The way the Land of the Rising Sun built and lost its dominance in photovoltaics shows just how vulnerable renewables remain to changing politics and national policies.

By Peter Fairley

Can Japan Recapture Its Solar Power?

It's 38 °C on the Atsumi Peninsula southwest of Tokyo: a deadly heat wave has been gripping much of Japan late this summer. Inside the offices of a newly built power plant operated by the plastics company Mitsui Chemicals, the AC is blasting. Outside, 215,000 solar panels are converting the blistering sunlight into 50 megawatts of electricity for the local grid. Three 118-meter-high wind turbines erected at the site add six megawatts of generation capacity to back up the solar panels during the winter.

Mitsui's plant is just one of thousands of renewable-power installations under way as Japan confronts its third summer in a row without use of the nuclear reactors that had delivered almost 30 percent of its electricity. In Japan people refer to the earthquake and nuclear disaster at Tokyo Electric Power Company's Fukushima Daiichi nuclear power plant on March 11, 2011, as "Three-Eleven." Radioactive contamination forced more than 100,000 people to evacuate and terrified millions more. It also sent a shock wave through Japan's already fragile manufacturing sector, which is the country's second-largest employer and accounts for 18 percent of its economy.

Eleven of Japan's 54 nuclear reactors shut down on the day of the earthquake. One year later every reactor in Japan was out of service; each had to be upgraded to meet heightened safety standards and then get in a queue for inspections. During my visit this summer, Japan was still without nuclear power, and only aggressive energy conservation kept the lights

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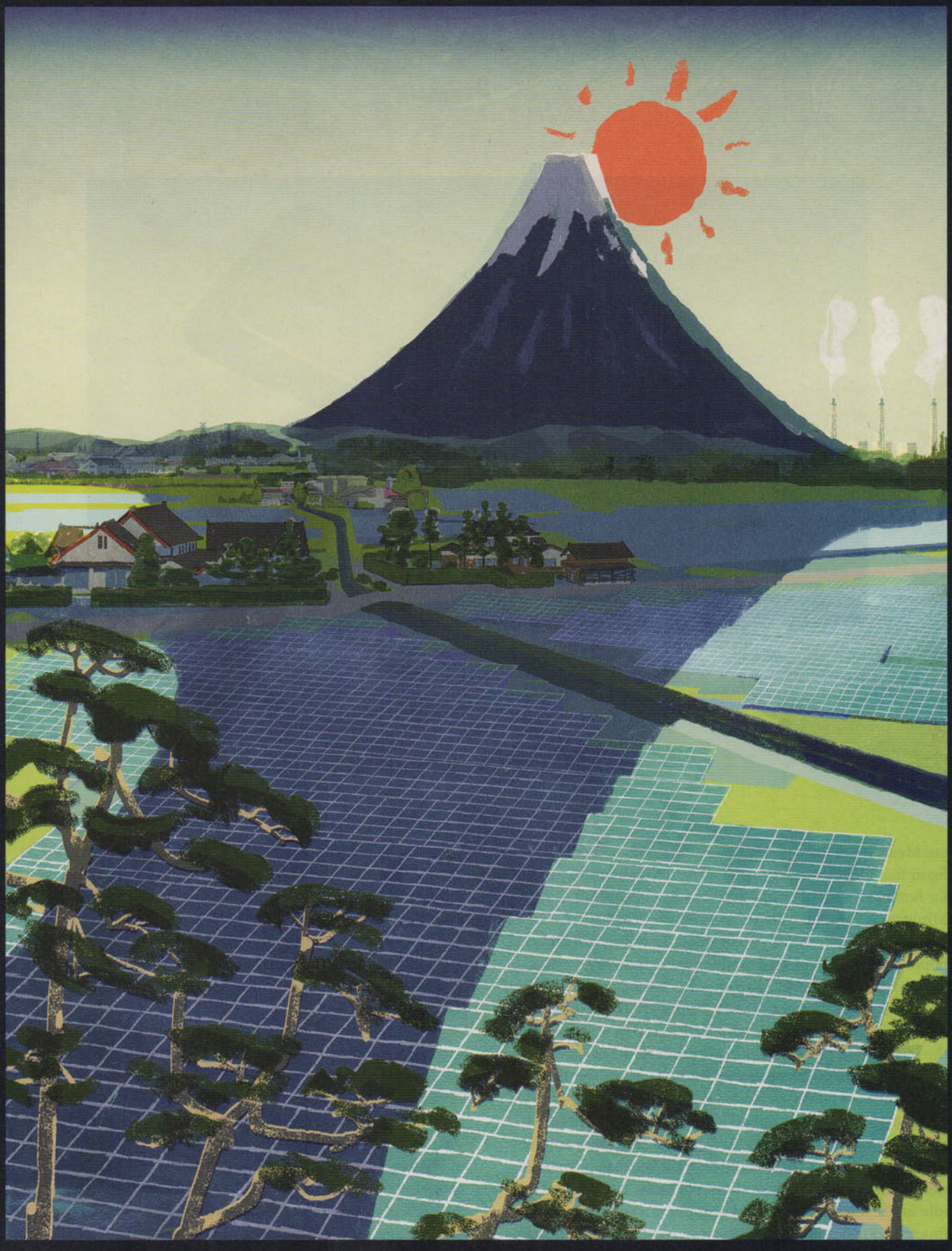

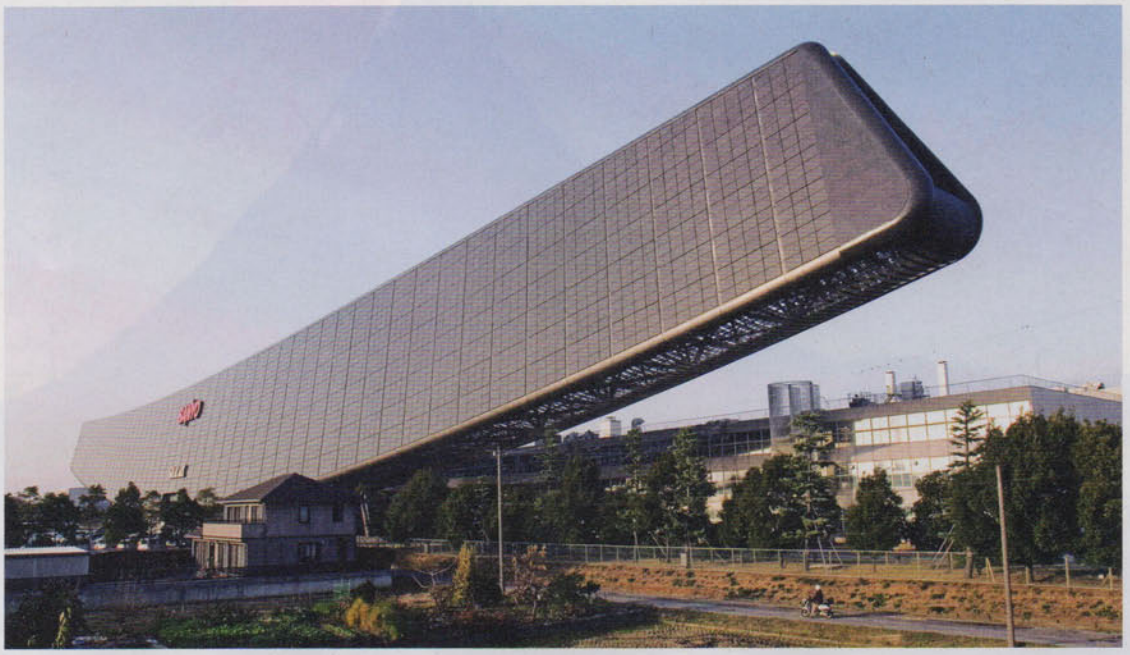

Sanyo Electric's so-called Solar Ark, built in 2001 during the heyday of the country's initial solar boom, was designed to generate 630 kilowatts of power, making it one of the world's largest solar facilities. It boasts 5,046 solar panels.

on. Meanwhile, the country was using so much more imported fossil fuel that electricity prices were up by about 20 percent for homes and 30 percent for businesses, according to Japan's Ministry of Economy, Trade, and Industry (METI).

The post-Fukushima energy crisis, however, has fueled hopes for the country's renewable-power industry, particularly its solar businesses. As one of his last moves before leaving office in the summer of 2011, Prime Minister Naoto Kan established potentially lucrative feed-in tariffs to stimulate the installation of solar, wind, and other forms of renewable energy. Feed-in tariffs set a premium rate at which utilities must purchase power generated from such sources.

The government incentive is what motivated Mitsui to finally make use of land originally purchased for an automotive plastics factory that was never built because carmakers moved manufacturing operations overseas. The site had sat idle for 21 years before Mitsui assembled a consortium to help finance a $180 million investment in solar panels and wind turbines. By moving fast, Mitsui and its six partners qualified for 2012 feed-in tariffs that promised industrial-scale solar facilities 40 yen (35 cents) per kilowatt-hour generated for 20 years. At that price, says Shin Fukuda, the former nuclear engineer who runs Mitsui's energy and environment business, the consortium should earn back its investment in 10 years and collect substantial profits from the renewable facility for at least another decade.

Overnight, Japan has become the world's hottest solar market: in less than two years after Fukushima melted down, the country more than doubled its solar generating capacity. According to METI, developers installed nearly 10 gigawatts of renewable generating capacity through the end of April 2014, including 9.6 gigawatts of photovoltaics. (The nuclear reactors at Fukushima Daiichi had 4.7 gigawatts of capacity; overall, the country has around 290 gigawatts of installed electricity-generating capacity.) Three-quarters of the new solar capacity was in large-scale installations such as Mitsui's.

POLARIS

An image from Japanese television captures smoke rising after a hydrogen explosion at Fukushima Daiichi's unit 3 on March 14, 2011, days after the initial earthquake. Following the Fukushima disaster, all the country's nuclear reactors were shut down.

AP IMAGES

Yet this explosion of solar capacity marks a bittersweet triumph for Japan's solar-panel manufacturers, which had led the design of photovoltaics in the 1980s and launched the global solar industry in the 1990s. Bitter because most of the millions of panels being installed are imports made outside the country. Even some Japanese manufacturers, including early market leader Sharp, have taken to buying panels produced abroad and selling them in Japan.

How Japan—once the world's most advanced semiconductor producer and a pioneer in using that technology to manufacture photovoltaic cells—gave away its solar industry is a story of national insecurity, monopoly power, and money-driven politics. It is also a tale with important lessons for those who believe that the strength of renewable technologies will provide sufficient incentives for countries to transform their energy habits.

In Japan, for most of the 2000s, impressive advances in photovoltaics were ignored because the country's powerful utilities exerted their political muscle to favor nuclear power. And despite resurging consumer demand for solar power and strong public disdain for nuclear, the same thing could happen again. Will a country with few fossil-fuel resources and bleak memories of the Fukushima disaster take advantage of its technical expertise to recapture its position as a leading producer of photovoltaics, or will it turn away from renewable energy once more?

Riches

Longer than three football fields and over 37 meters tall, the Solar Ark is clearly visible from the Tokkaido Shinkansen as the bullet train crosses central Japan. The structure, covered with photovoltaic panels, looks like a temple of energy from another era—a time when Japan owned the solar-power industry. Sanyo erected the Ark in 2001, arraying on it 5,046 solar panels capable of generating 630 kilowatts of pollution-free electricity.

The era that gave rise to this feat began with the energy crises of the 1970s, when spiking global petroleum prices pummeled Japan's export-driven manufacturing economy. The country harnessed its dominance in the production of electronic semiconductor chips to pursue alternatives for cleaner, safer power in photovoltaics. And unlike other countries, such as the United States, it stuck with the resulting solar development programs even when oil prices dropped in the 1980s. Between 1985 and 2007, Japanese researchers filed for more than twice as many patents in solar technologies as rival U.S. and European inventors combined. Companies like Sharp, Sanyo Electric, Panasonic, and Kyocera became the clear leaders in solar technology. Japanese producers began ramping up sales and solar installations in the 1990s. By 2001 total solar-power output in Japan was 500 times higher than it had been a decade earlier—a decade in which U.S. solar generation edged up by a meager 15 percent.

Then it all came crashing to a halt a decade ago as the country staked its future on nuclear power.

The government's nuclear plans were ambitious: by the time Fukushima Daiichi melted down, they would call for 14 additional reactors by 2030, which would have nearly doubled nuclear generation to account for 50 percent of Japan's power supply. Meanwhile, photovoltaic sales in Japan declined during the mid-2000s, and by 2007 Japanese producers had ceded global market leadership to U.S., Chinese, and European manufacturers. In just a few years, the country had gone from industry leader to has-been.

What turned Japan away from the sun was a pernicious blend of perception, culture, and politics. Nuclear power had an aura of strength, while energy based on intermittent renewable power sources looked weak and unreliable—an impression encouraged by the country's politically powerful utilities. Though Japan has numerous locations that are ideal for wind and solar power, power companies convinced the public that energy choices were limited. "We are really severely of the mind-set that we lack resources and that Japan has to depend on imported fuel," says Mika Ohbayashi, director of the Tokyo-based Japan Renewable Energy Foundation.

The utilities' view was colored by self-interest. Japan's 10 utilities were (and remain) vertical monopolies. Each controls power generation, transmission, and distribution in its respective region, and its grids are designed to deliver electricity from centralized power plants—including large nuclear reactors. They lack, by design, the interconnections that facilitate the safe use of variable power generation. In most industrialized countries, governments have broken up the monopolies in power markets, freeing operators of transmission grids to

A Parallel History

SOLAR

1961: Sharp makes a prototype transistor radio that uses solar cells.

1963: Japan installs a 242-watt solar array, the world's largest, on a lighthouse.

1976: Sharp sells the first calculators with solar cells.

1980: Sanyo produces the first solar cells from thin films of amorphous silicon.

1991: Kyocera installs Japan's first grid-connected solar plant.

1992: Sharp reports record efficiency of 22 percent for solar cells suitable for mass production.

1994: Japanese producers commercialize residential solar modules.

1998: Kyocera becomes the world's largest producer of solar cells.

2001: Sanyo builds a 630-kilowatt "solar ark."

2004: Government ends rebate for residential rooftop solar panels.

2012: Feed-in tariff provides incentives for renewable power.

2013: Kyocera starts up a 70-megawatt solar plant, the largest in Japan.

2014: Panasonic reports a silicon solar cell with record-breaking efficiency.

NUCLEAR

1966: Japan's first commercial nuclear power reactor, a 160-megawatt unit, begins operating.

1971: TEPCO's first nuclear reactor, a 460-megawatt light-water reactor, begins operations in Fukushima.

1995: TEPCO's nuclear power reaches one billion megawatt-hours.

1997: TEPCO completes the Kashiwazaki-Kariwa plant, with a capacity of 8.2 gigawatts.

2002: The government's 10-year plan calls for the addition of nine to 12 new reactors by 2011.

2011: Nuclear power, generated at over 50 reactors, accounts for 30 percent of the country's electricity.

2011: In the aftermath of the Fukushima accident, many of the country's reactors are shut down.

2012: The last operating reactor, the Tomari plant in Hokkaido, is shut down. Reactors at the Oi plant restart two months later.

2013: Oi plant shuts down for maintenance, leaving Japan without nuclear power.

2014: Officials approve restart of the Sendai nuclear power plant, the first since more stringent post-Fukushima safety regulations.

build those interconnections, but Japan's utilities have bucked the deregulation trend. The interconnection problem is further compounded by an artifact: two AC frequencies that split the country's electrical system in half. Eastern Japan operates at 50 hertz, while western Japan uses 60-hertz power—a barrier that proved crippling in 2011, in the immediate aftermath of the Fukushima disaster, when a suddenly underpowered Tokyo could access little of Osaka's surplus power.

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Asked why Japan chose not to push solar power aggressively when it dominated the global industry, former prime minister Kan told me he puts the blame squarely on the country's utilities: "The reason is very clear. The electric power companies, the people who wanted to promote nuclear power, were opposed."

Revival

In a subdivision spreading over reclaimed land in the bay in Ashiya, a city between Osaka and Kobe, a 400-unit residential development called Smart City Shio-Ashiya ("Salty-Ashiya") is taking shape, the brainchild of the Panasonic subsidiary PanaHome. On a Sunday in July, solar panels atop each of the 50 houses built to date are pumping surplus power into the local grid, and PanaHome salespeople are selling a couple with toddlers on the homes' energy benefits and earthquake resistance.

Shio-Ashiya's two-story homes include geothermal heating and cooling and other green design features to minimize power consumption, while the high-efficiency rooftop solar panels maximize power generation. The surplus power should, according to PanaHome saleswoman Saho Watanabe, earn residents roughly 100,000 yen ($825) each year. Watanabe touts another feature, which should be invaluable when the grid goes down—say, in an earthquake or typhoon. She opens a cupboard in the dining room of a model home to reveal a lithium battery that, working with an energy management system near the kitchen, can run the family's AC/heat pumps, first-floor lighting, and refrigerator for about two days.

Panasonic's solar hopes rest on a technology invented by researchers at Sanyo in the 1990s and acquired by Panasonic four years ago when the corporations merged. The solar cells combine conventional crystalline-silicon and thin-film amorphous-silicon technologies to achieve relatively high efficiency in converting sunlight to electricity. Called HIT, for heterojunction with intrinsic thin layer, the hybrid technology has become a mainstay of the company's solar strategy.

Shingo Okamoto, a materials scientist who spent his career at Sanyo Electric before becoming director of solar R&D for Panasonic's EcoSolutions business group, says the panels are earning premium pricing in domestic sales because they produce far more electricity from a given rooftop than the cheaper polycrystalline panels that dominate the market. Assuming that each household consumes electricity at the Japanese average of 1,400 kilowatt-hours per year during daylight hours, he says, a household with the Panasonic system will have 52 percent more surplus power to return to the grid than a home with an ordinary solar system.

Residential power in Japan is pricey—at 24.33 yen (20 cents) per kilowatt-hour in 2013, it was nearly double the U.S. average. And given that electricity prices are "sure to keep going up," says Okamoto, the most efficient rooftop photovoltaic systems will have a strong advantage. When we met in July at Panasonic's Shiga plant, east of Kyoto, the plant had just started shipping its newest and most powerful panel design. The advances behind the panel, which uses cells with an efficiency of 22.5 percent, include a light-scattering film on the backside to enhance light absorption. Assembly lines were running 24 hours a day to keep up with domestic demand.

Further advances are in the pipeline. In April, Okamoto's group produced a silicon solar cell that reached 25.6 percent efficiency, breaking a 15-year-old world record of 25.0 percent. Though the record was set in the lab using a prototype device, Okamoto predicts that the group will ultimately be able to produce commercial cells whose efficiency is within a few percentage points of crystalline silicon's theoretical limit, 29 percent.

Repowering

Across the coastal mountains from the smashed reactors at Fukushima Daiichi and the contaminated landscape they created, one of the world's most advanced facilities dedicated to renewable-energy R&D is gearing up. The $100 million complex opened in April in Koriyama, Fukushima Prefecture's commercial center, and pulls together previously disparate research by Japan's science and technology agencies. The insti-

tute is not here by accident. It's an explicit commitment to the emotionally and economically devastated region.

The verdant prefecture north of Tokyo remains depopulated after the earthquake, tsunami, and meltdowns of March 2011. Many of the more than 100,000 residents rendered homeless by the disasters will never return. Replacing lost residents and businesses in an area known for radioactive contamination is not easy. Solar-powered radioactivity monitors in Koriyama show that the air is safe, but 100 kilometers to the east, Tokyo Electric Power Company (TEPCO) still struggles to keep contamination from polluting both groundwater and the sea.

The Koriyama R&D facility boasts state-of-the-art labs for crystallizing, slicing, and patterning silicon wafers, and its production line can churn out up to 360 wafers an hour. Outside, a variety of photovoltaics are being tested, along with a modest-sized wind turbine and a large grid-connected battery. Its most ambitious program is directed by Makoto Konagai, one of Japan's most celebrated solar scientists, who has moved to Koriyama from the Tokyo Institute of Technology. His goal is to smash through the theoretical efficiency limit of silicon cells, demonstrating rates of 30 percent by 2016 and up to 40 percent by 2021. It is an ambitious plan, but three large manufacturers, including Panasonic, have signed on.

While some other researchers seek more efficient alternatives to silicon, which accounts for 90 percent of current solar production, Konagai seeks to redesign the silicon cell from top to bottom. One of his teams, for example, is developing a casting method to produce higher-quality silicon ingots. Another team is rethinking the way semiconductor structures are patterned to turn silicon wafers into cells: Konagai's plan is to etch or build vertical structures just a few nanometers across, almost 100,000 times narrower than the silicon wafer itself. If his simulations are good, the resulting nanowires or nanowalls will alter the electrical behavior of the silicon within, boosting its potential to absorb light and gather electrical charge.

In June 2011, Fukushima's previously pro-nuclear governor, Yuhei Sato, declared that Fukushima should pin its future on renewable energy. Community activists initiated dozens of projects across the prefecture, and in 2012 it set a goal of increasing renewable energy from 22 percent to 100 percent of its power supply by 2040.

The cold reality of Japan's energy predicament, however, is that such bold ambitions are likely to fall short. The type of solar expansion that can be expected from feed-in tariffs alone isn't likely to meet the prefecture's goals—or even to replace the power that Japan's nuclear fleet once delivered. And political and economic forces don't seem to favor policies that would expand renewables more dramatically.

Projections by the Japan Photovoltaic Energy Association, a Tokyo-based trade group, suggest that annual solar installations will peak this year just shy of seven gigawatts. The group predicts that total installed solar capacity in Japan will reach 102 gigawatts by 2030, which would be enough to meet only a small fraction of the country's electricity needs. Moderate deployment of wind power would provide some additional electricity. But Japan needs far more. While Japanese consumers and industry have cut power demand since 2011, utilities covered most of the nuclear shortfall by ramping up combustion of imported natural gas, petroleum, and coal. Fossil fuels accounted for some 89 percent of Japan's electricity generation in 2012. As a result, its total greenhouse-gas emissions were 7 percent higher that year than in 2010.

The prospects for renewable power could get worse. To hedge against the possibility that they may be unable to restart nuclear reactors, utilities are building a new generation of coal-fired power stations. By Ohbayashi's count, some 13 gigawatts of new coal-fired power generation are now in development.

Meanwhile, the relatively high cost of Japan's solar power threatens to incite a backlash against renewable energy, encouraged by the pro-nuclear utilities. "There is no doubt that with the current photovoltaics, power generation is expensive," says Okamoto, expressing his personal viewpoint rather than Panasonic's. He fears negative reactions from ratepayers, whose rising power bills pay the tariffs that fund photovoltaic systems on rooftops and at power plants like Mitsui Chemicals': "If we continue to expand our business with the current level of costs, we may have objections."

What's more, the old politics that favor nuclear power seem to be returning. Though opinion polls consistently show that a majority of Japanese oppose restarting the utilities' idled reactors, Prime Minister Shinzo Abe vows to restart those deemed safe by Japan's Nuclear Regulation Authority. In July the agency issued the first such certification, to a pair of reactors on the southern island of Kyushu—even though offsite emergency control centers mandated after Fukushima have yet to be completed and the reactors are dangerously close to an active volcano. Iodine pills were quickly distributed to the reactors' neighbors, and the precedent-setting restart is expected soon, after getting the green light from the local governor and the plant's host city, Satsumasendai, whose economy is crippled without the jobs, tax dollars, and business that the plant provides.

At the same time, utilities are delaying grid connections to renewable developments or imposing grid-upgrade fees that render renewable projects infeasible. The pushback is hitting

Workers watched in October as a crane lifted a section of a radiation shroud that had been placed over a reactor at Fukushima after the earthquake. Lifting the cover exposed the debris inside the destroyed building for the first time since 2011.

THE ASAHI SHIMBUN: GETTY IMAGES

wind power hardest. Japan's meager market for wind turbines has actually *slowed* since Fukushima.

This summer METI launched a committee to manage the implementation of new energy policies. One topic: recent efforts by utilities and the government to restrain further solar installations. Ohbayashi says METI is backpedaling because it misjudged the commercial potential of renewables and their potential impact on the utilities. Says Ohbayashi, "They didn't foresee the explosive growth of photovoltaics."

The Japanese government has plans to radically overhaul the country's balkanized wholesale market and power grid, preparing for a future in which producers compete for the right to deliver power. In that scenario, renewable energy could thrive.

The most critical step, however, is still years away: forcing the vertically integrated utilities to "unbundle" their power generation and transmission businesses. Unbundling is essential to create a level playing field for producers and a system optimized to deliver the cheapest and cleanest power available in real time.

Reëngineering the grid to accommodate massive flows of renewables such as wind and solar is a potentially expensive route for Japan. However, it's not necessarily more costly than the path back to nuclear that the current government and the utilities are charting. Factoring in the cost of insurance against accidents and upgrades to prevent them could double the cost of nuclear energy.

As former prime minister Naoto Kan told me, the disaster at Fukushima Daiichi has forever altered the economics of nuclear power. "In the past, nuclear power was said to be able to supply power at a very cheap cost, but we know now that is not correct," he said. "That calculation assumed that no accidents could occur. Now we know they can."

Peter Fairley is a contributing editor for MIT Technology Review.