

ESG PERSPECTIVES



IS THERE A FUTURE FOR NUCLEAR POWER IN AMERICA?

A BALANCED ASSESSMENT

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Executive Summary

As the topic of climate change grows increasingly relevant today, it is no surprise that socially responsible investors are looking to find new, alternative energy providers for their portfolios. While the majority of people have heard of the more traditional, renewable resources such as hydro-electric, wind and solar, nuclear power is often swept aside as an alternative in these discussions. This is a missed opportunity.

Events such as the 2011 Fukushima disaster in Japan, where the tsunami caused by the Tohoku earthquake flooded reactors leading to three nuclear meltdowns and three hydrogen explosions and HBO's Emmy award-winning miniseries, Chernobyl, which dramatizes the story of the 1986 nuclear accident — one of the worst man-made catastrophes in history* — have drawn significant global attention to the dangers associated with nuclear power. While tragedies such as these are devastating, when executed properly and with utmost care, nuclear power has the potential to be a strong, ESG-friendly alternative.

Nuclear power is readily available and able to provide large-scale quantities of carbon-free power with minimal land requirements and fewer capacity issues when compared to its alternative energy counterparts. With new technology developments, nuclear power will become an even more cost-effective, safe energy solution.

Climate change is a global, urgent issue that needs to be addressed as soon as possible. While there are certainly obstacles to face when it comes to successful implementation of nuclear power, its potential to complement other sustainable energy alternatives such as wind and solar power is remarkable.

* <https://itsh.bo/2nateBs>

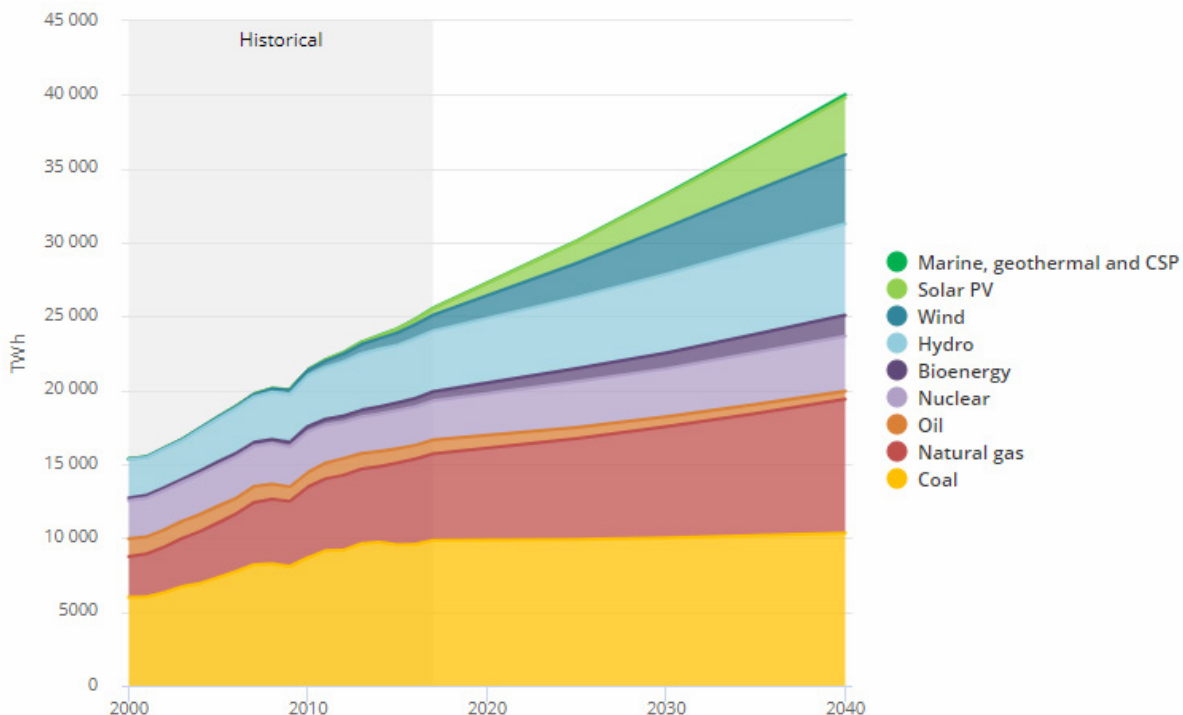
Why Nuclear, Why Now?

Climate change is real. Regardless of where exactly you stand on the issue of how to solve it, it is hard to argue against two key facts: the earth is getting warmer and human greenhouse gas (GHG) emissions contribute a significant level to global warming and climate change. The Earth is on track to warm upwards of two degrees Celsius above Pre-Industrial Revolution temperatures even with current climate mitigation plans in place, and that means exposure to many risks; including ecosystem damage through widespread droughts, possibility of natural disasters like the forest fires in the Amazon, and rising sea levels.ⁱ

Is All Renewable Energy Really Renewable?

Since fossil fuel consumption represents 76% of total GHG emissions in the United States, the critical debate lies in how we can shift our energy output away from using coal, natural gas, and petroleum products.ⁱⁱ The idealist sentiment is to use traditional renewable resources (hydro-electric, wind, and solar) as much as possible. However, the land requirement needed to fully replace our entire current consumption with all renewable energy certainly makes it a questionable idea. More importantly, the intermittent nature of the sources means that the energy harvested needs to be temporarily stored, which has added costs and difficulties, or another source must temporarily pick up the load. Though not necessarily the causal factor, this weakness came to light when fingers started getting pointed during the massive 2016 Southern Australia blackout and more recently during the 2019 London Blackout. These are both areas where renewable energy is heavily used but augmented by fossil fuel turbines. In addition, the burden placed on power grids globally is only going to get worse, as the International Energy Agency (IEA) predicts worldwide energy consumption will grow 27% by 2040.ⁱⁱⁱ

Increase in Renewable Energy Output Will Only Offset Higher Demand Worldwide¹

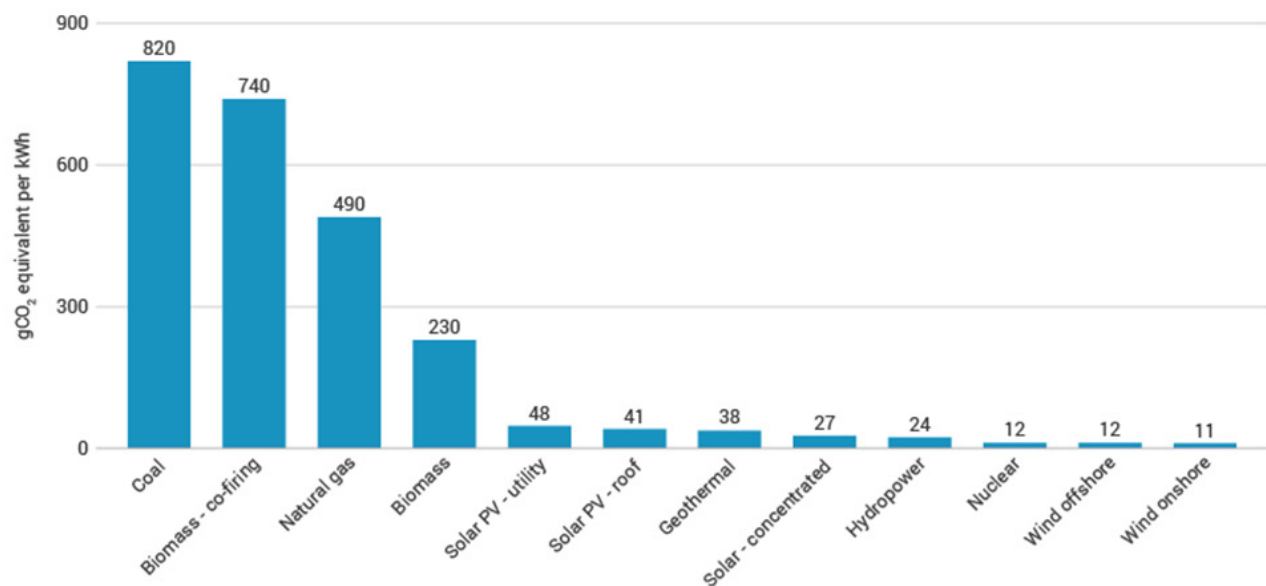


A further impact on energy consumption and power grids could be the current push to swap out traditional automobiles with electric vehicles, as one IEA scenario has global electric vehicle usage

as high as 220 million by 2030.^{iv} Another problem is most renewable power sources are a significant distance from the source of energy demand, which requires further infrastructure development and additional costs. In order to deal with these limitations, a traditional energy source such as coal or natural gas must be used to complement renewable energy, as companies can quickly turn on turbines powered by these sources when renewable output dwindles or demand increases. Within the United States, the abundance and low cost of natural gas has made it the predominant energy source for electricity generation and heating nationwide (35% of U.S. electricity generation and 31% of all energy consumption).^v However, though natural gas helps lower GHG emissions when compared to coal, the GHG levels are still significant and will be a key contributor to global warming and climate change for years to come, with trillions of dollars in possible damages expected. So, in order to help mitigate the impending issue, is there a better viable option for the United States' energy future?

Using Natural Gas for Electricity Consumption Produces Large Levels of CO₂ Emissions, but Is Better Than Coal²

Average life-cycle CO₂ equivalent emissions



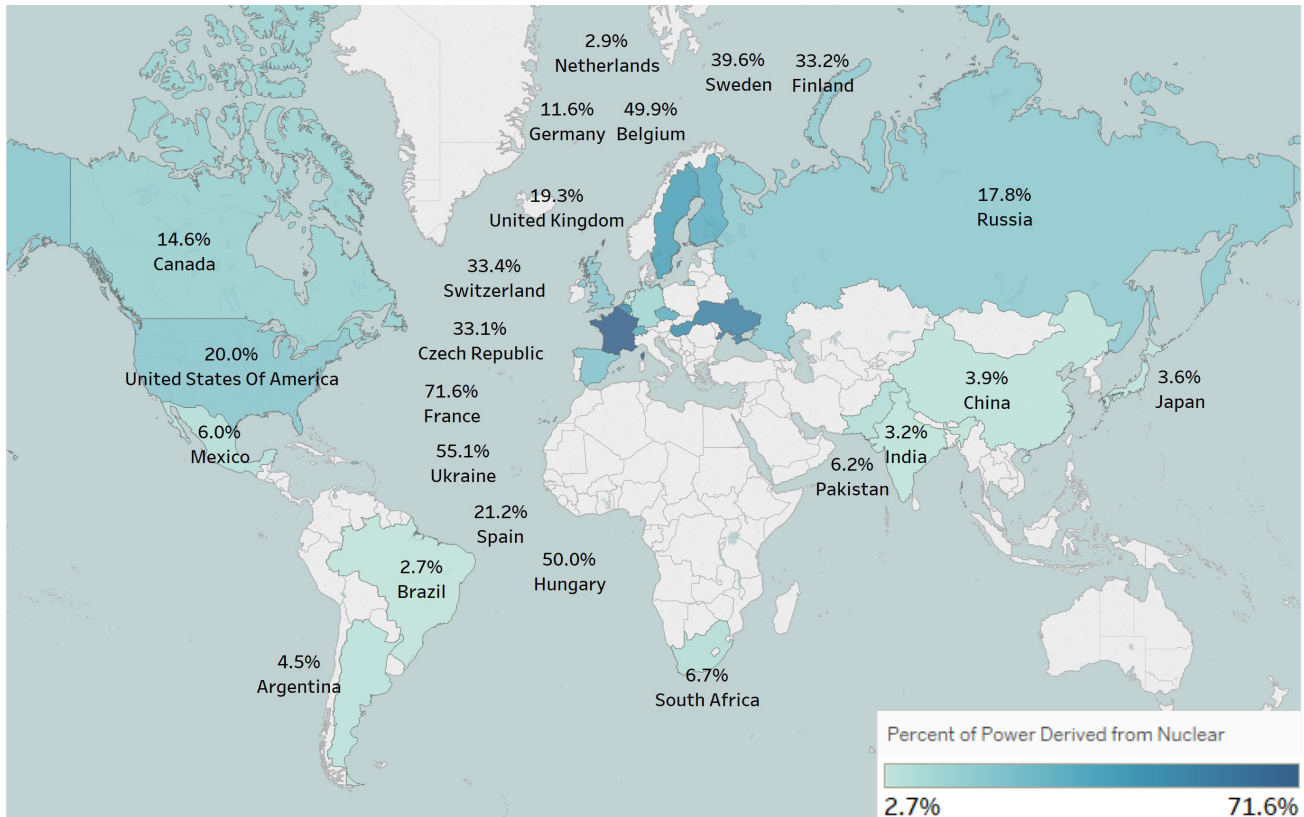
When considering all factors of production, renewables (including nuclear power) produce very little CO₂.

The Nuclear Alternative

Nuclear power, though often dismissed in the discussion, needs to be considered to address our current climate challenges. It is a readily available technology that provides large-scale quantities of carbon-free power that does not have the same land requirements and intermittent capacity issues that other renewables possess. Though some current nuclear power projects have become cost prohibitive, the industry has shown in the past that it can be an affordable power source and has many new technological advances on the horizon. Unfortunately, many across the United States, including the Environmental, Social, and Governance (ESG) investing community, seem to be heavily divided on the issue. Powerful investors like philanthropist Bill Gates have championed nuclear power as the savior of climate change as well a global poverty, as he launched his own start-up Terrapower to create advanced nuclear power technology.^{vi} On the other side, one only has to look at the differing views on nuclear power by the 2020 Democratic Presidential candidates, who are all eager to positively impact climate change, to realize there is no consensus. This lack of agreement trickles down to ESG investing, as some experts will

intentionally screen out nuclear power related companies from its ESG-based products, such as what MSCI does in creating its ESG Leaders Index.^{vii} Actively screening out nuclear power is essentially equating it to near universally admonished industries such as tobacco and controversial weapons production, not a potential savior of climate change. However, if we as Americans are truly committed to ridding our country of coal-power in the immediate future, and natural-gas power in the distant future, nuclear power is not only the best solution, but one of the few feasible choices available.

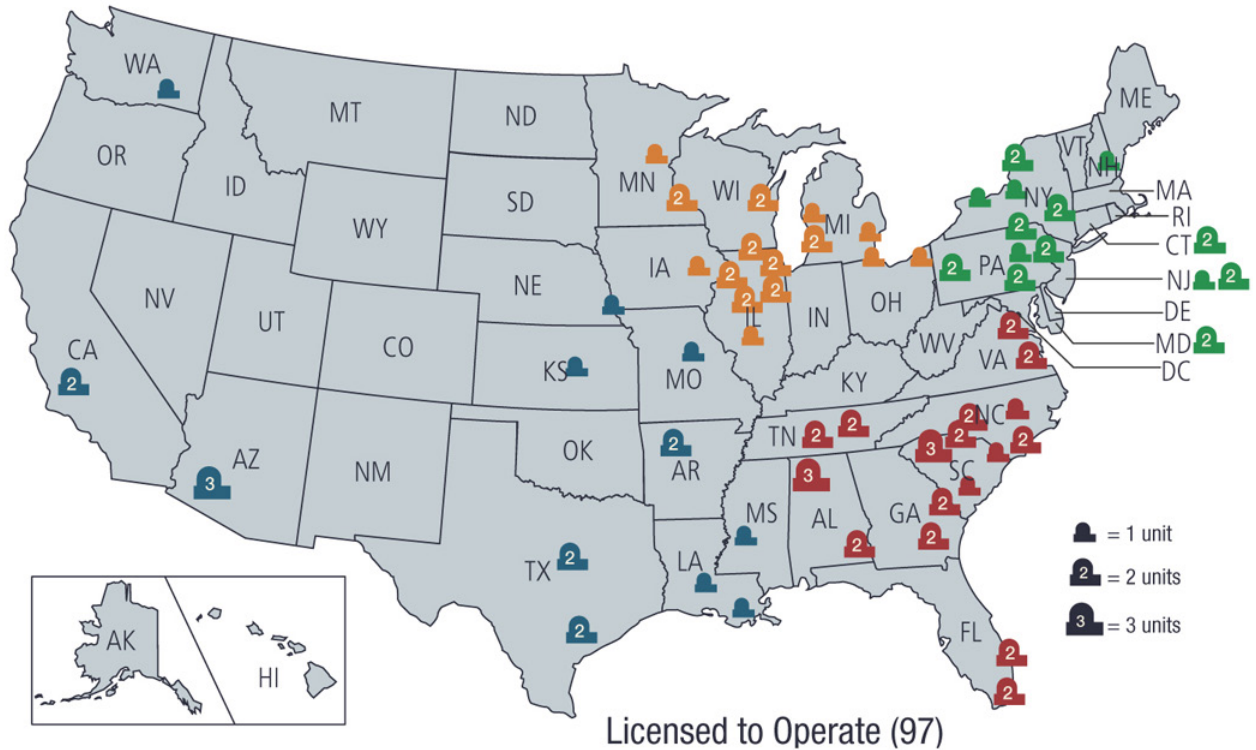
Nuclear Power Has Varied Levels of Usage Across Advanced and Developed Countries³



Nuclear Power Today and Its Fall in Popularity in America

Nuclear power may be the only readily available zero-emission energy source, even though its public support has continued to fall in America in recent years - no thanks to disasters like the 2011 Fukushima debacle in Japan, where the tsunami caused by the Tohoku earthquake flooded the reactors and led to three nuclear meltdowns and three hydrogen explosions.^{viii} Also, the fracking boom within the United States has made natural gas very affordable, crowding out other energy sources due to profitability constraints. While nuclear power is out of favor in the U.S. (for now) is still widely used across the globe. Even with countries like Germany pledging to cease use by 2022, there are 454 reactors in 30 countries that produce 11% of the world's electricity, with 54 new plants currently under construction. There is certainly a sharp divide though, as countries like China, Russia, and India look to nuclear power as an important future component of energy output, but the United States and many other western countries are trying to divest away from nuclear power consumption. The average age of the 97 U.S. nuclear reactors is 39 years old, with only one reactor built this century and only two new U.S. reactors under construction.^{ix} Many are set to decommission this next decade, so nuclear power's 19% share of the U.S. electricity generation market will likely continue to fall.

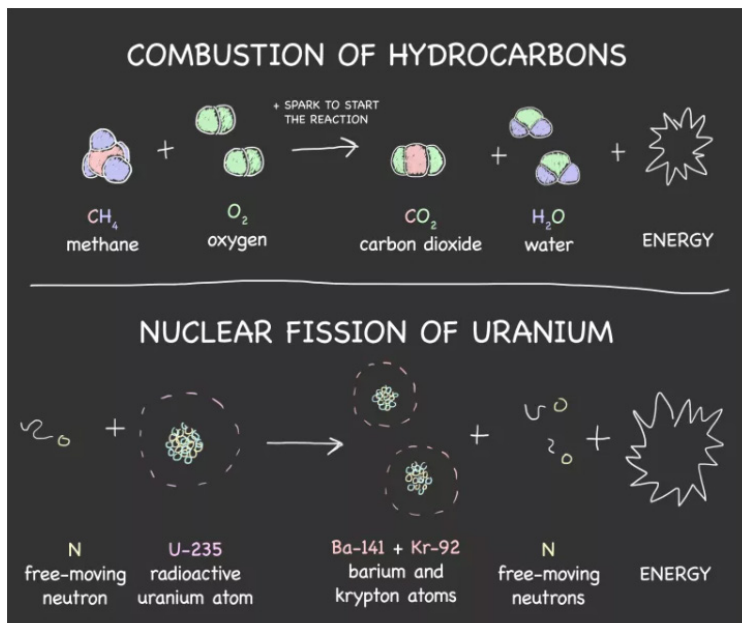
U.S. Operating Commercial Nuclear Power Reactors⁴



U.S.NRC
 United States Nuclear Regulatory Commission
 Protecting People and the Environment
 As of August 2019

Nuclear Power Plants are heavily concentrated in three distinct areas within the United States; the Southeast, Northeast, and Great Lakes Region.

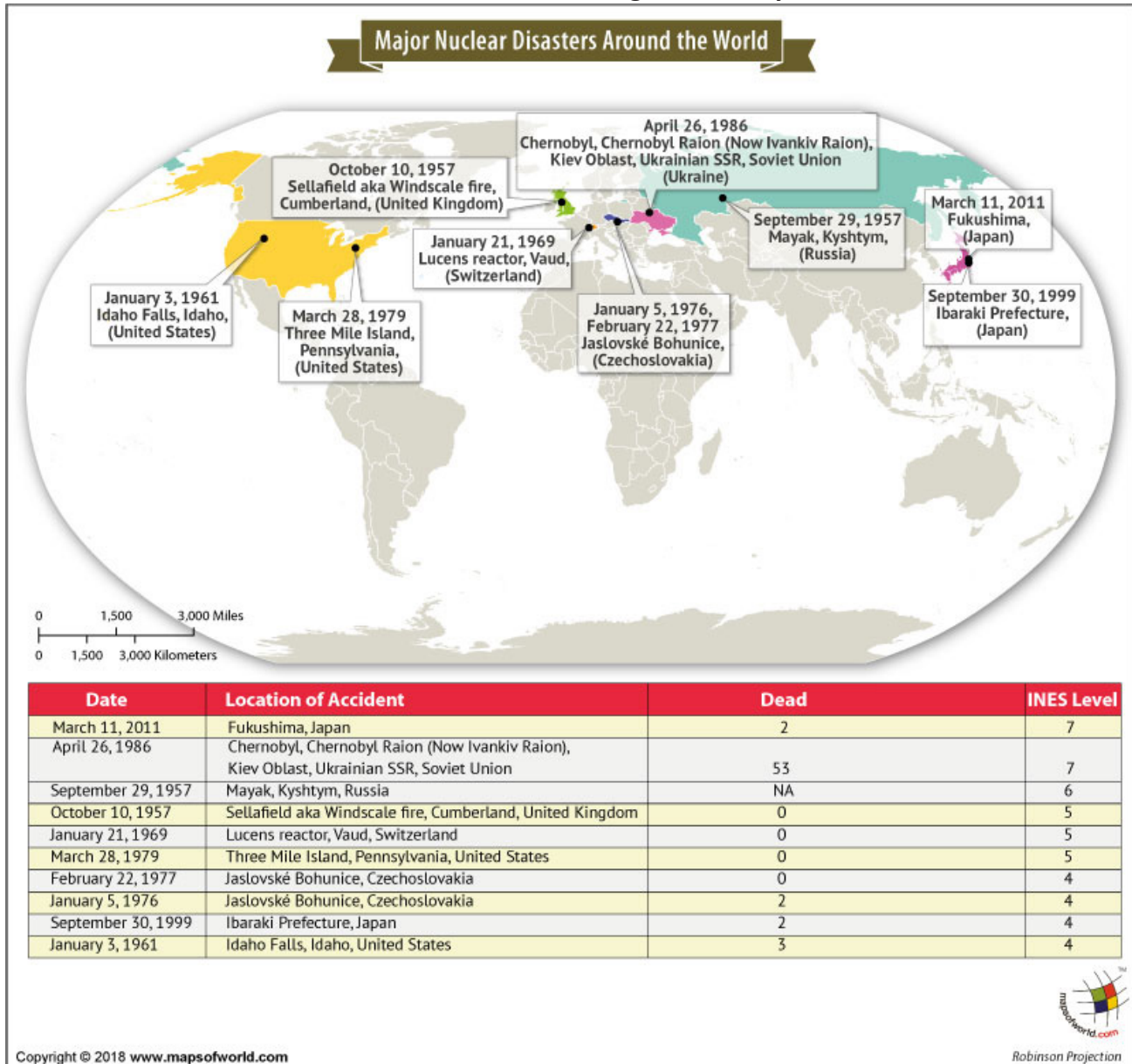
The Origins of the Nuclear Industry



How Nuclear Power Works⁵

Nuclear power is driven by nuclear fission. Fission usually uses an enriched element of ceramic pellets like uranium and is then shot by many neutrons to begin the reaction. The reactor uses a moderator (light water within the United States, but graphite and others can be utilized), which slows down neutrons to allow for a sustained chain reaction. The fission process releases energy to heat water outside the reactor core and produces steam which ultimately runs the turbine that creates electricity. Byproducts left behind include radioactive decay.⁶

Nuclear Accidents Throughout History⁷



Civilian nuclear incidents (including nuclear medicine) are rated on a 1-7 scale, with 7 being the most severe. To date, only three events have ever been rated at a 6 or above.

Italian physicist Enrico Fermi's experiments in 1934 set the stage for the future of nuclear power, where he discovered that when uranium was bombarded with neutrons, it resulted in much lighter elements. These experiments set the stage for rapid progress in the area over the next two decades, ultimately leading to creation of the atomic bomb in 1945 and the world's first nuclear power plant in 1951, the Atomic Energy Commission's Experimental Breeder Reactor in Idaho. These breakthroughs led to the United States' first commercial nuclear reactor in 1958, the Shippingport Nuclear Power Station near Pittsburgh, PA, and the nuclear power revolution was off and running, leading way to it becoming the popular energy choice throughout the 1960s and early 1970s.^x However, popularity had already started to dwindle in America when the Three Mile Island meltdown occurred in 1979, caused by a combination of mechanical failures and human errors, releasing nuclear reactor coolant into the environment while taking 12 years and \$1 billion to cleanup. The worldwide disaster at the

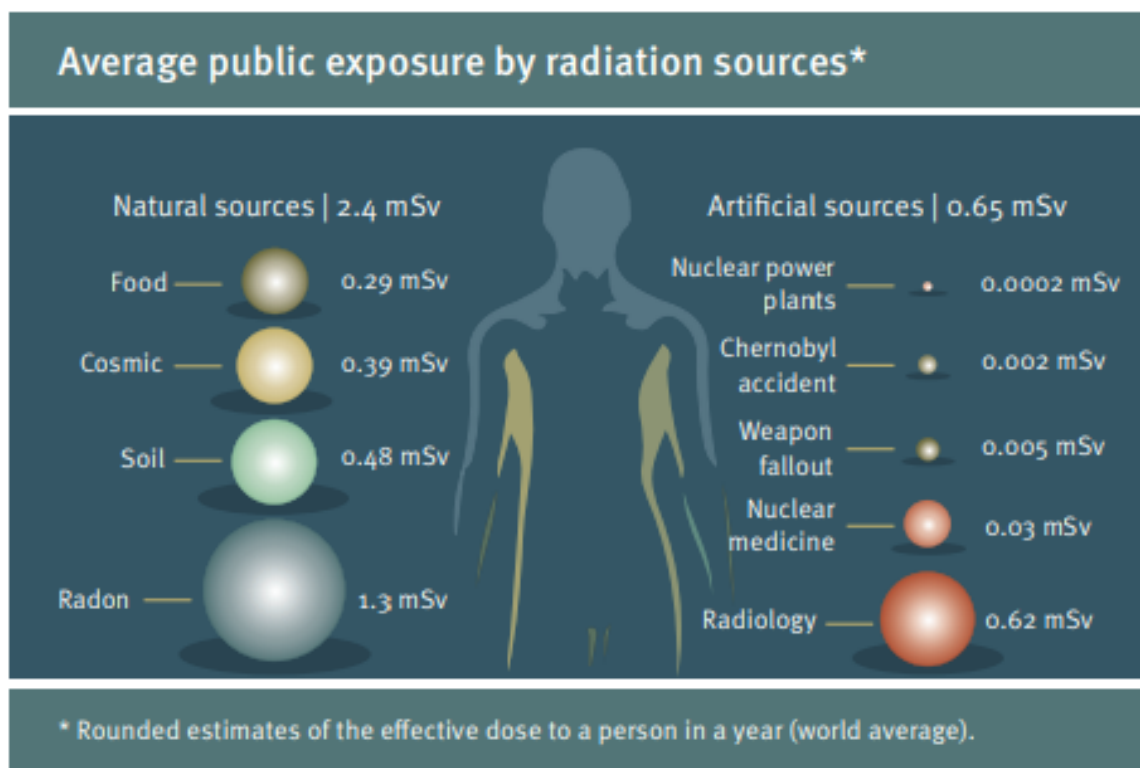
Number 4 powerplant in Chernobyl, Ukraine further eroded support, as a poor design and gross human negligence resulted in a mass explosion, where 31 people died within a few weeks due to radiation exposure - and when considering health effects such as the over 20,000 documented cases of thyroid cancer in the area, the death toll is much higher.^{xi} Obstacles such as regulatory hurdles and complex licensing processes also weakened favorability, so it is no wonder that new production of nuclear power plants in the United States went to a standstill, as only one new plant came online between 2010 and 2018.^{xii}

Addressing Major Concerns

Any technology that leads to a massive disaster like the incidents at Chernobyl and Fukushima should certainly be questioned to assess the viability of future operations. Reading about some of the multi-generational impacts caused by these events and the lasting damage is certainly eye-opening, but emotions aside, are some of the critics' current concerns of nuclear power warranted?

Radiation Exposure from Nuclear Power Is Minimal

Nuclear Accidents Throughout History⁸



Nuclear power plants have invoked fears of radiation exposure since their inception, with many individuals buying into the notion that normal operations of nuclear power plants are inherently dangerous from an exposure level. Harnessing the power of nuclear energy for the atomic bomb and the mass casualties associated with the events at Hiroshima and Nagasaki did not obviously help alleviate concerns of many from the start, as the monumental energy of the technology and the effects of radiation were clearly on display. However, when we look at civilian nuclear power operations, the fear of radiation exposure is largely unfounded. Natural sources of radiation such

as soil and radon gas (which seeps to surface from underground) contribute thousands of times more radiation to the average individual than nuclear power plants, and artificial sources such as x-rays are also sizeable contributors as well. Studies have shown nuclear power plant workers are far better off in terms of radiation exposure when compared to pilots (cosmic ray exposure above the ozone) or miners (soil elements and radon gas exposure), as both occupations deal with much higher levels of exposure.^{xiii} The United States Navy operates almost a hundred reactors and has accumulated almost 7,000 reactor-years of operations, and with proper safeguards, has maintained essentially a flawless record for both radiation exposure and safe operations. Annual radiation exposure levels are closely monitored for all their reactor workers, and exposure levels attributed to the reactor are less than 15% of the annual natural background exposure to radiation, despite living within feet of an active reactor.^{xiv} But even when trying to put the radiation risk into perspective, it will likely be hard to assuage human fears due to some of the harrowing scenes of what happens to the human body when exposed to excessive radiation levels.

Pilots and Miners Are Exposed to More Radiation Than Nuclear Industry Workers⁸

Trends in global radiological exposure of workers (mSv)*				
Decades	1970s	1980s	1990s	2000s
Natural sources				
Aircrew	—	3.0	3.0	3.0
Coal mining	—	0.9	0.7	2.4
Other mining**	—	1.0	2.7	3.0
Miscellaneous	—	6.0	4.8	4.8
Total	—	1.7	1.8	2.9
Artificial sources				
Medical uses	0.8	0.6	0.3	0.5
Nuclear industry	4.4	3.7	1.8	1.0
Other industries	1.6	1.4	0.5	0.3
Miscellaneous	1.1	0.6	0.2	0.1
Total	1.7	1.4	0.6	0.5
* Estimates of average effective dose per worker in a year.				
** Uranium mining is included in nuclear industry.				

A Safe Energy Resource

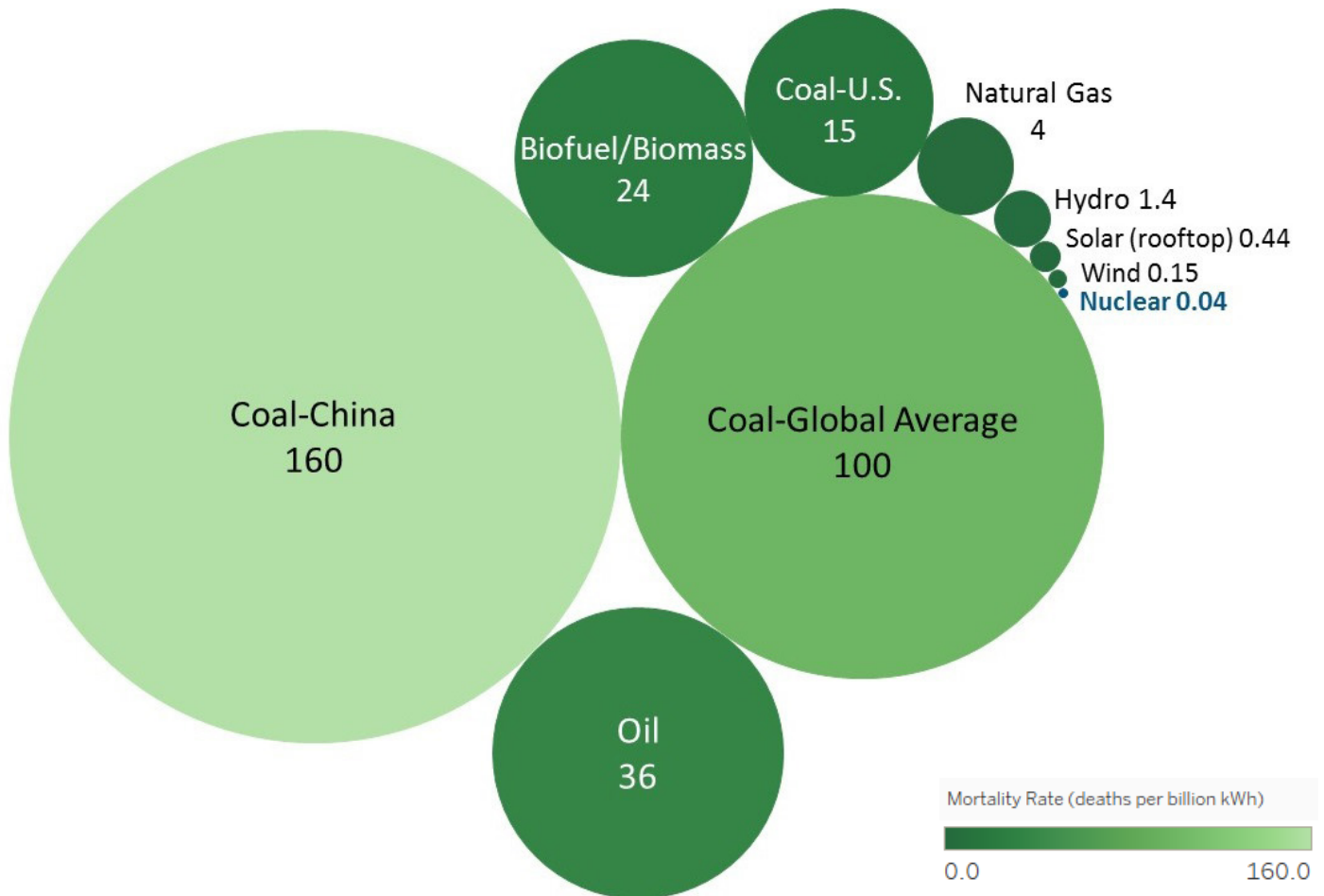
As mentioned earlier, catastrophes like the events at Fukushima and Chernobyl highlight the great danger associated with nuclear power; the meltdown risk. However, one only needs to closely examine the design flaws and human errors made during both of those events to realize that these calamities could have been prevented or at least had the damages mitigated. Connecting the true number of deaths to a nuclear power disaster is always a difficult task, as radiation exposure is a causal factor for cancer, but cancer is also naturally occurring in the population. Though 31 workers directly died from radiation exposure at Chernobyl, attributable death estimates range from as low as 4,000 to upwards of 60,000.^{xv} Losing lives to easily preventable mishaps is one of the more frustrating issues to come to terms with. However, we need to put these death tolls into perspective, and also consider where they happened. In the United States, there have been no deaths attributed to civilian nuclear power operations (though in 1961 three died in an accident at the Army's Idaho Falls Experimental Reactor), and when compared to other energy sources, it comes up as the safest energy source in multiple studies. Dangers in fossil fuels are obvious, as mining and extraction operations can be deadly and the emissions obviously contribute to air pollution, a causal factor in lung cancer and other health issues.

Nuclear Power as Seen in Pop Culture⁹



The sentiment that nuclear power is unsafe and managed by a bunch of greedy, incompetent individuals (as portrayed on the Simpsons) is shared by many Americans. This misinformed viewpoint unfortunately damages the possibility of future viability within America.

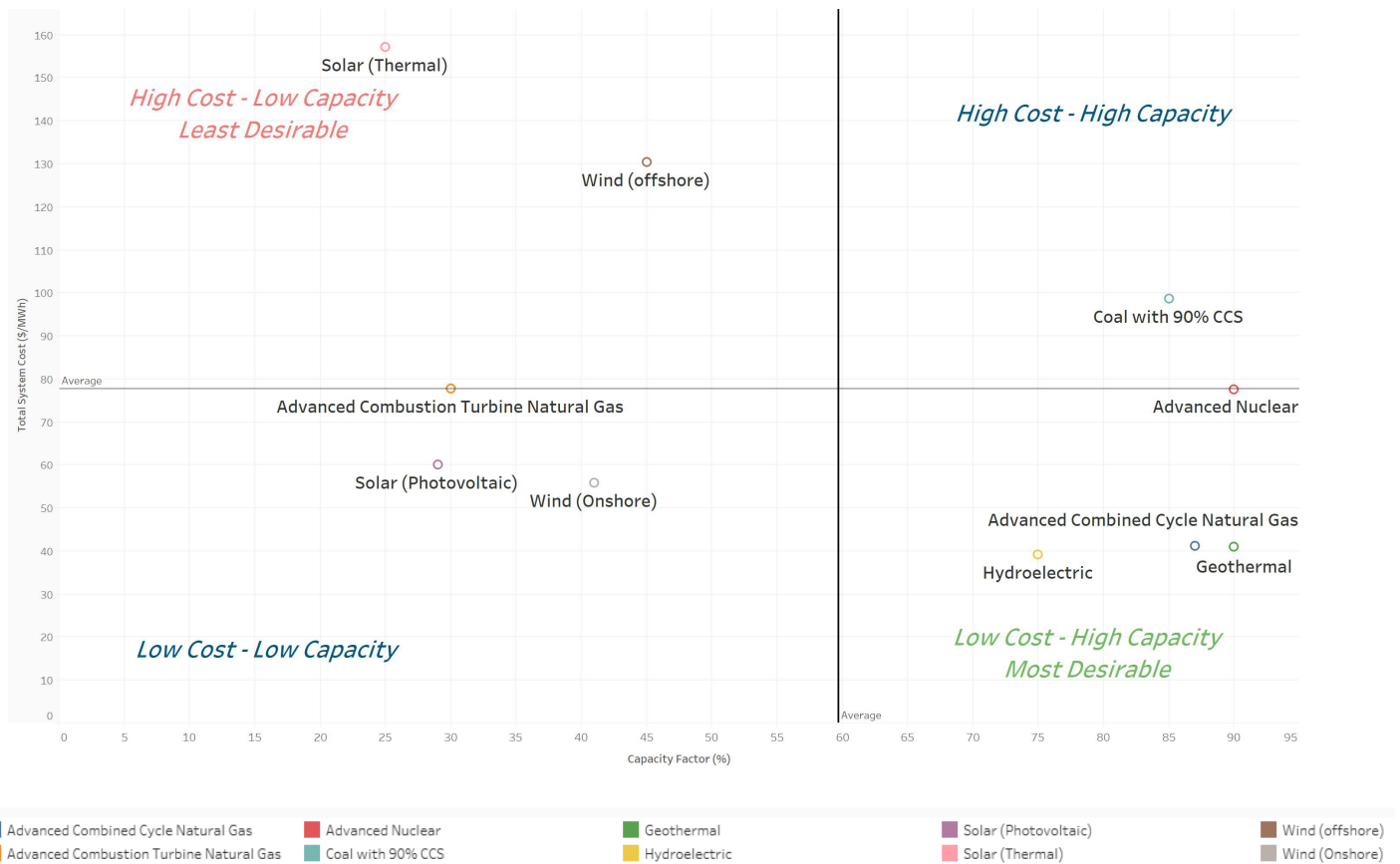
Nuclear Power Is the Safest Power Source per Unit of Energy Produced¹⁰



Nuclear Power is the safest power source per kWh produced, with no deaths in the United States ever attributed to civilian nuclear power production.

However, championed renewable energy sources are not without danger. As an example, in 2013, two men were burned to death while performing maintenance on top of a turbine in the Netherlands, and wind power maintenance statistically is currently one of the most dangerous jobs in America.^{xvi} Solar panel production exposes workers to toxic chemicals like silicon tetrachloride, and many of the growing number of workers in the industry do not always have the proper training, and as a result are increasingly exposed to lethal hazards like falling from heights and electrocution.^{xvii} Finally, many look at the Chernobyl nuclear reactor meltdown as the biggest energy disaster in history, but it pales in comparison to another tragedy. The seldom talked about 1975 Banqiao Dam collapse was far more perilous, when a typhoon broke the supposedly unbreakable dam on the Ru River in China, which was used to harness hydroelectric power. Over 26,000 drowned and upwards of 230,000 were killed when factoring in the resultant epidemics and famine in the aftermath.^{xviii} These points are not meant to necessarily be a critique of these power sources, but only meant to highlight that all power industries are exposed to certain risks, and risk mitigation is a key component of all energy production, including nuclear power.

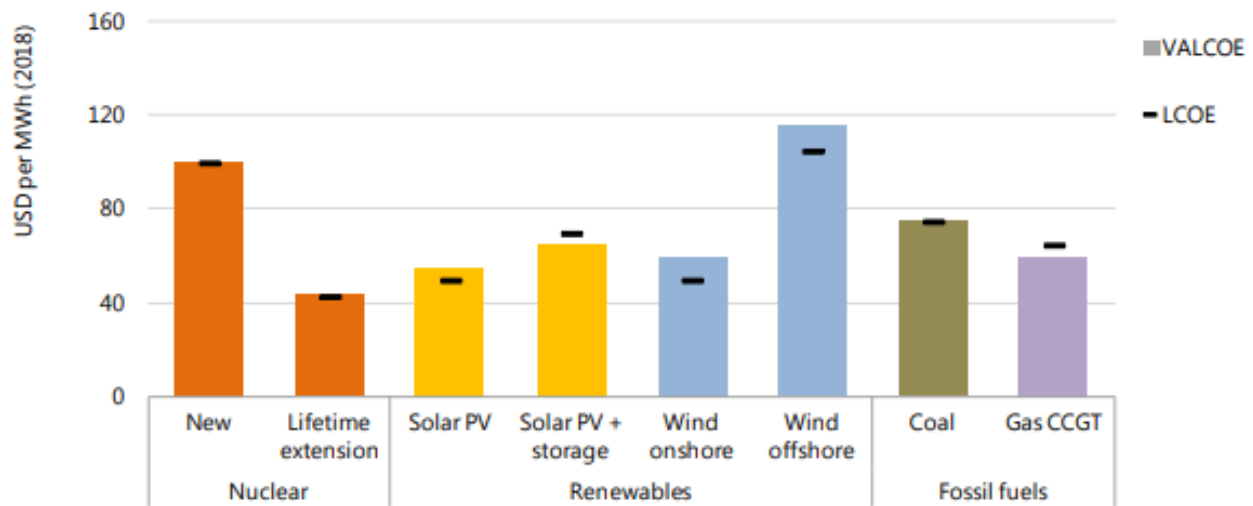
Cost of Energy Source Relative to Capacity Factor¹¹



Competitive on Cost With No Storage Issues

Nuclear power has always been plagued by the high upfront fixed costs that oftentimes exceed initial estimates. Furthermore, the regulatory process often delays completion, and life estimates for plant operation are cut short, diminishing any potential economic benefit. The first new U.S. nuclear power plant construction in the last three decades, Georgia Power's Vogtle project, highlights these concerns. The Vogtle Project, the construction of two 1100 Megawatt Westinghouse Reactors, was originally estimated to cost \$14 billion and be online by 2016. However, it is now expected to be complete by late 2021 at the earliest, and current final cost estimates hover around \$27.5 billion.^{xix} When comparing that project to solar power, Solar Star, America's largest solar farm, was created in only two years, creating a 579 Megawatt facility for only \$2.5 billion.^{xx} The solar project was cheaper (and both will likely be around for decades), but when considering that nuclear power historically operates at approximately 92% capacity, and solar at 26%, the costs become much closer, and also highlights a key weakness of all renewable sources (winds calm down, the sun sets, and rivers slow down seasonally).^{xxi} Study estimates that try to compare costs are usually varied in their results, but when considering new production (not current costs) solar power and wind usually end up being slightly cheaper than nuclear power, especially when considering any tax breaks. The U.S. Energy Information Department estimates, without tax breaks, the cost per Megawatt hour (MWh) for solar (photovoltaic cell) to be \$60/MWh, onshore wind \$55.90/MWh, and advanced nuclear \$77.50/MWh.

Projected Levelized Cost of Energy (LCOE) and Value-Adjusted LCOE by Technology, 2040¹²



Extending nuclear power plants operation lifetime (instead of closing them early) could be the cheapest energy option. LCOE is the average total cost of a unit of energy calculated using a source's entire life-cycle, allowing different technologies to be compared.

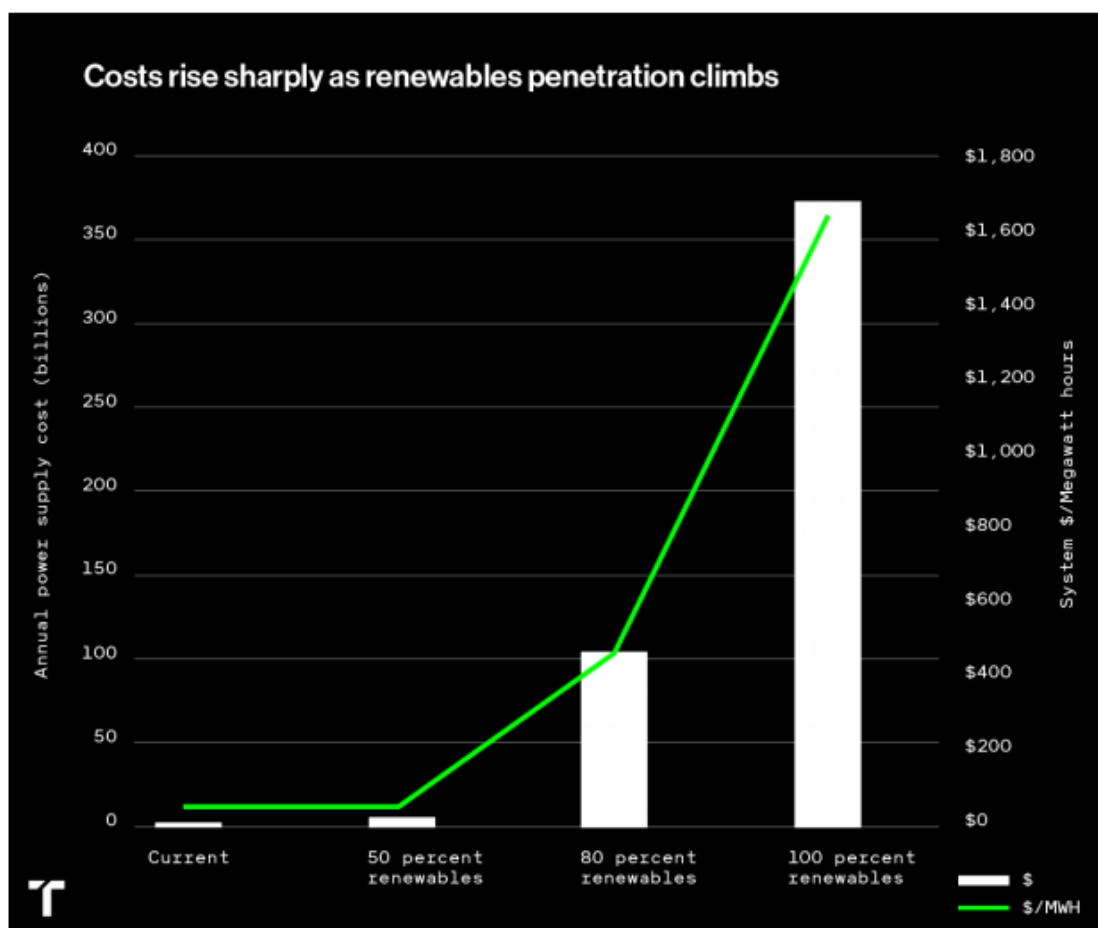
A study from the International Energy Agency shows similar costs for implementing new technology, but added another renewable option in its study: extending the life of current nuclear power plants. This action would go against the recent trend of early retirement for plants, but a \$500 million to \$1.1 billion investment will safely extend the life of current nuclear plants between 10 and 20 years and be the most cost-effective power option, as current nuclear power prices are competitive with fossil fuel sources. The study also highlights two key points to consider with the costs of nuclear. If costs associated with the damages relating to GHG emissions are factored in, nuclear power then becomes much more competitive relative to fossil fuel sources. But more importantly, especially in today's low interest environment, lower lending rates could have a significant impact on the diminishing upfront fixed costs and make nuclear more attractive as an option.^{xxii}

Unfortunately, one of the key aspects usually missed in the discussion of costs with renewable sources is an analysis on how much it would actually cost for long term storage of electricity in large quantities in addition to a grid re-design, which are key issues if renewable power is going to be a primary energy source and fully replace traditional sources. Most tend to look at electrical storage and envision the need for merely a nightly energy back-up with a reserve for a cloudy day (winds are also statistically calmer at night). However, based on seasonal differences of renewable power output, we would need storage to last through certain seasons, particularly winter. If we take a look at the capacity factors for solar power generation in the United States (photovoltaic technology), power plants are generating twice as much electricity in the peak month of June compared to December, due primarily to the length of day difference (34.5% versus 15.1% of capacity).^{xxiii} So, unless another renewable picks up the difference, or capacity is further increased, massive amounts of storage would be necessary. Unfortunately, hydroelectric power has its highest energy generating months in late spring and early summer, and wind power has varied swings in capacity depending on the time of day as well as the season. With these points in mind, even some of the most optimistic national renewable power optimization models indicate that in order to provide the United States with 100% renewable power, the U.S. would need at least three weeks of storage, and also

need to completely re-work the entire electricity grid to allow for transfer of power nationwide, as revealed by a team of experts from the University of California, Irvine and California Institute of Technology. In response to this optimization model, a Massachusetts Institute of Technology review paper estimated that to reach a level where the U.S. would only need 12 hours of nationwide battery storage (required for an optimal 80% renewable model), it would cost \$2.5 trillion at current prices. The review also used California as an example to illustrate what would likely happen to electricity prices with a shift to 100% renewable power, and they estimated prices would rise 33 times the current rate due to storage constraints, even with an assumption of future storage costs being a third of current prices.^{xxiv}

At the margin, solar and wind power may be a cheaper option, but when considering the capacity and storage difficulty, it is apparent that the costs of widescale implementation are far more expensive. Nuclear power operates at almost full capacity, and thus does not have to face the same storage challenge. So, if there is any desire to diminish GHG emissions, nuclear needs to be considered as an option. And, as we will highlight later in this report, future technology exists that could potentially help lower costs and make nuclear power safer. Therefore, if America wants to do its part in curbing global climate change, a combination of both government and corporate investment to help accelerate advances might be warranted.

MIT Experts Predict Electricity Costs Will Skyrocket If California Shifted to 100% Renewable¹³



Current implementation of renewable energy is cost competitive, but trying to adopt widespread implementation of renewables would likely result in an exorbitant increase in energy prices.

Radioactive Waste and Decommissioning: Complicated but Surmountable Challenges

One of the most difficult areas to address within the nuclear power industry is plant decommissioning and the disposal of the remaining nuclear waste. It is a major concern that the industry has struggled to adequately address. Overseen by the United States Nuclear Regulatory Commission, the decommissioning process is a detailed, lengthy, and tedious process, costing upwards of \$400 million per plant in the United States.^{xxv} Nuclear waste, particularly the high-level waste (“Spent” uranium fuel is no longer used in electricity production), is the biggest disposal concern. The uranium can be temporarily stored in spent fuel ponds, which are pools of water about 40 feet deep reinforced by concrete and steel, but it must find a permanent home, since Uranium-235 will be radioactive for years to come (710 million-year half-life).^{xxvi}

The Yucca Mountain Project in Nevada, once thought to be the answer for all U.S. nuclear waste storage, was cancelled by the Department of Energy in 2010, and now only temporary holding sites remain.^{xxvii} Potential exposure to nearby fault lines and possible run-off into the groundwater below the site made it a politically contentious topic, and ultimately the opponents won out, as President Obama ordered project cancellation. The storage issue continues to be very complicated and the biggest question mark moving forward, but innovative ideas are out there, such as sending waste down boreholes, creating storage facilities thousands of feet below the surface, and destroying the waste with lasers. We will look at these a little later in our report.

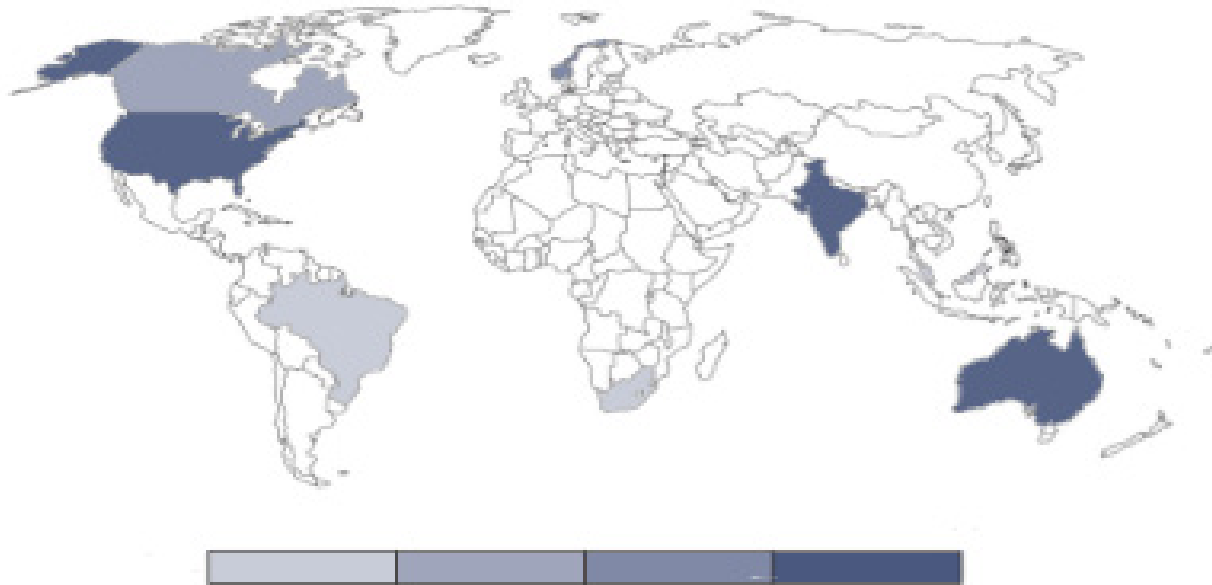
Future Advances in Nuclear Technology

What does the future hold for nuclear power technology? The status quo in this industry will likely not lead to nuclear power taking an increasing share in the energy sector, and costs need to improve as does waste storage technology. But there are intriguing, if not game-changing, ideas being proposed that could propel the industry forward.

Fast Breeder Reactors Use Less Uranium and Create Less Waste

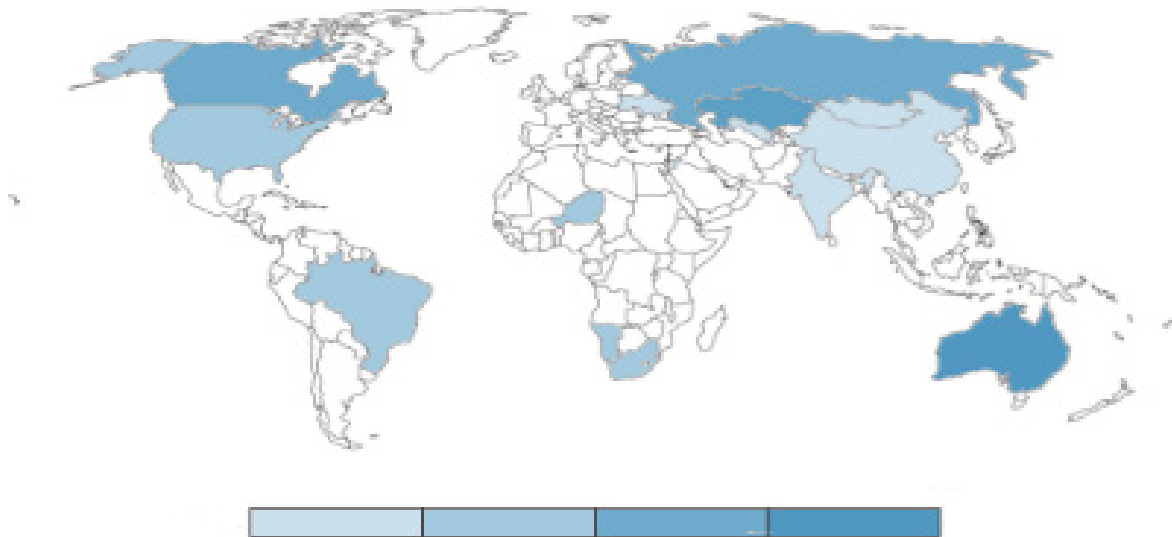
Nuclear waste mitigation is one of the few difficulties associated with nuclear power. But what if you wanted to continue to use the radioactive material and continue to extract power? Breeder technology, which has been around since 1951, essentially utilizes Uranium-238, which represents about 99% of naturally occurring uranium, to create a reaction where fissile atoms are simultaneously being destroyed and created. It is approximately 60 times better from a uranium usage perspective, and produces far less nuclear waste, two big challenges associated with nuclear power. Companies like Mitsubishi have been working on developing Fast Breeder Reactors since the 1970s, and with the Japanese government’s continued support it is hopeful that it can implement a readily available commercial option by 2025.^{xxviii}

Thorium-Based Breeder Reactors Have No Chance of a Meltdown¹⁴



Thorium is an abundant resource within the United States borders.

Global Reserve Map for Uranium¹⁴



The United States has sizeable uranium deposits, but the largest reserves are within the borders of Australia and Kazakhstan.

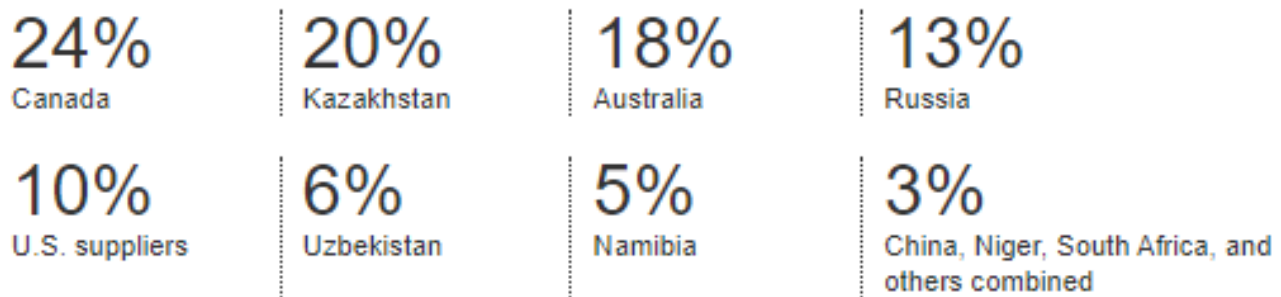
Is it possible that there is a better energy source than uranium? Some experts think so. Thorium, a mineral that is abundant within the United States' borders when compared to uranium, can be utilized in the breeder process, while creating very little waste and having no chance for a core meltdown. Since the coolant used in the breeder process is usually either a salt or molten lead which can operate at atmospheric pressure instead of the 150 times needed for the light water reactor, it

ends up being much safer in principal.^{xxxix} In 2017, the Nuclear Research and Consulting Group in the Netherlands began the first modern testing of a thorium-based Molten Salt Reactor. Though commercial designs are likely years off due to challenges like thorium being very radioactive in the short term and requiring significantly higher temperatures for creation, many countries like India and China are firmly committed to the technology as a clean, safe, and cheap evolution of nuclear power.^{xxx}

The other large benefit of using thorium is that it would make the United States further energy independent from outside countries, as currently 90% of U.S. uranium purchases are from other countries. Though a large percentage come from historical allies such as Canada and Australia, a significant portion comes from Russia and former Soviet Union countries.^{xxxi} The United States holds vast amounts of thorium in areas like the Lemhi Pass in Idaho and the Wet Mountain Areas of Colorado, but it is not being mined due to the lack of current demand.^{xxxii} In fact, the most suitable place to extract thorium may be from the beaches of Northeastern Florida, where it would be relatively easy to separate the low-levels of thorium from the sand on-site at a potentially low cost.^{xxxiii} Though challenges exist with any mining operation, the easy access to thorium with multiple readily identifiable sites could lead to both safer and cheaper mining extraction when compared to uranium, which is another reason to push for further exploration of thorium-based technology.

U.S. Nuclear Power Relies Heavily on Russia and Former Soviet Union Nations for Uranium¹⁵

Sources and shares of total U.S. purchases of uranium in 2018 were



Note: sum of shares does not equal 100% because of independent rounding.

Small Modular Reactors (SMRs) Provide Scalable Low-Cost Power Options to Remote Locations

One other idea that is gaining in popularity is the creation of small modular reactors (SMRs). SMRs would have quite a few advantages, such as lower upfront capital costs, updated safety measures with a simplified design, and can be easily implemented in remote areas. Current intentions seek to construct SMRs in factories, designed to be mobile enough to be transported around the globe, where depending on the amount of power needed, they could be connected for scalability.^{xxxiv} They would ideally replace coal power plants that are abundant in remote areas and provide smaller communities with a carbon-free energy source. Worldwide, companies are racing to successfully develop the technology. In the United States, NuScale Power, a company spawned off the research from a group of Oregon State scientists, is in the process of designing a power plant that combines up to 12, 60 MWh SMRs for an estimated cost of \$3 billion.^{xxxv} A plant of this size could create enough energy to power approximately 550,000 households based on average U.S. household electricity consumption (assuming a 90% capacity factor, NuScale claims their design can achieve greater than 95%), which would be the equivalent of all residences within the city of Phoenix.^{xxxvi}



Artist's conception of NuScale Power's proposed SMR plant

NuScale's proposed design can combine up to 12 SMRs to bring carbon-free energy to remote locations.¹⁶

Game-Changing Nuclear Waste Disposal Options Are on the Horizon

Regardless of what happens with nuclear power's future, current waste needs to be disposed of safely. And if a solid method is discovered, it will allow for current technology to be easily utilized, otherwise breeder reactors become the far better option due to the lower waste levels. Though not necessarily a revolutionary idea, and similar to the Yucca Mountain project, funding in Finland was recently secured for a 1,300-foot-deep underground nuclear waste storage facility. The Finnish government has offered strong support for this facility which could be operational by the mid-2020s.^{xxxvii} The success of a facility like this one could possibly spur reconsideration of the idea within the United States, but likely not soon.

Underground Facilities Could Be a Safe Option for Nuclear Waste Storage¹⁷



Finland's underground storage bunker represents a viable choice to permanently store nuclear waste.

So what other ideas are out there? One U.S. company thinks it has the answer. Deep Isolation, of Berkeley, California, thinks that utilization of the latest oil-fracking technology could lead to an answer for permanent disposal of waste. The company has already successfully demonstrated that it has the technology to shoot waste down a previously drilled borehole (could be up to 2 miles deep), and then use a tool called a “tractor” to send the waste horizontally another 400 feet. Another proposed method which gained popularity when French physicist Gerard Mourou mentioned it in his 2018 Nobel Prize acceptance lecture, is using lasers to neutralize nuclear waste. By shining laser beams that are a million times brighter than the surface of the sun onto the nuclear waste, it would reduce the half-life to a few years with little remaining radioactivity.^{xxxviii} Laser technology is likely a generation away, but it is intriguing to consider some of these innovative ideas as potential solutions.

Nuclear Fusion Would Solve Many of the World’s Energy Problems

The successful invention of a system to harness the potential of nuclear fusion would represent the largest game changer for the industry. Long considered a pipe dream that would never come to fruition, fusion harnesses energy from atoms being fused together to create larger atoms, neutrons, and a large amount of energy, just as our sun operates with hydrogen fusion. This technology would create a low environmental impact and utilize hydrogen isotopes which are readily available, while offering no meltdown threat. However, the difficulty lies in finding a way to keep the extremely high temperature required for continuous operation (150 million degrees Celsius).^{xxxix} The most optimistic prospect for finally perfecting fusion lies in the International Thermonuclear Experimental Reactor (ITER), a joint collaboration between the European Union, India, China, Japan, Russia, South Korea, and the United States. The idea of the ITER was originally brought about between President Reagan and General Secretary Gorbachev during the Cold War, but after plenty of delays the first experiments are expected to begin in France in 2025.^{xl} Though many experts are still skeptical of ever seeing nuclear fusion come to fruition, it would essentially solve the world’s problems from an energy perspective, and so it is admirable to see countries coming together to tackle this challenge.

ITER’s Success on Nuclear Fusion Development Would Be a Revolutionary Accomplishment¹⁸






What Does the Future Hold?



Nuclear power has some promising new technological advances that address major concerns, ideally leading to lower costs and safer operations. The question remains as to how long will it take to see some of them become a reality? Climate change needs to be looked at with a sense of urgency, and any further delays in addressing the issue holistically will only result in further damage. We believe nuclear power should be viewed as a critical variable in satisfying our future clean energy needs. It offers the potential to complement wind and solar sources and prevent the need for finding a way to completely reorient America's electrical power infrastructure. But for nuclear power to succeed, the Federal government needs to signal its long-term support for the industry, which will help alleviate corporate concerns on nuclear power's current limited future, and hopefully drive further innovation. The Department of Energy's guarantee of \$12 billion in loans at Georgia Power's Vogtle Plant shows that the industry is at least being considered as a player in the energy sector moving forward, which is a positive sign.






At Sage we hope that government resources will be aggressively used to further aid in the innovation of thorium-based breeder reactors, and possibly design them for use in a modular capacity. For investors, we believe these technologies can offer significant growth and potential financial success for the long term. However, for this to be realized, we will need to identify and develop more assured approaches to dealing with the nuclear waste storage dilemma regardless of our future power choices. Here too, it appears some of the new technology advances we reviewed are much closer to becoming commercial realities. We believe that with more public and private financial support, these important advances could become commercially viable in a shorter period, which would help to abate the seemingly inexorable growth of harmful GHG emission levels.





So, as we move forward, it is imperative we recognize industry players (both government and corporate) by utilizing material ESG criteria. We want to help society by curbing climate change and providing Americans with a large-scale, cost competitive energy source, but history has shown us how damaging the mistakes in this industry can be. Best-in-class ESG leaders must be recognized, promoted, and rewarded in the nuclear power sector, as these companies will ultimately give us the best long-term outcome with the least amount of risk. America needs to be a leader on climate change and do its part to help mitigate global warming. The advancement of nuclear power technology would be one of the most effective means to accomplishing that outcome.



Nuclear Companies to Watch for in the Future

Operators	Ticker	Operations	ESG Leaf Score
Southern Company	TKR: SO Bond Rating: Baa2/A-	Southern Company is an American gas and electric utility holding company. For more than 40 years, Southern Nuclear (a division of Southern Company) has operated its three nuclear energy facilities. They have a current average three-year fleet capacity factor of 93.7 percent.	
Duke Energy	TKR: DUK Bond Rating: Baa1/A-	Duke Energy is one of the largest electric power holding companies in the U.S., providing electricity to 7.7 million retail customers in 6 states. Duke Energy operates 11 nuclear units at 6 sites in North Carolina and South Carolina. Duke's nuclear plants generate about half of the electricity for our customers in the Carolinas, with production costs among the lowest in the nation.	
EDF	TKR: EDF.PA Bond Rating: A3/A-	Electricite de France is a French electric utility company that utilizes nuclear, thermal, renewable, and low-carbon hydrogen energies. France derives about 75% of its electricity from nuclear energy. France has 58 nuclear reactors operated by EDF.	






Operators	Ticker	Operations	ESG Leaf Score
Dominion	TKR: D Bond Rating: Baa2/BBB+	Dominion Energy is one of the United States' largest producers and transporters of energy. Dominion operates three power plants in the northeastern United States. These power plants power around 2.87 million homes.	
Exelon	TKR: EXC Bond Rating: Baa2/BBB+	Exelon is a Fortune 100 company that works in every stage of the energy business, from power generation to competitive energy sales to transmission and delivery. Exelon Nuclear (a division of Exelon) operates the largest fleet of nuclear plants in America with 22 reactors.	

Mining	Ticker	Operations	ESG Leaf Score
Cameco	TKR: CCJ Bond Rating: WR/BBB-	Cameco is one of the world's largest providers of uranium needed to generate clean, reliable baseload electricity around the globe. The company is also a leading provider of nuclear fuel processing services, supplying much of the world's reactor fleet with the fuel to generate one of the cleanest sources of electricity available today.	
BHP	TKR: BHP Bond Rating: A2/A	BHP is a resource company that extracts and processes minerals, oil, and gas. BHP has a uranium mine in Australia.	
Urenco	Private Company Bond Rating: Baa1/BBB+	Urenco is an international supplier of enrichment services and fuel cycle products for the civil nuclear industry, serving utility customers worldwide who provide low carbon electricity through nuclear generation.	
Rio Tinto (RIO)	TKR: RIO Bond Rating: A2/A	Rio Tinto is a metals and minerals exploration and mining company. The company supplies aluminum, copper, diamonds, gold, industrial minerals (borates, titanium dioxide and salt), iron ore, and uranium to the global market.	
Orano	Private Company Bond Rating: B2/BB+	Orano U.S.A. is headquartered in Washington D.C., however, Orano's global headquarters are in Paris, France. Orano offers products and services throughout the nuclear life cycle from exploration and mining, to decommissioning and nuclear waste management.	

Reactor	Ticker	Operations	ESG Leaf Score
Toshiba	TKR: TOSBF Bond Rating: B1/BB	Toshiba is a Japanese multinational conglomerate headquartered in Tokyo, Japan. Toshiba is committed to helping promote efforts in construction/maintenance/support for the restart, decommissioning, and dismantlement of nuclear power plants. Toshiba supports the decommissioning at Fukushima Daiichi, as well as fuel cycle and future energy source development such as next generation reactors and fast reactors. The company has also participated in domestic and international projects since the 1970s on nuclear fusion research.	
Westinghouse (Brookfield Asset Management)	TKR: BAM Bond Rating: Baa2/A-	Westinghouse Electric Company (a subsidiary of Brookfield Business Partners, which is a subsidiary of Brookfield Asset Management) provides a wide range of nuclear power plant products and services to utilities throughout the world. These include advanced nuclear plant designs, nuclear fuel, service and maintenance, instrumentation and control systems.	
Mitsubishi	TKR: MSBHY Bond Rating: A2/A	Mitsubishi Group is a group of autonomous Japanese multinational companies in a variety of industries. Mitsubishi Nuclear energy systems provides a range of replacement components, services, and technologies to U.S. utilities operating pressurized water reactor nuclear power plants. The company also offers U.S. utilities the next generation of clean nuclear energy, the US-APWR nuclear power plant. This type of power plant provides superior safety, reliability, economy, and compatibility with the environment.	
Lockheed Martin	TKR: LMT Bond Rating: Baa1/A-	Lockheed Martin is the world's premier systems integrator and leading provider of safety-critical nuclear instrumentation and control systems for commercial and Department of Defense customers. Lockheed systems are currently operating aboard all U.S. Navy submarines and aircraft carriers deployed worldwide.	

Reactor	Ticker	Operations	ESG Leaf Score
Doosan	TKR: 000150.KS Bond Rating: NR	Doosan Group is a South Korean conglomerate company. Doosan Babcock (a subsidiary of Doosan Group) designs and delivers smart energy products and solutions globally to help create a greener future for generations to come. The company provides asset support, as well as engineering, procurement, and construction of nuclear power plants. Doosan also provides support in plant maintenance and decommissioning.	
KEPCO	TKR: KEP Bond Rating: Aa2/AA	KEPCO (Korea Electric Power Corporation) is the largest electric utility in South Korea, responsible for the generation, transmission, and distribution of electricity and the development of electric power projects. The corporation views nuclear power as an eco friendly and economic energy source required for green growth. Korea nuclear power capacity is the sixth largest in the world and Korea is operating 25 nuclear power units as of 2016 with five under construction. They also plan to build four nuclear power plants by 2027.	

Startups	Operations
NuScale	Nuscale is a developer of new modular light water reactors that would be able to supply reliable and abundant carbon-free nuclear energy. Their small modular reactor (SMR) is capable of generating 60 MW of electricity using a safer, smaller, and scalable version of pressurized water reactor technology.
TerraPower	TerraPower is a leading nuclear innovation company that strives to improve the world through nuclear energy and science. It is an incubator and developer of ideas and technologies that offer independence, environmental sustainability, medical advancement, and other cutting-edge opportunities. Bill Gates is currently the Chairman of the Board of TerraPower and was the company's original founder.
ThorCon	At ThorCon researchers are developing ThorCon liquid fission power plants. The ThorCon liquid fission power plant is a molten salt fission reactor. This means that unlike solid fuel that is used in current nuclear reactors, the fuel for the ThorCon reactors is in liquid form.
Deep Isolation	Deep Isolation researchers are developing solutions for disposal of nuclear waste from an environmental and community friendly way. The technology will emplace nuclear waste in corrosion-resistant canisters deep into horizontal drill holes, in rock that has been stable for tens to hundreds of millions of years.
Elysium	Elysium is an advanced nuclear engineering company that specializes in the design, development and manufacture of its advanced reactor technology. Developing a molten chloride salt fast reactor (MCSFR) for commercialization, Elysium's mission is to develop a low-cost, safe, easy to manufacture, and environmentally friendly generation of nuclear reactor.
Terrestrial Energy	Terrestrial Energy developed the Integral Molten Salt Reactor, IMSR. This type of reactor uses a liquid nuclear fuel which is a molten salt. Two IMSR power plants could power a city the size of Denver. These plants will deliver reliable and clean heat and power. They also will be easier to build and finance, will be less expensive, and more versatile than today's conventional nuclear technologies. The first commercial IMSR power plant is expected to come online in North America in the 2020s.

Sage Leaf Score	Peer Group Percentile Rank	
Best-in-class companies from an ESG perspective.	80 th to 100 th percentile	
Above average companies from an ESG perspective.	60 th to 80 th percentile	
Average companies from an ESG perspective.	40 th to 60 th percentile	
Below average companies from an ESG perspective.	20 th to 40 th percentile	
Companies that are laggards from an ESG perspective.	0 to 20 th percentile	

Sage's Methodology*

Through the use of our Sage proprietary framework, we are able to identify, score and invest in organizations that focus on consciously building sustainable business models through better ESG management. By pinpointing the ESG issues that are financially material, we can compare organizations across industries with sustainability metrics. We then assign the company a leaf score based on our framework output and invest only in companies that are awarded three or more leaves.

* The Sage Leaf Score, which is based on a 1 to 5 scale (with 5 Leaf's representing ESG leaders), combines an ESG macro industry risk analysis with a company-level sustainability evaluation along with any possible exclusions to create an individual score for each issuer.

Sources

- ⁱ <https://www.un.org/en/sections/issues-depth/climate-change/>
- ⁱⁱ https://www.eia.gov/energyexplained/index.php?page=environment_where_gghg_come_from
- ⁱⁱⁱ <https://www.globalenergyinstitute.org/look-ieas-new-global-energy-forecast>
- ^{iv} <https://www.cnbc.com/2018/05/30/electric-vehicles-will-grow-from-3-million-to-125-million-by-2030-iea.html>
- ^v <https://www.eia.gov/tools/faqs/faq.php?id=427&t=3>
<https://www.eia.gov/energyexplained/us-energy-facts/>
- ^{vi} <https://www.nei.org/news/2019/bill-gates-on-nuclear>
- ^{vii} https://www.msci.com/eqb/methodology/meth_docs/MSCI_ESG_Leaders_Methodology_Feb2019.pdf
www.msci.com/eqb/methodology/meth_docs/MSCI_ESG_Leaders_Methodology_Mar_2019.pdf
- ^{viii} <https://www.iaea.org/newscenter/focus/fukushima>
- ^{ix} <https://www.eia.gov/tools/faqs/index.php#nuclear>
- ^x <http://www.phmc.state.pa.us/portal/communities/pa-heritage/atoms-for-peace-pennsylvania.html>
- ^{xi} <https://www.nei.org/resources/fact-sheets/chernobyl-accident-and-its-consequences>
- ^{xii} <https://www.eia.gov/todayinenergy/detail.php?id=38792>
- ^{xiii} http://wedocs.unep.org/bitstream/handle/20.500.11822/7790/-Radiation_Effects_and_sources-2016Radiation_-_Effects_and_Sources.pdg.pdf.pdf?sequence=1&isAllowed=y
- ^{xiv} https://www.energy.gov/sites/prod/files/2017/08/f36/nuclear_propulsion_program_8-30-2016%5B1%5D.pdf
- ^{xv} https://www.energy.gov/sites/prod/files/2017/08/f36/nuclear_propulsion_program_8-30-2016%5B1%5D.pdf
- ^{xvi} <https://gineersnow.com/industries/renewables/two-mechanics-died-wind-turbine-fire-helped-wind-industry>
- ^{xvii} <https://news.bloomberglaw.com/safety/as-solar-installations-surge-worker-safety-concern-also-rises-corrected>
- ^{xviii} <https://timeline.com/structural-failure-banqiao-china-7a402a25bb65>
- ^{xix} <https://www.powermag.com/georgia-psc-backs-additional-costs-for-vogtle-nuclear-project/>
- ^{xx} <https://web.archive.org/web/20190621222541/https://us.sunpower.com/sites/default/files/media-library/case-studies/cs-solar-star-projects-fact-sheet.pdf>
- ^{xxi} https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b
- ^{xxii} https://www.eenews.net/assets/2019/05/28/document_ew_01.pdf
- ^{xxiii} https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b
- ^{xxiv} <https://www.technologyreview.com/s/611683/the-25-trillion-reason-we-cant-rely-on-batteries-to-clean-up-the-grid/>
- ^{xxv} <https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html>
- ^{xxvi} <https://www.iaea.org/topics/spent-fuel-management/depleted-uranium>
- ^{xxvii} <https://www.cbsnews.com/news/yucca-mountain-nuclear-waste-storage-controversy/>
- ^{xxviii} https://www.mhi.com/products/energy/fast_breeder_reactor.html
- ^{xxix} https://inis.iaea.org/collection/NCLCollectionStore/_Public/49/103/49103899.pdf?r=1&r=1
- ^{xxx} https://www.engineering.pitt.edu/_Library/_Dao-Oneill-Whiting
- ^{xxxi} <https://www.eia.gov/energyexplained/nuclear/where-our-uranium-comes-from.php>
- ^{xxxii} <https://www-pub.iaea.org/MTCD/Publications/PDF/TE-1877web.pdf>
- ^{xxxiii} <https://pubs.usgs.gov/circ/1336/pdf/C1336.pdf>
- ^{xxxiv} <https://www.iaea.org/topics/small-modular-reactors>
- ^{xxxv} <https://www.sciencemag.org/news/2019/02/smaller-safer-cheaper-one-company-aims-reinvent-nuclear-reactor-and-save-warming-planet>
- ^{xxxvi} <https://www.census.gov/quickfacts/fact/table/philadelphiacitypennsylvania,philadelphiacountypennsylvania/PST045218>
<https://www.eia.gov/tools/faqs/faq.php?id=97&t=3>

Sources

- xxxvii <https://www.iaea.org/newscenter/news/developing-the-first-ever-facility-for-the-safe-disposal-of-spent-fuel>
- xxxviii <https://ensia.com/features/radioactive-nuclear-waste-disposal/>
- xxxix https://www.iop.org/publications/iop/2008/file_38224.pdf
- xl <https://www.economist.com/science-and-technology/2019/05/02/iter-a-reactor-in-france-may-deliver-fusion-power-as-early-as-2045>
- xli <https://www.energy.gov/articles/secretary-perry-announces-financial-close-additional-loan-guarantees-during-trip-vogtle>
- ¹ <https://www.iea.org/weo/>
- ² <https://www.world-nuclear.org/nuclear-basics/nuclear-energy-and-climate-change.aspx>
- ³ https://www.eenews.net/assets/2019/05/28/document_ew_01.pdf
- ⁴ <https://www.nrc.gov/reactors/operating/map-power-reactors.html>
- ⁵ <http://sitn.hms.harvard.edu/flash/2016/reconsidering-risks-nuclear-power/>
- ⁶ https://www.energy.gov/sites/prod/files/The%20History%20of%20Nuclear%20Energy_0.pdf
- ⁷ www.mapsoftheworld.com
- ⁸ http://wedocs.unep.org/bitstream/handle/20.500.11822/7790/-Radiation_Effects_and_sources-2016Radiation_-_Effects_and_Sources.pdg.pdf.pdf?sequence=1&isAllowed=y
- ⁹ <http://www.garethmillward.com/2015/03/23/1986-chernobyl/>
- ¹⁰ <https://www.sciencedirect.com/science/article/pii/S2214993714000050>
- ¹¹ https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b
- ¹² https://www.eenews.net/assets/2019/05/28/document_ew_01.pdf
- ¹³ <https://www.technologyreview.com/s/611683/the-25-trillion-reason-we-cant-rely-on-batteries-to-clean-up-the-grid/>
- ¹⁴ <https://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/deposits.html>
- ¹⁵ <https://www.eia.gov/energyexplained/nuclear/where-our-uranium-comes-from.php>
- ¹⁶ https://newsroom.nuscalepower.com/sites/nuscalepower.newshq.businesswire.com/files/doc_library/file/Nuscale-General-Fact-Sheet.pdf
- ¹⁷ <https://www.iaea.org/newscenter/news/developing-the-first-ever-facility-for-the-safe-disposal-of-spent-fuel>
- ¹⁸ www.iter.com

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