119981.

Energy Poverty

I have been lucky in so many ways throughout my life. I could try to list them all, but it would be embarrassing. I will only mention one: I was born in a two-parent family in the United States during the second half of the 20th century. That is winning the lottery. Most people don't win the lottery.

Perhaps only a billion people today enjoy the full package of liberty and energy and, sadly, more than two billion people still lack regular access to basic energy services like clean cooking fuels and reliable, affordable electricity. Most also live in societies without rule of law and secure property rights, the essential ingredients of human liberty. This human liberty and energy transformation is far from complete. We need to expand and improve it, not curtail it.

The most urgent and acute problem in global development is broadening energy access, particularly to energy that is of high quality and clean at the point of consumption. The United Nations estimates that "slow progress towards clean cooking solutions means that the health of 2.4 billion people is at risk." That's one-third of humanity who still lacks access to clean cooking fuel, including some 80% of Africans and half of the Indian population. In concrete terms, over two billion people still cook their daily meals and heat their homes with traditional fuels, typically wood, dung, agricultural waste, or charcoal, often on open fires. This results in low-temperature combustion and high levels of smoke and fine particulate matter — $PM_{2.5}$, one of the world's most deadly pollutants – which is believed to lead to the deaths of about two to three million people every year. This staggering loss of human life and potential could be prevented by providing access to a basic gas stove and a canister of Liquid Petroleum Gas (LPG), which is mainly propane.

Liberty launched the Bettering Human Lives Foundation specifically to address this most urgent energy access issue. If the world's least fortunate are to improve their lives and join the developed world, there must be a dramatic in-

crease in their personal energy consumption, and that of the societies in which they live. There is simply no other way to escape poverty.

Energy access for the world's least fortunate is no bolt-on social goal for Liberty; it is one of the driving principles upon which our company was founded. The greatest force combatting energy poverty has been the American Shale Revolution, the space in which Liberty works. The numbers are astounding: trillions of dollars saved for global energy consumers and over $3,000 each year for every American family. (More details on this in our Shale Revolution section, page 62).

Energy poverty is not limited to the developing world; it is present across all societies. In fact, energy poverty is growing fastest in high-income countries making policy choices that necessarily drive up the local cost of energy. In 2020, some 27% of U.S. households had trouble meeting their energy needs, and 10% of Americans reported keeping their homes at unhealthy temperatures to balance their budgets. This in the world's wealthiest country! Under-heated homes are a significant cause of death among the elderly and people in poor health. In the winter of 2022-2023, due to Russia's invasion of Ukraine and Europe's own failed climate policies, natural gas and electricity prices soared. The European Union estimated that increased heating costs led to 68,000 excess deaths.

Globally, around four million people die annually due to the cold, eight times more than people who die of heat. Raising the cost of home heating is deadly.

Many years of studying these issues has led me to a simple conclusion: Zero Energy Poverty by 2050 is a humane and achievable goal. Net zero carbon emissions by 2050 is neither achievable nor humane, as impeding energy access runs counter to emerging from poverty.

Bettering Human Lives Foundation

In response to the most urgent global energy challenge, Liberty launched the Bettering Human Lives (BHL) Foundation in January 2024. The Foundation strives to increase access to clean cooking fuels and cookstoves for the nearly one-third of humanity that still cook their daily meals burning wood, dung, charcoal, or agricultural waste indoors. We are doing this by supporting businesses, entrepreneurs, and innovators who are working in clean cooking, initially in Africa. Hundreds of businesses supply millions of Africans today with clean cooking fuels and cookstoves. We will help them grow and expand by addressing their most pressing challenges, such as working capital, better stove and fuel technology, and other barriers to growth.

We have already seen a tremendous reception for the BHL Foundation from companies and individuals, both in our industry and outside. Many are eager to join this effort to better millions of lives and expand opportunities for impoverished families, particularly women and girls who suffer most from gathering wood for fuel and preparing meals over smoky fires for hours on end. The size of the challenge is daunting. From the outset, we will focus on one or two countries, learn quickly from failures and success, and relentlessly innovate — the same approach we used building Liberty from a standing start only 13 years ago.

More about the foundation is included in this report. I particularly recommend reading the heartfelt letter on page 72 from Anne Hyre, the Foundation's Executive Director, who has spent her career working on public health in lower- and middle-income countries.

Liberty Energy is a proud passionate family of over 5,000 people who want to spread liberty and opportunity to those born in less fortunate circumstances. We do this through many avenues including educational scholarships, poverty-abatement programs, and hiring practices that don't exclude people who had a tough start in life, including formerly incarcerated individuals. We also focus on helping returning veterans from our armed services, and through the Bettering Human Lives Foundation we are assisting some of the world's poorest families. Our greatest impact, however, comes not from our extensive non-profit ventures but from our daily efforts that help our customers produce vast quantities of North American oil and gas more efficiently and cleanly. Over 10% of American primary energy comes from wells fractured by Liberty. These wells also provide clean cooking fuels for over 100 million people globally! More energy, and better energy, is the path to bettering human lives.

Energy and climate change are critical issues that impact everyone's livelihoods and future opportunities. We aspire to inform these dialogues and steer them towards fact-based discussions about trade-offs. Too many decisions have needlessly driven up energy prices and thereby reduced economic opportunity without making any significant progress on climate change. This report is aimed at providing thoughtful context for decision makers. But this report does not contain specific policy answers, as the social and political process is where these decisions should be made. Different priorities will lead to different choices even when starting from the same basic set of facts and understanding.

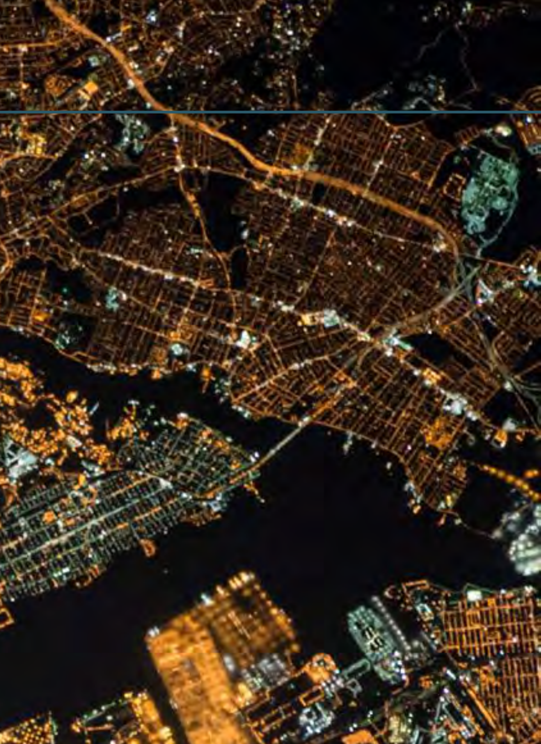
Thank you for joining me and the whole Liberty Energy family on this journey to understand these complex issues and better energize the world's eight billion people.

To Bettering Human Lives!

Chris Wright
Liberty Energy, Founder and CEO

ENERGY

History of Energy | Energy Today | Electricity | Energy Additions



Energy

Energy is the essential ingredient that makes everything happen. Every organism, from the smallest micro-organism to the majestic humpback whale, relies on energy. As far back as 3.5 billion years ago, the ability to harness energy released from chemical bonds has made possible the exquisite complexity of all life forms. As life grew in complexity, so did nature's technology, bestowing upon plant and animal kingdoms mitochondria — micro-powerplants that inhabit cells and facilitate movement, growth, repair, and even thought. Throughout human history, physiological demands for greater energy led to substantial and long-lasting cultural change. Our ability to harness the energy of combustion — fire — significantly altered the human diet by expanding the range of foods we consume.

Wood was the sole energy source for heat and cooking throughout human history until the arrival of the modern world. Wood is termed renewable because natural cycles of water and sunlight power photosynthesis to grow trees. Forests provide finite stores of energy that transcend seasons. Modern "renewables" lack natural energy stores. They also require copious amounts of finite, energy-intensive (sometimes exotic) materials to harness nature's daily and seasonal energy flows.

Food is the energy source that powers the human machine. Availability of this energy source was tied to seasonal weather patterns and competition with other humans and animals.

History of Energy

Roughly 10,000 years ago, human progress exploded with the harnessing of energy through the development of agriculture. Our species quickly grasped the benefits of agriculture and planned the use and production of vast quantities and varieties of food energy sources (vegetables, fruits, and grains). The soaring production of energy from agriculture provided cultural changes that led to a substantial rise in global populations previously stunted by hunter-gatherer lifestyles. Over time, greater cultural efficiencies in producing and delivering food, heat, light, tools, and information freed up unused energy to further advance human well-being and civilization. These advancements would not have been possible without growing access to energy.

Following the addition of fire and agriculture, civilization took another large leap, breaking free from the annual photosynthetic constraint by tapping into enormous volumes of energy from coal, oil, and later natural gas. These buried deposits of plant and animal species from millions of years ago provide a concentrated source of high thermodynamic quality energy that enables the rich complexity of life in the developed world. Hydrocarbons represent tens to hundreds of millions of years of energy stored from photosynthesis that freed humanity from the bounds of highly limited and unpredictable harvests of energy. Hydrocarbons now support billions of people's lifestyles that were unimaginable only a few generations ago. Planes, trains, and automobiles changed mobility, facilitating trade and expanding social networks beyond local communities. Improved communications led to the accumulation and availability of knowledge on an unprecedented scale, further expanding with the internet. Technology and research advancements in modern medicine have increased the lifespan, health, and well-being of billions of humans. The expansion of possibilities due to fossil fuels and the technologies they support means that people today enjoy greater freedom — to choose what to eat, where to live, with whom to interact, and how to live.

Figure 1.1 shows a rapid and overwhelming increase in energy supply with the arrival of fossil fuels coinciding with a miraculous increase

Figure 1.1

Global Primary Energy Demand by Source vs. Life Expectancy 1800–2022

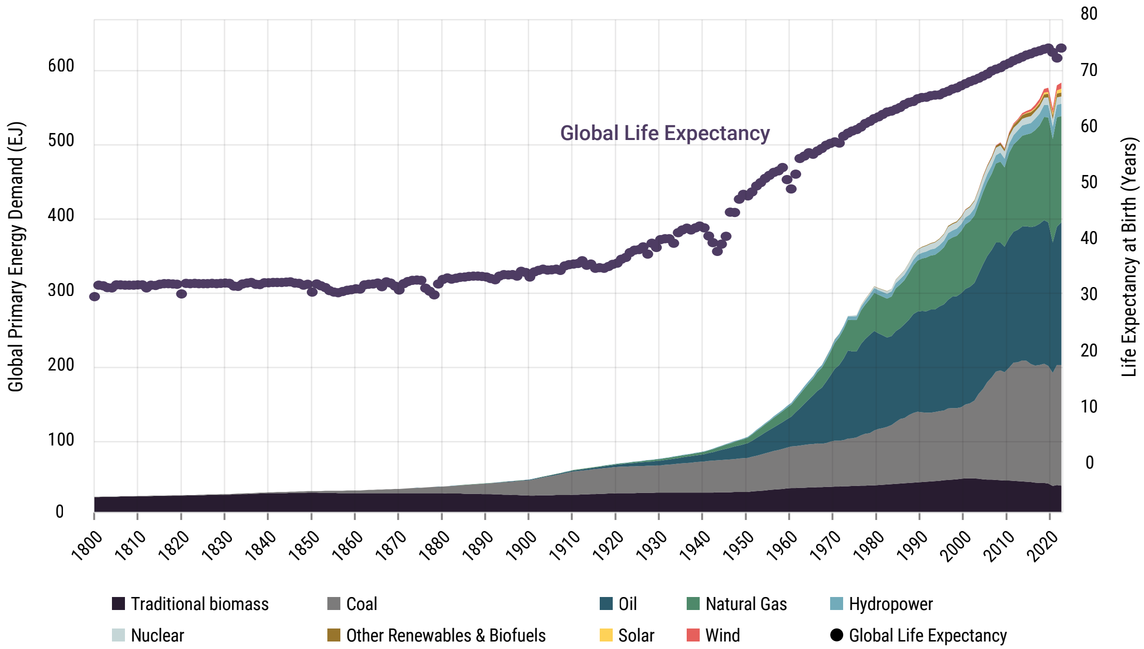
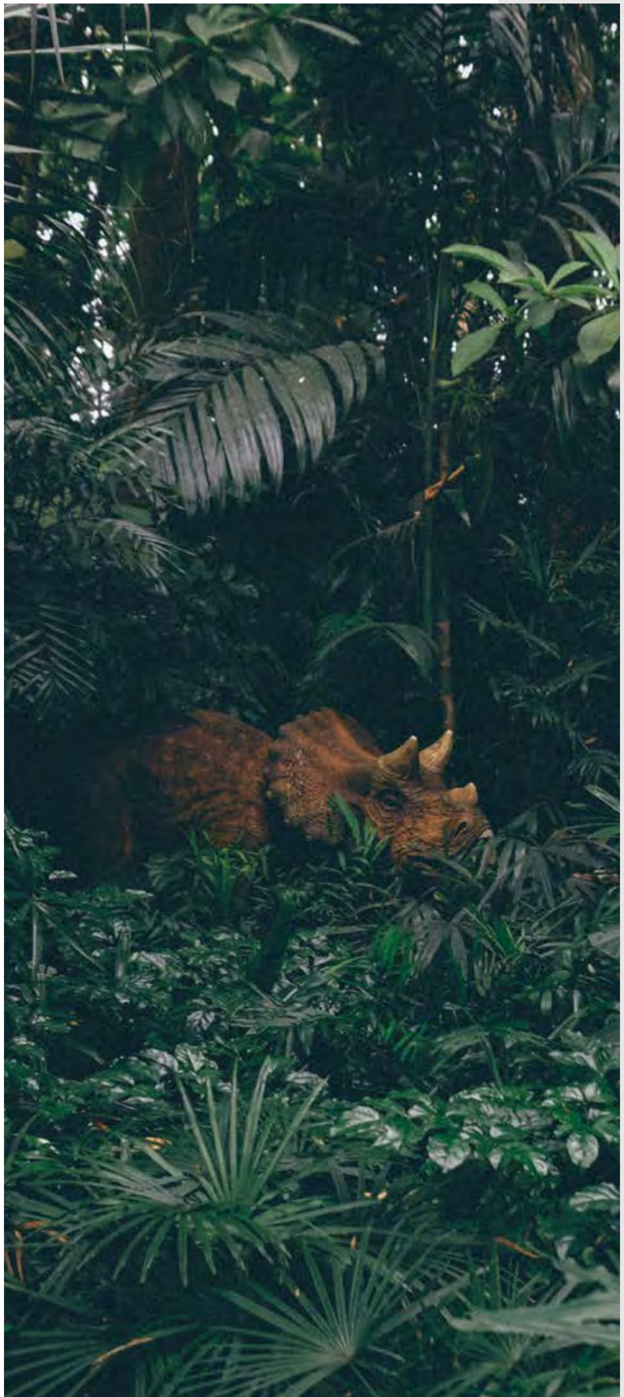


Figure 1.1 — Smil, Vaclav, 2017. Energy Institute - Statistical Review of World Energy (2023), IEA, OWID, Gapminder, and Bijou Insights

in life expectancy. Coal's contribution to global (as opposed to local) energy sources only really emerges in the late 1800s, which coincides with global life expectancy starting to rise significantly. The plot shows two brief 20th century periods of declining life expectancy. The first is World War II. The second, in the late 1950s, is explained by one country: China. Chairman Mao Zedong and the Chinese Communist Party took away the liberty of Chinese farmers and forced collectivization of agriculture on a massive scale. The result of what was termed the Great Leap Forward — tens of millions of deaths from starvation in one of the largest famines in global history.

Northwest Europe, particularly the Netherlands and Great Britain, was the first to adopt large-scale usage of fossil fuels, resulting in the first sustained rise in human productivity. Coal usage was widespread in Great Britain from at least the mid-1500s. Coal consumption grew between 1% to 3% annually up to World War I. Coal likely surpassed 50% of total UK primary energy consumption in the late 1600s. By the 1850s, British society obtained 90% of its primary energy from coal, transforming lives through additional wealth and geopolitical power while supporting a rising population during a period commonly referred to as the Great Enrichment. Coal also explains how a small island nation could have an empire covering one quarter of the earth by the early 1900s. Meanwhile in the United States, forestry timber dominated the energy supply well into the 1870s, although by 1900 coal surpassed wood as the largest energy source in the U.S. Going forward, energy supply growth was dominated by coal and oil in the first half of the 20th century.

The widespread appeal of the human benefits provided by hydrocarbons led to rapid global adoption. By the early years of the 20th century, more than half of the world's energy came from coal and oil. Soon after the end of World War II, the improvement in human welfare and access to hydrocarbons spread across the globe, lifting billions from poverty. This ongoing phase of the Great Enrichment elevated living standards at a rate not seen before in human history. Coal, oil, and more recently, natural gas, remain the primary catalysts in this transformation due to their superior physical qualities, making them indispensable high-quality energy sources.



Where Hydrocarbons Come From

Hydrocarbons represent millions of years of underground solar energy stored from photosynthesis. Photosynthesis consumes energy from sunlight to combine carbon dioxide (CO_2) from the atmosphere with water to form chlorophyll — the building block of earth's carbon-based lifeforms — and release oxygen into the atmosphere. The combustion of hydrocarbons is the reverse of this reaction: atmospheric oxygen is consumed to liberate energy while releasing into the atmosphere the carbon dioxide and water molecules that photosynthesis originally combined.

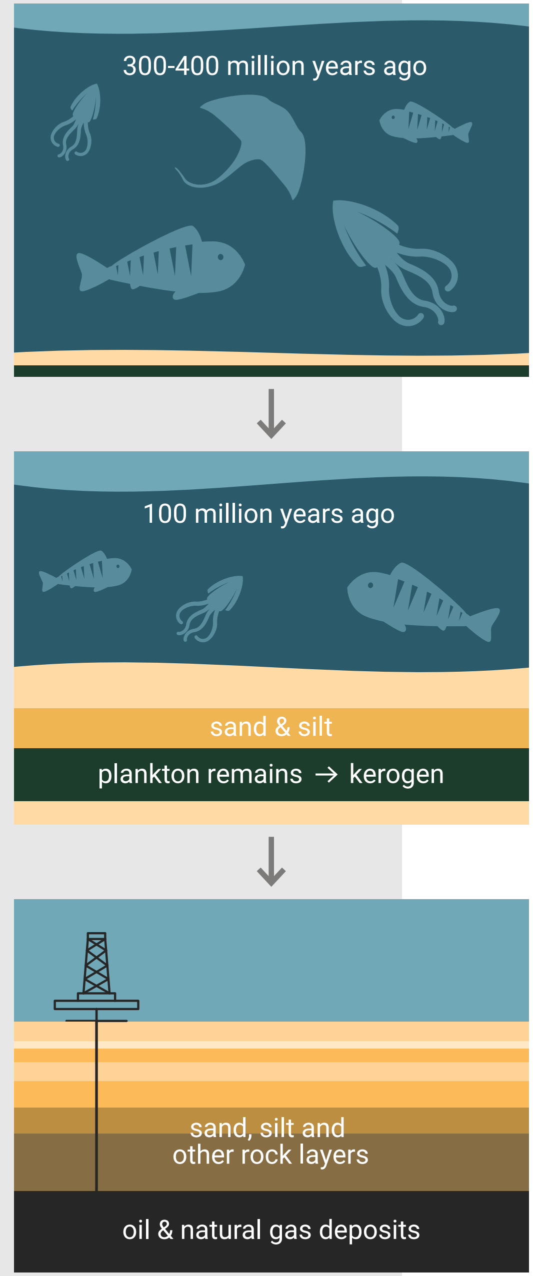
Earth was far more fertile for life during the time of the dinosaurs, starting roughly 250 million years ago and continuing until 66 million years ago. Ocean-dwelling micro-organisms like plankton and other lifeforms were far more abundant as the earth's average temperature was much higher and atmospheric carbon dioxide (plant food) levels were also far higher. Imagine how much plant life must have been readily accessible to support the giant dinosaurs' daily need for hundreds of pounds of food. This warm, lush, verdant time on earth led to copious amounts of biologic matter accumulating as plankton died and sank to the ocean floor, eventually being transformed into abundant deposits of oil and natural gas. The same thing happened on land in swampy environments as massive accumulations of dead plants were buried and began their long conversion into coal deposits.

The plankton skeletons on the ocean bottom were gradually deeply buried by sediments flowing into the sea from streams and rivers. Such clay particles eventually were hardened into shale through burial. The gradual accumulation of sediments on sea floors is how new rock layers are formed over millions of years. Geologic processes are very slow. The buried biologic matter from plankton decomposition goes through a sequence of transformations, known as catagenesis, as it heats and compresses over time. With time it progresses to kerogen, a precursor to oil. Further heat and pressure transform the carbon and hydrogen-dominated substance into a viscous black "heavy" oil such as that produced in Canada's oil sands and other places worldwide. Oil buried deeper and at higher temperatures "cooks" longer and further breaks down the long hydrocarbon chain molecules into ever smaller molecules, forming "lighter" and less viscous oil (think gasoline-like substance). Near the end of the "cooking" process, propane predominates (only three carbon atoms per molecule), then ethane (two carbons), and finally to the fully cooked, simplest hydrocarbon molecule of methane. Methane has only one carbon atom surrounded by four hydrogen atoms and is a fuel that burns so cleanly that it is commonly used to power indoor cooktops and hot water heaters. Because methane is the endpoint of the process, it is also by far the most abundant hydrocarbon. Methane exists not only in fully cooked "dry gas" underground reservoirs, but it is also present in nearly all oil accumulations (associated natural gas) and in all coal deposits.

Oil fields can be small or large surface areas where wells are drilled, typically one to three miles deep, to access underground accumulations of oil and gas that are brought to the surface with ever-advancing equipment and technology. Oil is typically transported via a vast network of pipelines to refineries where it is processed (similar to what Mother Nature does underground) into specific products for uses like gasoline, jet fuel, diesel, lubricating oils, asphalt, petrochemicals, and more.

Natural gas fields produce from rocks where the plankton has fully cooked into the end product: methane. Methane can be directly transported via pipelines to homes or businesses for heating and cooking, to power plants to produce electricity, to industrial plants to power production of materials or consumer goods, to petrochemical plants to make plastics and fertilizers, or exported to countries around the world to energize their societies. Natural gas liquids (NGLs) such as ethane (feedstock for plastics), propane, butane, isobutane, and pentane are derived from the processing of liquid rich natural gas.

Because methane is the simplest hydrocarbon, it burns the cleanest and is also the most abundant, and therefore typically the cheapest of the oil/natural gas family of hydrocarbons produced from marine life. The caveat is that its gaseous form requires a pipeline network to transport it from the wellhead where it comes out of the ground to where it is consumed. In rural areas and lower-income areas that lack an extensive pipeline infrastructure, propane is the common substitute fuel for cooking, heating, and such. Propane is a good substitute because it can be transported easily under pressure as a liquid in trucks and ships, allowing delivery nearly everywhere. At the point of consumption, when it is no longer under pressure, propane burns as a clean gas similar to methane.



Where Hydrocarbons Come From

Energy Systems Today

Following the brief history of energy sources and human advancement in the last section, we now cover where the world gets energy today and how that is evolving with far greater investment into non-hydrocarbon energy sources. We'll also cover what energy is used for and which energy sources can be used for different energy applications. Too often energy is equated with the electricity grid. In fact, the largest usage of energy is as heat in the manufacturing of materials and products. Transportation is also a large and growing usage of energy.

Over the last few decades globally, and in the U.S., hydrocarbons have supplied a little more than 80% of total primary energy. This is not to deny that significant changes are occurring in the flow of investment dollars and government policies in the energy space. Besides natural gas taking market share from coal in wealthy countries, we have also seen solar and wind rising rapidly, largely due to generous subsidies and political mandates in the developed world. But their low energy density, requiring large amounts of land and energy-intensive materials, as well as weather-dependent intermittency, have limited their role to modest players in the electricity sector in middle- to higher-income countries. Their intermittency is one reason that increased deployment of solar and wind has been accompanied by rising electricity prices, as expenditures rise to maintain the reliability of service. So far, these rising electricity prices have not dampened enthusiasm for expanding wind and solar in a quest to lower greenhouse gas emissions.

Figure 1.5 shows the breakdown of energy sources for the United States today, with the lengths of each bar representing a relative contribution to U.S. energy consumption. The bars are also color-coded to show the various uses for each energy source. Notice that the natural gas bar looks like a rainbow as significant quantities are used for multiple applications such as electricity production, home heating and cooking, industrial process heat in factories, direct usage of its molecules to form plas-

Figure 1.2

Number of Homes Served by One Acre of Land Use

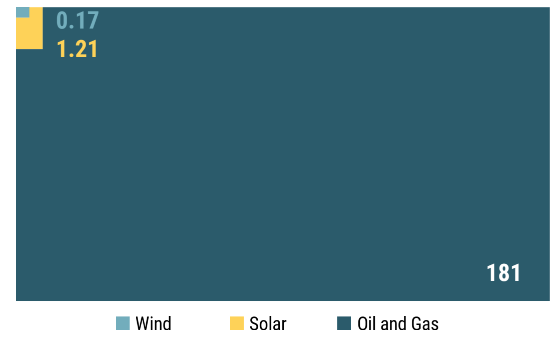


Figure 1.2 — Smil, Vaclav. "Power Density Primer: Understanding the Spatial Dimension of the Unfolding Transition to Renewable Electricity Generation (Part V – Comparing the Power Densities of Electricity Generation)", Liberty Energy.

Figure 1.3

Materials Requirements to Build Energy Machines

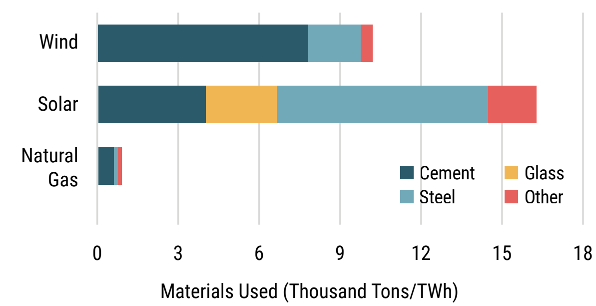


Figure 1.3 — U.S. Department of Energy (DOE), "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities," September 2015, p. 390G

Figure 1.4

Energy Source Capacity Factors in the U.S. 2022

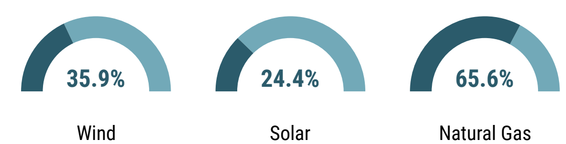


Figure 1.4 — Statista Research Department, and Nov 24. "U.S. Energy Capacity Factors by Source 2022."

Figure 1.5
2022 Estimated U.S. Final Energy Demand by Source & Purpose

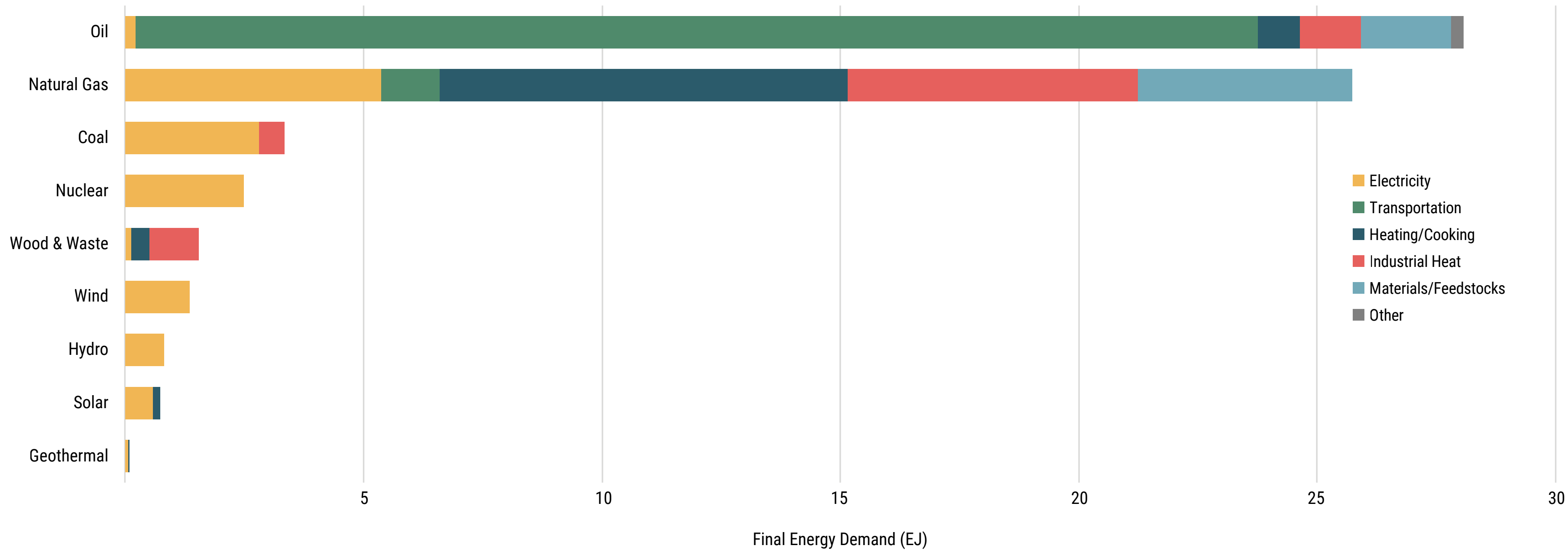


Figure 1.5 — IEA and Bijou Insights

tics and synthetic materials like nylon, and as a transportation fuel for buses, trucks, and cars. Transportation represents the dominant usage for oil in the United States. Globally the oil bar would be more of a rainbow as industrial, electrical, and raw material usage are larger on a relative scale overseas where natural gas is not as readily available to substitute. In contrast, wind and solar make far smaller contributions and are employed almost entirely in electricity production as they are not suited for most other energy usages.

Investment dollars today in wealthy countries are flowing strongly into low-carbon energy sources as part of climate change mitigation efforts. The two largest sources of low-carbon energy, nuclear and hydropower, have struggled to grow. Nuclear is seeing as much decommissioning of legacy plants as construction of new ones, leading to roughly flat energy production. Growth in global energy demand, however, has led to nuclear's share of total primary energy declining from a peak of over 6% in 2002 to only 4% today. It is hard to imagine meaningful global decarbonization without a strongly growing nuclear sector. Hydropower projects struggle with environmental pushback due to the very large land footprint and major effects on waterways and aquatic life. New dams today are only being built in the developing world, with China dominating in global capacity. China continues to grow its energy capacity from many sources to both lift its population out of poverty and continue its dominance as the world's energy-intensive manufacturing powerhouse.

Although opposition to hydropower development may be overstated in individual cases, the environmental concerns are understandable. Much like other renewable energy technologies such as wind and solar, the local regional environmental impact of hydropower can be highly significant. Nuclear, on the other hand, is held back by uncertainty around permitting and regulatory challenges in response to public fears over nuclear safety. In our view, the data does not support the public fears, as nuclear has an outstanding, indeed a pack-leading, safety record.

From the earliest days of humanity, the global energy system has been complex and critical to human welfare. It is too important to get wrong. Our modern world could not exist as it does without the massive increase in energy consumption that has taken place in recent centuries. The global energy system is massive in scale -- successfully redesigning and remaking it is a herculean task. Scientist and author Vaclav Smil said it best: "Energy transitions take time." Governments have been ignoring this fact at our peril.

Any future dialogue should be informed by the past. Despite the ubiquity of the term "energy transition" in today's energy discourse, so far, we have not seen any source of energy decline in absolute global consumption as it is replaced by something new. Instead, we have simply

Figure 1.6

Global Primary Energy Demand & Projections 1800–2050

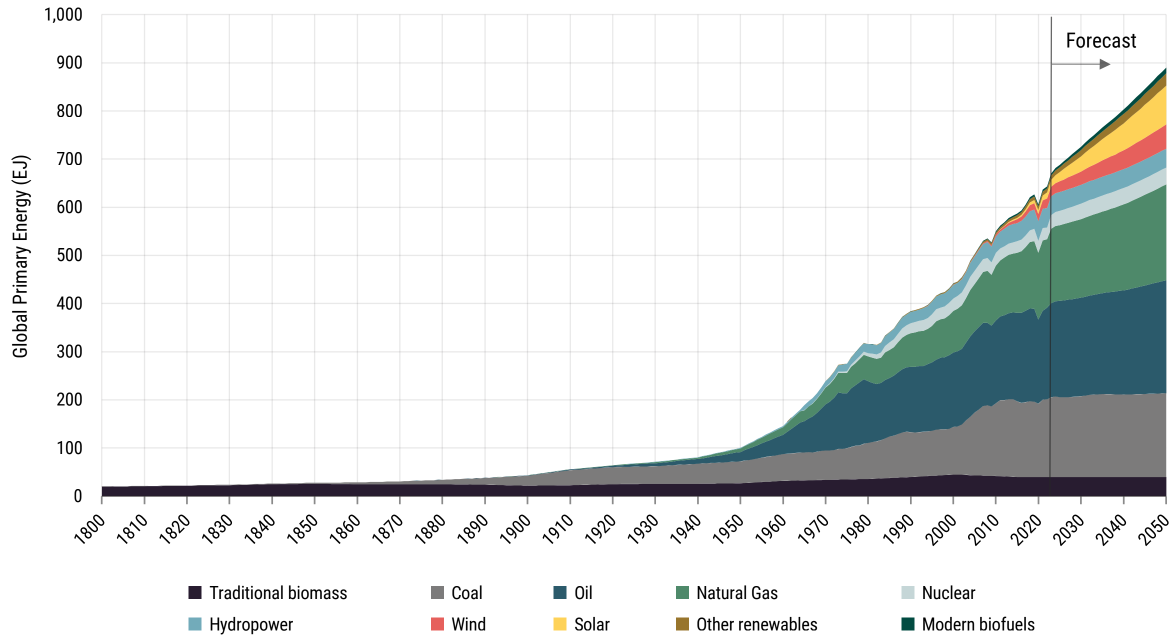


Figure 1.6 — Energy Institute - Statistical Review of World Energy (2023), IEA, EIA Annual Energy Outlook 2022, and Bijou Insights

been adding more sources as layers on top of existing sources to satisfy the insatiable demand for energy. A more honest discussion of the new energy sources being touted and heavily supported by mandates and subsidies would be called energy addition, not energy transition. As the following Energy Addition section shows, there is no evidence of an energy transition yet.

Figure 1.6 shows historical sources of primary energy production together with Energy Information Administration (EIA) Reference Case projections out to 2050. These projections are consistent with recent history, showing contributions growing from all energy sources to reach the projected nearly 800 exajoules of annual energy demand in 2050. In contrast, the International Energy Agency (IEA) shows scenarios of hydrocarbon demand peaking soon and dropping quickly as the renewables ramp rapidly and global per capita demand for energy declines in the future. The IEA projections appear less credible, as they do not align with historical trends. Furthermore, the IEA incorrectly assumes that renewable energy technologies are lower-cost, reliable substitutes for hydrocarbons that will drive down the price and market shares of hydrocarbons. What could possibly precipitate a change where people prefer to consume less energy?

Traditional biomass — such as wood, dung, and agricultural waste — supplied the majority of global energy throughout history and prehistory. Since the introduction of hydrocarbons, the share of renewable energy (traditional biomass) has declined precipitously to a low of 13% in 1975. The world did not see a decline in absolute consumption of solid biofuels like wood and dung during this period, only a decline as a total percentage of energy as hydrocarbons grew rapidly. Over recent decades, the percentage of total global energy supplied by renewable energy has increased slightly to 15%.

Unfortunately, the largest source of renewable energy today is still traditional biomass. This is the deadly source of heating and cooking fuel that still predominates among the poorest one-third of the global population. The growth in renewable energy comes from hydropower, the largest source of "modern" renewable energy, and the third largest source of global electricity after coal and natural gas. Growth has also come from the currently favored "renewables" wind and solar, which together account for about 3% of primary energy. The other source of renewable growth is modern biofuels such as ethanol, biodiesel, and aviation biofuel.

Shown in Figure 1.7 is the historical percentage of global energy from renewable sources since 1800, including the wide range of future projections of renewable energy's market share from the International Energy Agency and U.N. out to 2050. Even the most aspirational projection shows renewable energy from all sources only reaching 30% of total global energy by 2050. The transition of the global energy system is a gradual process. It is difficult to replace fossil fuels that are more abundant and possess a higher thermodynamic quality and incredible flexibility in applications. Renewables lack those physical advantages and need the support of policies and subsidies to be cost competitive and even then, only at low grid penetration rates.

Figure 1.7

Renewable Share of Global Primary Energy 1800–2050

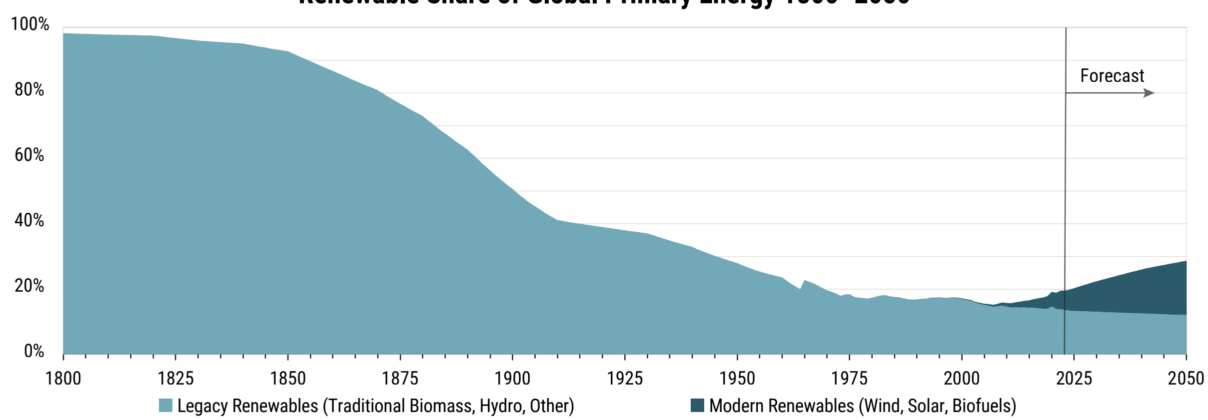


Figure 1.7 — Our World in Data (1800-2022), EIA 2023 Energy Outlook Reference Case (2023 - 2050)

CASE STUDY

Health & Hydrocarbons

Anti-fossil-fuel activists frequently claim that the production and use of oil and natural gas is dangerous to human health, pushing public policies or obstructionist campaigns to slow or stop the production and consumption of these fuels. Despite these impassioned claims, the data does not support their fear-based narratives — in fact, the data shows the opposite.

Access to abundant, scalable, reliable, and affordable energy is a clear precursor for individuals to create protection from their natural environment. As Figure 1.8 illustrates, populations with the highest per capita supply of energy have the lowest mortality risk attributable to environmental risk factors such as access to clean water, air pollution, and exposure to extreme temperatures. According to the Institute of Health Metrics and Evaluation at the University of Washington, global deaths attributed to all environmental risks total 10.1 million annually. Meanwhile, deaths attributed to behavioral risks (such as tobacco, low-quality diets, alcohol/drug use) and metabolic (including high blood pressure and high BMI) total 40.2 million per year.

Figure 1.8

Total Primary Energy Per Capita vs. Mortality Rate Attributed to Environmental Risks

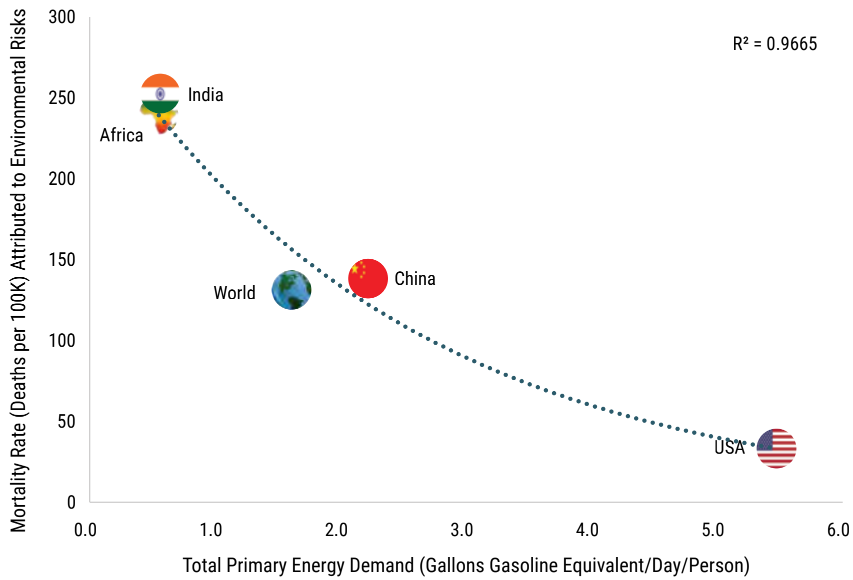


Figure 1.8 — Bijou Insights analysis based on the most recent data provided by the IEA (World Energy Balances 2022) and IHME (Global Burden of Disease 2019).

The U.S. is one of the largest consumers of energy per capita

and its energy mix is heavily weighted to the use of oil and natural gas. Yet, the negative impacts to human health related to environmental risks, including air pollution experienced by U.S. citizens, are among the lowest in the world.

Figure 1.9

Primary Energy Mix vs. Mortality Rate Attributed to Environmental Risks

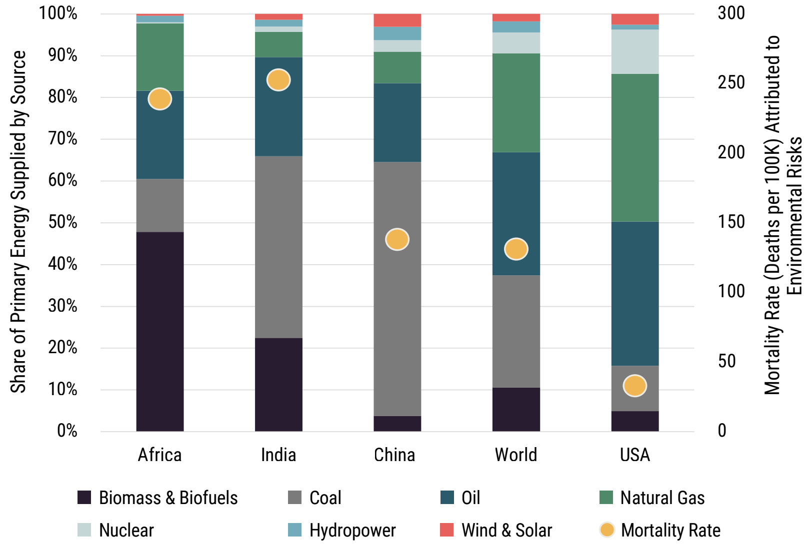


Figure 1.9 — Bijou Insights analysis based on the most recent data provided by the IEA (World Energy Balances 2022) and IHME (Global Burden of Disease 2019).

Figure 1.10

Oil Demand vs. Mortality Rate Attributed to Air Pollution

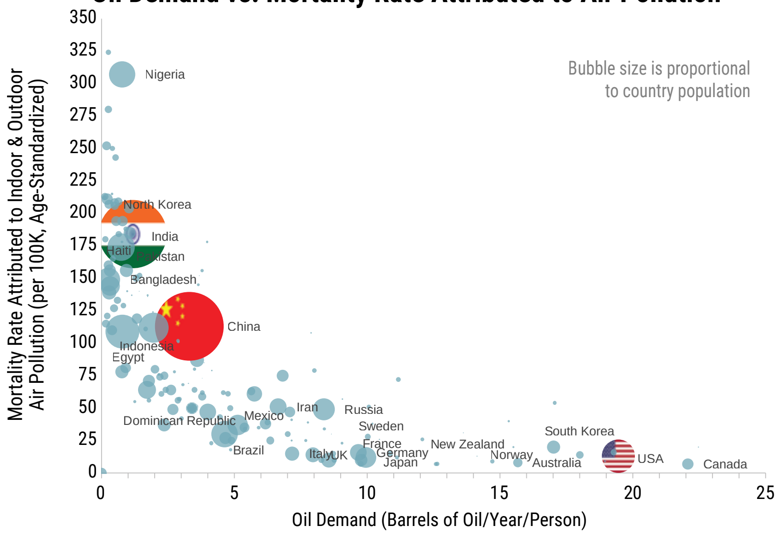


Figure 1.10 — Bijou Insights analysis of data from the WHO Global Health Observatory data repository and EIA.

The data is also clear that populations with access to the most abundant energy supply are those with access to oil and natural gas. Furthermore, those with energy menus that include the highest shares of oil and natural gas also have the lowest negative health impacts from environmental risk factors as shown in Figure 1.9.

One of the most disingenuous claims made by anti-fossil fuel activists is their portrayal of the negative impacts to human health related to air pollution resulting from the production and use of oil and natural gas. The worldwide reality is that an increasing use of oil and petroleum products correlates to lower mortality rates attributed to exposure to air pollution (Figure 1.10). Passion to better our environment and improve human health is laudable, but how best to direct these passions must be informed by an understanding of the tradeoffs involved if the goal is to better human lives.

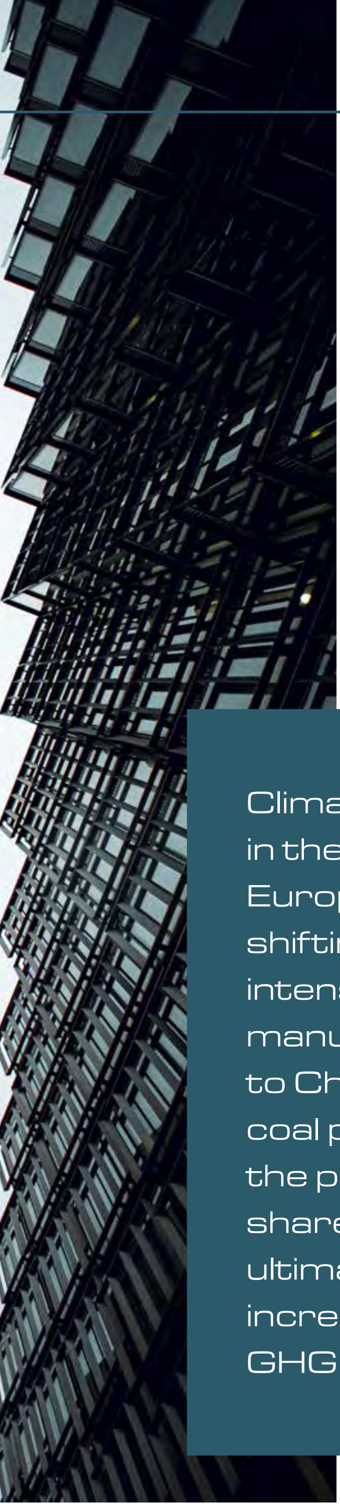
Globally, about half of total energy consumption is for industrial purposes -- in other words, making the modern world possible. This is the most fundamental use of energy. Without these materials and systems, there would be no electricity, we would lack transportation, healthcare, communications, and all the other derivative uses of energy. Every dialogue about energy should start with "How are we going to produce the required items?" Unfortunately, this critical issue is hardly ever highlighted. In the Energy and the Modern World Section (page 48), you will read about manufacturing the most important building blocks of the modern world: cement, steel, plastics, and fertilizer.

Industry and transportation combined account for 50% of U.S. energy consumption.

In the U.S., the two primary sectors for energy consumption are industry and transportation. In the U.S. alone, each sector uses approximately 25 exajoules of energy, each representing roughly 25% of the total U.S. primary energy consumption (100 exajoules). However, China's industrial sector uses 75 exajoules compared to only 20 exajoules for their transportation sector. China has become the world's energy-intensive manufacturing center. "Climate" policies often increase energy costs and, therefore, displace energy-intensive manufacturing from Europe or the U.S. to China. Is this an effective "climate" policy? China's industry is powered by coal, therefore, the shift of manufacturing away from Europe and the U.S. will not reduce Greenhouse Gas emissions (GHG), but instead have the opposite effect. Coal supplies over 50% of total primary energy in China compared to around 12% in the U.S. and 16% in Germany.

Energy systems are immense, complex and have evolved based on feasibility and available funding. It matters little what the preferences are among politicians, regulators, investors, businesses, or citizens. When political desires clash with fundamental physics, physics triumphs every time. The trillions of dollars fund-

**1 Exajoule (EJ) = 0.95 Quadrillion British Thermal Units (BTUs) = 278 Terawatt-hours (TWh)*



Climate policies in the U.S. and Europe are shifting energy-intensive manufacturing to China, where coal provides the primary share of energy, ultimately increasing global GHG emissions.

ed over the last two decades by governments seeking to remake their energy systems have made rather modest progress in changing the makeup of global primary energy sources. The Energy Addition section will show that they have made only a modest contribution to satisfying the growth in energy demand, not coming close to displacing any existing demand for hydrocarbons.

Political involvement has, however, resulted in significant increases in electricity prices in areas where solar and wind penetration is driven above modest penetration levels. High electricity prices and less stable grids are drawing significant citizen opposition, as are new land-intensive wind and solar projects. Robert Bryce has documented over 500 wind and solar projects rejected due to local opposition. The world energy system is unlikely to transform following this model but will evolve as improved energy technologies outcompete incumbent sources. We are also seeing the rise of new demand sources for energy from AI, cryptocurrency, and continued growth in streaming entertainment. Hydrocarbons have stubbornly dominated global energy systems over the last century and look to continue to do so until truly improved energy technologies arrive and gather scale.

Figure 1.11

Coal Share of Primary Energy Demand

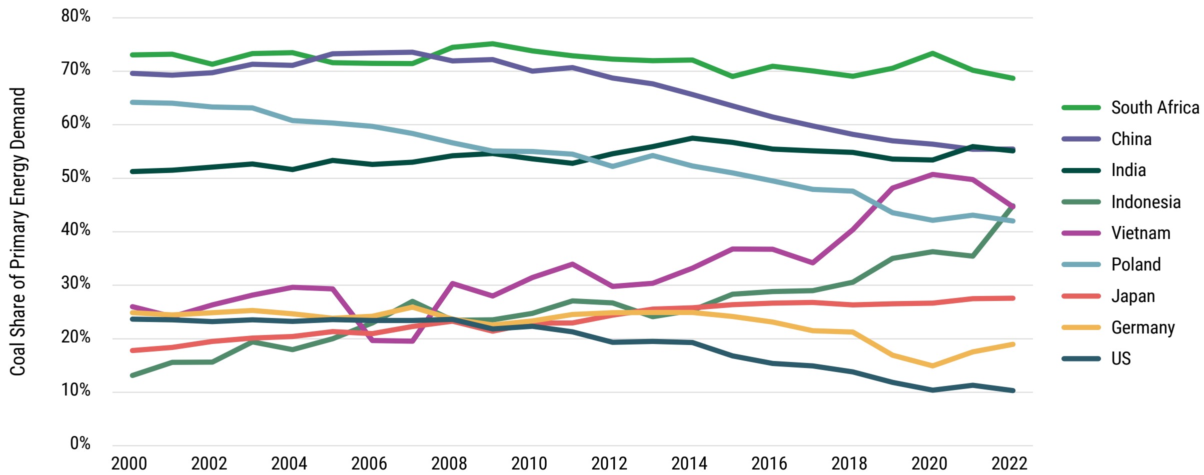


Figure 1.11 — JP Morgan Annual Energy Paper, Energy Institute - Statistical Review of World Energy (2023), and Bijou Insights

Electricity

Globally, electricity accounts for only 20% of total primary energy consumption; however, it dominates the conversation when discussing energy. Perhaps this is because it is so central in our homes and offices and because it is a focus of politicians and regulators. It is a wondrous form of energy, but its large and essential grid infrastructure means that it is delivered in the most top-down means of any energy. Electricity currently accounts for only a small part of industrial and domestic heat and transportation, the largest energy consumption sectors.

The U.S. EIA data in Figure 1.12 give a sense of the increasing demand and changing global sources of electricity over the last 50 years. All things being equal, a modernizing economy will tend to be increasingly electrified, although our case studies on the UK and Germany show that making electricity more expensive ultimately leads to declining demand.

Coal is the primary global source of electricity, contributing about 36%, with natural gas following at approximately 23%. In contrast, low-carbon energy sources such as nuclear, hydropower, wind, and solar collectively provide slightly over 35% of global electricity. Although this market share has remained relatively constant for the past 35 years, there is a modest upward trend.

> Well over half of the steep U.S. drop in GHG emissions over the last 15 years is attributable to natural gas displacing coal in the electricity sector.

Over the last 10 years, the American Shale Revolution significantly increased American natural gas production. This increase has introduced ample oil and natural gas to the global market, driving down prices of both commodities. One of the most visible impacts is evident in the U.S. electricity sector, where natural gas has surged to the forefront, now supplying 40% of electricity. In contrast, coal, which dominated over 50% of U.S. electricity supply until just 15 years ago, now provides only around 20%.

This shift has resulted in cleaner air in the U.S., with reduced levels of $PM_{2.5}$, SO_x, mercury, and other pollutants. It has also led to a noteworthy decline in U.S. per capita greenhouse gas emissions, reaching its lowest level in over 70 years. Well over half of the steep U.S. drop in GHG emissions over the last 15 years is attributable to natural gas displacing coal in the electricity sector. This displacement has also led oil and gas to their highest-ever market share of U.S. primary energy — nearly 70% in 2019–2022.

The story is not a surge in the market share of hydrocarbons, but instead a shift in the balance of oil, gas, and coal in the U.S. power sector. After coal and natural gas, nuclear energy provides the third largest share of U.S. electricity at nearly 18%. The rest comes mainly from wind, hydropower, and solar.

Figure 1.12

U.S. Electricity Generation by Source 1950–2022

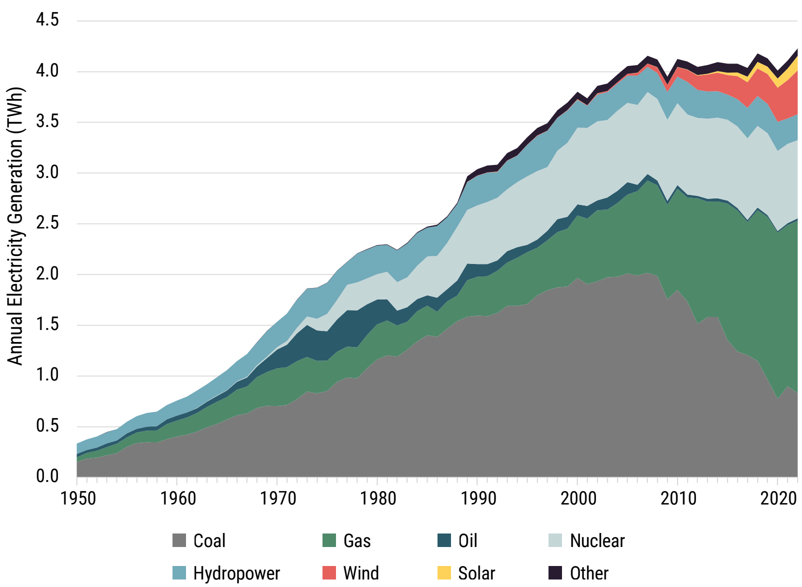


Figure 1.12 — U.S. Energy Information Administration, Monthly Energy Review, February and December 2023, and Bijou Insights

Figure 1.13

Global Electricity Generation: U.S. & Rest of the World (RoW)

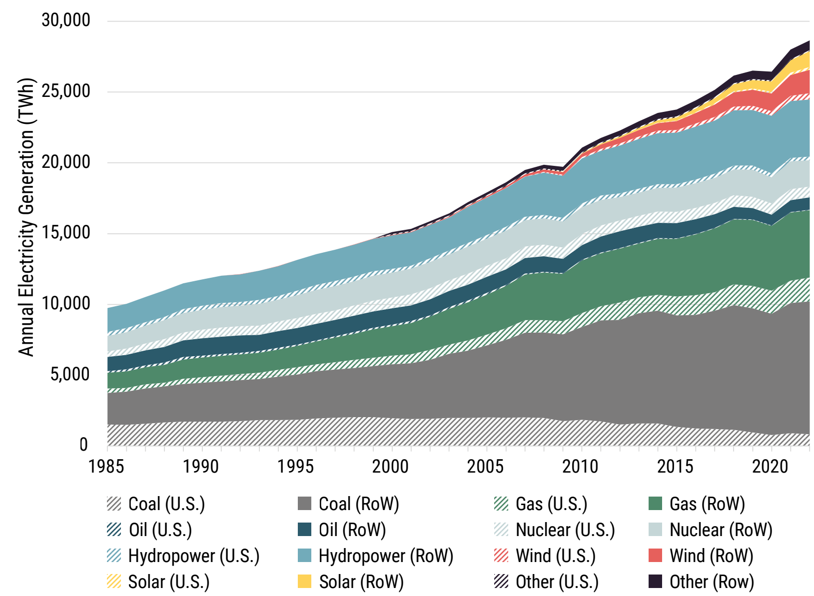


Figure 1.13 — Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute - Statistical Review of World Energy (2023), and Bijou Insights

CASE STUDY

Texas Electric Grid Reliability

In the 2022 edition of Bettering Human Lives, we profiled difficulties faced by Texas energy consumers who endured prolonged freezing temperatures and an unstable grid, which led to blackouts during Winter Storm Uri in February of 2021. Thankfully, the winter of 2022–23 did not produce a storm with the severity of Uri. However, as illustrated in Figure 1.14 the winter did produce four periods of minor cold and two periods of major cold weather that materially lifted demand for grid electricity. In each case, increases in dispatchable natural gas-fired generation acted as the shock absorber for wind generation, which declined in all six periods just when customer energy demand peaked during cold temperature periods. How valuable is an energy source that declines substantially when needed the most during demand peaks?

This dynamic was especially pronounced during Winter Storms Elliott and Mara, which could have been particularly dangerous had it not been for the reliability and flexibility of natural gas that proved itself again as the essential fuel for the protection of life and property during freezing conditions.

In the days leading up to Christmas in 2022, Winter Storm Elliott affected much of the central and eastern United States with temperature anomalies particularly wide along the Gulf Coast of Texas and the entire Midwest corridor. Power demand on December 23 exceeded the ERCOT day-ahead forecast by 9% and eclipsed prior summer daily peak loads. As power demand spiked, wind generation plummeted to its lowest level for the month with capacity utilization troughing at 3% at 7 P.M. on Christmas

Eve. In the void left by wind, natural gas met the power demand needs of ERCOT customers while concurrently meeting the highest priority for natural gas, the heating demands of residential and commercial customers who tripled their peak day use during the storm to keep people and properties warm.

Another bout of freezing weather visited Texas in late January and early February 2023. Unofficially named Winter Storm Mara, it spiked demand for electricity and heating, again demonstrating the critical role natural gas plays assuring reliable service to consumers during weather extremes. Unlike Winter Storm Elliott, solar output fell as grid load peaked. Similar to Winter Storm Elliott, wind output again faltered on high demand days during the worst of the freeze. On February 1, wind and solar combined to produce just 5% of ERCOT's electricity, while the share of ERCOT power provided by natural gas rose to 66%. Meanwhile, natural gas reliably met the even more critical heating needs of residential and commercial customers with deliveries of fuel that were 2.5x higher than pre-storm levels.

Figure 1.14
ERCOT Winter 2022–2023
Daily Average Power Demand vs Power Generation

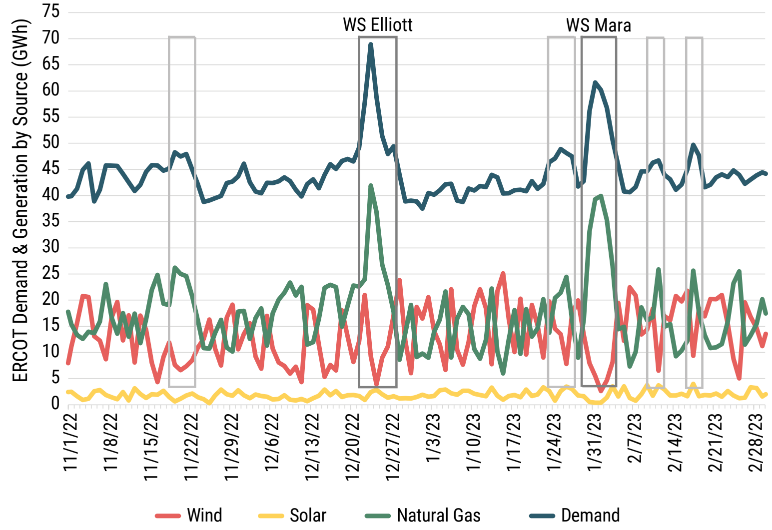


Figure 1.15
ERCOT Hourly Generation Dec 2022

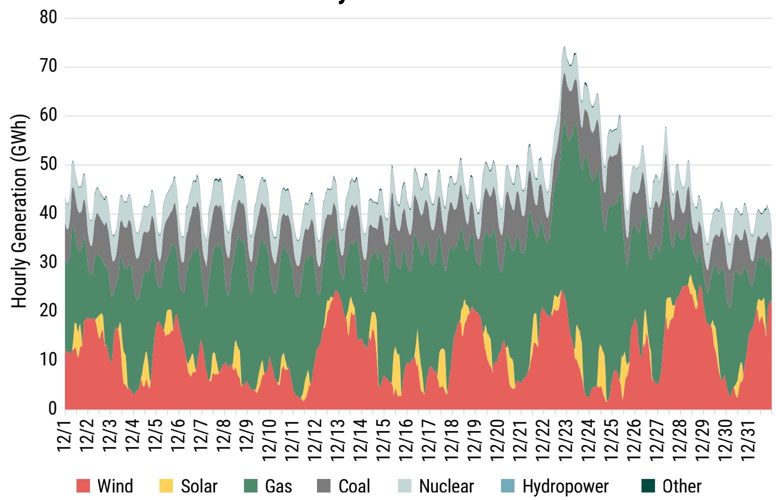


Figure 1.14, 1.15 — EIA Grid Monitor, Bijou Insights

Why is it so important to study power grid performance, especially during the winter months? According to the Institute for Health Metrics and Evaluation at the University of Washington, exposure to extreme temperatures is a risk factor attributed to 7,700 deaths per year (27 per 100,000) just in Texas. Of those 7,700 annual deaths from extreme temperatures in Texas, nearly 7,200 (93%) are attributed to exposure to cold temperatures. Heat exposure contributed to just over 500 deaths. Human exposure to cold kills considerably more than exposure to heat. It's true in Texas (14x), the U.S. (51x), and worldwide (5-10x). There is a growing political movement to push "climate" polices that incentivize and subsidize demand-side electrification for heating and cooking, and supply-side decarbonization of our generation fleet via wind and solar. The above examples show just how destructive and deadly such policies could prove if fully enacted.

Figure 1.16

ERCOT Hourly Generation Mid-Jan to Mid-Feb 2023

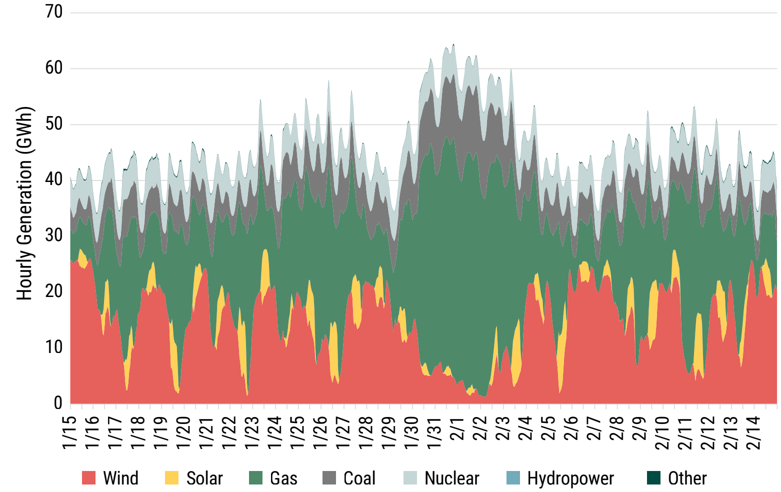
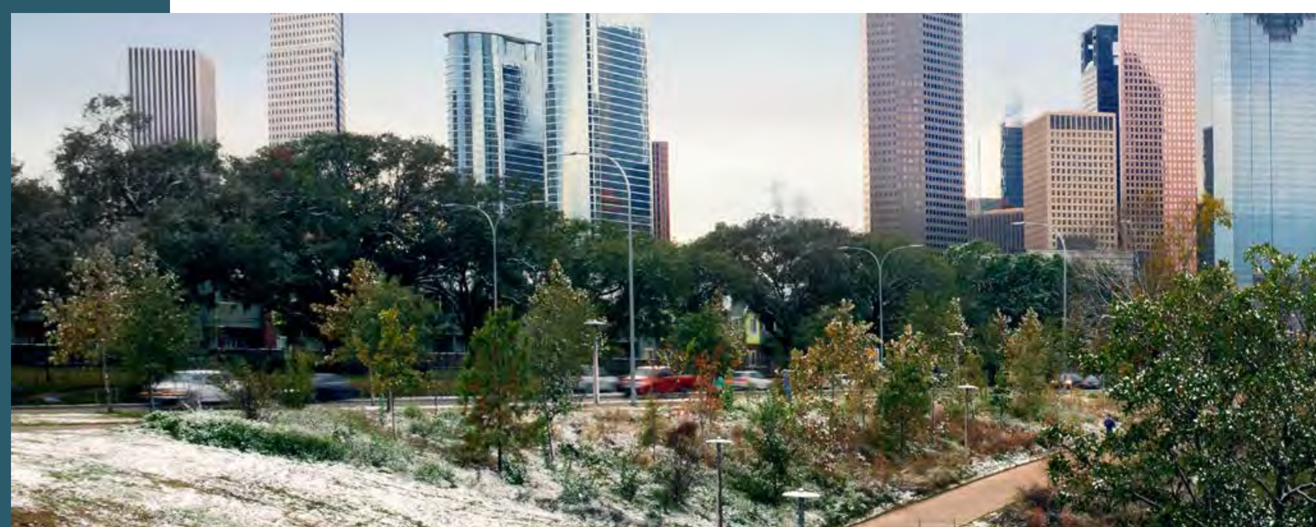


Figure 1.16 — EIA Grid Monitor, Bijou Insights



Energy Additions

The world needs far more energy if we are to better the lives of the less fortunate seven billion global residents who are aspiring to join the lucky one billion who today live highly energized lives. Clearly all those living with the drudgery of hand-washed clothes, dangerous cooking fuels, and unreliable, unaffordable electricity aspire to move up the energy ladder. Despite many setbacks and emerging threats, the world has grown economically and energetically over recent decades. Lives are improving. This section covers what energy sources are growing the total energy pie available to humanity.

In 2010 the world consumed roughly 507 exajoules of energy, rising to roughly 574 exajoules in 2022. Traditional biomass consumption dropped by seven exajoules during this 12-year period as two hundred million people gained access to clean cooking fuels and other substitutions. Traditional biomass, unfortunately, remains a very significant source of energy today (35 exajoules) — far higher than wind and solar combined.

What energy sources provided the extra 74 exajoules (67 growth in consumption plus replacing seven from biomass decline) of energy to expand and improve human life possibilities? Figure 1.17 shows the cumulative ***change*** in energy consumed, by source, annually from 2010 to 2022. You can see not only the total additional energy provided by each source over the last 12 years, but also the annual rate of new energy addition throughout the time period.

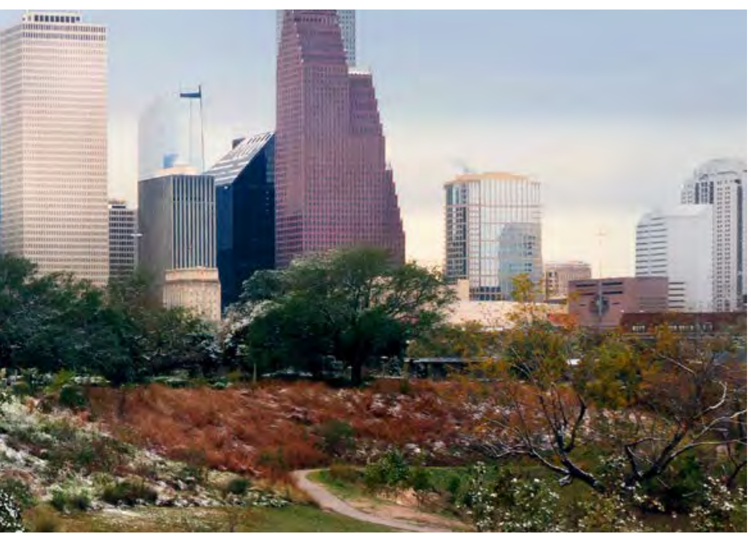


Figure 1.17

World Primary Energy Demand: Cumulative Change by Source

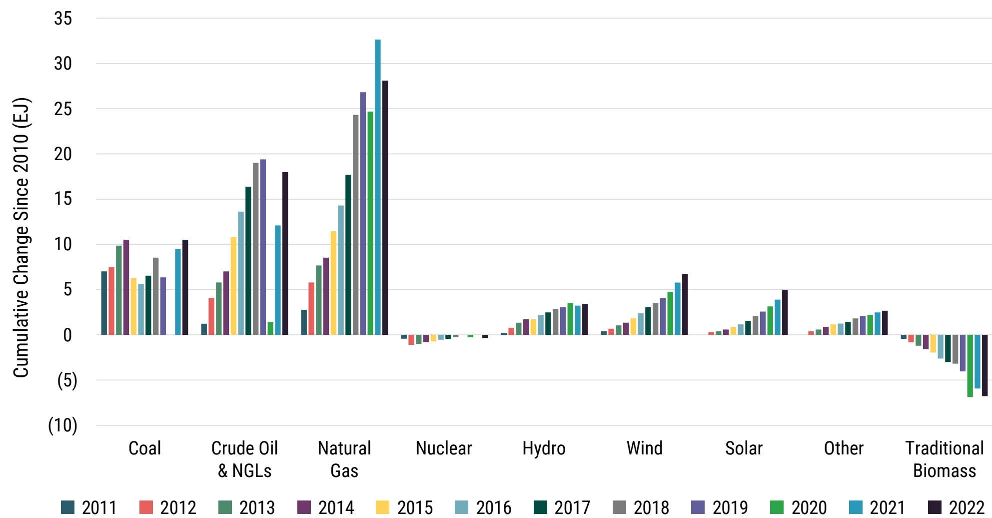


Figure 1.17 — Energy Institute - Statistical Review of World Energy (2023), Vaclav Smil & Bijou Insights

Natural gas has been by far the fastest-growing source of global energy over the last 12 years, providing 38% of the incremental energy added over that period. Oil is the next fastest-growing source, providing 24% of the energy addition even with the abrupt COVID-induced temporary decline in oil demand. Coal comes in third, providing 14% of the growth in energy consumption. Today, hydrocarbons provide over 80% of global energy and also provided 76% of the growth in energy consumption — the energy addition — over the last 12 years. This means that the hydrocarbon share of the total global energy pie has barely budged over the last 12 years.

Wind energy is growing rapidly in percentage terms, but growth in wind power supplied just over 9% of the additional energy consumed in 2022 versus 2010. Growth in solar provided just under 7% of the additional energy, and hydropower supplied about 4%. The growth from hydropower did not occur in the wealthy nations of the Organization for Economic Co-operation and Development (OECD), a club of 38 developed nations, founded in 1961. Hydropower grew in China, Latin America, and Africa. While each dam experiences annual variability in rainfall, water above a dam provides reliable electricity that can be ramped up or down to match demand variability or compensate for the weather-dependent intermittency of wind and solar power. The world has limited rivers suitable for hydropower, so capacity growth expectations may slow in the coming years.

Over the last 12 years, nuclear power has made no net growth contribution to energy demand, as there was roughly as much nuclear capacity retired as was added. The rise of exciting new technology for small modular reactors (SMRs) suggests nuclear energy will be a meaningful contributor to additional energy in the future. SMR technology should address many historical safety concerns and deftly navigate the government regulations limiting the construction of today's large, complex reactors.

The world needs vastly more energy to lift billions out of energy poverty. To achieve large-scale human betterment, we will need significant future energy additions from nuclear, hydropower, geothermal, and all other viable energy technologies.

Natural gas has been by far the fastest-growing source of global energy consumption over the last 12 years.

Figure 1.18

U.S. Energy Production: Cumulative Change by Source

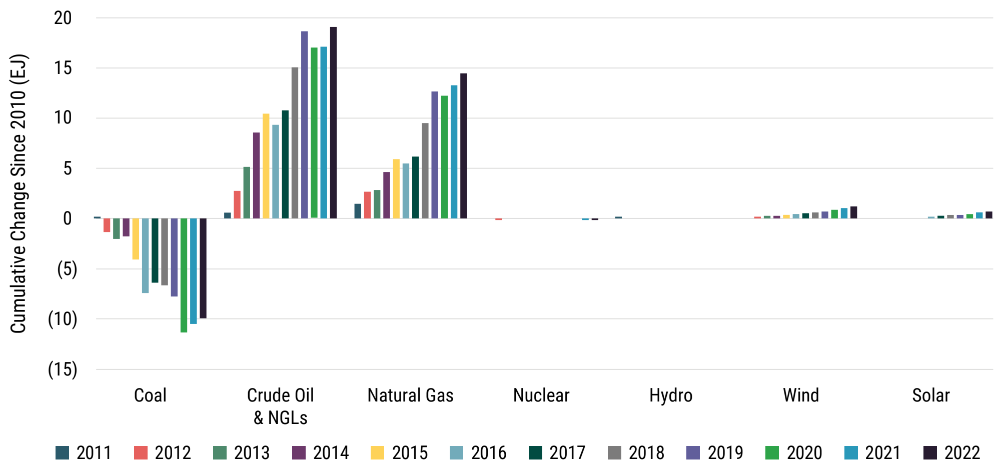


Figure 1.18 — Energy Institute - Statistical Review of World Energy (2023), Bijou Insights

A Closer Look at the U.S.

Figure 1.18 shows the energy addition data for the United States, which had very little growth in energy consumption from 2010 to 2022. However, it did have huge growth in energy production. Hence, Figure 1.18 shows the energy for the U.S. from an energy production perspective. The energy mix story is roughly the same here, with hydrocarbons providing over 80% of all energy addition, even though coal declined significantly. The relatively modest contributions from wind and solar can be seen along with a small decline from nuclear.

A Note on the EIA's Non-Thermal Multiplier

The reported energy quantities in this section are unadjusted. Earlier figures in this report from the EIA have a roughly 2.5x multiplier on electrical energy produced from non-thermal sources like wind, solar, and hydropower. The EIA makes this upward adjustment on non-thermal electrical production because thermal electricity production always involves lost energy in the form of waste heat. However, we take a broader view of the energy system and choose not to make context-specific adjustments. Electrical heating or cooking, or process heat, require a certain amount of thermal energy, whether it be from combustion or electrical matters. No adjustments make sense. Even in other electrical applications, we find the adjustments inappropriate, as electrical power requires precise matching of supply and demand at all times. Thermal electrical sources can provide this on-demand power, whereas wind and solar provide unpredictable, unreliable power. Hence, there is no direct equivalence between the two and we see no support for this 2.5x adjusting upwards of energy production from non-thermal sources. In either case, the central story remains unchanged with or without the adjustments.

CASE STUDY

ESG Incentives vs. Investment Realities

Given the political noise and stakeholder pressure that has influenced energy capital expenditure allocation on a global scale, it would be understandable if one assumed that global energy supply is experiencing a rapid transition to "carbon free" sources.

The political pressure has been intense. The Paris Climate Agreement was drafted in 2015 and signed on Earth Day in April of 2016. While the terms of the agreement were not binding on the parties, it gave increased license for political actors with anti-fossil fuel agendas to escalate pressure on energy producers and their capital providers to restrict capital spending on fossil fuels and accelerate capital spending (investment) on "carbon free" energy sources—namely wind and solar. Perhaps one indicator that illustrates the inflection in political activism is the attendance at the annual U.N.-sponsored climate Conference of Parties (COP). In the years leading up to the Paris Climate Agreement, COP attendance was relatively flat at approximately 10,000 and the tone of comments from then U.N. Secretary-General Ban Ki-moon did not make front page news. Contrast that to the opening remarks delivered at COP27 by U.N. Secretary-General Antonio Guterres, who spoke of a "climate hell highway" and fossil fuel companies "hijacking humanity," or the recent record attendance at COP28 of nearly 84,000. These pinnacles of rhetoric and attendance bookended a year during which leading academic research and the IPCC itself stated that its own most severe climate scenarios were highly improbable.

While energy producers are accustomed to political attacks, financial services companies were not as familiar with intense criticism of their commercial relationships with fossil fuel producers. Perhaps frustrated by their own inability to gather enough votes to pass climate legislation, members of Congress began writing public letters to CEOs of large asset management firms who control proxy voting decisions on behalf of investors and pensioners. The letters included demands that they cast votes for climate activist-sponsored shareholder proposals calling for banks to stop financing activities that supported fossil fuel development and for insurance companies to stop underwriting insurance policies for fossil fuel companies.

At the same time, climate activists dramatically increased their submission of climate-related shareholder proposals to financial services companies in North America and Europe from less than four per year during 2010-2021, to

15 in 2022 and 37 in 2023. Despite the political pressure applied, these proposals received very low levels of shareholder support, but added a nuisance for company management and a disincentive for some firms to maintain or seek new business with fossil fuel clients.

The formation of global coalitions such as the Glasgow Financial Alliance for Net Zero (GFANZ) has been potentially more damaging to efficient capital flows and allocation. Formed in 2021 and led by Michael Bloomberg and Mark Carney, GFANZ rapidly gathered signatories across the financial services sector to adopt business models aligned with the most aggressive (likely physically and socially impossible) net zero targets. Although there have been some who have already abandoned their membership in GFANZ due to anti-trust concerns, the organization currently spans 650 institutions across 50 countries representing 40% of global private assets.

Figure 1.19

Share of Global Energy Capital Expenditures & Primary Energy Mix by Source

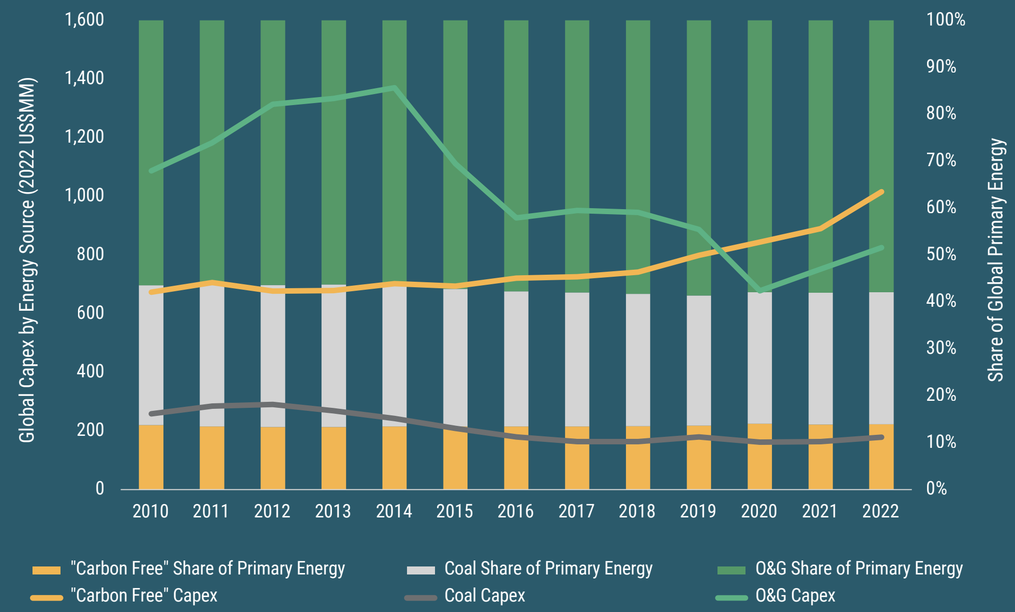


Figure 1.19 — IEA, Energy Institute - Statistical Review of World Energy (2023), EIA, Vaclav Smil, and Bijou Insights

These are just a few examples of the massive influence that a very small number of individuals have on the energy investment climate in which the business sector must traffic and on governments whose policies have followed their lead.

Since its peak in 2014, global capital expenditures for oil and natural gas projects declined by 40% while capital allocated to “carbon free” energy sources increased 45%. In fact, investments in “carbon free” energy sources have exceeded those for oil and natural gas in each of the past three years and are expected to do so again in 2023.

However, despite the material reduction of capital flowing to develop oil and natural gas assets since 2010, our industry was able to increase wellhead production by 51 exajoules per year, which boosted the share of primary energy supplied to the world from oil and natural gas by 1% to 58% — at the expense of coal. Meanwhile, over 50% of the world’s energy investments now flow to “carbon-free” energy projects, yet global production has increased just 14 exajoules since 2010 and its share of global primary energy supplied remains under 8%.

The impact from reduced equity, bond and bank debt capital into oil and gas is clearly going to be reduced production and, therefore, higher prices to consumers. It is laudable that oil and gas production still grew with less investment capital, but surely it would have grown a bit more and been a bit cheaper without the reduced investment levels. What does reduced investment mean to future oil and gas production levels? Exploration spending and success has dropped to alarmingly low levels. A lack of success in finding new oil and gas resources may not be felt for several years or even decades, but surely it will be felt eventually in the pocketbooks of consumers. It is dangerous to undermine the future of today's energy system until we have attractive replacements ready to go, which clearly, we do not today.

SECTION SUMMARY POINTS

- Energy is essential to life. The world is demanding more, not less, reliable energy.
- Global demand for oil, natural gas, and coal are all at record levels and rising — no energy transition has begun. Energy systems transform very slowly.
- Wind and solar are virtually one-dimensional in function and provide only modest amounts of total electricity generated which, in sum, provides only 20% of global energy consumption.
- We do not yet have the technologies to replace most uses of hydrocarbons. Nuclear appears to be the most viable option for growth in market share.

ENERGY & THE MODERN WORLD

Food & Hydrocarbons | Four Pillars of Civilization | Energy Security & Geopolitics | The American Shale Revolution

Energy & the Modern World

The surge in available energy has enabled the transformation in the human condition that is the modern world. This section highlights specific areas of transformation, starting with food production. Society was simpler and poorer when the majority of humans worked in food production, struggling to garner as many calories as possible to assure their survival. Energized food production freed most people from that drudgery to pursue jobs in manufacturing ever more complex goods, supplying a dizzying array of services to a wealthier populace, or participating in arts, entertainment, and more. Energy is liberating.

This section also covers the enormous scale of production in four basic materials that form the backbone of the modern world: cement, steel, plastics, and fertilizer. That's followed by longer subsections on the interplay between energy and geopolitics, and an overview of the biggest energy transformation of the last 50 years, the American Shale Revolution.

Food & Hydrocarbons

Food is the energy that powers the human machine. It is not optional. Food production, however, has transformed earth's ecosystems more than any other human activity. Roughly one-third of non-glaciated global land is utilized today for food production. Over the last century, the land devoted to food production has roughly doubled. However, the global population has increased four-fold while per capita calorie consumption increased by approximately 50% as billions have risen from near starvation diets.

In the United States, corn yields per acre have risen from two tons in 1920 to over 10 tons today. While this is impressive, the productivity increase per human labor unit is astounding. We can go back even further with wheat farming data. Two hundred years ago, it took 10 minutes of labor on an American farm to yield a kilogram of wheat. Today, it is less than two seconds! Why? A cascading series of innovations, materials, and machines made possible by the rise of hydrocarbons over the last two centuries.

Two centuries ago, over 80% of Americans were farmers and practices were not wildly different than those 2,000 years ago in ancient Egypt. The mechanical energy inputs came from humans and oxen. Thermal energy from wood produced metallurgical charcoal for smelting the iron in rudimentary farm equipment like plow plates, sickles, and scythes. With over 80% of Americans working on farms in the early 1800s, the rate of innovation was limited. A lack of energy, wealth, urban centers, and time for risky efforts that might or might not yield success left laborers stuck in inefficient farming practices.

The following century saw tremendous progress as rapidly rising coal consumption allowed steel production, which led to much-improved farm machinery such as larger plows pulled by teams of horses. Seed drills arrived, as did railroads and steam-powered locomotives that brought better tools, seeds, and access to markets at harvest time. Large steel silos allowed crop storage, giving farmers flexibility on when and where to transport their crops to market.

The 1900s brought further advancement to the agricultural industry through machinery and science. Diesel-powered tractors automated crop planting, harvesting, and processing. Farm seed quality, irrigation, farming practices, and hydrocarbon-enabled pesticides increased yield. And a globally significant breakthrough in chemistry introduced industrial-scale synthetic nitrogen fertilizer.

In the early 1900s German chemists Fritz Haber and Carl Bosch developed a process to use natural gas as both a source of hydrogen and for high-temperature process heat to produce nitrogen fertilizer on a massive scale. Before the Haber-Bosch process innovation, nitrogen content in soil was a major constraint on crop productivity. Existing nitrogen sources from bird guano, manure, and rotating cultivation of leguminous crops like peas, clover, and beans supplied only limited amounts of vitally needed nitrogen. It is hard to overstate the significance of the Haber-Bosch process to today's world. Elimination of natural gas-synthesized nitrogen fertilizer would cut global food production in half. There is no going back from hydrocarbon-enabled food production.

A well-functioning, well-supplied global liquefied natural gas (LNG) market is critical to the world's food production, as natural gas enables global nitrogen fertilizer production. At the end of the summer in 2021, global LNG demand began exceeding supply, unleashing a rapid escalation of LNG prices to reduce demand to match supply, which is inflexible in the short-term due to infrastructure constraints. Nitrogen fertilizer production was curtailed in many places that lacked domestic natural gas production, putting upward pressure on food prices. The rapid rise in LNG prices likely also impacted Russia's timing for the invasion of Ukraine, as the Russian government had maximum leverage when natural gas markets were in short supply. Global grain markets have seen elevated prices ever since, exacerbated further by the ongoing Russian invasion and war on Ukraine.

CASE STUDY

A Warning From Sri Lanka

In April 2021, Sri Lankan President Gotabaya Rajapaksa imposed a nationwide ban on the importation and use of natural gas-based, synthetic fertilizer and pesticides. This forced two million farmers to adapt to organic farming.

The results of these policies were devastating to humans and Sri Lanka's economy. Hungry and outraged citizens launched protests, forcing government officials to resign en masse and the president to flee the country. Nearly three years later, the ban has been reversed but Sri Lanka struggles to manage its hunger crisis and has been thrust further into political chaos.

The impact was rapid and brutal:

In the first six months of the ban, domestic rice production fell by
20%

Domestic rice prices — a staple of the national diet — surged by around
50%

Sri Lanka was forced to import
$450 million worth of rice

The ban also devastated the nation's tea crop, resulting in estimated economic losses of
$425 million

In 2022, Sri Lanka defaulted on
$40 billion in foreign debt

Four Pillars of Civilization

Skyscrapers, highways, dams, power plants, hospitals, airports, seaports, railroads, factories, and housing all rely critically on the "four pillars of civilization." Scientist and author Vaclav Smil coined this expression in his book *How the World Really Works*. Cement, steel, and plastics are central to nearly everything we build in the modern world, and fertilizer is responsible for half of all food grown today. All these pillars critically depend on the combustion of fossil fuels for process heat in their manufacture, and three of the four use hydrocarbon molecules as critical raw materials. Materials such as aluminum, wood, gypsum drywall, metal alloys, and silicon also rely on these essential products. The four pillars serve as the linchpins for every large-scale endeavor by enabling mining, production, processing, and distribution. They are crucial for any economic progress, whether in alleviating dire poverty or achieving a Western lifestyle.

In 2019, the world used a staggering 4.5 billion tons of cement, 1.8 billion tons of steel, 370 million tons of plastics, and 200 million tons of fertilizer. Global demand for these products is at an all-time high and continues to grow. Hydrocarbons are the only answer to producing enormous quantities of these materials.

01. Cement

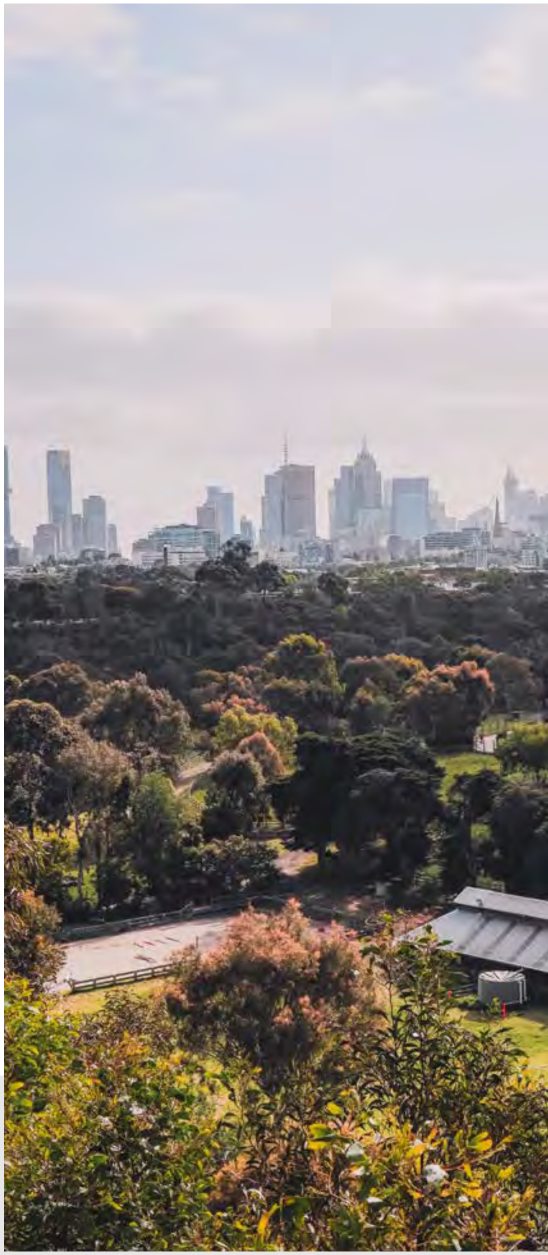
Cement is the key component of concrete, one of the most widely used materials in the modern world. While cement is the only pillar that does not employ feedstock from hydrocarbons, it does require enormous amounts of process heat from the combustion of coal dust, petroleum coke, and heavy fuel oil. Cement is the backbone of modern civilization, creating accessibility through roadways, bridges, tunnels, runways, and dams.

China produced more cement in 2020 and 2021 than the United States consumed in the entire 20th century. China's cement consumption has plateaued, but as large countries like India, Indonesia, Vietnam, and Nigeria develop, we can expect large increases in their cement usage — for the sake of bettering human lives. An example: Parasitic disease could drop nearly 80% if families in Asia and Africa could use concrete to replace mud flooring in their homes. Modernity is material intensive and universally sought.

02. Steel

Steel shapes the essence of modern civilization with robust, durable, and versatile qualities. From skyscrapers to surgical instruments, steel underlies both visible and unseen aspects of our world. Steel requires coking coal or natural gas as a carbon source to turn iron into steel, along with high-temperature process heat typically from natural gas or coal.

Steel alone accounts for 99% of metal consumption because its physical properties can be tailored to an endless array of applications. Steel is everywhere around you: jewelry, food packaging, refrigerators, railways, roads, cars, baby cribs, piano strings, oil pipelines and frac equipment. It is also 100% recyclable; today 90% of steel is recycled.



03. Plastics & Petrochemicals

Petrochemicals, like plastics, are custom-designed hydrocarbon chains tailored to highly specific applications. The building blocks of these wondrous materials are the organic molecules from natural gas or oil. Did you know 14% of worldwide oil demand and 8% of natural gas demand are used not for energy but as building blocks to make petrochemicals like plastics and pharmaceuticals? Petrochemical demand is growing faster than demand for oil or natural gas, representing between one-third and one-half of total projected future demand growth for oil and gas. Most all manufactured products today contain plastics, including two-thirds of global clothing fibers. Plastics and petrochemicals are most indispensable in health care: medical devices and machines, masks and gowns, flexible tubes delivering food or oxygen, sterile packaging, thermal blankets, and more.

04. Fertilizer

Rising crop yields from fertilizers have allowed the world to produce far more food on less land. Without petroleum-based fertilizers, we could not feed the world's eight billion people. Nitrogen fertilizer production typically utilizes natural gas for both high-temperature process heat and to source hydrogen atoms that are combined with nitrogen to make ammonia (NH_3). Hydrogen is the critical element that makes nitrogen chemically accessible for crop growth. Nitrogen accessibility is the limiting factor in crop yield. While air is over three-quarters nitrogen, the diatomic molecule (N_2) in air is not directly accessible by crops.

Phosphate and potassium (potash) are the other two major nutrient fertilizers that are mass produced via mining and chemical processing.

Can you think of anything today that does not directly contain or rely on one of the four pillars? These pillars are humanity's greatest fortune from hydrocarbons.

As demand continues to rise, there has been pressure for policies to reduce greenhouse gas emissions. Wealthy countries attempt to hit their emissions targets by displacing energy-intensive manufacturing. This has not changed the demand for these products. Instead, it has pushed energy-intensive manufacturing to lower-income countries with dirtier energy sectors. For example, China consumes 70 exajoules for manufacturing annually, compared to the United States' annual consumption of 20 exajoules. In only two years (2020 and 2021), China produced as much cement as the United States did in the entire 20th century.

Displaced manufacturing from the U.S. or Europe — where natural gas is the dominant industrial fuel — to Asia's coal-dominant manufacturing sector increases global greenhouse emissions, particulate matter and other global air pollutants. While this transfer has reduced the overall production cost of the four pillars and their countless derivatives, the global carbon footprint has increased. As Dr. Scott Tinker reminds us, there is only one atmosphere. Everything involves trade-offs.

Too often, the electricity (or power) sector is confused with the energy sector, of which electricity is only a modest subsector. Manufacturing — of everything, not just the four pillars — is the largest consumer of primary energy. Despite increasing efforts to electrify everything, less than 15% of energy used in manufacturing comes from electricity — the same fraction that it was 25 years ago. Let's celebrate advancements in electricity production but keep them in perspective as a modest piece of the global energy system.

Just under 20% of global primary energy is used to produce these four essential materials, roughly the same amount of energy provided globally by electricity!

Wind turbines are highly visible embodiments of hydrocarbons; they require enormous amounts of concrete, steel, and plastic. The bases that anchor the turbines are made of steel-reinforced concrete. The towers, nacelles, and rotors contain nearly 200 tons of steel per megawatt of capacity. A mid-size turbine blade uses 15 tons of energy-intensive plastic resins.

Silicon deserves an honorable mention as a pillar of the modern world due to its ubiquitous role in modern computing, communications, and consumer devices. Silicon's impact has been tremendously life-enhancing, but it merits only an honorable mention as everything silicon has brought depends entirely on the four pillars. Silicon is a derivative material of the four pillars, not a pillar itself.

Energy Security & Geopolitics

The intimate link between energy security and national security has been underappreciated in recent years. This all changed when Russia invaded Ukraine on February 24, 2022. Russia's invasion did not cause today's energy crisis. It's more the reverse: Today's energy crisis is likely a critical factor in the timing of Russia's invasion. Over the last 20 years, Europe has significantly reduced its hydrocarbon production, becoming ever more dependent on imported energy, primarily from Russia. Europe has invested massively in wind, solar, and biofuel energy to reduce GHG emissions. These energy sources are far more capital-intensive and lower in energy density and reliability. Europe was in the unenviable position of heavy reliance on Russia for natural gas, oil, and coal. Today, the United States has played a major part in filling the gap as Europe decreased (but not ceased) natural gas imports from Russia. Europe's energy pivot over the past 20 years appears to be a failure. It has delivered significantly higher energy costs, grave energy insecurity, and relatively modest GHG emissions reductions after factoring in the impact of Europe outsourcing manufacturing emissions to more coal-dependent regions. The European and UK Case Study (covered later in this report) provides more detail on this story.

A glance back to the history of energy and geopolitics is warranted.

The Netherlands and England led the rise of modern liberal democracy, the rule of law, free markets, free trade, and the tremendous growth of human liberty over the last several centuries. Perhaps the most critical driver of their rapid rise was substantial advantages in energy supply. The Dutch were famous for their thousands of windmills used to pump water and grind grain in the early 1600s. But windmills do not provide process heat to smelt metals, blow glass, make bricks, or refine sugar. Peat, an immature hydrocarbon produced from partially decayed plant matter, was the key energy source that enabled the rise of a small coastal nation into a worldwide leader in agricultural productivity, early manufacturing industries, and global trade. Peat made the Netherlands the most energized nation on earth and the wealthiest per capita. Peat supplied 20-100 times more energy than windmills in the Dutch Golden Age.

Unfortunately for the Netherlands, England had coal — an emerging source of energy that was far more extensive, energy-dense, and easier to transport. Pre-industrial societies had limited supplies of energy. Forests were rapidly exhausted, and everything else depended on highly variable annual crop yields. Reliable access to affordable energy in quantity has always been the primary constraint on improving the human condition. Coal transformed England and began the emergence of the modern world.

The rise of coal in England began long ago, playing a significant role even during Shakespeare's time. Coal is estimated to have provided half of England's energy before 1700, principally as thermal energy for heating, cooking, forging metal, and other process heat manufacturing uses. In the 1700s, the invention of steam engines displaced the historical constraint of mechanical energy only coming from humans and animals (horse and oxen) plus some from water wheels. Without the ability to transform thermal energy into mechanical energy with steam engines, most everyone reading this report would still be a farmer or agricultural worker.

The rise of the world as we enjoy it today resulted from more abundant and higher quality energy sources supporting modern transportation, manufacturing, communications, education, healthcare, computing, travel, leisure, and more. None of today's industries could exist in recognizable form without the energy and materials from hydrocarbons, including electricity production from hydropower, nuclear, wind, and solar. Energy supply is critical to all modern warfare — as was food and fodder in pre-modern wars — and has often been the origin of violent and deadly conflicts.

The immense rise in global trade in the 20th century brought economic benefits from harnessing different countries' comparative advantages. A relatively peaceful post-WWII order enabled the rapid spread of industrialization via foreign direct investment, global trade agreements, and capital flows. Rising geopolitical tensions over the last decade (at least) are unfortunately exposing the fragility of today's global economic order.

Today over 100 countries across every inhabited continent produce oil and natural gas. Global markets have generally been well-supplied and, importantly, the inflation-adjusted cost of oil over the last five years has been roughly equal to its average since the industry began in 1860. As the world gets wealthier, the share of total income needed for energy costs has been in long-term decline, a positive trend for human well-being. Unfortunately, we appear to be getting off-track recently.

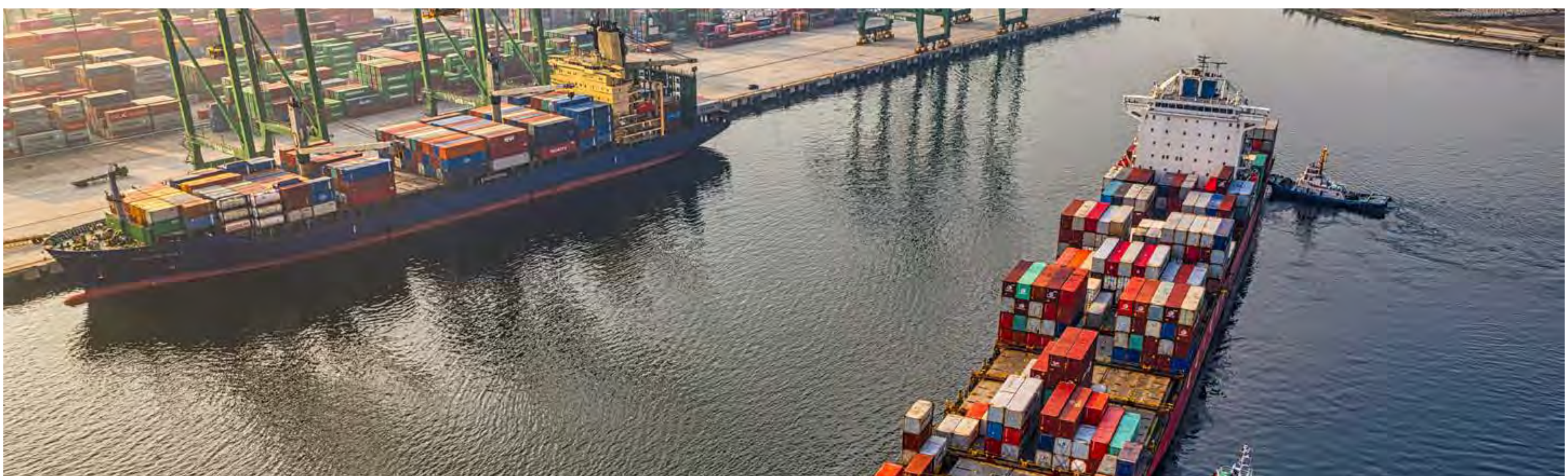
The world energy system requires meaningful spare capacity to handle inevitable bumps in the road. The last several years have seen this capacity whittled away for multiple reasons. Insufficient energy investment has partly resulted from recent low investment returns due to low commodity prices — in response to surging oil and gas production from U.S. shale. Excess energy production capacity has also shrunk due

to regulatory blockage of critical energy infrastructure such as pipelines, import terminals, and export terminals. In the U.S., roadblocks for well permitting and leasing on federal lands, low public energy literacy, and ill-informed climate alarmism are stymieing hydrocarbon development. Further constraining investment capital is an over-reaching regulatory framework, including some elements of the corporate Environment, Social and Governance (ESG) movement, that has been myopic in environmental concerns regarding hydrocarbons' negative climate impacts without an accompanying appreciation of their necessity for human well-being. The net result is a constrained supply of oil, natural gas, and coal — which means higher prices and a greater risk of market dislocations. High energy and food price inflation is the cruelest form of tax on the poor.

Unbalanced and unrealistic views of hydrocarbons are driving up the cost of energy for the global population and contributing to geopolitical instability. This was most evident by the rapid rise in energy and food prices that accompanied Russia's invasion of Ukraine. If the world economy continues to grow and we see increased movement from coal to natural gas in middle income nations, we risk another crunch in LNG export capacity. This would come amid an ever-growing demand for natural-gas-generated electricity, home heating, petrochemicals, industrial process heat and raw materials, and most alarmingly, nitrogen fertilizer production.

Should the current war in Israel expand to include Iran directly, as opposed to only supporting militant proxy groups, global oil supplies would be at risk. A loss of Iranian oil exports would significantly escalate global oil prices and the myriad products that flow from oil. Disruptions to the Strait of Hormuz or the Bab al-Mandeb Strait would also threaten flow of oil and natural gas. Hydrocarbon-dominated energy is not just a sector of the economy, it is the sector that enables every other sector.

Now is a time for reflecting on how we got here, how we can rebuild, and how to avoid these costly mistakes in the future. It is not clear how all this will play out in the coming years. It is clear, however, that elevated and uncertain energy and food prices are a real and present danger to the world order.



CASE STUDY

Germany

Germany has been the world's frontrunner in government-forced energy transitions. Over the past two decades, Germany has dramatically cut dispatchable electricity sources by reducing coal and eliminating nuclear power. Solar energy now accounts for 10% of electricity capacity, while wind accounts for approximately 30%. These "renewable" energy sources are not only unreliable, but their large grid penetration has resulted in the highest electricity prices for consumers in the developed world.

Several side effects stem from this government policy:

Between 2002 and 2022, total installed electric power capacity has grown from 115 GW to 222 GW, an increase of 93%. However, the percentage of reliable (nuclear and hydrocarbon) power generation capacity has decreased from 84% to 39%. Coal remained Germany's largest source of electricity in 2022.

While almost all of that 110 GW addition was solar and wind, total electricity production in Germany declined by about 15%. This large increase in capacity with a reduction in electricity production explains why electricity prices in Germany are so much higher than before and are about three times higher than average prices in the United States.

The risk of power outages during times of extremely low wind and low solar power generation, a so called "Dunkelflaute," has increased significantly. To maintain reliability over winter months, Germany has become more dependent on imports and has reactivated its domestic lignite-fired power generation — a higher-emission source per unit energy than standard coal.

German per capita CO_2 emissions were reduced by 28%, but this was mostly due to lower overall energy use (-17%). Higher energy prices consistently lead to reduced industrial activity and consumers rationing usage due to affordability.

U.S. per capita CO_2 emissions have decreased by roughly the same amount as Germany due to a switch from coal to natural gas in electricity generation. This change was not accompanied by significant electricity cost increases, except in states with high wind and solar penetration.

German primary energy from hydrocarbons dropped from 80% to 74% as a result of 20 years of huge investment in renewables. Is this an "energy transition"?

Germany used to be Europe's manufacturing hotspot, but high energy prices and expensive energy feedstocks have resulted in a nosedive in German industrial production as many manufacturers moved to more coal intensive countries. Most recently, BASF announced expansion plans in China, and German car manufacturing has also fallen.

The American Shale Revolution

Relative to impacts on energy supply, energy prices, and a country's geopolitical position, the U.S. Shale Revolution is the most transformational event ever executed by a broad collection of private-sector participants. Without change in government incentives or subsidies, the innovative paths of horizontal drilling and multistage fracturing technologies intersected in the early 2000s and unlocked massive domestic energy supplies on a globally unprecedented scale and pace (Figure 2.1).

Over the last 20 years the U.S. Shale Revolution has created over 20 times as much new energy than the entire U.S. wind and solar sector, and nearly five times as much as global wind and solar. The incremental energy supplied by U.S. shale oil and natural gas since 2000 would be sufficient to supply the cumulative 2022 primary energy needs of 2.8 billion people spanning India, Pakistan, and all the countries of Eastern, Western, and Middle Africa.

The rapid increase in domestic supplies of oil and natural gas from shale coupled with the freedom to export both dramatically altered long-standing geopolitical relationships and the flow of global energy commodities. Oil produced from U.S. shale formations is generally light in gravity with relatively few impurities, making it a highly desired barrel for refineries to blend with lower-quality crudes to produce optimal mixes of petroleum products around the world. Concurrently, the export of U.S. natural gas and natural gas liquids (namely, LPG/propane) are ably filling the void of Russian natural gas previously delivered to Europe. U.S. exports of propane are surging and enabling improvement in respiratory health and liberation of women and children in developing countries by displacing the burning of wood, charcoal, dried dung, and other biomass in open fires used for daily cooking and nighttime heating. The U.S. has rapidly transformed from the world's largest importer of natural gas to the world's largest exporter. For oil and petroleum products, the U.S. has transitioned from the largest importer to a net exporter.

The fiscal benefits of the Shale Revolution are substantial. In 2020, researchers at the Dallas Federal Reserve estimated that increased supply from U.S. shale oil had acted to lower oil price volatility by 25% and reduced 2018 global benchmark oil prices by 36% or $47/bbl (2022 dollars). The estimated reduction in oil prices saved nearly $1.7 trillion for consumers worldwide in 2018 alone. The U.S. share of avoided energy costs was $333 billion, or $3,000 per U.S. family.

Apart from lower global benchmark prices, being proximate to the surge in supply from shale has uniquely benefited the U.S. consumer through lower regional prices. Domestic regional prices for oil reversed long-term price relationships and now consistently trade below international prices, while U.S. natural gas prices have widened their cost advantage relative to international prices in the post-shale era. Since 2010, relatively stable and lower regional energy costs for U.S. households and businesses translated to savings of nearly $41 billion per year for petroleum expenditures and $197 billion per year for natural gas expenditures relative to global peers — yielding an additional average U.S. energy cost savings of $1,850 per U.S. family annually (Figure 2.2).

Figure 2.1
Global and U.S. Energy Production

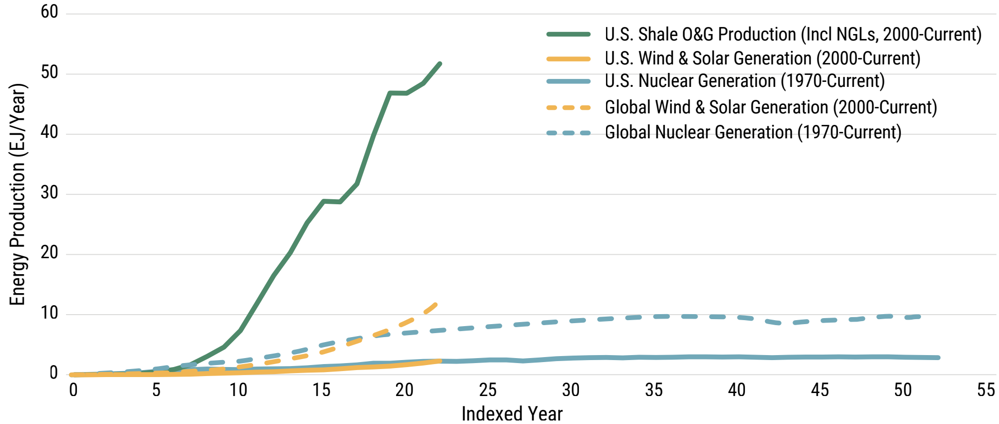


Figure 2.1 — Bijou Insights analysis of data from Energy Institute Statistical Review of World Energy 2023, EIA

Figure 2.2
U.S. Energy Costs Savings vs. Int'l Prices

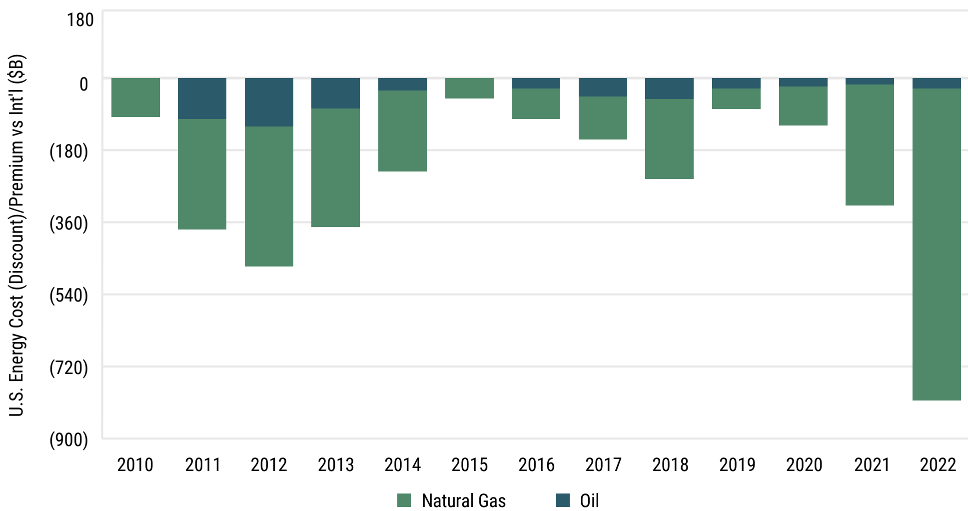


Figure 2.2 — Bijou Insights analysis of data from Energy Institute Statistical Review of World Energy 2023

Energy produced from U.S. shale is equivalent to 58% of U.S. primary energy demand and nearly 10% of global primary energy demand.

In addition to the direct consumer benefits, the U.S. rapidly shifted from an energy net trade deficit to a net trade surplus as the Shale Revolution gained momentum in the 2010s (Figure 2.3). Between 2008 and 2022, the U.S. energy trade balance improved by nearly $500 billion, or approximately $1,600 per person, while drastically reducing our reliance on exporting countries that have materially lower human rights standards and other factors valued by ESG activists and investors. All three figures illustrate the dramatic geopolitical and economic benefits realized by the United States from the Shale Revolution. However, the benefits expand to include public health and a healthy environment.

Are all the benefits provided by scalable, affordable shale oil and natural gas coming at a steep environmental cost? No. Since the Shale Revolution began, U.S. air quality continued to improve based on measured levels of six common air pollutants ($PM_{2.5}$ and PM_{10}, SO_2, NO_x, VOCs, CO and Pb) regulated by the EPA and, ironically, some of the most frequent pollutants anti-fossil fuel activists claim are exacerbated by oil and gas operations (Figure 2.4). Beyond immediately harmful pollutant reductions, U.S. per capita emissions of the most important greenhouse gas, carbon dioxide (CO_2), also began to drop concurrently with the advent of the Shale Revolution. Greenhouse gas emission reductions are largely thanks to shale gas displacing coal as the largest source of U.S. electricity production.

Figure 2.3

Shale Revolution Delivers American Energy Trade Surplus

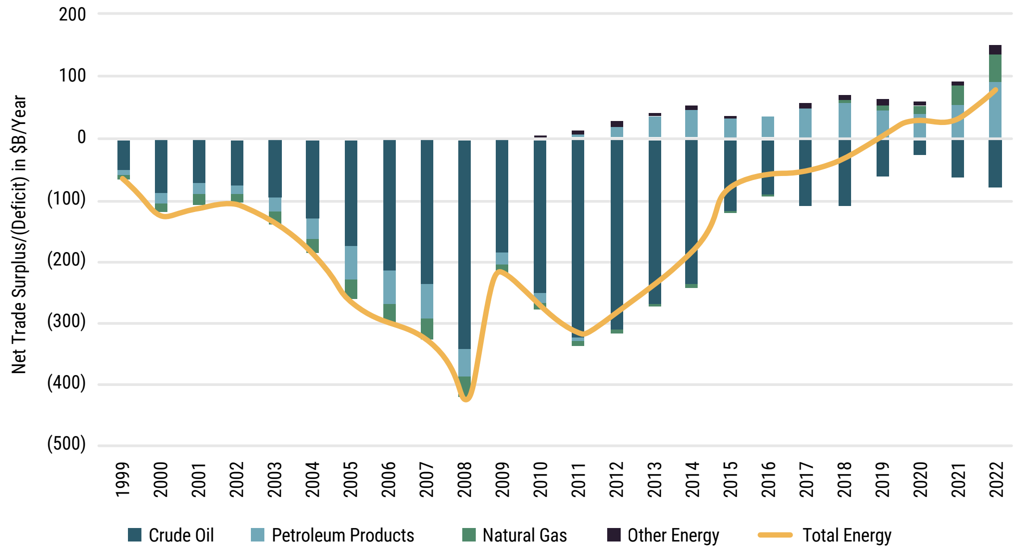


Figure 2.3 — Bijou Insights analysis based on data from the U.S. Bureau of Economic Analysis, IDS-0182, U.S. Trade in Goods.

Figure 2.4

Comparison of U.S. Air Pollution Declines vs. Economic Growth (per Capita)

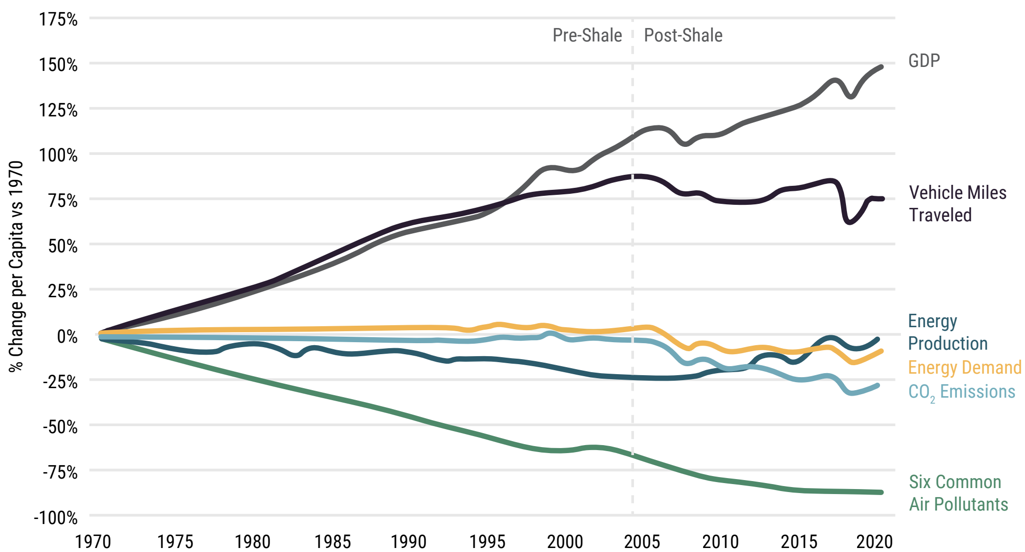
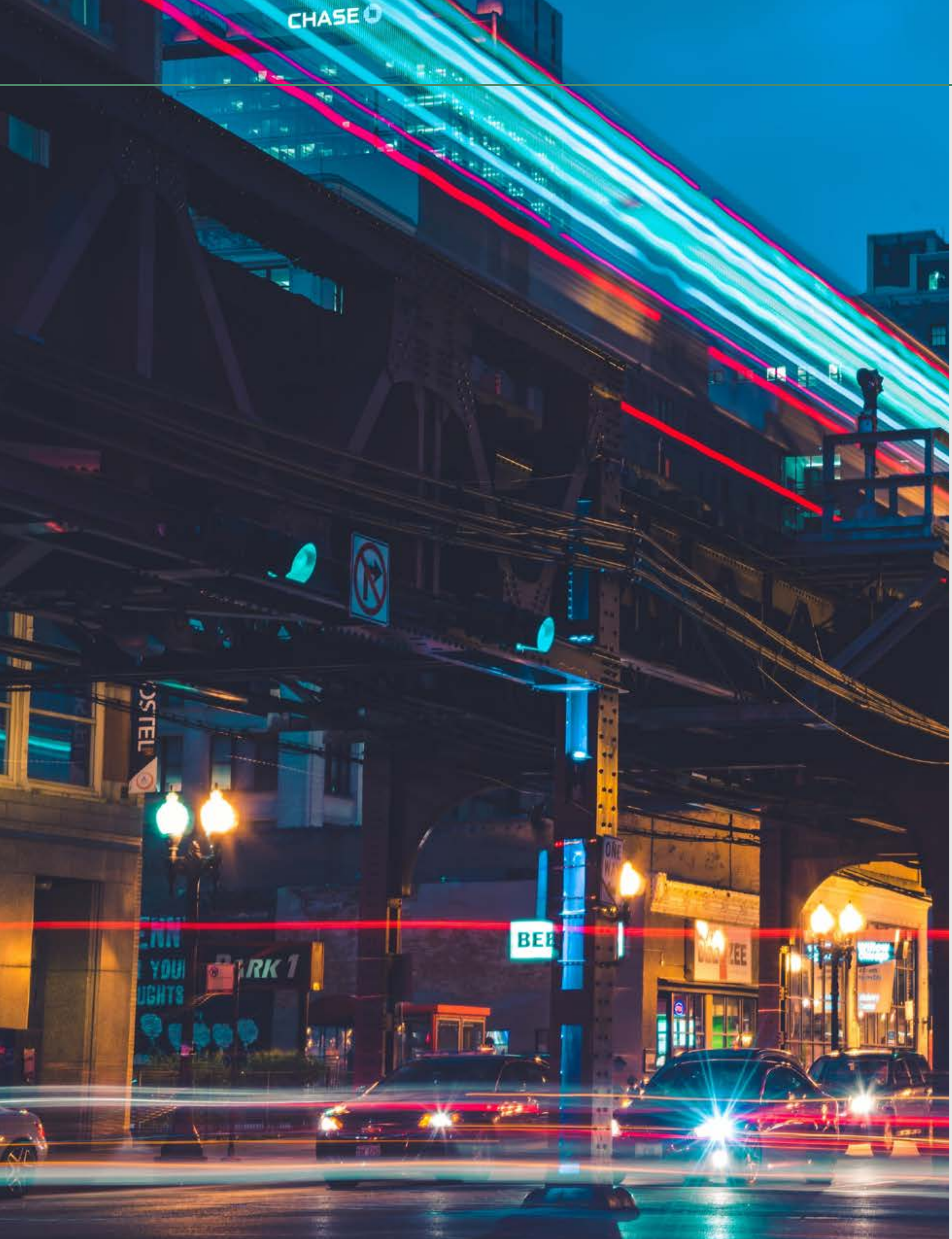


Figure 2.4 — U.S. per Capita Air Pollution and Various Growth Metrics. Data from the EPA and EIA & Bijou Insights



SECTION SUMMARY POINTS

- Coal, oil, and natural gas enabled the rise of the modern world. These hydrocarbons helped double human life expectancy and enabled most of humanity to rise from dire poverty.
- Hydrocarbons supply more than 80% of global energy. They offer unmatched flexibility, meeting the diverse needs of manufacturing, transportation, electricity, heating, and cooking while providing essential raw materials that enable the modern world, especially cement, steel, plastics, and fertilizer.
- The American Shale Revolution transformed energy markets, energy security, and geopolitics. It shifted the U.S. from the world's largest importer of oil (and petroleum products) to a net exporter. For many years, the U.S. was also the world's largest importer of natural gas and is now the world's largest exporter.
- Inflated energy costs around the world — driven by political and environmental initiatives — lead to deindustrialization and stagnating living standards. These societies are becoming increasingly dependent on energy imports, resulting in economic and geopolitical risks.

ENERGY POVERTY

Energy Access: Clean Cooking | Energy Access: Electricity | The Human Impact of Energy | The Future of Energy Access

Energy Poverty

It is too easy to forget that only about one-eighth, the lucky one billion, of the world's population lives in conditions like those enjoyed by most readers of this report. Our energy policies, climate policies, conventional wisdom, and the agendas of green activists typically focus on that top one-eighth — neglecting the realities of life for the remaining 85%.

The most urgent need is broadening energy access, particularly energy that is of high quality and clean at the point of consumption. Today, over 2.3 billion people remain hostage to the daily gathering of fuels and the tending of open-hearth fires to heat their homes and cook for their families. This degree of severe energy poverty is difficult to grasp for the 1.5 billion of us who consume nearly two-thirds of the world's energy. We at Liberty Energy are committed to the liberation of these underserved individuals, households, and economies by unlocking new supplies of modern energy that are scalable, reliable, and affordable.

To improve lives and accelerate economic development, families and societies must dramatically increase their energy consumption. There is simply no other pathway toward growth and prosperity. The surging availability of reliable, affordable energy enabled the modern world and all that followed in our highly energized society. Bringing these liberating, energy-rich living conditions to more people depends on keeping energy costs low. Alternatively, if energy costs are high and rising, this will result in slower or stagnating economic progress.

Figure 3.1

The Range of Living Conditions Among the World's Population

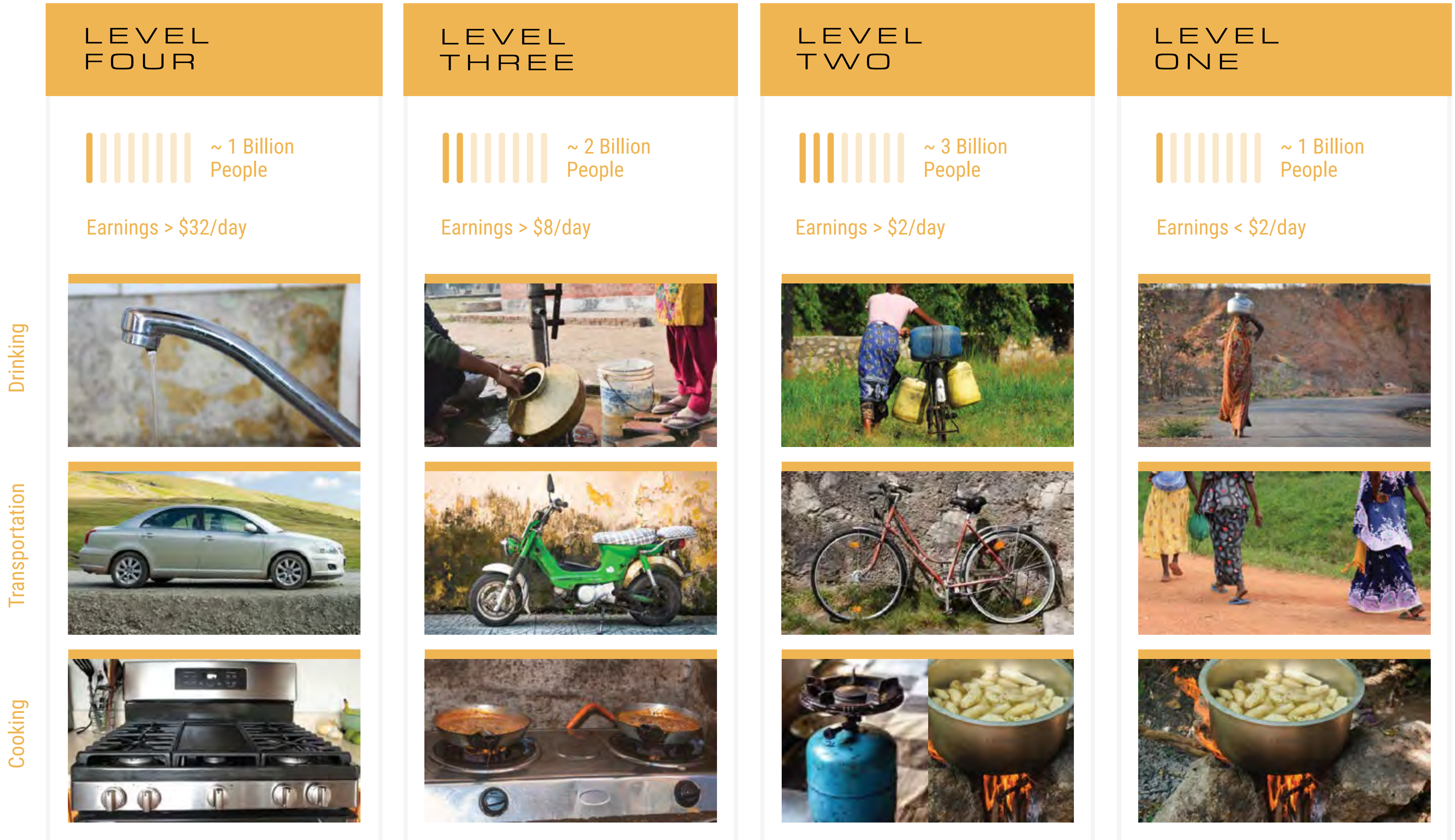


Figure 3.1 — Rosling, Hans, et al. Factfulness. Rizzoli, 2018.

Energy Access: Clean Cooking

The United Nations urges that "slow progress towards clean cooking solutions means that the health of 2.3 billion people is at risk." That's almost one-third of humanity who still lack access to clean cooking fuel, including 82% in Sub-Saharan Africa and nearly 30% of Indians. India has made rapid recent progress in clean cooking fuel access. Yet still over two billion people cook their daily meals and heat their homes with traditional fuels — typically wood, dung, agricultural waste, or charcoal — often on open fires. Burning these fuels results in low-temperature combustion and high levels of smoke and fine particulate matter, or $PM_{2.5}$, one of the world's deadliest pollutants. It is believed that about three million people die every year from the resulting indoor pollution. The World Health Organization (WHO) also estimates that outdoor air pollution — primarily from $PM_{2.5}$ created by the same biomass fires in domestic homes — causes several million additional deaths.

Figure 3.2

People in the World With & Without Access to Clean Cooking 2000–2021

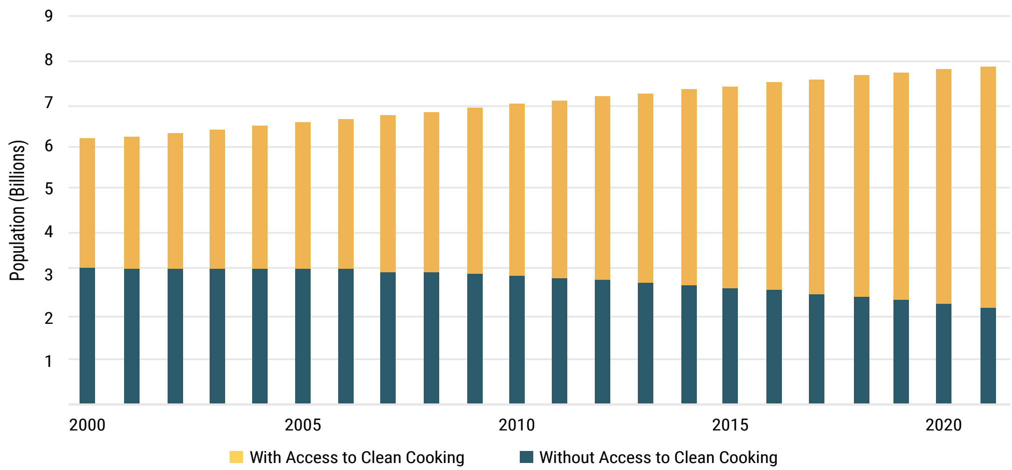


Figure 3.2 — World Bank, United Nations Sustainable Development Goals Report, 2022

Women in energy poverty spend more than an hour each day gathering wood for fuel to cook and an additional hour per day sourcing water.

Figure 3.3

Percent of Population with Access to Clean Cooking Systems

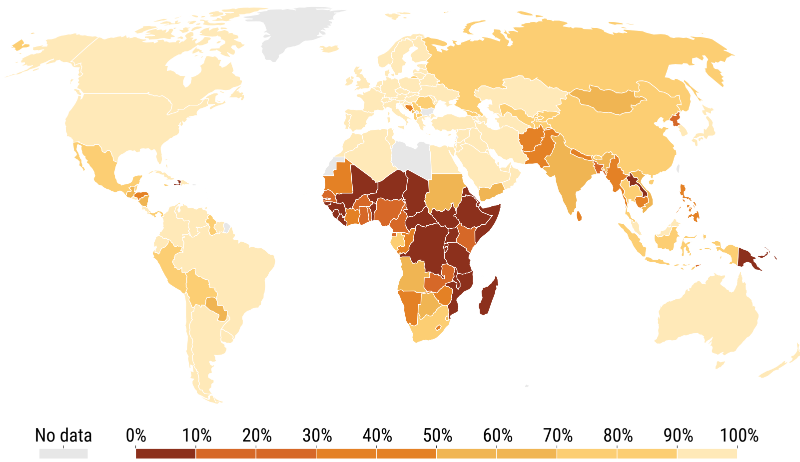


Figure 3.3 — World Bank, United Nations Sustainable Development Goals Report, 2022

Figure 3.4

Global Population-Weighted $PM_{2.5}$ Concentrations, 2019

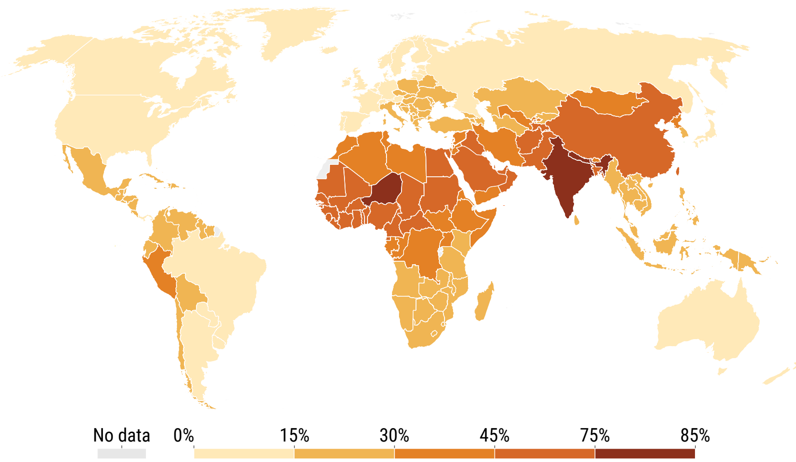


Figure 3.4 — State of Global Air, 2022

Figure 3.4 shows a global map of outdoor $PM_{2.5}$ pollution. This problem is worst in Africa, south and southeast Asia, and China, places where energy poverty drives the indoor air pollution crisis. A crucial step in decreasing outdoor and indoor $PM_{2.5}$ levels is offering a clean alternative to traditional solid fuels. Fortunately, providing access to a basic gas stove and viable fuel substitutes like Liquid Petroleum Gas (LPG), natural gas, and electricity, can prevent the staggering loss of human life and potential currently being experienced across the globe.

Liquid Petroleum Gas (LPG), mostly propane, has proven to be a transformational clean cooking fuel source for populations in developed and developing countries worldwide. Since the advent of U.S. shale development in 2010, the WHO estimates that nearly 700 million people have moved away from dirty cooking and heating fuels such as biomass and charcoal — with Africa being the lone region where the use of dirty household fuels has increased. Concurrently, annual deaths attributed to household air pollution decreased from 3.0 million to 2.3 million — great progress but still a horrific level of preventable deaths on par with the annual death toll due to COVID-19 since early 2020.

High income countries have used high-quality energy technologies to create clean living spaces, clean air, and food and water supplies that are free of pathogens and other pollutants. But in the poorer parts of the world $PM_{2.5}$ pollution, malnutrition, preventable disease, and lack of access to drinking water collectively cause over 10 million premature deaths each year. Affordable, reliable, modern energy is the key to solving these long-standing problems.

Residential LPG delivery in Fes, Morocco

The Toll of Household Air Pollution

In Kenya, using biomass from wood for energy is common, accounting for 65% of the total primary energy supplies. It is estimated that about 80% of Kenyan households depend on firewood for cooking and heating and that up to 95% of the energy consumed in rural areas is in the form of wood, agricultural residue, and animal waste.

Women are disproportionately impacted, as they are the primary gatherers and users of biomass fuels. Children living in households using solid fuel are 2-3x more likely to suffer from acute respiratory infections than children staying in households using clean energy.

The Kenyan Ministry of Health estimates that **21,500 premature deaths occur yearly** because of air pollution due to cooking and that acute lower respiratory infections are responsible for the second largest cause of death, accounting for 26% of all deaths reported in Kenyan hospitals.

Figure 3.5

Primary Fuels Used by Households in Kenya

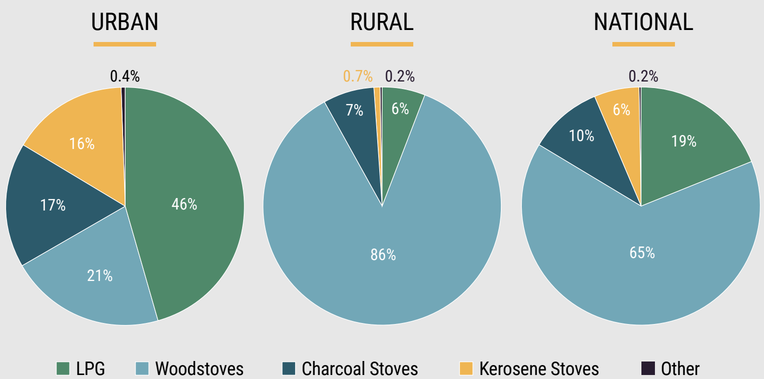


Figure 3.5 – Kenya Ministry of Energy, 2019, Shilenje, Zablon Weku, et al. "A Review on Household Air Pollution and Biomass Use over Kenya." Frontiers, Frontiers, 19 Oct. 2022, www.frontiersin.org/articles/10.3389/fenvs.2022.996038/full.

Introduction to Bettering Human Lives Foundation

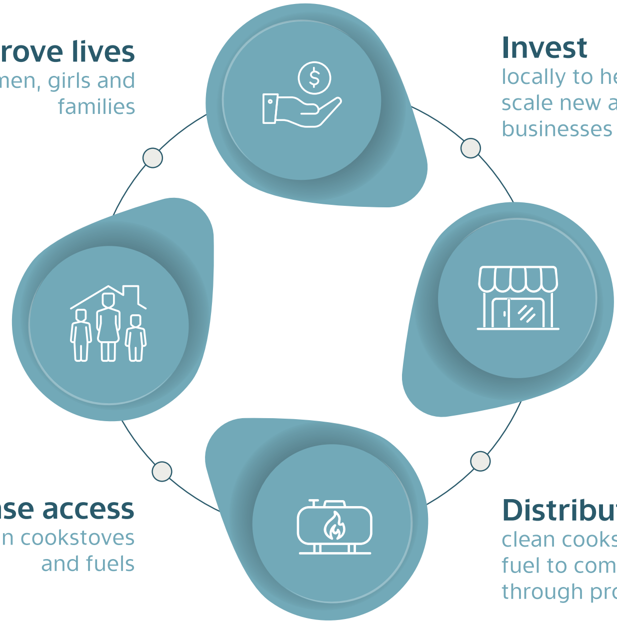
A letter from Executive Director, Anne Hyre

Despite significant cultural and geographical differences among countries in Sub-Saharan Africa, the scenes outside the window, as I drive from town to town, are remarkably similar, and all include women and girls standing in lines at water pumps, walking in groups in search of firewood and cow dung, and carrying heavy loads of firewood and water-filled buckets. Whether in Malawi, Burkina Faso, Ethiopia, or Kenya, I pass clusters of homes and see women cooking amidst harmful smoke from open fires fueled by wood or cow dung. How is this acceptable in the year 2024? I feel so disheartened that the daily lives of women and girls in many lower-income countries continue to be filled with the tedious, physically demanding, and often dangerous tasks of collecting fuel and water for cooking, cleaning, laundry, and heating homes.

I am a nurse-midwife, and I have spent the past 30 years working to improve poor quality health services for women during pregnancy, childbirth, and the postpartum period. For 25 years, I worked primarily in Southeast Asia, where access to energy and sustained economic growth contributed to visible progress in improving health and quality of life. For the past five years, my work has shifted to Sub-Saharan Africa, and I have encountered a very different reality. Governments and donors have made huge investments in health over decades, and yet most countries in Sub-Saharan Africa remain far from reaching global targets for development in any social sector, including maternal and newborn health. I continually ask myself, "How can a woman possibly enjoy a healthy pregnancy, access health services, and demand better quality

services when she spends her time collecting firewood, cooking over polluting stoves, and missing out on education and revenue-generating activities that ultimately translate into her ability to make decisions and take action to improve her family's well-being?" Better health services are essential, but far from sufficient. There is a great need to tackle more fundamental problems that perpetually constrain women and their families.

A clean-burning cookstove, such as those powered by Liquified Petroleum Gas, can be a life-changer for families, particularly women and girls. It liberates them from the drudgery of collecting fuel and cooking in smoke-filled spaces, affording them time for school or other income-generating activities. It immediately improves their health, safety, and quality of life. The Bettering Human Lives Foundation will mobilize financial and human resources to support LPG and cookstove entrepreneurs and innovators in Africa and Asia with one goal in mind: get a clean cookstove into one million households. As a midwife and a mother, my heart breaks when I see a postpartum mother and her newborns inside dark, smoke-filled homes. I am eager to get on a more impactful path toward bettering human lives.



A Pathway to Prosperity

Our Pathway to Prosperity starts off by offering much needed, catalytic funding to local small businesses and entrepreneurs working across the clean cooking value chain, enabling them to innovate, expand, and grow. This economic development approach leads to sustained increases in access to clean cooking, which, in turn, uplifts the well-being of women, children, and communities. We sustain this cycle through ongoing reinvestment, ensuring a brighter future for all.

Energy Access: Electricity

The developed world takes electricity access for granted, but for a very large part of the world's population, electricity is either an occasional luxury or altogether absent. The United Nations estimates that over 700 million people have zero access to electricity. There has been progress in improving this situation; one billion people received their first access to electricity in the last 20 years — the large majority from generators running on fossil fuels such as coal and gas or hydropower. The global electricity access rate has risen from about 83% in 2010 to 91% in 2020, but as the UN notes, the pace of progress has "slowed in recent years."

We also shouldn't forget that there are grades of electrification. While 91% may have access to electricity, one billion of those have access to electricity for only four hours per day. This is enough to power a light bulb or charge a cell phone, giving marginal improvements in quality of life, but nowhere near enough to drive a water pump or other machinery that could raise their productivity and income. Or power a refrigerator, one of the most important steps for health and hygiene after eliminating cooking with biomass.

The United Nations estimates that over 700 million people have zero access to electricity. There has been progress in improving this situation; one billion people received their first access to electricity in the last 20 years

Figure 3.6
People in the World With & Without Electricity

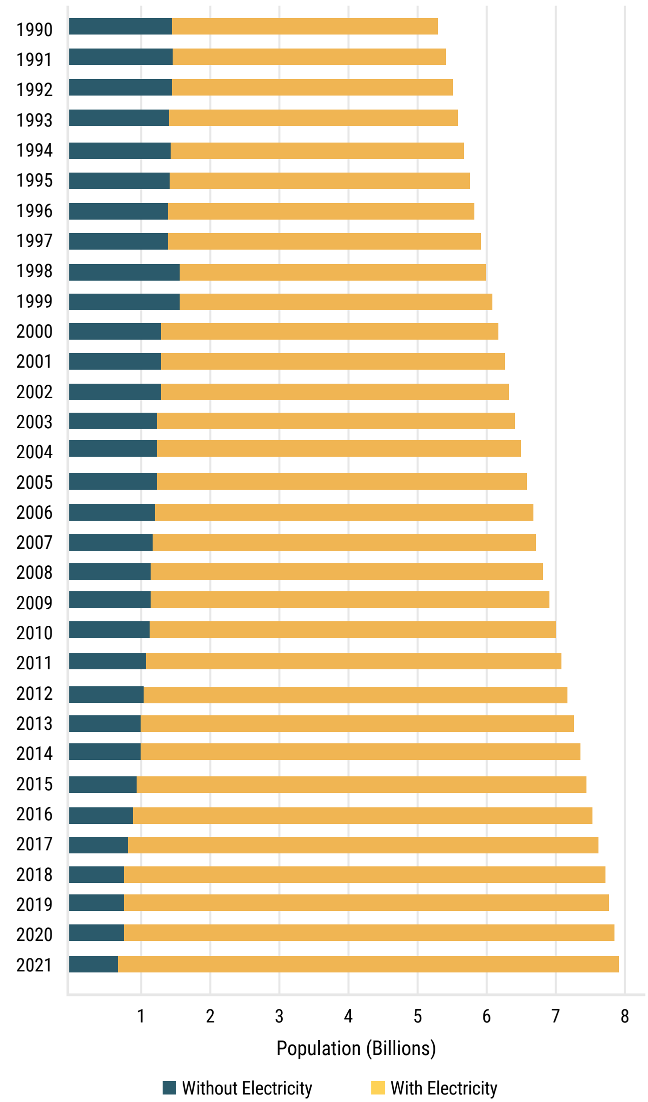


Figure 3.6 — United Nations, World Bank, Bijou Insights

We are very concerned that heavy-handed actions of the world's wealthy nations in the name of climate change are becoming headwinds to progress. Many large banks, including the World Bank and the European Development Bank, are now restricting or simply not offering funding for fossil-fueled power plants. These plants are crucial sources of electricity generation globally, particularly in developing nations where they provide the principal potential new source of low-cost, reliable electricity supply. To continue the improvements in the human condition achieved over recent decades, we must increase the supply of affordable, reliable energy — particularly electricity and clean cooking fuels.

Lower electricity demand directly correlates with child malnutrition.

Figure 3.7

Energy Consumption Per Capita

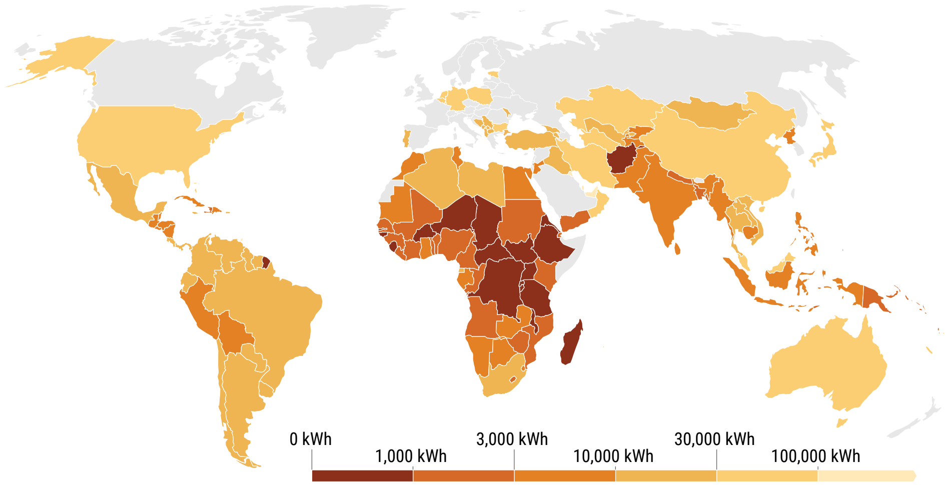


Figure 3.7 — Per Capita Electricity Consumption." Our World in Data, 2022, U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2023)

Figure 3.8

Percentage of Underweight Children Under Age Five

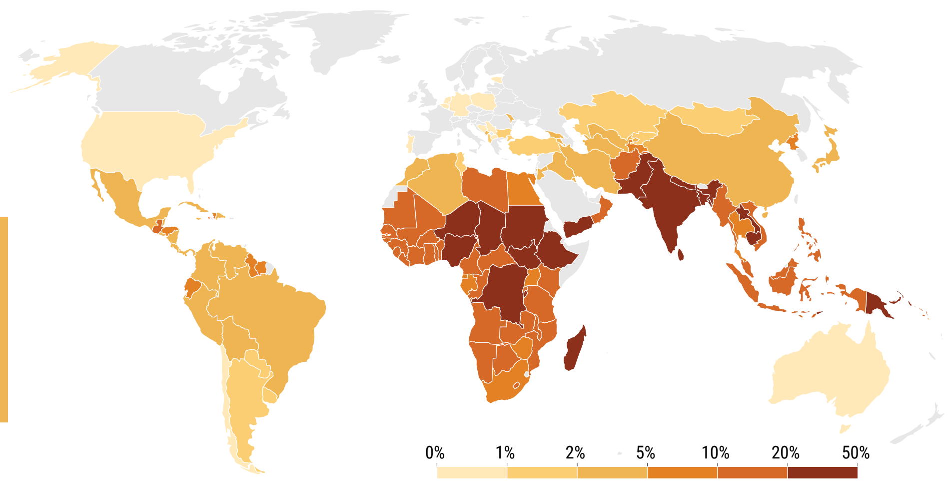


Figure 3.8 — Our World in Data, 2022, UNICEF, World Health Organization and World Bank

"As a child in Senegal, taking a shower was both time consuming and dangerous. When it was shower time, my grandma would use newspapers and a match to light a fire in our charcoal stove. After the coals turned red, grandma would put on a large pot of water and wait for it to boil while occasionally fanning the coals. About 45 minutes later grandma would carefully pour the boiling water into a bucket, adding more water to achieve a safe temperature. Then my uncle or cousin (or anyone stronger than my grandma) would drag the bucket to the shower area where I used a little pot to pour warm water over myself for bathing.

When I arrived in Germany, I was confused the first time my mother told me to take a shower. I asked her "where is the bucket of warm water?" She told me to turn the faucet handle. I was truly amazed when hot water came out almost instantly; this mundane task that took almost an hour back home now accomplished in mere seconds! I wondered why do they have this ease of life and back home we don't? This experience instantly changed my worldview and started my questioning on how and why some countries are wealthy while others remain poor."

Magatte Wade

Author, The Heart Of A Cheetah

Magatte Wade, Age 5

Mame Arame N'Gom, Magatte's Grandmother

The Human Impact of Energy

The United Nations Human Development Index (HDI) "is a simple composite measure of a nation's longevity, education, and income" and can be taken as a reasonable proxy metric for the quality of life in a particular location. In 1990, 62% of the global population (5.3 billion) scored "low" on the HDI. Three decades later, only 12% of the global population are living in countries with a "low" score. However, 12% of today's population equates to nearly one billion people. As with virtually any index of human well-being, higher HDI scores go hand in hand with higher energy consumption. The two figures illustrate the correlation between higher energy consumption and higher HDI's.

Figure 3.9

2021 HDI vs. Primary Energy Demand per Capita

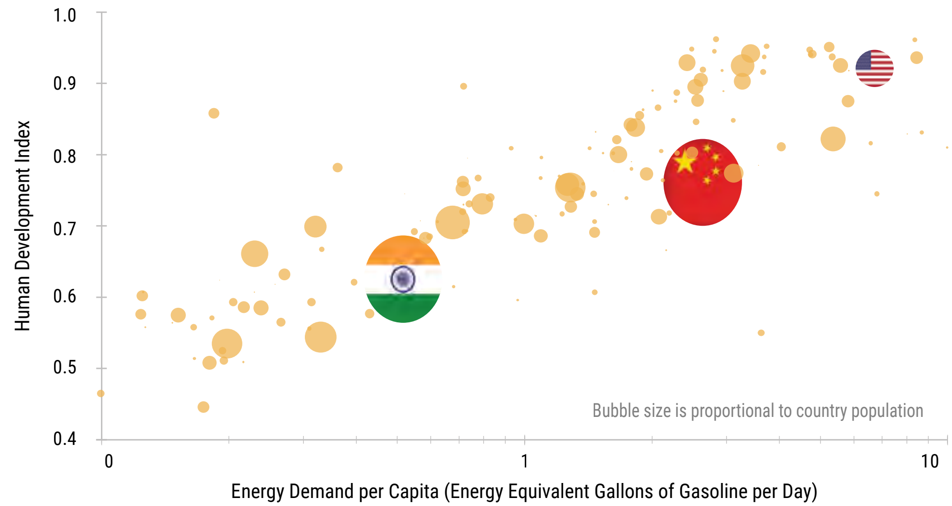


Figure 3.9 — United Nations, EIA, and Bijou Insights

Figure 3.10

China & India Experience Rising Energy Consumption & HDI Improvement

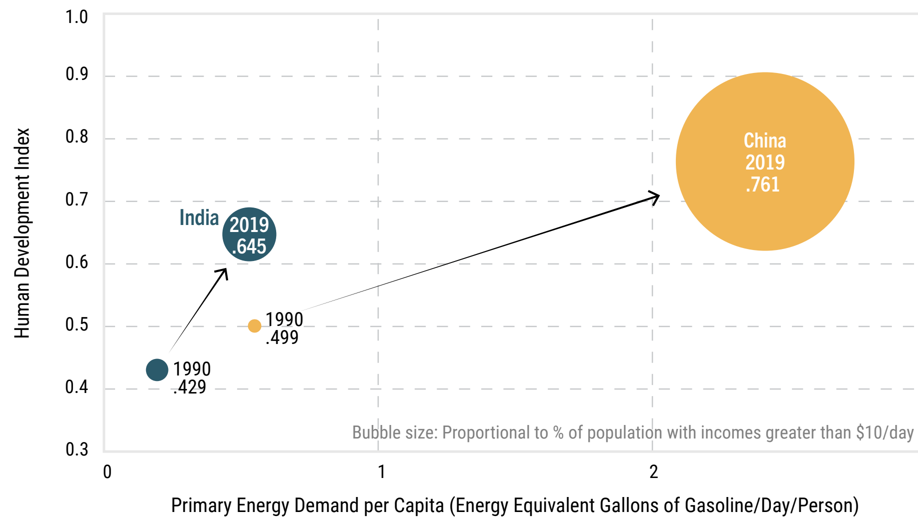


Figure 3.10 — World Development Indicators (WDI) | Data Catalog, 2022, EIA, Bijou Insights

Between 1990 and 2021, India and China have seen a 48% and 54% improvement, respectively, in HDI

None of this is surprising. To a physicist, energy is simply a way of measuring the potential to change the world, to increase or reduce its temperature, for example, or to reshape it in some way, or to move something from one place to another. Changing the world to enhance human well-being requires the use of energy.

INDIA

- Moved from Low to Medium HDI
- Mean education increased 2.4x
- Life expectancy increased 8.6 years *(was +12.3 years prior to COVID)*
- Energy per capita increased 167%

CHINA

- Moved from Low to High HDI
- Mean education increased 1.8x
- Life expectancy increased 10.2 years
- Energy per capita increased 371%

Energy Access Is Illuminating

The Korean peninsula starkly illustrates the penalties of living without abundant energy. North Korea's darkness at night reveals the border location— energy access is quite literally illuminating.

Only 52% of North Korea's population has access to electricity as compared to 100% of South Koreans.

South Korea has 17x higher per capita energy consumption than North Korea, primarily sourced from fossil fuels.

South Koreans are born with a life expectancy 11 years longer than their northern neighbors.

9.3% of North Korean children under age five are underweight compared to only 0.9% in South Korea.

Figure 3.11

Total Power Generation Capacity: North Korea vs. South Korea

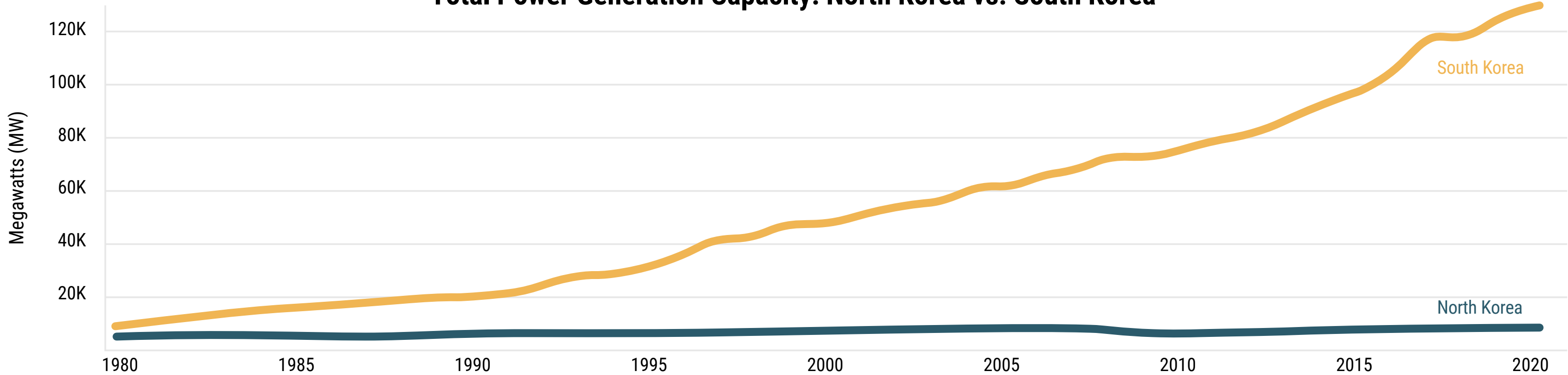


Figure 3.11 — 38 North, Statistics Korea, Martyn Williams

Energy Access Is Green

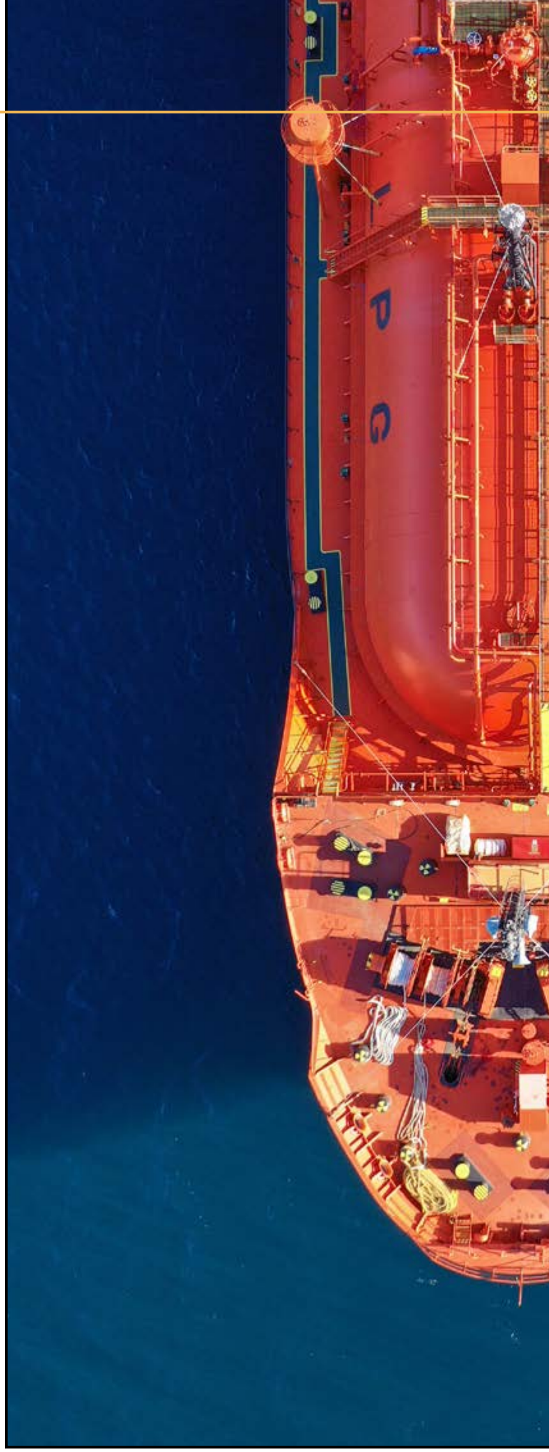
Energy access is also green. Haiti's extensive dependence on wood for heating and cooking fuel leads to significant deforestation and higher greenhouse gas emissions. Meanwhile, its neighbor, the Dominican Republic, has higher levels of access to modern fuels, is wealthier, and can allow its rainforests to flourish.

- The national border between Haiti and the Dominican Republic can be seen easily in this photo due to the severe deforestation in Haiti, which results from the use of traditional biofuels as a primary energy source for heating and cooking.
- The Dominican Republic, on the other hand, has eight times higher per capita energy consumption than Haiti, almost entirely from fossil fuels.
- Far fewer people relying on traditional energy sources like wood means thriving forests and a cleaner environment.

The Future of Energy Access

The good news is that energy access is increasing globally. Over the last decade, hundreds of millions of people have transitioned from traditional cooking and heating fuels to LPG and other modern fuels. The United Nations estimates that between 2010 and 2020, the proportion of the world's people with access to clean cooking fuel has increased by 12 percentage points to 69%. The American Shale Revolution has played a dramatic role in reducing the energy cost barrier for low-income families wishing to move from solid biofuels to clean-burning LPG stoves fueled by refillable canisters. The U.S. is now, by far, the world's largest exporter of LPG (mostly propane), and the source of virtually all growth in world LPG trade over the last decade. This has decreased LPG prices while greatly increasing available supplies. If we continue this trend, clean-burning cooking fuel could be universally available within two decades.

But there is no room for complacency. The admirable progress achieved over the last decade is being reversed as the world has been in and out of an energy crisis. This crisis is not due to a shortage of energy resources: The culprit is energy policies that lack common sense and humanity. These energy policies dismiss or distort the rational evaluation of the tradeoffs between the benefits of hydrocarbon fuels in the short and medium term and the longer-term risks of climate change. Policies aimed at reducing the emissions of greenhouse gases (GHG) have led to serious shortages in infrastructure to move Liquified Natural Gas (LNG) around the world, as well as emerging shortages in oil production capacity. The roots of the world's rolling energy crisis go back through years of overly restrictive hydrocarbon policies culminating in demand outstripping supply. Russia's invasion of Ukraine most certainly exacerbates the crisis but is not the source of the problem.



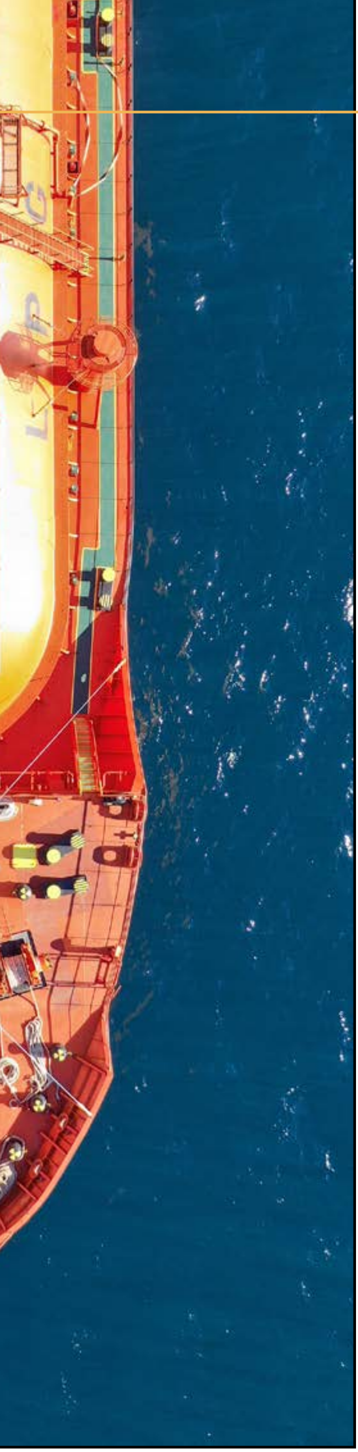


Figure 3.12

U.S. Responsible for Virtually All Global LPG Export Growth

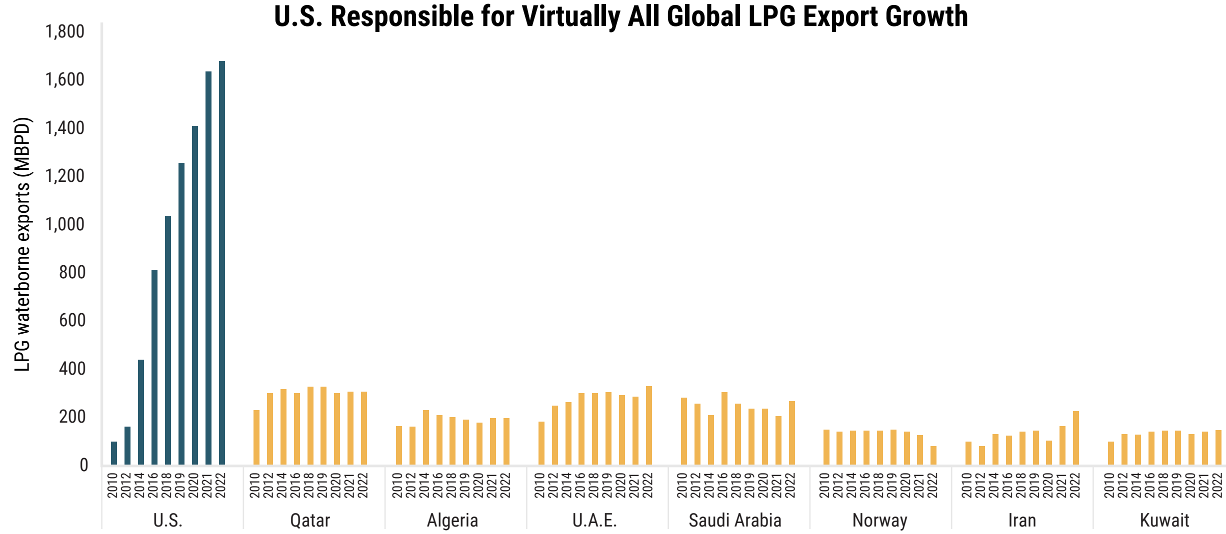


Figure 3.12 — IEA and IHS Waterborne, Enterprise Product Partners, Investor Deck, December 2023

The difficulties arising from careless climate policies are most acute in the global supply of natural gas. Many countries count on ship-borne imports of Liquefied Natural Gas as a critical part of their supply. As demand exceeded supply in the summer of 2021, LNG prices skyrocketed. The world experienced extremely elevated LNG prices for much of 2021-2023, which caused massive disruptions in countries. The most dramatic and tragic impacts of high LNG prices are in lower-income countries where unaffordable energy combines with soaring food prices to cause human hardship. Natural gas represents 80% or more of the cost to produce nitrogenous fertilizers (mostly synthetic ammonia), with nitrogen being the most important nutrient limiting agricultural productivity. The one-third of humanity living in energy poverty is now seeing much higher energy and food prices. This dire situation illustrates how costly errors in energy policy can be in human terms, and how critical it is that we get energy right. At the very least, we must prevent the globe's most comfortable and wealthy regions from imposing anti-energy policies that harm or even kill the world's least fortunate.

German wind farm dismantled to mine the coal underneath

Just how bad these energy and climate policy decisions are can be gauged by falling energy consumption in many Western countries. In the United Kingdom, energy use has fallen by 30% to levels not seen since the 1950s, while the rest of Europe has declined to 1990s levels. British electricity consumption, amazingly, has fallen by about a quarter since 2003 and is now back at levels last seen in the late 1980s. Even North American energy consumption is showing worrying signs. Increasing the cost of any good or service drives down the demand. For most products, higher prices simply shift demand to alternative products. But energy is different, as every good and service requires energy. Driving energy prices up is inflationary.

Faltering or falling energy consumption, particularly electricity, is not an indication of a healthy economy. And it likely isn't the result of efficiency, which tends to increase demand for energy, as we know from the Jevons paradox (detailed in the CEO Letter). Energy efficiency has been increasing for two centuries (as shown in Figure B) and we should strive to continue this trend, but there are limits to its role in reducing energy demand.

Case studies in this report on Germany, the UK, and the EU all show that making energy more expensive reduces demand by two main mechanisms: displacing energy intensive manufacturing along with blue collar jobs to other countries, and by reducing energy affordability for consumers. So far, the U.S. has not gone as far down this road, having spent "only" $125 billion between 2008-2018. But the recently passed "Inflation Reduction Act" appears poised to drive the U.S. electricity grid along the European path: higher prices and more grid stability problems.

The EU, where the biggest energy collapse is observed, has spent a staggering $800 billion since 2008, a total that has been increasing at $70 billion a year. And the U.K., a country of 65 million people, is shelling out well over $10 billion every year. And this is to say nothing of the increased cost of managing and making reliable an electricity system dominated by uncontrollable renewable generation. Grid expansion and system balancing costs have ballooned in Europe. All these massive expenditures have resulted in much more expensive electricity for consumers and consequently lower demand as households tighten their belts and energy-intensive businesses relocate to other parts of the world, such as Asia, with lower electricity and other energy costs. Industrial emissions are simply displaced to other countries. Consumption emissions may fall, but this is because the Europeans are experiencing what economists would call the "price-rationing" of energy. In other words, a lowered standard of living.

When designing our climate policies, we will do more harm than good if we don't consider all the world's citizens, including the poor in both the developing and the developed world. Costs that seem affordable for those already on high incomes are often inhumane and repressive for those on low incomes. Making energy more expensive, or otherwise impeding access to hydrocarbons, crushes opportunity for those struggling to better their lives.

To make matters worse, many of our current climate policies are not only bad for citizens but far from successful in reducing global emissions of greenhouse gases. There is a simple reason for this. Until our climate policies also deliver improvements in human welfare, rather than keeping billions in poverty, they won't be spontaneously and compulsively attractive to those in other regions of the globe.

Figure 3.13

2022 Oil Demand Per Capita

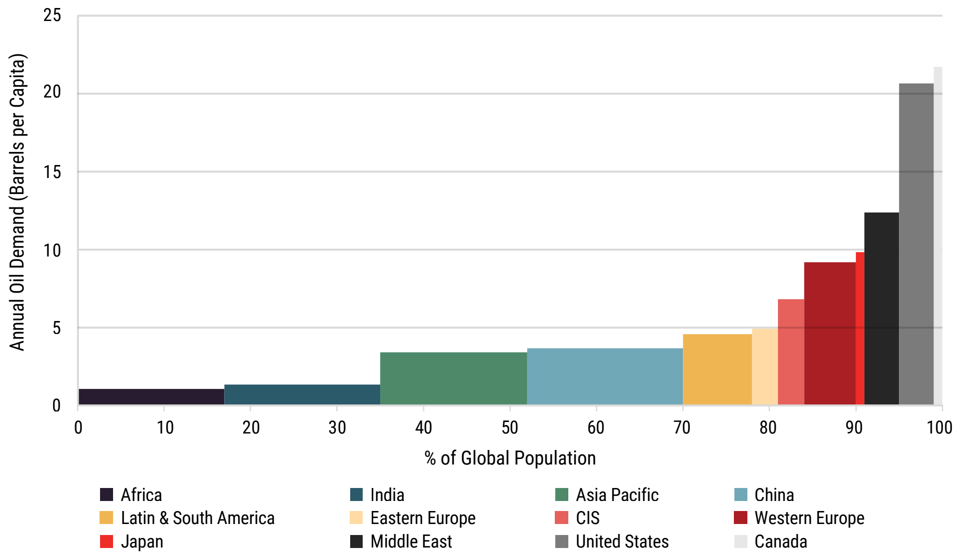


Figure 3.13 — Energy Institute Statistical Review of World Energy, and Bijou insights

Energy poverty is not only limited to the developing world; it is present across all societies.

In fact, energy poverty is growing fastest in high-income countries where policy choices are driving up the local cost of energy. In 2020, 27% of U.S. households had trouble affording their energy needs, and 10% of Americans reported keeping their homes at unhealthy temperatures to balance their budgets. This in the world's wealthiest country!

CASE STUDY

European Union & the United Kingdom

California has been an early mover in aggressive, coercive climate change policies in the U.S. The results do not appear positive. California has driven the state's electricity prices to more than 50% higher than the U.S. national average, leading some energy-intensive industries to leave the state. These policies disproportionately harm low-income residents. U.S. Census Bureau data shows that California now has the country's highest adjusted poverty rate. These strikingly negative impacts are coupled with only modest reductions in emissions and a large part of these reductions are more apparent than real, being transferred with migrating industries as they relocate to other states or countries. Ironically, California continues to import coal and gas fired electricity from other states to meet its energy needs.

Important though California is, by way of example, the European Union and the United Kingdom present the sternest warning against attempts to force emissions reductions while neglecting the physical realities that distinguish hydrocarbons from modern renewables such as solar and wind. This point is brought into sharp focus by the new U.S. Federal program of support for climate change policies known as the Inflation Reduction Act (IRA), a law which is clearly modeled on the European approach and likely to have similar consequences. But the European Union's policies and outcomes are poorly understood in the United States. If they were understood, there would be more concern with the IRA.

The European Union is a large economic area, consisting of 27 countries (28 before the UK left in 2020), with a population of 447 million people, the largest member states being Germany (83 million), France (68 million), Italy (59 million), Spain (47 million) and Poland (38 million). When the UK was still a member it was the third-largest state with a population of 67 million. For comparison, the United States has a population of 335 million. The GDP of the EU in 2021 was approximately $16.5 trillion (€14.4 trillion). The U.S. has a GDP of about $23.3 trillion. In summary, the EU has a somewhat larger population with a somewhat smaller economy, but the EU and U.S. are comparable in scale. The EU's experience of climate policies is relevant, despite differences both geographical, societal, and economic.

Starting around 2000 the EU pursued a program of rapid decarbonization based initially on emissions trading, but increasingly reliant on the subsidized deployment of renewable energy. The increased energy costs strongly suppressed energy consumption. This has rendered the EU less able to recover from exogenous shocks such as the financial crisis of 2008, and the global pandemic of 2020. Astonishingly, energy consumption in the EU has been falling since 2005 — an indication of underlying economic ill-health. In fact, the U.S. and EU economies were quite similar in size in 2008, but since then in dollar terms the EU economy has grown by only 6% versus 82% for the U.S. High energy prices are not conducive to economic growth.

The scale of the policy costs can be illustrated with headline figures. In the period 2013–2021 emissions trading in the EU added about $90 billion in total to industrial energy consumer costs, impairing international competitiveness and adding to the domestic cost of living. Emissions trading continues to add about $18 billion a year to industrial costs. But these costs are dwarfed by subsidies to renewables.

EU income-support subsidies to renewable energy in 2008-2021 added about $800 billion to consumer costs in the EU 27 (i.e., excluding the UK). The annual costs of renewable energy subsidies in the EU 27 now amount to about $70 billion; UK subsidies to renewable electricity generators alone amount to about $10 billion a year.

Unsurprisingly, subsidies on this scale have produced enormous growth in renewable generation capacity, from about 100 GW in 1990, when it was nearly all hydro, to over 500 GW in 2020. This amounts to about 17% of the global total of renewable capacity.

Electricity production capacity in the EU nearly doubled from 1990 to 2020, yet total electricity production declined. While thermal capacity (coal, gas, nuclear) has declined due to regulation and a lack of investment signals, a large but under-utilized thermal fleet necessarily remains in place to guarantee security of supply since wind and solar provide no firm capacity. The hospital neo-natal ward must operate even at night when the wind is calm.

With rising subsidies and declining energy sector productivity, it is no surprise that prices for consumers have risen sharply relative to international competition. Electricity prices to households in the EU have been about 80% higher than those in the non-EU G20. EU industrial consumers face electricity prices about 30% higher than their competitors in the G20, even after significant direct government subsidies attempting to mitigate this loss of competitiveness.

Uncompetitive prices are even worse with natural gas. Prices for home heating and cooking have been approximately double those in the G20, and industries have seen prices about 25% higher than those in the G20. Doubling home heating prices is unhealthy and even deadly.

High diesel and gasoline taxes in the EU have elevated fuel prices significantly higher than elsewhere in the world, with gasoline prices being between 30% and 50% higher than those in the G20 nations.

Since wholesale prices for electricity and natural gas were approximately the same in both the EU and the G20 prior to EU climate policies, we can conclude that these very large differences in consumer fuel prices were due to energy policies — mostly climate policies. A similar conclusion can be reached for diesel and gasoline, where wholesale prices were lower in the EU than the G20 prior to the arrival of climate policies.

Figure 3.14

U.K. Inland Primary Energy Demand 1970–2022

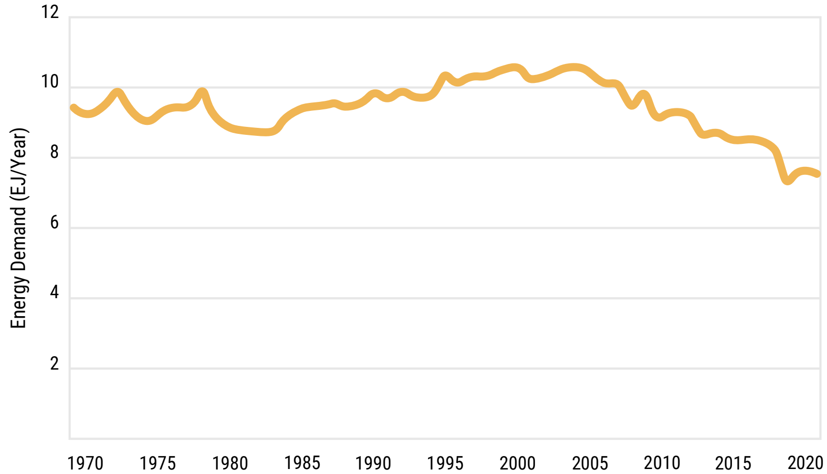


Figure 3.15

UK Electricity Supplied 1951–2022

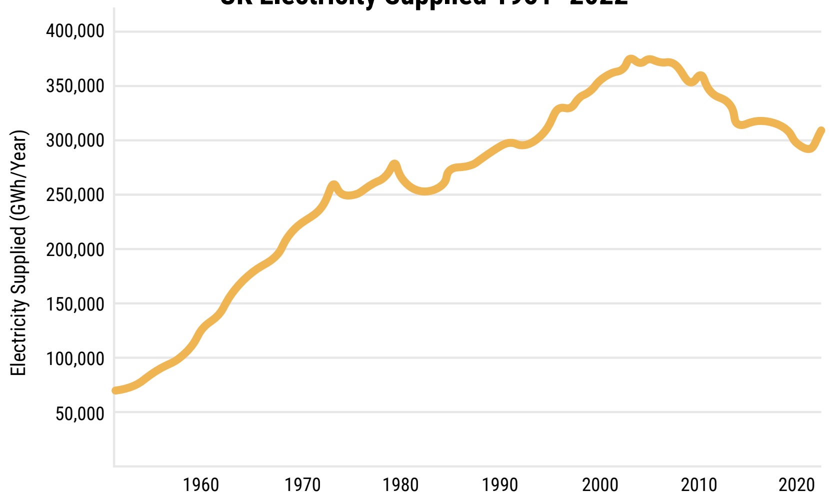


Figure 3.14 & 3.15 — Digest of U.K. Energy Statistics, John Constable

The UK, although no longer part of the EU, has continued aggressive climate policies that have driven up energy prices for its citizens and industry. The results are troubling. Figure 3.14 shows that primary energy consumption in the United Kingdom peaked in 2005 at 10.6 exajoules and has since declined by 28% to 7.6 exajoules in 2022! UK electricity consumption has fallen by 22% over the same period and is at levels last seen in the late 1980s.

These declines in energy consumption should not be misread as implying significant and effective reductions in greenhouse gas emissions. They do indeed track with reductions in the UK, but not necessarily with global emissions. Elevating energy prices has two major impacts: It depresses demand from consumers due to cost, and it leads to the reshoring of energy-intensive manufacturing to locales with lower energy prices. In simpler terms, citizens are impoverished. Industry has been, and continues to be, relocated to Asia and the United States. The first factor reduces emissions by making energy less affordable to citizens, and the second does not reduce emissions as they are simply relocated. Industry relocations are likely to increase emissions, as the EU's primary industrial fuel is natural gas, where coal dominates in Asia.

Far from being an encouraging sign, consumption reductions are an indication of systemic weakness; this is an economy and society that is less and less able to change the world in accordance with its requirements. However, the UK and European Union governments do not see it this way and have embraced these signs of policy failure as measures of success. They have set targets for further decreases in consumption. On current trajectories there is every reason to suppose that these targets will be met, as the climate policies render energy still more expensive. The once world-leading United Kingdom now has a per capita income lower than even the poorest state in the United States.

Three further observations can be added to these overwhelmingly negative results from Europe's green experiment. First, the costs to society have been simply enormous for relatively modest reductions in global emissions – exporting emissions to other countries are not actual reductions. As the next section will show, it is almost unimaginable that the costs incurred to reduce emissions will deliver climate benefits in line with the costs. Second, subsidies to renewables have not produced significant reductions in the capital and operating costs of wind and solar, a fact that will come as a surprise to many but is well-documented in the audited financial statements of European wind and solar operators. Third, subsidized deployment of renewables in Europe has failed to give European industries a secure position in the world markets for renewable energy, which is now dominated by Chinese manufacturers. In 2012 European companies held 20% of the world market for manufacturing wind and solar equipment, but by 2021 this had fallen to 13%.

As John Constable concludes in his review of the unfolding disaster of Europe's green adventure: "Distressed policy correction is inevitable but entails significant reductions in European standards of living. Deferring this correction and persisting with renewable energy will increase the depth of economic sacrifice required to put European society back on a thermodynamically sound energetic footing."

Even using the most generous possible assumptions about EU and UK emissions reductions, the estimated lessening in global warming by 2100 would be about 0.01°C using the IPCC consensus of models. That's a huge cost for an almost immeasurable benefit. On the other hand, EU public health records show 68,000 excess winter deaths during the winter of 2022–2023 – above the typical winter seasonal rise in deaths – as many residents could not afford to heat their homes to safe temperatures. It could have been far worse if 2022–2023 had been a

The once world-leading United Kingdom now has a per capita income lower than even the poorest state in the U. S.

cold winter. It is simply unfathomable that the enormous economic and human cost of EU and UK climate policies that enfeebled their energy systems can ever deliver climate benefits commensurate with their cost.

Unfortunately, this chilling example did not stop passage of the Inflation Reduction Act of 2022, putting the U.S. on a similar path to the EU and UK. The Inflation Reduction Act provides a large package of tax credits and energy and climate cash expenditures amounting to around $400 billion over about a decade. This subsidy will likely motivate the investment of several trillions of dollars, most of it for wind, solar and related transmission cables. These enormous investments in response to subsidies will necessarily reduce investment in other areas.

While energy consumption in the United States is not yet showing the decline evident in Europe, it has been nearly stagnant since the early 2000s as China has displaced the U.S. as the world's manufacturing powerhouse. It appears, at least in the electricity sector, that this trend might reverse based on recent projections from major utilities projecting rapidly growing demand for electricity to power the torrid pace of new data centers driven by AI, crypto, and other new applications. The location of these data centers is heavily influenced by cost and reliability of electricity, which is at great risk if the Inflation Reduction Act drives the U.S. electrical grid in a similar fashion to that seen in the EU and UK. It is likely that some states that avoid degrading their electrical grids will disproportionately attract data centers. Of course, the EU's damage to its energy system extends well beyond the power sector. The U.S. must be cognizant of growing harm to our economy and opportunities for our citizens with policies that drive up energy prices.

This report clearly shows that global poverty is a far more pressing problem than climate change (see Climate Economics section on page 114). Many of the West's low emissions policies are detrimental to global efforts to reduce poverty, both in the developing world and in the poorer sections of the West. We must hope that the U.S. learns from the European folly of a politically driven, forced weakening of their energy system. We cannot let the Inflation Reduction Act enfeeble our energy system. A great deal is at stake because energy matters.

A Better Way

In our survey of the top-down European experiment, we have seen that subsidized adoption of renewable energy on a very large scale has been unsuccessful as an energy policy, an industrial policy, and a climate policy. This conclusion begs the question: What is a better way forward? Since each country has its own unique opportunities, priorities, and difficulties there is no single answer. History shows that a competitive marketplace with companies vigorously competing to satisfy consumer preferences, overseen by sensible regulation, has been the most effective and efficient way of discovering low-cost, reliable energy resources. Left to themselves, businesses and consumers will gravitate spontaneously towards highly productive energy sources. Market participants respond to the fundamental signals arising from prices, government policies, and underlying strengths and weaknesses of each energy source.

The transformation of U.S. energy via the Shale Revolution of the past two decades provides a clear example of markets working, without government subsidies, to provide ever-cleaner, low-cost energy for American consumers and businesses. This is due to rapid innovation, in which Liberty is proud to have played a leading role. The enormous benefits of increasing energy supplies at lower costs reverberate outside the U.S. as well. (More details on page 62 in the American Shale Revolution section).

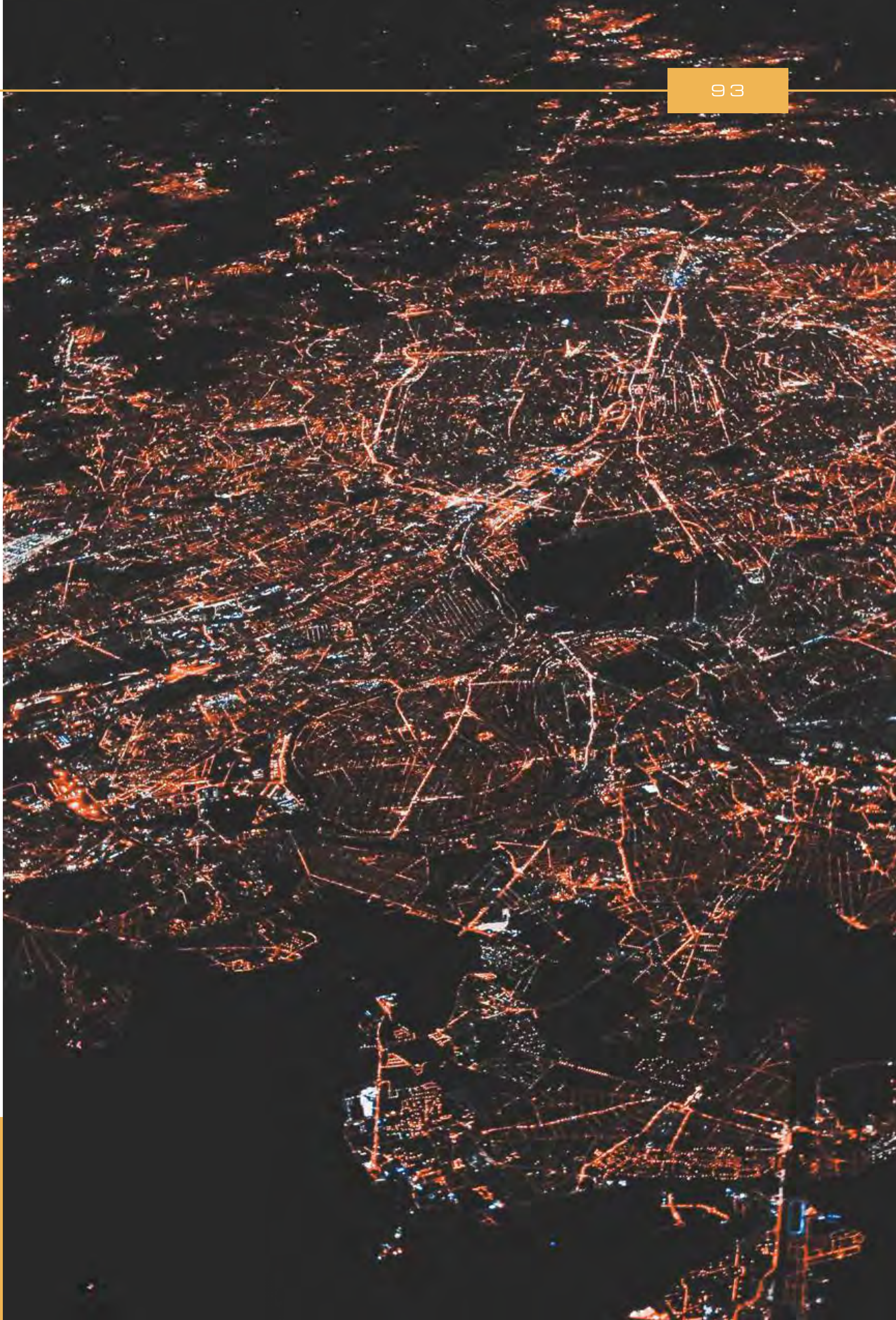
What trajectory might be followed by a nation focused both on bettering human lives and a responsible pathway to address climate change? The focus would need to be simultaneously on more energy and better energy. Technologies that significantly raise the price of energy will not help either objective.

Natural gas has been the runaway winner when it comes to energy addition as shown earlier in this report. Natural gas has provided 40% of the growth in global energy production since 2010 as it serves to keep energy affordable and reliable, while also being a major factor in reducing air-pollution and serving as the largest driver of greenhouse gas emission reductions in the U.S. It is likely that natural gas will remain the fastest growing global source of energy for some time into the future as it will continue displacing coal in wealthy nations while also growing in countries across the globe.

Coal remains the largest global source of electricity for a reason: It is a cheap and reliable source of electricity for billions of people, and is far cleaner than burning wood, dung, charcoal, or agricultural waste. Everything involves context-dependent tradeoffs. There is much room to run in deploying emissions reduction technologies to improve air quality for those living around coal generation. But these technologies have significant costs and hence are not yet widely deployed in lower income nations. Further down the road, perhaps, is the even more expensive endeavor to capture and store underground the carbon dioxide emissions from coal or natural gas combustion. This would significantly increase the cost of electricity generation, but if it can be done at a cost comparable to the benefits, surely it will take hold. Only time will tell.

Oil is prized for its portability and plethora of uses — transportation fuels, power, heating fuel, petrochemicals, plastics, asphalt, lubricants, and more. Oil will likely remain a major source of energy and materials for the foreseeable future simply because for most (not all) applications there are no viable replacements. Where change is occurring most rapidly with oil has been in the cleaning-up of production practices and the continual increase in engine combustion efficiency across autos, motorbikes, trucks, ships, and aircraft. Improved combustion technology lowers the emission of pollutants immediately harmful to human health and reduces greenhouse gas emissions by liberating more mechanical energy for each quantum of fuel burned. It is easy to demonize oil, but replacing oil is very difficult.

Nuclear, together with natural gas, appears the most viable option for an expanded role in powering the world and reducing global GHG emissions. Nuclear has the energy density, reliability, and scalability that would allow it to become a



large source of global energy. Wind and solar are limited to working in the electricity sector, which today supplies only 20% of total energy. There is much push to "electrify everything," but progress on this front has been quite modest. Electricity is a wondrous form of energy, but it requires a great deal of infrastructure, maintenance, rule of law, and political stability for it to flourish.

Another significant limitation of electricity: its inability to provide high-temperature process heat that is critical to manufacturing. Manufacturing — making stuff — is the largest user of energy globally. Electricity supplied about 15% of the total energy used in manufacturing 25 years ago. Today, it remains at only 15%. Nuclear, fortunately, can not only generate reliable electricity, but can also supply relatively high-temperature process heat. Nuclear-supplied process heat could displace up to 60% of today's hydrocarbon usage for process heat. Today nuclear provides only 4% of global primary energy, down from 6% around the turn of the century. There is no technical reason that nuclear power could not rise well into the double-digits of primary energy in the coming decades. Nuclear energy's biggest challenges are public perception, high capital cost to build, and government regulation. Small modular reactors may overcome these challenges, but significant contribution is likely decades out.

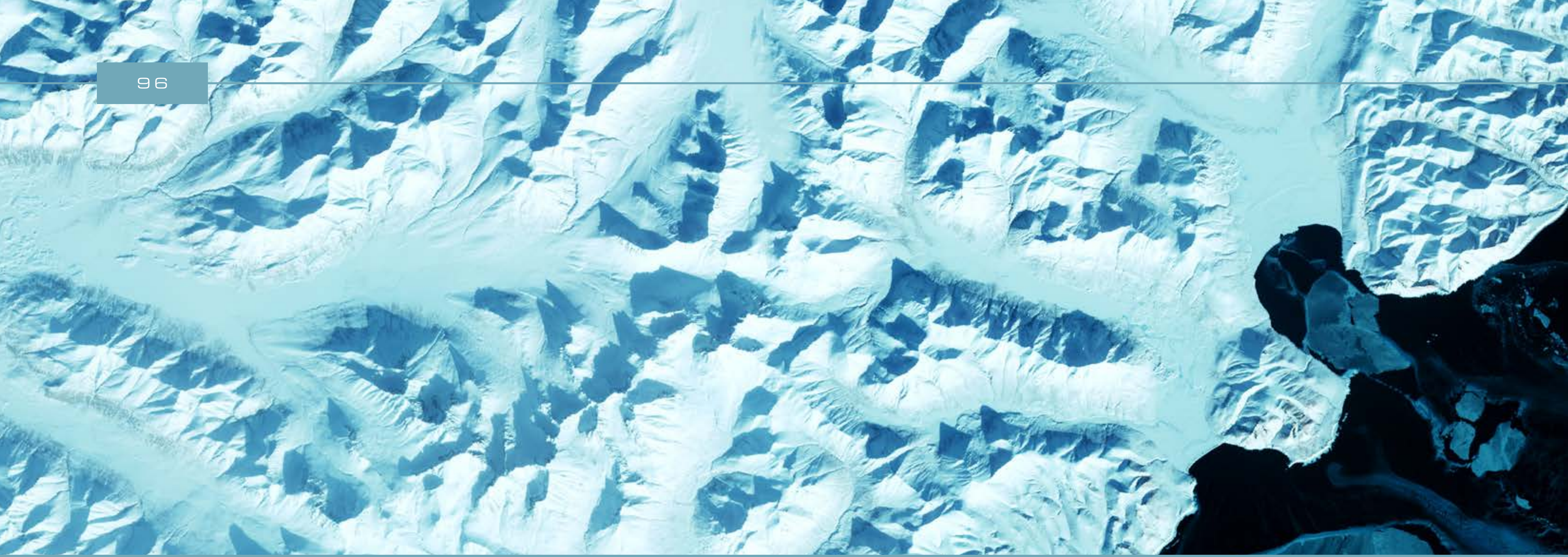
Next generation geothermal involves mining copious underground heat stored in deep rocks. This is achieved by injecting water into deep wells where it flows through underground fractures which heat the water to very high temperatures before flowing up nearby production wells. These production wells convey to the surface super-heated hot water and steam into a conventional turbine to generate electricity. While the technology is new, it appears to have significant running room to supply very low-carbon reliable electricity that can be turned up and down to follow grid demand. This idea from decades ago is made viable today by using Shale Revolution technology in geothermal resources.

We have discussed the relative failure so far of large-scale deployment of wind and solar. However, a huge breakthrough in energy storage could open the door (again) for valuable contributions from growing wind and solar penetration into the electrical grid. Unfortunately, this requires a step-change technological advancement that is not visible on the horizon. Hence today's political desire to increase "renewable" generation is mostly having deleterious impacts on both electricity costs and grid stability. Renewable is in quotes because the wide array of steel, cement, exotic metals, and other energy-intensive materials required to construct wind turbines and solar panels are at least as finite as our underground resources of oil, gas, coal, and uranium. The term "renewable" is hard to defend. All energy is hard.

Innovation is paramount for efforts to expand energy access and affordability, while also reducing GHG emissions. The last two decades have proven that we simply don't have the energy technologies, systems, patience, and political sobriety to simultaneously drive progress on both fronts. The only exception has been the American Shale Revolution, which was driven solely by market forces and not top-down government directives. Innovation thrives in free societies with free markets and aggressive competition for capital and customers. We can solve our energy and climate challenges, but only if we re-embrace the forces that lifted humanity out of grinding poverty and created the modern world.

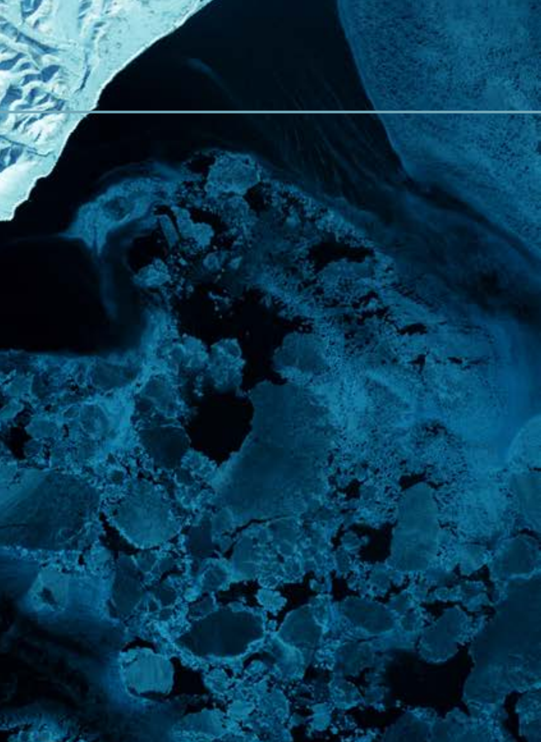
SECTION SUMMARY POINTS

- Humanity needs greater access to high-quality energy, enabling more individuals to enjoy lifestyles similar to those of the lucky one billion.
- Local availability and affordability of hydrocarbons directly impact living standards, opportunities, and health.
- While global energy access is on the rise, 700 million people do not have electricity, and nearly one-third of humanity lacks access to clean cooking fuels.
- Energy poverty permeates societies of all socio-economic levels not just developing nations.



CLIMATE CHANGE

CO_2 & the Planet | Climate Trends & Measurements | Extreme Weather



Climate Change

Messaging around climate change is typically catastrophist, projecting visions of planetary doom and gloom with one major culprit to blame: fossil fuels. This narrative is short on facts and shorter still on rational debate about the many trade-offs related to the very real economic, societal, developmental, and energy challenges facing the world.

The human condition has been progressively transformed by three major developments in our use of energy: the harnessing of fire, the advent of agriculture, and the addition of fossil fuels to the energy supply.

The expansion of the global energy supply by adding fossil fuels has greatly improved the human condition; it also brought the risk of climate change caused by increased atmospheric levels of carbon dioxide and other greenhouse gases.

CO_2 & the Planet

So long as agriculture was the primary source of human energy, including that harnessed from draft animals, the carbon cycle had annual flows and seasonal variations. Those organic flows continue today. During the Northern Hemisphere spring and summer, plant photosynthesis, using energy from sunlight, draws carbon dioxide (CO_2) out of the atmosphere to combine with water to make chlorophyll — the basic building block of plant biology. In the fall and winter, photosynthesis drops dramatically, and plant decomposition returns CO_2 to the atmosphere, completing the annual cycle.

Figure 4.1

Atmospheric CO_2 at Mauna Loa Observatory

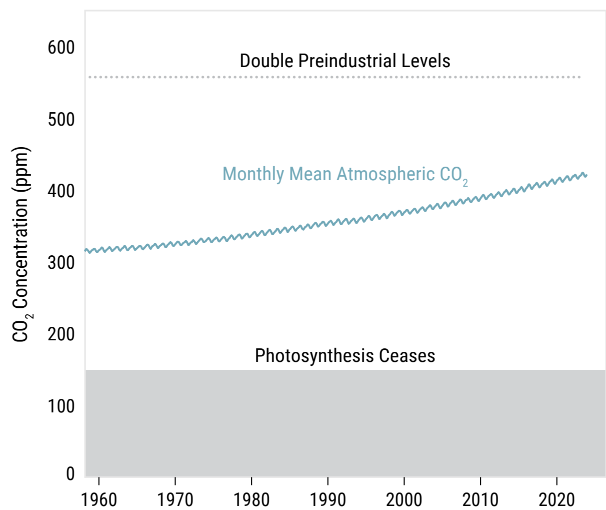


Figure 4.1 — Scripps Institution of Oceanography NOAA Earth System Research Laboratory https://www.e-education.psu.edu/earth103/node/1018

Photosynthesis requires a minimum atmospheric CO_2 concentration of around 0.015% (150 ppm). During the last glacial period (16,000 to 100,000 years ago), atmospheric CO_2 nearly breached this level, falling to only 180 ppm. Before the large-scale use of coal, oil, and natural gas, from the seventeenth century onwards, CO_2 concentration was estimated at just below 0.03%. The fossil-powered global economic growth since World War II has driven a steady climb in atmospheric CO_2 concentration (shown in Figure 4.1) to slightly above 0.04% (420 ppm in 2023) as humans liberated the solar energy stored hundreds of millions of years ago in ancient plants (coal) and marine plankton (oil and natural gas).

Atmospheric CO_2 concentration rises due to hydrocarbon combustion, which reverses the photosynthetic reaction in which oxygen combines with carbon. The equation below represents the chemical reaction of burning methane, the simplest hydrocarbon.

$$CH_4 + 2O_2 \blacktriangleright CO_2 + 2H_2O$$

One methane molecule reacts with two oxygen molecules to create one carbon dioxide molecule and two water molecules while liberating energy, primarily as heat, that can generate electricity, drive industrial processes, and home heating or be used for other life-enhancing endeavors.

Carbon dioxide is plant food, and roughly half the CO_2 released in this combustion reaction goes into the oceans or into "greening" the planet. Increased availability of CO_2 in the atmosphere has led to increased agricultural productivity and a significant increase in global plant matter, grasses, trees, and plankton.

Figure 4.2 shows the significant greening of the planet over the last few decades.

Figure 4.2

Global Greening from CO_2 Fertilization

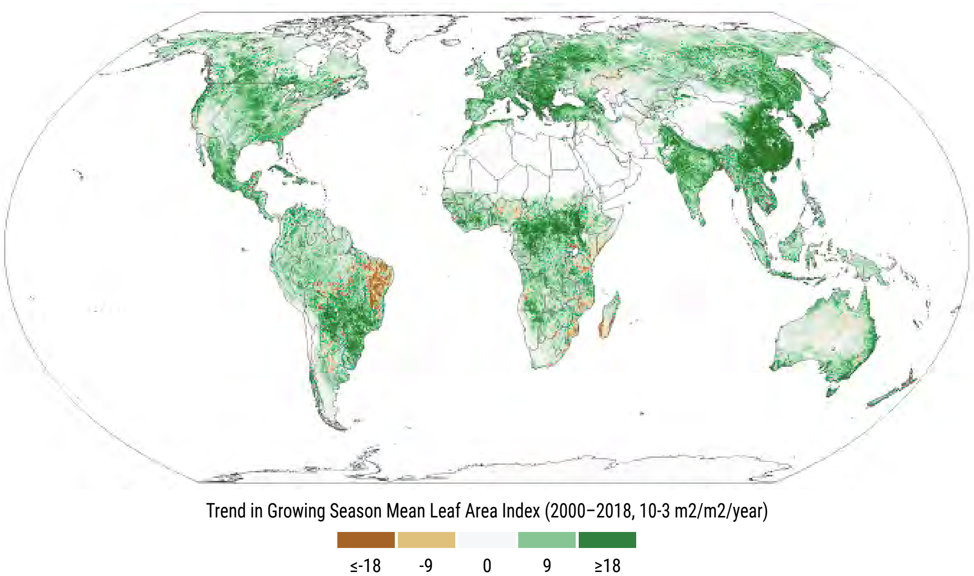


Figure 4.2 — Hille, Karl. "Carbon Dioxide Fertilization Greening Earth, Study Finds." NASA, NASA, 25 Apr. 2016

Climate Trends & Measurements

The other half of the carbon dioxide released has remained in the atmosphere, driving the increased atmospheric concentration shown in Figure 4.1. Since carbon dioxide, like water vapor, methane, and nitrous oxide, is a significant "greenhouse" gas, increased concentration has raised concerns about climate change, particularly rising global temperatures. Greenhouse gases (GHGs) are molecules that absorb the infrared radiation the Earth continually emits into space. The earth's infrared radiation sends heat into space that balances the incoming heat received from the sun. The largest warming is in the cold polar areas at night, with progressively less warming measured as we move towards the tropics. Even in the tropics, the warming impact is more pronounced at night than during the day. Estimates from radiation physics predict that doubling the pre-industrial atmospheric CO_2 concentration to 560 ppm, likely to occur by late this century, would result in a 1.3–1.4°C average warming of the planet in the absence of feedback effects.

A recent empirical study of historical temperature data provides similar warming estimates of 1.2–1.8°C in response to a doubling of atmospheric carbon dioxide levels. There remains significant scientific uncertainty around feedback effects, mainly induced changes in atmospheric water vapor (which is a more potent greenhouse gas than carbon dioxide) and impacts on cloud formation. This is a highly technical issue, with ongoing research focusing on this critical topic.

This summary intends to provide a basic understanding and context around climate change and, most importantly, provides a summary overview of historical observational data for global average temperature and sea level, both of which are rising. It will address extreme weather events, for which there is no significant

Figure 4.3

UAH Global Lower Tropospheric Temperature Variations (˚C) 1979–2023

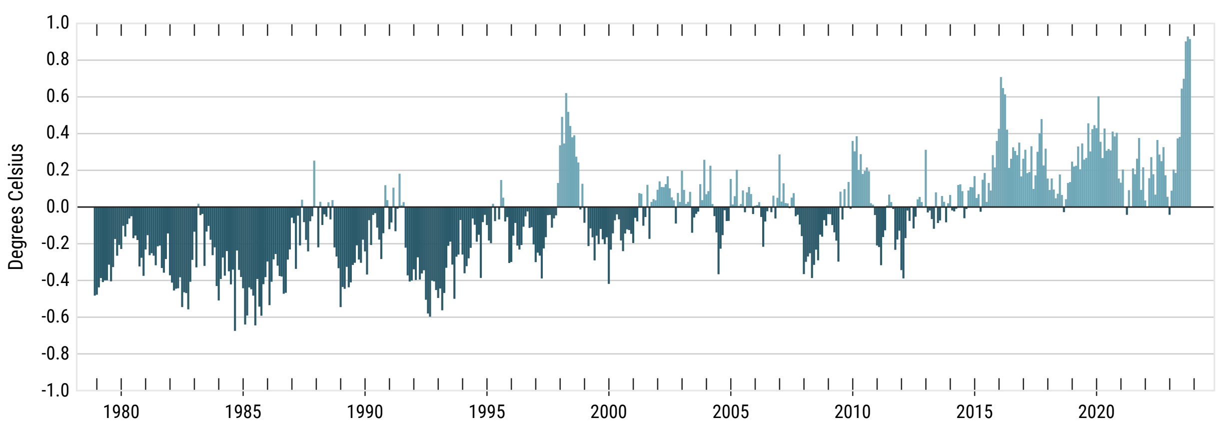


Figure 4.3 — Spencer. "New Reference for Annual Cycle 1991-2020., University of Alabama Huntsville, Apr. 2015, Global Temperature Report." Global Temperature Report: The University of Alabama in Huntsville, 2022

trend, and deaths from extreme weather events, which are falling sharply. These are far from the only areas of climate change discourse, but they are the central ones.

Figure 4.3 shows the entire atmospheric temperature record collected by the University of Alabama Huntsville (UAH) in a collaborative project between UAH, the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA). The data is gathered by advanced microwave sounding units on NOAA and NASA satellites to get accurate global temperature readings — including remote areas where reliable climate data is otherwise unavailable.

By contrast, land-based sensors suffer from uneven spatial coverage, fluctuating conditions around measurement sites, such as urban heat island effects, and a wide variety of temperature sensors employed — all necessitating the use of continuously evolving “homogenization” techniques. Atmospheric measurements are preferable.

Satellite measurement of global temperatures began in 1979. The full 40+ year record of lower atmospheric temperature in Figure 4.3 shows an average rate of warming of 0.14°C per decade. The years 2021 and 2022 experienced global cooling resulting from La Nina conditions. La Niña is the opposite phase of the more famous El Niño Southern Oscillation (ENSO), a cyclic pattern of the surface waters in the eastern tropical Pacific Ocean. During La Niña, there is a net transfer of heat from the atmosphere to the oceans, while during El Niño phases, the net heat transfer runs in the opposite direction. Recently, 2023 has seen a switch to (warming) El Niño conditions.

Remote Sensing Systems also provide global atmospheric temperature measurements that show a somewhat higher rate of warming. Averaging the two satellite temperature measure-

El Niño phases typically occur every three to five years and cause a net heat transfer into the atmosphere.

ment systems results in an observed warming rate of around 0.17°C per decade. This rate of warming implies that we would expect a little more than another 1°C of warming by the end of the 21st century. This is in addition to the roughly 1.2°C of warming that the world has seen over the last century. Economists most often estimate the impacts of climate change based on the total warming from pre-industrial times. (We discuss these projections in the Climate Change Economics section, page 114).

After increasing global temperatures, the principal concerns are sea level rise and extreme weather events. We include the data here on sea level rise over two different time scales and with two different measurement technologies. Tide gauges are the longest direct instrumental record of global sea level rise. Figure 4.4 shows a roughly 150-year tide gauge record of changes in global average sea level. The modern rise in sea level began in the middle of the 19th century as the Little Ice Age ended and the planet started warming. It shows an average rate of rise of a little less than one inch per decade.

The data set quality is limited by the number of tide gauges, as there were fewer in the early years of the record. Despite this limitation, the data provides a worthwhile longer-term perspective on sea level trends. From indirect proxy records, we also know that sea levels have risen around 400 feet since the end of the last glaciation nearly 20,000 years ago. The earth is a dynamic and ever-changing system.

Figure 4.5 shows changes in sea level as recorded by satellites, a time series that begins in 1993. It shows a relatively constant rate of sea level rise over its 30-year record of a little over one inch per decade (1.3 inches per decade). The discrepancy between the rates of

Figure 4.4

Global Mean Sea Level Variation 1700–2022

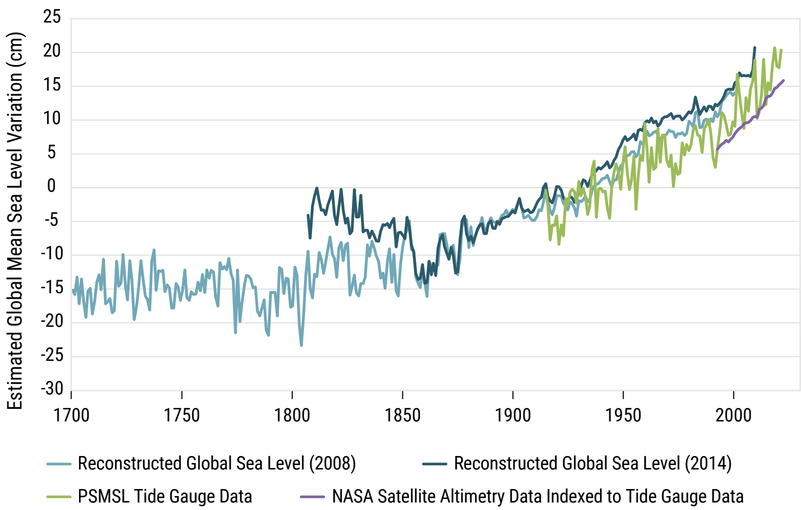


Figure 4.5

Mean Sea Level Rise from Satellite Data 1993–2022

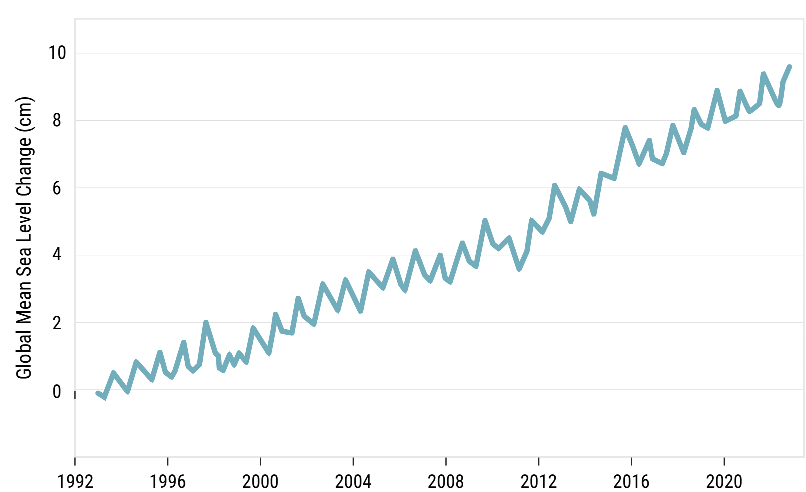


Figure 4.4 — NOAA, NASA, Bijou Insights. 2008 - S. Jevrejeva, J. C. Moore, A. Grinsted, P. L. Woodworth, Recent global sea level acceleration started over 200 years ago?, April 30, 2008; https://doi.org/10.1029/2008GL033611. 2014 - S. Jevrejeva, J.C. Moore, A. Grinsted, A.P. Matthews, G. Spada, Trends and acceleration in global and regional sea levels since 1807, Global and Planetary Change, Volume 113, 2014, Pages 11-22, ISSN 0921-8181, https://doi.org/10.1016/j.gloplacha.2013.12.004

Figure 4.5 — Nerum, R.S., et al. Climate-Change–Driven Accelerated Sea-Level Rise Detected in... - PNAS. Earth, Atmospheric, and Planetary Sciences, 12 Feb. 2018, "Sea Level." NASA, NASA, 18 July 2022, Jet Propulsion Laboratory. "Satellite Mission Keeps a Steady Eye on Sea Level Change from Space." SciTechDaily, Jet Propulsion Labratory, 15 July 2020

Polar Bear Population On the Rise

In the 1960s, the estimated polar bear population was about 12,000. Today, the U.S. Fish and Wildlife Service estimates the population at 26,000.

rise from satellite and tide gauges is visible in the most recent data and is likely from the different measurement mechanisms employed. It can be concluded, with a degree of confidence, that sea levels are currently rising at a global average rate of a bit more than one inch per decade, with no significant change in the rate of rise over the last few decades.

It must be emphasized that this observation refers to the "global average," as there are significant geographical variabilities in sea level change across the earth. At the end of the last glaciation (10,000 to 20,000 years ago), the massive, mile-thick ice sheets melted off the northern parts of North America, Europe, and Asia. As this weight was removed from the surface of the continental plates, there began an uneven rebound in the height of the land relative to sea level. For example, the sea level near San Francisco and along the U.S. West Coast is roughly static; it is rising at about the global average rate on the U.S. East Coast, and on Australia's West Coast, it rises more rapidly than the global average. Since rising sea level threatens coastal cities and their fresh-water aquifers, it is important to understand what is happening locally so that appropriate action can be evaluated.

Extreme Weather

Extreme weather features prominently in the news, perhaps due to the sense of fear and awe inspired by natural phenomena. This fear is understandable: extreme weather has killed millions of people over the years, displacing and impoverishing countless more. Fortunately, to date, there is no observed increase in the key extreme weather events: hurricanes, tornadoes, floods, and weather-related drought. Fortunately, there has been a dramatic decline in the most important metric of deaths from extreme weather events as a wealthier, more energized world is far more resilient and adaptable.

Cyclones & Hurricanes

Figure 4.6 shows the trend since 1970 in Accumulated Cyclonic Energy (ACE), a metric that captures the frequency, duration, and intensity of global hurricane activity.

Figure 4.7 shows a different hurricane metric: the trend in the number of global land-falling hurricanes since 1970.

Figure 4.6

Global Tropical Cyclone Accumulated Cyclonic Energy (ACE)

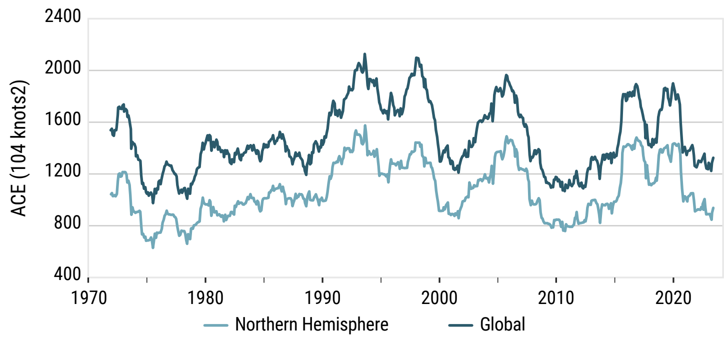


Figure 4.6 — Maue, Ryan. "Global Tropical Cyclone Activity: Ryan Maue." Global Tropical Cyclone Activity , 2023.

Figure 4.7

Global Tropical Cyclone Landfalls 1970–2022

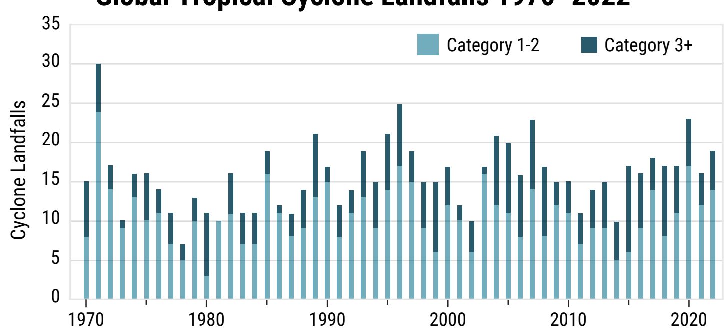
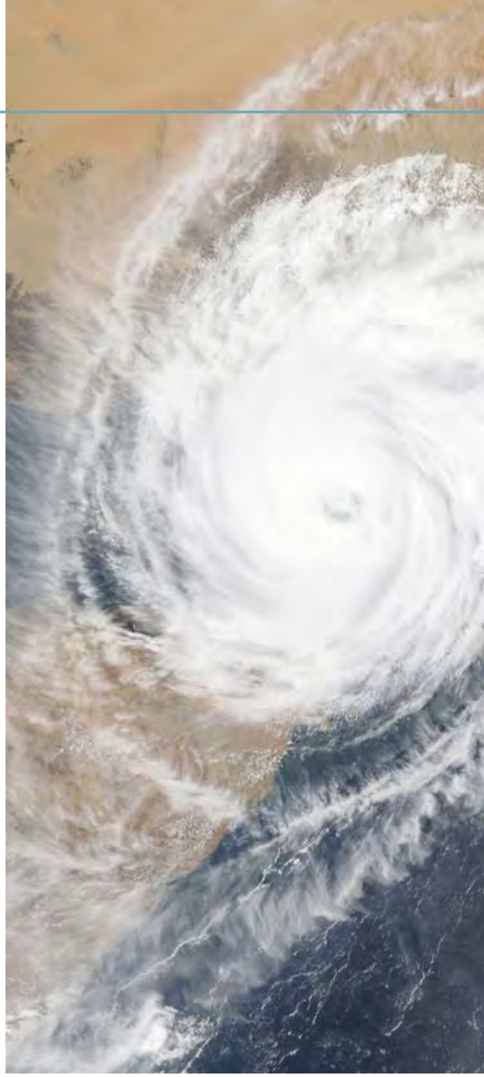


Figure 4.7 — Jr., Roger Pielke. Global Hurricane Landfalls 1970 to 2022, The Honest Broker by Roger Pielke Jr., 18 Jan. 2022. ; NOAA Hurricane Research Division, Colorado State University Tropical Meteorology Project



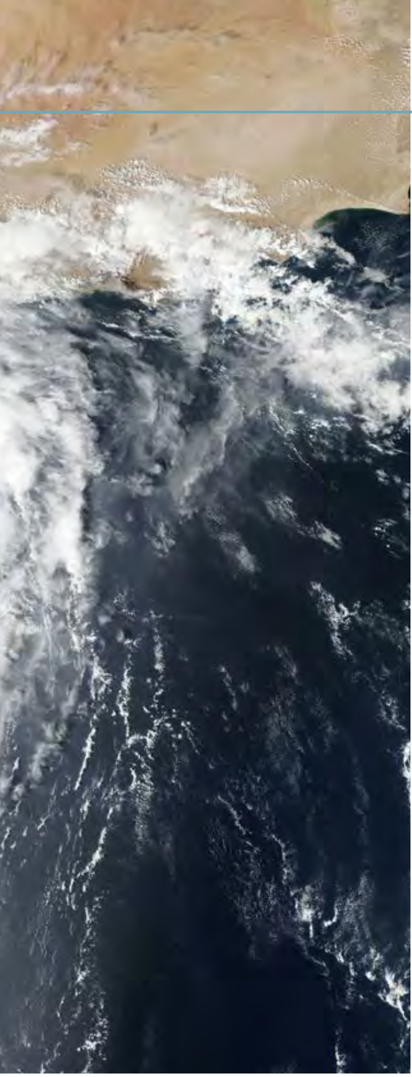


Figure 4.8

Continential U.S. Landfalling Hurricanes 1900–2023

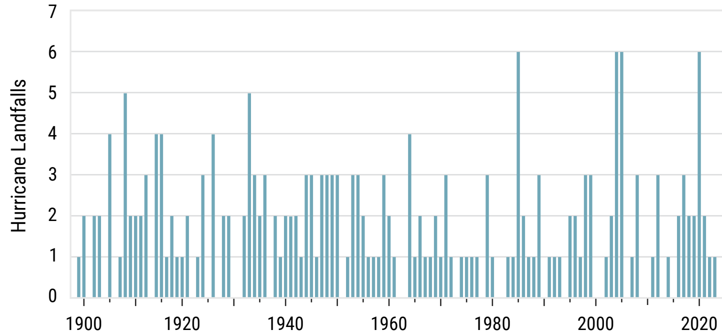


Figure 4.8 — "US Hurricane Landfalls." Atlantic Oceanographic and Meteorological Laboratories. ; Jr., Roger Pielke. "U.S. Hurricane Overview 2023."

Figure 4.8 shows the same metric for the United States dating all the way back to 1900.

As one can see from these figures, while there is large annual variability in hurricane activity, the data show no obvious rising trend. The year 2023 saw only a single U.S. landfalling hurricane (Idalia) with less than $1 billion in total damages, which is far less than the over $20 billion average seen in recent years.

Figure 4.9

U.S. Strong to Violent Tornadoes (>F3) 1950–2022

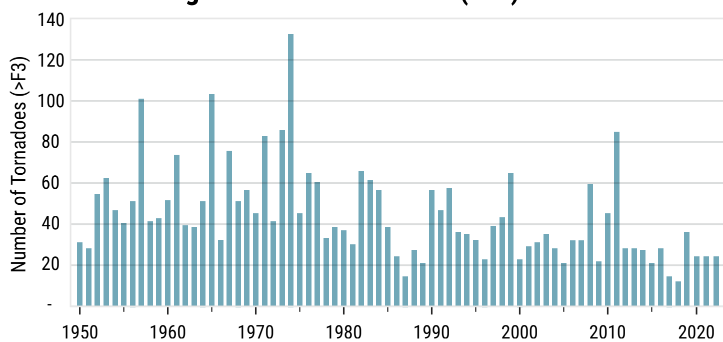


Figure 4.9 — "Storm Prediction Center WCM Page." Storm Prediction Center.

Tornadoes

Figure 4.9 shows the frequency of severe tornadoes in the United States since 1954. Fortunately, the trend here appears to be downward.

Figure 4.10

Global Area in Severe Meteorological Drought 1901–2017

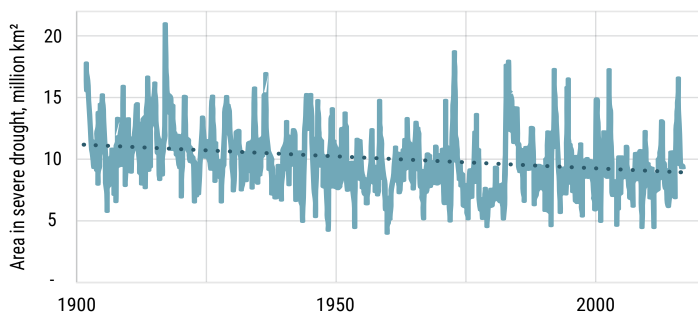


Figure 4.10 — Lomborg, Bjorn. "Welfare in the 21st Century: Increasing Development, Reducing Inequality, the Impact of Climate Change, and the Cost of Climate Policies." Technological Forecasting and Social Change, North-Holland, 24 Apr. 2020.

Drought

Figure 4.10 shows the percentage of the world experiencing extreme levels of drought, starting in 1900. There appears to be a slight decline in global drought prevalence over the last century, which is to be expected as a slightly warmer world implies a slightly wetter world due to increased evaporation.

CASE STUDY

Drought in the Colorado River Basin

During the 1800s, the earliest explorers of the southwestern United States quickly recognized that its hot, arid climate was the primary obstacle to the development of human-friendly conditions on which a society could thrive. In 1810 Zebulon Pike labeled the region as "The Great American Desert." Later that century, John Wesley Powell led multiple expeditions throughout the American West. Powell subsequently published a Report on the Lands of the Arid Regions of the United States in 1879, in which he argued the southwestern U.S. should be developed with great caution and that borders should be based on watersheds boundaries to minimize inevitable conflicts over the right to and use of the region's most scarce resource — water.

Almost 150 years later, Powell's warnings have proven prophetic.

Beginning in 1906, Colorado River flows began to be measured with gauges at Lees Ferry, Arizona. Armed with 15 years of "reliable data" that suggested a baseline river flow of 16.4 million acre-feet / year (MMac-ft/yr), the architects of the Colorado River Compact of 1922 allocated water rights for 15 MMac-ft/yr amongst seven states which had a combined population of almost six million.

Since 1922, average river flows of 14 MMac-ft/yr fell short of the Compact's baseline. Far more dramatic was the 10-fold increase in combined population in the seven states, now at over 60 million. Further, the region just emerged from 23 years of severe drought during which river flows averaged 12.2 MMac-ft/yr. The recent drought laid bare the original sin in 1922 of over-allocating water rights based on an extremely limited history of gauged river flow data. With the benefit of 116 years of gauge measurements and increasingly sophisticated science that now reconstructs river flows for the past 2,000 years, average river flows of the early 1900s were likely the highest in reconstructed or measured history (Figure 4.11).

Furthermore, as Figure 4.11 illustrates, there have been seven multi-year periods during the last 2,000 years where the reconstructed flows of the Colorado River have been below the average flows experienced during the just ended drought. All seven of these drought periods were well before human activities began to harness the energy of fossil fuels and the resulting impacts already discussed in the Climate Change Section of this report. In fact, there is no observable correlation between average reconstructed and measured river flows and the concurrent global temperature record recognized by the IPCC or regional temperature record reconstructed from tree ring data.

Figure 4.11

Colorado River Upper Basin Reconstructed & Measured River Flow at Lees Ferry, AZ

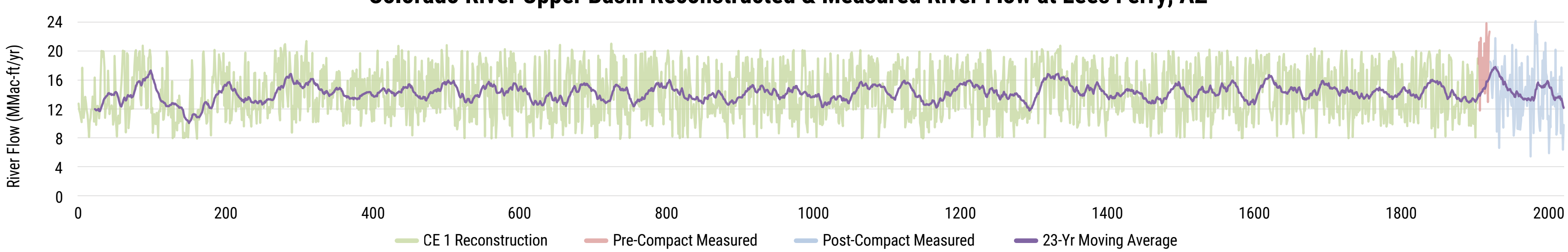


Figure 4.11 — Bijou Insights analysis based on U.S. Bureau of Reclamation data (1906+ CE) and Gangopadhyay, S.; Woodhouse, C.A.; McCabe, G.J.; Routson, C.; Meko, D.M. (2022-03-07): NOAA/WDS Paleoclimatology - Ensemble Streamflow Reconstruction for the Colorado River at Lees Ferry, AZ; Time Period, Water Years 1-1905 CE. NOAA National Centers for Environmental Information. https://doi.org/10.25921/6vba-4g33. Accessed June 2023.

Figure 4.12

Colorado River Flow vs Temperature

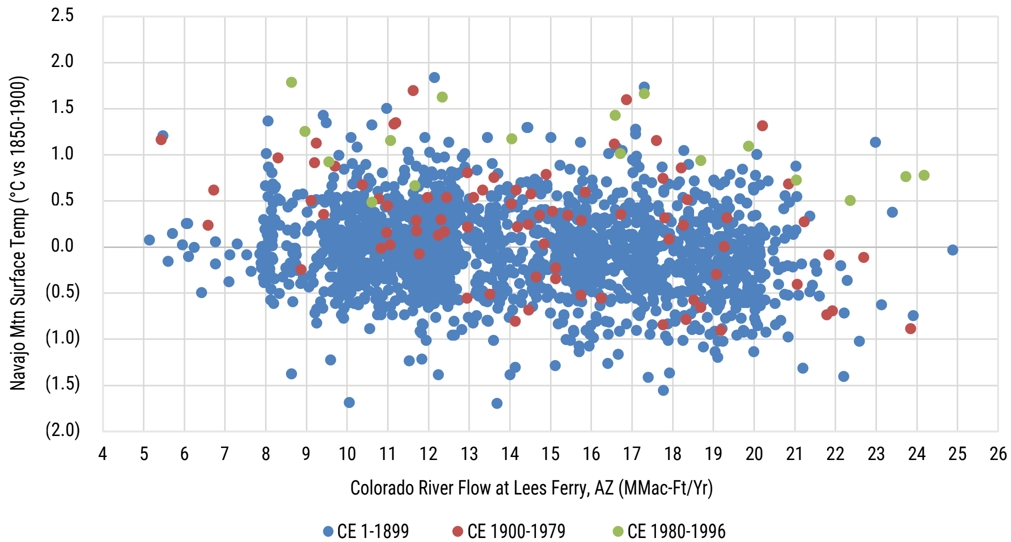


Figure 4.12 — Bijou Insights analysis based on (1) U.S. Bureau of Reclamation data (1906+ CE), (2) Gangopadhyay, S.; Woodhouse, C.A.; McCabe, G.J.; Routson, C.; Meko, D.M. (2022-03-07): NOAA/WDS Paleoclimatology - Ensemble Streamflow Reconstruction for the Colorado River at Lees Ferry, AZ; Time Period, Water Years 1-1905 CE. NOAA National Centers for Environmental Information. https://doi.org/10.25921/6vba-4g33. Accessed June 2023, and (3) Salzer, M.W. and K.F. Kipfmueller. 2005. Reconstructed Temperature and Precipitation on a Millennial Timescale from Tree-Rings in the Southern Colorado Plateau, U.S.A. Climatic Change, 70(3), 465 - 487. doi: 10.1007/s10584-005-5922-3.

Figure 4.12 clearly shows that there were high and low river flow years in both cold years and in warm years. The local temperature and river flow show no correlation at all.

This observation is confirmed by significant disagreement related to temperature attribution and considerable uncertainty of its impacts to the Colorado River flows offered by the latest scientific research. On a global scale, the latest IPCC report indicated low confidence in the assessment of trends in river flows and changes in drought that could be attributed to human influence. Despite the wide array of scientific opinions on the topic, policymakers and the media frequently blame the severity and duration of the recent drought solely on rising temperatures and suggest the river system will not survive if we do not eliminate emissions from fossil fuels. A brief study of the river's extended history quickly dispels this misguided conclusion which, unfortunately, serves as a core justification of their energy policy agenda. However, the challenge remains: How to manage water in the seven-state arid region that has seen a ten-fold growth in population since the original Compact was formed and no apparent slowing of this trend.

Floods

Floods are harder to quantify except in terms of their economic damage. Flood damage in the United States since 1940 is shown as a percentage of GDP shown in Figure 4.13. There is a significant downward trend, more likely due to better flood preparedness than an actual reduction in floods or extreme rain events. With the availability of abundant and reliable energy, humans have been better able to predict, prepare, and sometimes even prevent these deadly and costly flooding events.

Figure 4.13

U.S. Flood Damage as Percentage of GDP 1940–2019

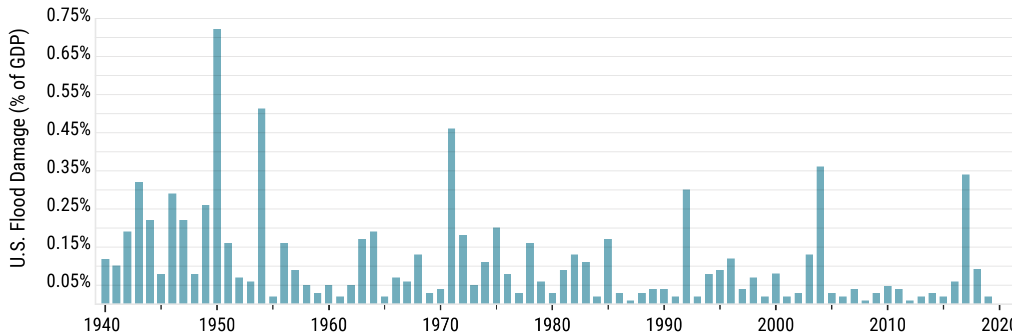


Figure 4.13 — Downton, Mary W., et al. "Reanalysis of U.S. National Weather Service Flood Loss Database: Natural Hazards Review: Vol 6, No 1." Natural Hazards Review, American Society of Civil Engineers, 1 Feb. 2005. ; Contribution of Historical Precipitation Change to US Flood... - Pnas. ; Jr., Roger Pielke. "Global Disasters: A Remarkable Story of Science and Policy Success." The Honest Broker Newsletter, The Honest Broker Newsletter, 14 Jan. 2021.

Extreme Weather & Global GDP

Damages from extreme weather events as a percentage of global GDP have declined by roughly 20% over the last three decades, in contrast to frequent proclamations of rising weather disasters. These proclamations are spurred by an annual NOAA report that documents a rising trend in "billion-dollar disasters." However, inflation and rising wealth automatically lead to increasing billion-dollar disasters unless extreme weather is rapidly decreasing. An honest evaluation of extreme weather costs requires GDP normalization.

Figure 4.14

Global Weather Disaster Losses as Percent of Global GDP 1990–2023

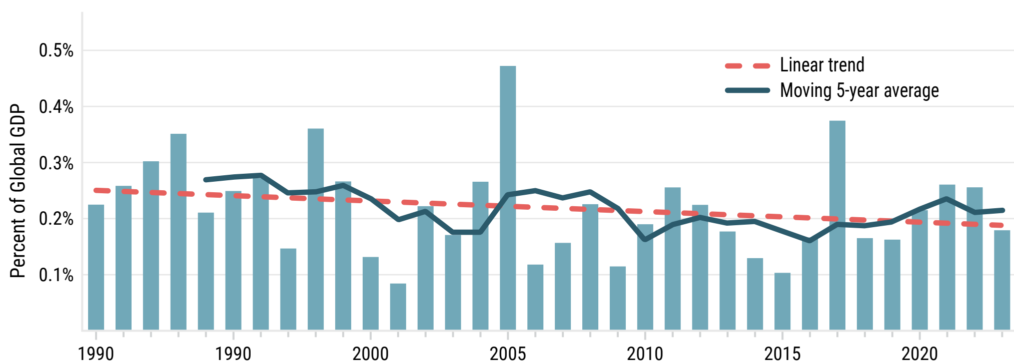


Figure 4.14 — Roger Pielke, Jr., Munch RE, 2023. NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2024).

Wildfires

Wildfires are intimately tied to forest management practices. In August 1910, the "Big Burn" in western Montana and northern Idaho covered an astonishing three million acres in just two days and killed 78 firefighters. This terrible and tragic event radically altered the national psyche in its attitude towards the ever-present natural phenomenon of wildfires, affecting not only the U.S. Forest Service and policymakers but the wider American public. This led to an extremist policy aimed at preventing and fighting wildfires above all else, with long-term counterproductive consequences.

A study of western U.S. Forests by U.S. Forest Service scientists concluded that increased "live fuel" due to changing forest management practices was responsible for more than 50% of the recent increase in wildfires. From 1977 to 2017, forested areas in the U.S. grew by 3%, yet forest wood volume grew by 34% during this period. Without active forest management, the fuel load for wildfires has grown significantly.

Figure 4.15 shows 100 years of U.S. Forest acres burned annually. In the 1930s, wildfires burned several times more acres every year than they do today. This graph also illustrates the dramatic impact of the U.S. Forest Service

Figure 4.15
U.S. Wildfire Acres Burned 1926–2023

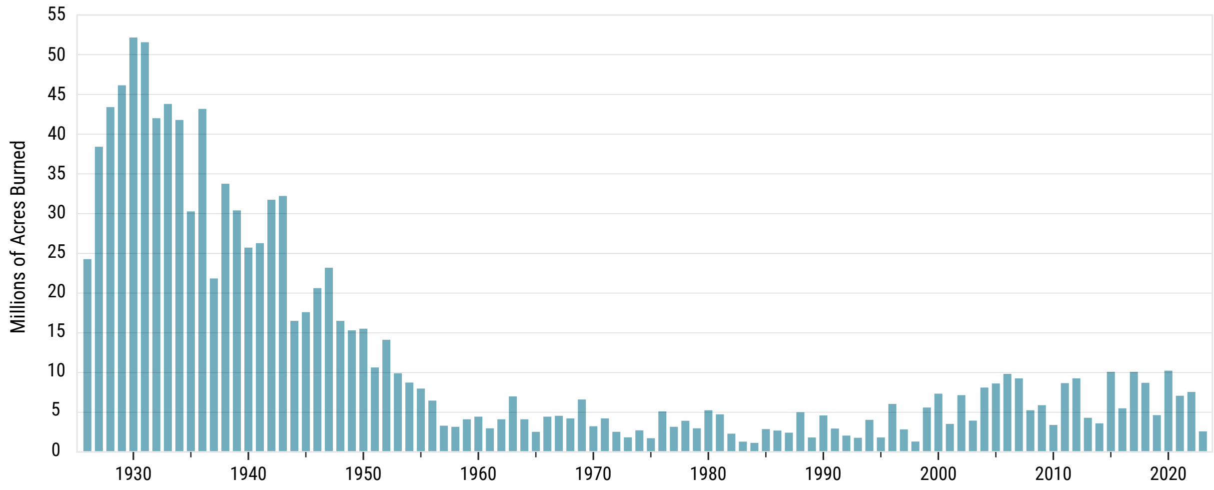
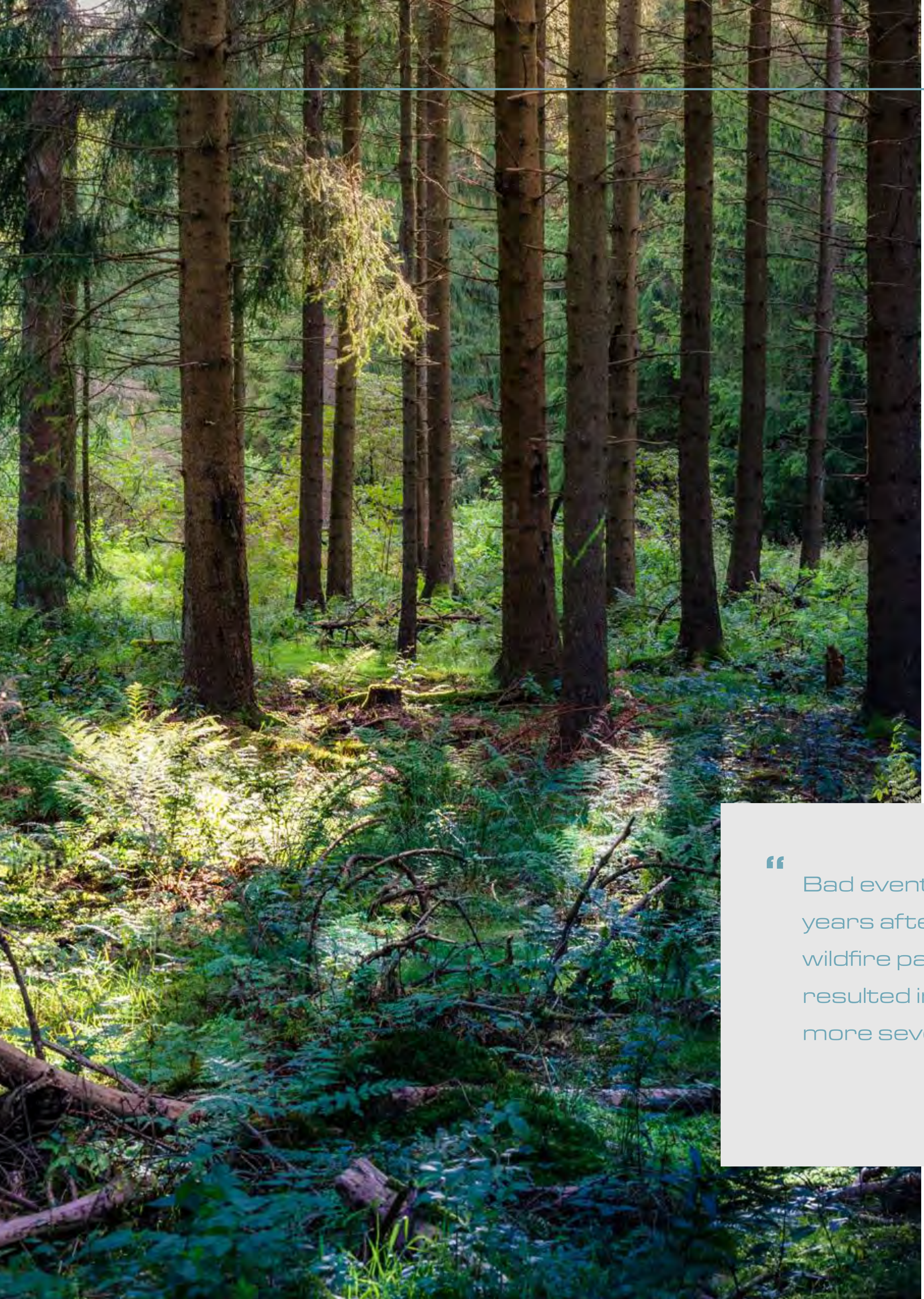


Figure 4.15 — National interagency Fire Center, Roger Pielke, Jr.



Smokey Bear campaign, launched in the 1940s, to expand fire prevention by enlisting the public in its efforts to prevent and quickly extinguish wildfires. Multiple regulatory changes from the 1960s onwards made it increasingly difficult to perform basic forest management practices like tree thinning, clearing undergrowth, and, importantly, controlled burns. Fortunately, the political will to address forest management practices appears to be growing. However, reversing 100 years of mismanagement will take significant time and resources, although 2023 saw the fewest acres burned in the U.S. during the 21st century. However, the risk of wildfires remains elevated as improved forest management practices are still more talked about than practiced.

> "Bad events create bad policy. Today, more than 100 years after the Big Burn, we are left with our current wildfire paradox: Decades of fire suppression have resulted in accumulated fuels that lead to larger and more severe wildfires that cannot be suppressed."
>
> — Brian Yablonski, PERC Executive Director

Extreme Weather's Impact

By far, the most important factor regarding extreme weather is the impact it has on human lives. Here, the trend is manifestly positive. Figure 4.16 shows the dramatic decline in the deadliness of extreme weather events. There has been a greater than 90% decline in annual global deaths from extreme weather during the last century while the world population has quadrupled over the same period. The downward trend in deaths from extreme weather continues unabated, with the last few years falling even further!

Wealthier societies with abundant access to affordable energy are simply far safer places in which to live. The large majority of the remaining deaths resulting from extreme weather are concentrated in low-income nations with high rates of both poverty and energy poverty, which are nearly synonymous. Improving energy access for the poor, as discussed previously, is the key to further reducing the risk to human lives from extreme weather.

While climate change is both broad and complicated, familiarity with basic science and empirical data is highly valuable and, unfortunately, quite scarce. This brief section is included to provide an introductory overview of the chemistry, physics, and empirical data surrounding the central climate change issues. The following section on Climate Economics touches on the work of economists to quantify the potential human impacts of climate change now and in the future.

Figure 4.16

Global Deaths from Severe Weather 1920–2020

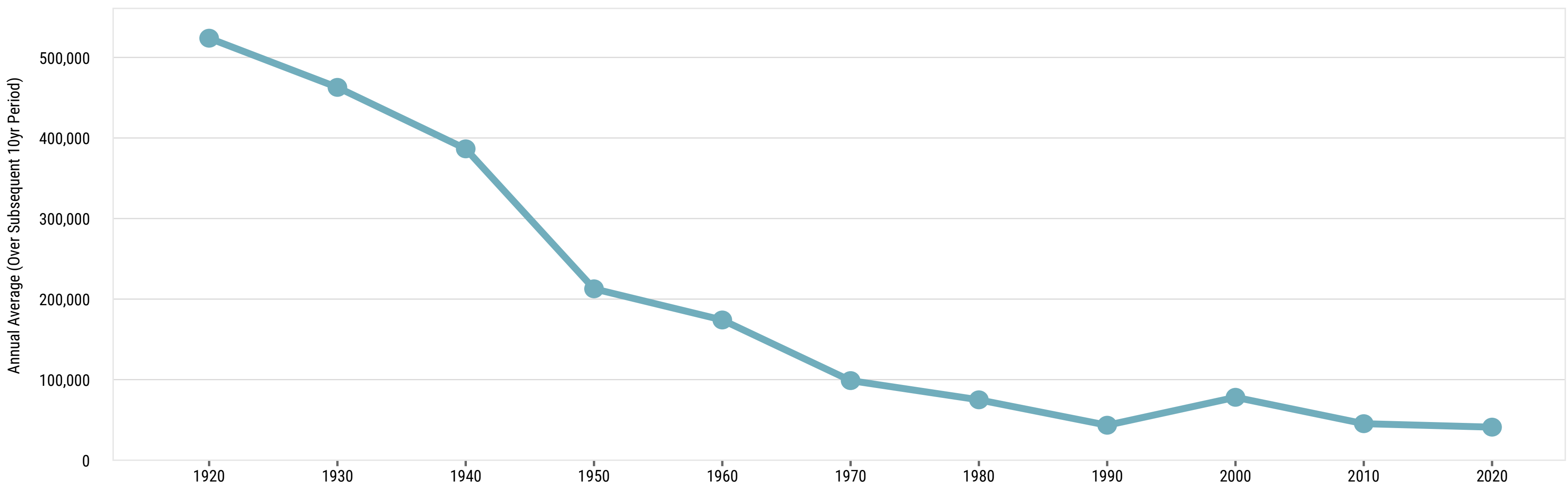


Figure 4.16 — "EM-DAT: The International Disasters Database." EM-DAT, Centre for Research on the Epidemiology of Disasters (CRED). ; Lomborg, Bjorn. "Welfare in the 21st Century: Increasing Development, Reducing Inequality, the Impact of Climate Change, and the Cost of Climate Policies." Technological Forecasting and Social Change, North-Holland, 24 Apr. 2020.

SECTION SUMMARY POINTS

- A higher atmospheric concentration of CO_2 is leading to a warmer, wetter, and greener planet.
- Sea levels are rising at a global average rate of a bit more than one inch per decade, with no significant change in the rate of rise over the last few decades.
- There are no notable trends in hurricane, tornado, flood, or drought frequency or severity.
- Global deaths from extreme weather have plummeted for over a century with cold-related deaths far outnumbering hot weather deaths.

CLIMATE ECONOMICS

The Cost of Climate Change | Future Adaptation & Mitigation | Net Zero is the Wrong Goal

Climate Economics

Climate economics is a rich and relevant topic in the energy industry. There are numerous complexities, such as territorial greenhouse gas emission targets that localize the costs but socialize the benefits across the whole planet. For example, if the U.S. were to rapidly decarbonize its entire economy, as many advocate, the costs would be counted in the trillions of dollars and the benefits to the U.S. would be rather modest. The United Nations' Intergovernmental Panel on Climate Change (IPCC) predicts that a rapid and complete de-carbonization of the U.S. economy would result in a less than 0.1°C reduction in global temperatures by 2100. For the U.S. to realize any material benefits, emissions must be reduced globally. This territorial problem is even more stark at the individual U.S. state level which, unfortunately, hasn't prevented many states from passing legislation with territorial emission targets. It is very difficult to imagine that any state-level emission reduction mandate could have benefits to their residents that exceed the costs.

The Cost of Climate Change

The recent IPCC Assessment Report 6 (AR6) provided — almost certainly incomplete — estimates of economic damage from a cumulative 2°C of warming from pre-industrial times. The report estimates that global per capita income would decline by somewhere between 0.2% and 2.0%. The large range is indicative of the fact that attempting to predict the economic impacts of climate in the coming century is immensely challenging. Nevertheless, for the sake of argument, we accept these estimates as a starting point for discussion.

The world is estimated to have so far warmed about 1.2°C since pre-industrial times. At the current observed rate of warming of 0.17°C/decade from averaging the satellite data, we would expect to hit 2°C total warming around 2070. It is possible that the rate of global warming may increase in the future, or it may decrease.

Nobel Prize-winning climate economist, William Nordhaus, analyzed a scenario at the upper end of the IPCC warming projections where the temperature rises by 3.5°C at the end of the 21st century, even after what Nordhaus calculates as optimal emissions mitigation efforts are undertaken. Nordhaus' Nobel Prize winning work calculated an optimal response to climate change, meaning only taking actions that provide benefits greater than their costs. His conclusion was that only limited cost-effective options were available, and that adaptation was the main appropriate response to the slow-moving impacts from climate change.

The scenario analyzed by Nordhaus, with future warming more rapid than currently being observed, is included in the figure included in the CEO letter at the front of this report (Figure C) and repeated here (Figure 5.1). The estimated current and future climate economic impacts are plotted together with impacts from malnutrition, air pollution, disease, illiteracy, and gender inequality. Nordhaus estimates a less than 1% economic impact from climate change through 2050, rising to over 3% by 2100 with 3.5°C of warming.

Figure 5.1

How Much Richer Would the World be Had We Solved Different Issues 1900–2050

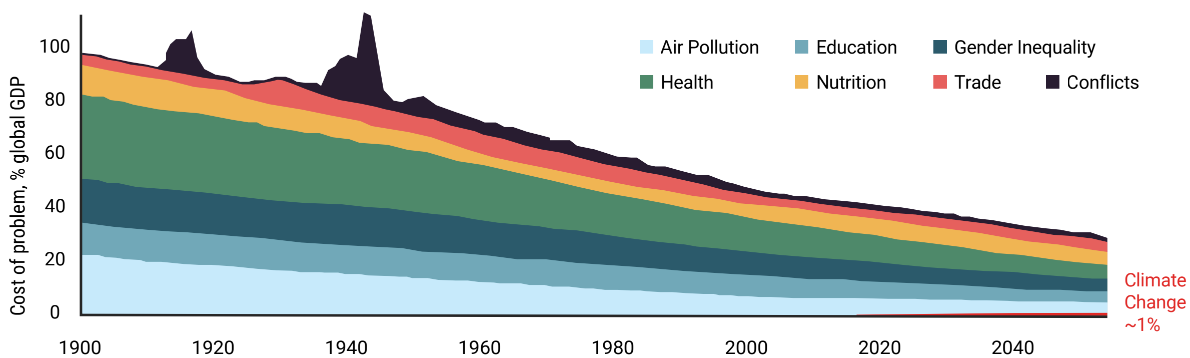


Figure 5.1 — Lomborg, Bjorn. "Welfare in the 21st Century: Increasing Development, Reducing Inequality, the Impact of Climate Change, and the Cost of Climate Policies." Technological Forecasting and Social Change, vol. 156, 2020, p. 119981.

Figure 5.2

Total Impact from Temperature Increase Measured in Percent of Global GDP

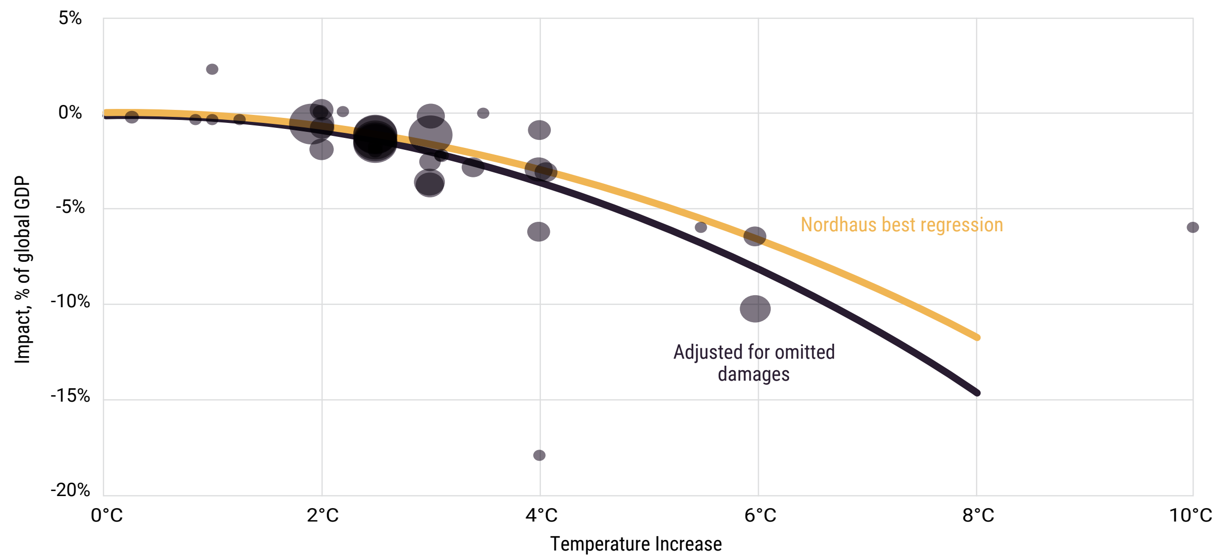


Figure 5.2 — Lomborg, Bjorn. "Welfare in the 21st Century: Increasing Development, Reducing Inequality, the Impact of Climate Change, and the Cost of Climate Policies." *Technological Forecasting and Social Change*, North-Holland, 24 Apr. 2020.

It is difficult to see nearly a century into the future with any confidence. However, if we accept these predictions, we must grant that while the projected economic impacts of climate change are global and large in gross dollar magnitude, they pale in significance to the challenges facing the one-third of humanity which still live in dire energy poverty. Poverty is a pressing and acute problem today, while the hazards of climate change are distant and uncertain.

To put this in concrete terms, the lack of access to clean cooking fuels alone is estimated to cause two to three million annual deaths. Climate change, by comparison, is probably resulting in a modest reduction in annual deaths, despite media proclamations of dramatic threats to human health from rising temperatures and extreme weather. The century-long decline in deaths from extreme weather has already been noted. Although deaths from extreme heat have likely risen, those deaths are almost certainly more than offset by a reduction in the number of deaths from extreme cold, which are globally roughly eight times greater in number than deaths from extreme heat. While there may well be impacts from climate change in the present day, these are quite modest compared to the terrible effects of energy poverty.

Figure 5.2 is a compilation of work by various climate economists projecting economic impacts from climate change over a wide range of possible future warming magnitudes. One thing that stands out is the broad agreement among the various economists that the economic impacts today and over the next few decades from climate change are likely to be modest. Climate change impacts are projected to rise to a few percentage point reductions in per capita income after temperature rises of 2°C–4°C, perhaps by late this century or early next century.

The time scale for energy poverty, on the other hand, is urgent and now. Growing global energy production coupled with sober energy policy could bring extreme energy poverty to an end before the year 2050. In this same period, we could also make major progress on energy technology to allow decarbonization over the latter half of the century without needless impoverishment.

Future Adaptation & Mitigation

These next few decades will likely see tremendous progress in low-carbon energy technologies, including reliable on-demand (non-intermittent) sources such as advanced nuclear, next-generation geothermal, economic Carbon Capture Use and Storage (CCUS), and possibly meaningful progress in energy storage. The main response to climate change so far, and likely the main response for decades to come, is adaptation. Pre-modern humans survived multiple glaciations with simply massive temperature and climate swings. Modern humans are vastly better equipped to deal with climate change today. Adaptation will happen in all scenarios. Mitigation efforts will depend on energy technology, policy, and social acceptance.

Figure 5.3

Annual CO_2 Emissions by World Region

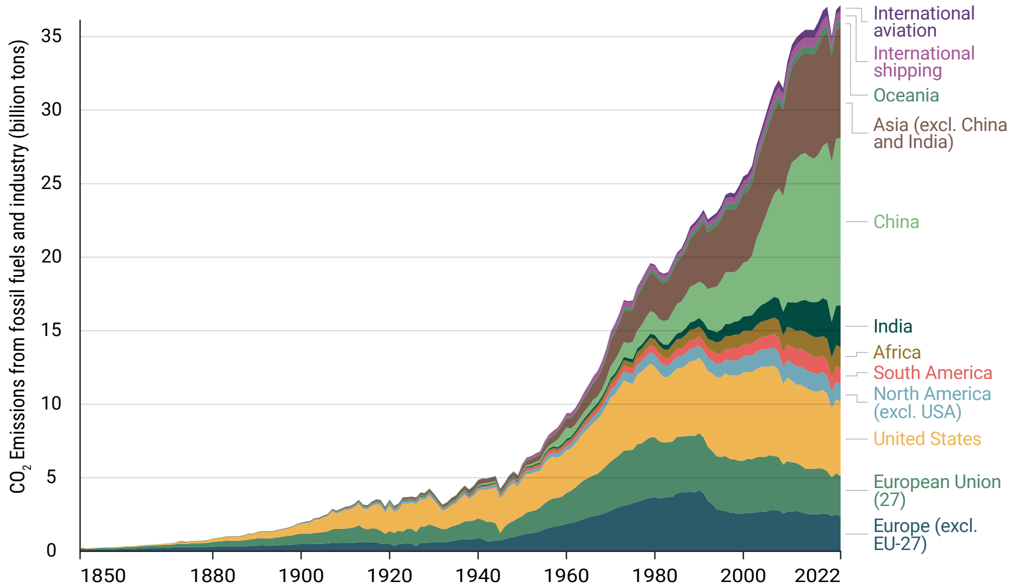


Figure 5.3 — Our World in Data based on the Global Carbon Project

Figure 5.4

Annual CO_2 Emissions from OECD and Non-OECD Countries 1850–2022

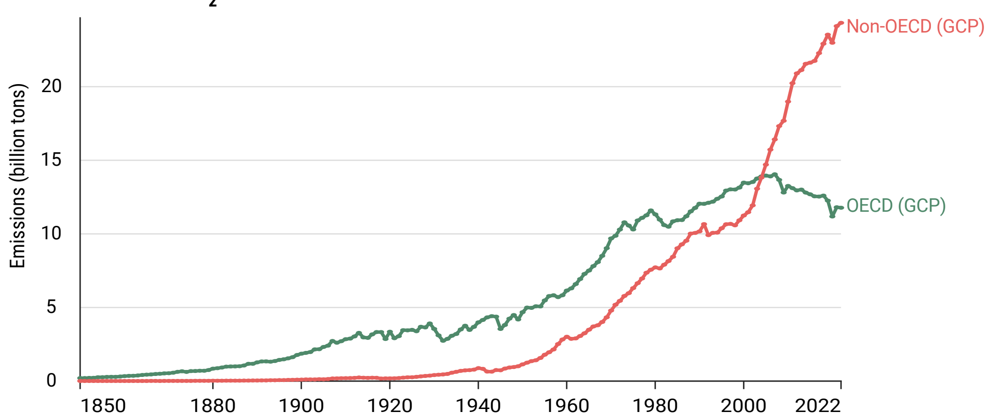


Figure 5.4 — Global Carbon Budget (2023)

Greenhouse gas mitigation efforts have been concentrated in the electricity sectors of wealthy countries. However, nearly all projected growth in emissions is in countries outside the advanced economies of the Organization for Economic Co-operation and Development (OECD).

Figure 5.3 shows global greenhouse gas emissions since 1850 broken down by major regions and countries. While the wealthy countries of the OECD have been reducing emissions for 20 years, those in non-OECD countries are rising as they energize their societies and improve their standards of living – see Figure 5.4. Further, the emission reduction efforts within the OECD have tended to increase energy costs, therefore failing to provide developing cultures with an economically enticing option to lower emissions. This must change if climate mitigation is to spread globally.

CONCLUSION

Net Zero 2050 is the Wrong Goal

This report has gone into detail about how the world is energized and how that has evolved over time and impacts everyone's quality of life. The overriding message is that too much of today's political and social pressures are pointing in the wrong direction. A myopic focus on only one factor cannot lead to a favorable outcome. If we broaden our lens to bettering lives and expanding opportunities for everyone, a different direction emerges.

The energy systems in societies are simply vital to the range of possibilities open to their citizens. Many societies simply don't have the energy systems available to open the door for healthy, prosperous lives for their citizens. Meanwhile, existing energy systems are being undermined to such an extent that industries are being outsourced and standards of living are being compromised for little apparent climate benefit. Energy systems should not be politically altered without a clear evaluation of the tradeoffs.

The world would benefit from a massive increase in energy research and innovation as opposed to simply massive subsidies for existing technologies that are not up to the task. Across the board innovation is the only road to more energy and better energy — energy with lower emissions and improved affordability. This will take time and concerted effort. Artificial urgency and timelines have been counterproductive.

> The global rallying cry for Net Zero 2050 should be reevaluated and replaced with a more humane and achievable goal: Zero Energy Poverty 2050.

Today's careless obsession with Net Zero 2050 is the wrong goal. In fact, strident pursuit of this goal has been obstructing attempts by the less fortunate to increase their life opportunities. What if the world instead vigorously pursued the eradication of human destitution and energy poverty by 2050?

Human destitution — poverty so severe that an individual lacks sufficient calories, clean water, basic healthcare, and shelter to simply assure survival — was all too common throughout human history. The rise of bottom-up social organization and the explosion in available energy from hydrocarbons have driven down the percent of humanity living in dire poverty from nearly 90% two hundred years ago to roughly 10% today. We should celebrate this tremendous progress.

However, 800 million people are still destitute today. An additional two billion people live with very limited opportunities and shortened lifespans due to energy poverty, specifically the lack of clean cooking and heating fuels. Ending destitution and energy poverty could prevent at least 10 million annual premature deaths from malnutrition, indoor air pollution, and easily preventable endemic diseases. In addition to the enormous lifesaving benefits, energizing the least fortunate would markedly expand the life possibilities for this one-third of humanity born in less fortunate circumstances. Affordable, reliable energy is the road out of poverty. Sober energy and climate policy would raise the standard of living and expand the opportunities for everyone, not just the poor.

Unfortunately, the wealthy world is distracted from humane, achievable goals. Today's energy and focus is on "Net Zero 2050." The goal appears unachievable and perhaps undesirable — certainly on the 2050 timeline. Economic analyses, including those conducted by the United Nations Intergovernmental Panel on Climate Change, estimate that achieving Net Zero 2050 would cost tens of trillions of dollars. Their analysis shows the costs of forcing an energy transition without viable replacement sources — a transition leading to insecurity, unaffordability, and unreliability in the energy supply — vastly overshadow the greatest potential climate change harm reductions by reaching net zero carbon emissions in 2050. We cannot achieve this aggressive climate goal without exacerbating widespread suffering and limiting opportunity for everyone. The narrow focus on Net Zero 2050 threatens immediate life-saving interventions. The cure is far worse than the disease.

At the 2021 Climate conference in Glasgow (COP 26) 20 nations — including the United States, Canada, Germany, and the United Kingdom — pledged to end direct public finance for fossil fuel projects. This will clearly impede efforts in developing nations to produce hydrocarbons or build infrastructure to supply clean cooking fuels, electricity, synthetic fertilizer, and other hydrocarbons critical to their advancement. Inflating energy costs — by reducing access, options, and reliability — guarantees more human suffering. Can the myopic focus on Net Zero 2050 really go so far as to stand in the way of saving millions of lives?

The biggest barriers to eliminating extreme poverty are low-quality, corrupt governance in poor nations combined with the obsession of wealthy nations to achieve Net Zero 2050. We can and must do better by refocusing on humans, particularly those least fortunate. The world can end destitution and energy poverty by 2050 by expanding energy access and affordability. The world needs more energy, better energy.

Liberty on location to frac a 16-well pad in the DJ Basin shale in Ault, CO.

The life-cycle energy produced from the wells on this 5 acre well pad is equivalent to the energy produced by 176 2MW wind turbines that stand 443 feet tall and occupy over 55,000 acres of open space.

Liberty Energy

Liberty was created with one overriding goal: to build a company that brings together great people and provides them with a culture to excel. The Liberty team creates services and technology that truly make a difference in delivering our mission to better human lives. Liberty is a leader in developing and commercializing technology that delivers safer, cheaper, and cleaner energy at scale to the world.

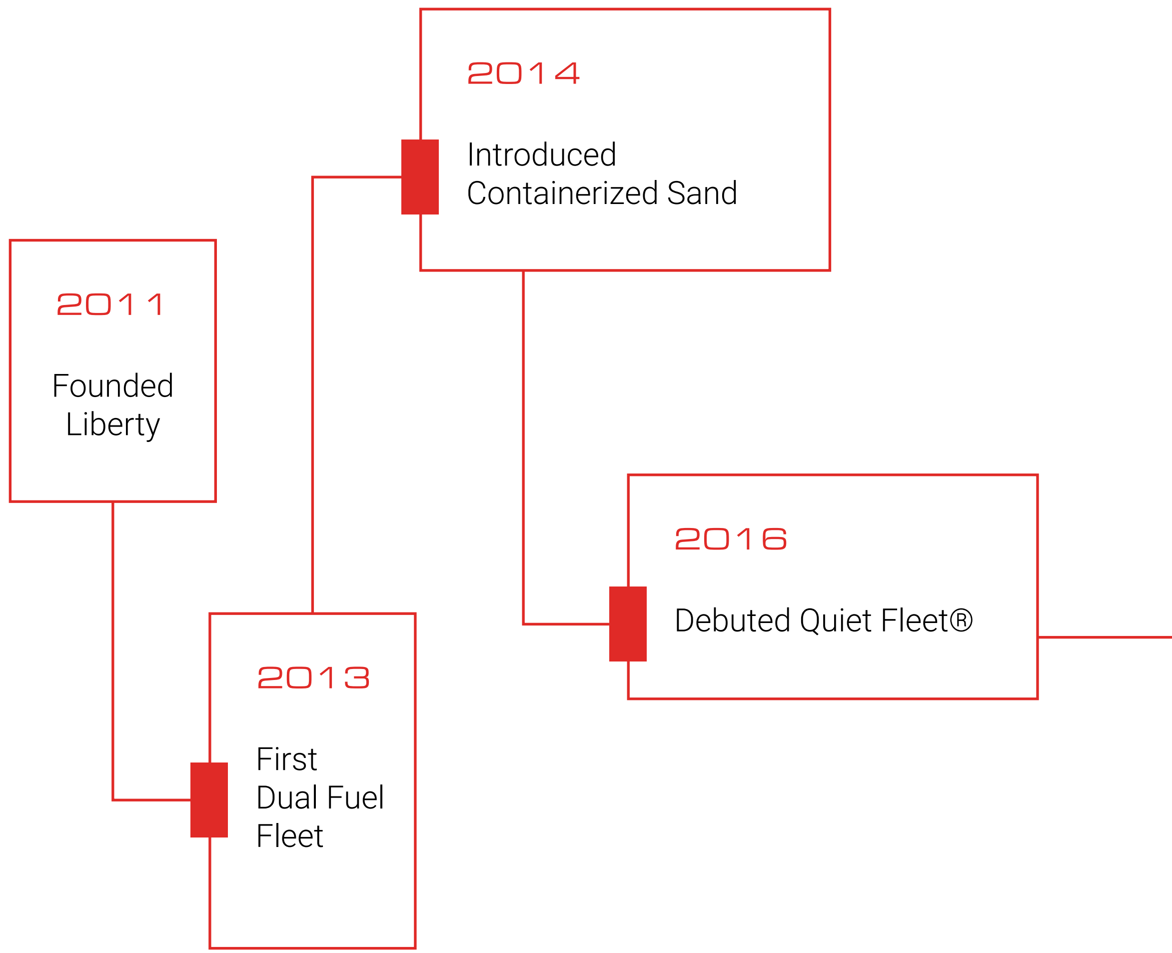
Our primary business operations are on-site hydraulic fracturing services to oil and natural gas producers in the United States and Canada. We work in the Shale Revolution, where hydraulic fracturing has replaced drilling as the largest and most mission-critical of all the steps to construct wells for oil and gas production. Shale production starts with constructing a well pad, which is a few acres of cleared land to site 3 to 30 wells and surface processing equipment.

These few acres of land provide access to several square miles of underground shale rock reservoirs to drain massive amounts of oil and natural gas. Drilling of each well is typically one to three miles vertically downward, followed by a gradual turning of the wellbore horizontally (parallel to the earth's surface) and then one to four miles of lateral wellbore length within the shale rock.

When drilling is completed, hydraulics fracturing of each well takes place. The Liberty section of this report overviews our people and technology that design, construct, and operate all the equipment and systems required to safely enable shale production in the United States and Canada safely.

Our History

Liberty began as a pure-play provider of hydraulic fracturing operations. We have grown into an integrated supplier of all the supporting services that are required to execute the frac operations. Harmonizing these parts into one orchestra is a big part of how Liberty has distinguished itself as the leading completion provider in North America (based on survey data from the industry's top research firm, Kimberlite).



Liberty emphasizes rapid innovation and growth through technology advancements and improved efficiency with mindful vertically integrated business lines.

2018

- Tier IV DGB Caterpillar Field Test Partnership
- Acquired ST9
- Began digiFrac℠ Development

2020

- Acquired SLB's OneStim®
- Added Wireline Service
- Added Freedom Proppant Mines

2021

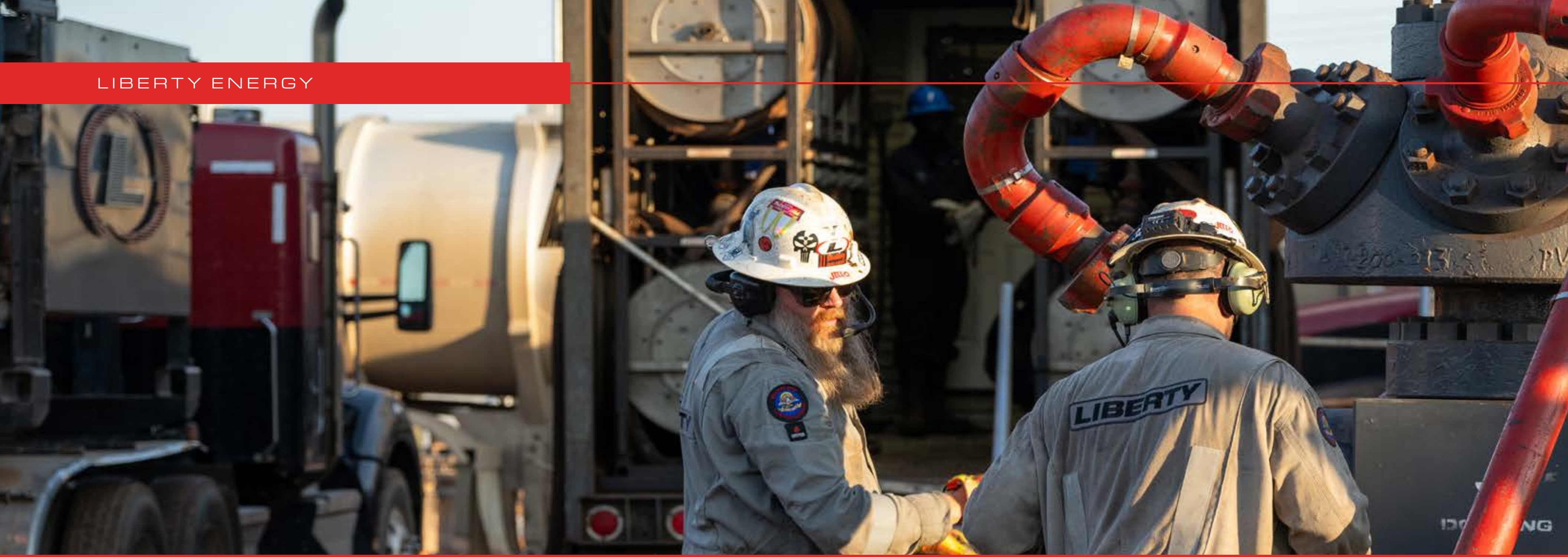
- Acquired PropX

2022

- Began digiPrime℠ Development

2023

- Launched Liberty Power Innovations (LPI)
- Expanded Manufacturing Division with Liberty Advanced Equipment Technologies (LAET)
- Deployed the Complete digiFleet™



DELIVERING SUPERIOR SERVICE

Vertical Integration | digiTechnologies℠ | Equipment Design & Manufacturing | Next-Generation Maintenance | Modular Fuel Supply & Power Generation | Liberty Power Innovations | Supply Chain & Logistics

Delivering Superior Service

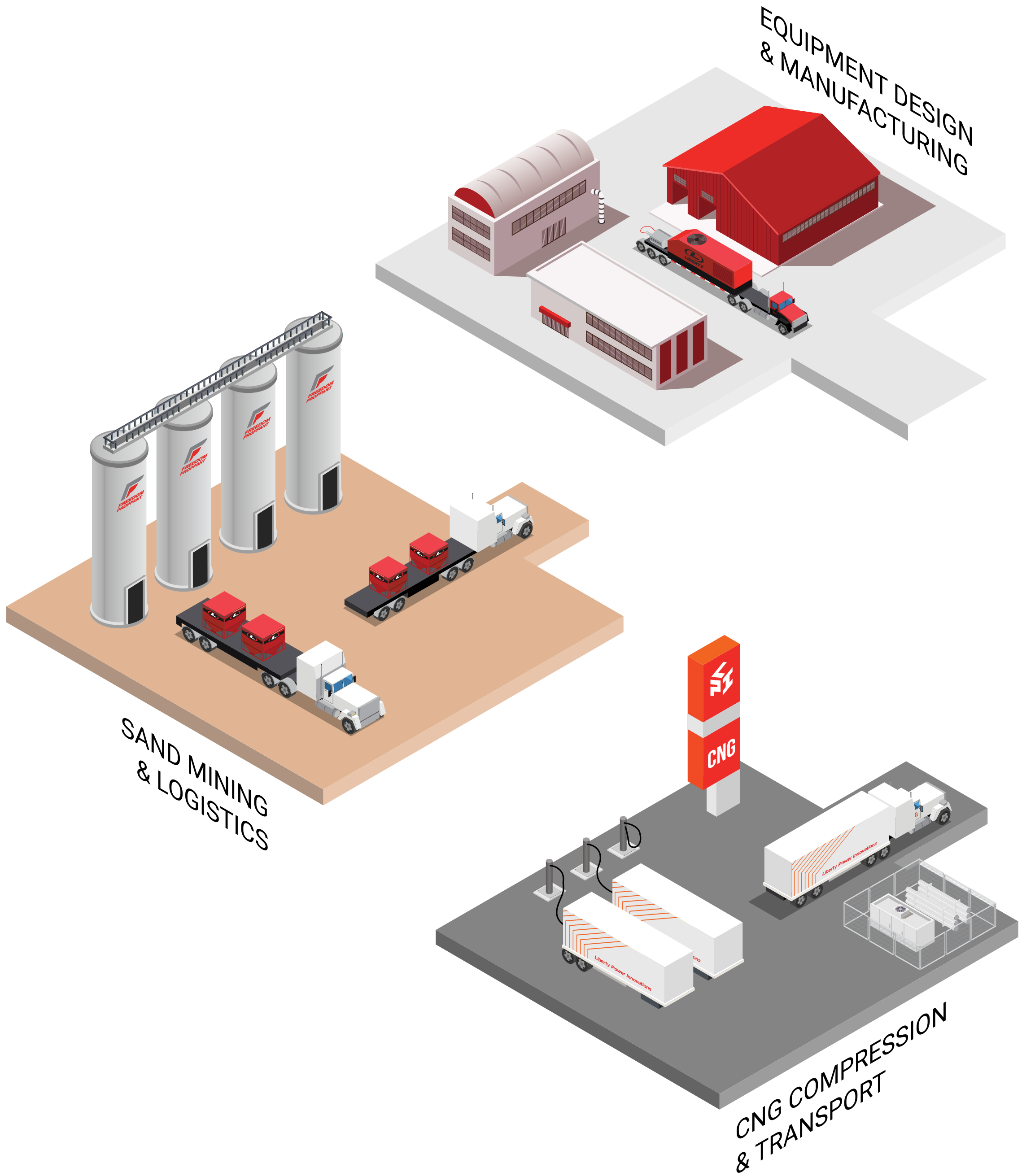
Hydraulic fracturing requires a fleet of equipment with 40,000 to 70,000 horsepower able to operate in remote locations 24 hours per day, 365 days a year. It is these frac fleets pumping sand and water down wellbores at high pressures (5,000 to 15,000 psi) that have enabled the world energy transformation that is the Shale Revolution.

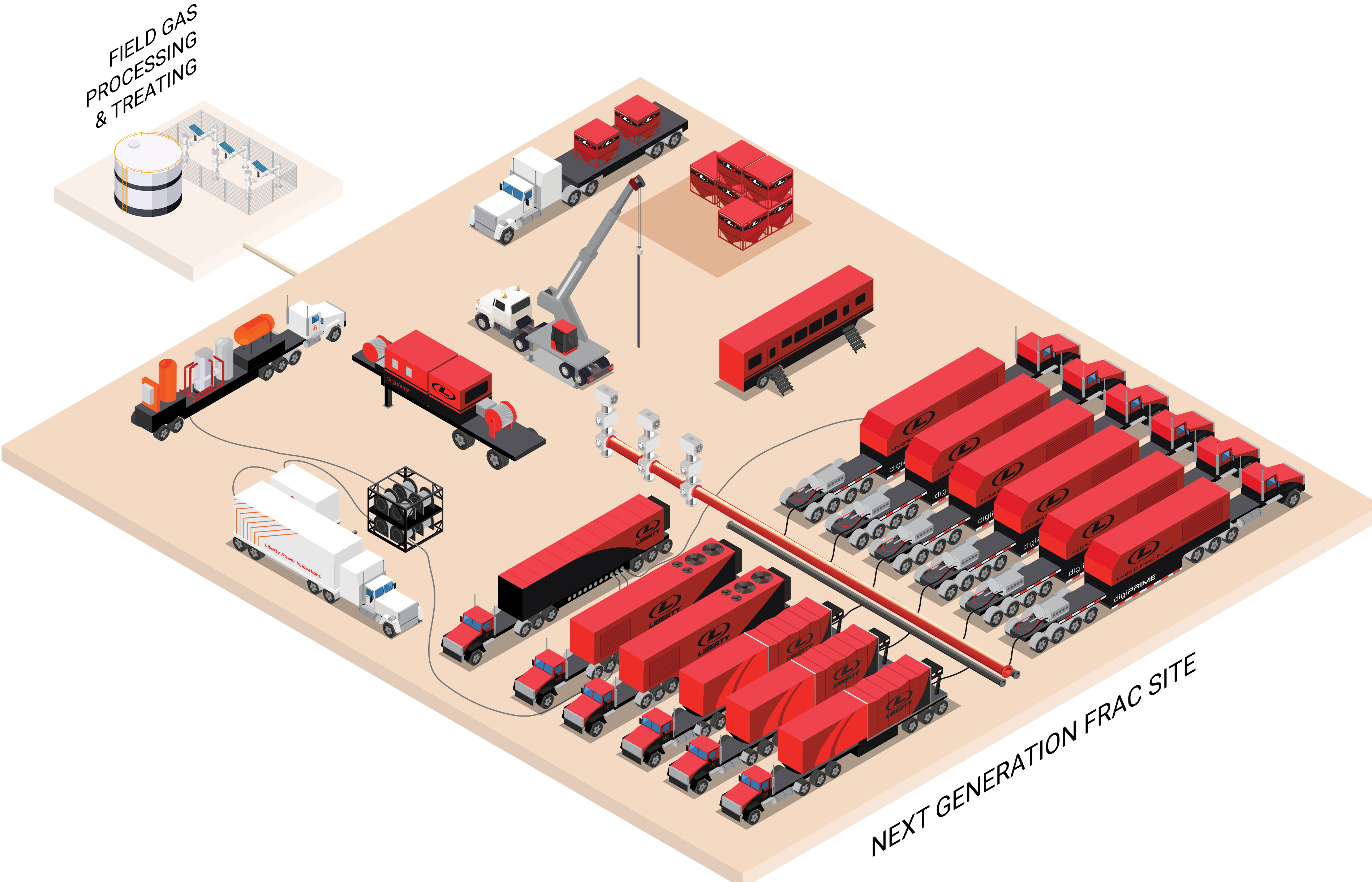
Energy produced from U.S. shale is equivalent to 58% of U.S. primary energy demand and nearly 10% of global primary energy demand.

Vertical Integration

Vertical integration plays a crucial role in shaping the Liberty Energy narrative. Liberty's integrated completions portfolio allows us to control the critical components of hydraulic fracturing operations, including frac, wireline, proppant, chemical sourcing, delivery, and power generation. Owning greater control of a breadth of services provides a range of benefits, including a more diversified supply chain, reduced costs, quicker response to market changes, and stronger technical leadership. These are all particularly true for manufacturing: for individual components and complete pieces of equipment.

To the right is a schematic of an oil and gas well pad location with a Liberty fracturing fleet, PropX sand management equipment, Liberty wireline, and Liberty Power Innovation equipment for a continuous supply of natural gas to power operations.




FIELD GAS
PROCESSING
& TREATING
NEXT GENERATION FRAC SITE

digiTechnologies

When Liberty built its first frac fleet 13 years ago, Tier II diesel was the best available engine technology. Since then, large diesel engine technology has evolved through three generations: Tier II dual fuel (substituting some natural gas for diesel), Tier IV diesel, and Tier IV dual fuel. Today, Liberty's digiTechnologies℠ suite of modular solutions for frac includes mobile power generation, our digiFrac℠ electric fleets, digiWire℠ electric wireline, and the industry's first hybrid pumps, digiPrime℠, which are powered by natural gas and also generate and use electric power with onboard battery storage.

Liberty has continuously led the development of the best available technology, from our Quiet Fleet — making the pumps undetectable above ambient noise 500 feet away — to developing the digiTechnologies that further reduce CO_2e by 40% and NO_x by 60%, while significantly reducing the cost-of-service delivery. Almost seven years ago, we began an internal program to develop the first purpose-built fully electric frac pump, culminating in successfully introducing our digiFrac units to the market in 2023. The introduction of digiFrac was an essential step in our journey to provide lower-emission, lower-fuel-cost horsepower and improve operational efficiency. These electric pumps can be powered by the grid or state-of-the-art low-emission digiPower℠ mobile generators driven by natural gas-burning reciprocating engines.

The newest addition to our fleet is digiPrime, the industry's first natural gas hybrid frac system. The digiPrime pump offers an even lower emission profile, higher power density, and 45% thermal efficiency with the MTU 16V4000 engine. This hybrid pump design utilizes direct mechanical drive for the pumps while simultaneously generating power capable of electrifying the entire site, including all frac fleet supporting equipment like the blender, wireline, and proppant handling equipment.

With the addition of Liberty Power Innovations, Liberty's integrated alternative fuel and power solution provider, we have built the internal expertise and capability to supply our digiFleet℠ with either reliable compressed natural gas delivered and managed on-site or to treat wellhead gas to use for frac power generation. Natural gas has two significant advantages over diesel: It is much cleaner to burn and far less expensive. The drawback is it requires different infrastructure, like pipelines, to transport. Liberty Power Innovations provides a "virtual pipeline" service to reliably deliver natural gas to remote locations not connected to existing pipeline systems, bringing huge benefits to ourselves, our customers, and the environment.

Today, we have truly differentiated frac fleet technology that sets operating performance records while delivering the industry's highest efficiency, lowest emission fleets.

Our fleet of digiTechnologies creates a modular system that can meet the requirements of any job.

digiPrime

The industry's first natural gas hybrid frac system concurrently generates the power required to electrify the entire site, including the blender, wireline, and proppant handling.

digiFrac

Liberty's electric frac system features the industry's first purpose-built power-agnostic electric pumps.

digiWire

Electric wireline unit fully compatible with both digiFrac and digiPrime pumps. Electric power removes the emission generation from prime mover engines and eliminates common failure modes.

digiPower

The Rolls Royce 20V4000 natural gas generator set provides high thermal efficiency along with the lowest emissions and lowest fuel consumption available on the market.

Equipment Design & Manufacturing

Since its inception, Liberty has been at the forefront of equipment design. In 2018, we created a manufacturing division and acquired ST9. This acquisition provided Liberty with control over our pump design and manufacture and provided critical components, including the valves, seats, fluid ends, and power ends that comprise a pump. By bringing this in-house, Liberty took back control of the supply chain to the steel forging process, including specifying the various components' metallurgy. These changes provided visibility and control that is not possible through third-party providers. Rapid innovation driven by real-time feedback from the field, together with sophisticated instrumentation and monitoring, all contribute to a faster product evolution.

In 2023 we launched our Liberty Advanced Equipment Technologies (LAET) division, further expanding our internal manufacturing capabilities to include complete equipment, specifically our mobile frac pump units including radiators, transmissions, and all other required components. Liberty plans to transition to a primarily natural gas-fueled fleet using digiTechnologies over the next several years. Given the growing demand for these units, we saw an opportunity to bring a portion of this manufacturing effort in-house, ensuring the same benefits we have seen in the pump components arena. Manufacturing centers in Texas and Oklahoma will improve our innovation cycle and deliver next-generation assets to our operations team. This integration will provide better visibility and quality control into the component supply chain, reduced costs, and seamless integration with existing Liberty assets.

We have carefully considered sizing our manufacturing centers to provide critical baseload capacity for the company while augmenting additional needs with our long-term third-party partners. This combination of internal capability paired with external partners allows us to optimize our capital spending to meet the needs of the business while innovating at the pace required to maintain our leadership position in the industry. We don't want to oversize this operation as we seek to provide stable employment despite industry downturns.

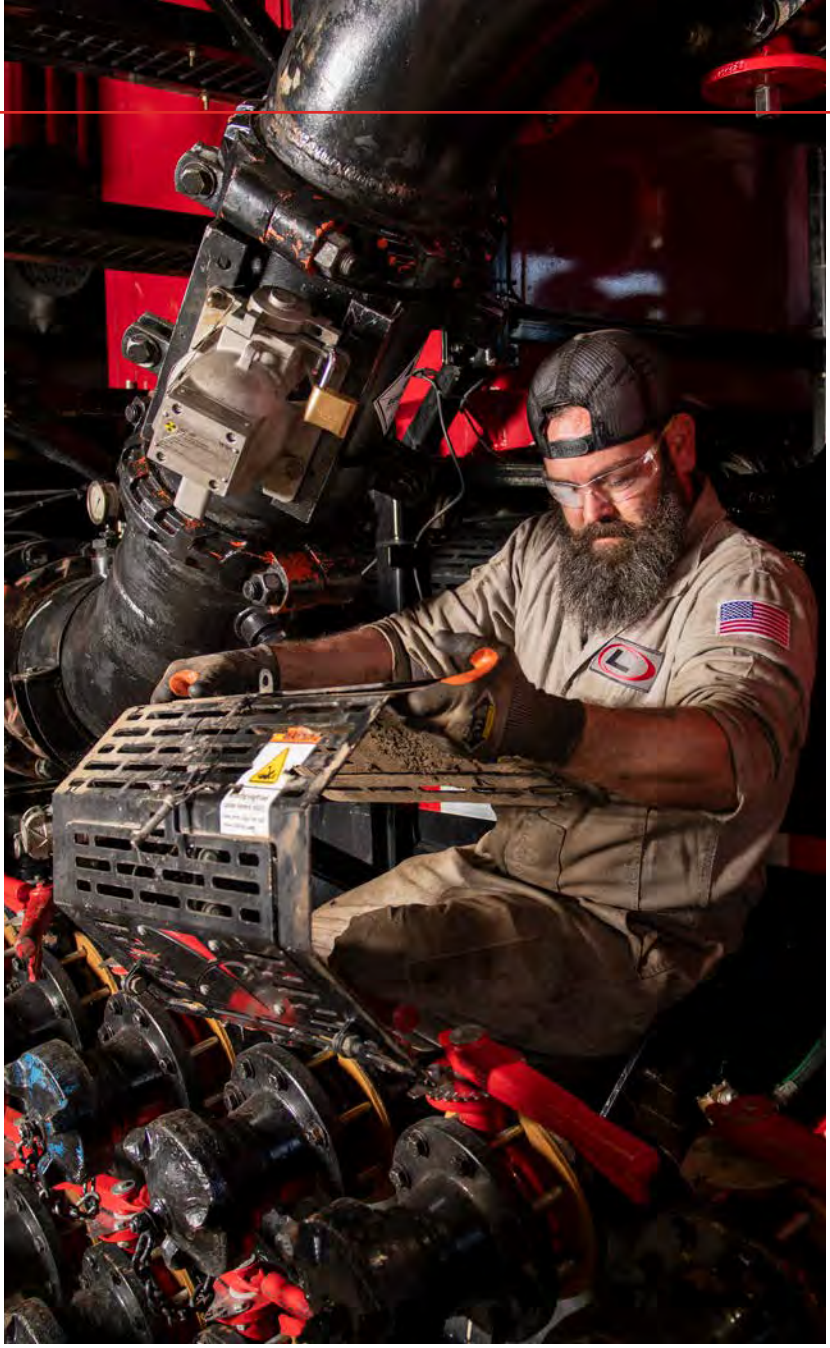
StimCommander™

StimCommander is Liberty's AI frac pump command system, which allows us to optimize pump operation for any pumping rate, pressure, and subsurface execution requirements, ensuring pinpoint control of every hydraulic fracturing job. This software enables Liberty to work with our customers to plan and execute pumping operations efficiently while taking maximum advantage of our digiTechnologies.

- Seamless integration with our digiFleet.
- Improves job execution.
- Orchestrates rate control of high-pressure pumps to achieve master rate setpoint.
- Operates pumps through their firmware to minimize gear shifts and provide flow path management.
- Automatically maintains treating pressure within a specified limit.

Next-Generation Maintenance

We design equipment to provide the lowest total cost of operation, which means the highest operational efficiency plus the lowest cost per pump hour. Maintenance goes hand in hand with our equipment design and operations. We are continuously deploying advanced functionalities throughout our fleet to optimize the monitoring and operation of our equipment and to provide a constant feedback loop to our design and supply chain teams. At Liberty, each of our crews has a dedicated maintenance team, facilitating improved communication between the field and the shop. This structure aligns with our focus on delivering superior service in the field by integrating how equipment is operated and maintained. It extends equipment life, reduces downtime, and reduces our cost of operations. For example, our patent-pending asset management platform, FracPulse, detects wear of fluid end valves and seats. Our AI machine-learning-driven algorithms trigger preventive maintenance events, helping our crews avoid failures predicted by a combination of factors that may not be obvious to equipment operators, ensuring minimal downtime disruptions.



FRACPULSE

Liberty's FracPulse asset management platform utilizes cloud-based maintenance management software to collect over 250 million data points daily, effectively taking the pulse across all our operations at any moment. FracPulse allows our equipment to interact with our maintenance and operations teams, providing access to concise real-time information and outlining a path to higher throughput and equipment longevity. Liberty's advanced technology enables our field personnel to continue leading our industry in frac performance (based on survey data from the industry's top research firm, Kimberlite).

Proactive Response to Equipment Issues

- Creates a health profile for equipment, allowing for prioritization of maintenance and optimizing turnaround times.
- Leverages advanced AI and machine-learning algorithms to detect subtle patterns, improving our ability to perform predictive maintenance.
- FracPulse notifies operators of irregularities in real time by analyzing telemetry data.

Real-Time Emissions and Gas Substitution Reporting

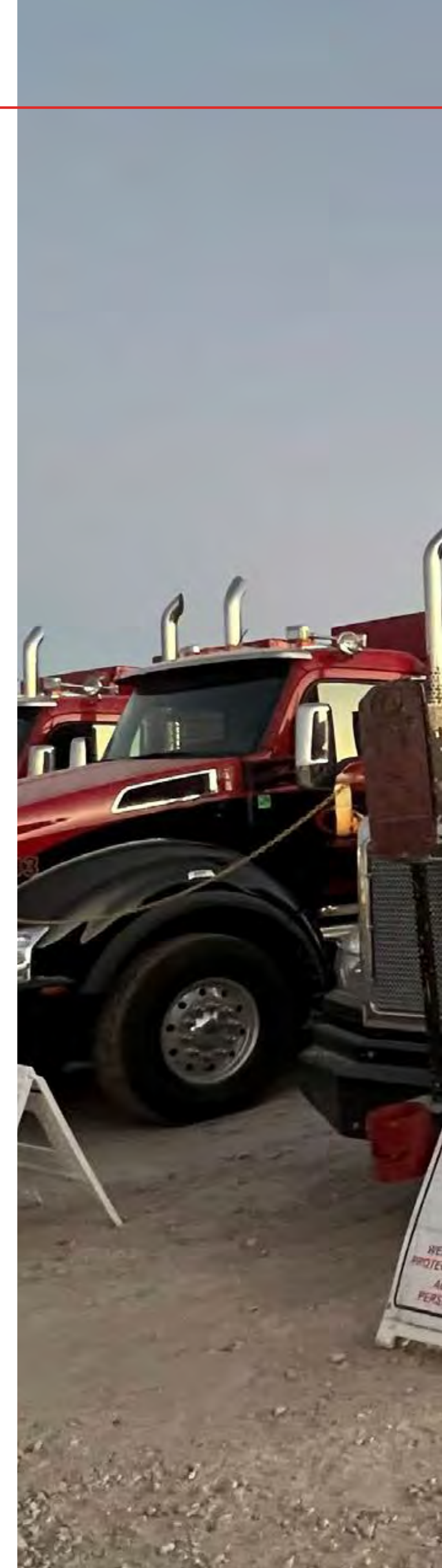
- Allows operators to view current and historical data on gas substitution and manage engine parameters to maximize the natural gas displacement of diesel fuel.
- Provides a summary of emissions data for all the wells and frac pads by combining the contributions of each engine's emissions profile and the hours it operated on the site.
- Targets optimum operating efficiency to produce the lowest emissions relative to the power requirements of each job.

Modular Fuel Supply & Power Generation

The world is becoming increasingly electrified, and the oil and gas industry is no exception. Drilling, hydraulic fracturing, and production facilities are all moving away from diesel-powered motors towards natural gas and electric motors. As this progression occurs, Liberty provides industry leadership through a thoughtful approach to the most efficient way to generate power for the unique demands of hydraulic fracturing. Through a five-year effort, Liberty developed and deployed a fully electric frac fleet centered around our digiFrac electric pump. An essential part of this effort involved determining the most efficient power supply for the electric fleet.

An electric frac fleet uses a significant amount of power — around 20MW, or enough power to supply a town of 25,000 people. Because of the high load and intermittency for frac operations, power from the public grid is impractical in most locations. Instead, power for the frac location is generated on-site with Liberty equipment. As we thought about how best to power the next-generation fleet, we had several minimum requirements:

1. Modular power generation — ensuring the right amount of on-site power to meet the needs of the job, from as little as 10MW to as much as 40MW for a simul-frac operation, which can more than double the lateral footage stimulated per hour of pumping.
2. Natural gas-fueled — the cleanest and most cost-effective fuel source for our needs.
3. Lowest emissions footprint per megawatt hour.
4. Redundancy — reliably maximizing pumping efficiency.
5. A robust supply chain with readily available parts and technical in-basin support.
6. The durability to withstand the rigors of a wide variety of operating conditions and regular moves on bumpy rural roads between frac locations.



An evaluation of these requirements pointed clearly to natural gas reciprocating engines as the right choice for power generation. Each digiPower trailer contains a 20-cylinder MTU (Rolls Royce) gas engine paired with a 2.6 MW generator. At 43% thermal efficiency, they provide the most efficient means of converting natural gas into mechanical energy. Gas reciprocating engines produce 25% less CO_2e and 60% less NO_x than Tier IV DGB, which is the next best technology on the market. This combination performs at least 25% better. Gas turbines are clear winners at large scale (hundreds of megawatts) and for continuous operations. However, reciprocating engines are superior at smaller scale and for intermittent power demand. The digiPower units are highly mobile and scalable. Over 3,000 of the 20V4000 engines are in service in various industries, which gives us access to a strong dealer network and robust supply chain for parts.

While digiPower units support the digiFrac electric fleets, they also provide Liberty Power Innovations with the ability to supply low-emissions, mobile power in a wide range of scenarios, including remote industrial applications, construction projects, and emergency backup power during interruptions in primary generation or where grid transmission infrastructure has been damaged.

Liberty Power Innovations

In 2023 we announced the launch of Liberty Power Innovations (LPI), which marked a pivotal moment in commercializing integrated full-service alternative fuel and power solutions for remote applications. Specializing in compressed natural gas (CNG) supply, field gas processing, and well-site fueling and logistics, LPI is leading the oilfield's transformative shift from diesel to clean-burning natural gas.

Uninterrupted access to fuel is paramount for optimizing well-site operations. LPI has multiple natural gas supply sources, in concert with our natural gas compression, creating a vast network of mobile CNG supply. LPI has acquired and built gross compression capacity of 38 MMcf per day by the end of 2023, which will likely double in 2024. LPI also offers a comprehensive suite of transportation, logistics, field gas treating and processing, and pressure reduction services.

CNG Delivery & Logistics

Virtual Pipeline Services

Natural gas is the fastest-growing energy source in the world, but gaseous fuels are more challenging to transport and use than liquid fuels. LPI aims to solve that problem for the oilfield and will continue to expand our expertise in delivering gas to applications outside the oilfield 24 hours a day, every day.

LPI provides just-in-time fueling services via a new fleet of CNG tankers, with technology enabling coordination with Liberty's industry-leading Sentinel℠ Logistics management platform.

Field Gas Processing

LPI provides fuel gas treatment and conditioning services. These enable producers to utilize gas produced on-site or at nearby wells to fuel today's ultra-clean natural gas engines for power production.

Seamless Integration with digiTechnologies

LPI and Liberty collaborate to offer on-site fuel management services, incorporating advanced cloud-based software that seamlessly connects with engine control systems, maximizing fuel efficiency and monitoring real-time consumption rates. These detailed insights and interactions facilitate efficient logistics management, granting the operations team timely access to fuel. This collaboration enhances capital efficiency and optimizes efficiency through just-in-time fuel delivery.

Transforming operations from diesel to natural gas-powered.

Liberty Power Innovations

Supply Chain & Logistics

Hydraulic fracturing has become increasingly efficient, leading to a continued trend of more hours and higher volumes pumped daily. We operate at a faster pace while doing more with less. These improvements benefit the surrounding communities, the environment, North American energy production, and Liberty's profitability.

Liberty's commitment to supply chain excellence is apparent during the entire span of a frac job, including proppant sourcing, delivery, and on-site management. Our strategy combines diverse partnership-driven sand sourcing with a vertically integrated solution to supply and delivery.

We pride ourselves on our strong partnerships with various sand and last-mile trucking providers across North America. Our strategy emphasizes working closely with our supply partners to understand what makes our operations most efficient and how we can streamline our supply chains into one cohesive process. This partnership requires proactive open lines of communication for long-term accurate forecasting and daily interaction to ensure execution efficiencies.

Liberty's frac sand mining division, Freedom Proppant, acts as a pillar of our vertical integration. Freedom Proppant offers eight million tons of sand mining capacity in the Permian Basin annually, with both wet and dry sand capabilities. Our ownership of these mines and our expansive partnership network allows Liberty to ensure a reliable product flow to all our operations. This also provides cost and supply stability for our customers throughout all market conditions.

Liberty acquired sand handling technology company PropX in 2021. PropX complements our robust sand network with versatile state-of-the-art equipment, delivery, and storage solutions. This union allows our team to be an

industry leader in sand handling and delivery. PropX and Liberty's collaboration has led to further expansion of technology, allowing for a simplified, efficient, and reliable well-site proppant management system.

The Liberty and PropX engineering teams have worked together over the past four years to develop a new process to transport and manage wet sand which retains the moisture content created during the mining process. Drying sand is energy-intensive, which could be cost-prohibitive for new sand mines and impossible for mobile small mines built near frac operations. Wet sand handling technologies are a lower cost and lower emissions alternative in sand mining — an economic and environmental win.

The transportation and handling of wet sand is made possible by PropX's second-generation sand delivery system, the Sand Scorpion®. This system is purpose-built for wet sand, ensuring consistent on-site product delivery while allowing a broader range of sand sources and moisture contents. The integration of this system reduces operating costs, enhances safety by eliminating silica dust exposure, and improves mine accessibility. The Sand Scorpion is the most versatile sand handling system; integrated with Liberty's robust supply chain network, we can source any proppant from any sand mine or transload facility. Proving the ability to add wet and proximity mining to the Liberty supply network, the Sand Scorpion raises the bar for efficiency, cost-savings, and safety. This addition has allowed Liberty to adapt to the ever-changing proppant supply and logistics landscape, creating a model that can efficiently utilize as many options as possible.

The execution efficiencies derived from vertical integration and the development of next-generation equipment would be impossible without Liberty's most crucial differentiating factor—our exceptional team of individuals.

The Liberty supply chain team oversees specified basins and crews committed to real-time monitoring of live jobs, making agile adjustments for optimal performance that reflect our dedication to precision and efficiency. Our ability to quickly respond to changing demand facilitates our supplier partnerships and allows for the successful delivery of over 20 million tons of proppant and one million truckloads annually across North America. A unique and complex supply chain, choreographed in real-time behind the scenes, makes this possible.

To support our teams in achieving efficient and proactive execution, we have created a specialized, fully integrated supply chain platform tailored for frac operations. Liberty's Sentinel Logistics platform expands on the foundation built by PropX's PropConnect™ software. Sentinel provides real-time updates on truck driver selection and trip segment execution. This data is combined with driver trip data in our engineering database to provide accurate and timely executable data for our supply chain team. Sentinel's visibility and predictive analytics have allowed Liberty to maximize pick-up and delivery efficiencies while substantially reducing our overall active truck count. With Sentinel, we do more with less.

The strategic combination of the sand supply network, the vertical integration provided by Freedom Proppant and PropX, and the Sentinel platform allow Liberty stability in a complex, ever-changing world.

Streamlining Proppant Logistics with Sentinel

Liberty's Sentinel platform is an advanced system that harnesses real-time data from every frac location to precisely predict on-site proppant inventory for the upcoming 24- hours. This comprehensive data set considers current on-site sand inventory levels, consumption rate trends, proppant truck count, truck locations, loading facility wait times, traffic conditions, and weather updates to forecast sand volumes to ensure our team is optimizing inventory levels on location.

Utilizing Sentinel, we execute proppant delivery, monitor frac location and road conditions in real-time, and analyze all data points in-house to create a streamlined and cohesive process. The strategic combination of the entire Proppant Supply Chain (Freedom Proppants, 3rd Party, Wet & Dry) and Logistics (Trucking and PropX Delivery System) eliminates supply interruptions, stabilizes costs, and maximizes safety, reflecting our commitment to excellence and efficient execution.

Sentinel Makes a Real Impact

- 90% reduction in proppant delivery downtime, leading to emission reductions.
- 35% decrease in drivers needed for a job, lowering Liberty's footprint on the road.
- 33% decrease in total time required to deliver a load of proppant.
- Leverage real-time data from each frac location.
- Understand the cadence of every job and proactively plan for proppant delivery.

Chemistry, Engineering, & Frac Design

Liberty is a pioneer in advancing frac fluid chemistry, enhancing production efficiency while reducing the cost of extracting natural gas and oil from shale. Our commitment includes developing and using environmentally friendly chemicals, reflecting our pledge to continuous improvement of frac fluids.

Water is the most critical and dominant ingredient in hydraulic fracturing. First, pressurized water breaks the rock in tension, creating complex networks of underground hydraulic fractures. Second, water is the carrier fluid that places sand in these hydraulic fractures. After a frac job, the remaining sand holds open a flow path for hydrocarbons that flow from the pore space within the rock, through the propped fracture into the well, and then up to the surface to empower our world.

Frac fluid chemistry continues to evolve, and Liberty leads the way in this process. Previously, favorable placement of sand in fractures was achieved using viscous fluid systems derived from various chemicals, like guar, an ingredient commonly used in ice cream, toothpaste, and chewing gum. These guar-based systems dominated fracturing until a decade ago, but have primarily been replaced with slickwater fluid, a simpler, more water-dominant fluid with a low-concentration of Friction Reducer (FR).

The current fluid mixture Liberty pumps is over 99% water. We aim to continue innovation in frac fluid systems, ultimately pumping swimming pool-like water with some friction reducer, biocide, surfactant, and 99.8% water. We can achieve proppant placement through faster pumping, which achieves more velocity to allow low-viscosity water to carry the proppant downhole to its desired location.

Additionally, Liberty's advanced pumping system employs commodity chemicals commonly found under household sinks, replacing the proprietary chemicals used in the past. This approach lowers the cost of placing a pound of proppant downhole and ensures we use the best available products.

GreenSelect℠ Hazard Scoring

Liberty's GreenSelect program uses a chemical hazard scoring system for each of our products. This system incorporates a product's complete Globally Harmonized System of Classification and Labeling of Chemicals (GHS) classification, transport classification, and hazardous disposal information to generate a numerical score.

The GHS, developed by the United Nations and adopted globally, categorizes hazards into health, physical, and environmental aspects, each with different severity levels from Category 1 (most severe) to Category 4 (least severe). Our hazard scoring system assigns a weighted numerical score based on these categories, considering a product's transport classification and hazardous disposal information.

We diligently gather all relevant information to facilitate this process in collaboration with our chemical vendors. The resulting GreenSelect score for each product serves as a valuable tool for both us and our customers, aiding in the selection of safer and more environmentally friendly products for use in oilfield applications.

Good Chemistry Makes for Good Neighbors

Liberty is a leader in reducing the cost of placing proppant downhole, driven by efficiency gains and considerations of well economics. This initiative has resulted in cost savings and paved the way for cleaner and safer alternatives. Liberty's commitment started on day one in North Dakota's Williston Basin, where we. Liberty was the first company to advocate for slickwater-based frac jobs, now standard practice in the Williston Basin and other basins nationwide.

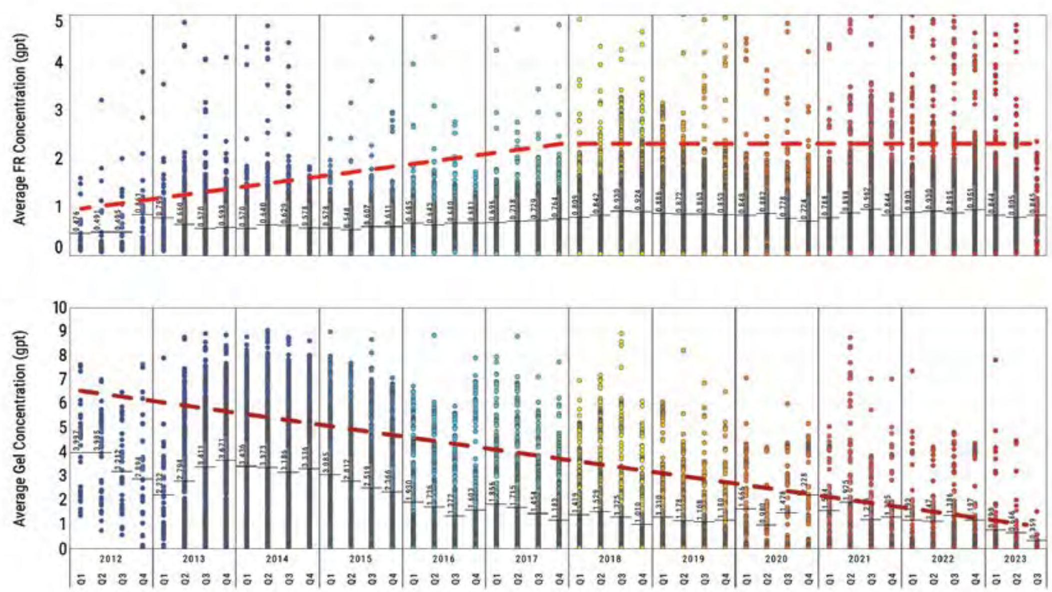
In Colorado's DJ Basin, Liberty's arrival was crucial in steering the industry away from the expensive, chemical-intensive frac fluid systems to simpler, cleaner alternatives. Our engineers and chemists have utilized advanced technologies, including flow-loops, oscillating rheometers, and mass spectrometers, combined with extensive knowledge, to enhance shale gas and oil production economics. This approach reduces costs while mitigating environmental impacts and risks.

Our industry's compliance with state and federal regulations, including the Safe Drinking Water Act, is paramount. The sector has been BTEX-free (no use of benzene, toluene, ethylbenzene, and xylenes) since the early 2000s, thanks to innovation and these regulations.

Frac Design Optimization

Liberty has built and rigorously maintains a database of over 100,000 wells across all major North American shale basins and the Western Canadian Sedimentary Basin. We began assembling this database right at the launch of Liberty to bring cutting-edge big data analytics to the Shale Revolution. Our proprietary FracTrends™ database, coupled with our expertise in advanced data analysis, gives us a unique understanding of what happens underground during a frac job and spots trends in the key drivers of oil and gas production. This analysis leads to efficiency on location while lowering the cost of producing a barrel of oil. Liberty is widely recognized as a leader in frac optimization, helping improve production economics while minimizing land surface disruption.

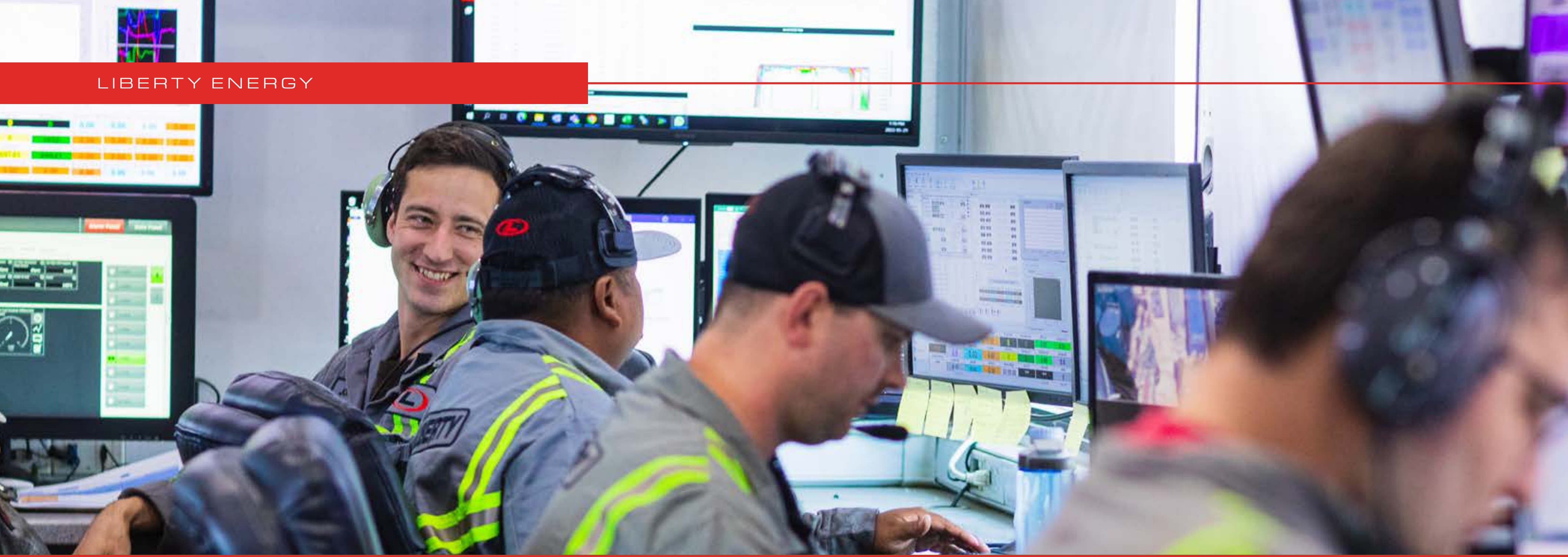
FR and Gel Use by Liberty 2012–2023



Water Use in Context

- 11,000 wells were hydraulically fractured in 2022 in the United States, using an average of 61.3 acre-feet per well.
- Total water use for hydraulic fracturing is about 670,000 acre-feet. That is 0.17% of all U.S. water consumption; 15,000 U.S. golf courses combined use 2.5 times more water than hydraulic fracturing.
- Irrigation consumes the most U.S. water, at 84 million acre-feet —140 times the amount used for hydraulic fracturing.
- Liberty's frac jobs in Texas use 27% recycled water, based on Liberty's tracking of the origin of the water source.
- Combusting a gallon of oil produces more than a gallon of new water. Thus, the overall water balance of fracking is water-positive after the end product's use.
- Over its productive lifespan, a shale well using 20 million gallons of water produces 50 million gallons of oil and 75 million gallons of new water in the form of water vapor during combustion that is returned to the water cycle via rain or condensation.
- The energy derived from hydraulically fractured wells creates 58% of America's energy production, serving the needs of 193.3 million Americans — using only 0.17% of U.S. water!

Since 2011, the industry has disclosed the composition of every pound and gallon in the FracFocus database, which is accessible to the public. Liberty welcomes these disclosures and uses this data in our FracTrends frac-optimization database.



PEOPLE & CULTURE

Safety & Training | Amplifying Employee Voices | Community Engagement

People & Culture

At Liberty, we anchor our unwavering commitment to excellence with our guiding philosophy: Consistently embed our values in our operations. We embrace innovation, diversity, and progressive practices to create a positive impact within our organization and the broader community. This philosophy is the bedrock upon which we build our actions, decisions, and interactions. It reflects our core values in all that we do. We do more than adopt our values; we integrate them into our day-to-day operations.

We recognize that Liberty's team members are the heart and soul of our success. We know there is a direct correlation between employee satisfaction and long-term commitment. We have built a culture of dedication, loyalty, and consistent growth by fostering an environment prioritizing the well-being of our workforce and their families. Bettering human lives starts with those in the Liberty family. A happy workforce translates into a driven team that delivers exceptional service quality, leading to heightened customer satisfaction, safer operations, and lasting relationships.

Safety & Training

Liberty views safety as a collective responsibility. We are proud to maintain a culture in which all team members know others have their back — whether in the field, shop, or office. The results are evident in that it is twice as safe to work at Liberty versus our industry.

Comprehensive training, often in a team environment, helps ensure that the Liberty team can adeptly navigate the intricacies of day-to-day operations. Liberty works to continuously evaluate and expand our health, safety, and training programs. These efforts include improving alignment with our customers and vendors through ongoing communication and participating in industry working groups to share best practices.

"If I can do my part, to make sure my guys go home, get to hold their kids, kiss their wives, see their moms — whatever it is they do when they leave here, safety is our highest priority."

- Brian Fields, Field Safety Representative, Haynesville district

Balancing Data with Human Factors

Our culture is, and always will be, people first. In an increasingly digitized world, we stay on top of technological advancements while maintaining the human touch. We expanded our ability to collect and analyze safety trends by implementing our Behavior Observation Card (BOC) app, which simplifies reporting of potential hazards, unsafe behaviors, and safe behaviors.

While this data provides valuable and actionable insight, we carefully avoid allowing it to supersede the human element of our work. Our field safety representatives maintain routine communication with their crews, working to ensure everyone adheres to our procedures and the highest safety standards.

- Positive acknowledgment of employees.
- Direct notification of hazards.
- Tracking of serious injury and fatality (SIF) and potential SIF events to identify, mitigate, and prevent life-altering injuries and fatalities.

Safety Top 10

Liberty emphasizes a commonsense approach to safety. Over the last year, we have analyzed our internal data, spoken with our crews, and identified 10 core concepts that positively impact our culture of safety. The Liberty Top 10 campaign, deployed across our operations, establishes simple, clear, and actionable directives that align with our belief that keeping it simple keeps it safe.

01. Eyes on Path – Watch for slips, trips, and falls.

02. Proper PPE for the Task – Use your last line of defense.

03. Situational Awareness – Keep your head on a swivel.

04. Working at Heights – Tie off to safety harness every time.

05. Fit for Duty – Show up ready.

06. LOTO (Lock Out Tag Out) – Kill the energy.

07. Stop Work Authority – Trust your gut.

08. Drive Right – Follow the regulations.

09. Brother's Keeper – Keep an eye out for one another.

10. Proper Tool and Procedure for the Task – Take the time.

Training & Development

Liberty established its training program with a dual purpose: to prioritize hands-on training and ensure our team masters core competencies and to provide a pathway for career development.

Our training team immerses new employees in our distinctive culture, emphasizing the paramount importance of safety and competency. Liberty has designed a structured career path and assembled comprehensive training materials, equipping team members with the skills to excel and to ensure a safe and competent work environment.

Selected Training Offered at Liberty

- AFEX system training for operations
- Access to employee exposure and medical records
- Basic SafeLand Training
- Bloodborne pathogens
- CMV driver basics
- CMV pre/post-trip
- CPR/first aid/AED
- Explosives Awareness Level 1
- Fit test respiratory protection
- Forklift training
- Hazard communications
- Hazards materials handling general awareness and security awareness
- Hot work
- Hours of service
- H2S awareness training
- Loads securement
- Lock-out tag-out training
- Manlift training
- Portable fire extinguishers
- Pressure Awareness Level 1
- Radiation Awareness
- Telehandler forklift
- Drug and alcohol policies
- Working in extreme temperatures
- FSU Training
- Fire Theory and Elements of Fire Training
- Behavior-Based Safety/ Human Performance Using Behavior Observation Cards
- SAMSARA / Driving

Liberty Offers Over 400 Individual Trainings Through Our Training Department

Samsara Partnership

- Our partnership with Samsara gave us a single solution to unify our processes, capture accurate data in real-time, and ensure the safety of our distributed teams.
- Together, we created an application programming interface (API) to build 24/7 driver record, allowing us to provide coaching and monitor drivers across our operations.
- We can understand and predict risk to keep everyone as safe as possible while on the road.
- Able to identify and support drivers with training, ensuring that we are targeting the right tools for their jobs.
- We leverage Samsara's data to optimize our routes, resulting in a 25% reduction in fuel usage across our on-road fleets.
- Using Samsara's AI Dash Cams has resulted in a 50% reduction in vehicle accidents!

Evolution of the Fire Suppression System

- Redesigned skids that are effective and easy to use, essential in responding quickly.
- Our units rely on non-carcinogenic, environmentally safe foam to protect our employees, the communities where we operate, and the environment.
- Our Armor unit is mounted in a trailer for quick access and easy deployment on location.
- There are two fire suppression units on each supported Liberty fleet.

In 2023, our Total Recordable Incident Rate (TRIR) was 2x better than the industry average.

Leading Liberty

Liberty believes in the quality of our people. We focus on development and promotion from within, fostering a highly passionate and dedicated workforce. As employees grow into leadership roles, they require additional skills and support to contribute to the success of their colleagues and teams. To set our leaders up for success, we built a course that addresses the unique challenges these employees face. The Leading Liberty program works hand in hand with our Training Department to provide a course structure that equips new and long-term leaders with the skills and tools they need to thrive.

Classes in the Leading Liberty program invite a range of employees from Crew Lead level up through our executive team to come together as peers. Courses cover various topics: how to transition into a leadership role, tips on working with different personality types, and implementing conflict management skills. The program teaches that leadership is a journey, not a destination, and that we must constantly evaluate and reflect on ourselves as leaders. As of publication, 81% of Liberty leadership have participated in the Leading Liberty program.

The Leading Liberty program remains dedicated to its mission to add value to its participants through continued support and engagement.

"Leading Liberty taught me new skills to apply in all aspects of my life. Strong leadership and integrity are a necessity for success for myself and my team."

- Stephanie Vossler,
Senior Manager of Financial Reporting

Amplifying Employee Voices

We pride ourselves in building a workplace where everyone feels heard, respected, and included. Our commitment to our employees includes ensuring everyone can contribute to and shape their futures, Liberty's future, and our customers' futures.

Liberty believes a diverse workforce is more than beneficial— it is essential. We enrich our collective knowledge, creativity, and problem-solving capabilities by welcoming individuals from various backgrounds, perspectives, and experiences.

Liberty's community culture empowers each team member to help shape our narrative and values, regardless of background, ensuring that everyone has the chance to rise, innovate, and lead.

Women of Inspiration Series:

Our Women of Inspiration series was launched in 2022. To date, we have welcomed six unique guests, providing valuable insight from diverse voices within our community. This program will continue to offer encouragement and support to help our team flourish.

Support for Liberty Families:

On day one, every employee – and their families - has access to our full suite of benefits, a robust network of spouses to offer support, and opportunities to meet other Liberty families in their districts. Unique to Liberty, our spouse network is built and managed by Liberty families and provides the relationships and networking that connect the broader Liberty family.

Flexible Work Schedules:

Liberty offers a flexible work schedule for our non-rotational employees. We base these schedules on practicality and business needs at each location. Our rotational employees work a schedule that is two weeks on and two weeks off, which is dramatically more family-friendly than our industry's typical schedule of two weeks on and one week off.

A Family-First Approach to Benefits:

At Liberty Energy, our unique approach to benefits goes beyond providing traditional offerings focused solely on the employee. We recognize that the well-being of team members directly correlates with the health and happiness of their families, who are no less important than our employees.

As part of our commitment to the families of our team members, Liberty proudly offers comprehensive medical, dental, vision, and supplemental coverage. And, true to style, we have gone above and beyond to make an impact on our families' lives.

A few examples include:

- The Wellness Rewards Program offered through our Liberty Mobile App and used by 76% of Liberty employees.
- Heart Health Monitoring and digital coaching that drives lifestyle change in the field and at home.
- Legal Plans that allow convenient and affordable legal protection for life's big and small moments.
- Direct contact with the Benefits Team through our Mobile App for employees, spouses, and dependents during crisis or life events.
- Dedicated HR Rep for each basin, 24-hour, or less, response time.
- Childcare benefits through Bright Horizons, with local options for employees.

Our family-first approach to benefits is a compassionate and responsible choice. We want every employee to know that they matter, their family matters, and we are here to support them.

44% of employees are minorities

Our corporate offices are 39% women, with 22% of our management roles held by women

Over 300 internal promotions in 2023

Veterans make up 11% of our workforce

Community Engagement

Liberty's passion for our communities began in 2011 when we chose our name. We believe everyone should have Liberty — the freedom to pursue their dreams without barriers. To support that mission, we established three pillars of outreach that are now ingrained in our company culture: education, alleviating poverty, and military services. We have built lasting and impactful partnerships with organizations to support our shared passion for creating opportunity and meaningful change in our world.

We feature three organizations in this publication: Montana Tech University, ACE Scholarships, and the Permian Basin Strategic Partnership. All three of these partnerships have been built and cultivated throughout the years and will continue to impact Liberty and our communities well into the future.

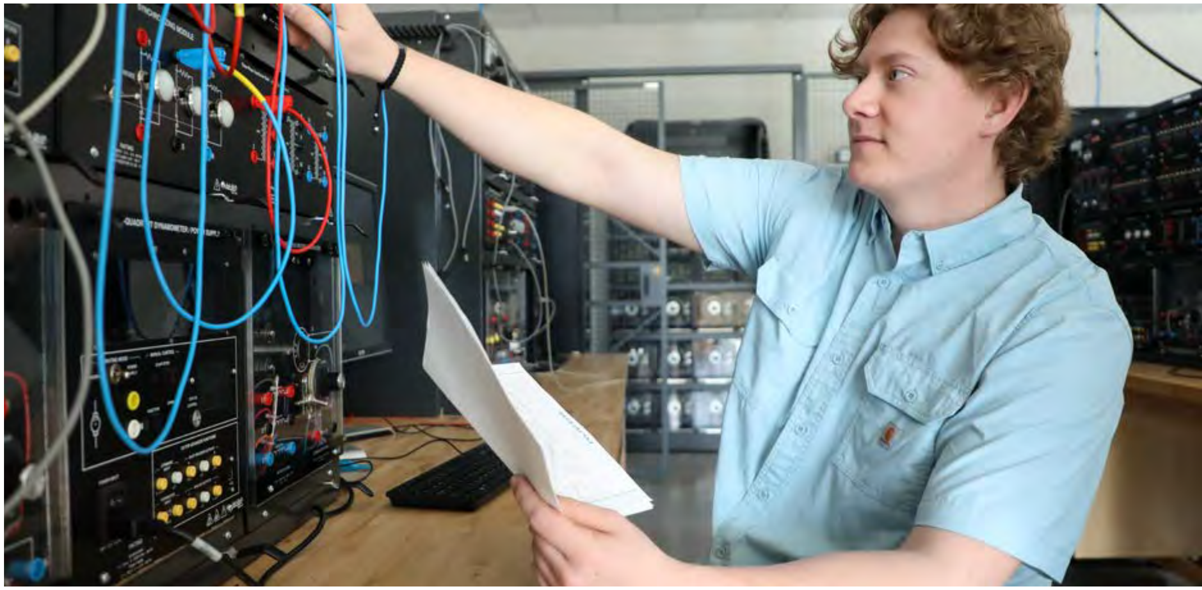
Montana Tech

MONTANA
TECHNOLOGICAL UNIVERSITY

As an organization committed to promoting education and empowering students, Liberty established a scholarship program in 2020 at Montana Tech University. The Liberty Scholars program recognizes and supports low-income high school students who demonstrate exemplary academic achievements, leadership qualities, and a passion for advancing in science, engineering, and technology. This scholarship provides financial assistance to deserving individuals and fosters a community of scholars dedicated to making meaningful contributions to the world around them. With Liberty's generous support, the scholarship ensures that talented students at Montana Tech have the opportunity to pursue their dreams of higher education. Since the program's inception, Liberty has bettered the lives of 31 students through our donation of $200,000.

"The program is providing opportunities for students who would have never considered education as an option. We couldn't be more grateful for Liberty's support and the difference they are making in the lives of our students."

- Les Cook, Montana Tech Chancellor



ACE Scholarships

ACE Scholarships is Liberty's longest community partner. Our mission, to better human lives, aligns with ACE. At Liberty we believe that there is no greater return than investing in children's futures, leading to our 11-year partnership with ACE.

ACE Scholarships was founded in Colorado in 2000 to help low-income parents provide a better education for their children. Their mission is twofold: provide children of these families with scholarships to private schools in grades K-12 and advocate for expanded school choice.

Throughout the years, Liberty has proudly provided 770 scholarships and donated over $1.9 million to ACE. In addition to monetary donations, we are avid supporters of ACE Annual Luncheons to help spread their vision and mission to our many customers. Liberty has had the honor of hiring many ACE graduates in internship and full-time employment roles.

ACE scholarships

"Kids like me can still achieve the American dream because of people like you. For any of you who have given to ACE Scholarships in the past to allow me and my siblings to get a good education, you are the unsung heroes"

- David Banda, ACE Alumnus

Permian Basin Strategic Partnership

In 2023, Liberty joined the Permian Strategic Partnership (PSP), a coalition of energy companies and academic institutions collaboratively addressing the evolving challenges of the Permian Basin in Texas and New Mexico. The Permian Basin Strategic Partnership focuses on education, healthcare, housing, workforce development, and road safety — all issues that Liberty cares about deeply.

Liberty invests in communities where our employees work and live, and there is no better vehicle to make a difference than the Permian Basin Strategic Partnership. Liberty is committed to an annual contribution of $1 million dollars for five years. Members of the partnership pool funds together to address issues that maximize the community's benefit. This partnership shows the unique characteristic of our industry with our ability to stand beside our customers, competitors, and suppliers for noble causes. Through dedicated efforts across the region, the PSP has leveraged over $145 million in member company contributions into more than $1 billion in community investments throughout the region.

"Liberty exemplifies the Permian Basin Strategic Partnership's dedication to innovation and community focus. With a shared dedication, we join forces to improve lives in the Permian Basin. We are fortunate to have Liberty's thought leadership and transformative efforts as invaluable assets in our partnership."

- Tracee Bentley, President and CEO of the Permian Strategic Partnership


LIBERTY

RESULTS WITH INTEGRITY

Corporate Governance | Business & Regulatory Affairs | Cybersecurity | Metrics & Disclosures

Corporate Governance

Liberty is committed to operating our business with integrity and in a manner aligned with the long-term interests of our stakeholders. Good governance principles fortify our commitment to acting ethically, thoughtfully, and responsibly in pursuing value creation. As we work to support societal needs for reliable and affordable energy, our team continually finds ways to enhance our service offerings and deliver value. Our dedication to economic, environmental, and societal leadership and performance is an integral part of our corporate strategy. This has led to a track record of strong cash returns over the lifespan of our company. The Liberty Board of Directors provides independent judgment that strengthens accountability, promotes the long-term interests of our shareholders, and builds public trust in our company. Our senior management team further utilizes sound governance practices to ensure we manage our risks and opportunities toward the continued vitality and sustainability of our business in a responsible, transparent, and ethical manner.

Board of Directors

Liberty Board of Directors have a unique set of leadership experiences and perspectives that foster productive dialogue and decision-making when conducting strategic and oversight responsibilities. Our board has adopted Corporate Governance Guidelines aligned with New York Stock Exchange (NYSE) rules within which our board and committees operate. This includes practices and policies that relate to the board's structure and composition, membership criteria and qualifications, director responsibilities, evaluation of management and succession planning, and interaction with external constituencies. We regularly assess our governance principles to ensure they effectively support a culture of high ethical standards.

Through its ongoing guidance, the board protects the interests of our shareholders and believes those interests are best served by combining the roles of chairman and CEO with a strong and independent lead director. Our board believes a combined chairman and CEO role allows the company to execute its strategy more effectively, especially where our chairman's deep industry expertise, technical leadership, and company knowledge can be leveraged in a cyclical industry. The combined chair and CEO role, coupled with a strong and independent lead director, has enabled the board to respond to challenges and opportunities as they continue to arise. Liberty is fortunate to have William Kimble serving as the lead director. The lead director has many critical duties, including conferring with the chair on board agendas, serving as a liaison between the chair and non-management directors, and presiding at executive sessions of non-management directors and other board meetings at which the chairman is not present. Our board believes that this structure, combined with our corporate governance policies and processes, creates an appropriate balance between strong and consistent leadership and independent business oversight.

7 of 9 independent board of directors

4 female or ethnically diverse directors

The board met formally 6 times in 2022 and 5 times in 2023.

Adopted incentive compensation recovery policy, director resignation policy and stock ownership guidelines for officers and non-employee directors

All board committees are comprised entirely of independent directors

Audit Committee

The Audit Committee oversees, reviews, acts on, and reports on various auditing and accounting matters to our board. Those include ensuring the integrity of our financial statements, compliance with legal and regulatory requirements, independent auditor's qualifications and independence, and effective performance of our internal audit function and independent auditors

Compensation Committee

Our Compensation Committee assists our Board in establishing salaries, incentives, and other forms of compensation for officers and other employees. Our Compensation Committee also assists the board with the administration and oversight of incentive compensation and benefit plans, incentive compensation recovery policy, and stock ownership guidelines.

Nominating & Governance Committee

Our Nominating and Governance Committee oversees our corporate governance framework, including identifying, evaluating, and recommending qualified nominees to serve on our board, succession planning for senior management, evaluating director independence, continuing education for directors, and leading the annual performance evaluation process of the board and committees and senior management.

The board provides robust oversight through three fully independent committees: Audit, Compensation, and Nominating and Governance. William Kimble, Peter Dea, and Gale Norton are chairpersons for the respective committees. Each director has a background particularly relevant to the committee's oversight. The diversity of perspectives thought leadership, skills and industry experience, and personal background, including gender, of our directors is a strength. Increasing board diversity remains an ongoing emphasis at Liberty. Our board includes two female directors, two ethnically diverse directors, and directors from a wide variety of backgrounds in technology, energy, public policy, finance and accounting, and international business. Liberty maintains an independent board in adherence with NYSE rules and our Corporate Governance Guidelines, with seven of our nine directors meeting the qualifications of independence. All directors are serving staggered three-year terms. Our director resignation policy provides for majority voting in uncontested director elections.

Bettering Human Lives is Foundational to Our Business

Liberty believes that access to life-enhancing modern energy presents the most pressing global energy challenge. The Liberty team works passionately to better the process of bringing hydrocarbons to the surface in a clean, safe, and efficient fashion. Liberty views environmental, social and governance principles as foundational to our success. The board and its committees provide oversight of risks and opportunities associated with the company's ESG initiatives, with ongoing review of matters and challenges by the full board at each regular board meeting. Various aspects of our mission to better human lives are managed in board committees depending on the topics, including technology innovation, human capital management, and enterprise risk management. The board assesses investment decisions through the lens of risk and opportunities.

At the heart of investment is whether the deployment of capital resources towards new or leading-edge technology, mergers, acquisitions, and other areas aids the company's ability to maintain top-tier service and efficiency for our customers while mitigating any adverse environmental impacts of our business. Liberty is uniquely positioned to take a leadership role with continuous innovation and investment in subsurface engineering and equipment design and optimization, which improves operational efficiency and reduces emissions. Of note, our digiFrac electric fleet investment, coupled with technological upgrades to dual fuel equipment, allows customers to choose what works best for them. These technologies serve the dual purpose of lowering emissions and providing fuel cost savings, thus a more economically viable opportunity for customers to pursue environmental benefits while efficiently providing the world critical energy resources.

Leadership Accountability: Pay For Performance

The Liberty team has been aligned with shareholders since our founding. Our pay-for-performance compensation philosophy strategically uses incentives that align employee behaviors with their responsibilities to drive better business outcomes. This persists across all areas of the company, from our employees in the field managing efficiency and safety, to our sales team's ability to improve profitability. At the helm, our executive team has a compensation program with a high percentage of variable compensation designed to align with the long-term interests of the company and our shareholders. Incentive compensation includes a focus on pre-tax earnings per share, pre-tax return on capital employed (ROCE), and adjusted ROCE benchmarked against a peer group and the broader marketplace. Our peer group includes the S&P 500 and the OSX. Measuring our results against the broader market enhances our commitment to meeting shareholder priorities. The Compensation Committee reviews shareholder votes and feedback to ensure executive compensation programs align with their interests on an ongoing basis. Additional details on our executive compensation program are available in our 2023 proxy statement.

Our executive officers and non-employee directors are subject to stock ownership guidelines intended to foster equity ownership and align interests with shareholders. Under the guidelines, officers and directors are expected to beneficially own shares having a value based on a multiple of their base salary or cash retainer, as applicable, ranging from two to six times within five years of serving in such position, and to maintain that ownership level for the duration of their service.

Business Ethics

Liberty thrives with robust partnerships that we have cultivated with our customers, suppliers, and communities over the years. The basis of these relationships includes a strong sense of business ethics that underscores the reputation and trust we have built with all our stakeholders. Our Corporate Code of Business Conduct and Ethics (Code) and our Financial Code of Ethics set the stage for how we operate our business by establishing expectations for our team to maintain high integrity, ethical standards, and compliance with all legal requirements. Liberty's Code includes topics ranging from conflicts of interest, employee practices, and compliance with applicable laws. We require annual employee commitments to the Code, acknowledging an understanding of our key policies. This includes a strict policy against improper payments or gifts from the company that benefit any government, labor union, customer, or supplier. Doing so guards against corruption and bribery across the supply chain. To protect the company, Liberty has an anonymous whistleblower hotline, found on its website, and encourages employees and members of the public to report suspicious conduct. Liberty prohibits retaliation for good faith reporting of violations. All reports are investigated, including those of retaliation.

Today, we have 1,072 employee-owners.

Risk Oversight

At the core of our business is leading-edge innovation and technology, which often involves measured risks. Risk assessment and oversight are integral to our governance and management processes. Our board is responsible for monitoring and assessing strategic risk exposure and providing oversight of risk management with the assistance of the Audit Committee. The board encourages management to promote a culture incorporating risk management into our corporate strategy and day-to-day operations. Liberty management discusses strategic and operational risks at regular management meetings and conducts specific strategic sessions during the year, which include a focused discussion and analysis of material, operational, and financial risks.

The company also conducts a comprehensive risk management session with the executive leadership team regularly. Liberty includes the help of outside consultants, where key risks are identified, prioritized, and documented with mitigation strategies assigned to the appropriate risk owner. Throughout the year, senior management reviews risks with the Audit Committee and board and acts to mitigate or eliminate such risks. These ongoing discussions assist us with identifying, monitoring, and controlling or mitigating exposures, providing assurance that the risks we take are consistent with the board's risk tolerance. For a comprehensive discussion of material risks Liberty has identified, please refer to our filing with the Securities and Exchange Commission, including our most recent Annual Report on Form 10-K.

Cybersecurity & Data Protection

At Liberty Energy, safeguarding our systems, networks, applications, and data is paramount, especially as cyber threats are becoming more frequent and sophisticated. Recognizing this, Liberty Energy is committed to continuously enhancing our cybersecurity practices, protocols, and standards to stay ahead of emerging risks and evolving requirements.

Advancing Cybersecurity Practices

Liberty Energy adheres to a rigorous cybersecurity framework, aligning with top-tier standards like those from the National Institute of Standards and Technology (NIST) and the Center for Internet Security (CIS). Enhancing this framework, our strategy includes regular evaluations by independent assessors, ensuring compliance and proactiveness in identifying and addressing vulnerabilities. This approach follows industry benchmarks and also incorporates third-party auditing, providing an objective assessment of our cybersecurity readiness and effectiveness. Through these measures, Liberty Energy maintains a dynamic defense posture, consistently fortified against evolving cyber threats.

Innovative Security Strategies

Our cybersecurity strategy incorporates advanced practices such as “Defense in Depth” and “Zero Trust” models. These strategies are designed to fortify and protect our computing assets, networks, data, and user access against potential breaches. We employ strong endpoint protection and network, cloud, and mobile security, coupled with effective threat detection and incident response mechanisms. Regular external penetration testing and continuous evaluation of our security protocols keep our defenses robust and responsive.

Empowering Our Workforce

Understanding that human factors play a crucial role in cybersecurity, Liberty Energy provides comprehensive annual training for all personnel with access to company systems. This training focuses on information security best practices and adherence to company policies. We also conduct regular phishing simulation campaigns and provide additional security awareness training in high-risk areas.

Staying Ahead of the Curve

Liberty Energy proactively monitors the dark web and employs advanced cybersecurity strategies to identify and mitigate threats, ensuring operational resilience. Their approach includes sophisticated dark web surveillance integrated into their broader digital risk protection and incident response planning. Liberty Energy actively monitors sources such as the Microsoft Security Response Center, InfraGard, US-CERT, and CISA for the latest data security guidance. This vigilance allows us to adapt to emerging threats swiftly, maintain data security and system integrity, and align our practices with the latest standards from NIST and CIS. By utilizing these comprehensive cybersecurity measures, Liberty Energy remains equipped to handle disruptions and maintain continuous operations.

Cybersecurity

Our commitment to cybersecurity is part of a broader focus on operational resilience. Liberty Energy has developed and rigorously tested plans to ensure the continuity of our operations in various crisis scenarios. Our swift and effective response to disasters and incidents, transitioning to a fully operational remote workforce within days, is a testament to our preparedness and adaptability.

Investing in Digital Infrastructure

In Liberty Energy's strategic governance, a key focus is on building a resilient digital framework. By adopting a 'Cloud First' policy and collaborating with leading cloud service providers, Liberty has developed a geographically diversified and redundant infrastructure. This design is crucial in ensuring Liberty's preparedness for supporting alternative operational sites in the event of disasters or disruptions. Additionally, the segmentation of Liberty's technology infrastructure plays a pivotal role in isolating and managing any threats or downtime scenarios, enhancing the company's ability to maintain continuous operations under various conditions.

In summary, the governance aspect of our Bettering Human Lives mission report highlights Liberty Energy's comprehensive approach to cybersecurity and data protection. Our strategies, encompassing advanced technology, skilled personnel, and strategic partnerships, demonstrate our commitment to maintaining the highest cybersecurity and operational resilience standards. This commitment is a testament to our dedication to responsible governance and protecting our stakeholders' interests.

Employee Ownership

Liberty takes pride in fostering an entrepreneurial workplace where employees have the autonomy to take ownership of their work and grow professionally. Some 19 percent, more than one thousand, of our team members are employee-owners. As a part of our professional development and annual goal setting for our team, Liberty offers restricted stock units to attract, engage, retain, and reward our employees while further aligning their interests with our public shareholders. Employee ownership connects our employees' work to Liberty's strategic decisions, supporting both our long-term business model and our people.

Business & Regulatory Affairs

At Liberty, our success intertwines with that of our customers. This means close collaboration with our customers and industry allies and active participation in legislative and regulatory procedures via workgroups and trade associations. The alliances we have built extend far beyond our physical borders, with the entire Liberty family serving as staunch advocates for the industry — wherever they live.

We are committed to the idea that through concerted effort and transparent dialogue, we can advocate for policies prioritizing health and safety while sustaining our industry's ability to deliver the affordable energy we all rely on.

Key Metrics & Disclosures

FORWARD LOOKING STATEMENT

In order to utilize the 'safe harbor' provisions of the United States Private Securities Litigation Reform Act of 1995 and the general doctrine of cautionary statements, Liberty is providing the following cautionary statement. This report contains certain forecasts, projections, and forward-looking statements – that is, statements related to future, not past events and circumstances with respect to the financial condition, results of operations and businesses of Liberty and certain of the plans and objectives of Liberty with respect to these items. For this purpose, any statement that is not a statement of historical fact should be considered a forward-looking statement. These statements may generally, but not always, be identified by the use of words such as 'will', 'expects', 'is expected to', 'aims', 'should', 'may', 'objective', 'is likely to', 'intends', 'believes', 'anticipates', 'plans', 'we see' or similar expressions; however, the absence of these words does not mean that the statements are not forward-looking. These forward-looking statements are subject to certain risks, uncertainties, and assumptions, including those disclosed from time to time in Liberty's filings with the Securities and Exchange Commission (the "SEC"). As a result of these factors, actual results may differ materially from those indicated or implied by such forward-looking statements. Any forward-looking statement speaks only as of the date on which it is made, and, except as required by law, we do not undertake any obligation to update or revise any forward-looking statement, whether as a result of new information, future events or otherwise. New factors emerge from time to time, and it is not possible for us to predict all such factors. When considering these forward-looking statements, you should keep in mind the risk factors and other cautionary statements in "Item 1A. Risk Factors" included in Liberty's latest Annual Report on Form 10-K and in our other public filings with the SEC. All forward-looking statements, expressed or implied, included in this report are expressly qualified in their entirety by this cautionary statement. This cautionary statement should also be considered in connection with any subsequent written or oral forward-looking statements that we or persons acting on our behalf may issue.

Sustainability Accounting Standards Board (SASB) Index

TOPIC	ACCOUNTING METRIC	2021	2022	2023
Emissions Reduction Services and Fuels Management	Total fuel consumed, percentage renewable, percentage used in: (1) on-road equipment and vehicles and (2) off-road equipment	Off-road: 20,271,760 GJ On-road: 604,165 GJ	Off road GJ: 26,863,499, On Road GJ: 709,379	Off-road GJ: 32,099,769, On-Road 848,736.82 GJ
	Discussion of strategy or plans to address air emissions-related risks, opportunities, and Discussion of strategy or plans to address air emissions-related risks, opportunities, and impacts	Environmental Performance, Frac Engines		Delivering Superior Service
	Percentage of engines in service that meet Tier 4 compliance for non-road diesel engine emissions	21%	21%	20%
	Scope 1 Greenhouse Gas Emissions ($MTCO_2e$) calculated in accordance with GHG Protocol	1,427,200 ($MTCO_2e$)	1,995,196 ($MTCO_2e$)	2,329,847 ($MTCO_2e$)
Water Management Services	(1) Total volume of fresh water handled in operations, (2) percentage recycled		(1) 124,500,375.2 m3, (2) 20%	(1) 147,400,009 m3, (2) 15.8%
	Discussion of strategy or plans to address water consumption and disposal-related risks, opportunities, and impacts	Water		Chemistry, Engineering, Water Use in Context
Chemicals Management	Volume of hydraulic fracturing fluid used, percentage hazardous	98,063,510 m3 of frac fluid slurry (includes sand volumes); 0.076% hazardous chemicals	131,545,232 m3 pf frac fluid slurry (includes sand volumes); 0.075% hazardous chemicals	155,273,040 m3 of frac fluid slurry (includes sand volumes); 0.071% hazardous chemicals
	Discussion of strategy or plans to address chemical-related risks, opportunities, and impacts	Frac Fluid Chemistry		Chemistry, Engineering, Water Use in Context
Ecological Impact Management	Average disturbed acreage per (1) oil and (2) gas well site			Energy, See footnote
	Discussion of strategy or plan to address risks and opportunities related to ecological impacts from core activities	Ecological Impact		Energy

Workforce Health & Safety	(1) Total recordable incident rate (TRIR), (2) fatality rate, (3) near miss frequency rate (NMFR), (4) total vehicle incident rate (TVIR), and (5) average hours of health, safety, and emergency response training for (a) full-time employees, (b) contract employees, and (c) short-service employees	(1) TRIR .51 (2) Fatality rate 0.0 (3) NMFR 1.76 (4) TVIR 6.16 (5a) 18.3 (5b)not relevant (5c) not relevant	(1) TRIR .89 (2) Fatality Rate .032 (3) NMFR .36 (4) TVIR 5.91 (5a) 19.15 (5b)not relevant (5c) not relevant	(1) TRIR .49 (2) 0.0 (3) NMFR .22 (4) TVIR 3.12 (5a) 28.7 (5b)not relevant (5c) not relevant
	Description of management systems used to integrate a culture of safety throughout the value chain and project lifecycle			Safety
Business Ethics & Payments Transparency	Amount of net revenue in countries that have the 20 lowest rankings in Transparency International's Corruption Perception Index			See footnote
	Description of the management system for prevention of corruption and bribery throughout the value chain			Results with Integrity
Management of the Legal & Regulatory Environment	Discussion of corporate positions related to government regulations and/or policy proposals that address environmental and social factors affecting the industry			Results with Integrity
Critical Incident Risk Management	Description of management systems used to identify and mitigate catastrophic and tail-end risks			Results with Integrity

ACTIVITY METRIC	UNIT OF MEASURE	2021	2022	2023
Number of active rig sites	Quantitative			See footnote
Number of active well sites	Quantitative			See footnote
Total amount of drilling performed	Quantitative			See footnote
Total number of hours worked by all employees	Quantitative	9,797,096 hours	9,425,456.09 hours	12,043,579 hours

1. Ecological Impact Management was deemed not applicable, as management of disturbed acreage per oil and gas wellsite is outside of Liberty's operational control.

2. Liberty does not operate in any countries that fall within the 20 lowest rankings in Transparency International's Corruption Perception Index.

3. Number of active rigsites, number of active wellsites, and total amount of drilling performed are not relevant to the Liberty's operational control, and have been omitted.

Find our full list of sources and view the report online at:
https://libertyenergy.com/esg/bettering-human-lives/

Cooking amidst harmful smoke from traditional fuels such as wood, dung, agricultural waste, and charcoal is

life threatening.

Worldwide,

2.3 billion people

— predominately women and girls — cook today using these harmful fuels.

Household air pollution kills an estimated

3.2 million people

per year. In 2020 it claimed over 237,000 children under five — more than the combined annual toll of HIV, tuberculosis, and malaria.

Gathering fuel and cooking over inefficient, polluting stoves **consumes considerable time** for women and children, preventing them from pursuing education and other productive activities.

Bettering Human Lives Foundation

OUR MISSION

We believe in the power of clean cooking to transform lives.

One-third of humanity prepares meals over open fires or polluting stoves, contributing to premature death and limiting human potential. The Bettering Human Lives Foundation aims to increase access to clean cooking fuels by directly supporting local innovators and entrepreneurs to start and grow their businesses. Together, we are committed to providing families with a pathway out of poverty through access to modern energy that betters human lives.

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