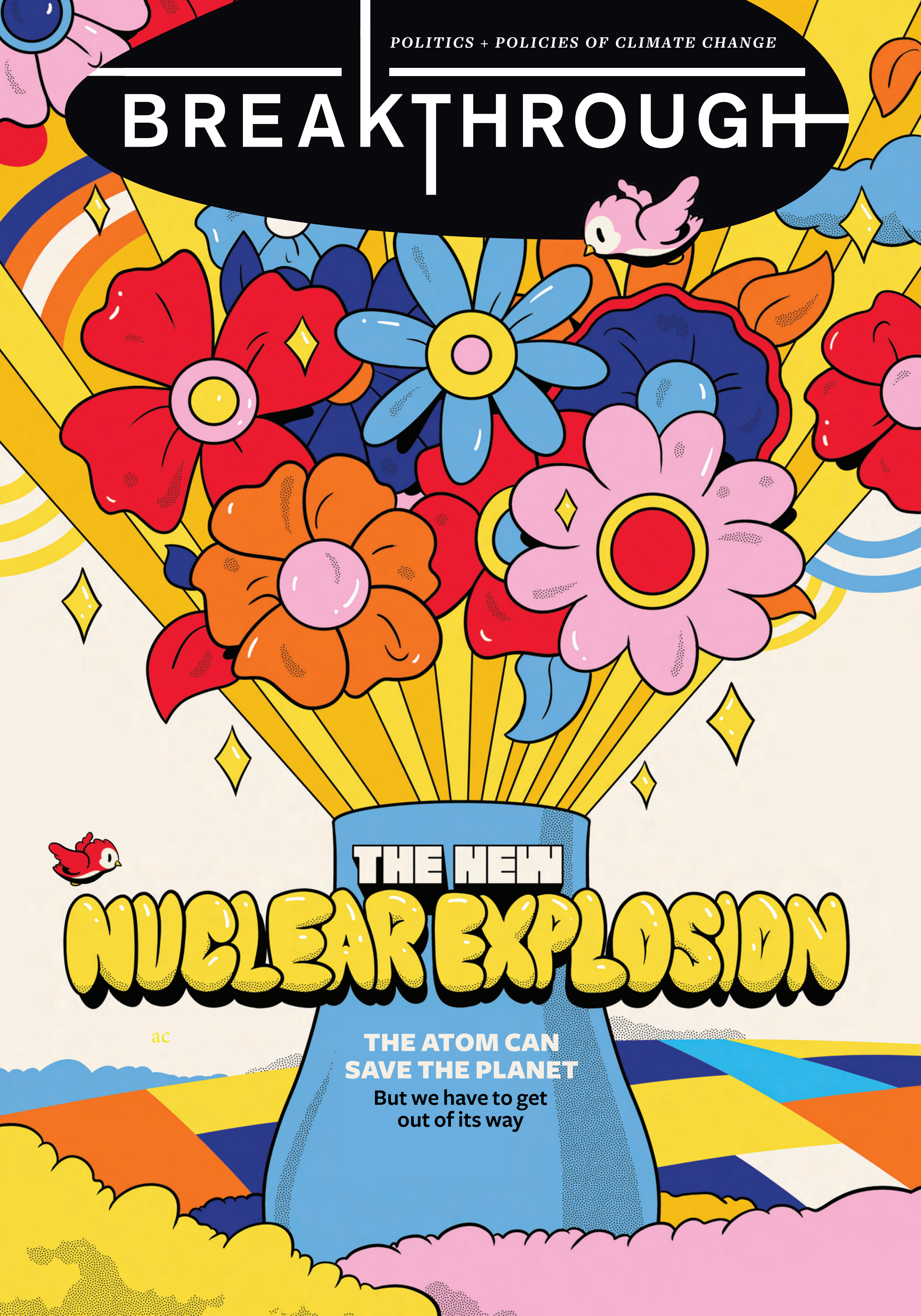
POLITICS + POLICIES OF CLIMATE CHANGE

BREAKTHROUGH



THE NEW NUCLEAR EXPLOSION

THE ATOM CAN SAVE THE PLANET

But we have to get out of its way

BREAKTHROUGH

POLITICS + POLICIES OF CLIMATE CHANGE

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FALL COVER: This issue's cover is by Ryan Snook, an illustrator from Toronto, Canada. His work has been commissioned for magazines, websites, books, apps, animated commercials, and advertising campaigns. He specializes in bright humorous cartoons, which made him a perfect illustrator to bring vibrancy, life, and fun to this issue on nuclear energy.

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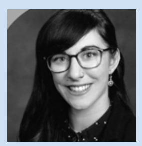

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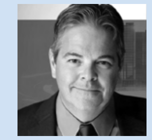

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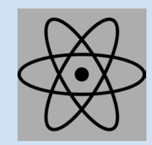

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FROM THE EDITOR

THE NEW NUCLEAR EXPLOSION

KATHRYN SALAM

Kathryn Salam has been Editor of the *Breakthrough Journal* since 2021.

While the last two issues of this magazine have attempted to add complexity to topics the mainstream climate discourse usually treats as relatively simple—what to do about agriculture and how climate change will alter geopolitics—creating this issue started from a very different place. If there is one certainty regarding the climate, it may well be about the environmental benefits of nuclear power.

As we at the Breakthrough Institute often point out, nuclear power can generate vast quantities of emission-free electricity with the smallest land footprint and environmental impact of all low-carbon energy sources. It also imposes the lowest public health cost of any major energy technology. Indeed, if we don't ramp up nuclear power in the coming years, it is unclear how the world will be able to draw down its use of fossil fuels while still generating enough power to keep modern economies ticking and provide decent living standards for everyone around the world.

Ecomodernists have been making this basic argument for years. Of late, though, others are increasingly catching on.

Russia's invasion of Ukraine in February sent natural gas markets spinning and those who rely on Russian pipelines scrambling for alternative fuels. Months later, the European Union parliament voted to designate some nuclear energy projects as "green," paving the way for potentially billions of euros in cheap loans and subsidies. And even anti-nuclear stalwart Germany has had to think seriously about postponing plans to close its remaining nuclear facilities. In the United States, meanwhile, President Joe Biden's landmark climate bill, the Inflation Reduction Act (IRA), includes funding and loans for nuclear projects and uranium enrichment, and efforts to prematurely close California's Diablo Canyon nuclear power plant recently failed.

With this friendly tailwind behind us, our fall issue, **The New Nuclear Explosion**, charts where nuclear energy may be heading next.

Policy analyst Michael Moran opens the nuclear feature with "**Nuclear Dreams, Nuclear Realties**," a round-the-world tour of where nuclear is winning, where it isn't, and why. "Nuclear energy won't take over the entire world fast," he finds, "but it is doggedly marching forward." In a follow-on piece, "**Atoms and Influence**," *POWER Magazine* editor Sonal Patel compares the current moment—complete with nuclear influencers on TikTok—to previous leaps forward for nuclear energy in world history.

From there, writer Fred Stafford zooms in on the United States to argue in "**We Need a Nuclear New Deal**" that Biden's IRA presents an opportunity to revive an older American institution, the Tennessee Valley Authority, which could take its oversight of nuclear infrastructure in parts of the South nationwide. By doing so, it could produce, at cost, reliable and constant electricity for consumers and businesses. Also focusing on the United States is Good Energy Collective's Ariel Gould in "**Nuclear's Uranium Problem**." In her piece, she charts the damage caused by the United States' historical mining practices, especially to Native communities, and shows how the country can do better this time. "Mining does not need to be destructive," she concludes. "It can be rethought to include cleaning up the dirty legacy of mining's past, protecting the environment and investing in the community."

Checking in on a few other places, in "**The Sources of Germany's Nuclear Aversion**," German Marshall Fund's Sudha David-Wilp explains how anti-technology and anti-nuclear sentiments came to dominate the country's Green movement after World War II—and how they might be overcome now. "Germany's stance on nuclear may seem irrational, but it is in fact a fully logical result of a collision of history, economics, and idealism that all pointed the country down one path. And that's a hard but important lesson for anyone puzzling over stalled nuclear programs in other countries.

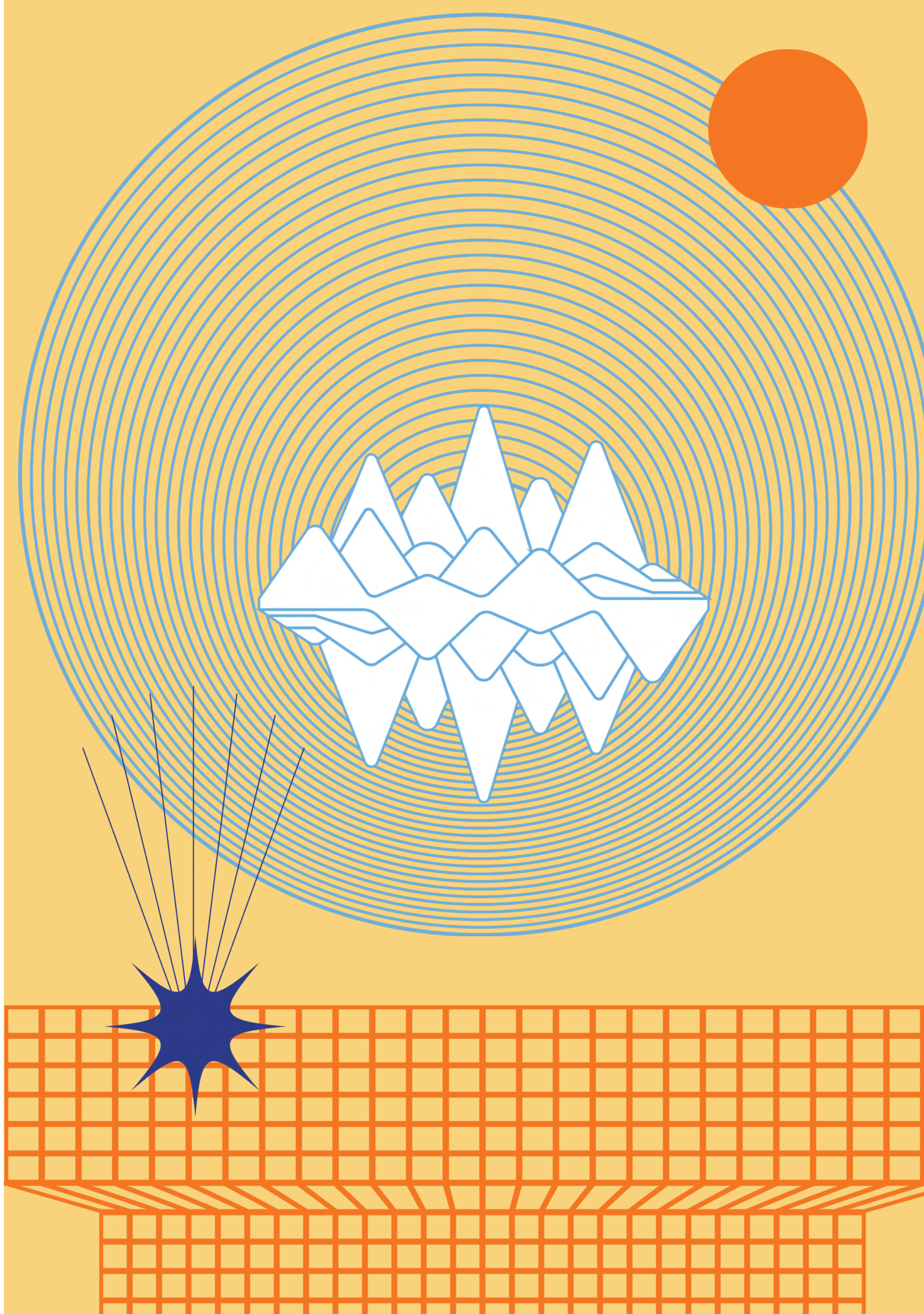
Meanwhile, Manhattan Institute's Jordan McGillis and Taiwanese journalist Angelica Oung discuss in "**Taiwan's Nuclear Option**" the increasingly good conditions for revamping the nuclear energy sector there, including an energy crunch that threatens to derail the country's manufacturing economy if new sources of energy are not found, a desire to be independent from China, the fact that its officially "closed" nuclear power plants were never fully taken offline, and more.

Next, nuclear experts Rauli Partanen, Kirsty Gogan, and Eric Ingersoll explore the bright future of offshore nuclear power plants in "**The Future of Nuclear Is at Sea**." Around the world, shipyards are only operating at 50 percent of their manufacturing capacity, and if they dedicated even a portion of that to building modular reactors on ships and oil rigs, the environmental benefits would be huge.

Finally, the Breakthrough Institute's Seaver Wang checks in on the fighting around Ukraine's nuclear power plants in "**The Real Risks at the Zaporizhzhia Nuclear Plant**." Although nuclear critics like to point to the situation there as evidence that nuclear is not safe, he argues, "objectively, any risks to human health and the environment from the Zaporizhzhia plant remain low." And what "minor risks do exist are overwhelmingly the fault of Russian military forces and lie wholly within the power of Russian leaders to eliminate."

Woven through **The New Nuclear Explosion** are helpful charts and graphs about the environmental rewards of nuclear power reprinted from the recently released *Carbon Almanac*, with discussion from entrepreneur Seth Godin. And if the climate benefits aren't convincing enough, this discussion of nuclear energy is capped off with a look back at the decades of technological, economic, and political wins the Soviet Union reaped from pursuing nuclear between the 1970s and 1990s. In "**Red, White, and Blue Atom**,"—his review of the book *Red Atom* by Sovietologist Paul Josephson—former *New York Times* reporter Matthew Wald urges the United States to recognize the similar victories it could amass by doing the same.

The arguments collected in this issue all point in one direction—that nuclear energy will have to be a big part of any Net Zero future. But within that broad understanding, they reveal many differences in strategy, prioritization, political concerns, and readiness across technologies and countries. In doing so, this issue's authors both reflect the very real ways in which the basic arguments in favor of nuclear power have won and offer some realistic guidance for where the debate should go now.



ESSAYS

01

THE FUTURE OF TRANSPORTATION IS GREEN

The new technologies that could fix shipping and commuting—and the old

ELISABETH BRAW

EVEN THE RARE PERSON WITH NO HUMANITARIAN INTEREST IN Ukraine found it hard not to pay close attention to the war as gasoline prices skyrocketed. Just two weeks after Russia's invasion of its neighbor to the southwest in late February, drivers in the United States were paying a record $4.17 for each gallon of gas, a price that rose to around $5.00 in June, before creeping back down this fall. But with the war continuing, inflation still rising, and the world fearing energy shocks if Europe cannot secure natural gas supplies, few are looking forward to filling their car up at the pump this winter.

But automobile despair may have an upside: alternative transportation might finally be attractive enough to substantially reduce transportation emissions.

Beyond Electric Vehicles

In the United States, transportation accounts for about 27 percent of carbon dioxide emissions. Around the world, the figure is about one-fifth, but despite cars becoming

more fuel-efficient and sales of hybrid cars increasing, the sector's emissions are growing. One only needs to look at China's transition from a bike-and-train-based society to a car-and-airplane one to see what's going on.

In response, many governments—especially wealthy, Western ones—have put their money behind electric vehicles. For personal transportation, that makes some sense.

Every year, the average American drives 13,500 miles in their car. That figure is higher than in other countries, but when it comes to carbon dioxide, location doesn't really matter. The emissions all end up in the same atmosphere. And while some pollution is unavoidable, much of the emissions annually caused by America's around 230 million licensed drivers may not be.

In 13 years' time, half of all passenger cars sold worldwide are expected to be electric. Indeed, U.S. President Joe Biden's infrastructure bill, signed into law at the end of 2021, includes an EV Charging Action Plan that will see 500,000 electric-vehicle charging points built across the United States. Based on carbon emissions per mile traveled, if even a quarter of existing combustion vehicles are replaced with EVs it will save millions of tons of CO_2 emissions each year. A typical car emits nearly five metric tons of carbon dioxide per year.

While personal electric vehicles may emit less than traditional ones while in use, though, the mining and processing of the minerals found in their batteries, including lithium, nickel, and cobalt, is anything but clean. As the journal *Nature* put it last year, batteries "contain tens of kilograms of materials that have yet to be mined." An average car battery, often referred to as a lithium battery, contains some eight kilograms of lithium, 35 kilograms of nickel, 20 kilograms of manganese, and 14 kilograms of cobalt, according to figures provided to *Nature* by Argonne National Laboratory. For every tonne of lithium mined, meanwhile, 15 tonnes of CO_2 are released into the air. Factor in emissions related to manufacturing and shipping, and depending on the fuels used to power any given country's electrical grid, the environmental benefits of EVs may be less than overwhelming.

There are other technical problems for electric vehicles. Much road pollution comes from cargo trucks, but because of trucks' enormous size and weight, electrifying them is far harder than electrifying cars. The same goes for shipping, which accounts for between 2.5 and 3 percent of the world's CO_2 emissions. To reduce that total, some shipping companies are steaming ahead with efforts to electrify their vessels, but it is difficult because batteries built with existing technology that could provide enough power to run today's massive supertankers would be so heavy as to sink the ships. The same goes for air travel; a battery able to carry a Boeing 747 for five hours would weigh nearly seven times as much as the plane itself.

The geopolitics around batteries can get messy, too. Lithium extraction today is dominated by Australia, China, and Chile. Nickel is primarily found in Indonesia, the Philippines, Cuba, and the French territory of New Caledonia. Indonesia, the global center of nickel mining, maintains close links to China; in 2019 it suddenly announced that it would impose a ban on nickel exports to try to attract foreign investors, mostly Chinese, to Indonesia to help build smelters and other industries there. As for cobalt, 70 percent is mined in the Democratic Republic of Congo, where local workers toil under conditions akin to slavery. Today, most of the DRC's cobalt mines are Chinese-owned.

Even more troubling for supplies, China—clearly anticipating the rush on metals for electric cars—has been buying up lithium as fast as it can. By 2021, its national lithium reserves held 1.5 million metric tons of the metal, compared to the United States' 750,000. Government holdings are just one piece of the puzzle. Last year, Chinese companies also went on an lithium-buying spree, acquiring an estimated 6.4 million tonnes in reserves and resources. The total amount of lithium acquired by non-Chinese companies? Only 0.4 million tonnes.

That doesn't mean the world should turn away from electric vehicles; every measure that can reduce CO_2 emissions is needed. It does mean, however, that electric vehicles as they exist

today can't be the only—or main—answer for transportation. What if we need whole new ways of moving around?

Cubicycles and E-Roads

Let's start with new ideas for shipping and long-haul travel. Specifically, e-roads. Sweden and Germany are pioneering these novel roads, which are fitted with powerlines underneath the surface. The powerlines automatically recharge vehicles as they travel along, typically using the same induction technology that many people know from induction stoves.

Germany, for its part, has built several kilometers-long stretches of e-roads, including on the autobahn outside Frankfurt. Because vehicles need to be fitted with receivers that can absorb the electricity, the truck-maker Scania has joined the effort. E-roads may be an ideal solution for semi-trucks, since electrifying those through batteries is more daunting than for cars.

Today, neither trucks nor cars can travel very far on e-roads, but German researchers have calculated that electrification of one-third of the autobahn road network could power 80 percent of all trucking journeys. The researchers didn't provide a cost estimate, but it is conceivable that a chunk of the cost could be covered by trucking companies, which would gain the convenience of having their vehicles constantly fueled without drivers having to look for gas stations. (Of course, the journeys are only as clean as the energy that powers the electric road. In August this year, the German government announced that the country would have to reactivate coal plants in order to maintain its energy supply, in the face of Russia's invasion of Ukraine and Berlin's drive to shutter the country's remaining nuclear plants.)

German researchers have calculated that electrification of one-third of the autobahn road network could power 80 percent of all trucking journeys.

Sweden, meanwhile, pioneered a stretch of e-road six years ago and opened the first complete e-road in December 2020, on the island of Gotland. It is also testing further roads featuring an electrified rail, similar to underground railways' third rail. When cars drive on top of it, a charging arm added to the chassis automatically extends to touch it, which charges the car until it leaves the area.

And last year, Yara, a Norwegian chemicals and fertilizer company premiered the world's first fully electric, autonomous cargo vessel. The *Yara Birkeland* is much smaller than most of the large cargo ships that traverse the world's oceans (it has a carrying capacity of 120 TEU compared to the largest ships' 24,000 TEU) and is more suited to travel around Norway's coasts. Its batteries can be recharged almost exclusively on hydropower, the source of more than 90 percent of Norway's electricity. The innovative vessel will replace an estimated 40,000 diesel-powered truck journeys per year thanks to the company's operations throughout Norway, according to Yara.

Once cargo arrives by rail, road, or boat in any given city, of course, there are other problems to deal with. Delivery stops and sitting in traffic produce more emissions per vehicle mile traveled, and the more trucks enter the cities, the more traffic there is. So cargo companies are teaming up with cities to make deliveries less CO_2-intensive by, for example, delivering packages by bicycle-powered cargo carts. Such carts are already becoming a frequent sight in cities like London.

The climate crisis is urgent, and in acting, we won't only avoid the future sorrows of a six- or eight-degree warmer world—we might also end up happier in the process.

Innovations like this, often prompted by new city ordinances and fees for CO_2-emitting vehicles, are crucial, not least because booming online shopping means delivery emissions will rise by 32 percent by 2030 (compared to 2020) if goods continue to be delivered by gasoline-powered cars and trucks. "Cities are trying to reduce the number of truck-delivery trips by having reloading points outside the city," noted Henrik Gudmundsson, a consultant with the firm Concito, and who is considered one of Europe's leading experts on sustainability economics. "This way, rather than having 20 diesel trucks going into the city the drivers reload the cargo to an electric vehicle that makes the trip."

International delivery giant Deutsche Post DHL has gone further still: It now uses its "cubicycles" in several cities worldwide, including in New York. The cubicycle is a bike powered by the rider, who sits in front and can, if needed, use electric pedal assistance powered by the cycle's own solar panels. Behind the driver is a trailer hauling removable containers.

Each cubicycle can replace two delivery vans in ideal conditions—an amazing CO_2 savings—though in hilly, dangerous, or extremely hot or cold cities, bike delivery is not expected to take off. There's another reason innovations like cubicycles don't dominate, too: consumers. Delivery companies simply don't want to invest—and even a cargo bike costs money when you are buying a fleet of them—because their low fees have accustomed consumers to cheap and easy ordering. If delivery companies charged the real cost for deliveries, including fair prices for all the components in the supply chain, fair wages for workers, and an accounting of carbon emissions, many consumers would think differently about their orders.

Indeed, while businesses clearly have an interest in keeping shopping, especially online shopping, booming, the more the world can reduce machine-born transportation of packages, the better for the environment. While governments and the private sector will have to encourage innovation when it comes to how packages are moved, then, there's also work to be done on consumer expectations.

Transportation for the Public

There's more to move in cities, though, than packages. For some people, existing public transportation can be great, but in the United States it has a long history of subpar performance and, in turn, underuse. There's thus a chicken and egg problem—to get better, the system would need more investment. But to have more to invest, it would need more users. But imagine transport of humans that involves little public investment and delivers public-health benefits. Biking and walking can be unmitigated good. Pedestrian and bicycle lanes wouldn't even involve new infrastructure; the space for them could be reclaimed from cars.

In the United States, the Walk Score website ranks major cities on their walkability—that is, residents' ability to conduct daily life without access to a car. San Francisco tops the list; other top-scoring cities include New York City, Washington, D.C., and Boston. These cities are also expensive places to live; people are willing to pay for walkability, or at the very least, needing to walk doesn't turn off many buyers.

According to a National Association of Realtors survey from 2018, 62 percent of millennials say they preferred to live in a place that didn't require car ownership. For example, "in Copenhagen," Gudmundsson noted, "we've had a revolution in how we treat pedestrian traffic and car traffic. Spaces that were parking 20 years ago have been converted into green spaces. ...If you make the city attractive for pedestrians with things like greenery and safe crossing points, it's a no brainer that people will walk."

Walking and biking aren't just pleasant, when possible, they are increasingly smart financial choices, too. "Putin's invasion of Ukraine has driven up gas prices and food prices all over the world," Biden said in an address on April 1, around the same time gas prices hit $4.33 per barrel. The high prices caused driving to drop in the United States below pandemic levels. In short order, Washington responded to the price hike by releasing gasoline from its strategic reserves, but it won't be able to tap into the reserves for the benefit of drivers every time there's a global crisis, and such crises may become more frequent as the comfortable post-Cold War world continues to crumble.

Some cities have a head start on preparing their infrastructure for this future. Today more than 35 million Europeans use some sort of bike as their primary mode of transportation, including cargo bikes for doing the shopping, toting the kids, and making deliveries. Copenhagen and London, among others, have even created cycle superhighway networks that allow bicyclists to travel in separate lanes from cars.

Even outside of bike-loving Europe, cargo bikes are becoming familiar in the United States. I've spotted a few in Washington, D.C. Car-centric Los Angeles boasts its own cargo-bike startups. And in New York, cargo baskets with a kid or two are becoming a common site in Brooklyn on weekends. To further boost uptake, last year New York City conducted a pilot project involving delivery cargo bike trials with Amazon, UPS, DHL, and three other delivery firms. Between May 2020 and January 2021, the subsequent evaluation found, "the number of cargo bike deliveries increased 109%." In January 2021 alone, it noted, New York saw more than 45,000 cargo bike deliveries, 80 percent of which were to residential addresses. It also noted that each cargo bike was able to cover an average of 20 service miles per day. Depending on traffic, that's between 50–100 percent of the service miles of a van or box truck. If 20 cargo bike miles per day replace 20 van or truck miles, that is seven tons of carbon dioxide per year.

But what about longer distances? E-bikes are an option, but they have batteries (although much smaller than EV batteries) with all the problems those entail. Public transport may be key, but it will have to be environmentally efficient and attractive enough that residents come to prefer it over the car. In June this year, as part of a package to promote energy efficiency the German government introduced a €9 ticket for unlimited rail travel around the country. When the experiment wound down in August, around 52 million Germans (and no doubt many visitors) had used the offer.

Some cities are finding other ways to discourage single passenger car trips. Bus rapid transit systems, known as BRTs, are advancing quickly and now chauffeur city dwellers around the

world in a fast, safe, and efficient manner. The buses involved are not all CO_2-efficient, but they're an attractive alternative to cars because they have their own lanes and are thus unencumbered by any slow-moving traffic. Further, "BRTs are also much cheaper to build than subways, and once you've established them you can set up feeder lines to different station stations," Gudmundsson said. "You have very efficient movement at small expense." It's also better for the environment, since the infrastructure already exists, which eliminates the need for new CO_2-emitting construction projects.

Innovations in battery technology, electrification, and consumer preferences have been quite rapid over the last decade. But not so fast that we've solved all of the technical problems, figured out implementation, and ensured that the markets will work.

BRTs are a particularly attractive option for cities less wealthy than Amsterdam, Copenhagen, and London. Indeed, the Brazilian city of Curitiba pioneered a system in the 1970s, and today residents of cities as different as Mexico City, Bangalore, and several Chinese cities travel in this manner, arriving faster and reducing CO_2 emissions in the process. The routes can also be changed more easily than can rail transport routes.

As with shipping, then, there is change coming to personal transportation—provided the right public, private, and individual priorities.

On Transportation, We Must Start Somewhere

There is good news in all this. Around the world, many people, companies, and governments are ready for a change.

For urban dwellers, quality of life increasingly means having fewer cars altogether, not just temporarily escaping their constant presence by moving to a different neighborhood. Shipping companies are starting to think about a future in which they are no longer able to send goods cheaply across countries by truck. And governments understand that their cities will be more attractive and resilient if they get the solutions right.

In the long term, then, the future looks bright. It seems very likely that there will be more people on foot, bikes, cargo bikes, and the like. There will be more deliveries in cities that are not facilitated by truck, more shipping on e-roads, more trips by better and better electric ships, and countless other improvements.

The question, of course, is what the next five or 10 years look like. In the grand scheme of things, innovations in battery technology, electrification, and consumer preferences have been quite rapid over the last decade. But not so fast that we've solved all of the technical problems, figured out implementation, and ensured that the markets will work.

Elisabeth Braw is a senior fellow at the American Enterprise Institute. Before joining academia she was a journalist and wrote extensively about sustainability.

But events this year may provide a further nudge. Russia's brutal war against Ukraine has reminded people around the world that the time of cheap gasoline is mostly over. Oil-and-gas exporters' order books are full. The United States will squeak through the winter, but things look bad for consumers in Europe. We may not have batteries worked out quite yet, nor good ways to electrify heavy shipping by tomorrow. But what if we start where the solutions are easiest?

What if, say, a city council were to introduce a couple of experimental bus lines that feature Wi-Fi and charging points? What if it made riding free of charge for one day a week? What if it turned one car lane on some popular streets into a cargo-bike lane? What if it incentivized delivery by bike, or in-person purchases? All this would cost some money—and none of these initiatives would represent a singular solution to the world's transportation emissions at scale—but these efforts would at least be a step, or pedal, toward the future.

ESSAYS

02

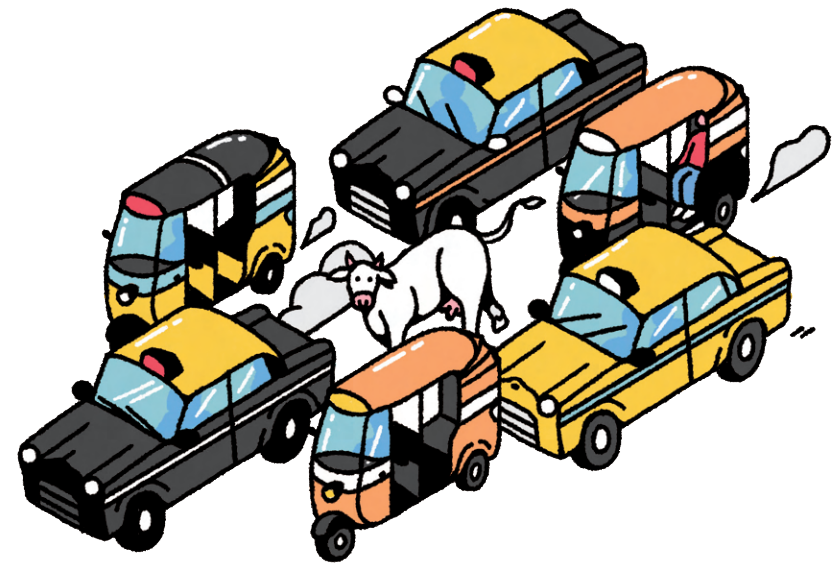
HOW TO MAKE INDIA'S URBANIZATION BETTER FOR THE PLANET

Density won't be beneficial unless India rethinks the way it manages cities

JAGAN SHAH AND SAM DOWNES

India made global headlines during the 2021 U.N. Climate Change Conference (COP26) as one of the first low-to-middle-income countries to commit to a net-zero target. As the country with the third highest greenhouse gas emissions in the world, comprising around 7 percent of emissions worldwide, reaching this target is a global priority. While the move was rightly lauded, India's new commitment highlights a challenge many countries in the developing world are grappling with: How can countries facing rapid urbanization manage their cities in a way that unlocks both the economic and environmental benefits of urban growth?

Much of the current climate conversation in India (and elsewhere) is a sectoral one, focusing on decarbonization in specific economic sectors: energy, transportation, agriculture, industry, and the like. But spatially, many of these transitions will come together in cities. After all, cities shape the demand that drives emissions. And over the next 30 years, low-to-middle-income countries will add thousands of kilometers of new urban infrastructure to accommodate the needs of 2 billion more people.



For residents of these urban areas and for the world, understanding the link between cities and decarbonization is crucial. It is not too late for India's booming metropolises to follow the path of other emergent cities like Dubai or Singapore, which are recognized for their livability and efforts towards sustainability. But without intervention, livability in many cities in the Global South will only come through energy-intensive means, as things like air conditioning, cars, and private generators compete with vulnerable buildings, crowded streets, and unreliable power supplies. And, given the costs of those conveniences, comfort will only be available for the wealthy.

India's Urban Growing Pains

By official estimates, in 2011, 31 percent of India's population—375 million people—lived in urban areas, mostly in towns and cities of various sizes ranging from 5,000 to over 20 million residents. But the facts on the ground look a bit different. Our own organization has put the true urban percentage at 50 percent—a whopping 605 million people—if not higher. Such "unrecognized" urban growth is clearly visible via satellite imagery, comprising entire neighborhoods on the outskirts of cities that tend to be informal, unplanned, and sprawl for miles unserviced by urban infrastructure like arterial roads, sanitation, and open spaces such as parks and public plazas.

We're not the first to pinpoint this problem; in 2016, the World Bank described urbanization in India—and across South Asia—as "messy" and "hidden." This is in part due to India's definition of urbanization being narrower than it is in other countries. Weak enforcement also means some areas aren't recognized as part of a city when they should be, leading to some actors playing the system to buy up land on the cheap before it is formalized and contributing to sprawl. Meanwhile, the government is left playing catch-up.

Even where new towns and neighborhoods are recognized and serviced by the state, they are hobbled by outdated planning practices. In globally recognized livable and sustainable cities, like Barcelona and Amsterdam, up to 40 percent of urban land is in the public sphere, including roads and open space. The remaining 60 percent is land underneath buildings. In India, cities fritter away most of their land; in Mumbai's downtown office district, just about 24 percent of land is in the public sphere and only 22 percent in building footprints. A whopping 56 percent of land is used as "private open space," typically underutilized space around buildings that is walled off from the main street. Imagine if downtown Manhattan were 50 percent larger but accommodated the same square footage of buildings, parks, and roads.

> *While per capita emissions in global cities such as London, New York, and Seoul may be up to 60 percent lower than the national average, the reverse is true in India.*

What the lack of publicly available space means in practice is congested roads, a larger urban footprint, and expensive real estate. This is because significant portions of private land remain vacant due to regulations that restrict the amount of a plot that can be built upon, unlike in Barcelona, for example, where building frontages can extend to the streets. Plots of land have also shrunk over time, meaning that building density has tended to increase on the peripheries of cities, where plots are smaller, compared to the center. In turn, average commute times in Mumbai are double those of New York and Singapore. The gap between lower rural productivity and higher urban productivity, found in more developed nations, has also narrowed in India.

Environmental consequences follow. While per capita emissions in global cities such as London, New York, and Seoul may be up to 60 percent lower than the national average, the reverse is true in India, with large cities like Delhi and Kolkata emitting up to double the national average. There is ongoing debate about how energy efficient density is, but density in the wrong place—in sprawling, informal, and poorly integrated peripheries—is certainly bad. It

leads to a reliance on diesel generators for power, unregulated fuel burning for heat, illegal and poor-quality construction, and intense traffic on unprepared roads. Debates about density aside, then, what is clear is that the ultimate driver of emissions in Indian cities is runaway and unmanaged urbanization.

Urbanization as it currently exists in India stands to lock the country into a high-emissions future, and it is projected to add another 217 million people to its urban areas between 2011 and 2036, accounting for 73 percent of population growth in India in the same period. Keep in mind the prevailing pattern: Growth has happened where regulations are weakest, on the fringes, as gradually informal areas have been absorbed as regular neighborhoods. Already, India's cities comprise many of the most polluted and congested in the world and are prone to extreme heat and flooding. Unless something changes, those problems will only get worse.

For India to meet its emissions targets, it must rethink how its cities are planned and managed. Retrofitting existing urban growth, planning ahead for more compact development, and investing in the infrastructure that can tie together sprawling urban areas can move Indian cities to a lower-carbon pathway. These too promise a better life for citizens.

Decarbonized Cities, Happy Citizens

Beyond the form of India's cities, cities' economies play a pivotal role in enabling green transitions in energy, transport, industry, and agriculture. Investing in the capabilities of cities to manage emissions in the sectors that they are a part of will be required if net-zero targets are to be reached.

Energy consumption comprises around 75 percent of emissions in India, with cities already making up a major source of demand. Their share is set to further increase, with energy demand in India's buildings estimated to balloon by 800 percent between 2012 and 2047 according to NITI Aayog, a government think tank. Driving that growth is greater need for heating and cooling, more consumption, and new buildings for a growing population.

Making new buildings energy efficient and retrofitting old buildings can bring down energy demand, reducing the pressure to keep old, carbon-intensive sources, like coal, online for longer. More efficient air conditioning, LED lighting, and sensors, for example, could reduce energy consumption 17 percent in institutional buildings, and up to 42 percent in hospitals.

Beyond buildings, cities are also the frontline of reducing emissions from other types of construction projects. In 2016, the cement, iron, and steel industries produced 11 percent of India's total CO_2 emissions, and further urbanization promises steady growth in those sectors. What buildings are constructed of and how they are built will thus play a role in reducing emissions. Further, many of the businesses that comprise this sector, the smallest in particular, are spread across the fringes of cities and rely on inefficient legacy technology that produces excessive emissions. City-level interventions like regulation and outreach will be necessary to change the situation. Clustering these enterprises together in industrial parks could also improve conditions in suburbs by moving some pollution and congestion elsewhere and by providing emissions savings through industrial recycling.

There is also the question of the grid. Further integration of renewables, energy storage, smart metering, and better management of distribution can also support the transition. This will mean retrofitting grids within cities and harnessing them for energy supply, such as by deploying rooftop solar panels. Standing in the way are pricing subsidies, delayed payments, and energy theft, which have left power distribution companies in poor financial shape. Micro-grids, a network disconnected from the main grid, could allow separate new neighborhoods and towns to manage their own systems. Removing companies' state-wide monopolies has been touted as a solution, too, by NITI Aayog. Doing so could spur competition, open new market opportunities, and allow for more city-level operations.

Transportation is responsible for 10 percent of India's emissions, of which 87 percent is from road transportation. With car ownership projected to rise from 22 cars per 1,000 people in 2018 to 175 per 1,000 by 2040, and the commercialization of electric alternatives still to happen, more public transportation is needed to provide an alternative. Strategies that focus on public transport, shared mobility, walking, and cycling could bring the sector's emissions down by an estimated 20–37 percent. But significant investment is required. India's state with the biggest bus fleet, Karnataka, provides only 3.9 buses per 1,000 people. For citizens who use private vehicles, charging infrastructure to support the use of electric cars and two- and three-wheelers will also have to be created. Meanwhile, the use of natural gas as an alternative fuel, which has fluctuated in recent years, is projected to grow in India. Although its use is a short-term bridge toward a greener future, in the long term the city will still need infrastructure for electric vehicles.

Lastly, one may think of the agricultural sector as largely rural, but its decarbonization is, in fact, closely linked with cities. Urban areas consume 60 percent of all food produced and represent 80 percent of the market value of consumption in India. A lack of cold chains and cold

storage is linked with up to 16 percent of some crops spoiling on route to market. Wastage means that more must be produced than is needed, leading to higher emissions during cultivation, as well as emissions from what spoils. The central government has recognized that what it calls the "hinterland" of cities needs to be planned along with urban jurisdictions. Considering development on a regional basis would open the door to synchronizing agriculture to what is actually in demand nearby.

Decarbonization, with its long timeframes, can sometimes feel like tomorrow's problem. But in Indian cities, economic and other benefits will materialize in the short term.

Decarbonization, with its long timeframes, can sometimes feel like tomorrow's problem and the next generation's benefit. But in Indian cities, economic and other benefits will materialize in the short term. Citizens can save on rising bills if they live in more energy-efficient buildings and if the grid is upgraded. Public transport can lower air pollution and improve commuting times, improving quality of life. Better supported industry will help lower pollution, and India's agricultural sector, with its well-known subsistence and subsidy problems, could be made more productive. These benefits will raise the quality of life for citizens today, not tomorrow.

Managing Space, Managing Cities

Cities have to be part of the solution if they are to avoid being part of the problem. And in India, nothing will be more important to these efforts than better urban administration. Cities will have to monitor, understand, and manage their "metabolism," something that data and remote sensing technologies can help with. So-called digital twins represent the gold standard of this sort of technology. Deployed in places like London and Singapore, a digital twin is a virtual model of the city that uses static and real-time data to help manage transport and energy in buildings, and plan for change amongst a range of uses.

Tools like these can drastically enhance an administration's ability to plan, finance, and monitor the performance of the city as an economic, demographic, and environmental entity—all tasks that have been historically neglected in India. Planning, finance, and implementation are chronically weak skill sets in India's municipalities due to a historic concentration of power, resources, and skilled manpower at higher levels of government, a problem that is further exacerbated by the use of outdated technologies. Combined with informational silos and hierarchical governmental structures, the result is poor coordination at higher levels of government, which struggle to effectively gather and relay information to the municipal level, undermining work across city-level bureaus.

Many city-level operations, for example, are managed by state and central governments, although precise powers vary country-wide. This affects accountability by mystifying who to punish at the ballot box. It also means that duties, like urban planning, can get shirked in policy decisions and departmental tussles too far removed to consider the ground impact. Urban planning failures have already been linked to serious water scarcity and flooding in Hyderabad and Chennai, respectively.

Empowering cities to take on planning responsibilities can enable them to regulate and plan for the changes that will actually happen to them. "Planning for economic and social development" is one of the 18 functions that, as per the Constitution of India, may be devolved by state governments to city administrations. Implementation of that rule, though, has been slow because it is optional and because of the fractious politics around land. More progress must be made.

The climate crisis is urgent, and in acting, we won't only avoid the future sorrows of a six- or eight-degree warmer world—we might also end up happier in the process.

But such efforts can only go so far as long as funding remains highly centralized. Transfers from New Delhi and state governments to cities often come with little room for choice on how and when it is spent. The little funding urban areas do control typically covers only the maintenance of existing infrastructure. For cities to play a greater role in setting local priorities, more funding should flow to them—not just through them. Municipal bonds and a localized carbon tax could provide independent revenue.

Improved land management will also remove one of the key bottlenecks to efficient city growth. Rigid implementation of plans distorts markets, increasing the price of development. Under the old Mumbai plan, 69 percent of land use changes needed government approval and 22 percent went ahead illegally. Improving spatial management of brownfield locations, easing land use changes, and digitizing land records can help overcome these barriers.

To underpin a paradigm shift in urban management, improved data systems will change the game. E-governance innovations, such as "e-nagarpalika," a push to digitize municipal services, are making many of the tasks handled by municipal administrations redundant. An improved National Inventory Management System for measuring carbon emissions will also be required as part of India's course to net-zero, as will local equivalents at the state and the municipal level that can truly bring together economic, spatial, and environmental data. Linking emissions with geographical and economic data will help cities spot opportunities and risks and allow them to anticipate, for example, the impact of shuttering a coal plant in a city's vicinity. Linking this up with smart systems will allow for real-time data, unlocking the ability for cities to both plan for decarbonization and adapt that plan in real time—significant steps to India's own version of "digital twins."

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Carbon-Free Planning for the People

Managing cities as the frontlines of climate change requires a paradigm shift that must be led by the national government while also empowering individual municipalities. If cities continue in their current state, the Global Commission on the Economy and Climate estimates it could cost up to $1.8 trillion a year by 2050, eclipsing the $1 trillion requested by India at COP26 to tackle climate change.

Like in India, in the rest of South Asia, Southeast Asia, and Africa, poor local government capacity, urban sprawl, and deteriorating air and water quality remain huge barriers to decarbonization. These countries are where climate change will be felt the most, and so without intervention, the quality of life for residents will stagnate or deteriorate.

Yet, it is not too late to turn the situation around. Strategic approaches, looking at how cities can be empowered to plan, finance, and implement ambitious plans to tackle climate change, promise not only to improve the environment, but also to improve the quality of life for residents today and for the 2 billion more who will live in these cities in years to come. Climate change is a global issue, but success or failure to stop it will be felt nowhere more than in the cities of the Global South.

FEATURES

01

IT'S NOT TOO LATE

How to create the world we want

SETH GODIN

This is a text about energy. For more than a hundred years, we've had the opportunity to pump energy out of the ground virtually for free. We've used that fuel to build the world around us. We've created amazing things, wasted resources, and made a mess while we were at it.

At the same time, there is another kind of energy. The energy of hope and connection. The ability that humans have to solve problems and to make things better.

It's not too late to make a difference. But we're going to have to hurry. We can't waste a moment arguing about the size of our problem or mourning what used to be. Instead, we can lean into hope and connection. The hope that comes from realizing that it's not too late. And the power, nearly unlimited, that comes from coordinated action and community reinforcement. Connected we are far more effective than each of us acting individually.

Seth Godin is an entrepreneur, best-selling author, and speaker. In addition to launching one of the most popular blogs in the world, he has written 20 best-selling books, including *The Dip*, *Linchpin*, *Purple Cow*, *Tribes*, and *What To Do When It's Your Turn (And It's Always Your Turn)*.

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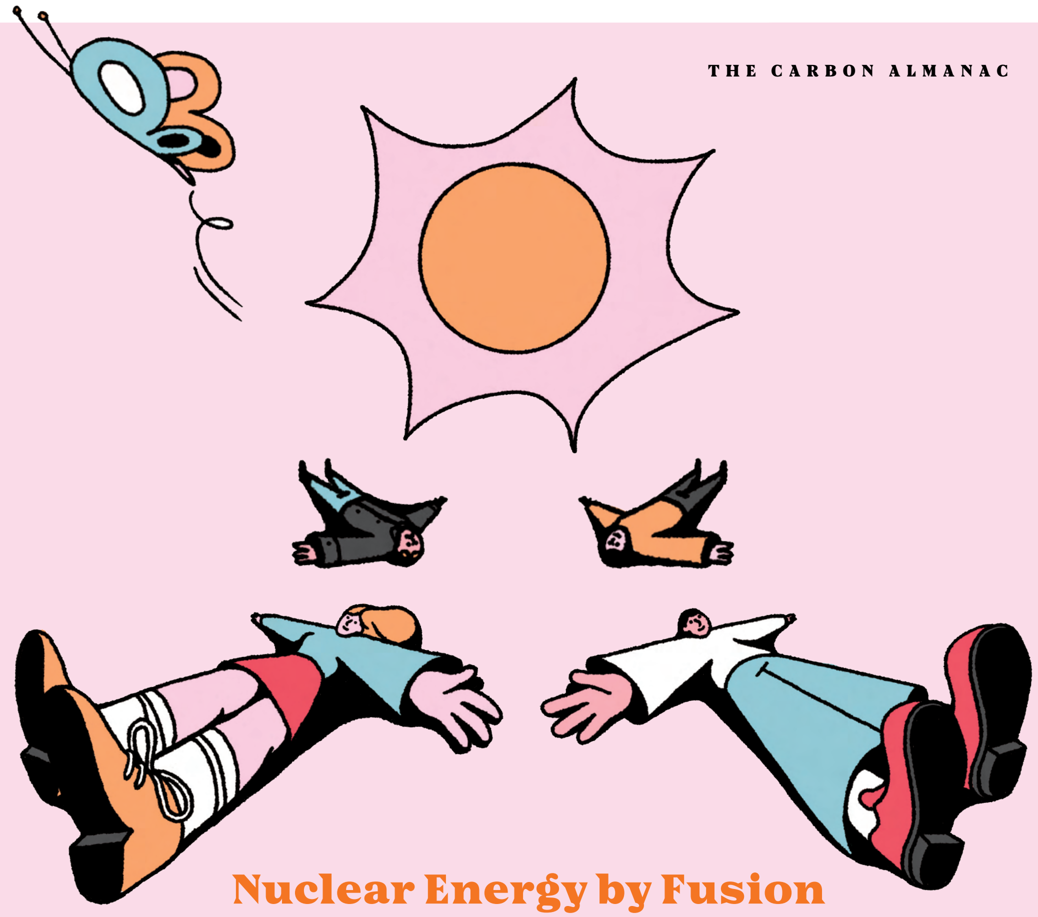


Nuclear Energy by Fusion

Atoms create nuclear energy using two physical processes: fission and fusion. Fission is the process that produces electricity in nuclear power plants across the globe. Fusion is the energy source of the sun and stars, but it's currently very challenging to contain and manage as usable energy on Earth.

Inspired By the Sun

In the 1920s, British physicist Arthur Stanley Eddington was the first to suggest that nuclear fusion powers the universe. Fusion uses hydrogen, the most abundant element in the universe, to generate energy in the form of heat and light. The waste products of that process are helium and tritium.

Fusion is clean, safe, powerful, and efficient and has been in constant use for about 4 billion years by the sun. The Earth has enough of fusion's primary fuels—heavy hydrogen and lithium, which are found in seawater—to last 30 million years.

If fusion could be harnessed effectively, it could potentially generate endless amounts of pure and waste-free energy.

How Fusion Works

Unlike fission, which creates energy by splitting atoms apart, fusion occurs when two atoms combine and fuse to form a third, heavier element. In the process, some of the atoms' mass is converted into a massive output of energy.

Challenges of Nuclear Fusion

Earth does not have the same intensity of gravity as the sun, so a fusion reactor needs a different way to contain the reaction. A practical fusion reactor would require ten times more heat than found on the sun.

To produce a fusion reaction on Earth, the intense heat and pressure found in the sun's core needs to be reproduced. This intense heat, as well as internal pressures needed to fuse the atoms, requires sufficient containment to hold and maintain that fusion reaction long enough for a net power gain.

As no material is capable of containing such a hot and dense plasma where the fusion reaction is taking place, magnets far more potent than those used in an MRI machine suspend the plasma in a special doughnut-shaped apparatus known as a Tokamak. Unfortunately, a Tokamak is not very efficient at maximizing energy output. Research into more advanced magnetic confinement geometries is a significant area of interest for nuclear physicists.

> Fusion is clean, safe, powerful, and efficient and has been in constant use for about 4 billion years by the sun.

Ongoing Fusion Research and Development

More than 50 countries are researching nuclear fusion and plasma physics. Fusion reactions have been successfully achieved in many experiments, although none as yet has demonstrated a net power gain.

In southern France, 35 nations are collaborating on project ITER to build the world's largest Tokamak to prove the feasibility of fusion as a large-scale and carbon-free energy source. ITER holds the possibility of being the first fusion device to produce more energy output than is required to run the reactor and currently holds many records for sustained reactions.

Investment in Fusion Reactors

NAME	FUNDING*	APPROACH	LOCATION
Avalanche Energy	33 Million	Palm-sized reactors	Seattle, WA
Commonwealth Fusion Systems	2.5 Billion	Tokamak	Cambridge, MA
ENN Energy Research Institute	Public Company	Field Reversed Configuration	Langfang, Hebei
First Light Fusion	25 Million	Impact Inertial Confinement	Yarnton
General Fusion	322 Million	Liquid Liner Compressor	Burnaby, BC
HB11	4.8 Million	Laser Boron Fusion	Sydney, NSW
Helion Energy	2.7 Billion	Field Reversed Configuration	Redmond, WA
Lockheed Martin Skunk Works	Public Company	Compact (truck-sized) reactors	California
TAE Technologies	90 Million	Field Reversed Configuration	Foothill Ranch, CA
Tokamak Energy	10 Million	Spherical Tokamak	Abingdon
Zap Energy Inc.	50 Million	Z Pinch	Seattle, WA

* In U.S. Dollars

Source: Carbon Almanac. Created with Datawrapper

In China, the China Fusion Engineering Test Reactor (CFETR) will be slightly larger than ITER, with a radius of about seven meters. As of 2020, CFETR was in the design and technology prototyping phase, with construction to begin later in the decade. Initially, it will demonstrate fusion operation at about 200 MW fusion power and will eventually upgrade to at least 2000 MW of fusion power and 700 MW of net output.

By 2021, investors began embracing the possibility of fusion energy as never before. Some and the money they've raised are above.

CONTINUED ON PAGE 124

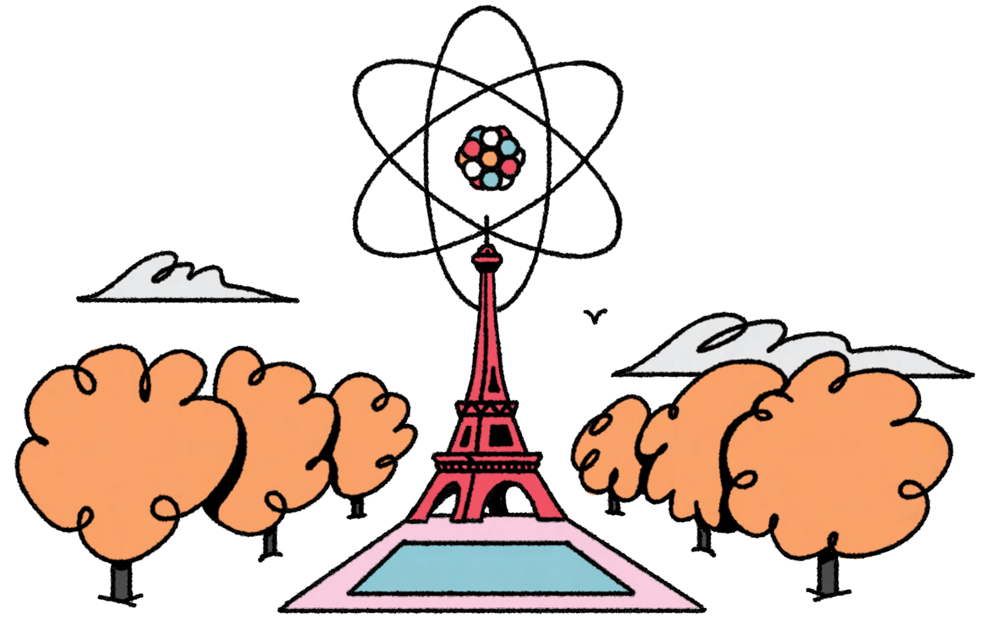
FEATURES

02

NUCLEAR DREAMS, NUCLEAR REALITIES

A look a nuclear programs around the world shows where nuclear's future really lies—and what it will take to make the next generation of plants successful

MICHAEL MORAN



Since 1987, two pressurized water reactors have produced about 4 percent of France's electrical power. Located on the Cotentin Peninsula, about 15 miles southwest of the port city of Cherbourg on the English Channel, they form a significant part of a 56-plant network that satisfies 70 percent of all electricity consumption in the world's seventh-largest economy.

These "Generation Two" reactors—identifiable the world over by their round containment domes—share many characteristics, and some of the flaws, common to the hundreds of plants built across the world in the 1970s and 1980s. There have been routine shutdowns for turbine issues, fires, corrosion, concerns about tensile steel resilience, and of course, local backlash caused by the very real anxiety average people feel living close to these behemoths. Indeed, over the summer both were offline for maintenance checks amid record heat that has sorely tested France's electrical grid. But no meltdowns, no serious releases of radioactive gas, no tsunamis. In the cold calculus of risk and reward, these plants have produced enormous benefit: Per capita annual CO2 emissions in France are one-third what they are in the United States (4.24 metric tons versus 14.24 metric tons per person), largely due to nuclear power's contribution to the French electricity grid.

The French model of nuclear energy, long cited by advocates of nuclear power as an example of how the atom can be safely harnessed to produce green power at scale with minimal safety issues, stems from a simple decision: build plants based on a proven design, iteratively improved but not radically altered to ensure lessons learned and efficiencies gained are reproduced. It's the same way Henry Ford once rolled out Model Ts in Detroit.

France's first nuclear reactor, the Zoe reactor near Paris, became operative in 1948. Like other reactors of that era, Zoe was a research reactor: in effect, a prototype which until its decommissioning in 1976 was meant to define what is possible, and what is not. Based on these learnings, France built several Generation One plants that began contributing electricity to the national grid in the 1950s and 1960s. But its nuclear build-out really took off just after the Arab Oil embargo reminded the world in 1973 of the drawbacks of depending on foreign oil imports. By 1980, the country had embarked on an unprecedented effort to replace all fossil fuel power generation with nuclear. While that particular goal proved too ambitious, the country did build 50 Generation Two plants in the 15 years starting in 1980, most from a common design, making France a net exporter of electricity and the leader among industrial nations in meeting electrical demand without carbon emissions. France maintained this distinction until 2020, when China's nuclear power construction efforts finally overtook its own.

When France first opted for nuclear power, climate change science was still in its infancy, so observers were not focused on the emissions benefits. But they did care about cost and safety. And on that score, France performed admirably. Since 1947, when post-war statistics first reflected nuclear power's contribution, French electricity rates have consistently been the lowest in Western Europe. And while by no means accident free (a short timeline of French nuclear mishaps can be found on Reuters), the plants have operated safely enough to keep nuclear power popular in France.

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The secret to French success, its nuclear engineers say, are common design features across most plants, technical prowess, and aggressive regulation. All of France's 56 active nuclear plants, spread across 20 sites, are operated by EDF, a company which is 84 percent-owned by the French state. This has led many, including those who oppose state ownership, to accuse France of papering over problems. There's also the issue of potential regulatory capture.

But the numbers tell a good story for French nuclear power, and France has doubled down on its success. In 2022, President Emmanuel Macron announced that the country would construct at least 14 advanced nuclear plants in the next 15 years, with six plants of the new European Pressurized Water 2 (EPR2) design slated to begin construction in 2025 and start coming online by 2035. This will coincide with the scheduled retirement of many of the Generation Two plants built during the 1970s and 1980s, some of which have already been extended beyond their planned 40-year life. The new plants would—at least on paper—produce far more electricity than the legacy plants they will ultimately replace.

After decades of pursing a "rinse, wash, repeat" approach to nuclear power, France's decision to co-develop the EPR design, with Siemens of Germany, involved significant risk. But leaders of the French nuclear industry committed to advancing the power generation capacity while at the same time adding new, often double- and triple-failsafe backstops that would make these plants even safer than the Generation Two plants, which already performed so well.

France's Nuclear Drawing Board

In a country like France, where nuclear power has earned a generally positive reputation by following a proven blueprint, the attempt to leap a generation with the EPR design exposed the country's nuclear engineers to perils their American counterparts know all too well.

In the American system, where nuclear power had its own golden age of construction in the 1970s and 1980s, innovation and variable designs among plants proved a disadvantage. It gave designers invective to prioritize cost savings and other commercial concerns over safety. Variable design also stretched the U.S. regulator, the Nuclear Regulatory Commission (NRC), to its intellectual breaking point as it was forced to regulate so many new types of plants. At Three Mile Island in 1979, one could argue, that breaking point was reached when a combination of mechanical failure, erroneous sensor readings, and human error caused the reactor core to overheat and release a small amount of radioactive material into the atmosphere.

For its part, with the introduction of the EPR2, France has argued that it can innovate and then return to its proven "rinse, wash, and repeat" blueprint of success. Not everyone has faith. Since the new plan was announced during the recent French general election campaign in which Macron was seeking reelection, his political opponents pounced. And Greenpeace France, which opposes nuclear power, criticized Macron's faith in the EPR design. It called the new plan "irresponsible" and pointed out that EPR design had become an embarrassment since its launch in the late 1990s.

Greenpeace may be wrong about nuclear power in general, but on the EPR reactor design, it has a point. The problems of the EPR program are well documented. The design, created by a partnership of EDF and Siemens of Germany, was originally meant to be a template for Generation Three European nuclear plants. France also planned to offer EPR technology as an export in Asia and, indeed, the first EPR plant opened in China in 2019. The first attempt to build one in France, though, has gone badly awry.

Flamanville 3, as the plant is known, is located just a few miles south of where some of France's 1980s vintage reactors continue to churn out reliable, clean power. Under construction since 2006, Flamanville 3 should have gone online in 2012 but has been subject to design, construction, and other delays. Its price tag has ballooned from €3 to €12.7 billion, with its completion date extended to 2023. An EPR reactor under construction in Finland has faced similar problems and, initially due to open in 2009, only went online in March. Two more EPR plants recently broke ground in 2018 in the United Kingdom at Hinkley Point on the Irish Sea in Somerset, with cost overruns soon following. The completion date for the first, currently 2026, has not yet been officially revised. But news reports say delay is inevitable.

In an effort to rescue the reputation of EPR plants, the Franco-German design team, consisting of EDF's nuclear division, Framatome and Siemens of Germany, have simplified the design. The new EPR2 plan commits to what its designers call a "Defense in Depth" approach meant to cast traditional engineering assumptions aside and radically redesign them to "over-engineer" key components. The work is meant to address one of the main causes of pain in the original EPR design: a double containment dome that has proven difficult and terribly expensive to construct. This second dome at Flamanville 3 and other EPR sites contains not only the core but all the steam pipes that cool it, an ambitious step forward from traditional pressurized water reactor designs. Perhaps too ambitious, however, to be commercially viable, as the previously-cited cost overruns demonstrate. Instead, the new EPR2 design will massively strengthen the steam pipes, a proposal known as "break preclusion" that drew condemnation from anti-nuclear activists and skepticism, at least initially, from the French regulator ASN. That skepticism led to further redesigns and ultimately ASN's approval.

To understand the concept of over-engineering, it may be helpful to think of the Brooklyn Bridge, a revolutionary structure when completed in 1883. Its raw beauty and iconic design aside, the reason engineers marvel at the bridge is its ability to bear modern loads. Engineers like John A. Roebling, who designed the bridge and oversaw much of the construction, had no real idea what kind of stresses the bridge would face over the course of its life. It was setting precedent, not building upon them. As such, the bridge was designed to be six times stronger than needed, such that, even after suppliers delivered weaker cables, the bridge was still four times stronger than necessary.

This is what EPR2 engineers are committing to. The reactor's coolant lines will be so over-engineered that failure is highly improbably under any conceivable conditions. With coolant lines one of the main potential causes of a catastrophic failure, this appears to be sensible. But that modifier "highly improbable" will never be enough for some.

Is Nuclear Making a Comeback?

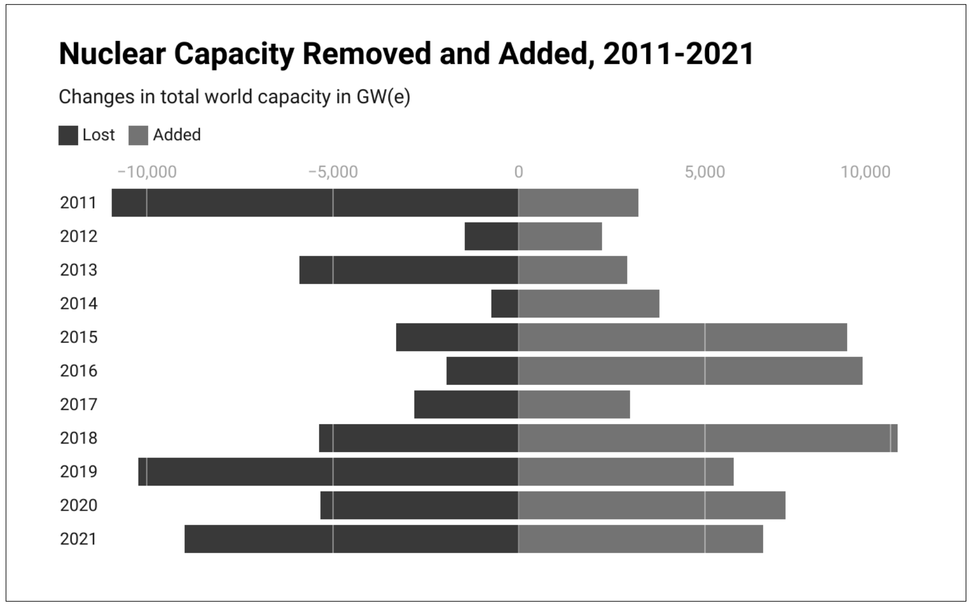
If France's reputation for nuclear competency has taken a bit of a hit with the latest designs, it still remains a leading exporter of nuclear technology and know-how, and it has played a role in the construction of new Generation Three plants in China, India, and Russia, as well as the aforementioned EPR plants in China, the United Kingdom, and Finland. France's struggle to templatize the EPR design, however, has not stopped other nations from launching their own new wave of nuclear plant construction.

Some countries never slowed their pace, of course, including China, India, and Russia. But in the past two years, countries that had either forsworn further construction or seemed unlikely to reengage have reversed themselves, including the Czech Republic, the Netherlands, Poland, South Korea, and the United Kingdom. In announcing plans to build nuclear plants, all these nations have cited climate change as a primary motivation. After decades of dormancy, the United States has two Generation Three nuclear plants under construction—the Vogtle Units 3 and 4 in Georgia. More poignantly, Japan has reversed itself and restarted plants shuttered after the Fukushima disaster.

Starting in 2014, more nuclear capacity was added each year than subtracted globally, a sign hailed by advocates of ultra-low-carbon nuclear power as evidence that a world facing a global climate crisis was coming to its senses.

Of course, there are exceptions. Headlines have been dominated of late by Germany's dithering over its decision to retire the last of its once-robust network of nuclear power plants by the end of this year, despite fuel shortages caused by Russia's marauding of Ukraine. And such closures have taken their toll.

Starting in 2014, more nuclear capacity was added each year than subtracted globally, a sign hailed by advocates of ultra-low-carbon nuclear power as evidence that a world facing a global climate crisis was coming to its senses. As Bill Gates, Microsoft co-founder, Net Zero evangelist, and nuclear energy entrepreneur, told Congress in 2019, nuclear power is the only available solution that avoids the intermittency problems of renewable sources like wind and solar. "Nuclear [...] is the only carbon-free, scalable energy source that's available 24 hours a day," Gates said in testimony.



Source: IAEA. Created with Datawrapper

As of this writing, the revival that peaked in 2018 is being somewhat reversed, mostly by Germany. In 2021, preliminary figures from the International Atomic Energy Agency (IAEA) indicated the retirement of three mid-life reactors with good safety records producing 5.1 GW(e) of carbon free energy. But they also recorded the opening of six new reactors accounting for 5.2 GW(e), all of them in Asia. For now, Germany will temporarily keep two of its remaining three reactors operating and close the third as planned by the end of the year.

And yet, in 2020, the IAEA's annual report also noted that, in total, for the first time in many years the world generated slightly more from new and remaining nuclear power plants—some 5.5 GW(e)—than the 5.2 GW(e) from retired plants. The slight gain, the IAEA noted, "doesn't yet constitute a trend," especially with the figures for 2021 still out. But it was a clear improvement over previous decades, which all saw global declines: from a peak of 17.6 percent of global electricity production in 1996, nuclear now stands at 6 percent of global production.

It is not wishful thinking to expect that nuclear power's fortunes are reversing. Last fall, the IAEA raised its "upper case" scenario for global nuclear power production by 2050, forecasting nuclear may by then produce as much as 792 GW(e), more than double today's total. This will give some succor to those hoping for a nuclear revival. To be sure, that sum would still constitute only about 12 percent of expected global electrical demand, but an energy revolution has to start somewhere. The questions, of course, are where and how.

Europe's Nuclear Prospects

In Europe, the overall prospects for nuclear power are good. In early July this year, the European Parliament, normally a left-leaning body and previously quite hostile to nuclear power, voted to designate nuclear and natural gas as sustainable energy sources for the purposes of financial regulations. The Parliament's action remains controversial in some circles—particularly in doggedly anti-nuclear Germany—yet it reflects a changing perception of the risk calculus surrounding nuclear power and the technology behind it.

Europe's move regulates the financial services sector, and its impact on the nuclear industry will be primarily in terms of capital. In effect, listed companies involved in the industry will have a lower cost of borrowing, which should incentivize further construction.

Criticisms abound; accusations of greenwashing are rife. And with Europe under intense pressure to respond to the threat of a Russian gas shutdown and wean itself from its unwise reliance on Moscow's whims, the rebranding of nuclear power strikes some as opportunistic, if not downright cynical.

But whatever the reason for re-regulating it now, the fact remains that the new laws are a boon to a zero-carbon nuclear energy future and could portend a new wave of deal-making by nuclear energy companies to export technology to countries where coal and other fossil fuels still represent the main sources of electrical power.

One place they likely will not matter, though, is Germany. It will push nuclear power generation from 12 percent of its energy mix as recently as 2020 to zero percent if it closes its remaining three reactors as planned. When Russia's stranglehold on European gas became impossible to ignore last winter, some thought Germany's new government, led by the SPD Chancellor Olaf Scholz in coalition with the Greens and Liberals, might revisit or at least delay its nuclear plant retirements. In the end, Berlin did temporarily delay the closure of two of the three, but the aversion to nuclear by German citizens, who remember the radioactive cloud Chernobyl sent over areas of continental Europe in 1986, remains strong.

Of course, reasons beyond Chernobyl gave nuclear a bad name. The turn away from nuclear also has roots with the former Social Democratic (SPD) Chancellor Gerhard Schroeder, the originator of the plan to close all Germany's nuclear plants. Following his political tenure, Schroeder became CEO in the 1990s of the company that built the Nord Stream I natural gas pipeline that has since tethered Germany and European neighbors to Russian gas. For a few decades, the decision had few consequences despite frequent warnings from Washington and from Germany's eastern NATO allies that Moscow is not to be trusted. They were right, and Schroeder now faces charges from Germany's public prosecutor for complicity in crimes against humanity for his close ties to Putin.

Germany's ideological flexibility on green reached new levels of absurdity in July, when the country chose to restart coal-burning power plants before delaying nuclear shutdowns.

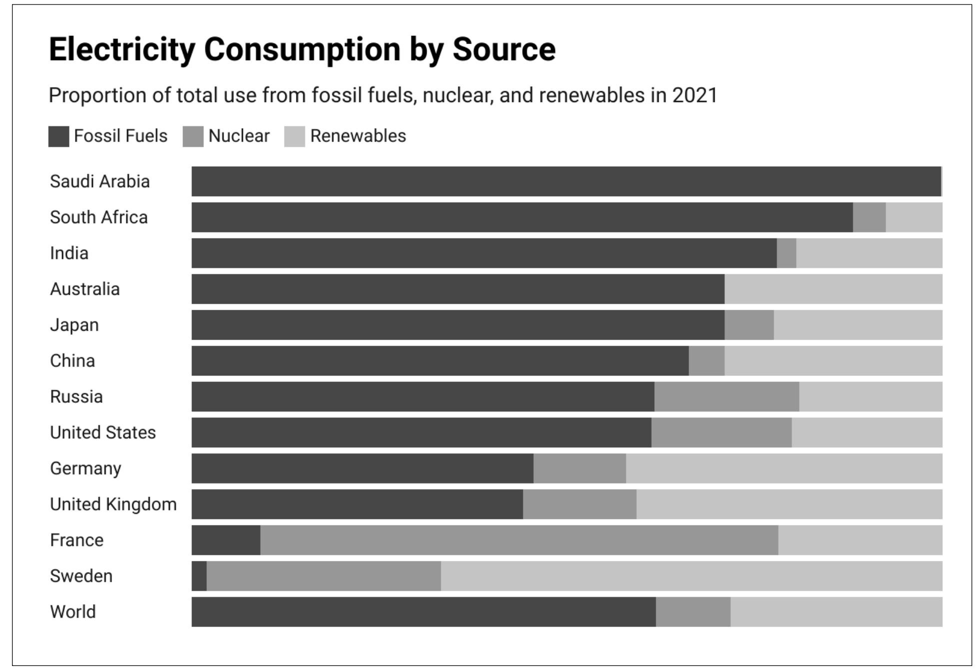
France, of course, stands to be a clear winner with the new EU regulations. It continues to outpace global trends, supplying three-quarters of its domestic demand with nuclear power and also exporting electricity. This summer threw France two new challenges, however: record heat waves affecting plant performance, and the specter of Ukraine and Russia fighting over the world's most powerful nuclear power station at Zaporizhzhia in eastern Ukraine. Anti-nuclear activists point to both scenarios as evidence that unpredictable risks still stalk nuclear technology, regardless of whether "lessons learned" from Chernobyl and Fukushima are integrated into future designs.

Start with Europe's heat waves: Because of the record temperatures across the continent, the rivers that serve as the primary coolant for nuclear plants became too warm (between 28 and 30 degrees Celsius/82 to 86 degrees Fahrenheit) to safely cool reactors. As a result, four reactors were shut down until the rivers cooled. Combined with scheduled maintenance on a half dozen of the country's 56 plants, this brought French nuclear electrical output to a multi-decade low at precisely the wrong moment. Similar shutdowns and power curtailments due to river temperatures went in effect over the summer at Swedish, Finnish, German, and Swiss plants. Such unreliability has raised new challenges for nuclear advocates.

Meanwhile, the situation at the Zaporizhzhia plant in eastern Ukraine was nothing short of extraordinary. Consisting of six Soviet-designed reactors, in 2021 it produced 23 percent of Ukraine's electricity. Russia forces turned the grounds, which they captured in March, into a missile-launching platform, presumably to deter the kind of devastating counter-battery strikes that Ukraine has used to pound Russian headquarters in other regions. But Ukraine has not refrained from targeting missile batteries housed at Zaporizhzhia, raising international fear of a meltdown. Whatever the dangers, the plant remains on the front line, an object lesson about the limitations of risk planning.

Nuclear Power to the North

Despite such setbacks, the overall trend in Europe is for expansion. Earlier this year, the



Source: Our World in Data. Created with Datawrapper

Netherlands, which had previously planned to phase out its Generation Two plant when its expected lifespan expired later in the decade, announced plans to spend €5 billion (about $5.2 billion) to build several nuclear plants by the mid-2030s. The goal, the Dutch government said last January, would be to complement wind, solar, and other renewables and raise the percentage of Dutch electrical power generated by nuclear above the current 3 percent.

France's example within the EU, although burdened by fits and starts with the new EPR design, nonetheless has won regional converts. Besides the Netherlands, Switzerland, Czechoslovakia, and Poland all now have robust programs to expand nuclear capacity in the name of weaning themselves from carbon fuel and Russia. Meanwhile, Finland and Sweden, in addition to bidding for NATO membership this year, have populations who strongly favor nuclear energy, both due to its carbon profile and its ability to bolster their energy sovereignty.

Earlier than most, these two Scandinavian nations saw through Moscow's push to bring natural gas to Europe. So while in the 1980s, Sweden vowed to phase out nuclear power, which at one time produced nearly 40 percent of domestic electricity, the country changed course in 2009 and plans to build up to 10 small nuclear reactors, the first two just south of Gothenburg on the Baltic Sea. It would come online in the early 2030s.

Finland also has remained a constant in nuclear power generation but has struggled with a legacy of Russian nuclear plant design and uranium supplies. Two of its older Russian-designed plants were retrofitted with Western-style containment domes following the Chernobyl meltdown in 1986. Today, the Finns meet about 33 percent of their electricity needs with nuclear power and have become known for their skill in retrofitting and upgrading existing plants, which also include Swedish designs and one of the Franco-German EPR design.

Like Sweden, Finland is studying the idea of smaller "modular" nuclear plants to replace and augment existing capacity. But a more pressing issue involves a plant under construction in Pyhäjoki, which would be the northernmost plant in Europe if completed. Russia's atomic agency, Rosatom, owns a 34 percent stake in the plant. In May, Finland canceled its contract with Rosatom despite construction being well underway for a 2029 completion. Rosatom has said it will seek its investment back through international arbitration, although its prospects are dim given tight Western sanctions regime against Russia. Finland could complete the project with Western assistance, but it also depends on Rosatom for uranium to fuel the plants.

In fact, the legacy of Soviet and Russian involvement in Eastern and Central European plants has complicated the nuclear energy infrastructure picture. Columbia University's Center on Global Energy Policy notes that of the 439 nuclear reactors operating worldwide in 2021, 42 were of Russian design. Another 15, including Finland's Pyhäjoki, were under construction with Russian technology. Add 38 active plants within Russia, and this is a big footprint.

What's more, Russia dominates the supply and refining of uranium to fuel these and many more reactors. Europe gets some 20 percent of its uranium from Russia. The figure for the United States is 14 percent. Another 35 percent of U.S. uranium comes from Kazakhstan. And Russian state entities or private firms own 40 percent of global uranium conversion infrastructure and 46 percent of total uranium enrichment capacity, the Columbia report says.

In the countries of the former Soviet bloc, the dependency goes deeper than just finding another supplier. There are 18 nuclear power plants in Poland, the Czech Republic, Hungary, Slovakia, Bulgaria, and Romania calibrated to use the hexagonal fuel elements provided by Rosatom. This has placed the governments of these NATO member states in a difficult position.

In April, the Czech Republic threw Russian contractors and Rosatom itself out of the bidding process to build a new reactor at Dukovany. In neighboring Hungary, heavily dependent on Russian energy, populist President Viktor Orbán flirted with blocking nascent EU ascension talks for Ukraine if the EU enacted sanctions on Russia—something a single member state can do in the EU's all-for-one, veto-for-all system. In the end, Hungary relented, but Orbán's government has decided to continue construction of two Russian-designed plants with Rosatom's assistance in the Danube town of Paks.

Even where plants aren't locked into Russian fuel, the problem of supply is tough. That's why, despite relative unity of purpose among Europe, the United States, Japan, and other nations against Russia, no mention of uranium has been made by European or American leaders touting the effectiveness of sanctions. While there are belated efforts to jump-start once-common uranium mining operations in Australia, Canada, the United States, and elsewhere, such mines are often unpopular, and locals have mixed feeling about reviving them.

> A 2014 report from the U.S. Energy Information Administration forecast an increase of 4 percent in U.S. greenhouse gas emissions by 2040 if the current rate of plant retirements goes forward without life extensions or new plants to replace them.

Can Biden Bring Back Nuclear?

In many ways, the nuclear energy picture in the United States looks like a race between those who would revive the industry to address climate change and the utility companies that operate the aging fleet of mostly Generation Two plants, who face many economic pressures. Ninety-two nuclear reactors at 55 plants still operate in the United States, but that figure is shrinking. Nuclear power in GW(e) terms peaked in 2019, but the industry still meets about 20 percent of U.S. electrical needs thanks to refits that have increased output in the legacy plants. That figure will begin falling quickly after 2025, as plants dating from the early 1970s are decommissioned and new plants fail to materialize. A well-trafficked report from the U.S. Energy Information Administration in 2014 forecast an increase of 4 percent in U.S. greenhouse gas emissions by 2040 if the current rate of plant retirements goes forward without life extensions or new plants to replace them.

Earlier this year, the administration of President Joe Biden—navigating political straits around nuclear power—announced a $6 billion program of financial credits to help existing nuclear plants extend their lives beyond 2025. The first two plants targeted were the Palisades plant in Michigan and the Diablo Canyon complex, California's last operating nuclear facility. Both are Generation Two plants, designed in the 1960s and subject to economic headwinds as the price of wind, solar, and geothermal sources has dropped. In June, Entergy Corp. sold the Palisades plant to Holtec International, who will carry out the plant's decommissioning due to concerns about aging components. As for the Diablo Canyon plant, after many years of debate, lawmakers recently agreed to keep it open for five more years.

> Democrats' change of heart on nuclear creates a genuine way forward in Washington to secure funding for a new round of nuclear construction, which could enable plants to supply as much as 48 percent of U.S. electricity demand by 2050

Nuclear energy proponents see hope in the two new Generation Three plants, Vogtle 3 and 4, which are nearing completion in Georgia, as well as in the $1 trillion infrastructure plan that became law last November. It won bipartisan support, despite some $25 billion in funding for nuclear-related projects, including the $6 billion credits discussed above and $3.2 billion to fund the Advanced Reactor Demonstration Program to create a template for nuclear expansion.

Some had feared Biden's fraught relationship with progressives in the Democratic Party might lead such funding to be struck from the final bill, but it wasn't. And that outcome was a first practical effect of a change in the party's official stance during the 2020 presidential-election year, when the Democratic platform embraced a "technology-neutral" approach to reducing reliance on fossil fuels that included "all zero-carbon technologies, including hydroelectric power, geothermal, existing and advanced nuclear, and carbon capture and storage."

The change of heart creates a genuine way forward in Washington to secure funding for a new round of nuclear construction, which independent reports, including one from The Breakthrough Institute, suggest could enable advanced plants (Generations Three and Four) to supply as much as 48 percent of U.S. electricity demand by 2050 as the clean energy transition reaches critical mass. The cost could reach $1.1 trillion by mid-century, but then again, U.S. taxpayers would extend at least $574 billion to the fossil fuel industry in subsidies and incentives over the same period, given the current rate of $20.5 billion annually.

China as the Next Nuclear Powerhouse

The real growth story for nuclear power, as in so many other realms, is in Asia. In 2022 so far, the U.S. Energy Information Administration (EIA) reports that 35 civilian nuclear power plants are under construction there in 2022, over twice as many as in Europe, including Russia, and far more than in North America or elsewhere.

Many of the new Asian construction projects involve China, either because the construction is in China or conducted with loans and expertise from China. According to Chinese President Xi Jinping, 19 currently underway are a down payment on 150 new reactors in planning stages. This will cost about $440 billion over the next 15 years and aims to replace all of China's coal generation capacity by that year, as Bloomberg noted when China's nuclear lending program was announced at the COP26 climate summit in Glasgow last November.

China's plans carry echoes of the Messmer plan, announced by French Prime Minister Pierre Messmer in 1974 in the wake of the first Arab oil embargo. Under the plan, France was to construct 170 reactors by 2000. Such ambitions quickly faded in the face of budget constraints and competing priorities. But China's plans cannot be so easily dismissed. The country did not complete its first nuclear plant until 1992, yet it operates 55 today. And being late to the game has not prevented China from overtaking legacy powerhouses in other sectors. During the past 20 years, for instance, it has shot past European and the Japanese economies in terms of GDP; taken the lead in manufacturing from Germany, Japan, and the United States; become the leading generator of solar, wind, and hydroelectric power; and now challenges U.S. naval supremacy in the Pacific. Underestimating China is a chump's game.

But China is not alone in pressing forward in the nuclear power sphere. India operates 22 nuclear reactors, mostly of Russian design, and has another nine under construction. Pakistan has a new Chinese-designed plant funded by Belt and Road Initiative money, which came online in March, and which augments its current network of six. In Japan, which famously vowed to retire all its nuclear plants after the Fukushima disaster in 2011, 10 of the country's 36 reactors are operable, and the country is planning new construction, too. Two new operations are currently under construction even as the country continues restarting plants mothballed after the tsunami.

If China has a rival in Asian nuclear power production, though, it is South Korea. With 25 reactors in operation and three more under construction, the country recently reversed a pledge to get out of the nuclear power business. It is also exporting its expertise, currently involved in the construction of four plants in the United Arab Emirates. President Yoon Suk Yeol, elected in March, has promised to make South Korea a "nuclear reactor superpower," a sensitive topic on a crowded peninsula with a rogue state testing nuclear weapons with some regularity. Yoon has announced plans to extend the life of 10 of the 25 existing reactors with an eye toward increasing nuclear's share of energy generation from 27 percent to 30 percent by 2030. These moves won praise from the Biden administration, which invited South Korea to participate in a U.S. Energy Department project to develop small modular nuclear reactors.

Nuclear Dreams and Realities

Beyond Asia, the cost and complexity of nuclear energy has proven a barrier to entry. The World Nuclear Association, a global industry trade group, reports a desire for nuclear power in more than 70 countries—everywhere from Yemen to lithium-rich Chile to Ireland. But even the industry's mouthpiece admits that "in the foreseeable future—the main growth will come in countries where the technology is already well established."

Sub-Saharan Africa is a good example. Outside of two Generation Two South African plants that went into service in 1984, at the height of the Apartheid government's pursuit of a nuclear weapon, no other nation in the region operates commercial nuclear plants. South Africa, which like many African countries has faced severe power shortages over the past decade, has issued a request for proposals for future plant construction and has said it will make a decision on resulting bids by 2024.

Both Nigeria and Ghana have likewise announced they will hold similar bidding rounds. But experts believe the most likely source of new plants in Sub-Saharan Africa outside of South Africa would be China, likely through the kind of Belt-and-Road financing that has built ports, railways, and other infrastructure from the Horn of Africa down to the Cape of Good Hope.

That's not to say nuclear energy isn't breaking new ground in the rest of the world. First-ever plants are under construction in Bangladesh and Turkey, and a two-reactor Generation Three plant of South Korean design opened in early 2021 in the United Arab Emirates. Contracts for new plants have been signed by Egypt (with Russia) and Poland (with U.S. firms Westinghouse and Bechtel). And a half dozen other nations are reported to be negotiating similar projects, including Jordan, Uzbekistan, and Saudi Arabia.

Nuclear Power in the Age of Climate Change

The picture that emerges from a review of global developments is of an industry—and a technology—being granted an eleventh-hour reprieve from whomever or whatever it is that governs us humans. Nuclear energy won't take over the entire world fast, but it is doggedly marching forward in some places and making incremental gains in others. France, along with the

The Four Generations of Nuclear Power Plant

Compared with many power technologies, nuclear power generation is still relatively new, with the first small reactors dating to the Manhattan Project, when in 1942 a research team generated electricity from Chicago Pile 1 at the University of Chicago. Zoe was the French equivalent. The ability to connect reactors to the electrical grid ushered in the first generation of commercial nuclear power stations.

Generation One: Soon after the war, France, the United Kingdom, and the Soviet Union moved ahead with their own experimental reactors, the largest of which became commercially viable in the 1950s. These reactors were precursors to the wave of Generation Two reactors that still make up the bulk of the world's nuclear fleet. Among the well-known plants in this group, all of which are now closed, are Indian Point 1 in New York (closed in 1974), Calder Hall-1 in Northern England (1957–2003), and France's Fessenhem 1 (also known as EDF-1), which was decommissioned in 2020.

Generation Two: Entering service beginning in the late 1970s, these were larger and generally more standardized designs than their Generation One predecessors, though the fragmented nature of the U.S. utility sector led to less standardization there. Most of the world's existing reactors power Generation Two plants. These mostly commenced operation with a 40-year planned lifespan but were typically extended to 50 or 60 years. The most famous nuclear accidents—at Three Mile Island in 1978 and at Chernobyl in 1986—involved Generation Two reactors, as did the 2012 Fukushima disaster.

Generation Three: These latest designs include significant safety and operational innovations gleaned from decades of operating experience with Generation Two plants. For instance, many have a "core catcher," a pre-positioned abyss that a reactor core would fall into if it ever became molten. This gives the reactor a "passive cooling" ability that engineers designed to preempt the kind of disaster that took place at Chernobyl. While still scarce, Generation Three plants are operating in China, Russia, and South Korea. And more are under construction, including in China, Finland, France, and the United Kingdom.

Generation Four: These designs, still on the drawing board or in small test beds, will stress sustainability and a closed fuel cycle. These include sodium fast reactors, molten salt reactors, and very-high-temperature reactors, which allow for the use of carbon-neutral fuels. None will likely be in commercial use until the late 2030s.

United States, Russia, China, and emerging technology leaders like South Korea, appear determined to export Generation Three technologies that they say will make good on the deferred, decades-old promise of harnessing the atom to produce safe, efficient, carbon-free energy.

Yet France's effort to leap forward with its EPR reactors shows how reality will be more difficult than rhetoric. So complicated has it proven that the French government, which owns 84 percent of the nuclear operator EDF, has decided to begin the process of nationalizing it to shield it from the share price hit that every setback to innovation inevitably brings.

Indeed, in a few decades, the question may not be whether a private or public entity should run the show but rather whether mega-plants of the kind being built in Flamanville are the way forward. Generation Four plants will bring new ideas, among them small, modular plants based on the reactors that have powered warships since the launch of the USS Nautilus in 1954. Should they take hold, Flamanville 3 and its ilk could be viewed as dinosaurs, less a great leap forward than a still-born third generation that gives way to more radical and sustainable designs.

> Breaking a democratic nation's dependence on fossil fuel imports poses challenges, but not body blows. The same cannot be said of the world's fossil-fueled autocracies.

That nuclear power will remain controversial in many circles is undeniable. Even the most fervent evangelists for nuclear power will not claim to have solved messaging around the public understanding of risk. Accidents that lead to an uncontrolled release of radiation, for instance, or the question of what to do with their deadly byproduct, nuclear waste, are still ever-present in the discourse. Warfare like that in Ukraine, which has imperiled an active nuclear power station, is yet another. The main defense against charges that nuclear plants are dangerous is in risk calculus: If nuclear plants have, occasionally, threatened to cause widespread contamination and death, those outcomes have largely been avoided to date. And while deaths among nuclear power workers certainly happen, they pale compared to the 100,000 deaths annually in the United States alone that the National Academy of Sciences attributes to particulate matter and other pollution related to fossil fuel consumption.

Opponents of nuclear power took heart when Germany at first refused to buckle to international pressure (and some might add, logic) and extend the life of its nuclear plants rather than burn coal to address an energy crisis. Fervent opposition to nuclear power, intermingled as it is with social activism of the 1960s, as well as anti-nuclear-weapons protests and emotional pleas for a return to a simpler, more agrarian way of life, will not be dislodged easily—especially not by risk assessments, however favorable.

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The conclusion of the latest chapter in nuclear power is not written, but the emergence of climate change as an existential concern has certainly changed the game. The pro-nuclear argument has clearly gained ground. The relevance of nuclear power to the fight against global climate warming is a major driver of this change, and polls tend to show that inflexible opposition to nuclear power skews older in demographic terms. It may be that the coming generation, with its unbridled faith in everything technological, can live with the atom, too.

But another factor should not be underestimated: the convenient alignment of enemies that nuclear power creates. Breaking a democratic nation's dependence on fossil fuel imports poses challenges, but not body blows. The same cannot be said of the world's fossil-fueled autocracies. The less natural gas imported to run turbines, the fewer dollars that flow into the Sovereign Wealth Funds of Nigeria's kleptocracy, the dictators of Angola and Equatorial Guinea, the Gulf monarchies and, of course, Russia. Calculating risk and reward, in business, in geopolitics or in life, has spawned a cottage industry of consultants, academic programs, and psychologists geared toward getting the balance just right. But adding the potential of nuclear power to lengthen the habitability of planet Earth tips the scales toward a new embrace of the atom. Seen in this larger context, nuclear power, faults and all, appears indispensable as a part of the difficult transition to Net Zero.

FEATURES

03

ATOMS AND INFLUENCE

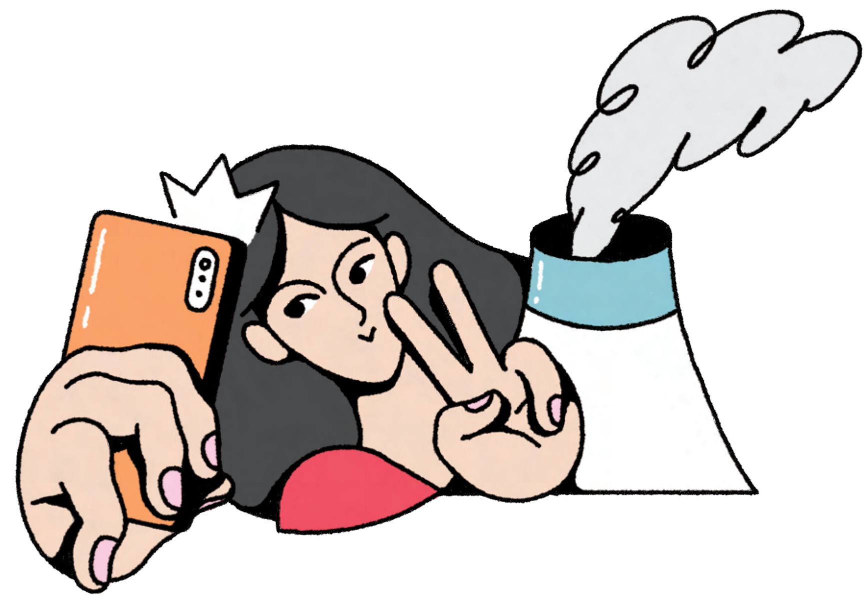
The drivers of nuclear innovation, from light bulbs to TikTok

SONAL PATEL

When *POWER* magazine, where I am an editor, launched its first issue in 1882, the world was only beginning to grasp how electricity, a new and versatile form of energy, could revolutionize human life. Since then, the magazine's pages have reflected the rapid evolution of the technologies and markets that have characterized the world's power sector.

Yet a recent attempt by the magazine's editors to parse that evolution into a clear chronology—from the invention of the light bulb through the rise of today's nuclear influencers, such as Isabelle Boemeke, or Isodope, as she's known on TikTok—proved nearly impossible.

The assignment set out to capture the power sector's most significant breakthroughs in the hopes of providing historical context for today's energy transition. But what it revealed was an unruly treasury of technology breakthroughs fueled by policy intervention, environmental and safety concerns, shifting market expectations, and ambitious ideas. Attempts to even organize those tales into a particular thread—for example, the history of steam, or coal,



or natural gas, or hydrogen—was just as tangled, always driven by pressures and tumult within any number of interconnected areas.

And while every one of the 13 decades that *POWER* magazine has been in print has been definitive for electricity generation technology, policy, and business in some significant way, few have been as transformative—or as jumbled—as the last.

The power industry has grappled with multiple disruptions, including decentralization and electrification, a boost in shale gas production, a proliferation of renewable power and battery storage, an increasing embrace of digitization, and greater consumer interest in—and concern about—where their power comes from. Each one of those developments has been complicated and nuanced in its own right—to say nothing of the myriad ways in which they've combined.

Even so, it is important to try to zoom out from time to time, and especially when it comes to nuclear energy, which is today enjoying a revival championed by grassroots climate advocacy, including the new nuclear influencers, who focus solely on the benefits of reactors. Their work may push nuclear energy some way toward social acceptance, but if my colleagues and I have learned anything of late, it is that only by finding where all the threads of all the energy stories weave together—and where they leave gaps—can we identify the real opportunities to push innovation and collaboration further.

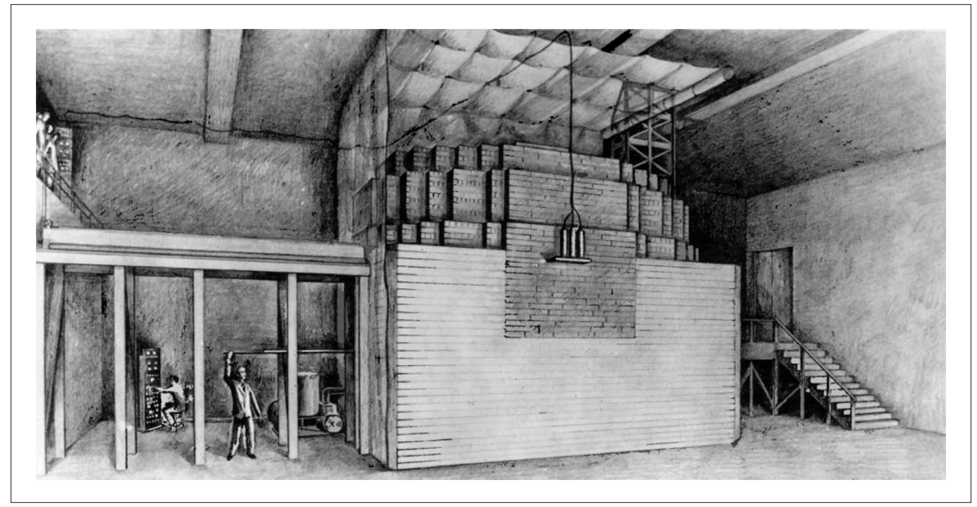
A History of Breakthroughs

Innovation in other sciences has driven a good chunk of nuclear energy's history. Although the concept of the atom was fairly well-developed when *POWER* released its first issue, scientists had not yet figured out how to harness the energy contained in atoms. Just 13 years later, though, in 1895, the accidental discovery of X-rays by German engineer Wilhelm Röntgen started a wave of experimentation in the atomic field. Close on his heels came French physicist Antoine Henri Becquerel, who discovered radiation. Then Marie and Pierre Curie conducted their radiation research and coined the term "radioactivity." Ernest Rutherford, a New Zealand-born British physicist who many consider the father of nuclear science, postulated the structure of the atom, proposed the laws of radioactive decay, and conducted groundbreaking research into the transmutation of elements.

In the decades that followed, with a base understanding of atomic principles established, wilder discoveries took center stage. In 1934, Italian physicist Enrico Fermi showed that neutrons could split atoms. Two German scientists—Otto Hahn and Fritz Strassman—expanded on that knowledge in 1938 when they discovered fission. Scientists then turned their attention to the puzzle of developing a self-sustaining nuclear chain reaction. In December 1942, a team led by Fermi demonstrated the world's first nuclear reactor, Chicago Pile-1, transforming scientific theory into technological reality. And so the world was launched into the nuclear age.

From there, most early atomic research focused on developing high-power reactors to produce plutonium fuel for nuclear explosives as part of the Manhattan Project. But after the end of World War II and the deployment of the first nuclear weapon, Congress passed the Atomic Energy Act of 1946, which transferred the development and production of atomic weapons—as well as budding research and development projects for civilian uses of nuclear energy—to the civilian Atomic Energy Commission (AEC).

The same year, the Manhattan Project began developing a pilot "pile" or plant for nuclear power at Oak Ridge, Tennessee, intending to harvest heat energy at a conventional central station for steam electric generation. And in 1947, the AEC proposed and funded four new reactors that would make use of enriched uranium, which was then newly available: a fast



A drawing of Chicago Pile-1.
Source: Argonne National Laboratory.

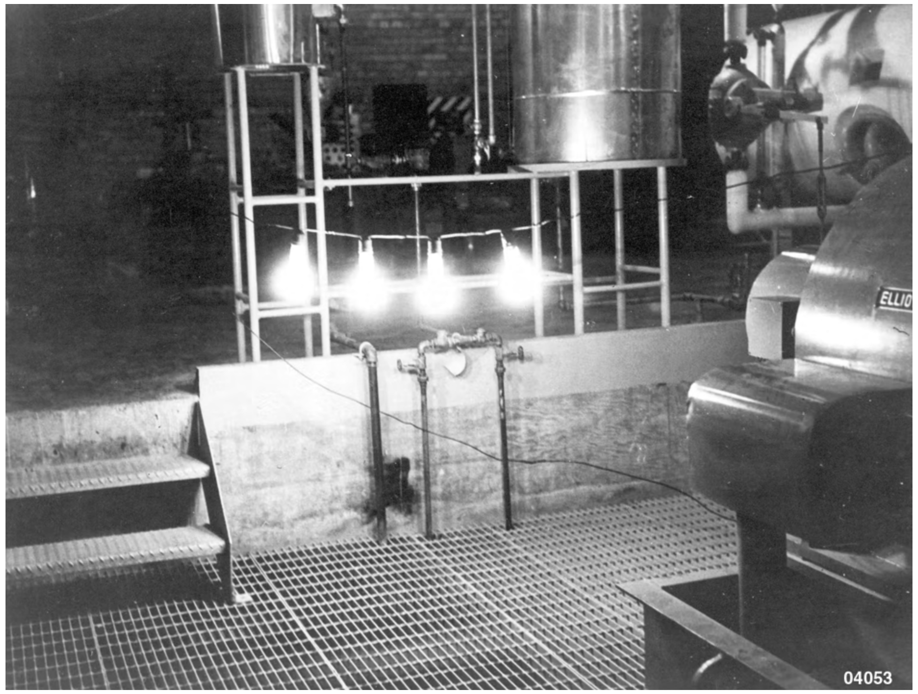
reactor to explore the fuel "breeding" possibilities; a navy thermal reactor that would serve as a prototype for submarine propulsion (now known as STR or S1W); a materials testing reactor; and the Knolls intermediate reactor.

Three were developed at the National Reactor Testing Station (now Idaho National Laboratory, or INL), which was established in 1949 on an 890-square-mile desert site. Its mission was to develop civilian and defense nuclear reactor technologies and manage spent nuclear fuel. Over its long history, INL, now a U.S. Department of Energy laboratory, has hosted 52 pioneering nuclear reactor projects. In 1951, its first, Experimental Breeder Reactor-1, became the first reactor to generate usable amounts of electricity.

Or, at least, that is the most straightforward and linear plotting of the story.

Nuclear Ideals Meet Geopolitical and Economic Realities

Of course, the real story of nuclear can't be told without the race between the United States and Soviet Union to establish domestic nuclear defense capabilities while also cornering the market on nuclear energy. In the Soviet Union, scientists modified an existing graphite-moderated channel-type plutonium production reactor for heat and electricity generation. In June 1954, that unit, located in Obninsk, began producing electricity. A few years later, in 1957, the first commercial U.S. nuclear power plant—Shippingport Atomic



Experimental Breeder Reactor-I generated electricity to light four 200-watt bulbs on December 20, 1951. This milestone stands as the beginning of the nuclear power industry.
Source: DOE

Power Station, a light-water reactor (LWR) with a 60-MW capacity—was synchronized to the power grid in Pennsylvania.

While Shippingport's success marked a major starting point for the commercial viability of nuclear power in the United States, nuclear's adoption, as with other early power technology designs, stemmed partly from unanticipated events and some path dependency. Shippingport's most prominent legacy was perhaps to deliver a stronghold for the LWR, which remains the most widely used design of nuclear power generation.

LWRs use ordinary water as both the coolant and the moderator for a controlled nuclear reaction. The technology is split into two basic types: pressurized-water reactors (PWRs), which keep water under high pressure and achieve high temperatures without boiling in the primary system, and boiling-water reactors (BWRs), which generate steam directly. Both types produce steam to drive power-generating turbines.

Some power industry historians posit that the LWR triumphed over several other reactor designs because of technical and economic advantages. General Electric, for example, spearheaded the commercialization of the BWR because the design was seen as the least risky available alternative.

But initial decisions set the playing field for later ones. To encourage investment in the costly new technology by risk-averse utilities, the AEC subsidized an extended a series of demonstrations between 1953 and 1960 under the Power Reactor Demonstration Program (PRDP). While the program included reactor types other than LWRs, the PRDP did not provide sufficient assurances about cost competitiveness for any nuclear models. That led to a period in which the government had to subsidize construction and demonstration, including underwriting research, development, and design costs; government ownership of the reactor became common; and fuel allowance clauses were par-for-the course.

Cost concerns prompted General Electric and Westinghouse to offer reactors with larger generating capacities. Initial acceptance, starting with the Oyster Creek plant in New Jersey, eventually laid the foundation for the first turnkey plant contracts—characterized by vendor offers to construct and guarantee plant operability at a fixed price.

Critical to these sales was the assumption that nuclear plants could compete on cost with fossil fuel plants. But by 1966, when the first 25 nuclear plants had been deployed, capital cost investments were still roughly twice the initial estimates at purchase.

That looked like trouble for nuclear, but then came a sharp surge in coal prices later in the 1960s, alongside the establishment of a concerted and expanding grassroots environmental movement. By the early 1970s, nuclear innovation began a ramp-up to meet market demand for fuel diversification. Fuel diversification during and after the oil crisis in 1973 offered another lucrative avenue for nuclear. Through it all, accidents—prominently, Three Mile Island in 1979, Chernobyl in 1986, and Fukushima in 2011—reshaped design innovation, spurring safer designs for reactor and fuel technology.

Nuclear Nationalism

Around the world, as in the United States, a healthy dose of scientific nationalism was overlaid on the economic factors driving (or stalling) nuclear innovation, particularly in the United Kingdom, France, Germany, and Canada. Domestic designs still comprise the bulk of these countries' nuclear fleets. Canada, notably, chose to pursue a version of a pressurized heavy-water reactor (PHWR) called the CANDU (Canadian Deuterium Uranium), owing to the country's abundance of uranium but lack of uranium enrichment resources. The conservative technical approach paid off in later years, given major changes in world fuel economies that made PHWR costs attractive and because CANDU fuel did not require reprocessing.

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Meanwhile, technology uptake in several other countries evolved from technology transfer from vendors abroad into domestic development. That includes PWRs in France, Japan, South Korea, and China and BWRs in Japan. In these countries, governmental drive and international collaboration proved essential for the success of nuclear development. How future generations of reactors—which promise to be highly economical and digitally capable while incorporating enhanced safety measures, producing minimal waste, and being resistant to proliferation—will fare will depend on a number of emerging factors, including economics, market viability, and their precise application in any given country.

According to the International Atomic Energy Agency (IAEA), 437 nuclear power reactors, a combined 389.5 GW(e), were in operation at the end of 2021—making up around 11 percent of the world's global installed power capacity. The world's fleet mainly comprised pressurized-water reactors (PWRs), boiling-water reactors (BWRs), pressurized heavy-water reactors (PHWRs), and Soviet light-water gas reactors (LWGRs). A smaller fraction of the world's fleet comprises gas-cooled reactors (GCRs) and fast reactors. High-temperature gas reactors (HTGRs) have been under development since 1947. Although a handful have commercially operated at one time or another, only one (in China) is currently in trial operation.

Innovation Is a Fine Balance

Innovation in the nuclear industry still relies on a complex set of factors—many of them unchanged since nuclear power's inception 80 years ago.

The nuclear industry continues to be a vast amalgam of utilities and power plant operators, R&D performers, regulators, technology vendors, and fuel providers. Over the past few years, this set of key players has absorbed policymakers, as well as the rapidly expanding realm of climate change advocacy and, most recently, influencers.

Since 2020, a consensus has solidified around the idea that energy-related decarbonization cannot occur without nuclear energy. But boosting nuclear is easier said than done, since decisions affecting nuclear innovation intermingle climate goals, technological advancement, legislation, makeup of the existing power structure, domestic concerns, and national ambitions, including prestige, national security, and energy independence.

Policymaking has to think of all that, and rely on laborious policy direction, including sound visioning and planning practices and proper evaluation and oversight mechanisms. Policymaking may also bear on nuclear legal frameworks, which include regulatory constraints related to health and safety regulations.

> Messaging that has mostly highlighted the inevitable continued reliance on fossil resources if nuclear plants are shuttered—and that mainly underscores nuclear power's carbon-free and reliable operations—has not done much to push the needle.

All these influences are then laid over what some in the industry deem the "realistic" drivers of innovation. One is market demand, which all power-generating technologies have had to respond to in some way or another since the birth of the electric generating industry.

In the United States, power companies and utilities have played an outsize role in bolstering demonstration or supporting nuclear technology advancement. While power company financial outcomes have historically determined where investments are prudent, the sector is currently grappling with a long list of energy transition–related risks, foremost among them reliability, resilience, and environmental compliance.

Ultimately, however, innovation driven by the power sector also relies on the availability of qualified personnel and access to research and development facilities and knowledge. It thrives on organizational culture for innovation. While aligning these factors won't likely be immediate, change is undoubtedly afoot.

Driven by the urgency of keeping the nuclear sector relevant in the push for decarbonization, the industry's biggest asset today may be multi-armed campaigns to underscore the power resource's role within a larger, and rapidly changing, power system and within society.

Messaging that has mostly highlighted the inevitable continued reliance on fossil resources if nuclear plants are shuttered—and that mainly underscores nuclear power's carbon-free and reliable operation—has not done much to push the needle. Of course, these messages are not wrong, but by focusing on one narrow dynamic within the power system, they miss the complexity behind what's gone right—and wrong—so far. After all, power is a terribly complex integration of resources, processes, and output.

Ensuring nuclear's future will thus require appealing not just to needs in the moment but recognizing nuclear energy's complementary contributions for the long term. That includes its capabilities for more agile and flexible power, its applications for industrial heat production, its benefits for industrial electrification, the promise of nuclear hybridization with energy storage and renewables, and even the possibility of distributed energy from "micro" reactors.

All of these messages are perhaps too much for one spokesperson, influencer, or chronology. But it is the truth.

IT TOOK ALL MY ENERGY

It took all my energy to want you
and the rest of me to go after you
and then one day I knew
that I had you.
I was standing at the sink rinsing dust
from a bunch of grapes.
All my energy had been spent
pursuing you and then I had you
and then
I sat down at the kitchen table and ate the grapes.
The day was hot, that day
when I knew I had you. The man
in the house across the street
was cursing his wife.
An hour later I went to see about a job,
and the woman behind the desk
with her gold spectacles
caused me to remember that I had you.
Outside the sky was blue as a china plate.
There is nothing to do
on a day like that
but go to the beach. I caught three fish,
black and heavy as paperweights.
After the third I stopped to clean them in the ribboning surf,
three black fish flecked gold as the capes
of Egyptian kings,
strong swimmers, broad across the backs.
I slit the bellies, tossed the guts and roe
to the waiting gulls, cut the heads off slant
and lay them one by one on the gurgling sand
while I thought of you. Three small boys
picked them up
and carried them away,
holding them aloft as if on pikes.
Even as I fry these fish I think of
their heads against the sky
while the birds worked on a patch of sea
on the lee side of a sand bar that split the water
like the broken spine of a ship,
and as I turn these fish in the pan
I think of the day when I knew I had you,
and then the next, and then the day after that.

— *Tony Wallace*

FEATURES

04

WE NEED A NUCLEAR NEW DEAL

And the Tennessee Valley Authority is the perfect utility to manage it

FRED STAFFORD

UNDER A CLEAR BLUE SKY, ON OCTOBER 19, 2016, THE TENNESSEE Valley Authority (TVA) became the first—and still only—American utility to bring a new nuclear reactor online in the 21st century. The moment was decades in the making; although construction on Watts Bar Unit 2 had started back in 1973, the project was put on ice in 1985 once the aftershocks of the 1970s energy crisis abated and demand for electricity slowed once more. It wasn't until 2007, in the face of rising power needs, that the TVA resumed constructing the plant.

On the nuclear reactor's first day of operation, TVA's chief executive shared an outlook that matched the blue sky. After the long process of building the plant, "we set off on a new journey, a 40-year minimum journey, maybe longer, of reliable, low-cost electrical power for people of the region." Since that speech, this one reactor in eastern Tennessee has generated almost as much carbon-free energy as all the wind turbines and solar panels in New England combined. In fact, TVA's entire nuclear fleet of seven reactors, with a total nameplate capacity of about 8.5 GW of power, has generated more over that period than the approximately 34.2 GW of intermittent power that California's great wind and solar industry has brought to market, and with only a tiny fraction of the land (and rooftop) footprint. Moreover, unlike much of New England and California's green energy installations, all that TVA nuclear power is publicly owned, generating energy at cost, not for profit—and not for Wall Street, which federal tax credits for "green energy" were set up to enrich. That's a lot of clean public power.

Despite this public enterprise's demonstrated capacity to invest in and build clean infrastructure—and in a more conservative part of the country at that—American politics seems woefully incapable of recognizing TVA's potential as "big public power."

Now, with the passage of the Inflation Reduction Act (IRA)—which breaks with decades of tradition by extending federal clean-energy subsidies to public power systems—it's time to revive that older American tradition. We need a new bipartisan politics of nuclear-powered decarbonization, and TVA should be front and center.

A Century Since the New Deal

Former U.S. President Franklin D. Roosevelt established the TVA in 1933 as a government-owned corporation that would develop the impoverished, rural Southeast with massive public works focused on the Tennessee River system. A source of devastating floods, the river would instead be harnessed for the public good, and its electrical potential in particular would be tapped for the modernization of the area's residents and economy. It was a crown jewel of the New Deal—one of the few to endure to the present day.

Still the nation's largest public power system, the TVA today operates a grid cleaner than neighboring market-based grid areas MISO and PJM, according to EPA data, and it provides power at cost for 10 million people. That's thanks to TVA's legacy hydropower infrastructure and, in particular, its seven nuclear reactors that churn out four times more clean energy than its hydroelectric sites.

These days, Roosevelt's crown jewel seems more like a forgotten relic. From the 2016 presidential election that took place three weeks after the activation of Watts Bar, to the 2018 Green New Deal resolution of Senator Ed Markey and Representative Alexandria Ocasio-Cortez, to the 2020 presidential election, all the way to the Inflation Reduction Act (IRA), U.S. discourse around green energy has been changing, and yet the TVA's potential for clean public power goes mostly unnoticed.

> The success of the TVA deserves political attention. After all, its originator, Roosevelt, won elections in part on the promise that the federal and state governments could produce cheap power themselves.

Instead, our contemporary politics of decarbonization, as voiced by Conservatives and Liberals alike, sees the government's role as merely coaxing private investors in certain directions, say, with federal tax credits. Last year, *Damage* magazine described such policy-making as "the invisible hand of the state," in which government is merely "a referee who will occasionally assist the players but never partake in the game itself." The IRA exemplifies exactly this approach by appropriating hundreds of billions of dollars as lucrative tax credits to entice private investors into building clean energy infrastructure. Thankfully, though, the law also breaks decades of tradition by finally making public entities like the TVA eligible for some of these tax credits—a development *The American Prospect* has deemed "a quiet revolution on public power."

Yet the success of the TVA deserves even more political attention. After all, its originator, Roosevelt, won elections in part on the promise that the federal and state governments would produce cheap power themselves. "Electricity is no longer a luxury. It is a definite necessity," Roosevelt declared in a landmark 1932 campaign speech to a packed audience in Portland, Oregon. At the same time, he castigated private utilities for fraudulent practices and for underinvestment in electrification. ("Judge me by the enemies I have made," he implored in the same speech.) His enormously popular New Deal coalition delivered the TVA, and then the Bonneville Power Administration in the Pacific Northwest, as a direct government investments in public infrastructure, aimed at electrification lower prices. Back then, the state had a very visible hand, and a popular one at that.

On the national stage, there has been only one player with much interest in replicating the TVA model for clean energy infrastructure: Senator Bernie Sanders. In his 2020 presidential campaign, he attempted to rekindle its New Deal vision. Echoing the "Green TVA" proposal from the People's Policy Project, the Democratic Socialist Sanders called for "expanding the existing federal Power Marketing Administrations [and TVA] to build new solar, wind, and geothermal energy sources."

Unfortunately, that plan suffered a tremendous drawback: Whereas the broad goal—clean, cheap, publicly-held energy—was laudable, its precise energy mix—100 percent renewables by 2030—was fantastical. To meet that goal, the plan proposed drawing down not just fossil fuels but clean nuclear power. It included a moratorium on license renewals, which would cut short Watts Bar's decades and decades of projected life, and even new plant construction. Progressive climate wonk Leah Stokes called the proposal "very expensive and very technically difficult" without nuclear, and Nick Loris at the Conservative Heritage Foundation opposed it, arguing instead for market competition. In the end, of course, Sanders' campaign for president was unsuccessful, leaving the policy proposal just that. Later invocations of the Green New Deal abandoned his focus on the New Deal's big public power.

Good for Clean Energy, Bad for Investors

For a modern industrial society, nuclear energy presents many benefits.

In the United States, nuclear accounts for one-fifth of the nation's electricity—just behind coal, and about half as much as natural gas—and it's a solid half of our clean electricity. The sector churns out clean energy around the clock, no matter the weather. Its fuel is not a volatile global commodity, like the liquefied natural gas supplies disrupted by the war in Ukraine.

Its massive steam-powered turbines provide critical inertia for the power grid. Its intense heat offers an irreplaceable input for industrial processes like the production of hydrogen—which can be used as a clean fuel.

Particularly important for the nationwide politics of decarbonization is nuclear energy's minimal land use. According to recent research, the land-use intensity of nuclear generation is 100 times lower than that of ground-mounted solar, and more than 1,000 times lower than that of wind turbines, when counting the land between turbines, but without even considering all the transmission lines needed to connect turbines to cities. Critics of nuclear highlight long, difficult fights for plant permits, but the task of acquiring 1,000 times the land area for wind turbines—plus property rights and environmental permits, as well as winning over local opposition—sounds more like a game of SimCity than a democratic political program.

Finally, nuclear infrastructure is long-lasting and demands large, permanent workforces of highly skilled labor ripe for unionization. Anywhere from 500 to 1,000 people work at a conventional nuclear plant, not to mention all the additional "induced" jobs that pop up in the towns around a nuclear plant to support its workforce, and that plant can last more than half a century. Attracting local support for nuclear projects with these good jobs might prove easier than it is for wind and solar projects that offer essentially none for the local working class after construction.

With all those reasons to invest in nuclear power, why isn't the market doing exactly that? Why is it that the federal government, through the TVA, is the only entity that's so far managed to turn on a new nuclear power plant in the 21st century?

In short, it's because capitalists—the private investors with the power to decide what gets produced in "the market"—haven't seen a strong enough guarantee of returns on investment in nuclear plants. Plants like Pilgrim in Massachusetts and Oyster Creek in New Jersey have recently closed because they aren't earning high-enough profits for shareholders. Analyst Edgardo Sepulveda shows that privately-owned reactors have fared worse than publicly-owned ones over recent years. The total capacity of the former has declined, while that of the latter has risen slightly due to plant upgrades.

After waning for decades, the 2000s seemed to usher in a "nuclear renaissance" of private investment in nuclear power, with as many as 31 new reactors having been proposed. The

Energy Policy Act of 2005, for example, signed by former U.S. President George W. Bush, mitigated some of the investment risk of nuclear plant construction through new federal loans for construction and a production tax credit like what had long been available for renewable energy projects. As part of a public power system with no tax bill, however, TVA's Watts Bar Unit 2 wasn't eligible for the latter; since such benefits were only for new plants, and there haven't been any, no plant ever got them.

By 2017, only two modern reactor projects were left standing—that is, under construction: the private utility Southern Company's long-delayed, over-budget Vogtle Units 3 and 4 in Georgia. "No one involved seemed to fully appreciate just how difficult it would be to build new reactors," the *Financial Times* reported, "especially the AP1000—a 'first of a kind' design—when much of the industry's experience and capability for managing such large nuclear projects had been lost." Reusing the design, licensing, and even some of the construction crew to repeat the installation for new nuclear plants would go a long way to lowering the costs—that is, if anyone ever dared to invest in doing so.

> Why is it that the federal government, through the TVA, is the only entity that's managed to turn on a new nuclear power plant in the United States in the 21st century?

"Capitalism irrationally constrains what we have," writes Socialist science writer Leigh Phillips. "It limits production to the set of things that are profitable, while the set of things that are useful is much larger." Nuclear power seems to be a case in point.

Electricity Deregulation Reshapes Markets, and Nuclear Suffers

But why have the projects been so bad for investors? Increased construction costs, due to expanding regulatory demands for example, played a part in the withering of nuclear investment. The general perception of major risks after the Fukushima disaster contributed too. But the real culprit, the one also causing owners to close existing plants, lay in the inability for investors to guarantee profitable returns over the long—very long—lifetime of a plant after that pricey construction.

The Great Recession hit shortly after the nuclear renaissance was announced, causing electricity demand to stagnate. "It was the first time in the 60-year data series … that electricity use fell in two consecutive years," the federal Energy Information Administration stated in 2010. And thanks to the rise of fracked natural gas, electricity prices remained relatively low as well. Both factors undermined the case for nuclear investment. An electrified politics of clean energy investment—for decarbonization, for energy security, and for new industrial development—had not yet gripped American politics to the extent it has today, when it has bolstered future demand for reliable, clean electricity.

But something else was perhaps more important than stagnant demand. For the last several decades, a bipartisan wave of electricity restructuring, generally known as "deregulation," rocketed around the United States, beginning in the 1970s and later picking up speed. Conceived out of an ideology of efficient markets and the awesome power of consumers, deregulation fundamentally remade electricity markets in much of the country, as did the same spirit in sectors like trucking, air travel, and telecoms.

> All this goes to show that in capitalist practice, the prospects for nuclear are leashed to the volatile, unpredictable swings of fossil fuel prices.

In the restructured markets, generation assets would no longer be built by monopoly utilities that also owned distribution systems and collected state-regulated revenues from retail customers, but instead by "merchant generators" that compete in intricately-designed exchanges. These exchanges would be set up to reward either assets that can generate energy passively, without operational costs, like wind and solar generators, or assets that can "flexibly" react to those passive generators on demand, like energy storage and generators powered by waste and natural gas. Investments in the former were incentivized by the design of the exchanges, by governments, and by corporations seeking green credentials, while investments in the latter offered safe returns because of how well they complemented the former. When the wind is blowing or the sun is shining, renewables outcompete the rest, while natural gas flexibly picks up where they left off.

As a result, infrastructure that serves as a constant, firm source of power, like nuclear and coal plants—which aren't easily ramped up or down, and therefore require continuous operation—have struggled to compete in the exchanges. It doesn't matter that nuclear energy is carbon-free. The incentives set up by deregulation reward renewables and flexibility instead.

"Natural gas is queen right now," a major nuclear executive proclaimed to the Conservative American Enterprise Institute in 2011, back when natural gas prices had plummeted after a long climb. "The price of natural gas sets the price for electricity in a number of the competitive regions in the country … So the output of my nuclear plants has greater or lesser value depending in part on the price of natural gas."

Since last year, the price of natural gas in the United States has been surging once more, partly because of supply chain issues around the world related to Russia's invasion of Ukraine. "There's nothing like an energy crisis to make nuclear look really good," as the CEO of a clean-energy think tank told *E&E News* earlier this year. In Europe and in Asia, too, skyrocketing natural gas prices are helping make the case for new nuclear investment.

All this goes to show that in capitalist practice, the prospects for nuclear are leashed to the volatile, unpredictable swings of fossil fuel prices, particularly of natural gas. And in large part, that's the result not of government regulation and subsidies in favor of renewables or against nuclear, but of electricity deregulation—a historical project of the investor class itself aimed at making the most money for the least expenditure. Large industrial customers sought the ability to play the market for their power purchases, and they got it. Fast forward a few decades and corporate behemoths like Amazon have become the leading agents of investments in (renewable) energy.

To be sure, with all that natural gas and renewable generation replacing coal in much of America's grid, there's been a material, positive impact on the air and the environment since deregulation started. But, in theory, shouldn't it also have resulted in lower prices for consumers? "Contrary to the objectives of deregulation," argue researchers at MIT and Harvard in work published this summer, "prices increased in deregulated markets." The efficiency gains it produced were gobbled up by the investors, not transferred to consumers as lower retail prices—or at least not residential consumers. Federal data shows that, since 2001, average residential prices have slightly increased, while average commercial and industrial prices have indeed decreased, after accounting for inflation.

Deregulation brought flexibility but also enticed investors toward safer investments in smaller-scale power, away from nuclear plants. Because they're "long-term assets in a short-term world," nuclear economics consultant Edward D. Kee has argued, nuclear plants are "a poor fit with wholesale electricity markets." In a 2016 analysis of energy market failures, one solution he proposed is direct government ownership of struggling plants, "as in France, China, South Korea, Russia, and the United Arab Emirates." France, for example, has its original nuclear utility EDF (Électricité de France), which Paris recently moved to renationalize. But what could possibly play a similar role in the United States?

The answer might be staring us right in the face, or at least those of us bothering to look ahead: the TVA.

What Would a Nationwide Nuclear TVA Look Like?

"Just as the TVA was used to achieve the electrification goals of the first New Deal, it should be used to achieve the (carbon-free) electrification goals of the Green New Deal." That sentiment formed the basis of the 2019 Green TVA report from the People's Policy Project, which Sanders' 2020 campaign later incorporated into its Green New Deal plans.

That high-level idea was never fleshed out in detail, and the call hasn't been picked up by any politician since. But it should be. Here's what it would mean to put TVA front and center of a new national politics of nuclear-powered clean industrial development.

The first big question for a TVA National Nuclear Program would be, Who will use all that new power? It's one thing to project that, nationwide, we'll need a three- to-fourfold increase in electricity generation for economy-wide decarbonization, as Princeton's landmark Net Zero America study does; but it's another to build the new capacity and demand in tandem. Rather than tossing subsidies to private investors and hoping the market works it out, a TVA National Nuclear Program could strategically direct resources, with two core purposes.

First, it would direct the process of building new nuclear plants so that such development can restart in the United States, as in China, Finland, and South Korea. The domestic capacity to carry out such projects—in licensing, in construction, in management—requires experience and practice, something TVA has. Perhaps most importantly, building requires the kind of coordination and political will that state-owned enterprises have traditionally offered nuclear development in many countries.

Second, the nuclear plants built by this program would produce reliable, constant electricity or heat, both of which could be used as input in all kinds of new industrial facilities. Between the Bipartisan Infrastructure Law and the IRA, there will be a wave of investment in research and development in clean industrial technology, like hydrogen fuels and direct air capture of carbon. The Department of Energy is already working on two programs to create regional hubs for each of these two technologies. And due to subsidies in the IRA, private investment for new mining and manufacturing facilities—needed for clean energy—should be forthcoming. Those facilities will surely demand intense amounts of power.

> The first big question for a TVA National Nuclear Program would be, Who will use all that new power?

In addition to its service to national industrial policy, the power from new plants in a TVA National Nuclear Program could be used to supply TVA's existing customer base as well. Municipal utilities could have more electrical potential for decarbonizing infrastructure, like electric-vehicle charging and electrified heating. Or TVA could potentially reduce generation—and therefore fuel costs and emissions—in some of its combined-cycle gas plants. Building out the TVA's nuclear capacity could enable the authority to retire its last coal plants, and perhaps even obviate TVA's current plans to build more natural gas infrastructure.

The second big question for a TVA National Nuclear Program is, Who's going to pay for it? Here, the answer might be a combination of direct federal appropriation—not unlike those that have "paid for" various energy tax credits for decades, now ramped up in the IRA—and TVA bond debt. The latter is how TVA has financed its power program for over half a century: by issuing bonds that are repaid over long-term horizons using revenues from electric sales.

In the original days of TVA, the authority relied on federal appropriations to construct its dams and hydroelectric generators. In 1959, however, new legislation gave TVA the power to raise its own bonds, up to a certain debt limit, in order to finance its power program. To facilitate TVA construction, Congress increased the body's debt limit four times in the 1960s and 1970s, landing in 1979 on the present nominal value of $30 billion—a staggering amount at the time, worth over $100 billion in today's dollars.

According to its most recent Securities and Exchange filing, TVA has about one-third of this

$30 billion debt remaining to use. And that limit could even be raised by Congress; after all, the 1979 increase was intended to facilitate the completion of the (scaled-back) fleet of nuclear reactors that included Watts Bar Unit 2. Or perhaps TVA could be granted the authority to raise something analogous to green bonds, as the People's Policy Project proposed, to attract capital from investors seeking to meet so-called Environmental, Social, and Governance goals. That would likely rest on the challenge of legally to codifying nuclear power as "green"—an uphill battle, to be sure, but one recently won in Europe and Canada.

If TVA were to build new nuclear plants as a matter of national energy policy, then TVA's existing customers shouldn't be expected to foot the bill. The national aims of the program suggest that the federal government should pay for the fraction of new power allocated to new clean industrial development, while the normal TVA electric sales should pay for the fraction of power allocated to its existing system.

> TVA has enjoyed strong bipartisan support for decades. Attempts by former Presidents Barack Obama and Donald Trump to privatize or break it up were both soundly rejected.

Such an accounting split has precedent. The original TVA power program rested on the divided valuation of a key federal dam—built by the U.S. Army Corps of Engineers for the wartime production of nitrates, split between its navigational and hydroelectric purposes. The former purpose was a matter of national policy, while the latter was part of the TVA system, to be paid for by customers. The earliest TVA administrators applied clever accounting to ensure the latter portion was small, to the chagrin of private utilities but to the gain of its customers. That strategy could be applied again.

What's Keeping the TVA From Providing Power Nationwide?

Perhaps the greatest legal stricture on a TVA National Nuclear Program is what's called "the TVA fence." Established in 1959, the TVA fence was the solution to the problem that former President Dwight D. Eisenhower had, in 1953, called TVA's "creeping socialism"—that is, the use of federal money to subsidize a particular region of the country at the expense of others.

By freezing its geographical territory in statute—the fence—TVA would be prohibited from expanding and thereby snatching away yet more businesses hungry for its cheap power. The United States has maintained that fence ever since, along with protections for TVA's monopoly to supply power within it.

If the fence were removed and TVA could somehow build new nuclear plants anywhere in the nation, how would it market the power? In the closed TVA system, it more or less controls the resources in the grid; anyone looking for power has to go through TVA. But the rest of the country is a different story.

In particular, if TVA behaved as a merchant generator in a restructured market—like in New York, for example—how could it find customers for its new nuclear power? Would it sell into the wholesale markets, like other generation assets do, or find distribution utilities to sell to? How could it escape the same economic problems faced by other nuclear plants in such markets, where natural gas, wind, and solar generators eat into the potential revenue streams when gas prices happen to be low or weather happens to be favorable?

Perhaps new nuclear plants in this program could be restricted to the public power systems of the four federal Power Marketing Administrations, all of which sell power (mostly hydroelectric) from federal resources. Roosevelt created the first and largest, Bonneville, as part of the New Deal national policy of electrification and development in the wake of the Great Depression, like the TVA. These PMAs already have business relationships with a constellation of rural and municipal utility customers—ranging from Jonesboro, Arkansas, to Los Angeles, California—along with large industrial customers as well.

But what about the politics? TVA has enjoyed strong bipartisan support for decades. Attempts by former Presidents Barack Obama and Donald Trump to privatize or break it up were soundly rejected. But despite that solid base of support, TVA would draw many opponents if it pursued a new National Nuclear Program, and not entirely without reason.

First and foremost would be the investors and businesses that see it as unfair government competition, or perhaps "creeping socialism." Even though the IRA opens the door for public power in clean industrial development, the law also solidifies decades of political consensus that it's the private investors, not government or the TVA, who should direct our resources.

Then comes the environmental opposition to nuclear. As recently seen in the closure of New York's Indian Point and in the (thankfully failed) fight against California's Diablo Canyon, well-funded and highly litigious environmental groups actively try to stop nuclear power. As they have for decades, many liberal environmentalists insist only on renewable energy for new clean generation capacity.

TVA in particular has drawn the ire of liberals for its sluggishness on deploying renewable generation. Environmental groups and Democratic politicians blast the authority for planning to replace coal plants with natural gas plants rather than with renewables, battery storage, and incentives for residential rooftop solar. Though the feasibility of these opponents' proposed alternatives is questionable, TVA's often tight-lipped rationale hinders outside evaluation.

> To escape the same old game of coaxing private investors to act, we should instead return to the New Deal politics of public power. And although the recently passed IRA does perpetuate the former, it also opens new doors for the latter.

In a recent Senate hearing on TVA, the progressive Senator Ed Markey of Massachusetts had particularly intense words: "You guys figure out nuclear power plants, brag about it, but energy efficiency, wind and solar, eludes the scientists, eludes the management of the TVA. It is kind of disgusting, actually." The Green New Deal champion, like liberal environmentalist groups, made no mention of TVA's heretofore ineligibility for crucial federal subsidies.

To be sure, environmental opposition to the TVA is not without merits. A history of voracious coal power development more than half a century ago—the technology that made sense for scaling up public power in the 1950s and 1960s—created a difficult, messy legacy for TVA in the present. A 2008 coal ash spill at one of TVA's plants, along with its mismanaged aftermath, was an environmental disaster and national disgrace, leading to the deaths of dozens of cleanup workers from the toxic, radioactive coal waste. And today, TVA faces allegations of environmental racism for its handling of waste from a different legacy coal plant that would, if not relocated, threaten the Memphis, Tennessee, water supply. TVA's decades of accumulated nuclear waste, of course, have remained contained and safe.

The Way Forward

Today is not the 1970s, when nuclear power programs expanded and then came crashing down to earth with the energy crisis. The political call for decarbonization grows more palpable by the day, ensuring a steady demand for new clean electricity for years to come. That's the logical result of three different concerns, each with its partisans: the climate impact of greenhouse gas emissions, energy security in an increasingly volatile global economy, or strong union jobs and robust domestic supply chains.

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With this monumental task at hand, should we place our trust in the investors at the top of the pyramid to invest in what's socially needed, not just what's sufficiently profitable to them? That they won't simply eat up the gains for themselves instead of lowering prices for the masses? The connected experiences of American nuclear and electricity deregulation don't warrant much hope. Today, skyrocketing bills have left 20 million American homes facing utility shut-offs, while corporate profit margins across the United States are at levels not seen since the 1950s.

To escape the same old game of coaxing private investors to act, we should instead return to the New Deal politics of public power. The recently passed IRA perpetuates the former at the same time it opens new doors for the latter. In Roosevelt's original words, "a corporation clothed with the power of Government but possessed of the flexibility and initiative of a private enterprise" can directly plan, invest in, and build what we know we need, all for modern living and for clean industry, and all produced at cost, not for profit. The TVA could and should be at the center of it, to kickstart the national decarbonization effort in the American Southeast with revitalized nuclear power.

Instead of only seeing its warts, we should recognize TVA's enduring strength and potential. In a 1941 exhibit on the New Deal's crown jewel, New York City's Museum of Modern Art heralded its achievement: "Look at it, and be proud that you are an American."

FEATURES

05

NUCLEAR'S URANIUM PROBLEM

The history of extraction on Native lands shows what went wrong—and how to make things right

ARIEL GOULD

Nuclear energy currently supplies 10 percent of electricity globally and 19 percent in the United States, but nuclear generation could grow significantly in the coming decades to meet environmental and energy security goals. With that growth will come challenges, particularly when it comes to uranium supplies.

In comparison to extractive activities for oil, coal, and gas, the footprint of mining for nuclear is tiny due to the high energy density of uranium fuel. However, demand for uranium is expected to grow in parallel with demand for low-carbon energy. And the location of mining to satisfy that demand may shift; the United States currently imports almost all its uranium fuel and European countries are looking to reduce their reliance on Russian nuclear fuel.

Especially in the United States, the extraction of uranium has a troubled legacy. Uranium mining has often disproportionately harmed Indigenous communities and other marginalized groups. Historic mining left radon-emitting waste piles, dispersing radioactive particles and contaminating local water.

Such environmental degradation and public health problems are among the primary reasons that many environmentalists do not consider nuclear energy to be "green" or sustainable. It can be. But as I recently wrote in a longer report for Good Energy Collective, the environmental and public health impacts of new uranium extraction must be included in decision-making—and the federal government and other responsible parties must remediate legacy contamination.

How the United States Got 15,000 Abandoned Uranium Mines

A look back at mining's legacy in the United States is illustrative. Here, mining has a long history of boom and bust. The first boom began in 1849 and was centered around gold in California. One byproduct, though, was uranium ore, which was seen more as a nuisance than a treasure and was largely tossed aside. That started to change in the 1930s, with the discovery of nuclear fission and the realization that it could be harnessed for weapons. That led to the creation of the Manhattan Project in 1941, through which the U.S. government sought large quantities of uranium to build nuclear weapons.

After World War II ended and the first nuclear bomb was dropped, the government established the U.S. Atomic Energy Commission. The new commission helped prioritize the prolific leasing of new uranium mining claims on federal public lands through the

1872 Mining Law, which covers most all hardrock mining exploration on federally-managed and public land.

The law allows individuals to purchase titles to unappropriated federal land for a small fee if they "discover a valuable deposit" of minerals on the land, and then extract the useable resources and sell them royalty-free. It was an attractive deal; during the height of the uranium boom from the 1940s to the 1980s, mining communities saw their economies thrive and populations double.

> The Bureau of Land Management estimates that there around 15,000 abandoned uranium mines on federal lands. Cleanup can cost hundreds of millions of dollars and can take many years or decades.

But there was a problem. There is nothing in the 1872 law that prevents companies from abandoning their claims (and mining-related waste) when their operations are no longer profitable. Facing a mining bust in the 1980s, when nuclear became less popular due to the Chernobyl accident and the global price of uranium started to drop, companies and workers fled mine towns in droves, leaving behind hazards that linger today.

All told, the Bureau of Land Management (BLM) estimates there are 100,000–500,000 abandoned mines of all mineral varieties, with more than 52,000 on federal land. That total includes 15,000 abandoned uranium mines on federal lands. Cleanup can cost hundreds of millions of dollars and can take many years or decades. On average, from fiscal year 2008 through 2017, federal agencies spent about $287 million annually identifying, cleaning up, and monitoring abandoned hardrock mines on federal land. The estimate to clean up all abandoned mines of all types on federal public lands is around $50 billion.

Radioactive Contamination in Native Lands

Left-behind nuclear hazards are not spread evenly across the country, since most of the highest-grade uranium is located in Western states. And a large portion of those uranium deposits are on Native lands.

A case in point is the Navajo Nation, which borders New Mexico, Arizona, Colorado, and Utah. It opened its land to vanadium mining at the government's request during WWII. The Navy used vanadium as a waterproof coating for ships during the war, and the government told the Navajo people that the extraction of this precious resource would help young Navajo soldiers win the war.

In reality, vanadium was not Washington's true prize. Rather, the government was searching for uranium (or what the Navajo people call "Leetso," or "yellow dirt") for atomic bombs. From 1944 to 1986, miners extracted 30 million tons of Leetso from the Navajo Nation to aid federal programs to fuel nuclear weapons and nuclear reactors.

That mining done in those years wrought havoc. Although the detrimental effects were not initially understood in the 1940s at the beginning of the uranium mining boom, they were widely studied starting in the 1950s because of growing concerns that uranium mining could cause lung cancer.

The concerns were correct. In the early days, uranium miners extracted the metal without protective equipment or radiation monitoring, and mines were poorly ventilated, resulting in miners breathing in hazardous levels of radioactive particles daily. Indigenous mine workers and their families in the Navajo Nation suffered some of the worst impacts from mining, because mine supervisors and government officials failed to warn them of the radiation risks. According to a 2000 Health Physics study, uranium miners' lung cancer rate was nearly 29 times more than people who did not work in the mines.

To this day, large amounts of uranium mine waste on the Navajo Nation remain unsecured and migrate from abandoned mine sites through the wind into washes and tributaries, leading to surface and groundwater contamination. For example, although there are no uranium mines in the Sanders, Arizona community 80 miles from the Navajo Nation, studies have found evidence of uranium in groundwater and unregulated water sources tested in Sanders in 1986 and 1987 and again between 2003 and 2015. Livestock studies in the Navajo Nation have also uncovered uranium in the organs of animals.

So far, the EPA has received funding to assess and remediate 230 of the 523 mines on the Navajo nation and has invested as much as $5 million per year toward investigation, cleanup and technical support for Navajo government agencies.

This story is familiar to some tribes. The Lakota Tribal Nations Territories, which cover South Dakota, North Dakota, Nebraska, Wyoming, and parts of Colorado, host approximately 3,272 abandoned uranium mines with unknown reclamation status. But the experiences and preferences of various communities as they relate to those has differed. Many indigenous leaders and environmental activists in the United States prioritize the cleanup of legacy sites and oppose new or expanded mining operations. However, some community members value the stable employment that can come from mines close to reservations, where other economic opportunities are sometimes few and far between.

From Environmental Disaster to Clean New Nuclear

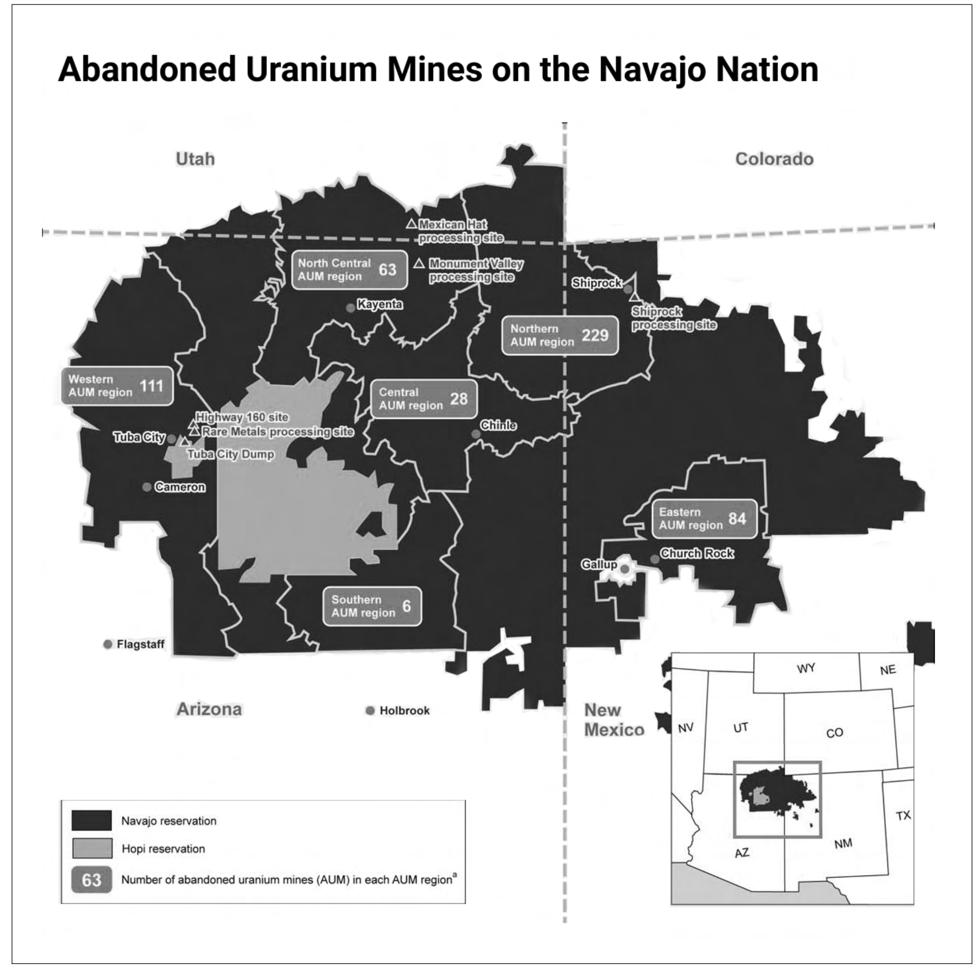
If cleaning up abandoned mines were the main problem, the solution for those places that prioritize cleanup would be relatively straightforward—albeit vastly expensive. But the 1872 Mining Law could still create new disasters today.

In theory, most major new projects on U.S. federal public land are subject to the National Environmental Policy Act, which requires an accounting of the potential environmental impacts of large infrastructure projects with federal involvement.

But, in practice, many of the historic uranium mining sites that could come back into operation in the coming years could avoid this regulation, since it applies only to mining claims established after 1976, or to mining operations "causing undue or unnecessary degradation of lands and resources or adverse environmental effects." In turn, observers have raised concerns that the current U.S. mining law framework may not prevent companies from reopening existing uranium mines, creating waste, and then abandoning their operations once again.

Given that the future does likely hold a new uranium mining boom, there are a couple of initiatives worth considering now. These should both remediate the ongoing impacts from abandoned mines and prevent future mining from recreating the same problems.

First, Congress should reform the General Mining Act of 1872 to prevent the future abandonment of new mine sites, and to make sure that licensees pay the government and local communities more than a token fee for the exploitation of resources on public land. Reform of the law has recently gained traction as the demand for U.S. critical mineral mining increases to support the clean energy transition.



Abandoned Uranium Mines on the Navajo Nation.
Credit: Government Accountability Office.

Second, the federal government will need to do more to fund cleanup. In 2012, the U.S. Government Accountability Office estimated it would cost $39 million just to inspect all U.S. Bureau of Land Management mine sites of all types. It is unclear how many of these are uranium mine sites or may contain uranium. Congress must ensure that there are adequate resources, potentially by appropriating funds to the BLM and cooperating federal agencies.

Another initiative could come through the EPA's Brownfields Program, which provides grants and technical assistance to communities, nonprofits, and others to clean up contaminated structures and revitalize them for productive use. A 2002 amendment expanded the program to include "mine-scarred land." While the focus has so far centered on abandoned coal mines, abandoned uranium mine lands could be a viable new focus.

There's also room to reform the Good Samaritan Initiative, an effort started by the EPA in 2007 to reduce barriers to volunteers cleaning up abandoned mine sites. Through the program, volunteers can apply for Good Samaritan Orphan Mine Permits to conduct remediation activities in their community. However, many prospective volunteers are concerned that they will be held liable under the Clean Water Act for any pollution that remains there after their work, or any possible mistakes made during their cleanup efforts.

> Perhaps most important of all will be co-management of new uranium mines with tribal nations whose territory is affected.

Reform of this initiative and its liability provisions could allow more communities to address legacy mine pollution in their own backyards. Such a reform could also be a win for mining companies because it would allow them to take part in mineral reprocessing efforts at abandoned mines.

Fourth will be co-management with tribal nations of uranium projects on federal lands. Past uranium mining occurred on sacred Indigenous sites and delicate ecosystems. To protect these areas from the impacts of new mining, the federal government and developers should work with tribes to allow more co-management and ensure that Indigenous communities have a say in whether extraction is allowed near sacred sites.

At a minimum, tribal consultation is a legal requirement for the federal government whenever large infrastructure projects may encroach on a tribe's land, natural resources or cultural resources. In January 2021, the Biden administration issued a memorandum directing all federal agencies to plan and engage in regular, meaningful and robust consultation in the development of policies that have implications for tribal nations, including hardrock mining regulations.

As part of this work, federal agencies should work to identify which communities are most interested in hosting new uranium mining and milling projects. In these communities, permitting should be executed as efficiently and effectively as possible while still prioritizing environmental protection and environmental justice.

Ariel Gould is Environmental Justice Policy Counsel at Good Energy Collective.

And fifth, to make sure that agreements made are upheld, it will be important to adopt stricter standards for water quality protection—as soon as possible. These should include standards for aquifer testing, chemical use, monitoring, and water restoration, and for in-situ leach mine operators to use continuous water-monitoring techniques rather than computer models to monitor the aquifers—a concern for many environmental groups.

The Future of Uranium Mining

To fight climate change, the world will need to transition global energy systems away from fossil fuel-based energy to carbon-free energy, including nuclear. But however clean the production of nuclear energy itself, the dangers that come from mining nuclear fuel simply cannot be ignored.

The future of uranium mining will hinge on community support for mining projects. Mining does not need to be destructive. It can be rethought to include cleaning up the dirty legacy of mining's past, protecting the environment, and investing in the community. There's a long way to go to build community trust and support, but cleaning up legacy pollution, strengthening existing regulations, and successful community consultation practices offer a good start.

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FEATURES

06

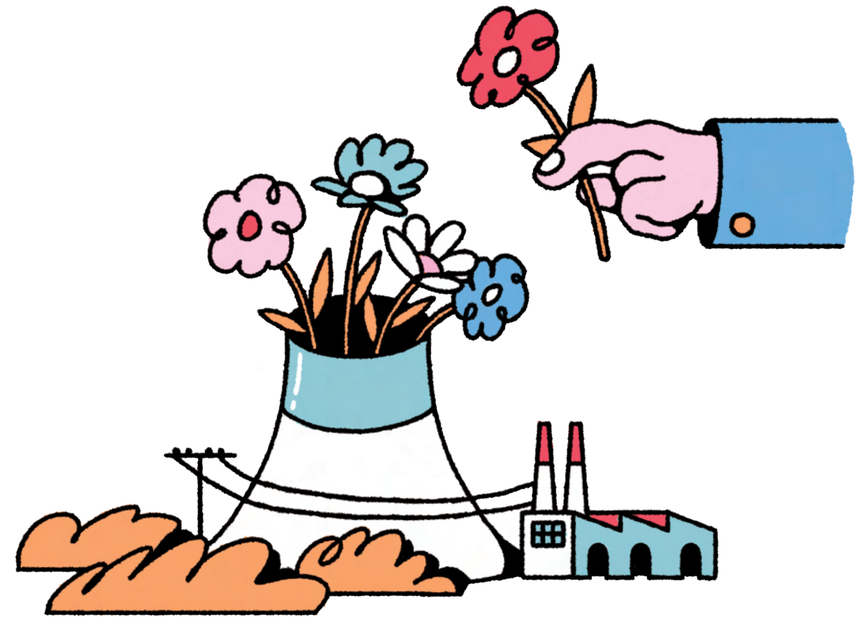
THE SOURCES OF GERMANY'S NUCLEAR AVERSION

As the country faces a cold winter and a failed energy transition, it will need to overturn old dogmas to endure

SUDHA DAVID-WILP

When Russia invaded Ukraine at the end of February, many aspects of German policy were turned on their head. Few would have expected before the invasion, for example, that by mid-2022, Germany would send weapons to a conflict and scupper plans for its much-awaited Nord Stream 2 natural gas pipeline from Russia. Yet in all that change, some things have remained stubbornly the same. Namely, Germany's stance on nuclear energy.

It is true that Russia's belligerence stirred the usually reluctant Germany to make some tough calls. Germany went along with European sanctions on Russia, a decision it surely knew was dangerous considering that around 55 percent of its natural gas came from Russia. It declined to halt imports of Russian natural gas altogether, yet its intake has dwindled anyway, because Russia itself first reduced supply to Germany, and now the pipelines lay damaged under the Baltic Sea.



In the meantime, Germany has pledged to wean itself off Russian gas by 2024. It is now boosting its gas reserves for the coming winter, and municipalities are crafting individual plans to lower electricity consumption. These run the gambit from lowering the thermostat to forgoing Christmas lighting. Berlin is also evaluating steps such as price caps, tax relief, and a special 200-billion-euro fund to navigate a turbulent energy market.

Facing hard realities, pressure has mounted for Berlin to reverse course on the country's more than two-decade quest to rid itself of nuclear energy or at least pause plans to shut down Germany's remaining nuclear reactors by the end of the year. In late summer, German Chancellor Olaf Scholz, from the SPD, signaled that postponing the closures might be necessary. Finance Minister Christian Lindner, from the FDP, likewise expressed skepticism that now would be the right time for them to be taken offline.

Then, in late September, the country's traffic-light government, consisting of the center-left SPD (the Social Democrats, whose color is red), the Greens (Green), and the liberal FDP (the Free Democrats, associated with yellow), announced that it would keep two of the remaining three nuclear reactors running until next spring. Apparently, the Greens, long particularly opposed to the idea of extending the deadline, at last acquiesced as the reality of the energy crisis became clearer and clearer.

At the same time, the public has also started to question anti-nuclear policies in a way unseen in German politics for years. To be sure, anti-nuclear sentiments still run deep in Germany and cross the country's party lines. The Greens may have started the campaign against nuclear power more than four decades ago, but ever since the Fukushima disaster in 2011, the campaign has been an unshakable tenet of mainstream party platforms.

Germany is now facing a cold winter, a rattled public, and a failed energy transition that was supposed to replace nuclear with natural gas until renewable energy was widely available. Plenty of people saw this coming. Yet Germany refused to act until now, the very last minute. And even then, its plans to put only a temporary hold on closing two plants will be too little to solve the country's long-term energy problems.

Germany's allergy to all things nuclear long predated skepticism in other countries, and it is likely to remain a thread in German politics for decades to come. Yet the country is also now regretting its plan for a rapid departure, launched without viable alternatives in sight. The result of the clash between those two sentiments will very much determine the economic, political, geopolitical, and environmental future of Europe's largest player.

Germany's *Zeitenwende*

In Berlin, pledges to increase military spending and recognition of the limits of diplomacy with autocratic powers like Russia are now par for the course. These major shifts occurred in a country not inclined toward speed except on the autobahn.

On February 27, a few days after the start of Russia's war in Ukraine, Scholz delivered a groundbreaking speech on the floor of parliament. Major taboos of post-war German politics, such as remilitarizing or confronting Russia, were brushed aside as he declared 2022 a watershed moment for Germany.

With the stability of Europe on the line, the unthinkable in German policy was suddenly possible. In short order, decisions to purchase drones and meet the NATO requirement that 2 percent of GDP go toward military expenditures were a matter of course.

In some ways, then, it would make sense to believe that Germany's aversion toward nuclear energy could be the next domino to fall. For one, with energy bills expected to triple this winter on the back of already astonishing growth, 78 percent of those surveyed in a Civey poll for *Der Spiegel* magazine supported extending the deadline for closing Germany's three remaining nuclear power plants to next summer.

Today, the three plants generate 11 percent of the country's electricity; in the past, nuclear accounted for upwards of one-third of Germany's energy. Very soon, though, the total could go down to zero, if Germany decides to uphold the commitment it made in 2011 to bid farewell to nuclear while expanding avenues for renewable energy. Natural gas was supposed to serve as a plan B, but that created dependency on Russia, especially since building out of renewable energy infrastructure lagged behind.

With the stability of Europe on the line, the unthinkable in German policy was suddenly possible. In short order, decisions to purchase drones and meet the NATO requirement that 2 percent of GDP go toward military expenditures were a matter of course.

For now, the German government will decommission one nuclear reactor at the end of the year and will keep two others online. One factor, claims Robert Habeck, the Economics and Climate Minister from the Green Party, is that keeping them running comes with a higher price tag than the cost of simply closing them as planned. His calculation is hard to justify among European Union partners, though, who are scrambling to come up with energy to get through the winter and have found Germany's position inconvenient, if not outright puzzling.

Habeck and his fellow party members are also dubious about the green designation the European Union gave nuclear energy over the summer, of course, but that seems unlikely to be their real motivation. After all, Habeck has noted his willingness to swallow a reversal on coal, potentially firing those plants back up while he seeks to eliminate Russian natural gas from the country's energy mix by 2024.

Beyond the supposed cost issue, the coalition government has said that fully reversing long-term plans already set in motion is simply unrealistic due to the difficulties in sourcing equipment. There are also the liability issues, and the matter of reissuing labor and maintenance contracts. The plants' operators have signaled that it wouldn't be easy, byt the necessary work could be done if the decision were made sooner rather than later.

In fact, in July, a board member of TÜV, Germany's well-respected testing and certification body, stated that not only could the reactors stay operational if the government only agreed to it, but that the plants decommissioned last December, which produced around 30 billion kilowatt hours—or approximately half of Germany's nuclear energy at that point—could be brought back to life on relatively short notice.

This is not necessarily good news for Berlin. Rather than fears about contracts and bureaucracy, it is likelier that the current government believes that, if it allows the door on nuclear energy to remain open even a little bit, it will never close again. And that spells trouble for its hard-fought plans to make renewables the source of all its electricity demand by 2035. They know it would be difficult to say goodbye to nuclear once it is re-introduced as a clean and efficient way to keep the economy running. The Greens' high hopes for renewable have often been stymied by slow permitting procedures and a healthy dose of NIMBY-ism.

> In July, a representative of Germany's nuclear testing and certification body stated that even nuclear plants decommissioned last December could be brought back to life on relatively short notice.

The Greens and SPD are also proud of their legacy in enacting the laws known as the *Energiewende* that set in motion the nuclear phaseout in 2000, during their first term in federal government. Without continued progress on that front, they would lose one of their major political calling cards.

The Greens and SPD have already bucked tradition with their newfound comfort with militarism. Embracing nuclear could be a toppled pillar too far.

The Original Anti-Nuclear Activists

Still, to call today's opposition to nuclear a product of sensible electioneering is also too simplistic. Especially for the Green Party, to reverse course on nuclear would be to reject the party's own origin story.

In the 1970s, oil price shocks cast nuclear power as a smart option for domestically supplying energy needs for both West German consumers and industry. By the time the Berlin Wall fell in 1989, West Germany had nearly 30 reactors. Throughout that time, protest against nuclear energy was not uncommon. Nuclear weapons chaffed against Germans' post-war pacifism, while nuclear energy upset their commitment to an ecologically-friendly lifestyle.

Germans involved in the student and democracy movements of the 1960s organized demonstrations against nuclear power, some veering into violent confrontations with the police that were eventually so frequent they became normalized. At one of the biggest, in 1975, 28,000 protesters occupied the construction site of a nuclear power plant in Wyhl and ultimately blocked the project. The accident at Three Mile Island in 1979 prompted 200,000 to march in Hannover and Bonn.

But with the founding of the Green party in West Germany in 1980, anti-nuclear sentiment was given a singular vehicle for political influence.

The Greens burst on the scene as mainly a single-issue party. Although they were also active in human rights, anti-war protests, and reckoning with Germany's Nazi past, the Greens were primarily known for their zeal in protecting the environment. This meant that they were vehemently opposed to fossil fuels and nuclear power. Although it is a carbon-free energy source, nuclear energy was nonetheless viewed as a hazard to the environment because of nuclear waste and potential for meltdown. And even through technological advancement and decades of nuclear plants running in Germany without incident, anti-nuclear sentiment has remained a cornerstone of the party.

Over time, that position has become more mainstream within German society as well. At first, nuclear power was relatively popular; it is what gave Germany the capability to grow its economy, the post-war measure of its power and strength. Yet, over time, the Greens' calls for better stewardship of the environment sunk in. And not just on the left, since the Greens' cause appealed to church leaders and farmers to form broad anti-nuclear coalitions within German society.

No longer on the fringes, in 1985, the Greens' Joschka Fischer became state environment minister in Hesse, ushering in the end of the party's anti-establishment days. The Greens' sunflower logo, once an emblem largely reserved for protest posters, became a fixture in Germany's political opposition.

In the second half of the 1980s, anti-nuclear sentiment among the public reached a fever pitch. At the start of that decade, massive protests had erupted in Bonn and all over Germany against the stationing of nuclear weapons in West Germany as part of NATO's dual-track decision, which maintained that the United States could both start arms reduction negotiations with the Soviets while simultaneously stationing additional nuclear weapons in Europe. The Chernobyl meltdown in 1986 intensified the situation. Worries over contamination led to crop destruction and the replacement of sandboxes on playgrounds across West Germany. The Federal Ministry of the Environment, Nature Conservation and Nuclear Safety sprung up that same year in response to Chernobyl.

In time, the Greens' ecological stance gained even more support. The party was no longer a lone voice in German politics calling for an end to nuclear power. It was joined, in fact, by the center-left SPD, which saw a growing desire among their voters, too, to abolish nuclear energy. While the SPD called for a phase-out of nuclear power within the next decade, the Greens demanded immediate action.

The Berliner Republik

In 1998, the Green Party entered the federal government as a junior partner to the SPD. The red-green government symbolized a new, reunified Germany with its capital and seat of government in Berlin. The time was ripe to present to the world a modern, progressive Germany, conscious of its past but forging a new future for itself and a Europe whole and free. Part of that progressiveness was going green.

The German government did not need to work hard to sway the electorate toward a green transformation. Recycling, biking to work, and organic foods were already customary in German society, born of resourcefulness during the post-war years as well as a cultural emphasis on respect for nature.

By the time Angela Merkel became chancellor in 2005, it was almost a given that, in its drive toward environmentalism, Germany would eventually cease use of nuclear power. It was under Merkel, from the center-right Christian Democratic Union (CDU), that the *Energiewende* was put on turbo charge. Merkel even became known as the climate chancellor for expanding renewable energy targets and pledging to aggressively lower carbon emissions. But in 2010, she proposed postponing the nuclear exit until the mid-2030s, instead of the approximate three-decade deadline established in 2000.

Merkel, a quantum chemist by training, thought nuclear would be the best technology to bridge the present and a future in which Germany could switch completely to renewables. She feared higher electricity prices, observing that, despite the *Energiewende*, renewables were not being ramped up as fast as nuclear and coal were winding down. Slow and bureaucratic processes, she said, were hampering the spread of renewables in Germany.

> By the end of the 1990s, the time was ripe to present to the world a modern, progressive Germany, conscious of its past but forging a new future for itself and a Europe whole and free. And part of that progressiveness was going green.

Her tentatively pro-nuclear stance, though, came at the wrong time. The tsunami that destroyed Japan's Fukushima nuclear plant in March 2011 had political repercussions in Berlin. In state elections in Baden-Wuerttemberg held just a few weeks after Fukushima, the Greens were able to capture the conservative stronghold of Baden-Wuerttemberg, coming in second and forming a coalition with the SPD to crown the first Green Minister President of a German federal state.

Meanwhile, protesters mobilized all over Germany to condemn Merkel's proposed rethink of nuclear. She tried to make concessions, with a three-month moratorium on nuclear energy, but she saw the writing on the wall. Demonstrations continued and polls showed that most Germans rejected nuclear power. By summer of 2011, Merkel not only revoked her government's plan to extend the terms of nuclear plants, but also accelerated Germany's nuclear exit to 2022.

Merkel may still have bet on a future with renewable energy, but she, along with the backing of the SPD, leaned on increased flows of natural gas from Russia as an insurance policy for Germany's economic future. With Russian President Dmitry Medvedev, French Prime Minister François Fillon, and Dutch Prime Minister Mark Rutte, Merkel formally opened the Nord Stream 1 pipeline in 2011. Nord Stream 1 was soon joined by the construction of Nord Stream 2.

There was debate in parliament but no public uproar when, in 2011, Berlin sped up the timeline for phasing out nuclear energy. The main sentiment, at least among anti-nuclear activists, was disappointment, given that the process was still expected to take a decade. The country was counting on the Renewable Energy Sources Act (EEG), initiated in 2000 and amended over the years, which promoted wind and solar with tariffs and purchase guarantees to ensure wide adoption.

Merkel, originally a fan of nuclear power and pragmatic about her country's slow rollout of renewable energy, focused her attention on importing cheap natural gas from Russia.

Pipeline Politics

And so Germany had set the stage for the latest act in its energy play. For a country constantly claiming its dedication to Europe, its energy trade with Russia baffled partners within the EU and was an irritant in transatlantic relations. The conservatives and SPD referred to the North Stream pipelines as commercial projects, not political ones—a weak excuse to try to appease allies in other countries.

When the Berlin Wall fell in 1989, the Soviet Union supplied nearly one-third of Germany's natural gas. At the outset of the war against Ukraine this year, Russia now provided well over half.

Likewise, Germany often pointed out that, even during the height of the Cold War, economic ties with Russia were a way to keep communications channels open. The term *Wandel durch Handel* became a central plank in German foreign policy for achieving change through trade. But along the way, mutual trade turned into German dependency.

When the Berlin Wall fell in 1989, the Soviet Union supplied nearly one-third of Germany's natural gas. At the outset of the war against Ukraine this year, Russia provided well over half. Arguments that this trade was all some grand plan to make Russia European became far harder to believe during and after the negotiations over Nord Stream. The architect of the pipeline plans in Germany, former Chancellor Gerhard Schroeder, advocated building the network as a direct link between Germany and Russia through the Baltic Sea, avoiding transiting fees through other countries, for example Ukraine, in Eastern Europe.

Before he left office in 2005, the contract for Nord Stream 1 was signed, and Schroeder went on to become chief lobbyist while serving in the supervisory board of Nord Stream AG. Contracts for North Stream 2 got underway in 2015, despite Russia's annexation of Crimea in 2014. When the United States proposed issuing sanctions against Nord Stream 2, aiming to pressure Germany, Germans were outraged.

Even the most hard-brow German politician must now recognize their mistake. But to be fair, they were always going to be trapped in a perfect storm. The anti-nuclear movement is linked with Germany's post-war transformation and its interpretation of modernity. It is tied to the success of Germany's Green and SPD parties. And the decisions those parties made also coincided with Germany's soft attitude toward Russia, built on historical guilt and a naïve belief in German power to manage the partnership. Further, although Berlin's mistake of overestimating the country's ability to build out the necessary infrastructure for a fully renewable economy is apparent now, a decade ago the country was more confident. "Made in Germany" labels were respected worldwide and the country was known as a manufacturing and export machine. It wasn't so unreasonable to believe that the country could figure out renewables, too.

A New German Purpose

But what does Germany's history say about the future? The European Union is urging member states to cut gas consumption by 15 percent as quickly as possible in a bid to build a united front against Russia.

In the short term, that and the ballooning energy crisis will make it hard for Germany to stick to its transition away from nuclear. As the economy falters, the German public may become less rigid; in fact, Putin's war against Ukraine has already created a majority in favor of prolonging nuclear energy in Germany.

Meanwhile, Germany's EU partners will expect Germany to examine all avenues toward secure energy and European solidarity. And Germany will have to take that pressure more seriously than it has in the past. Not only has the war against Ukraine shattered Germany's reputation and exposed its dependency on cheap Russian gas, it has also placed Germany in an economically-vulnerable position from which it will find it much harder to bigfoot its European partners.

Germany's stance on nuclear may seem irrational, but it is in fact a fully logical result of a collision of history, economics, and idealism that all pointed the country down one path. And that's a hard but important lesson for anyone puzzling over stalled nuclear programs in other countries. In so many cases, decisions to phase out or avoid nuclear are not just a failure to understand the environmental and economic benefits of the energy source. Rather, they come from a tangle of pressures, ideas, and constraints that are hard to even unravel, much less push aside.

For Germany's part, now forced to adapt quickly, it could come to appreciate nuclear energy's original role as a temporary bridge to renewable energy. Or the existing plants could simply stay in place as Germans get comfortable with (or at least turn a blind eye toward) what they previously shunned. Getting over the nuclear taboo would signal that Germany is eager to take up its intended role after reunification: a modern, progressive country, conscious of its past but ready to forge a new, better future for itself and a Europe whole and free.

Sudha David-Wilp is a senior transatlantic fellow at the German Marshall Fund, and deputy director of GMF's Berlin office.

FEATURES
07

TAIWAN'S NUCLEAR OPTION

Facing an energy crunch that could hamper its economic geopolitical security, Tsai should turn nuclear reactors back on. Luckily, many of them stand at the ready.

JORDAN MCGILLIS AND ANGELICA OUNG

Taiwan packs a mighty economic punch. Its population numbers under 25 million, but it claims a spot close to the top 20 globally in GDP, and it continues to ascend the rankings ladder even as its neighbors slip into low-growth malaise. In fact, in 2021, Taiwan's economy grew at an astonishing 6 percent.

The country's economic heft is exemplified by Taiwan Semiconductor Manufacturing Co, Ltd. (TSMC), which consistently ranks near the top 10 of global companies by market capitalization. Last year was yet another banner year for the firm. As shifts in consumer behavior precipitated by the coronavirus carried over from 2020, demand for TSMC's chips climbed higher than ever, with the company hauling in 24 percent more revenue in 2021 than in the year prior.

Anchored by companies like TSMC, Taiwan is an export-oriented, manufacturing economy. Beyond semiconductors, other leading companies produce electronic devices, plastics, and machine tools—even bicycles. Despite its minuscule size, it is the ninth-largest supplier of goods imported by the United States. And put together, Taiwan's manufacturing sector makes up more than 30 percent of its GDP, higher than any member of the Organization for Economic Cooperation and Development. Germany's vaunted manufacturing sector accounts for less than a quarter of the country's GDP. The U.S. manufacturing sector barely musters 10 percent. Even China lags Taiwan on this score, despite Taiwan being far richer on a per capita basis—typically a harbinger of manufacturing's relative decline.

With manufacturing such a crucial part of its economy, industrial power and heat sources are of even greater importance to Taiwan than they may be in other countries. According to the Bureau of Energy, as of 2021, industrial production accounted for 56 percent of total electricity consumption in Taiwan. Of this 56 percent, electronics manufacturing (including chipmaking) accounted for 37 percent.

Unfortunately, Taiwan has some big problems ahead. First are the natural hurdles to energy security. Second are the self-imposed policy constraints limiting energy possibilities. And third, its space in global geopolitics jeopardizes its energy status quo. As difficult as these problems are, though, they point to one solution: a nuclear renaissance.

Taiwan's Looming Energy (and Economic) Crunch

As researchers Sih Ting Jhou and Huei-Chu Liao wrote for the Brookings Institution in

September 2013, "Taiwan has almost zero energy endowment, and relies on imports for nearly 98 percent of its consumption." Little has changed in the intervening decade. The island lacks a domestic energy production base capable of powering its industrial economy and, therefore, it imports an almost identical portion of its total energy supply today as it did in the early-2010s.

Taiwan uses fossil energy for the vast majority of its electricity, with 45 percent coming from coal and 37 percent from natural gas. Meanwhile, 10 percent comes from nuclear power and 6 percent from renewables, including solar, hydropower, biomass, and wind, according to a 2022 Bureau of Energy report on current and future electricity demand.

Tsai Ing-wen, who has been president since 2016, champions radical changes to Taiwan's electricity mix. In 2017, she proposed increasing natural gas's share to 50 percent of the power mix by 2025, reducing coal's share to 30 percent, and ramping up renewables, with an aim of hitting 20 gigawatts of solar photovoltaic installations and 5 gigawatts of offshore wind, for a total renewable percentage of 20 percent.

As the economic growth figures would suggest, rising manufacturing prowess has led to surging industrial power demand, which is driving the island's electricity consumption higher than ever. In 2020, Taiwan used over 270,000 gigawatt-hours compared to 250,000 gigawatt-hours in 2015. Industrial electricity use now constitutes well over half of Taiwan's power consumption according to the Bureau of Energy. Complicating matters, Taiwan maintains distorting caps on rate increases for both industrial energy consumers and residential users. Amid the ongoing global natural gas crunch, this consumption stretches the grid to its limits. All too frequently, those limits are exceeded, and the island is subjected to productivity-sapping blackouts, as occurred in May 2021 and March 2022.

Given its power requirements and its geographic and geological constraints, Taiwan would seem to be a prime candidate for nuclear power, the low-emissions electricity source that provides the best combination of dispatchability and energy-density. Tsai and the Democratic Progressive Party, however, have spurned nuclear power, excluding it from power plans and arguing against life extensions for Taiwan's existing nuclear fleet.

Taiwan's electricity choices make it vulnerable. The Bureau of Energy report may have predicted a peak usage of 39.7 GW in 2022 and 40.64 GW in 2023, but actual peak usage

jumped to 40.74 GW just a day after the report was released. The state-run Taiwan Power Company, or Taipower, has since adjusted its 2022 peak usage estimate above 41 GW.

Taiwan is already suffering from an unsettling number of destructive, island-wide blackouts—one in March 2022, which caused rush-hour chaos as traffic lights stopped working up and down the island, particularly spooked Taipower. Major industrial customers now find themselves on the receiving end of unusual phone calls from Taipower managers and even political higher-ups pressuring them to reduce power usage, or even pause operations, whenever capacity looks tight. Those calls for help have become routine, much to the dismay of industry, as unplanned stopping and starting of machinery is disastrous for productivity. At the macro level, too, the repercussions are a potential loss of confidence in Taiwan.

> Taiwan's electricity woes will soon be made worse. Taiwan's three nuclear reactors, which together supply around 10 percent of its electricity, are slated to go offline by 2025.

Matters will soon be made worse. Taiwan's three nuclear reactors, which together supply around 10 percent of its electricity, are slated to go offline by 2025. According to Tsai's plan, the power shortfall is supposed to be made up by renewable energy, which currently sits at just 6 percent of total generation. The Tsai administration's original goal of 20 percent renewables by 2025 was adjusted downward to 15.1 percent by 2025 earlier this year. And with natural gas constrained by both spiking global prices and limited LNG receiving capacity, an increase in coal being politically impossible, and the growth in demand galloping beyond expectations, it is unclear how Taiwan is going to fill the nuclear gap.

Tsai's Gamble on Renewables Goes Bust

And so, Taiwan finds itself in a dangerous place. To understand how it got here, we have to press the rewind button. When Tsai, now two years into her second term, was first elected in 2016, Taiwan's electricity mix was 45.9 percent coal, 31.5 percent natural gas, 12 percent nuclear, and 4.8 percent renewables.

While campaigning for the presidency, Tsai championed renewable power, but stumped even more explicitly on eliminating nuclear power plants, promising a "nuclear-free homeland," among other steps away from the Chiang-era policy legacy. After Tsai won, the Electricity Act of Taiwan was updated to say that nuclear power shall be phased out by 2025. A 2018 referendum changed the law so that it would be legal to keep nuclear in the mix beyond 2025, but it didn't change the fact that all currently operating reactors are slated to shut down by 2025. A 2021 referendum to start the mothballed fourth Nuclear Power Plant at Lungmen was unsuccessful.

> Taiwan's gas-forward plan entails significant risks. Although it is dependent on imports for virtually all hydrocarbons and nuclear fuel, its reliance for natural gas is especially problematic.

But something will need to give. Taiwan's current 6 percent figure for renewables is an anemic increase from 4.8 percent at the start of Tsai's term in 2016. Meeting the new 15.1 percent goal by 2025 will be a monumental challenge. Some of the slow growth in solar and wind generation can be attributed to NIMBYism. Solar projects near farmland must seek Council of Agriculture approval. Offshore wind farms have faced construction delays due to pandemic-related supply chain and labor issues. Meanwhile, coal has barely budged, decreasing from 45.9 to 44.3 percent, and natural gas still has a long way to go if it's ever going to reach the 50 percent goal.

Emissions aside, Taiwan's gas-forward plan entails significant risks. While Taiwan is dependent on imports for virtually all hydrocarbons and nuclear fuel, its reliance is especially problematic for natural gas. Natural gas, which is mostly purchased via long-term contracts, has to come to Taiwan in highly-specialized liquefied natural gas (LNG) vessels, as geopolitics and geography rule out pipelines. There are currently only two receiving terminals in Taiwan, with a third due to come online in 2025, and a fourth location under discussion. To reach the high natural gas penetration called for in Tsai's plan, four or even five receiving terminals would be necessary.

With only two terminals, Taiwan can currently hold only two weeks' worth of natural gas at any time. In summer, that drops down to 10 days. This creates a couple of problems.

Low storage capability means that until more terminals come online, Taiwan is always going to be two badly-timed typhoons away from an outage. The situation becomes more dire in the scenario of a blockade by China. In the past, most invasion scenarios assumed that China would invade via sea. But regional experts now increasingly forecast a blockade as a probable tactic for Beijing to attempt to subdue Taipei.

As *New York Times* chief China correspondent Chris Buckley and co-authors wrote in the wake of Nancy Pelosi's August 2022 Taiwan visit and ensuing Chinese encirclement exercises, a key textbook for officers in China's People's Liberation Army describes a "strategic blockade" as a way to "destroy the enemy's external economic and military connections, degrade its operational capacity and war-fighting potential, and leave it isolated and unaided." Concurring with Buckley, Ou Si-fu, a fellow with a Taiwan Defense Ministry research affiliate, told the *Times*, "I think they have shown their intentions, encircling Taiwan and countering foreign intervention."

The ability of Taiwan's energy system to hold while allies mobilize would be key to its survival. Nuclear generation can increase its chances; as opposed to gas plants, nuclear power plants routinely hold 18 months of fuel on site. A common knee-jerk concern pertains to the risk of direct Chinese attacks on nuclear plants, but it would be unrealistic for China to attack those without contaminating its own cities on the mainland.

Given the energy and geopolitical challenges the Tsai administration faces, it makes little sense to be so adamant about phasing out nuclear power. To understand why it maintains its position—and to see how it might be overturned—we need to go back even further.

Nuclear Rods at the Ready

Taiwan's nuclear power plants were built under the authoritarian regime of Chiang Kai-shek, who wanted to boost technological standing and economic growth and to hedge against the risks revealed by the 1970s oil crises. The first still-operating reactor was built at Jinshan in 1978, followed by reactors at Kuosheng in 1981 and 1983, then at Maanshan in 1984 and 1985. Chiang is remembered by many as a brutal dictator who crushed dissent, and nuclear energy became tainted by association.

At its nuclear zenith in 1987, the final year of the rule of Chiang Kai-shek's son, Chiang Ching-kuo, Taiwan's nuclear power reactors produced just over 50 percent of the island's power mix. When combined with hydropower, these meant that Taiwan was running on almost 60 percent zero-carbon energy that year.

In fall 1986, meanwhile, the pro-democracy forces in Taiwan had coalesced into the Democratic Progressive Party. Earlier in that year, of course, the meltdown at Chernobyl had happened. The freshness of that episode so close to the founding of the DPP, combined with nuclear power's association with Chiang's rule, meant that anti-nuclearism was baked into the DPP's political DNA.

Fast forward to the present day, and the energy battle lines have not much shifted, with most pro-nuclear advocates also representing the Kuomintang (KMT), the party of Chiang Kai-shek and whose candidate drew just 39 percent of the vote in the 2020 presidential race. Meanwhile, the DPP, which has grown to become dominant, remains heavily anti-nuclear. Over time, the distinctions on nuclear have become less about anti- or pro-authoritarianism; rather, the DPP is widely seen as the young, pro-environment party, while the KMT is seen as pro-business (and, paradoxically given its origins, too cozy with China). This leaves very little political space to advocate for nuclear energy on the premises of ecomodernist environmentalism.

There is the possibility, however, of change. The 2018 referendum to strike the part of the Electricity Act outlawing nuclear power by 2025 could not have been passed on KMT votes alone. The vote breakdown shows that both traditionally "blue" (pro-KMT) and "green" (pro-DPP) municipalities passed the referendum by comparable percentages. This means that there must be defections on both sides. In short, there may be plenty of DPP members who are voting for nuclear, even if party representatives are not yet willing to stand up for it in public.

Perhaps due to the 2018 showing, DPP politicians are now quietly scoping out the possibility of life extensions for Taiwan's nuclear power plants, according to Yeh Tsung-kuang. Yeh, who was formerly a professor of nuclear engineering within the island's top nuclear program and now holds a professorship within National Tsing Hua University's Department of Engineering and System Science, is optimistic.

"More than one legislator from the DPP has approached me to ask about the possibility of life extension for Taiwan's nuclear fleet," Yeh said in a telephone interview. Those inquiries are strictly off the record, said Yeh, because it is currently political suicide for a

DPP politician to "come out of the closet" as pro-nuclear and will be as long as Tsai remains in office. Indeed, Yeh said, "despite the fact that her energy transition plans have not worked out, Tsai will resist doing a U-turn on nuclear energy at all costs as she was elected on the 'nuclear-free homeland' platform," adding, "but after her term ends in 2024, there is a chance for the DPP to pivot."

> Fast forward to the present day, and the energy battle lines have not much shifted, with most pro-nuclear advocates also representing the Kuomintang, the party of Chiang Kai-shek

By the time that chance arrives, there may be even more momentum. In addition to the looming power crunch, two other factors have begun to sway public opinion on nuclear energy: the soaring price of LNG in the wake of the Russian attack on Ukraine and the European Union's 2022 decision to designate nuclear energy green energy, which will impact Taiwan's electronics exports.

Asked if 2024 would be too late, as more reactors are slated to shutter by then, Yeh was hopeful. He confirmed that "it is possible to turn all the nuclear power reactors in Taiwan back on, even the First Nuclear Power Plant." And Taiwan's first three nuclear power plants did all turn on in relatively quick succession in the late 1970s and early 1980s—a trick the country may be able to pull off again.

The first, Jinshan, has two 604MW Boiling Water Reactors (BWRs); the second, Kuosheng, has two 985MW BWRs; while the third, Maanshan, has two 951MW Pressurized Water Reactors (PWRs). Jinshan's two units have already closed, along with the first unit in the Kuosheng plant. A fourth nuclear power plant was built and almost finished but never commissioned, with two 1,350MW advanced boiling water reactors that Yeh estimates could be made operational with two to five years of lead time.

According to Yeh, the potential for life extension for Taiwan's reactors is excellent, even for the first plant at Jinshan, which went offline in 2018 and 2019. Similar makes and models of reactors have received at least 20 extensions in the states. Further, Taiwan is in a unique position to restart even shuttered reactors, which, in an enigmatic twist of fate, have never actually been decommissioned, due to the way Taiwan stores waste.

Usually, when nuclear reactors stop producing power, they undergo a decommissioning process that makes it extremely difficult if not impossible for them to be restarted. That process never happened in Taiwan because, despite a 40-plus year history of using nuclear power there, it never approved any dry storage location site due to its political quagmire. This means that the wet storage pools for nuclear power waste, only ever meant for short-term storage, are full. Upon shutdown, there is no room for the last batch of fuel rods in wet storage, meaning that those rods are still in the now-offline reactors at Jinshan and Kuosheng. To keep those spent fuel rods safe, none of the three reactors have fully shut down. Yeh estimates that it will take less than a year to bring the ones in "stasis" back into service.

> Upon closure, there was no room for the last batch of fuel rods in storage, meaning that those rods are still in the offline reactors. To keep those spent fuel rods safe, none of the three reactors have ever fully shut down.

Unfortunately, the 2021 referendum to activate the fourth nuclear power plant failed to pass (and was, in fact, defeated by a slighter greater margin than each of the other three unrelated proposals on the ballot). The fact that the failed referendum is so fresh, and that it would still take longer to start than the others—or just to grant life extensions for the reactors that are still online—means that the fourth plant is not likely to churn out more clean electricity in the near future.

Complicating matters, the fourth plant is also maintained with care as an asset in Taipower's books, simply for the fact that if maintenance stopped, Taipower would have to write it off. The resultant red ink would threaten to bankrupt the state-run utility giant.

The Case of SMRs

If Taiwan manages to switch on all its existing reactors and complete the fourth nuclear power plant, that could be 7.78 GW of additional nuclear energy by 2027, equivalent to almost 20 percent of 2022's roughly 41 GW demand peak.

More creative effort, however, will still be needed. There probably won't be high demand for further large-scale nuclear projects in the immediate term, and, of course, there is a big waste storage issue to deal with. But in parallel to the political discussions, industry leaders have also been focusing more and more on Small Modular Reactors (SMRs) as a route to greater nuclear power.

With their passive "fail-to-safe" features, by which failed systems revert to a safe position, SMRs are a second chance to sell nuclear power to a fearful public. Even Taiwan's Ministry of Economic Affairs has said that they have not ruled out advanced nuclear technology such as SMRs and fusion from their future energy plans.

Meanwhile, Taiwan's industrial giants are keen to control their own power security, i.e., to avoid the blackouts and political pressure to cut back that has been put on them in recent years. Just as a savvy homeowner in Texas might purchase a powerwall or a backup generator to ensure their family can weather the next winter storm, major Taiwanese manufacturers are looking to secure their own power sources.

More than one Taiwanese firm, Yeh says, has reached out for his advice in securing their own SMR. Formosa Plastics, one of the most avid of the Taiwanese companies pursuing SMR research, is reportedly looking to develop an SMR project in the Philippines. This makes sense from the point of view of ultimately bringing the technology back to Taiwan, said Yeh. "The political environment in Taiwan is not yet mature, but the Philippines is bullish on nuclear power," and so, "if Formosa Plastics can successfully develop an SMR in the Philippines, it can then quickly transfer that experience into a Taiwan project."

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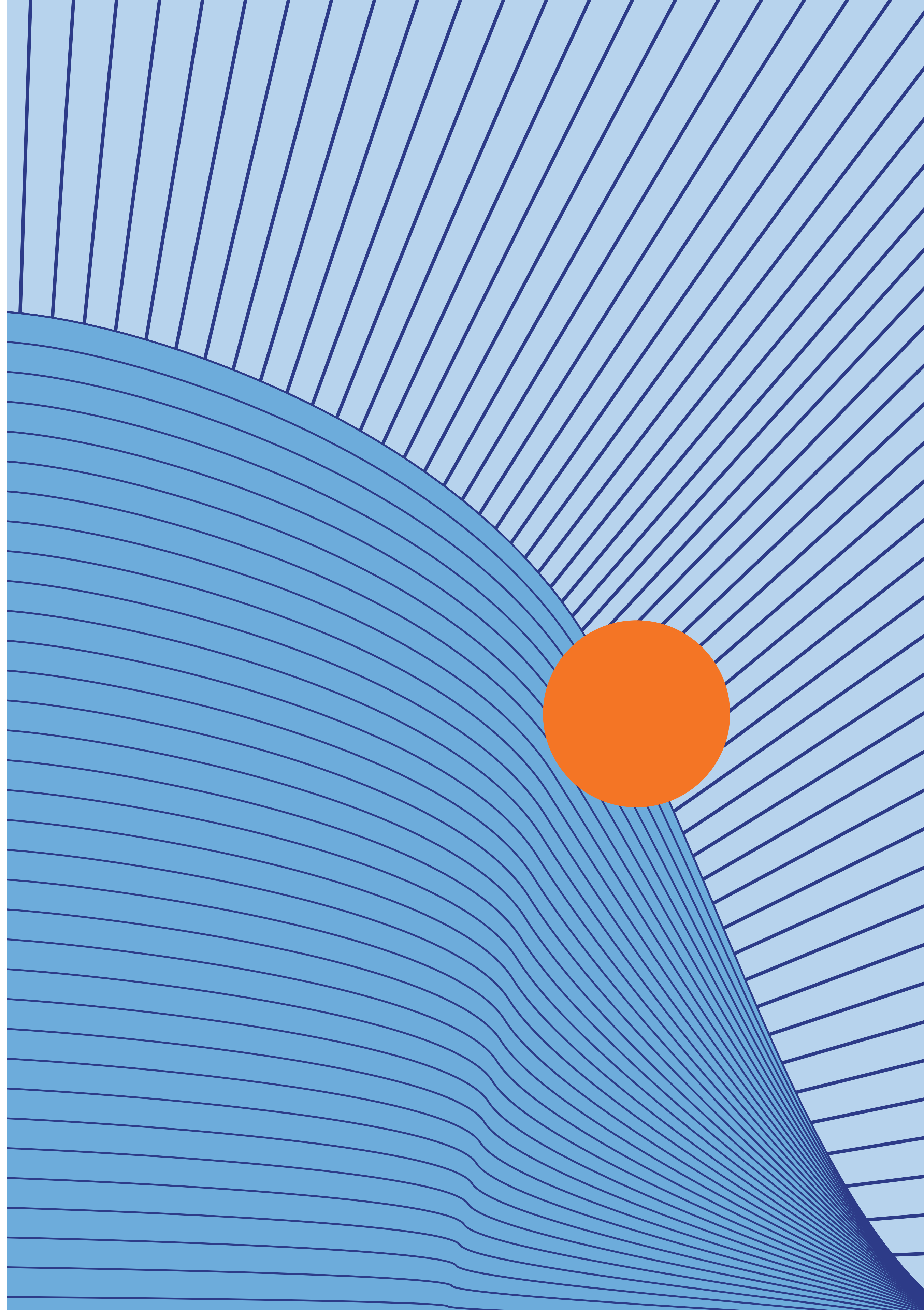
Angelica Oung is an independent Taiwanese journalist focusing on Taiwan's electricity system. She also writes the newsletter *Elemental*.

"I can easily see a SMR in Taiwan before 2035," said Yeh. If this occurs, it would free up generation sources, and potentially activated or reactivated large-scale nuclear, to meet demand elsewhere.

Whatever the overall mix, given its increasing demand and roaring economy, it is more important than ever for Taiwan to secure its energy supply. Due to its precarious geopolitical situation, ending its dependence on just-in-time natural gas delivery is paramount. Nuclear energy presents the best option to satisfy Taiwan's various needs. While baseload nuclear power is crucial, Taiwan's tangled energy politics make SMRs an important new option, taking nuclear energy out of political tug-of-war and putting it under the care of trusted industrial institutions.

Because the KMT is seen by so many young voters as out of touch, most commentators expect the DPP to dominate elections on the national level for the foreseeable future. And this will change the DPP's political calculus considerably. With the KMT fading as a threat, the DPP can afford to reassess its "no nuclear homeland" strategy. Indeed, it can't afford not to; the greatest political dangers it faces are regular blackouts or power shortages that damage Taiwan's export industries. And with neighbors and rivals like China, South Korea and Japan all returning to nuclear power with various degrees of enthusiasm, the DPP will be wise to put power stability over long-held ideology.



FEATURES

08

THE FUTURE OF NUCLEAR IS AT SEA

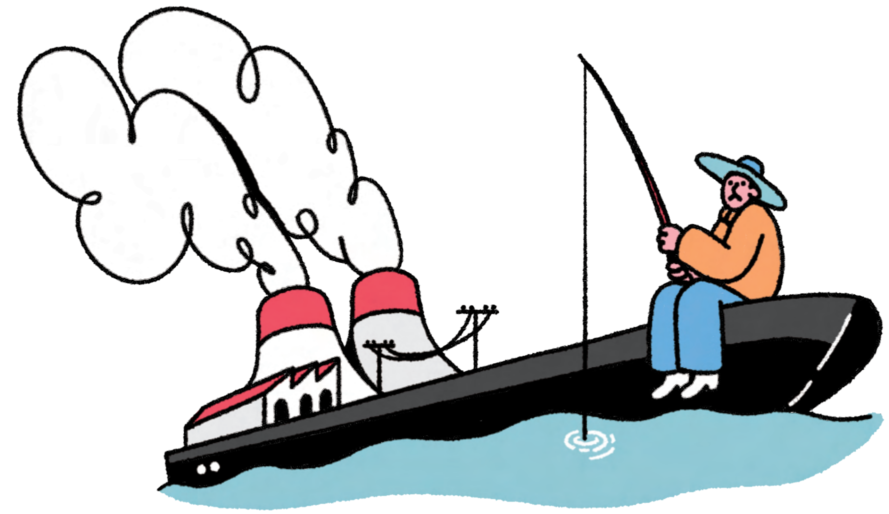
Shipyards around the world are already equipped to build small reactors and put them on ocean-going vessels. Let's let them.

RAULI PARTANEN, KIRSTY GOGAN, AND ERIC INGERSOLL

THE WORLD USES ROUGHLY 100 MILLION BARRELS OF OIL AND gas per day) for fuel alone. Although it has made great strides in replacing that direct use with electrification—the main way, so far, we've tried to move on from fossil fuels—much of the remaining consumption takes place in sectors that are hard or expensive to electrify.

These sectors include marine shipping, aviation, long-haul road-transport, heavy machinery, flexible power generation, and sectors for which fossil fuels are an input in industrial and chemical processes. In all of these, direct fossil fuel use is difficult to overcome due to existing infrastructure and assets, the properties of the fuels themselves, and fossil fuels' low historical cost relative to that of alternatives.

In turn, while electrification has historically increased by about two percentage points per decade—today electricity stands at 20 percent of final energy use—it remains to be seen how fast it will continue in the next couple of decades, once all the low-hanging fruit is gone.

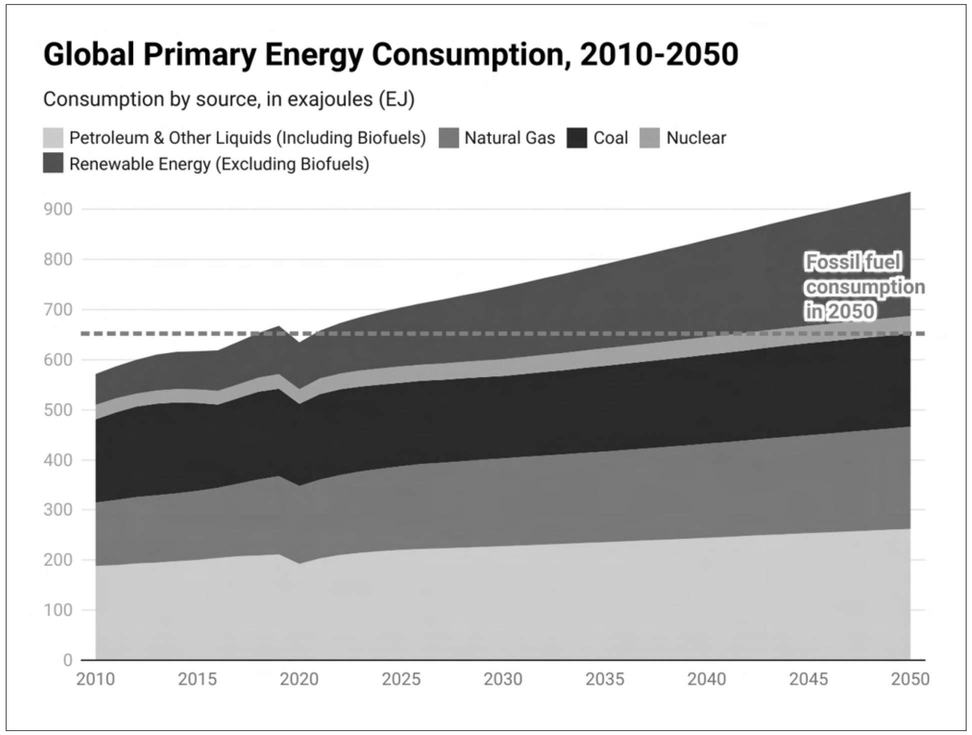


Even if we do somehow find a way to start transitioning the most difficult sectors and the electrification trendline somehow doubles the historical rate, by 2050, electricity would still make up only 30 to 35 percent of end energy use. Much of the rest would be fossil fuels. In turn, total consumption of fossil fuel energy could well be even greater in 2050 than in 2020, since energy demand is still growing.

Facing these facts, if the world is to succeed in its climate efforts, while also increasing global energy supply to let developing countries grow their economies and developed countries maintain healthy ones, it will need to find solutions in addition to direct electrification.

One promising route is through clean hydrogen and other synthetic fuels, like ammonia, that produce zero emissions when burned. Synthetic fuels are generally made by combining hydrogen and nitrogen, or hydrogen and carbon. As long as the hydrogen and carbon atoms that are added to the mix come from a clean source (the air, the ocean, sustainable biomass, and the like) instead of from fossil fuels, the production of the "e-fuel" is also clean. The problem is, of course, scale. For e-fuels to replace fossil fuels en masse, we need to produce vast quantities and at very low cost. But how to get there?

Clean hydrogen can be made by separating hydrogen from oxygen through electrolysis, but this process takes electricity. Further, if this hydrogen goes on to be added to carbon or



Source: EIA 2021. Created with Datawrapper

nitrogen to produce a synthetic fuel, more energy is required still. If we use every bit of electricity we currently generate around the world for these processes, we would still only be able to replace less than one-fifth of the fossil fuels we use with synthetics.

Further, it would be senseless to use our fossil-fuel-dominated electricity grid to power the creation of hydrogen fuel. But other fuel sources have drawbacks as well. The cost of wind and solar power has been decreasing, but their intermittency and low availability make them expensive choices for hydrogen production. Indeed, hydrogen produced using wind and solar power could cost between $3 and 7 per kilogram, depending on location and configuration. Yet, according to our estimates, clean hydrogen would only even start to replace some fossil fuels at around $2 per kg. To use hydrogen to make competitive synthetic fuels, the cost would need to be closer to $1 per kg.

To get to these low prices levels, the electrolysers in the facilities that produce the fuels need to be low-cost, high-efficiency, and operate continuously at a high capacity, not just when the sun shines. They'd need the kind of power that nuclear reactors generate; once on, reactors tend to operate at the same productivity for decades with pauses only for maintenance.

But new-build nuclear has not been particularly cheap lately, especially not in the West, where projects have stalled and gone overbudget, and nuclear is struggling politically. Especially in the United States, low-cost natural gas has been the preferred option, despite nuclear energy's zero-carbon emissions. And that's why we need to rethink how we deploy nuclear power.

Why Is Nuclear So Expensive?

To better deploy nuclear, we need to first understand why it is so expensive. The 2018 "Nuclear Cost Drivers" report, commissioned by the Energy Technologies Institute and produced in part by two of us through Lucid Catalyst, an international consultancy for decarbonization and clean tech, found several fairly straightforward reasons. These range from the building of a single reactor instead of many, the expenses that come from starting construction with unfinished designs, a lack of good supply chains due to a long hiatus in building new nuclear, and inexperienced project management and regulators.

Building the same reactor at the same site with the same crew multiple times in a row is a clear way to bring down costs. But a big remaining chunk of the expense would still be that constructing something large and complex on-site is relatively inefficient and expensive.

Indeed, large infrastructure projects, where we drag materials, components, and thousands of people from all over the world to a site—often in the middle of nowhere—is among humanity's least productive ways of building things. Sometimes it can't be helped: a bridge, an airport, or a subway needs to be built where it needs to be used. But inefficiencies related to siting certainly contribute to high expenses.

Manufacturing in a factory-like environment, on the other hand, is among the most productive environments in which to build large things like airplanes and ships. Many small modular nuclear reactors (SMRs) are also designed to be manufactured in a factory and then transported to a site for assembly, which should help cut costs.

But there is a slight chicken-and-egg problem here. A nuclear reactor vendor needs to have a reasonably fat order book to justify (and get funding for) the construction of a major manufacturing center for the reactors and their modules. And to get those orders in, one should have a high level of certainty on the design and the (low) cost at which it can be built.

For now, none of the new reactor developers are at a stage where these issues are solved. But there is a way circumvent the chicken-and-egg problem altogether—and perhaps many of the other obstacles and bottlenecks standing in the way of deploying massive amounts of new clean, nuclear energy.

The solution? Design the nuclear power plant so that it can be built at a modern shipyard.

Shipyards build ships, of course. But they are more than that; in reality, they are manufacturing centers for all manner of extremely large, complex, and highly regulated items, such as oil drilling platforms, cruise ships, and other marine vessels. In addition to large things, shipyards specialize in constructions that are designed for extremely challenging environments and operations, such as submarines or ice breakers. Modern shipyards already have the professionals and the supply chains in place to deliver safe, reliable, and ready-to-go products at impressively high levels of quality control and assurance.

There's no real reason that they couldn't turn that expertise toward building modular reactors and assemble them into barges and other offshore platforms that could operate as offshore power plants—perhaps even offshore power plants linked directly to hydrogen and synthetic fuel production. At least this is what two recent studies led by Lucid Catalyst demonstrated.

In the first study, "The Missing Link–How Hydrogen-Enabled Synthetic Fuels Can Help Deliver the Paris Goals," we did the math on the global need for clean, low-cost hydrogen and e-fuels, the cost reduction potential of shipyard manufacturing and off-shore siting, and the overall scalability of global shipyard capacity. We also looked at the potential of building "Gigafactories" at industrial sites to manufacture advanced reactors to be deployed right there at the site and to make clean hydrogen and other e-fuels at the scale of dozens of gigawatts. The second study, "Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors," commissioned by Electric Power Research Institute, went deeper and more technical on the potential of global shipyard industry, as well as the Gigafactory concept.

The main finding of both papers was that these novel deployment models look extremely promising—both for reduced costs down and scaled-up production.

Scale Today

Today, the world has around 280 shipyards, and they have been working at roughly 50 percent average capacity due to overcapacity compared to demand. If even a small part of this free capacity were harnessed into producing nuclear power plants of various configurations, we could add hundreds of gigawatts of clean, low cost, and reliable energy production to global production capacity each year. Indeed, a single shipyard in South Korea—which, to be fair, is a very large one, since it represents almost 5 percent of global shipyard capacity—could produce 40 ships with 500 MW(e) capacity each, per year.

If we harness a larger chunk of idle shipyard capacity, we could perhaps add 200 GW(e) of new nuclear capacity each year. For context, the global nuclear fleet currently stands at just below 400 GW(e) capacity and supplies around 10 percent of world's electricity.

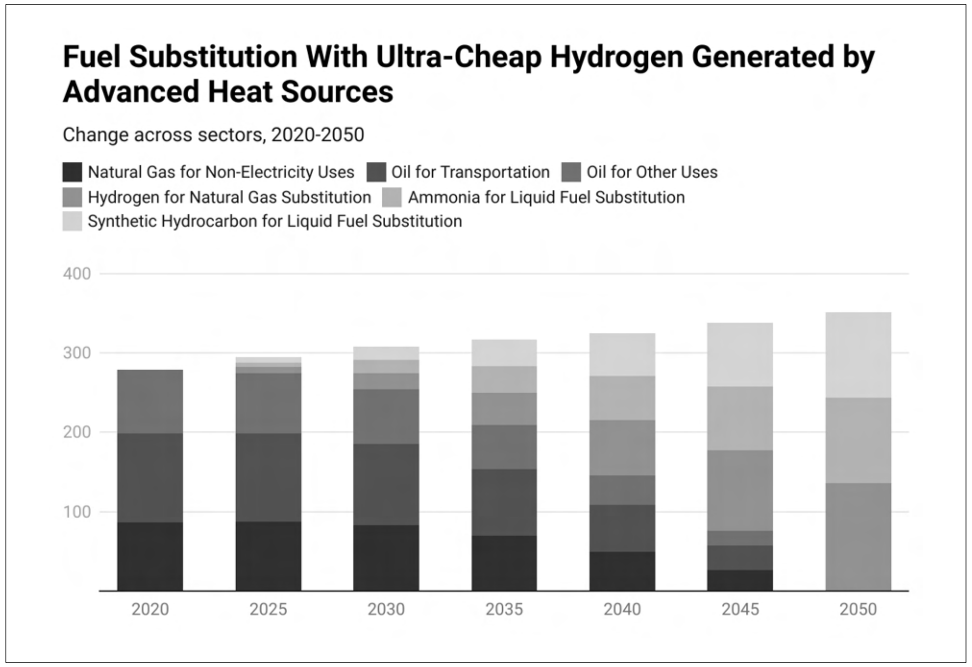
By utilizing most currently idle shipyard capacity—and perhaps building some new capacity or modernizing old shipyards—we could essentially decarbonize the entire fuels sector by midcentury if those reactors pour their cheap, zero-carbon energy into generating synthetic fuels.

By utilizing most currently idle shipyard capacity to build nuclear reactors—and perhaps building some new capacity or modernizing old shipyards—we could essentially decarbonize the fuels sector by midcentury.

As low-cost e-fuels replace petroleum products made from crude oil, there would be less need for offshore oil and gas drilling. This would free up even more capacity, as oil and gas rigs are a significant part of shipyard output.

As our Electric Power Research Institute study found, it might even end up costing less to build offshore nuclear vessels that produce e-fuels such as ammonia and jet fuel than it would to keep on investing in exploring and extracting new oil and gas fields. It would also be far less expensive than doing the same with renewable energy sources.

The Electric Power Research Institute study presented conceptual designs for large ships with 1.2 GW(e) of nuclear capacity, used for making both ammonia and jet fuel, as well as a design



Data assumes no major carbon fees or taxes, which could allow synthetic fuels to reach market price parity sooner.
Created with Datawrapper

for a 600 MWe multi-production platform that could produce electricity, ammonia, and desalinated water. The capital investment costs for Nth-of-a-kind vessels (that is, licensing work was done for the first-of-a-kind) were around $1.5 billion, depending on configuration.

The cost of the end-products from these vessels was competitive with the long-term average costs for their fossil fuel-based counterparts—even without carbon-taxes or fees that would increase their competitiveness even further. Ammonia could be produced below $250/ton ($290 for the multi-product platform), and jet fuel at below $85/barrel.

The larger, dedicated ships would each produce 1.2 million tonnes of ammonia per year and 4 million barrels of jet fuel per year, respectively. At the moment, the world uses 170 million metric tons of ammonia and more than 2 billion barrels of jet fuel per year.

Obviously, there would be bottlenecks as well; training operators, availability of uranium and uranium mining to feed the nuclear reactors, enrichment, and fuel fabrication capacity come to mind first. But it is a powerful fact that the manufacturing capacity, along with most of the

necessary supply chains, already exists within the shipyard industry.

Why Finland is the Best Place to Get Shipyard Nuclear Started

So, where do we start? One idea is Finland, a proposal that Partanen looked into with his recent study, “Shipyard Nuclear in Finland.”

Besides the fact that one of us is Finnish and therefore had the interest in, the contacts for, and cultural context needed to write such a study, there are plenty of good reasons to start there. First is that Finland has a significant and high-quality maritime industry, with experience in building all kinds of special vessels such as ice breakers, even nuclear-powered ones (although the reactors themselves were installed in Russia), large offshore oil and gas drilling platforms, military vessels, and so forth. The needed expertise and infrastructure are largely already there, along with supply chains, a high-quality domestic metal industry, and machine workshops. Finland, even if it is a small country, still manufactures big components and machines and has substantial heavy industries.

Second, Finland also has a high-quality nuclear industry that has continued operating—and even building more—nuclear plants, even as most other Western countries have turned their backs on the technology. Every decade or so, the Finish nuclear industry has applied to get a “decision-in-principle” from the Finnish parliament to build a new reactor unit, and about 60 percent of the time, they have secured that political permission. That’s not perfect, and the approved projects have not been great successes. But the continued interest in building nuclear infrastructure at least places Finland ahead of many of its peers.

Finland also has public and political support for nuclear. In fact, both are now higher than ever. Public approval for building more nuclear is at 50 percent, with an additional 24 percent accepting current levels and only 18 percent desiring a decrease. Most political parties are also constantly nudging their positions towards more positive outlooks, with the Finnish Greens becoming the first green party anywhere to dismiss its anti-nuclear stance and opt to support nuclear among other clean technologies. More than in other cultures, many people in Finland seem to recognize that nuclear is essential for meeting not only local climate targets, which are among the most ambitious in the world, but also global ones.

Like nuclear in general, SMRs have garnered support in Finland, including from most political parties. In 2020, the government started a major reform effort of nuclear legislation, in which

SMRs and new uses for nuclear are among key topics. The country's nuclear regulator is also looking into reforming its own safety regulations to be more suitable for small reactors and new use-cases. It seems that now, more than ever, is the time for novel ideas regarding nuclear, including shipyard manufacturing and offshore or nearshore siting.

In interviews of the Finnish shipyard and nuclear industries, politicians and ministry officials, the national regulator, and other key stakeholders in 2021 and 2022, it became abundantly clear that shipyard could be a significant opportunity. Finland has three large shipyards capable of designing and manufacturing floating nuclear power plants, and an additional one that already has the necessary licenses and certificates to produce nuclear-grade pressure components. Indeed, that shipyard (Pori Offshore Construction) was originally created to manufacture just those components for a planned nuclear power fleet in the 1970s. That buildout never materialized and, instead, Pori had to pivot into oil and gas drilling platforms.

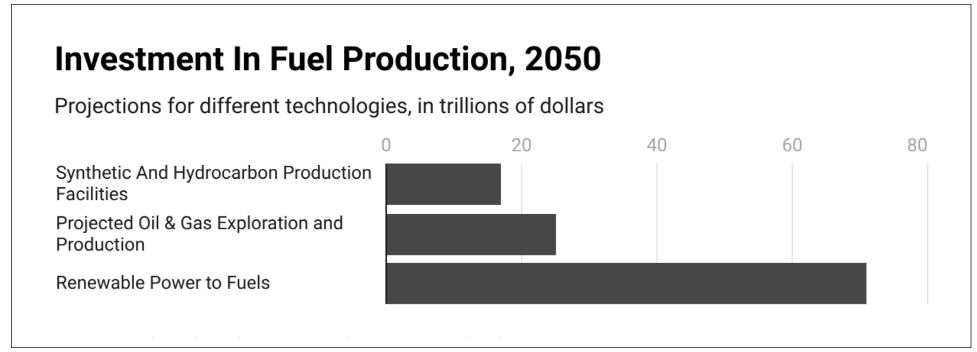
If these 4 Finnish shipyards used half of their capacity to manufacture and assemble floating nuclear power plants with 300-600 MW(e) of capacity each, they would be able to release somewhere between 1 to 2 gigawatts of new capacity, or some 15 percent of current electricity consumption, annually within about a decade. Every year, then, they would roll out new nuclear capacity about equal to the energy produced by Finland's Olkiluoto 3 reactor, a third-generation reactor that started producing power in March this year and took 16 years to build.

Shipyard nuclear would be a major boon, then, for Finnish carbon neutrality, as well as for the export of clean energy and the platforms for producing it, in Europe and beyond.

OK, But What is Shipyard Nuclear Going to Cost?

Initial estimates on the capital costs of these ships (Nth-of-a-kind) are roughly 2,500 euro per kW (close to $2,500 at current exchange rates), with a levelized cost of electricity below 40 euro per MWh. That is getting close to the cost of onshore wind; but, in this case, the money buys reliable, 24/7 energy with almost no land footprint. Indeed, the ships might take no land at all, given that they can be sited at sea or in a harbor, depending on the application. Power-production barges would likely be placed relatively near shore, with their electricity transferred back through underwater cable. As with offshore windfarms, though, farther away is also a possibility.

With costs this low, the market for shipyard nuclear energy could quickly expand from just



Source: Lucid Catalyst, The Missing Link, 2020. Created with Datawrapper

power and heat into hydrogen and synthetic fuels. Hydrogen could be produced at costs below 2 euro per kg and, with mass manufacturing, operational optimization, and advanced technologies, this cost could get close to 1 euro per kg as the technologies and systems progress. Not only would this cost be low enough to replace hydrogen that is currently made from fossil fuels and used in oil refining and the fertilizer industry, but it could eventually replace fossil fuels themselves with synthetic, carbon neutral alternatives in uses where batteries and other direct electrification options are not feasible.

If this sounds like a moonshot, let's come back down to earth for a moment. Marine nuclear, after all, is really nothing new. Hundreds of small marine reactors have been built and operated in the last 70 years, albeit mainly for military vessels. No doubt there are issues to be resolved in licensing, operating, and proving the safety case for commercial plants. And for international commercial applications, global maritime regulation and trade regimes would need to get up to speed. But, at least according to the 2022 IAEA book on Nuclear Law, the legal infrastructure is at least in place for pilot projects. And these pilot projects themselves would have a substantial technical history of maritime nuclear to start from.

It is, of course, too early to say whether Finnish actors will move forward with this particular concept, but initial interest among stakeholders with whom we've discussed the project has been good, and plans for next steps are underway. For example, the state innovation and export technology fund, Business Finland, has shown enthusiasm for providing funding for programs aimed at the commercialization and creation of this new industrial sector in Finland.

Internationally, too, there has been increasing interest in floating power plants and offshore and nearshore applications from reactor developers in the larger markets. The Russian Akademik Lomonosov, a floating nuclear power plant, has already been in operation for a couple years, and both the United States-based ThorCon and the Danish Seaborg have designed their reactors as shipyard-manufactured barges from the start. Others, like Core Power, NuScale, and KEPCO are working on various marine applications, as are the big Chinese nuclear companies. Shipyards have started to awaken into the opportunity as well, signing MoUs with reactor developers to eventually build these ships.

Obviously, all the best-case scenarios we've set out assume that governments, utilities, oil companies, and shipyards seize the opportunity. And that will, of course, be up to them—and to the individual political, economic, and regulatory conditions they face. But what we can say is that the opportunity is there, and it is massive. While the idea of manufacturing hundreds of gigawatts of nuclear plant capacity per year sounds almost impossible in the context of the current nuclear industry, this particular way of doing so at least replicates something that we already do in other industries. We already make thousands of passenger airplanes and ships per year. We already make millions of tons of ammonia to help feed us, mainly from fossil natural gas, and use billions of tons of fossil fuels in many different purposes annually.

The urgency and scale of the climate emergency demands that we leverage this existing know-how, infrastructure, network of global supply chains, and human ingenuity to transform our global energy system to keep the global economy moving, protect the wellbeing of all people, and support the health of the planet.

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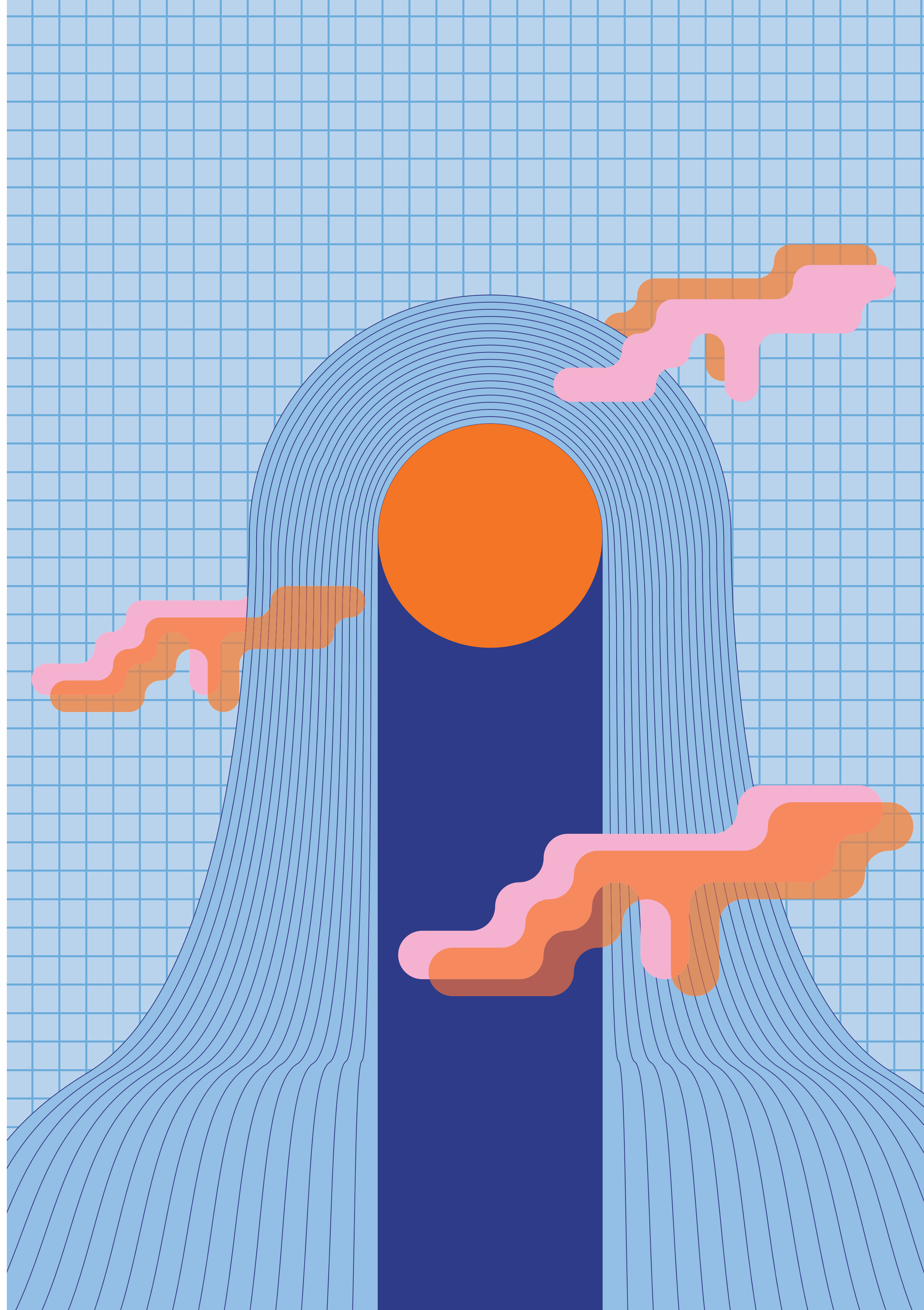
Kirsty Gogan is Co-Founder and Managing Director of the consulting firm LucidCatalyst and the climate-focused non-profit TerraPraxis. Gogan is also a member of the UK Government's Nuclear Innovation Research and Advisory Board (NIRAB).

Eric Ingersoll is Co-Founder and Managing Director of the climate-focused non-profit TerraPraxis. He is a strategic advisor and entrepreneur, and also a managing partner of LucidCatalyst.



FEATURES

09

THE REAL RISKS AT ZAPORIZHZHIA

What does the Ukraine war's new phase mean for the power plant?

SEAVER WANG

"ANY POTENTIAL DAMAGE TO ZAPORIZHZHIA IS SUICIDE." On August 18, U.N. Secretary-General António Guterres used these words to describe the risks of ongoing fighting between Russian and Ukrainian forces around the Zaporizhzhia Nuclear Power Plant in southern Ukraine. The comments came during a meeting with Ukrainian President Volodymyr Zelenskyy in western Ukraine, which Guterres was visiting during an attempt to spur peace talks.

As Ukraine continues to battle Putin's unprovoked invasion, the Zaporizhzhia Nuclear Power Plant has become a metaphor for Russia's unhinged continuation of a conflict that Russian leaders and generals had initially expected to win within days or weeks. Their nerves wracked by pinpoint Ukrainian artillery and drone attacks, Russian troops have been forced to retreat from vast swaths of Ukrainian territory in the north, northeast, and south. Russian troops near the power plant in southern Ukraine have increasingly used the facility itself as a shield to protect themselves from enemy fire.

Under international humanitarian law, nuclear power plants sit in a protected category of large-scale civil infrastructure, alongside dikes and hydroelectric dams. Some countries, including both Russia and Ukraine, maintain a longstanding policy that such protection may become invalidated if hostile forces actively use the facility as a base of operations, or if the facility is actively aiding the enemy army. With increased Russian military activity around the Zaporizhzhia plant as of this writing, such considerations have become concretely relevant.

But in this charged environment, media coverage has become less of a rational discussion of scientific risks than a focal point for moral symbolism. As of this writing, the war marks its six-month anniversary as Ukraine simultaneously marks its 31st anniversary of independence, with rumors circulating of an impending incident at the plant. Given the intense propaganda value of the current situation, observers and the general public should critically evaluate public statements and verify the details of any alleged events that may occur there over the next few days.

For months now, the situation has remained continually ripe for misinformation and misunderstanding. For one, Russian attacks on the city of Zaporizhzhia dozens of kilometers upstream are frequently mischaracterized on social media as strikes aimed at the Zaporizhzhia nuclear power plant. The city of Zaporizhzhia remains free Ukrainian territory, whereas Russian invaders have occupied the Zaporizhzhia nuclear power plant—even as Ukrainian staff have continued their work there—and the nearby city of Enerhodar since the first days of March. When Russian troops first seized the power plant before dawn on March 4th, numerous journalists and commentators mistook a fire at a training facility as a full-blown nuclear disaster, despite the fact that this building sat over half a kilometer away from the nearest reactor containment building.

Since the power plant's capture, worrying reports have surfaced regarding how occupying Russian troops have interfered with plant operations, preventing power plant workers from changing shifts, detaining plant staff, and even killing local civilians in the nearby town. A detailed FAQ from the Breakthrough Institute documents how the facility faces numerous crises that would be unacceptable during peacetime operations, from fatigued personnel to loss of several power lines that could supply backup electricity to the plant in the event of power loss. At the same time, experts, including representatives from the International Atomic Energy Agency (IAEA), have reassured the public that to date, no detectable, let alone harmful, release of radioactivity from the power plant has occurred.

So why are international observers once again directing intense attention towards the situation at the Zaporizhzhya plant, with statements like Guterres' and others warning of imminent disaster?

In September, the situation in southern Ukraine was particularly tense. To the plant's southwest, Ukrainian forces have launched a major offensive toward the Russian-occupied city of Kherson. This assault pushed Russian troops back by around 30 km at some points along the frontline and threatened to cut off enemy forces thanks to precision strikes that have damaged bridge crossings over the Dnipro River to the Russian rear.

At the same time, advanced artillery systems donated to Ukraine by the United States and allied countries have allowed Ukrainian forces to target Russian supply bases and high-value targets with devastating effect. At the local level, Ukrainian drone operators have continually harassed enemy occupiers with small explosives dropped from hovering quadcopter drones.

Russian forces in southern Ukraine are thus both on the defensive and increasingly paranoid about the threat of air and artillery attack. In recent weeks, video footage recorded inside the nuclear power plant showed that Russian forces have begun parking military vehicles inside buildings within the facility itself. Russian forces in the area also find themselves increasingly under fire from Ukrainian artillery and drone strikes, attacks which Russian spokespeople have blamed for risking damage to the plant. In response, Ukrainian officials and allies have criticized Russian actions for exposing the facility to danger, while raising the alarm over the possibility that Russian forces might stage a false-flag incident at the Zaporizhzhia plant to blame Ukrainian leaders for a nuclear accident.

> The tension around Zaporizhzhia has given the power plant symbolic significance. While threats to it are serious and real, both the combatants and their allies have incentives to exaggerate the potential danger of damage.

In this context, the increasing tension over the Zaporizhzhia facility has lent the power plant symbolic significance within the war at large. While threats to the power plant are indeed serious and real, both the combatants and their allies possess numerous incentives to exaggerate the potential danger of damage to the reactor buildings.

On August 23rd, for instance, the UN Security Council met to discuss the ongoing threat to the Zaporizhzhia plant. In a political twist, it was the Russian Federation that demanded the meeting, with the Russian representative attributing all danger of damage to the nuclear power plant to Ukrainian actions.

Neutrally-positioned countries such as Gabon and Ghana called simply for a rapid ceasefire to halt hostilities, while the United States and allies such as Norway directly condemned Russia's invasion of Ukraine and exhorted Russian leaders to withdraw their troops back behind Ukraine's internationally-recognized borders. Calling for restraint, the Kenyan representative implied, incorrectly, that damage to the nuclear facility could turn it into a nuclear weapon. Meanwhile, Ukrainian workers at the Zaporizhzhia plant took to social media to reproach occupying Russian forces for their recklessness: "Think about the future of our Earth, about the future of our and your children."

In spite of growing international drama, it is objectively clear that the Zaporizhzhia plant poses little threat to nearby populations, let alone to the world at large. The

Zaporizhzhia plant's thick steel-and-concrete reactor containment structures offer protection that significantly exceeds that of older plants like Chernobyl or Fukushima, and are rated to survive highly destructive events such as a direct jetliner collision. In addition, four of the six reactor units at Zaporizhzhia are in cold shutdown—that is, the reactors are inactive with their coolant systems resting at low temperature and atmospheric pressure. As for onsite spent fuel storage pools, the combination of backup diesel generators, a substantial reservoir of coolant, and robust containment facilities minimize risks.

Seaver Wang is the Co-Director of the Breakthrough Institute's Climate and Energy team.

The greatest concern at the Zaporizhzhia Nuclear Power Plant is rather the safety and well-being of the brave plant personnel. Russian troops have already committed numerous atrocities against Ukrainian civilians in half a year of warfare. A prolonged situation in which plant workers prioritizing the safety of the plant and local populations must confront hostile soldiers with an uncertain agenda increases the risk of interference and violence. In light of this, the logical safest path forward for the Zaporizhzhia plant is clear. Inspectors from the IAEA should receive safe passage and full access to the plant. Russian military commanders should go further by declaring the power plant and its vicinity to be a demilitarized zone. The entirety of the ongoing situation could, of course, be rapidly resolved if Russian leaders were to abandon their bloody, senseless war of aggression against Ukraine.

In the meantime, the public in Europe and across the world at large should remain skeptical in the face of both political rhetoric and misinformation on social media. Over the past six months, investigation has revealed many breaking news claims regarding the Zaporizhzhia plant to be false or misleading.

With any luck, Russian military commanders in southern Ukraine will see reason and allow the local situation to stabilize. Yet should a crisis erupt, observers should wait for reliable information from expert institutions like the IAEA before leaping to unsubstantiated conclusions. Countries at war understand well that moral victories can matter alongside military victories. Ukrainians, Russians, and their respective allies all possess powerful incentives to overstate the risks and potential consequences of damage to the Zaporizhzhia plant in order to condemn and blame the other side. Such messaging builds upon existing popular misperceptions about nuclear power plants while overshadowing more level headed evaluations of potential risk.

Objectively, any risks to human health and the environment from the Zaporizhzhia plant remain low. What minor risks do exist are overwhelmingly the fault of Russian military forces and lie wholly within the power of Russian leaders to eliminate.

Updates: In late August, a neutral mission of experts from the International Atomic Energy Agency arrived at the Zaporizhzhia plant. As of September 14, they were still there. All six reactor units at the power plant are now in cold shutdown, while three backup power lines are now able to supply electricity to the facility. The IAEA is working with Ukrainian and Russian officials to negotiate a protective zone around the nuclear power plant. As such, safety considerations at Zaporizhzhia have improved markedly, running counter to alarmed rumors of pending catastrophe. This further emphasizes the importance of level-headed analysis based on reliable, up-to-date information.

On Wednesday October 5, following a sham referendum in which the Russian Federation formally annexed Ukraine's Zaporizhzhia administrative region along with three other regions of Ukraine, Putin signed a degree nationalizing the Zaporizhzhia Nuclear Power Plant as property of the Russian state. The Ukrainian government and Ukraine's state-owned nuclear energy corporation Energoatom are refusing to acknowledge this Russian effort to forcibly transfer ownership and operation of the nuclear power plant, while the International Atomic Energy Agency still seeks to negotiate a safety and security protection zone around the facility to protect it from military operations.

It is unlikely that Russia will be able to pursue increased operation of the power plant in the near term. While the situation continues to evolve, the annexation does not likely pose any immediate threat to the plant infrastructure itself. The major concern remains the status, safety, and well-being of the plant's Ukrainian operators.

FEATURES

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Nuclear Energy By Fission

Nuclear energy by fission generates about 10 percent of the world's electricity, representing the second-largest source of low-carbon electricity after hydropower. Because nuclear power plants do not burn fuel, they do not produce greenhouse gas emissions. About 450 nuclear power reactors are in operation worldwide.

Usage of nuclear power varies from country to country. In France, for example, nearly 70 percent of the country's energy is produced by nuclear power; in Australia, that number is zero.

How fission works

Two types of physical processes produce nuclear energy from atoms: fission and fusion. Fission splits a larger atom into two or more smaller ones, whereas nuclear fusion joins two or more lighter atoms, forming a third, heavier element. Fission is the process most commonly known and referred to as nuclear power.

> Nuclear fission splits uranium atoms to generate heat and steam. It is among the most effective processes to produce the grid-scale quantities of electricity we need.

Nuclear fission splits uranium atoms to generate heat and produce steam, which is then used by a turbine generator to produce electricity. It is among the most effective processes to produce the grid-scale quantities of electricity we need.

Types of fission reactors

All nuclear fission power plants make electricity from steam created by the heat of splitting atoms. But there are two different ways that steam is used.

Pressurized Water Reactors keep water under pressure so it heats but does not boil. Water from the reactor and the water that is turned into steam are in separate pipes and never mix.

In Boiling Water Reactors, the water heated by fission boils and turns into steam to turn the generator. In both types of plants, the steam is turned back into water and can be used again in the process.

How safe are nuclear reactors?

Nuclear accidents are rare, but those that have occurred—at Chernobyl, Three Mile Island, and Fukushima—have had catastrophic consequences. Research on death rates from energy production scores nuclear among the safest, just below renewables such as wind and hydropower.

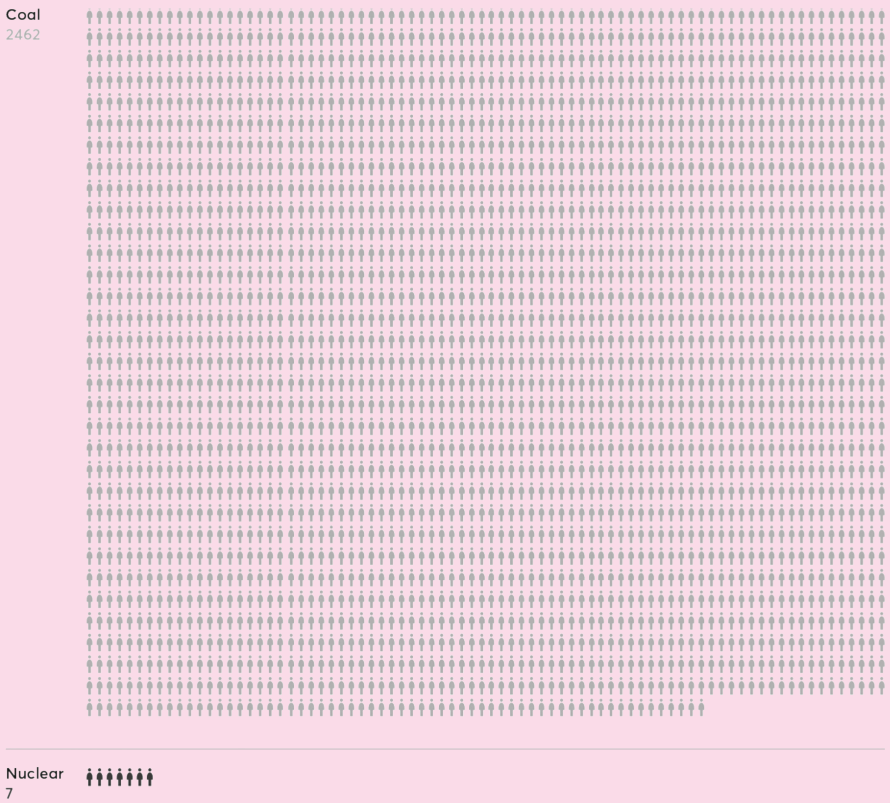
Construction and fuel

Unlike fossil fuel-fired power plants, nuclear reactors do not produce air pollution or carbon dioxide while operating. However, the processes for mining and refining uranium ore and making reactor fuel do require significant amounts of carbon-producing energy.

Nuclear power plant structures and facilities also depend on substantial amounts of metal and concrete for construction, which means significant amounts of energy in the manufacturing

Death Rates from Energy Production Per 100 TWh

As measured based on deaths from accidents and air pollution



Source Carbon Almanac

process. This contributes a great deal of carbon because concrete is a major contributor to the planet's carbon load.

Radioactive waste

A major environmental concern related to nuclear power is the creation of radioactive wastes such as uranium mill tailings, spent (used) reactor fuel, plutonium, and other radioactive wastes. The half-lives of the radioisotopes produced are very long—some greater than one million years.

Control and management of nuclear waste poses challenges. The most current method for

Land Required for Generating Energy

	ELECTRICITY GENERATED PER ACRE (GWh)		ACRES PER GWh PER YEAR*	OPTIONS FOR RECLAMATION**
	Over 75 Years	*Over 25 Years*		
Solar	25	8.33	3 (perpetual)	Remove panels or dual-use
Nuclear	16.66	16.66	0.06 (only once)	Very high cost (radioactive)
Coal	11.11	11.11	0.09 (only once)	Costly (<15% reclaimed)
Wind	2.9	0.96	26 (perpetual)	Remove turbines or dual-use
Hydro	2.5	0.83	30 (perpetual)	Drain dam and restoration
Biomass	0.4	0.13	188 (perpetual)	Replant trees

*A GWh is the same as a million Kilowat hours. ** Reclamation may not be necessary because land can be simultaneously used for other purposes.

Source Carbon Almanac. Created with Datawrapper

nuclear waste disposal is storage, using either steel cylinders as a radioactive shield or deep and stable geologic formations. The disposal of nuclear waste by storage is controversial, as the leakage of nuclear waste may cause environmental disasters. These techniques are still under development.

The future of nuclear energy by fission

The future of nuclear power plants is undecided. The world's about 450 nuclear reactors are getting older. With an average usable age of 35 years, one-quarter of all nuclear power plants in developed countries will need to be shut down by 2025.

Following the Fukushima meltdown, a number of countries began to consider phasing out nuclear programs, with Germany expected to shut down its entire nuclear fleet by 2022. The United States has 95 nuclear reactors in operation, but only one new reactor has started up in the last 20 years.

However, more than 100 new nuclear reactors are being planned in other countries, and 300 more are proposed, with China, India, and Russia leading the way. The International Atomic Energy Agency estimates that nuclear energy production will double from 2019 levels of 392 billion watts to 715 billion watts in 2050.

REVIEW

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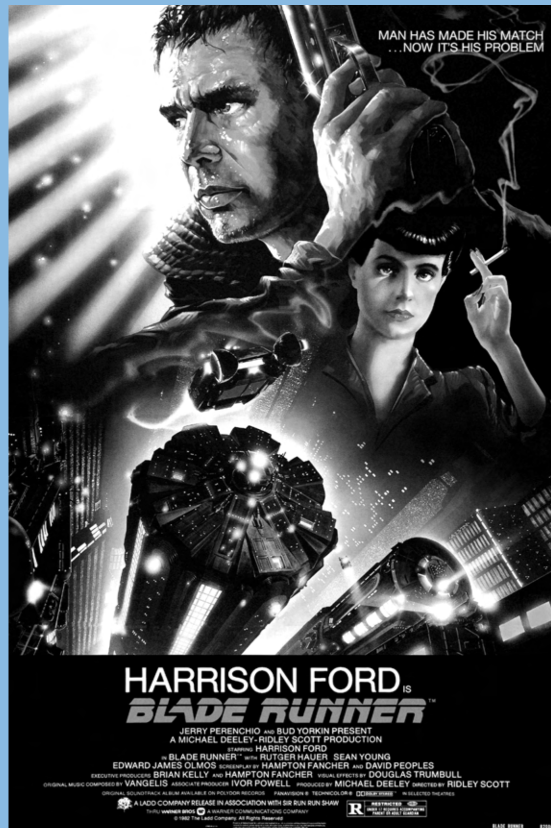

Poster from Blade Runner

Warner Brothers, 1982.

BLADE RUNNER AT 40

To address climate change, should we geoengineer the environment to be better for people—or engineer people to suit the environment?

MICHAEL PECK

If it rained in hell, this would be the Los Angeles of the future.

It drizzles in the morning, and in the evening. There is no sunshine, not even a solitary ray of light to relieve the gloom. The only illumination comes from the flames belching from smokestacks, the neon dazzle of billboards mounted on giant blimps, and the probing spotlights of omnipresent police hovercars.

This year, 2022, marks the 40th anniversary of the release of "Blade Runner." A classic science-fiction film of a dystopian future, "Blade Runner" appears to be more of a thriller than an environmental tale. But like many of its characters, the movie is deceiving.

Based on Philip K. Dick's classic 1968 novel *Do Androids Dream of Electric Sheep?* the movie is set in Los Angeles in a fictional 2019, some 37 years in the future when the movie was released. "Blade Runner" depicts a society in which synthetic human beings—called "replicants"—have been created to perform dirty and dangerous tasks ("That's Leon. Ammunition loader on intergalactic runs. He can lift 400-pound atomic loads all day and night."). They are the slaves who power humanity's colonization of the stars; the pioneers, miners, laborers, soldiers, assassins, and prostitutes who keep society functioning.

Except that this society isn't functioning. Housing on Earth is scarce and decrepit. Abandoned vehicles are strewn over streets crowded with people and prowled by gangs of thieves and roving police. The Los Angeles skyline is dominated by giant pyramids that serve as the headquarters of various megacorporations. Overhead float airships with loudspeakers and digital signs urging emigration from Earth ("A new life awaits you in the off-world colonies! A chance to begin again in a golden land of opportunity and adventure!").

And like any slave society, there is an undercurrent of fear. Replicants are engineered to be faster, stronger, and smarter than their creators. So their masters have forbidden them to live on Earth upon pain of being "retired." But sometimes, they go rogue. Now, the authorities are worried about four particular replicants who have hijacked a colonial spacecraft, slaughtered its crew and passengers, and returned to Earth.

Enter Rick Deckard, who is a former blade runner, or a human cop who hunts down replicants who have gone rogue. Deckard—played with hard-boiled cynicism by a young Harrison Ford—is forced out of retirement to locate and eliminate the four "skin jobs" who have been mingling among the real human population. But the search for humanity (or, rather, not humanity) here is nonsensical. What does it mean to be a real human? It's a deeply philosophical question, but in this frightened world, also a matter of arbitrary and instant death.

The main method this Los Angeles has found to identify replicants is by administering the so-called Voight-Kampff test, where the interviewer asks questions that would theoretically evoke an emotional response only in a real person. But the questions themselves reveal more about society, as in a test that Deckard gives Rachael, a replicant who doesn't know she is synthetic. "You're reading a magazine," Deckard prompts. "You come across a full-page nude photo of a girl. You show it to your husband. He likes it so much he hangs it on your bedroom wall." Rachel responds: "Is this testing whether I'm a replicant or a lesbian, Mr. Deckard?"

In some ways, the Voight-Kampff test doesn't even matter, whatever it measures. Fearing that their superhuman creations would develop emotions such as hatred or jealousy, the Tyrell Corporation built an organic fail-safe system into their products: replicants would be genetically engineered to live no more than four years.

But the corporation failed to consider a basic contradiction. If replicants did develop human emotion—and realized that they only enjoyed the life span of a hamster—wouldn't the will to live motivate them to somehow extend their life spans? And isn't that fierce will to live a characteristic of people rather than machines?

Engineered People

"Blade Runner" would seem to be a tale of humanity, not climatology. No one ever complains—or even mentions—the weather. Indeed, the thought of nonstop rain in Los Angeles seems almost appealing as real California bakes under a long-term drought.

The Earth in "Blade Runner" has faced a different sort of climate change. If it's always raining in southern California, then there is probably a drought somewhere else. The causes of that environmental shift are not made clear, but one look at these fictional California skies tells you that pollution must be a factor. Los Angeles doesn't look like a futuristic apocalyptic fantasy as much as it looks like a horrid industrial town out of the 19th century, with slums abutting grimy factories and belching smokestacks.

Ironically, "Blade Runner" was released in the summer of 1982, when a record El Niño unleashed massive drought and rainfall across the globe. Scientists do warn of megafloods today, but in truth, 1982's "Blade Runner" (not to be confused with the sequel, "Blade Runner 2049") is more heir to dystopian films such as "Planet of the Apes" and "Soylent Green," which depict an Earth wrecked by nuclear war or overpopulation.

While the environment is not a direct protagonist in "Blade Runner," the visuals certainly suggest that it is hostile. And a hostile earth creates the framework—or prison—in which all life and decisions are made.

Indeed, on an Earth gripped by incessant rain and darkness, only fools, misfits, and predators remain. They are essentially squatters, treated as rejects deserving of neither resources nor pity. "My glands, they grow old too fast," laments a young scientist who is 25 but looks 45. "Is that why you're still on Earth?" asks a replicant. "Yeah. I couldn't pass the medical," the scientist replies. "We've got a lot in common," the replicant sighs. "Accelerated decrepitude."

When the whole Earth is the enemy, sympathy seems almost unnatural. In a different telling, the replicants might seem heroic as they fight for the right to live. But they are not. They are scary, especially their leader, Roy Batty, an advanced Nexus 6 combat model memorably played by the late Rutger Hauer (who wrote some of his own dialogue).

If darkness is a problem, then do we need geoengineering to bring back the sun, or do we need genetically engineered people who thrive in darkness?

The replicants are human in all the ways that we register humanity: howling in pain from a gunshot wound, expressing loyalty toward one another, or even bonding with humans (as Rachael does with Deckard). They even have memories—borrowed from human people—that are implanted in their minds so that they feel less stressed.

But there is also a calculated, impersonal aspect to their personhood; they are slightly too laboratory-perfected. Do replicants really feel, or is that just a glitch in their programming? And how is it possible to spot the difference? "That Voight-Kampff test of yours," cries Rachael, when Deckard tells her she is a replicant. "Did you ever try to take that test yourself?"

In this future, then, technology is in many ways the enemy. And what is left for humanity is a muddle. In the logic of a Darwinian universe in which Earth is uninhabitable and other worlds need to be formed, it makes a certain terrible sense to create synthetic people to do the dangerous work of terraforming other planets.

But the irony of the movie is that the replicants are also the beings best suited to live on an environmentally damaged Earth. And by that logic, why not also respond to climate change on Earth by redesigning humans? If rain and darkness are a problem, then do we need geoengineering to bring back the sun, or do we really need genetically engineered people who thrive in rain and darkness?

Technology As Cheating

We already see echoes of this question in our world. Genetically modified foods are one of the greatest breakthroughs in human history. And we're busy tinkering with supplements that can make cows belch less, with meat that grows itself and with food that takes longer to go bad.

Techniques to edit human genes are likewise established. There are gene-editing therapies for some genetic disorders. A Chinese scientist was even jailed in 2019 for altering human embryos that became genetically modified babies. It may only be a matter of time before gene-editing is widely available and even used to eliminate "undesirable" physical and mental traits.

From there, it may not be such a big leap to deliberately adapt people to their environments. Earth's temperature heating up? Design people who like it hot. Water shortages? Design people who require less water. In some ways, that might be easier than colonizing other planets. While the rest of our solar system is inhospitable to human life without terribly elaborate means to keep people alive, people have been found in nearly every corner of our planet. To some extent, it happens naturally: people who live in high-altitude areas of East Africa or Nepal, for example, have a reputation for extraordinary performance as distance runners or for enduring low-oxygen environments.

The problem, of course, is the truly appalling ethics. Who would decide what genetic traits are necessary? Who would decide which are aesthetic? Is there any plausible way that this process of decision-making doesn't end with races of servants and slaves?

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Starting down this path would be an astonishing act of hubris, and as much as anything, "Blade Runner" is a parable about hubris. From the pyramid-headquarters of a corporation, a scientist decided to play God. The resulting synthetic humans revel in their mental and time-limited physical superiority. And "real" humans are left decide life and death based on the most arbitrary assumptions of what it means to be human.

Ultimately, hubris is both a cop-out and a dead end. If humanity can respond to climate change by either fleeing Earth for other worlds or modifying humans to live on a hellish Earth, then there is no incentive to try to damage the planet less now.

And that is a good lesson for us today. In the end, "Blade Runner" is not really anti-technology, but a warning not to let technology become a form of cheating. When humanity creates artificial people to do its dirty work, then it is admitting that the original Homo sapiens are incapable of taking care of themselves. A slave society is a society insecure in its abilities and too ready to compromise its morals.

It is also a society that replicates its own problems. "Blade Runner" depicts Earth as a man-made hellhole, where people seem to have given up hope of making their world a better place. Flee to another planet? Those who ruined the original are likely to repeat their mistakes.

That's an unsentimental conclusion in an unsentimental world. But the movie does have poignant moments, and one of the most comes in the words of a dying Roy Batty: "I've seen things you people wouldn't believe. Attack ships on fire off the shoulder of Orion. I watched C-beams glitter in the dark near the Tannhauser Gate. All those moments will be lost in time like tears in rain."

No one in "Blade Runner" can escape the rain—neither by fleeing nor by creating humans who don't so much mind it—and neither can we.

REVIEW

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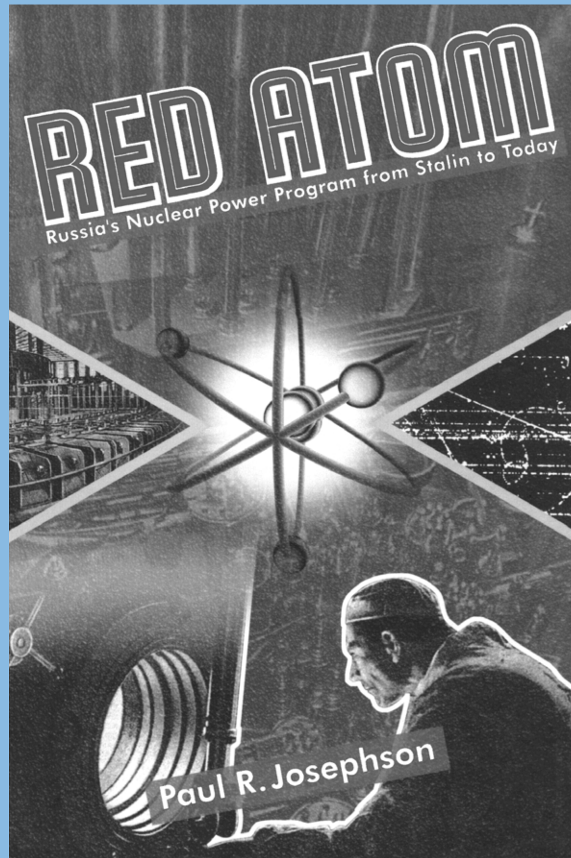

RED, WHITE, AND BLUE ATOM

What the United States should learn from the Soviets' efforts to spread nuclear energy around the world

MATTHEW L. WALD

TECHNOLOGY IS AN INSTRUMENT OF foreign policy. Energy technology is that plus a tool in the fight against climate change. Nuclear energy technology is all that and even more. It conjures energy independence from shaky global markets, physical security against great power rivals, an economic opportunity to corner new technology markets around the world—indeed, a path to a much more promising future.

All that ought to make the next generation of nuclear reactors very important to the United States, as it focuses its considerable powers of innovation and high-tech manufacturing on the challenges of carbon-free, dependable, and independent electricity generation while also facing down a resurgent Russia and a powerful China. If policymakers have doubts about nuclear's centrality to their goals, it is worth a glance backward, at the Soviet Union.

What the Soviets Got Right About Nuclear

In their day, Soviet leaders weren't very good at lots of the basics, like supplying food, clothing, and shelter. But they outperformed in other areas, including in the electrification of their vast territory. Earlier than in many other nations, they recognized electricity as an essential precursor to health and prosperity. Communism, as Vladimir Lenin once famously defined it, was "Soviet power plus the electrification of the whole country."

Red Atom: Russia's Nuclear Power Program from Stalin to Today

By Paul R. Josephson

University of Pittsburgh Press, *1999, 352 pages.*

Part of that electrification was novel ways of producing power, namely through nuclear. Russia today gets about 20 percent of its electricity from nuclear reactors, a proportion that has been gradually rising. Adding reactors to the Russian grid helps the country meet rising energy demand, while also reducing domestic use of fossil gas, which can be sold to Europe. It also reduces the amount of coal that must be dug and shipped on the railways, which have limited capacity. In addition, some Russian reactors produce steam that is used for heating homes, factories, and businesses, thus reducing the country's use of fossil fuels still further.

All that would be evidence enough that Russia's decision to focus on electrification through nuclear was a wise one. But Soviet Moscow's nuclear ambitions never stopped in Russia proper. Instead, Soviet leaders strove to spread nuclear technology to all the Soviet republics, under the slogan, "Physics to the Provinces!" And then the Russians pushed further still, to the satellite countries of Eastern Europe, and to China. That campaign has never really stopped.

Over the years, Russia has sold its water-based Vodo-Vodyanoi Energetichesky Reactor (VVER) models, its modern class of reactor, to Armenia, Bangladesh, Belarus, Bulgaria, China, the Czech Republic, Egypt, Finland, East Germany, Hungary, India, Iran, Slovakia, Turkey, and Ukraine. (Some are still in the planning or construction phase, some have been shut down, some have been modified to meet Western safety standards, and at least one in Ukraine is now occupied.) Moscow is also discussing building a reactor with two former Soviet republics, Kazakhstan, which is a major uranium exporter, and Uzbekistan. That is in addition to

Russia's graphite-based reactors, the most famous of which was at Chernobyl but which also include installations in Lithuania that are now shut down.

Russia's Lessons for the United States

As the world enters an era of rapid growth in electricity consumption, concern about human-caused climate change, and increasing rivalry between the West and Russia and China, it may be time for a closer look at how the Soviet Union pulled off its nuclear feat. In 1999, Paul R. Josephson, a professor of Soviet and Russian history, published *Red Atom*, a thorough work on the subject. Although the book is more than 20 years old, it is looking timelier than ever.

For the Soviets, electrification was the key to growth and, in turn, great power. Nuclear technology was the medium, explains Josephson, because it gave the regime prestige and legitimacy. Along with other achievements like Sputnik, the first artificial satellite, it also advertised the scientific superiority of the Communist system. And, as a side benefit, nuclear technology would be a way to engage the technological elites of societies that the Soviets wanted to pull into their orbit, some already within the USSR, some adjacent.

The Soviets pursued some technological dead-ends, notes Josephson, but they did build the first reactor connected to an electricity grid, Obninsk, and they took the first steps toward fusion. (That's why the heart of experimental fusion reactors is still named with a Russian term, *Tokomak*.) They also built nuclear icebreakers, which still operate. Other efforts were unsuccessful, but finding dead-ends is an inevitable cost of pioneering new technologies.

More than dead-ends, however, the Soviet Union and then Russia found experts, collaborators, and markets, all of which formed the basis of enduring relationships with many developing countries. Plans for new reactors wax and wane, but even in the last few years Russia has established nuclear cooperation agreements with Argentina, Bangladesh, Brazil, Cambodia, Myanmar, and Zambia, who join the other countries already in Russia's nuclear orbit.

Old trade and infrastructure ties persist, too. As of 2021, according to a May 2022 report from Columbia University, about 46 percent of the world's total uranium enrichment capacity was in Russia. In fact, although the Soviet Union broke up more than 30 years ago, it is only now that Ukraine, the Czech Republic, and Slovakia are starting to really break free from the Russian nuclear supply chain by obtaining uranium fuel assemblies from the West. Even 16 percent of the United States' uranium, according to the U.S. Energy Information Administration, has come from Russia, with another 30 from Russian-allied Kazakhstan and Uzbekistan.

There is a lesson here for the United States: if the future is still nuclear, it is best to dominate advanced nuclear technology, expertise, and markets as early as possible. U.S. policymakers should not wait for the top engineering talent of the countries in Africa, Asia, and Latin America that are now industrializing to look to Beijing or Moscow for technology, assistance, or parts—much to less have to look to Beijing or Moscow for those things themselves.

Nuclear for the Planet

Beyond the geopolitical reasons to pursue next-generation nuclear are the environmental ones. In wealthier countries, it is clear that domestic transitions to clean energy will require a very large build-out of nuclear energy, as the Breakthrough Institute's recent "Advancing Nuclear Energy" report made clear.

In much of the rest of the world, the problems are even more basic. Even today, hundreds of millions of people around the world lack access to reliable electricity, and burn dung or wood harvested from eroding hillsides for fuel. They cook food over indoor fires and inhale the smoke. Billions more get electricity by burning coal, which is still the world's largest energy source and still growing robustly.

> *There is no reason besides lack of consistent government policy and clumsy regulation that the United States can't catch up on nuclear deployment.*

If the world wants to phase out coal, provide enough electricity so that everyone can enjoy its benefits, and do so sustainably, we are going to have to invent cleaner ways of making electricity, prototype and perfect them, and then make them available worldwide.

Nuclear will have to part of those plans. The reactors currently moving toward commercial deployment in the United States and elsewhere are better suited to the electric grids of emerging economies than the behemoths now in operation. The new ones are smaller, which is essential if they are going to be deployed on grids that are less extensive or weak. In fact, today's reactors are so contained that they can be factory-built and then delivered by rail or barge, in a limited number of pieces. That makes construction easier in difficult geographies or where infrastructure that is less reliable.

The main nuclear enterprise owned by the Russian government, now called Rosatom, expects to turn a profit by supplying fuel and nuclear services, as well as by building and owning the reactors and selling the electricity. But it also buys Russia influence. And influence is something the United States should want, too.

Making American advanced reactors ready for export is going to take policy support. But because of the overlap between military and civilian technologies, there are good reasons here, too, for the United States to seek to dominate the export trade, so that it can send its nonproliferation tools along as part of the package. (This was ostensibly a Russian goal, as well, with reactors built under the slogan "Let the atom be a worker, not a soldier." But presumably American export controls would be a bit more robust.)

How the United States Can Regain Its Edge

None of this means much, though, if the United States doesn't act soon. Around the world, pressurized water reactors derived from American designs still predominate, but the United States is no longer the leading exporter of reactors.

Nuclear industry lobbying materials once called for "maintaining" American leadership in nuclear exports, but now they speak of "regaining" it.

China, the preeminent nuclear builder (including on the construction of four Westinghouse-designed large advanced reactors in China), and South Korea, a close runner-up (which is now completing construction of a four-reactor complex in the United Arab Emirates) hold a clear edge in construction expertise for current-generation technology. Yet tellingly, when the United Arab Emirates began work on its giant nuclear project, it also hired American experts in reactor operations to go along with its South Korean designs.

Russia, likewise, operates two "fast spectrum" reactors, models with more safety advantages, and that can use a wider variety of fuels, including some materials now considered waste. It recently deployed a floating reactor. By invading Ukraine, Russia may have set itself back, alienating many export markets, although Egypt, at least, is moving ahead with a Russian-built, Russian-financed nuclear project.

Matthew L. Wald is an independent energy analyst and writer. He was a reporter for 38 years at *The New York Times* where he covered climate, energy, and other subjects. He was also a policy analyst and communications consultant for six years at the Nuclear Energy Institute.

Still, there is no reason besides lack of consistent government policy and clumsy regulation why the United States can't catch up. This country invented the Internet and the personal computer, sent space probes to planets across the solar system, and developed and deployed effective COVID vaccines in a matter of months. It is brimming with venture capitalists and engineers who are stalking the next big thing. It has the proper combination of entrepreneurial ambition, technical expertise, and freedom to innovate.

The country just needs a little imagination and a clear understanding of the task ahead. Job two will be using zero-carbon reactors to cleanly meet galloping demand for electricity around the world and displace coal as the default option. Job one is demonstrating to the world that we know how to do this at home.

POEMS

02

AMPHIBIOUS

Turtle beds, I imagined, seeing turtles bask
on a sunny log, their shells the shell game
missing from the sand below.

But no—
a friend, mother of a budding fisherman,
taught me to see instead the fish sweeping
debris from the creekbed: male fish, sculpting
with their tails these ovals a little longer
than their bodies, building stony nests
to woo a mate, to host a swarm of eggs.

Once you know to look, you can't help but see
that whole line of nests, down where the creek
curves south and the shallows catch full sun.
Yet for years I had passed, unseeing,
as those fish nests sketched an amphibious world,
modeled the same rules in force above and below
the water's blazing, blinding surface—

a world where today we might see sunfish
sailing through the clouds, where tomorrow we might
startle at our constellated bodies swirling
through the waters, or discover a swallow
of bluegills nesting on the river's bed,
singing of summer in a different key.

— *Betsy Bolton*

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