Enabling the Energy Transition

Industry Report and Investment Case

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Declining Costs and Net-Zero Targets are Driving a New Era in the Energy Transition

The energy transition represents a massive shift in how we produce and consume power — moving from fossil fuels to sources that produce little or no carbon. A range of products and services are enabling this transition, including:

- Renewable Energy: Energy sources including solar, wind, geothermal, and hydroelectric power
- Energy Storage & Conversion: Offerings such as advanced lithium-ion batteries, solid-state batteries, pumped hydro and other long-duration storage solutions, inverters, and fuel cells
- Smart Grid & Grid Infrastructure: Products and services that enable a resilient modern grid, such as transmission and distribution systems, grid operations, and enabling software
- Energy Intelligence: Products including smart meters, energy management systems, power controls, and light-emitting diodes (LEDs)
- Enabling Materials: Mined, manufactured, and recycled materials such as lithium, silicon carbide, gallium nitride, copper, nickel, rare earths, and waste-derived fuels

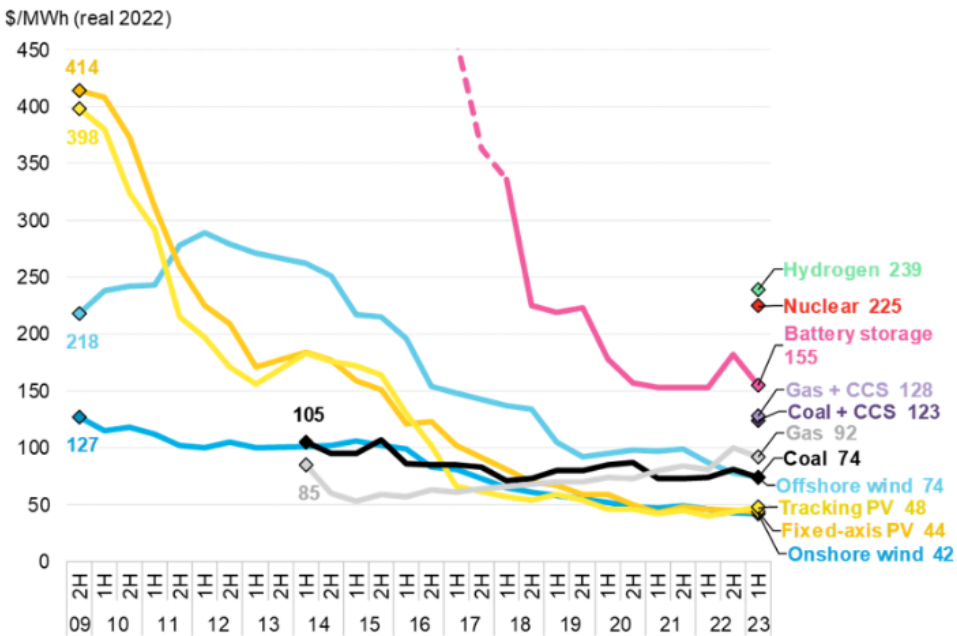
The Five Major Drivers of the Energy Transition

We estimate that humanity is about halfway through the global energy transition as businesses, utilities, consumers, and other stakeholders embrace the benefits of clean energy and work to battle the ravages of a changing climate. While solar power was developed at Bell Labs in the 1950s and back-to-the-earth denizens embraced off-grid renewable energy (RE) systems in the 1970s, it wasn't until the beginning of this millennium that the modern energy transition truly began. Around 2000, a growing number of venture capitalists, government agencies, corporations, and think tanks began to pursue the technological scaling opportunities inherent in the burgeoning clean-tech sector. Like other energy transitions, the shift from fossil fuels to clean energy is expected to take about 50 years. At the forefront of this dramatic shift has been the rapid growth of renewable energy (primarily solar and wind), the recent rise of energy storage and electric vehicles (EVs), and the advent of smart and connected electric grids.

The key technology, capital, and policy-related developments driving this significant change include:

Declining Costs. Solar and onshore wind are now the most cost-effective forms of new electricity generation globally, beating out nuclear, coal, and, in many cases, even natural gas plants. The levelized cost of onshore wind has declined 67% between 2009 and the first half of 2023, while fixed-axis solar costs have dropped 89% in the same period, according to BloombergNEF[1]. Levelized costs are measured in dollars per MWh of electricity "generated" over the lifetime of a system, whereas up-front capital investments are measured in dollars per kW of "installed" capacity. Technological innovation has enabled entirely new economies of scale for renewable energy sources, resulting in cost reductions that were unthinkable by many market players just a decade ago. These cost declines have greatly exceeded the projections outlined in the National Renewable Energy Laboratory's 2012 *Renewable Electricity Futures Study*, which predicted that the U.S. could reach 80% renewable energy by 2050[2]. The report's main scenario projected that the capital costs to build a utility-scale solar PV system in 2050 would run between $2,200 and $2,700 per kilowatt (kW) of capacity. But in 2023, the capital costs to build utility-scale solar ranged between one-third and one-half of those costs – just $700 to $1,400 per kW, according to Lazard, a financial advisory and asset management firm[3]. As technology-centric energy sources, with no cost for their fuel inputs, solar and wind power are seeing economies of scale more akin to the semiconductor industry than traditional energy sectors.

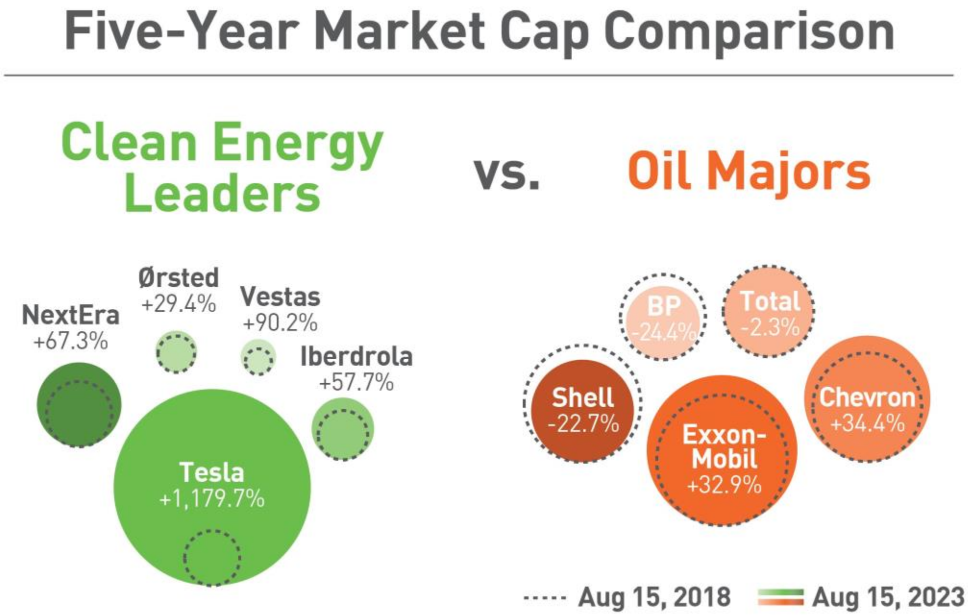
Global Levelized Cost of Electricity Benchmarks, 2009-2023



Source: BloombergNEF, 2023[1]

- Investment Shift from Fossil Fuels to Clean Energy. Both private and public investors are becoming cognizant of the long-term geopolitical and financial risks of fossil-fuel investments and are increasingly moving away from fossil fuels. Total investment in the clean energy sector is expected to reach $1.7 trillion this year (after breaking the $1 trillion threshold for the first time in 2022), exceeding investment in fossil fuels for the eighth consecutive year[4]. At the same time, renewable energy projects' financial benefits drive investments in this sector. In the decade ending in 2020, average returns from renewable power investments were more than seven times higher than those from fossil fuels (422.7% compared to 59%), according to the International Energy Agency (IEA) and the Centre for Climate Finance at Imperial College Business School[5]. This trend is also reflected in the market capitalization of major oil & gas and renewable energy companies. During the five-year period examined (see chart on following page), Clean Energy Leaders experienced growth in their market capitalizations, whereas Oil Majors exhibited mixed results (three declined and two increased). Even with a recent downturn in clean energy valuations and a significant rebound in oil company valuations in 2021 and 2022, Tesla surpassed all five Oil Majors in both total market cap and five-year growth, expanding from $57.8 billion in 2018 to $739.4 billion in 2023 (up 1,179.7%).

Clean Energy Leaders vs. Oil Majors Market Capitalization, 2018 vs. 2023



Source: Clean Edge, Inc., 2023[6]

- Smart Grid & Electrification Trends. With energy storage and EVs continuing to experience cost declines similar to renewables, the concept of "electrification of everything" is emerging. The resulting increased electrical load will require utilities to modernize grid infrastructure, driving continued investment in this sector. The move to electric heat (utilizing highly efficient electric heat pumps) is perhaps the largest potential driver for expanding residential electrification. Fossil fuels (mainly natural gas and heating oil) have historically provided 90% of the energy for residential space heating and 80% of the water heating in the U.S., according to the U.S. Energy Information Administration (EIA)[7]. Also underlying these trends is the digitization of energy, from smart meters to connected IoT devices, and the smart grid backbone that supports it.
- Climate & Energy Policies. With global emissions from fossil fuels at their highest levels in history, national governments worldwide are signing commitments to reduce their carbon emissions. China, which has been issuing Five-Year Plans with clear economic targets since the 1950s, now leads the world in the manufacturing and production of solar panels, wind turbines, EV batteries, electrolyzers, and heat pumps. The U.S. dramatically transformed its federal clean energy policy in 2022 by passing the Inflation Reduction Act (IRA), offering the promise of building a robust, reliable, and competitive domestic ecosystem for the clean-tech industries of the future – spanning energy storage, renewables, EVs, enabling materials, and grid infrastructure. Rather than primarily using sticks (penalties and regulations), the nearly $370 billion policy is focused on carrots (namely manufacturing and production tax credits and consumer tax credits and rebates). The IRA is already paying big dividends, with billions in corporate commitments announced to build U.S.-based mining, EV, energy storage, and solar production and manufacturing facilities. As a result of these and many other aggressive policies by European Union

Source: Clean Edge, Inc.

countries and other nations, global fossil-fuel emissions are projected to peak in 2025, according to Rystad Energy[8].

- Public Support. The demand for low-carbon energy sources is coming not only from governments but also from corporations and the public at large. A Pew Research survey found that in 2022, 69% of U.S. adults favored renewable energy over fossil-fuel production[9]. At the same time, private companies are significantly increasing their efforts to become carbon neutral. Over 400 multinational corporations, including Apple, Nestle, Bloomberg, and GM, have committed to getting 100% of their electricity from renewables as part of the global RE100 campaign[10].

Challenges Facing the Energy Transition

While the energy transition is bolstered by strong public support and growing economies of scale, key challenges remain in the sector. These challenges include:

- Higher Interest Rates. Renewable energy installations tend to come with high up-front costs, so low interest rates in recent years have been a boon for renewables development. But the industry has been impacted by rising interest rates in the current inflationary environment, causing more renewable projects to seek alternative funding. One solution gaining momentum is “green banks” – typically publicly-owned institutions created to help fund climate-focused projects like renewable energy installations by covering financing on the margins that make deals pencil out for private-sector investment. These institutions are on the rise globally, with the Natural Resources Defense Council reporting 27 green banks in 12 countries as of 2020, with another 20 countries actively exploring the model[11].
- Transmission Bottlenecks. Renewable energy can be expensive to produce at scale in dense urban areas. In the U.S., wind power is cheapest to produce in the Great Plains and Intermountain West, while solar power production is cheapest in the Southwest and Southeast. For highly populated coastal and other urban areas to reach 100% renewable targets, electricity needs to be transported from where it’s cheap to where it’s needed. In June 2023, construction began on the TransWest Express Transmission Project, which will carry wind-generated energy from the 3 GW Chokecherry and Sierra Madre wind farm in Wyoming to southern California, helping individuals and organizations meet decarbonization goals. This project has faced pushback from residents and politicians in Wyoming[12]. Due to high costs and issues with siting and permitting regulations, transmission projects are not being completed as quickly as is needed to keep up with electricity demand, according to research firm ScottMadden[13]. In 2021, the U.S. approved $65 billion in funding for clean energy transmission in the $550 billion Bipartisan Infrastructure Law[14]. In July, the Federal Energy Regulatory Commission approved new rules to help speed up U.S.-based transmission projects and hopefully address long wait times in bringing renewable energy onto the grid[15]. Some states are also working to improve transmission infrastructure in their territories, allocating capital to move the needle. In 2023, California announced $7.3 billion to build thousands of miles of high-voltage transmission lines[16]. Finally, to speed up the process, the use of existing rights-of-way (like rail lines) or retrofitting older, existing transmission lines with advanced transmission technology could, in some instances, be a cheaper and faster alternative to constructing new lines.
- Safety Issues. For companies and consumers to widely adopt electrified vehicles, storage systems, and other devices, trust in the safety of these emerging products is paramount. While generally limited in scope, the improper manufacturing, charging, and/or storage of lithium-ion batteries has led to some high-profile explosions and fires. In April 2019, for example, a thermal runaway incident at a 2.16 MWh lithium-ion energy storage facility in Surprise, Arizona, injured four experienced firefighters[17]. The following year saw a massive Chevrolet Bolt and Volt vehicle recall due to two

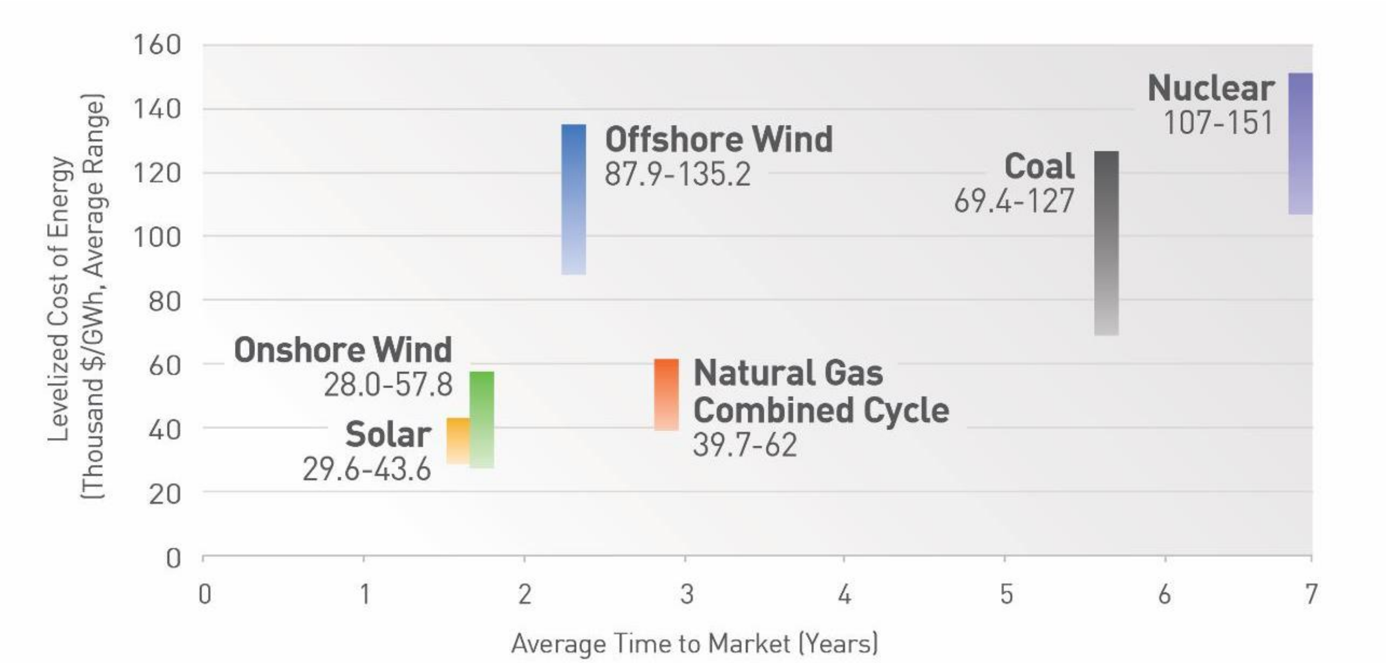
known manufacturing errors causing around a dozen fires[18]. This year, three separate fires from e-bike battery explosions have caused the death of 10 people in New York City alone[19]. These events highlight the need for consistent (and enforceable) standards in the burgeoning global battery industry. Many opportunities exist to improve safety, including alternative storage chemistries, better-engineered containment systems, and thermal barriers. The energy storage industry must act aggressively to fix safety issues – there is no room for error.

- Public and Political Opposition/Entrenched interests. Pushback from the public, entrenched interests, and political figures pose roadblocks to renewable energy and grid transmission deployment. Among the public, a general attitude of “not in my backyard” (NIMBY-ism) can halt siting or permitting of renewables and grid transmission projects, as in the case of the Rail Tie Wind Project near the Wyoming-Colorado border. Local landowners opposed the development, bringing the issue all the way to the Wyoming Supreme Court[20]. As is the case with many such projects, the courts ultimately decided in favor of the wind farm. In Texas, with a major push against renewables from some residents and politicians[21], NIMBY-ism has had limited success. Contrary to the beliefs of some politicians who disparaged and blamed renewables during the historic deep freeze of 2021– inadequately weatherized natural gas plants had the most significant failures – renewable energy is benefiting the state economically and in terms of climate resiliency. Texas doubled its solar power production between 2022 and 2023, creating many new jobs in the energy sector[22]. Texas now trails only longtime solar champion California in total solar capacity deployment among the states. In an unprecedentedly hot July of 2023, this solar power (combined with new utility-scale energy storage systems) helped keep the grid operating[22]. Even as political leaders recently tried to jerry-rig the system to favor natural gas over clean energy, solar and battery storage systems are now poised to expand significantly in the state.

Economics and the Rise of Clean Energy

As noted earlier, solar and wind power are now the most cost-effective forms of new electricity generation in many regions – beating out coal, nuclear, and even natural gas. Additionally, onshore wind and solar are the fastest sources of utility-scale energy to bring online; on average, both sources take less than two years to produce energy after projects begin[23]. According to Lazard, which has been tracking the levelized cost of energy (LCOE) for more than a decade, the LCOE for wind power dropped from $135 per megawatt-hour (MWh) in 2009 to just $50 per MWh at the start of 2023, a decline of 63%. Even more dramatically, utility-scale solar declined 83% over the same period, from $359 to $60 per MWh[3]. Both coal and nuclear power remain above the $100 per MWh range, making them approximately two to three times the cost of new solar and wind on a levelized cost basis[3]. While costs rose in 2022 for all energy sources except for gas peaking, they are beginning to fall again over the first half of 2023[1]. It’s important to note that these costs do not include energy storage, which will be necessary for an increasing number of applications for renewable power to be broadly integrated into the grid.

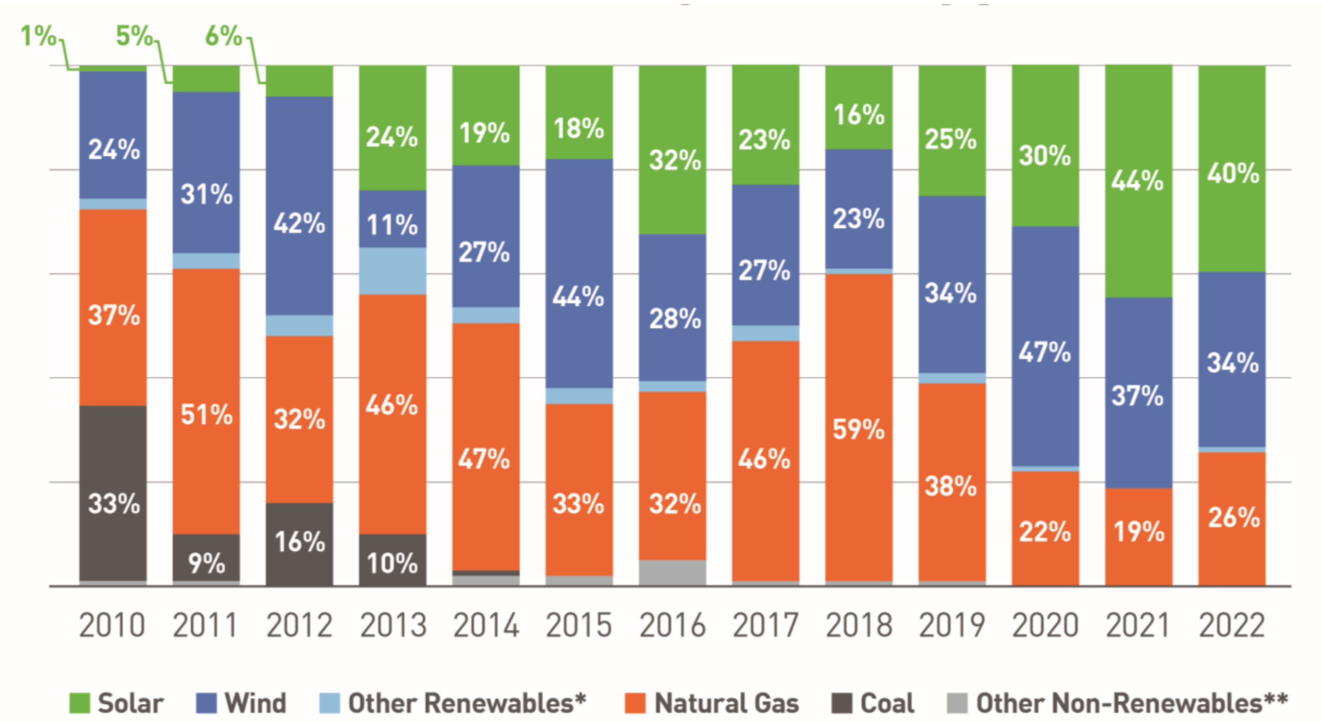
Average Cost and Time to Market for Utility-Scale Energy Sources



Source: Clean Edge, Inc., 2022[23]

In the U.S., the lower cost of clean energy is having a huge impact, with renewables recently overtaking coal for overall electricity generation for the first time. In 2022, electricity generated from renewable sources (including hydropower) accounted for a record 21.5% of the total generation in the U.S.[24] In the same year, another milestone was hit – coal capacity in the U.S. fell below 200 GW, down 38% from its peak in 2011[25]. No new coal plants have been added to the U.S. grid in nearly a decade[26]. With coal generation capacity declining and demand for electricity on the rise, renewables are filling the gap, and this shift has played out consistently over the past 13 years of new energy installations in the U.S. In 2010, about 70% of new capacity additions came from natural gas and coal. By 2022, the fossil fuels vs. clean energy script had flipped entirely: 74% of new capacity consisted of solar and wind, and these trends are expected to accelerate[27] (see chart on following page). In 2023, the EIA projects the U.S. will add a record-shattering 29.1 GW of solar capacity – more than the total capacity additions from all sources combined in 2022[28].

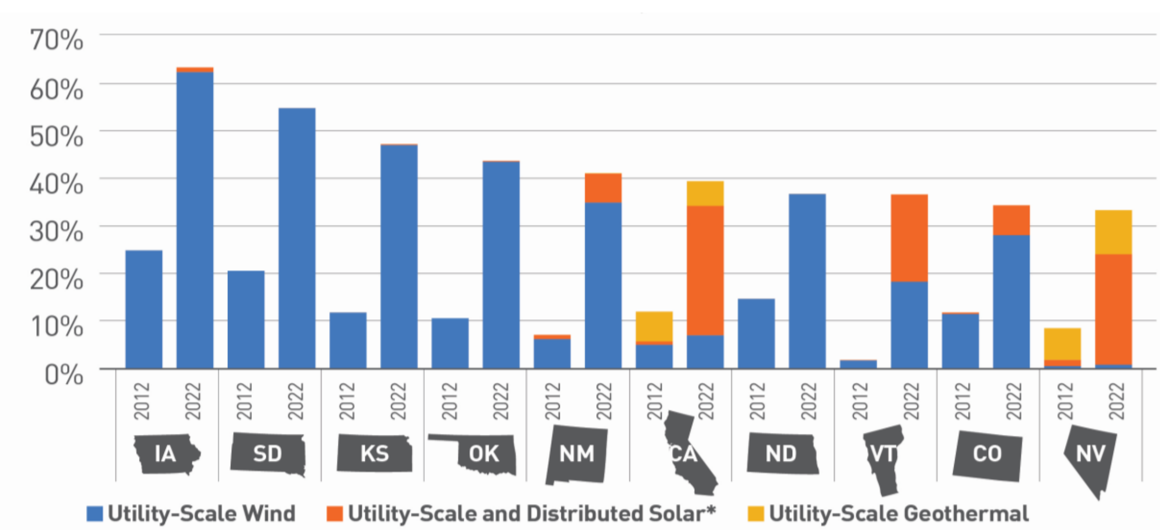
U.S. Electric Utility-Scale Capacity Additions by Fuel Type



Source: Clean Edge, Inc., 2023[29]

At the state level, the rise in renewable energy generation is even more dramatic. A decade ago, only four states received 10% or more of their in-state electricity generation from non-hydro, utility-scale renewables (i.e., solar, wind, and geothermal). In 2022, 26 states were part of the 10% or more club, with 11 states – Iowa, Kansas, Oklahoma, California, Vermont, New Mexico, Colorado, Nevada, Nebraska, and the Dakotas – getting 30% or more of their electricity from renewables. Iowa generated more than half of its in-state power from renewable sources for the second straight year, and South Dakota exceeded the 50% threshold for the first time[30].

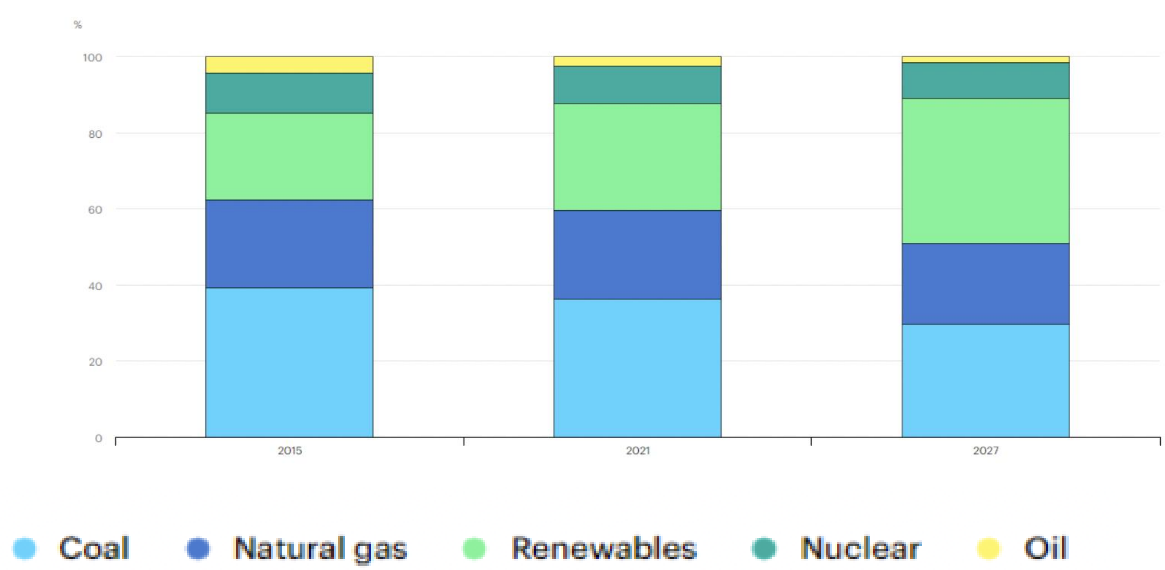
Top 10 Renewable Energy (Wind/Solar/Geothermal) States, % of Generation, 2012 vs. 2022



Source: Clean Edge, Inc., 2023[30]

As in the U.S., the adoption of low-cost, low-carbon energy solutions continues to rise globally, with 83% of new electricity capacity additions worldwide attributed to renewables last year[31]. According to the IEA, if countries hit all their climate and low-zero-carbon energy targets, mass-manufactured clean energy technologies will increase their worth to around $650 billion annually by 2030[32]. Despite unexpectedly high raw material costs, worldwide renewable capacity (including hydro) rose by a record-breaking 335.7 gigawatts (GW) in 2022. The IEA predicts that global renewables capacity will grow by another 440 GW in 2023, a 31% increase[33]. Forecasts for future renewable capacity were revised in 2023 due to a bolstered European market, where economic and policy incentives led to higher-than-expected renewables demand (particularly for distributed solar) following the 2022 Russian invasion of Ukraine[33]. But China, as noted earlier, is the undisputed leader in clean energy manufacturing and renewable energy deployment. China accounts for over half of the world's wind and solar PV installed capacity[33]. Many other countries, including Australia, India, and Brazil, invest heavily in renewable projects. As a result, renewables are projected to become the world's largest source of electricity generation by 2025 and reach 38% of the global electricity mix by 2027 (according to the IEA)[34]. Globally, electricity produced from renewables will soon exceed coal, while it has already overtaken natural gas and nuclear power.

Global Electricity Generation by Technology, 2015, 2021, and 2027



Source: IEA, 2022[35]

National and corporate commitments are projected to support the continued expansion of renewable capacity and generation through at least 2050. All this activity means healthy job growth in the renewable energy sector for the foreseeable future. In 2022, the U.S. energy sector grew by 3.8%, adding 300,000 jobs and outpacing broader job-market growth. Forty percent of all energy jobs (3.1 million) are now in the clean energy sectors, according to the Department of Energy's (DOE) U.S. Energy and Employment Report[36]. Such job offerings are projected to rise significantly globally, with the International Labor Organization predicting that 24-25 million new jobs will be created worldwide in this sector by 2030[37]. In the U.S., the Bureau of Labor Statistics predicts jobs in U.S. solar installation alone will grow 52% between 2020 and 2030, and wind turbine service technician roles will grow 68% in the same period, far outpacing most other industries[38]. And according to the International Renewable Energy Agency's *World Energy Transitions Outlook* report, up to 43 million energy sector jobs will be filled by renewable energy workers by 2050[39].

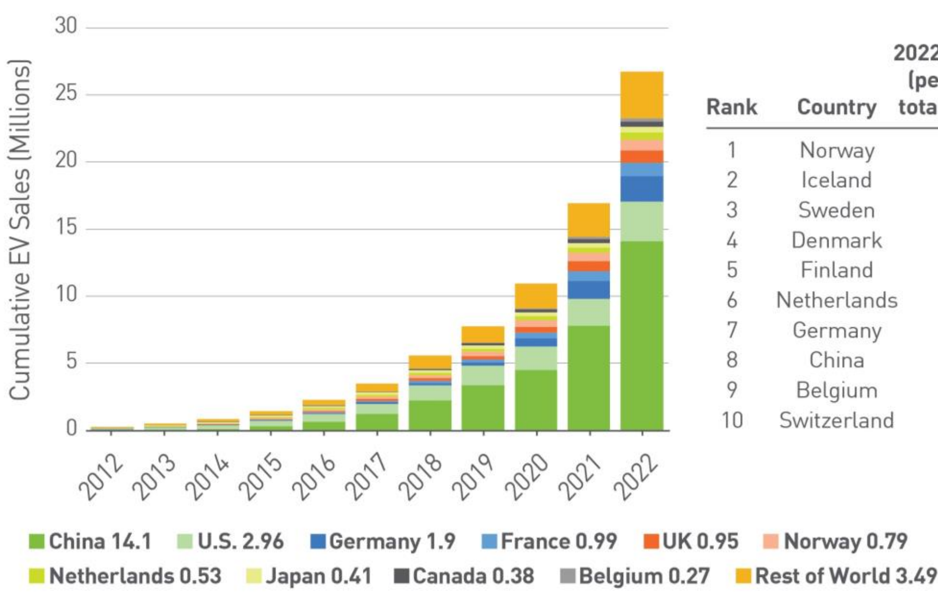
Smart Grid Infrastructure

Against the backdrop of the massive shift to renewable energy and the electrification of transportation and heat, the electric grid, which has remained remarkably unchanged over the past century, is experiencing a technological renaissance. A more modernized grid, based on technological advances such as big data, artificial intelligence, distributed networks, and advanced transmission lines, is emerging, enabling a more resilient and efficient grid. Smart meters, which can be used to manage aggregated demand from residential and commercial buildings, are helping to provide more significant customer insights, pinpoint outages, and better manage electricity usage. The U.S. reached two-thirds penetration of smart meters in 2020 and is expected to reach 80% by 2025. Europe, France, Spain, and the Netherlands reached the EU's goal of 80% penetration in 2020[40]. These devices, communicating via 5G and LTE networks, promise to improve service reliability by optimizing real-time usage while reducing costs.

High-voltage direct current (HVDC) transmission lines are also being deployed to deliver power from areas of abundant wind and solar power to regions that have insufficient local capability for renewable generation. HVDC power lines lose significantly less energy than traditional ones, particularly over distances exceeding 300 miles. They also allow for rapid change in the direction of energy flow, so renewables can more easily be hooked into the grid. Several long-distance HVDC transmission projects have been completed, such as a line connecting Spain and France, one of the most powerful HVDC lines in the world[41]. The highest-capacity line is in China, spanning 3,284 km and boasting a transmission capacity more than six times an average nuclear power plant (12 GW)[42]. According to research firm Global Market Insights, many other projects are underway, with the annual deployment of HVDC lines expected to reach nearly 11,200 miles by 2030[43].

The rapid growth of EVs and energy storage is poised to dramatically rewire the electric grid across transmission, distribution, and microgrid networks. In 2022, for example, global sales of EVs grew 55% over 2021, exceeding 10 million for the first time ever. This came in a year when total car sales were down 3%. By the end of 2022, more than 26 million electric vehicles will be deployed globally. China leads the EV market in total sales and stock, but EU nations are making strides too; in EVs as a percentage of total new vehicles sold, nine of the top 10 markets are in Europe. According to the IEA, about 21% of all European cars sold last year were electric[44].

Electric Vehicle Deployment by Country, 2012-2022



Rank	Country	2022 EVs sold (percent of total market)
1	Norway	88%
2	Iceland	70%
3	Sweden	54%
4	Denmark	39%
5	Finland	38%
6	Netherlands	35%
7	Germany	31%
8	China	29%
9	Belgium	26%
10	Switzerland	25%

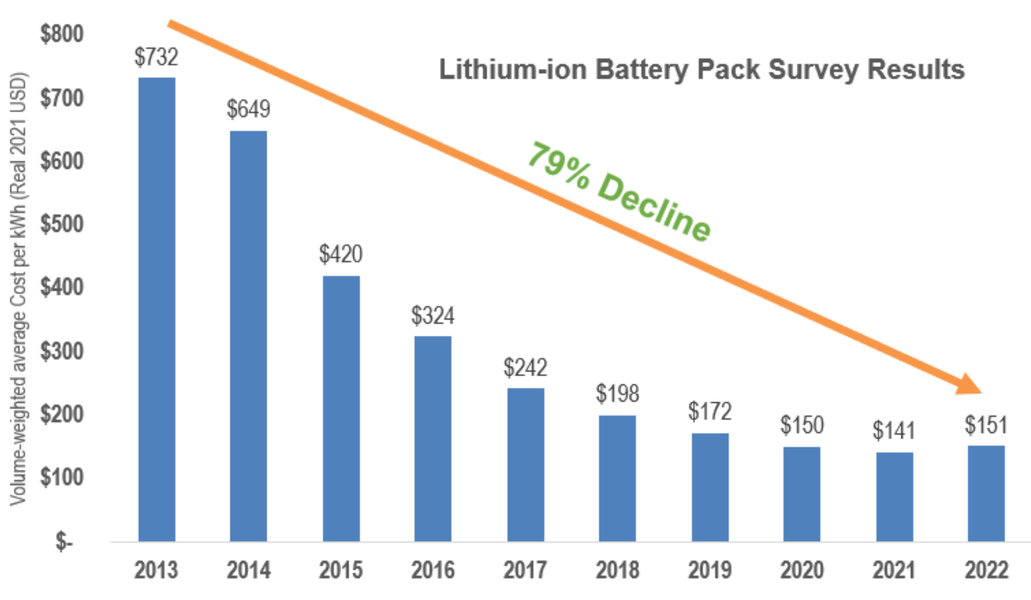
Source: Clean Edge, 2023[45]

As consumer demand for EVs increases, early pioneers such as Tesla and BYD and major auto manufacturers including Ford and Hyundai are positioning themselves to compete in this new electrified world. The growing need to recharge vehicle batteries will require innovations in developing higher-power and more ubiquitous EV charging infrastructure and establishing charging standards. Many utilities are developing or have applied for permits to develop a charging location backbone to better serve customers in their service territories.

While charging EVs will increase electricity demand, it's not expected to exceed utility capacity, reaching just 4% of global electricity demand by 2030, according to the IEA[46]. Integrating EVs provides grid operators with a somewhat flexible load that can absorb excess capacity and offset the variability of renewable generation. To grow the vehicle-grid integration market (also referred to as vehicle-to-grid or V2G), utilities and automakers in the U.S. have launched pilot programs that use the Open Vehicle Grid Integration Protocol (OVGIP) to send demand response messages from utilities directly to EVs' telematics systems. Vehicle-grid integration services, including advanced energy storage, will become even more critical when hundreds of millions of EVs are plugged in.

With an ever-increasing supply of renewable power coupled with high demand from electrified transportation and heating, the next major hurdle is the storage and distribution of all this clean energy. Lithium-ion batteries are the current leading technology in the energy storage market, and deploying existing and emerging technologies will remain vital to the energy transition. Battery storage solutions, including utility-scale and distributed systems, are already proving critical in periods of high electricity demand[47]. The widespread production of these batteries has led to dramatic price declines of 79% between 2013 and 2022[48]. A spike in global commodity prices last year caused lithium-ion battery packs to increase in cost for the first time in decades, despite wider adoption of cheaper lithium iron phosphate (LFP) chemistries (which are gaining traction, particularly in EVs). BloombergNEF predicts costs will start to decline again in 2024, and the price of lithium-ion batteries will reach $100 per kilowatt-hour by 2026[49], down from $151/kWh in 2022. One technology that will help reduce battery pack prices is recycling older lithium-ion batteries (from smartphones, laptops, and EVs, for example), which could dramatically increase existing supplies in a circular loop.

Lithium-ion Battery Pack Cost, 2013-2022



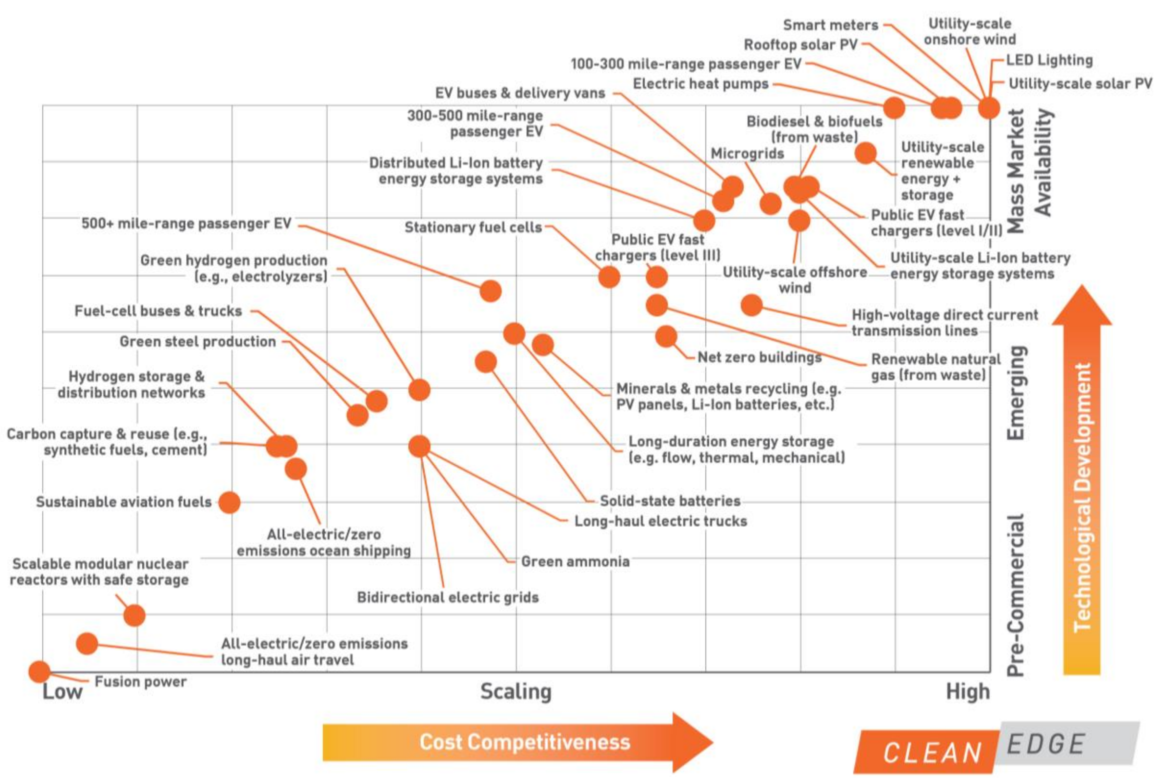
Source: BloombergNEF, 2022[48]

Solid-state batteries are another technology that will enter the market in the coming years. While many of the solid-state batteries in development do still use lithium, they have solid electrolytes, rather than liquid. This results in a more energy-dense battery (using less material) and a lower risk of explosion. This means the same total footprint can store more energy more safely. Indeed, the fire risk of lithium-ion batteries, which has caused concern in scaled deployment, is driving the development of safer storage solutions, including solid-state batteries and better thermal barriers and encasements for traditional lithium-ion chemistries. Additional large-scale, long-duration energy storage solutions include pumped hydro, flow batteries, and below-ground compressed air storage.

Tech Maturation Model

The energy transition relies on the massive scaling up of many technologies, which range in technological maturity. The Clean Edge Tech Maturation Model, shown below, is a tool for business leaders, investors, policymakers, and other stakeholders to assess major clean technologies' technological development and cost competitiveness. Technologies at the top right of the chart (e.g., utility-scale solar, onshore wind, and LEDs) are fully mature technologies, while those at the bottom left are still in the lab and many years from commercial viability.

The 2023 Clean Edge Tech Maturation Model



Source: Clean Edge, Inc., 2023[50]

Building a Robust Materials Ecosystem

The clean energy transition will demand a high volume of minerals, rare earth metals, and other critical materials. The IEA's Sustainable Development Scenario estimates that 28 million tons of lithium, copper, cobalt, and other metals will need to be produced annually by 2040, a big leap from the 7 million tons of "transition materials" mined globally in 2020[51]. Recent modeling from Tesla estimates that 444 million tons of transition materials will be needed annually to support renewable energy generation, storage, and transmission worldwide[52]. This is still orders of magnitude less material than is currently mined for a fossil-fuel-driven economy. According to Circle Economy, a research and advocacy organization, 15.5 billion tons of fossil fuels were used last year[53]. While the clean energy economy will require less volume, the materials are significantly scarcer and more expensive than oil and gas. Recent spikes in battery pack prices[49] drive home the effects material shortages could have on the cost of the energy transition.

To accommodate rapidly expanding demand, industries will need to adopt diversified strategies. Below is Clean Edge's proposed framework for a practical energy transition materials pathway.

ENERGY TRANSITION MATERIALS PATHWAY: THE 5 Rs

Recycle

Reclaiming materials from used battery packs, solar panels, and other clean-tech offerings is one of the best ways to ensure a robust supply stream. Ørsted, for example, has entered into an agreement with Solarcycle to recycle all end-of-life solar panels distributed by Ørsted in the U.S. Currently, this amounts to 1.1 GW of solar panels (with over 4,000 panels already recycled). This agreement is expected to cover 17.5 GW of solar capacity by 2030[54]. This type of cradle-to-cradle circularity will be a crucial aspect of a sustainable energy transition.

Reduce

By reducing the amount of material needed to manufacture clean-tech products in the first place, existing supplies can be stretched much further. Materials can be reduced through various actions, including more efficient products and services and material-use optimization. Examples include higher-density energy production and storage (as accomplished in next-generation solar panels and storage solutions) and more efficient electricity delivery (as in HVDC transmission lines, where less energy is lost over distances). Regarding material optimization, constant manufacturing improvements (from economies of scale) should enable similar or even better outcomes with less material usage.

Refine: There is no way around it: more materials must be produced to meet demand. This will involve the expansion of mining and refining from sources that were previously uneconomical to mine. For example, under the Bipartisan Infrastructure Law, the U.S. DOE is investing $12 million to advance research in extracting lithium from geothermal brines, a potential key source of domestic energy supply[55]. More importantly, the energy transition must be built off as many sustainably sourced materials as possible, requiring better next-generation refining operations that support green mining principles.

Replace: Existing technologies rely heavily on select metals, which are expensive, polluting, and scarce. New iterations must reduce reliance on these materials to reduce cost and increase the adoption of clean technologies. Examples include LFP batteries, which are increasingly used in EV battery packs and rely on widely available iron instead of more scarce heavy metals such as nickel and cobalt.

Ramp-up: These strategies must be pursued simultaneously, and at scale, to ensure we have enough material to reach the energy transition by 2050. The energy transition economy will look much more like the high-tech economy (chips and cell phones) that preceded it than the century-old fossil fuel economy. In other words, the success of the transition will rely more on learning curves (price reductions per every doubling of manufacturing) than simply on the extractive side of the equation.

7-Point Energy Transition Action Plan

As mentioned, we estimate the world is approximately halfway through the modern energy transition (2000—2050). If companies, governments, and individuals are going to meet their net-zero and carbon-reduction targets by mid-century, then how and where we focus our collective actions will matter. Targeted technology, policy, and capital innovations must be deployed *at scale* to meet the challenges of this monumental shift. We offer Clean Edge's 7-Point Energy Transition Action Plan as one possible pathway to ensure the viability and success of the clean-energy transition.

- FOCUS ON EFFICIENCY FIRST
  Pursue energy efficiency's low-hanging fruit for the most bang for your buck, including LEDs, insulation materials, building controls, and energy management systems.
- SCALE UP WIND & SOLAR MASSIVELY
  Support aggressive global deployment of solar and wind power, both utility-scale and distributed, to reach 100% zero-carbon emission electric grids.
- PAIR RENEWABLES WITH STORAGE AT SCALE
  Deploy storage at scale to enable 100%, 24/7 renewable power. Focus on both utility-scale and distributed storage, using electrochemical batteries (lithium-ion, solid-state, flow, etc.) and mechanical energy storage (pumped hydro, compressed air, etc.).
- ELECTRIFY HEATING & VEHICLES ASAP
  Although we often hear the demand to "electrify everything," we recommend focusing on two high-impact areas: passenger vehicles (two-, three-, and four-wheelers) and heating and cooling systems for homes and buildings (via the adoption of electric heat pumps).
- MODERNIZE TRANSMISSION & DISTRIBUTION GRIDS
  Build out a range of electricity grid modernization efforts, including digitization, smart meters and devices, bi-directional meters and charging, smart substations, and high-voltage, direct current transmission lines. A modern 21st-century grid is critical to enable the clean-energy transition.
- DEVELOP GREEN HYDROGEN, AMMONIA, AND FUELS
  Decarbonizing heavy industry will be complex, requiring green fuels above and beyond electrification. We recommend the adoption of green hydrogen and fuels to support the production of steel, fertilizer, and other energy-intensive industries, as well as for long-haul transport such as trucking, marine shipping, and air travel.
- SECURE SUSTAINABLY MINED AND RECYCLED MATERIALS
  Ensure the availability of mined and recycled materials for EV, solar, wind, and other clean-energy technology production. The future of energy depends on secure and reliable supplies of sustainably mined or recycled materials (lithium, rare earths, silicon, nickel, etc.) rather than the extraction of fossil fuels (coal, oil, gas).

The Clean Edge 7-Point Energy Transition Action Plan

1 Focus on Efficiency First
Pursue energy efficiency's low-hanging fruit for the most bang-for-the-buck, including LEDs, insulation materials, building controls, and energy management systems

2 Scale Up Wind & Solar Massively
Support aggressive global deployment of utility-scale and distributed solar and wind

3 Pair Renewables with Storage at Scale
Deploy energy storage at scale using electrochemical batteries (lithium-ion, solid-state, flow, etc.) and mechanical energy storage (pumped hydro, compressed air, etc.)

4 Electrify Heating & Vehicles ASAP
Target two high-impact areas: electrification of passenger vehicles and heating and cooling systems for homes and buildings (via adoption of electric heat pumps)

5 Modernize Transmission & Distribution Grids
Accelerate grid modernization efforts including digitization, smart meters and devices, bi-directional meters and charging, smart substations, and HVDC

6 Develop Green Hydrogen, Ammonia, & Fuels
Adopt green hydrogen and fuels to support the production of steel, fertilizer, and other energy-intensive industries, as well as for long-haul transport such as ships and planes

7 Secure Sustainably Mined & Recycled Materials
Ensure the availability of mined and recycled materials for EV, solar, wind, and other clean-energy technology production

Source: Clean Edge, Inc.

How Does Someone Track the Clean Energy, Smart Grid Infrastructure, and Wind Energy Sectors?

Investors can track the Clean Energy, Smart Grid Infrastructure, and Wind Energy Sectors through three Nasdaq Clean Edge indexes:

- Nasdaq Clean Edge Green Energy™ Index (CELS™),
- Nasdaq OMX Clean Edge Smart Grid Infrastructure™ Index (QGRD™), and the
- ISE Clean Edge Global Wind Energy™ Index (GWE™).

In addition, investors can gain exposure to the indexes through the corresponding ETFs. Please see below for an overview of the respective indexes.

Nasdaq Clean Edge Green Energy Index (CELS) / Total Return (CEXX™)

The Nasdaq Clean Edge Green Energy Index is a modified market capitalization-weighted index designed to track the performance of companies that are primarily manufacturers, developers, distributors, and/or installers of clean energy technologies, as defined by Clean Edge. It is reconstituted semi-annually in March and September and is rebalanced quarterly in March, June, September, and December. The index began on November 17, 2006, at a base value of 250.00. As of July 31, 2023, the index had 63 components. Investors can gain exposure to the index through the corresponding ETFs:

- First Trust Nasdaq Clean Edge Green Energy Index Fund (Nasdaq: QCLN),
- First Trust Nasdaq Clean Edge Green Energy UCITS ETF (London: QCLU),

- First Trust Nasdaq Clean Edge Green Energy ETF (Toronto: QCLN), and
- Samsung KODEX US Clean Energy Nasdaq ETF (South Korea: 419420)

Eligibility Criteria

To be eligible for inclusion, issuers of the security must be classified, according to Clean Edge, as technology manufacturers, developers, distributors, and/or installers in one of the following sub-sectors:

- Advanced Materials (silicon, lithium, bio-based, and/or other materials and processes that enable clean-energy and low-carbon technologies);
- Energy Intelligence (conservation, efficiency, smart meters, energy management systems, LEDs, smart grid, superconductors, power controls, etc.);
- Energy Storage & Conversion (advanced batteries, power conversion, electric vehicles, hybrid drivetrains, hydrogen, fuel cells for stationary, portable, and transportation applications, etc.); and
- Renewable Electricity Generation (solar, wind, geothermal, water power, etc.).
- A security must also have a demonstrated ability to capture the potential of the clean-energy sector by receiving a majority (50% or more) of its revenue from clean-energy and low-carbon activities or, in the case where a constituent has multiple business units and revenue streams, have substantial exposure to the clean-energy and low-carbon sector, as determined by Clean Edge.

In addition, a security must meet the following criteria:

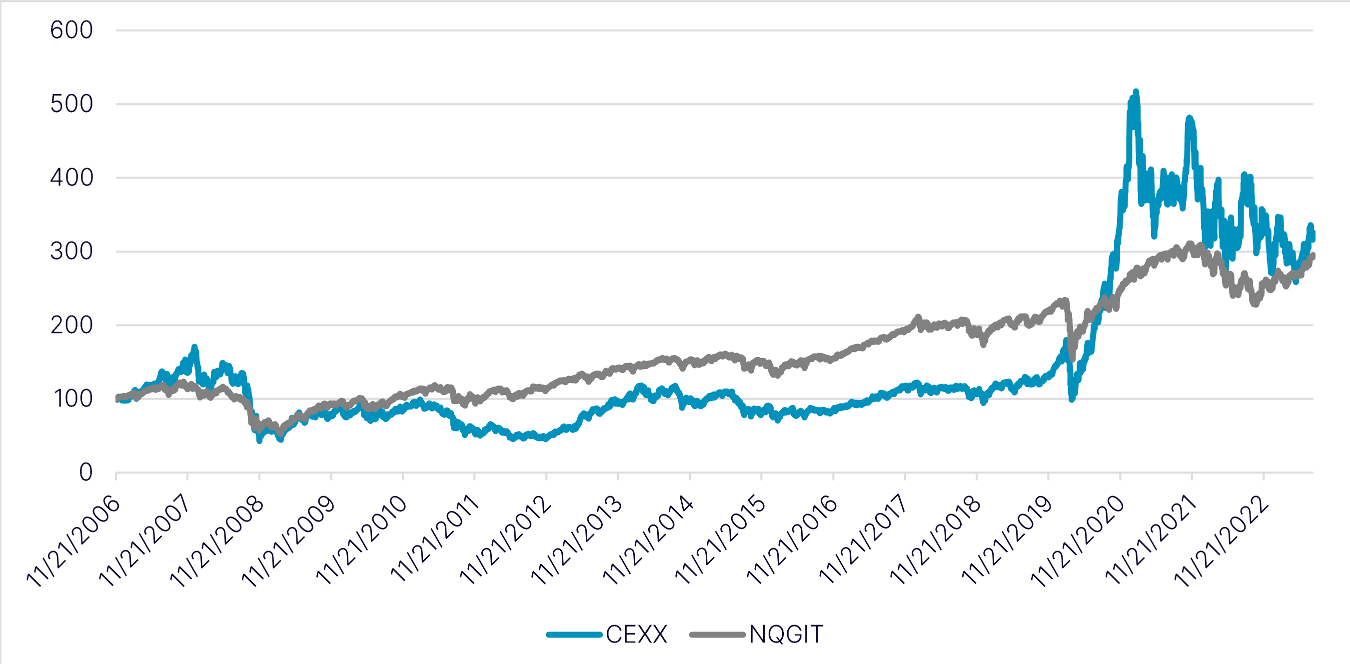
- Be listed on the Nasdaq Stock Market® (Nasdaq®), the New York Stock Exchange, NYSE American, or the CBOE Exchange;
- Have a minimum market capitalization of $150 million;
- Have a minimum average daily trading volume of 100,000 shares.

For complete eligibility criteria, please visit the index methodology.

Performance

Below is a look at the performance of the Nasdaq Clean Edge Green Energy Total Return™ Index (CEXX) since its inception. The index generated a cumulative return of 225.42%, with an annualized return of 7.32% and an annualized volatility of 34.99%. The Nasdaq Global Total Return™ Index (NQGIT™), which tracks the performance of securities representing over 98% of the entire listed market capitalization of the global equity market, generated a cumulative return of 214.60%, with an annualized return of 10.22% and an annualized volatility of 16.75% over the same time period.

Cumulative Performance



Data from 11/17/2006 – 7/31/2023. Source: Nasdaq.

How Does the Index Compare to Competitor Clean and Traditional Energy Indexes?

Let's start by looking at cumulative returns by comparing the Nasdaq Clean Edge Green Energy Total Return Index (CEXX) to a competitor clean energy index [Wilderhill Clean Energy Index TR (ECOTR)] as well as a traditional energy index [S&P 500 Energy Select Sector Total Return Index TR (IXETR)].

Since November 30, 2007, the beginning of the ECOTR history, as seen in the table and chart below, Nasdaq's CEXX has significantly outperformed ECOTR and IXETR. The volatility profile of all three indexes is relatively similar in the mid to low 30% range despite very different return profiles. The cumulative performance chart and the annual performance table show that CEXX had an impressive run of outperformance between 2020 and 2021 before pulling back in 2022. Since then, the index has moved relatively sideways. For those following the clean energy space, it shouldn't be surprising that CEXX and ECOTR drastically outperformed the traditional energy space, as shown through IXETR in 2020 and by a good margin in 2019. However, there was a solid return for traditional energy in 2022. It's worth noting that despite the impressive traditional energy rebound in 2022, when IXETR gained 65%, CEXX fell 30%, outperforming ECOTR by over 14%. CEXX's year-to-date return of 16.18% has outperformed ECOTR and IXETR by 2.17% and 12.05%, respectively.

Index	Cumulative Return	Annualized Return	Annualized Volatility
CEXX	164.45%	110.70%	35.46%
ECOTR	-27.50%	-3.31%	37.39%
IXETR	16.97%	1.65%	32.05%

Data from 11/30/2007-7/31/2023. Source: Nasdaq, Bloomberg.

Cumulative performance vs Competitors

Data from 11/30/2007-7/31/2023. Source: Nasdaq, Bloomberg.

Annual Performance

Year	CEXX	ECOTR	IXETR
2007	10.54%	16.15%	8.03%
2008	-63.44%	-69.89%	-38.71%
2009	44.72%	29.78%	21.79%
2010	2.71%	-4.76%	21.98%
2011	-40.81%	-50.43%	3.13%
2012	-1.32%	-18.11%	5.41%
2013	89.34%	58.51%	26.42%
2014	-3.13%	-16.94%	-8.47%
2015	-6.38%	-10.24%	-21.56%
2016	-2.65%	-22.00%	28.24%
2017	32.05%	39.32%	-0.86%
2018	-12.11%	-14.57%	-18.09%
2019	42.66%	59.31%	12.09%
2020	184.83%	203.78%	-32.84%
2021	-2.64%	-30.21%	53.43%
2022	-30.15%	-46.11%	64.56%
YTD 2023*	16.18%	14.01%	1.96%

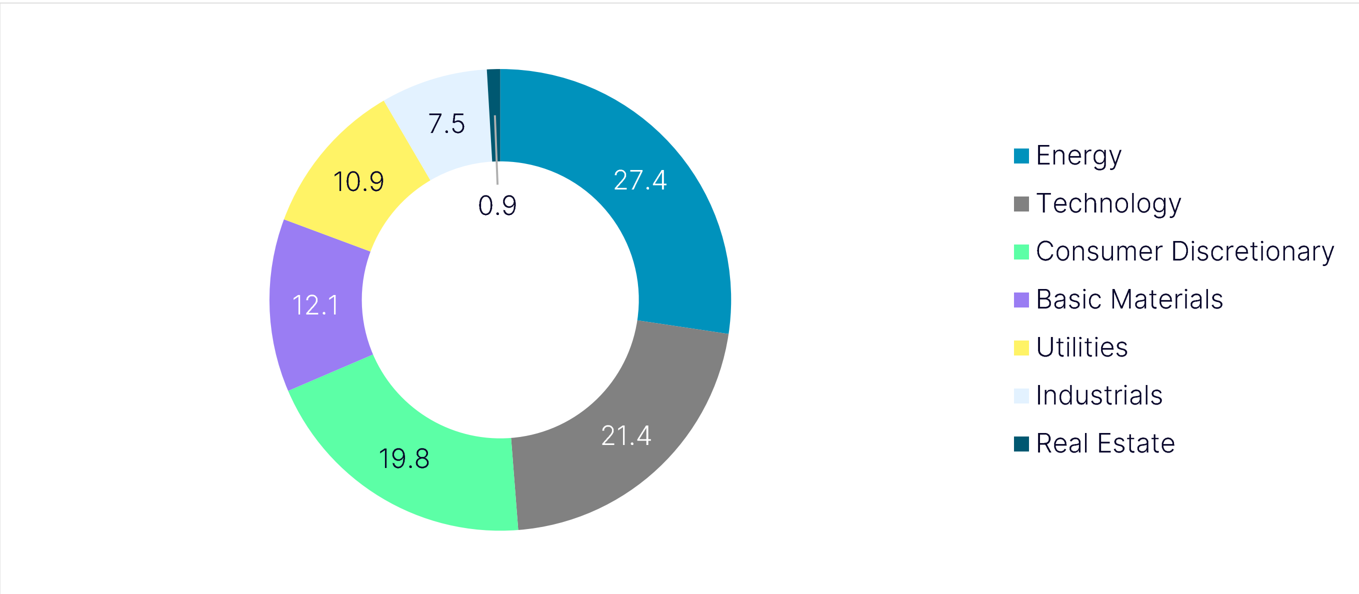
*Data from 11/30/2007-7/31/2023. Source: Nasdaq, Bloomberg.

CELS ICB Industry Allocations (%)

The index is currently allocated to seven of the 11 industries, with the most significant weights across Energy (27.36%), Technology (21.40%), and Consumer Discretionary (19.79%).

ICB Industry	Weight (%)
Energy	27.36
Technology	21.40
Consumer Discretionary	19.79
Basic Materials	12.12
Utilities	10.91
Industrials	7.49
Real Estate	0.93

Index Weight by ICB Industry: CELS



Data as of 7/31/2023. Source: Nasdaq.

Top 10 Constituents

Name	Weight (%)	ICB Industry
Tesla	9.21	Consumer Discretionary
ON Semiconductor	9.05	Technology
Albemarle	7.70	Basic Materials
First Solar	6.85	Energy
Rivian Automotive A	6.59	Consumer Discretionary
Enphase Energy	6.13	Energy
Lucid Group	3.44	Consumer Discretionary
Allegro Microsystems	3.30	Technology
SolarEdge Tech	2.98	Energy
Wolfspeed	2.73	Technology

Data as of 7/31/2023. Source: Nasdaq.

Nasdaq OMX Clean Edge Smart Grid Infrastructure Index (QGRD) / Total Return (QGDX™)

The Nasdaq OMX Clean Edge Smart Grid Infrastructure Index is designed to act as a transparent and liquid benchmark for the smart grid and electric infrastructure sector. The index includes companies listed globally that are primarily engaged and involved in the electric grid industry; electric meters, devices, and networks; energy storage and management; connected mobility; and enabling software used by the smart grid and electric infrastructure sector (including both pure play companies focused on the smart grid sector and diversified multinationals with smart grid sector exposure). It is reconstituted semi-annually in March and September and is rebalanced quarterly in March, June, September, and December. The index began on September 22, 2009, at a base value of 250.00. As of July 31, 2023, the index had 84 components. Investors can gain exposure to the index through the corresponding ETFs:

- First Trust Nasdaq Clean Edge Smart Grid Infrastructure Index Fund (Nasdaq: GRID)
- First Trust Nasdaq Clean Edge Smart Grid Infrastructure UCITS ETF (London: GRDU)

Eligibility Criteria

To be included in the index, a security must meet the following criteria:

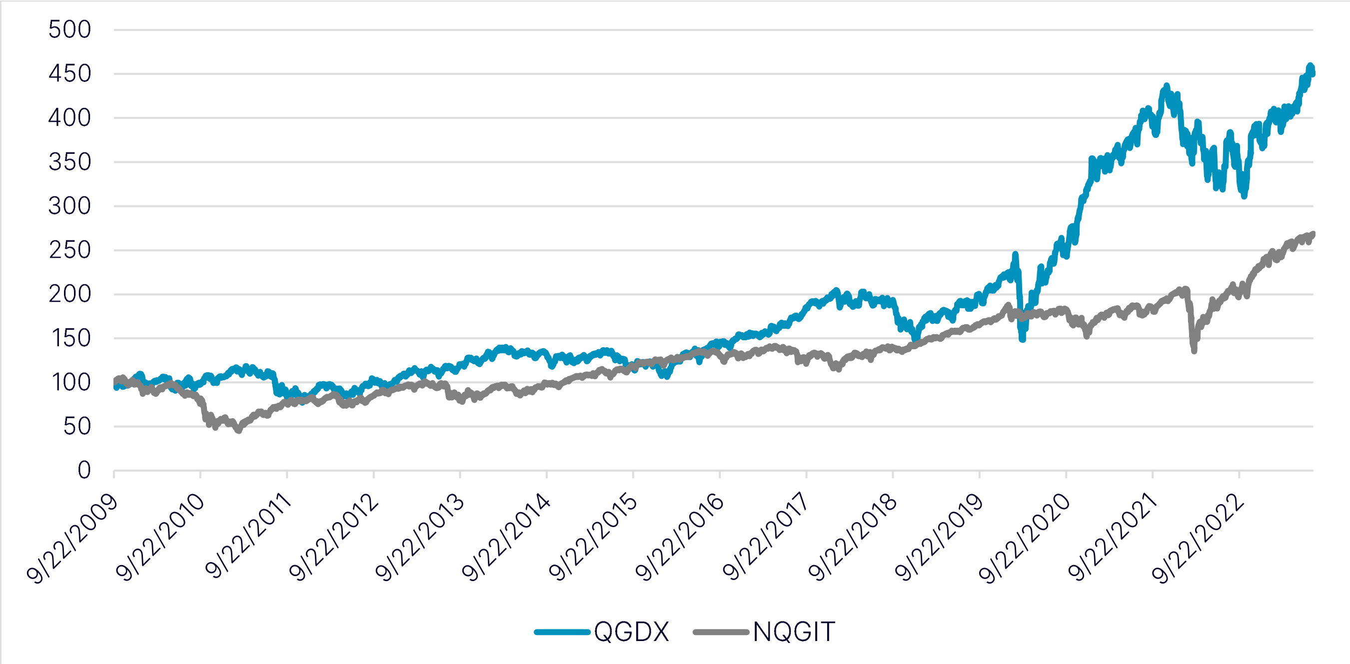
- Be classified as a smart grid, electric infrastructure, EV network, smart building, software, and/or other grid-related activities company according to Clean Edge;
- Be listed on an index-eligible global stock exchange;
- Have a minimum worldwide market capitalization of $100 million;
- Have a minimum three-month average daily dollar trading volume of $500,000; and
- A minimum free float of 20%.

For complete eligibility criteria, please visit the index methodology.

Performance

Below is a brief look at the performance of the Nasdaq OMX Clean Edge Smart Grid Infrastructure Total Return Index (QGDX) index since its inception. The index generated a cumulative return of 351.11%, with an annualized return of 11.48% and an annualized volatility of 20.45%. The Nasdaq Global Total Return Index (NQGIT) generated a cumulative return of 245.71%, with an annualized return of 9.36% and an annualized volatility of 14.61% over the same time period. Looking at the annual performance figures, the relatively high concentration of underperformance early on in 2010/2011 held QGDX back from establishing a clear track record of outperformance throughout most of its first decade of existence. Since 2019, QGDX has had solid returns and, on average, has outperformed NQGIT by 16.5% annually. Its last observed point of cumulative underperformance was a brief dip below NQGIT during the Covid-19 bear market in March 2020, after which it began the most impressive period of outperformance in its history.

Cumulative Performance



Data from 9/21/2009 – 7/31/2023. Source: Nasdaq.

Annual Performance

Year	QGDX	NQGIT
2009	5.94%	4.61%
2010	0.71%	15.64%
2011	-20.29%	-7.65%
2012	20.21%	18.31%
2013	26.15%	23.79%
2014	0.32%	4.49%
2015	-6.16%	-1.59%
2016	25.30%	9.02%
2017	28.83%	24.54%
2018	-21.94%	-9.72%
2019	43.90%	26.58%
2020	49.84%	16.28%
2021	29.34%	18.64%
2022	-13.34%	-17.84%
YTD 2023*	22.52%	18.17%

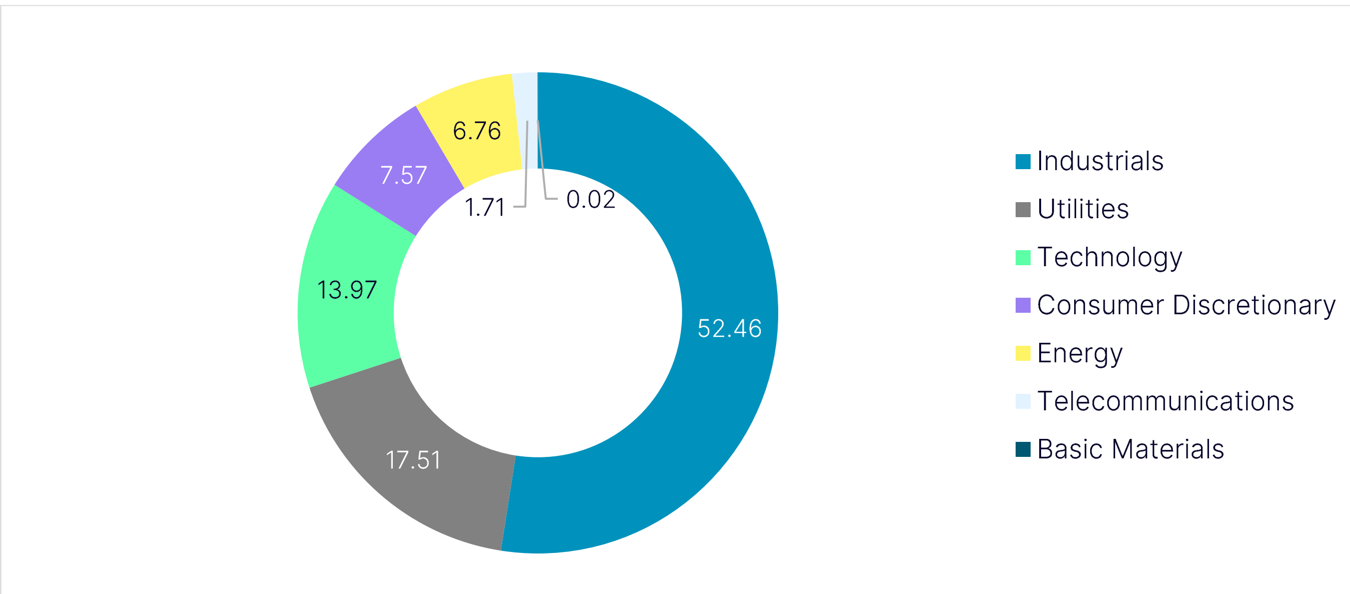
Data from 9/21/2009 – 7/31/2023. Source: Nasdaq.

QGRD ICB Industry Allocations (%)

The index is currently allocated to seven of the 11 industries, with the most significant weights across Industrials (52.46%), Utilities (17.51%), and Technology (13.97%).

ICB Industry	Weight (%)
Industrials	52.46
Utilities	17.51
Technology	13.97
Consumer Discretionary	7.57
Energy	6.76
Telecommunications	1.71
Basic Materials	0.02

Index Weight by ICB Industry: QGRD



Data as of 7/31/2023. Source: Nasdaq.

Top 10 Constituents

Name	Weight (%)	ICB Industry
Eaton	8.64	Industrials
Johnson Controls Intl	8.52	Industrials
ABB	8.18	Industrials
Schneider Electric	7.69	Industrials
National Grid	7.16	Utilities
Aptiv	4.60	Consumer Discretionary
Quanta Services	4.20	Industrials
Samsung SDI	3.57	Technology
Enphase Energy	3.23	Energy
Hubbell	2.85	Industrials

Data as of 7/31/2023. Source: Nasdaq.

ISE Clean Edge Global Wind Energy Index (GWE) / Total Return (GWETR™)

The ISE Clean Edge Global Wind Energy Index (GWE) is designed to track the performance of companies listed globally that are primarily engaged and involved in the wind energy industry based on analysis of the products and services offered by those companies (including both pure play companies focused on the wind energy sector and diversified multinationals with wind energy sector exposure). It is reconstituted and rebalanced semi-annually in March and September. The Index was launched on December 16, 2005, at a base value of 100.00. As of July 31, 2023, the index had 55 components. The First Trust ISE Clean Edge Global Wind Energy Index Fund (NYSE: FAN) is the ETF that tracks the index.

Eligibility Criteria

To be included in the index, a security must meet the following criteria:

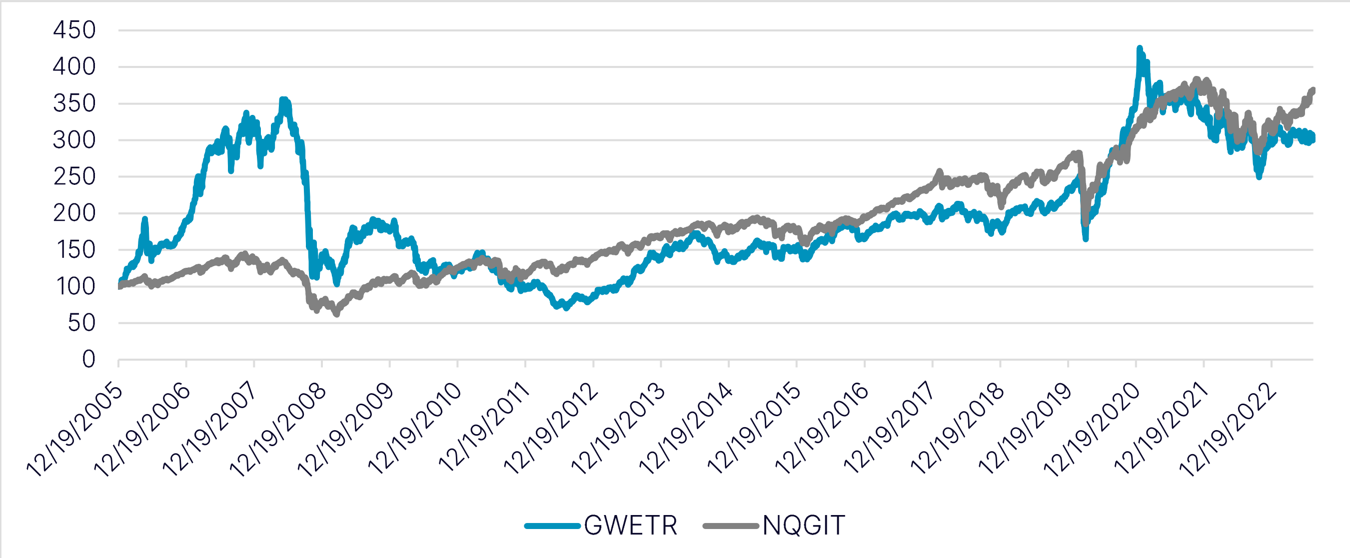
- Be actively engaged in some aspect of the wind energy industry, such as the development or management of a wind farm, the production or distribution of electricity generated by wind power, or involvement in the design, manufacture, or distribution of machinery or materials designed specifically for the industry according to Clean Edge;
- Be listed on an index-eligible global stock exchange;
- Have a minimum worldwide market capitalization of $100 million;
- Have a minimum three-month average daily dollar trading volume of $500,000; and
- A minimum free float of 25%.

For complete eligibility criteria, please visit the index methodology.

Performance

Below is a chart of the cumulative performance of the ISE Clean Edge Global Wind Energy Total Return Index (GWETR) since its inception. The index generated a cumulative return of 200.38%, with an annualized return of 6.44% and an annualized volatility of 22.71%. The Nasdaq Global Total Return Index (NQGIT) generated a cumulative return of 269.23%, with an annualized return of 7.69% and an annualized volatility of 16.48% over the same time period. From the GWETR low-point (on a cumulative basis since inception occurred) on July 25, 2012, through July 31, 2023, GWETR had a cumulative return of 329%, outpacing the 202% of NQGIT.

Cumulative Performance



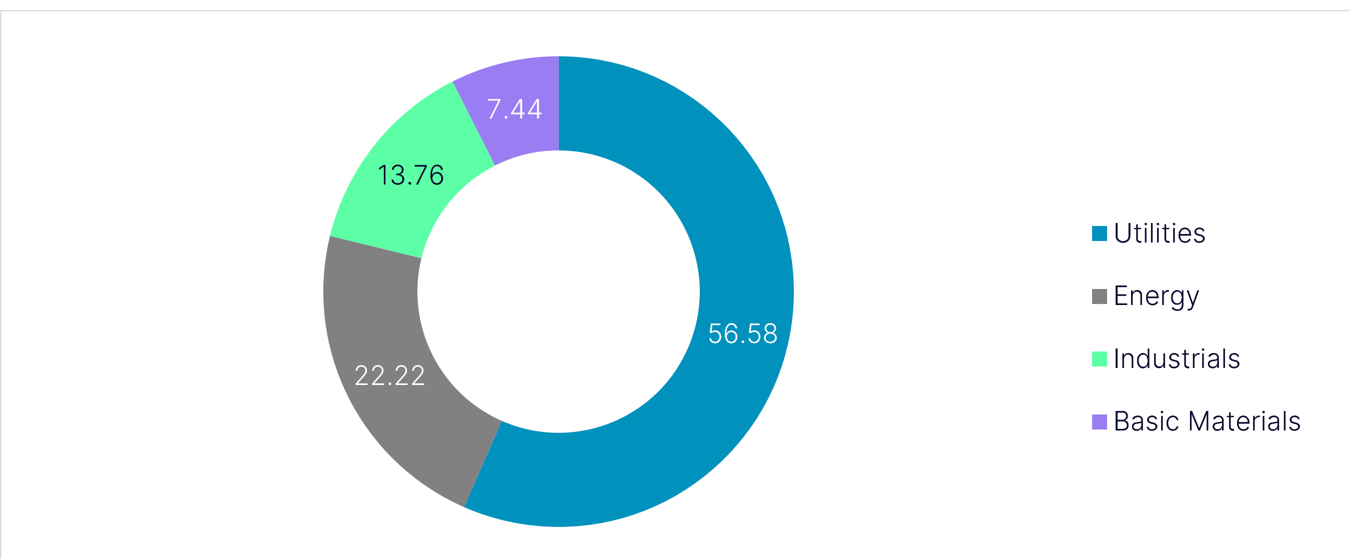
Data from 12/16/2005 – 7/31/2023. Source: Nasdaq.

GWE ICB Industry Allocations (%)

The index currently allocates to four of the 11 industries, with the most notable weights across Utilities (56.58%), Energy (22.22%), and Industrials (13.76%).

ICB Industry	Weight (%)
Utilities	56.58
Energy	22.22
Industrials	13.76
Basic Materials	7.44

Index Weight by ICB Industry: GWE



Data as of 7/31/2023. Source: Nasdaq.

Top 10 Constituents

Name	Weight (%)	ICB Industry
Orsted	8.08	Utilities
Vestas Wind Systems	7.62	Energy
EDP Renovaveis	7.54	Utilities
Northland Power	6.45	Utilities
China Longyuan Power Group H	4.29	Energy
Boralex A	3.10	Utilities
Owens Corning	2.90	Industrials
General Electric	2.73	Industrials
Hitachi	2.62	Industrials
Enel	2.48	Utilities

Data as of 7/31/2023. Source: Nasdaq.

Conclusion

While the energy transition is bolstered by strong public support and growing economies of scale, key challenges remain in the sector, including higher interest rates, transmission bottlenecks, safety, and political opposition. We estimate that humanity is about halfway through the global energy transition as businesses, utilities, consumers, and other stakeholders embrace the benefits of clean energy and work to battle the ravages of a changing climate. The key technology, capital, and policy-related developments driving this significant change include:

- Declining Costs. Solar and onshore wind are now the most cost-effective forms of new electricity generation globally, beating out nuclear, coal, and, in many cases, even natural gas plants.
- Investment Shift from Fossil Fuels to Clean Energy. Both private and public investors are becoming cognizant of the long-term geopolitical and financial risks of fossil-fuel investments and increasingly moving away from fossil fuels.
- Smart Grid & Electrification Trends. With energy storage and EVs continuing to experience cost declines similar to renewables, the concept of “electrification of everything” is emerging.
- Climate & Energy Policies. With global emissions from fossil fuels at their highest levels in history, national governments worldwide are signing commitments to reduce their carbon emissions.
- Public Support. The demand for low-carbon energy sources is coming not only from governments but also from corporations and the public.

These and other developments create unique opportunities of which investors should be aware.

Ways to Access

Investors can track the Clean Energy, Smart Grid Infrastructure, and Wind Energy Sectors through three Nasdaq Clean Edge indexes:

- Nasdaq Clean Edge Green Energy Index (CELS),
    - First Trust Nasdaq Clean Edge Green Energy Index Fund (Nasdaq: QCLN)
    - First Trust Nasdaq Clean Edge Green Energy UCITS ETF (London: QCLU)

  - First Trust Nasdaq Clean Edge Green Energy ETF (Toronto: QCLN)
  - Samsung KODEX US Clean Energy Nasdaq ETF (South Korea: 419420)
- Nasdaq OMX Clean Edge Smart Grid Infrastructure Index (QGRD)
  - First Trust Nasdaq Clean Edge Smart Grid Infrastructure Index Fund (Nasdaq: GRID)
  - First Trust Nasdaq Clean Edge Smart Grid Infrastructure UCITS ETF (London: GRDU)
- ISE Clean Edge Global Wind Energy Index (GWE).
  - First Trust ISE Clean Edge Global Wind Energy Index Fund (NYSE: FAN)

Sources: Nasdaq Global Indexes, Bloomberg, FactSet.

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