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RESILIENCY:
How Superstorm Sandy Changed America's Grid

by Stephen Lacey

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Forward

The electricity industry is on the cusp of a dramatic transformation as the proliferation of distributed energy resources and customer energy management solutions create complex and wide-reaching changes to power infrastructure, market design and business models. Increasing customer adoption of distributed generation, microgrids, energy storage and demand response presents an unprecedented opportunity for utilities, technology providers, third-party energy providers and customers to create a sustainable, digital, interactive and efficient power network.

Like many areas of innovation and transformation in adjacent markets, this activity plays out at the boundary, or edge, of traditional, stable and well-understood territories. This is what the industry is coming to know as the grid edge.

Here at Greentech Media, we're excited to publish our first ebook, Resiliency: How Superstorm Sandy Changed America's Grid, under our Grid Edge program umbrella. Since our founding, we've set out to cover three major topical areas in great detail: solar power generation, distribution grid modernization and consumer energy efficiency evolution.

Over the last decade, these areas have grown independently of one another in terms of market size, regulatory reform and technology evolution. But we knew there would come a point when these markets would converge, signaling the need to view them more collectively as a holistic, next-generation energy system. That point in time came in 2013 when we launched the Grid Edge program across the entire Greentech Media product platform – including the Grid Edge Executive Council and the Grid Edge Live 2014 conference.

The Grid Edge program has blossomed in 2014 and will continue to grow across the GTM platform in 2015 and beyond. There are five primary catalysts that led us to sharpen our focus on the grid edge, several of which are central to the topic of this ebook.

1. Rapidly growing distributed PV generation
2. Expected increase in climatic-related events causing widespread resiliency issues across the energy system
3. Energy-centric consumer behavioral evolution
4. Architectural decentralization combined with the availability of energy-centric IT solutions
5. Electric utility business model transformation

At GTM, we're confident that these will be the drivers of the market going forward and the continued catalysts for industry evolution. For more information about all of our Grid Edge initiatives, please visit www.greentechmedia.com and www.gtmresearch.com.

Rick Thompson
President & Co-Founder
Greentech Media, Inc.

Introduction:
A Wake-Up Call

Superstorm Sandy was arguably one of the most significant storms in the history of the U.S. power sector. It was not a worst-case scenario. It was not the most expensive. And it was not the deadliest. But a confluence of factors made Sandy into an extraordinary event with a deep and lasting impact on how American utilities think about the future of the electric grid.

Extreme weather is a normal part of doing business in the power sector. Ever since America began putting up poles and wires to electrify the nation in the late 19th and early 20th centuries, wind, rain, ice and lightning have been there to knock them down. As this book was being written, severe flooding and tornadoes slammed the Southeast, leaving tens of thousands of people without power.

While not as commonplace as they are in the Southeast, hurricanes in the Northeast have threatened utilities since the dawn of the electric era. In the earliest days of the power grid, from the late 1880s to early 1890s, tropical storms and snowstorms wreaked havoc on the tangled network of electrical wires hanging above New York City. Decades later, as the electricity system expanded widely outside urban areas, the Great New England Hurricane of 1938 – a Category 3 storm more powerful than Sandy at landfall – caused outages for tens of thousands in Connecticut, Massachusetts, New York, New Hampshire and Vermont that lasted for weeks.

Over the last century, dozens of hurricanes and tropical storms, snow and ice storms, and other extreme weather events have damaged the Northeastern grid and forced massive outages. In other regions of the U.S., tornadoes, hurricanes, hail and wildfires remain a constant threat to the electricity system. All utilities deal with these threats and must build weather risks into their planning. Some do it far more effectively than others.

"Sandy was a watershed event for the industry in terms of planning. It was a wake-up call."

So if extreme weather planning is already such an integral piece of the power sector, why revisit the story of Sandy?

A combination of size, scope and timing set Sandy apart from past events that have caused trouble for the grid. Consequently, in the year and a half since the storm ravaged the East Coast, there's been a meaningful shift in the way that utilities, regulators and policymakers talk about the electricity system.

Tens of billions of dollars have been proposed or spent to modernize the grid; power companies have become more vocal about factoring climate change into planning; and new smart grid technologies have proven their value to the electricity system. Meanwhile, utilities are witnessing the beginning of a structural change to their business models as clean, distributed generation becomes more competitive – in turn influencing the way regulators think about grid resiliency.

"I think Sandy was a watershed event for the industry in terms of planning," said Peter Fox-Penner, a utility expert and principal with the Brattle Group, an economic consulting group in Washington. "It was a wake-up call."

The most obvious differentiator was Sandy's timing. The storm hit the highest populated area of the U.S. at high tide – just as a large nor'easter made its way over to the East Coast and a high-pressure system forced the mixing systems to slow down. It was an unprecedented series of meteorological events.

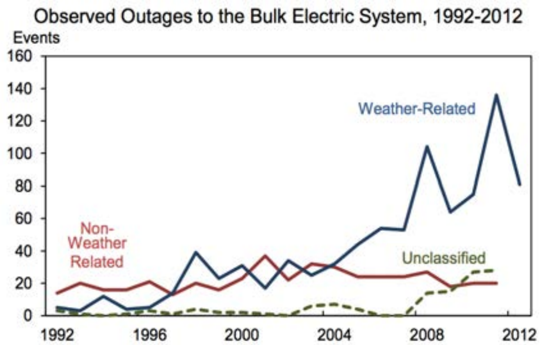
When the storm finally dissipated over the Great Lakes, it left 8.5 million people without power in twenty-one states – the highest outage total for any U.S. extreme weather event in history. Sandy didn't cause the same level of displacement and economic destruction as Hurricane Katrina seven years earlier, but it was the second-costliest hurricane ever to hit America. It caused $65 billion in damage and took the lives of 117 people in the U.S.

In this blackout composite, yellow regions show urban areas that lost power during Superstorm Sandy.

Source: NASA.

It wasn't just the record-breaking outages and damage figures that made Sandy so unique. The storm followed three major extreme weather events on the East Coast in the preceding eighteen months that each caused outages for millions of people.

In August 2011, Hurricane Irene cut power for 4 million people on the Eastern Seaboard, causing $15.6 billion in total damages. A few months later, a Halloween nor'easter caused more than outages for more than 3 million people in the Mid-Atlantic and Northeast. And then, in June 2012, a powerful wind storm called a “derecho” carved a 600-mile path through the Mid-Atlantic and Midwest, bringing 91 mph winds and causing outages for more than 4 million people.



Documenting the surge in weather-related “grid disturbances” over the last two decades.

Source: Energy Information Administration.

“It was kind of off the charts,” said Fox-Penner. “I think it changed everybody’s outlook.”

That series of events was part of a long-term trend. Since the 1980s, there has been a documented increase in the number of U.S. power outages due to extreme weather. According to the U.S. Energy Information Administration, weather caused 87 percent of the outages that impacted more than 50,000 customers between 2002 and 2012 – including rainstorms, hurricanes, snowstorms, wildfires and extreme temperatures. In 2011, the U.S. was hit with fourteen weather disasters causing more than $1 billion in damage each. And 2012 brought eleven events costing more than $1 billion each.

“We’ve seen a lot of unprecedented weather events in recent years – Sandy being one of them,” said Jeff Masters, a meteorologist with the commercial weather service Weather Underground. “When you start seeing unprecedented weather events more numerously, then you need to ask yourself, ‘Is the change in our weather and climate partially responsible?’ And I think the answer has to be ‘Yes.’”

A recent report from independent think tank Climate Central documented the surge in weather-related threats. Since 1951, heavy downpours have increased in the Northeast by 74 percent, in the Midwest by 45 percent and in the Southeast by 26 percent. In the West, where there were more heat waves in the 2000s than in any decade over the last century, wildfires have increased by 40 percent. And since the 1980s, there has been an increase in the number and strength of Category 4 and 5 hurricanes forming in the Atlantic Ocean.

Faced with this growing problem, regulators are considering how to integrate climate science into long-term planning – a move that could help reshape the way electricity infrastructure is built through the middle of the century.

With the average power plant now more than 30 years old, the average transformer more than 40 years old and the average transmission line more than 25 years old, there will be a significant turnover of grid infrastructure in the coming years. Adding climate considerations into the planning process will accelerate adoption of information technology (IT), operational technology (OT), grid hardening techniques and distributed generation.

There's a third factor making power outages like those caused by Sandy different than in the past: changing customer demands. America's power consumption has flatlined in recent years due to an economic slowdown, structural change in the industrial sector and economy-wide efficiency improvements. But the need for constant connectivity has made electricity an even more valuable commodity.

After Sandy, thousands of New Yorkers ventured northward from Manhattan looking for places to charge computers and cell phones. Some walked more than 50 blocks to locate a working outlet or a coffee shop with functioning internet service. Throughout New York and New Jersey, mobile charging stations – some powered by solar – were set up to help get basic power services to "digital refugees."

Expectations of constant connectivity have changed the public's perception of utilities. At a time when businesses can track virtually any product in real time, customers became increasingly frustrated after Sandy when power companies couldn't give them an accurate timeline for restoration. Many people reported seeing crews unfolding paper maps and scribbling notes manually; others said they talked with out-of-state lineworkers who had no details as to when a neighborhood would be electrified.

"The situation seemed pretty ridiculous in modern America," according to Scott Olson, the deputy mayor of Byram Township, New Jersey, describing his thoughts as he watched crews comparing paper road maps with utility infrastructure maps.

In the weeks after the storm, public officials criticized utilities for their slow restoration times and seeming ineptitude. The reality, however, is more complicated. An analysis one month after the storm showed that power restoration was faster than average – even though Sandy was worse than any storm East Coast utilities had ever faced.

Using data from ABB, a company that provides industrial software and analytics provider for utilities and other heavy industries, the Associated Press found that power companies were able to restore electricity to customers faster than after any major hurricane or tropical storm since 2004. This is because utilities – despite their slow adoption of new technologies – have started investing in 21st-century hardware and software to better monitor and control the grid.

Sandy highlighted some glaring vulnerabilities in the way utilities manage the electricity system and communicate with customers. But it also helped build momentum for another round of spending on innovative technologies. According to a 2013 survey from the global management and technology firm Accenture, 83 percent of utilities in North America said that recent extreme weather had directly influenced investment in technologies to network the grid.

“This is now a top priority,” said Jack Azagury, head of Accenture’s global smart grid business. “We saw Sandy give the utilities an environment to consider broader investment” in smart meters, fault detection and software tools to monitor the distribution grid.

Nearly two years after the storm, a new buzzword has emerged as a framework for this next round of investment: “resiliency.”

The National Association of Regulatory Utility Commissioners defines resilience as “robustness and recovery characteristics of utility infrastructure and operations, which avoid or minimize interruptions of service during an extraordinary and hazardous event.”

The term is not new for the power sector. But it’s taken on a more urgent meaning within utility boardrooms, regulatory proceedings, government agencies and the technology companies. It is partially driving the business plans of East Coast utilities – and consequently spreading throughout the U.S. to influence the broader power sector. Although resiliency is only one lens through which power companies view the world, it has arguably become a central one for many of them.

“We’re seeing this convergence of three things: power outages from increasing extreme weather combined with emerging technology solutions and changing business models. Those are driven in large part by resiliency planning,” explained Lewis Milford, president of the Clean Energy Group, a nonprofit clean energy advocacy organization. “We’ve seen a pretty dramatic response to Sandy and other weather events.”

This is the story of how power providers are adapting their businesses through that lens in a post-Sandy world.

Trouble

On the morning of October 22, 2012, Jeff Masters sat down at his computer to monitor Tropical Depression Eighteen, which was then forming in the Caribbean. After taking a look at the weather conditions, one word came to his mind: "trouble."

Two days later, Hurricane Sandy was born.

Masters certainly knew what trouble meant. Thirty years before, he started his meteorological career as a hurricane hunter in Miami, Florida, flying into Category 5 storms at the speed of a Formula One racecar. In 1989, Masters was almost killed when the engine of his plane caught on fire as it soared into the eyewall of Hurricane Hugo. The pilot lost control of the aircraft, diving down the calm side of the eye toward the Atlantic. With only 900 feet left before crashing into the ocean, his pilot regained control, steadied the plane and maneuvered it out of the 140 mph winds to safety.

That was enough to scare Masters into going back to school, completing a doctorate in meteorology, and try something less dangerous. Rather than traveling directly into extreme weather, he started writing about it. In 1995, Masters and a small team at the University of Michigan founded the first commercial website devoted to weather called Weather Underground, spawning a new era of online meteorology reporting.

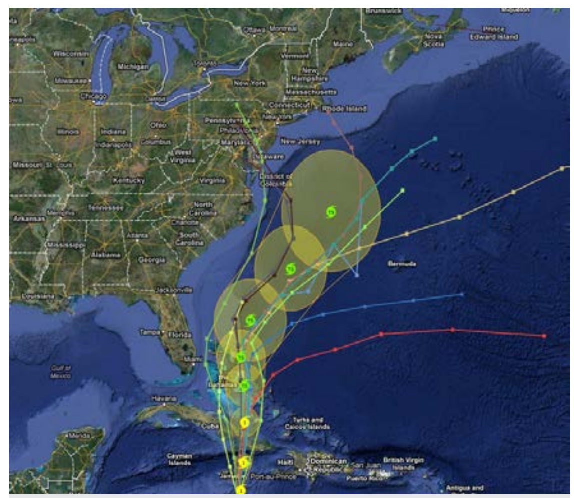
"When you start seeing unprecedented weather events more numerously, then you need to ask yourself, 'Is the change in our weather and climate partially responsible?' And I think the answer has to be 'Yes.'"

On October 24, 2012, just a few months after his site was acquired by The Weather Channel, Masters was busy writing about the formation of Hurricane Sandy on his popular meteorology and climate blog. That year had already tied for producing the third-most named storms in history, so there was plenty to write about. Masters was particularly interested in this new storm gathering intensity so late in the season. Any time a storm system builds in the warm waters of the deep Caribbean, its potential to become a major hurricane drastically increases.

Masters followed Sandy as it looped over the Caribbean Sea, morphing from a tropical depression into a tropical storm, and finally into a hurricane with 80 mph winds. And with nowhere to go but land, Sandy was headed straight toward Jamaica and Cuba as it sucked up energy from the warm ocean. "It was immediately obvious it was going to be trouble," said Masters.

That evening, Sandy grazed Jamaica, cutting power for 70 percent of the island. It then moved offshore and grew into a Category 3 hurricane before hitting Cuba head-on, completely destroying 24,000 homes and leaving more than 1 million people without access to clean water or energy. It was a harbinger of destruction to come. But most Americans outside of meteorology circles were only starting to take Sandy seriously as a threat.

The issue, wrote Masters on his blog, was that the long-range forecasts were “clear as mud.” In the days leading up to Sandy’s initial formation, numerous computer models showed the storm harmlessly moving out into the Atlantic Ocean or grazing the Mid-Atlantic coast of the U.S. But one model, from the European Center for Medium-Range Weather Forecasts, predicted Sandy would make direct landfall on the East Coast near Delaware.



Conflicting long-range forecasts for Hurricane Sandy.
Source: Weather Underground

It would take another few days after Sandy reached hurricane status in the Caribbean before the other models started matching up. With so many contradictions, few people, including Masters, could then fully imagine the confluence of factors that would turn Sandy into a “superstorm” with the largest area and most kinetic energy on record.

“At that moment, I certainly didn’t foresee the interactions that led to the kind of destructive power it had,” said Masters. It wouldn’t take long before he did.

Over the next two days, as Sandy pushed passed the Bahamas and moved further north into the colder waters of the Atlantic Ocean, the tone from meteorologists changed dramatically.

Although Sandy had lost a bit of intensity, it was headed straight for the Gulf Stream where waters were 2°C warmer than average. That allowed it to maintain hurricane strength and expand to an area 1.5 times the size of Texas, a remarkable occurrence so late in October. At the same time, a strong high-pressure system over Greenland created a “block” that prevented Sandy from moving further east into the Atlantic, slowing its advance and putting it directly in the path of a winter storm moving across the continental U.S.

The combination of weather systems had created the conditions for a record-breaking storm. By October 27, most of the forecasting models were showing a probable hit to the most populated area of the U.S. around New York and New Jersey – just when the tides were at their highest.

That day, President Obama held an emergency meeting with top national security and federal emergency response officials to talk about a worst-case scenario. But with doubts lingering over how far west Sandy would turn, the National Hurricane Center held off on issuing a federal advisory.

Weather forecasters sounded the alarm. Bryan Norcross, a hurricane specialist at The Weather Channel, called Sandy "unprecedented and bizarre" due to its intensity so late in October. Privately, Norcross was worried about the lack of a federal advisory. "What the hell is going on?" he asked bluntly in a blog post for Weather Underground, referring to the mix of conditions making Sandy so unique. Jim Cisco, a forecaster with the National Oceanic and Atmospheric Administration, warned about the lack of "any modern precedents for what the models are suggesting." Journalists latched onto the freak nature of the storm, calling Sandy the "perfect storm" and a "frankenstorm."

It was, by all accounts, a superstorm.

As Masters continued monitoring the forecasting models and writing daily technical updates on the storm's track, he kept thinking the same simple thought: "This is not good."

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Long before Ralph Izzo became CEO of New Jersey's largest utility holding company, PSEG, he was a research scientist at a Princeton laboratory running numerical simulations for experiments on fusion energy. Along with knowing how to run a large energy company, Izzo happened to be skilled in computer simulation as well.

A week before Sandy made landfall, Izzo sat down to his desk at PSEG's headquarters in downtown Newark to monitor the conflicting computer models tracking the storm. He was interested in the variances in weather prediction both out of personal curiosity and for business reasons. Izzo was, after all, in charge of ensuring a reliable supply of energy for 4 million gas and electricity customers throughout New Jersey.

One model from England stood out. It was the same one that caught Jeff Masters' attention, generated by the European Center for Medium-Range Weather Forecasting. While the U.S. models predicted Sandy would move safely to the east and get dismantled by the cold ocean, the European model showed a westerly track toward the Eastern Seaboard. Izzo found it unusual and hoped it was just an outlier.

"I'll never forget looking at that model with a hard left turn into the Mid-Atlantic," he recalled. "That was the one that ended up being correct."

The mood at PSEG's headquarters was still calm, but alert. In the underground control room, computer screens monitored transmission lines and the distribution network. Television screens silently played news reports and weather updates. Some put on headphones to listen to the televisions; others compared notes about what they thought would happen. It was still unclear what path Sandy would take.

A PSE&G employee monitors electric system operations.
Source: PSEG

Engineers in the control room took stock of field operations. The situation was normal: the occasional pole down from heavy winds or a car accident, a few extra tree-trimming jobs being conducted around wires, and some maintenance work on substations. Knowing exactly how many jobs were being worked in the field – and why – was critical for understanding if there were any vulnerabilities during a major storm event.

Since Hurricane Irene in August 2011, PSEG had replaced older transmission lines, spent $28 million on tree pruning to protect wires and circuits serving local homes and businesses, and improved its automated calling system. Izzo felt prepared. But a strong hurricane would always be a problem for the grid. While hardening efforts could help prevent outages, the crucial indicator of a utility's performance would be how quickly it brought power back to those who had lost it.

On October 28, the calm started to break. The Europeans were correct. Sandy was on its way to New Jersey, and it was increasingly looking like a direct hit. Finally ready to mobilize federal agencies for a worst-case scenario, President Obama signed an emergency declaration for five East Coast states, including New Jersey.

"By 8 p.m., the world as we knew it had come to an end."

Public Service Gas and Electric (PSE&G) the utility run by parent company PSEG, called in more than 1,300 lineworkers from around the country to assist with preparation and storm response efforts. Plans were made to staff the call center with as many people as possible. And a warning was issued to customers to be prepared for outages and emergency evacuations.

Ralph Izzo (right) discussing Sandy planning and restoration efforts with PSE&G president Ralph LaRossa
Source: PSEG

The following morning, October 29, Izzo left home and did something he hadn't done before: packed an overnight bag. If the models were even half right, he told his wife, he shouldn't be expected home for a couple of days. He immediately went to his desk to monitor the weather models. There were no outliers any more.

Izzo and his team immediately launched the Delivery Emergency Response Center into operation. Located in a bunker underneath PSEG headquarters, DERC is only opened during major events. It features its own backup generator, a kitchen and a stash of portable air mattresses for the inevitable overnight stays. It had been opened numerous times in the last eighteen months for extreme weather events, including Hurricane Irene, which had caused what at the time was the worst series of outages in the utility's history. The engineers responsible for monitoring Sandy knew they would likely be sleeping in that underground room for more than one night.

That evening, Izzo sat down with the utility's president, Ralph LaRossa, as Sandy – now a post-tropical cyclone – closed in. It was clear that New Jersey was in for a hard hit. At 6:30 p.m., however, the storm wasn't as strong as the two men expected. "Ralph, I think we dodged the bullet," said Izzo. LaRossa agreed. Perhaps the forecasters had gotten it wrong after all.

But two hours later, as Sandy continued its hard left turn toward the abandoned Atlantic City boardwalk, it was clear that no one had gotten it wrong. "By 8 p.m., the world as we knew it had come to an end," said Izzo.

In a matter of hours, 85 percent of PSEG's customers had been cut from the grid.

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When Pat Mullin left home to prepare her storm restoration team on the morning of October 29, she was aware of what could be coming for her coastal town of Toms River, New Jersey.

Mullin, a 26-year veteran of the utility workforce who had seen plenty of storms, was still unsure whether she should evacuate her family. The summer before, she and her husband Bob moved their two children away from the coast to avoid Hurricane Irene. That storm hadn't been a direct hit, and their home was spared any major damage or flooding. Mullin wondered if Sandy would take a similar track. She decided to stay home and ride it out.

Whatever the coming storm's exact path, it was clear Sandy would be an important test for Mullin and her company, Jersey Central Power & Light (JCP&L), a utility serving more than 1 million customers throughout the state. JCP&L had a lot to prove when it came to storm response efforts. Ten months earlier, regulators had released a report criticizing the utility's response to a pair of devastating weather events in 2011: Hurricane Irene and an early-winter nor'easter.

JCP&L's Pat Mullin overseeing restoration efforts in coastal New Jersey.
Source: FirstEnergy Corp

With 750,000 outages in its territory during Hurricane Irene, JCP&L had taken a bigger hit than any other utility. Some outages lasted for up to eight days, even as other utilities had reconnected all of their customers. The state's Board of Public Utilities singled out JCP&L for its inconsistent communication with local officials, inaccurate restoration estimates and slow requests for outside help from other utilities.

Then, just three months after Irene, New Jersey was blasted with a record Halloween snowstorm that knocked out power for more than 1 million homes and businesses, including 425,000 JCP&L customers. Local officials reported improved communications with the utility, but customers became infuriated with a lack of information. New Jersey's governor even requested that JCP&L halt its automated calls to customers after the snowstorm because of informational inaccuracies. In an after-action report, state regulators concluded that JCP&L's response plan "still needs work."

And then, in less than a year's time, another record-breaking storm was on its way to test whether that additional work had been done.

In Trenton, an hour's drive northwest of where Mullin was stationed, Tony Hurley flew in from Ohio to represent the utility at the Regional Operations and Intelligence Center (ROIC). Hurley was director of operations services at Toledo Edison, another utility owned by JCP&L's parent company, FirstEnergy. He was there to meet with state regulators and officials from the Department of Energy, the Federal Emergency Management Agency (FEMA) and the Army Corps of Engineers. Utility officials understood the potential consequences of the coming storm, and they were out to show improved coordination. For the next twelve days, the ROIC would be Hurley's home base where he would stay in close contact with the military, state officials and utilities supplying workers from around the country.

Mullin was one of the regional managers responsible for securing on-the-ground resources needed to get electricity flowing after any major disruption. Her territory covered the barrier islands along New Jersey's coastline, some of the most iconic – and vulnerable – communities in the state. Operating from a trailer on the side of New Jersey's Route 35, Mullin worked to secure cleanup equipment, get hotel rooms for utility crews visiting from the West Coast, work with emergency response officials and manage on-the-ground operations. It was a challenging job that had her coordinating a lot of moving pieces, but she loved it.

A few hours after settling into her rhythm, Mullin got a call from her husband. The fire department was strongly urging them to evacuate in preparation for Sandy. Their neighbors were leaving as well. Mullin urged Bob to pack some bags and bring the children to a friend's house a few miles south, farther from the coast, thinking they'd stay away from home for only a night.

Assured that her family was safe, Mullin did the only thing she could do: continued following protocol and preparing for a storm she hoped wouldn't be as bad as predicted.

"This is what I do for a living," said Mullin. "As with any storm that we get, I went back to work, because that's what we do."

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Sandy's winds, rain or scale weren't the biggest concerns for Kevin Burke. It was the storm coming in at high tide that made him most nervous.

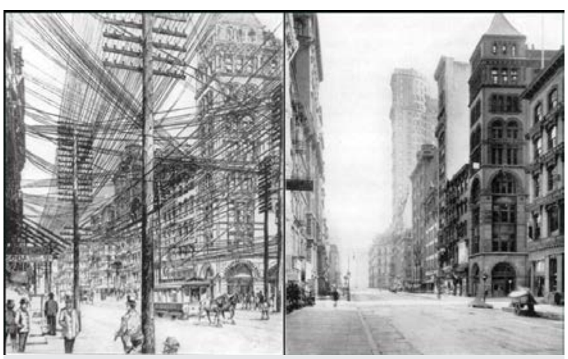
Then the CEO of Consolidated Edison, a utility serving more than 3 million electricity customers around New York City, Burke was responsible for the world's biggest underground network of power-delivery equipment. With twelve-foot surges expected to inundate low-lying areas of the city, Con Edison engineers understood that Sandy would push the limits of what their system could handle.

That system is immense. Buried beneath New York City's streets is a complex network of transmission and distribution wires, transformers, and gas pipelines. The web of cables operated by Con Edison is so extensive – amounting to 94,000 miles in length if uncoiled – it could wrap around the world more than three and a half times.

The origin of New York City's underground wiring system dates all the way back to the beginning of commercial electricity itself. In 1882, when Thomas Edison built the first series of steam power plants in the city and connected them to buildings through a copper wiring system, he decided that burying the lines was safer than stringing them overhead. Most of Edison's subsequent commercial power projects throughout the Northeast were built in the same way. But as more power companies received licenses to operate in New York and the electricity market grew more competitive, operators started putting lines overhead in order to speed up electrification. By the late 1880s, the streets of Manhattan had transformed into a dense plantation of wooden poles covered in a thick web of copper wires.

It was a historic snowstorm in 1888 that helped make New York's electric system what it is today. In March of that year, the city was hit with a nor'easter that brought 21 inches of snow in Manhattan and 36 inches in Brooklyn. Within hours, the flourishing electricity system collapsed on itself, blacking out the city for days. Electrical poles snapped under the weight of the crisscrossing wires. Residents were warned not to walk in the streets due to risk of electrical shock. And local politicians expressed outrage at the lack of planning. "The poles will come down," declared Hugh J. Grant, New York's newly elected mayor, months later, in an effort to put the grid underground.

As early as 1884, New York officials had been trying to force companies to bury their lines. Snapping wires, block-wide outages and electrocutions were frequent problems for the crowded above-ground electricity system. But companies successfully challenged local ordinances in court, avoiding any changes. In the years after the 1888 storm – which brought numerous accidental electrocutions on the streets – the courts finally demanded that electric companies follow local laws. By the 1890s, large portions of the vast tangle of copper and wood had been placed underground for good.



New York's flourishing electricity network in the 1880s.
Source: Old York Foundation

After more than a century of consolidation and regulatory reform that whittled down the number of electricity companies in New York, Con Edison eventually emerged as the controller of all that underground equipment – helping deliver electricity from other competitive suppliers to the $19 billion energy market across the five boroughs in the city. Today, about three-quarters of Con Edison's electricity system is buried.

Having such an intricate network of equipment below ground protected Con Edison's system from winds and more conventional storms. But the ocean – the salty, corrosive, dirt-laden water brought by storm surges during hurricanes – had always been the real threat to the utility. And Sandy's landfall directly at high tide was going to bring the biggest storm surge Con Edison had ever seen. "We knew that the big issue we had to concern ourselves with was the storm surge," said Burke.

Twelve-and-a-half feet. That was the number in the minds of employees at Con Edison. If the storm surge stayed below that level, Con Edison's critical substation in lower Manhattan – a piece of equipment on 13th Street that keeps one-third of the borough powered – would be safe. No storm surge previously recorded had ever hit that level.

By the night of Sunday, October 28, Burke had already been on three press calls with Mayor Michael Bloomberg to brief the public on storm scenarios. He was blunt: the power company would need to preemptively shut down two networks in Manhattan and one in Brooklyn to avoid serious damage to equipment. It was a precautionary measure started in the early 1990s, when a storm surge destroyed equipment that hadn't been powered down. But the operations team decided not to cut the 13th Street substation, thinking the 12-foot barricade would keep it safe from the threatening ocean.

A Con Edison engineer climbs underground to work on a feeder line.
Source: Con Edison

Burke went home that evening, feeling comfortable that his company had its response plan and that the emergency center was fully staffed. After a weekend of preparation, it was time to take a breather before the storm rolled in. Later that night, President Obama finally signed an emergency declaration for New York and New Jersey as the superstorm closed in.

The floodwaters were already rising around the edges of the city when Burke got back to the office on Monday morning. Bridges, schools, public transportation and the New York Stock Exchange were all shut down. But the backbone of the city – electricity – was still working as usual.

"It hit like nothing we had experienced before – nothing that we even could have anticipated."

By late afternoon the wires, poles and transformers above ground came under threat. The winds were fierce. In midtown Manhattan, a construction crane 75 stories tall had been ripped loose and was swaying dangerously over the streets. Images of the crane played on a television screen in Con Edison's auditorium, where emergency teams watched news and weather reports. If a steel crane was that vulnerable to the storm, the electric system was in for a pounding.

At 4:45 p.m., Con Edison reported nearly 69,000 outages. An hour later, Michael Bloomberg called Sandy "the storm of the century," and warned New Yorkers that peak flooding had yet to come.

The outages spiraled quickly after that. Over the next two hours, 70,000 more Con Edison customers lost power. With water rushing into the city, Burke finally made the decision to power down substations in Manhattan and Brooklyn, cutting off electricity for tens of thousands more people. At around 8:30 p.m., just as storm surges neared their peak, Burke jumped on the phone with the mayor's office to provide an operational update.

Minutes later, looking out the window as he talked, Burke witnessed his company's most catastrophic event: a cascading power outage across lower Manhattan. Suddenly, the lights went out in his office. "At that point, I knew we had lost another couple of networks," said Burke. Another 200,000 people were cut off.

A videographer filming the storm captures an electrical arc at Con Edison's substation in Manhattan.

Source: YouTube

The worst-case scenario was worse than Con Edison imagined. A 14-foot storm surge – nearly two feet higher than expected – had inundated the 13th Street substation, causing an electric arc. Within minutes, a YouTube video had been posted showing what looked like a bomb exploding at the location from miles away. When the flashes of light finally sputtered out after 30 seconds, the buildings in the background were dark.

"It hit like nothing we had experienced before – nothing that we even could have anticipated," said Burke.

It wasn't just catastrophic equipment failure that Burke had to worry about. He also had eleven engineers trapped in the flooded substation where the arc had just occurred.

Before power restoration efforts could begin, Con Edison had one mission: get its eleven-person crew out of the flooded substation. As the rain and wind battered the city, an electrical engineer familiar with the building met up with two firefighters. They rafted through the waist-deep water in the street to the entrance of the brick building, and managed to open the door. Inside, ten employees were huddled in safety on the second floor; one was on the first floor atop a filing cabinet. Luckily, there were no fires. But 4 to 6 feet of water inundated the control room and substation equipment, shorting it out.

"It was this one-two punch of wind and water that hit our underground systems and our substations," said John Miksad, Con Edison's senior vice president of electrical operations. "It was very intense."

The next morning was when the real work began.

A Strategic Surprise

Only a week before Sandy emerged as a threat to the East Coast, the DOD's Paul Stockton traveled from Washington, D.C. to New York City to meet with local emergency managers. Coincidentally, he was there to discuss what kind of "complex catastrophes" – including severe flooding – could cause overwhelming devastation to the city and trigger support from the Defense Department.

The meeting was based on hypothetical scenarios. Participants were unaware how quickly those hypotheticals would get turned into action.

At that time, Stockton was Assistant Secretary of Homeland Defense and Americas' Security Affairs, which made him the chief advisor to then-Defense Secretary Leon Panetta on civil issues. Stockton was responsible for helping provide Defense Department resources to governors, mayors and FEMA during events such as terrorist attacks or natural disasters. He had recently started working with his colleagues at the Pentagon and officials from the National Guard and U.S. Northern Command to plan for an extraordinarily severe event like Sandy – or something far worse.

Since 2008, the Pentagon had started taking climate change more seriously. Officials ran war games modeling the role of extreme weather as an "accelerant of instability or conflict" around the world. They reviewed the impact of sea-level rise and storm surges on military bases. And those responsible for civil affairs, like Stockton, studied how domestic events could challenge the deployment of defense resources to local response efforts.

Superstorm Sandy constituted a strategic surprise for me and much of the Department of Defense."

On the domestic security front, power reliability was getting more attention at the highest levels of the Pentagon. In May 2012, speaking at the Environmental Defense Fund, Defense Secretary Leon Panetta raised concerns about the stability of the electricity system from climate or terrorism-related threats. "I have a deep interest in working to try to ensure from a security perspective that we take measures that will help facilitate and maintain power in the event of an interruption of the commercial grid," he proclaimed.

At an Aspen Institute security forum that summer, Stockton worried publicly about a "long-term, large-scale outage" that could come about due to terrorism. "Our adversaries, state and non-state, are not stupid. They are clever and adaptive," he warned. "There is a risk that they will adopt a profoundly asymmetric strategy, reach around and attack us here at home, [targeting] the critical infrastructure that is not owned by the Department of Defense."

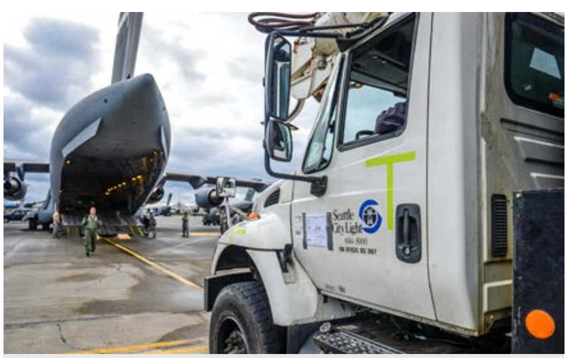
Although climate change had moved up the priority list under Secretary Panetta's leadership, Pentagon officials were still mostly thinking about power outages caused by cyberterrorism or physical attacks on the infrastructure. Extreme weather was not yet a primary focus of planning exercises when it came to power restoration and grid resiliency. Getting the electricity flowing after a crisis was regarded as critically important, but the Pentagon hadn't anticipated some of the specific challenges brought by Sandy.

"To be candid, Superstorm Sandy constituted a strategic surprise for me and much of the Department of Defense in terms of the scale of support requests and the novelty of those requests," said Stockton.

Shortly after Stockton returned to Washington, D.C., Sandy officially formed into a hurricane. FEMA soon contacted the Defense Department for support with critical operations. Federal emergency responders had learned a hard lesson about early preparedness during Hurricane Katrina. President Obama was weighing when to make an emergency declaration, and it was essential to get what Stockton called "the giant machine" within the Pentagon prepared to operate 24 hours a day before the storm made landfall.

The federal response was swift. But when the cleanup process started, there were immediate challenges, even for an entity with the vast reach and resources of the Pentagon. The president initiated a task force within FEMA to get power back as quickly as possible. As the backbone of FEMA's operations, the Pentagon was responsible for providing military resources to support the effort. But defense officials had very limited situational awareness, and weren't anticipating many of the requests coming their way.

Utilities dispatched nearly 70,000 workers from around the country to help with electricity restoration – the biggest such deployment in history. Defense officials suddenly found themselves coordinating deployment of the military's largest cargo aircraft, the C-5A, to fly utility trucks from Arizona, California and Washington state to the East Coast.



A utility truck from Seattle City Light is loaded onto a C-17 aircraft on November 3, 2012. Nearly 70,000 utility workers from around the country traveled to the East Coast in the week after Sandy to help restore electricity.

Source: U.S. Air Force/Staff Sgt. Sean Tobin.

Then the Department of Energy informed Stockton that the military needed to provide hundreds of generators for critical power at emergency centers, while also securing 200,000 gallons of gasoline and diesel per day. Figuring out exactly where to deploy the generators – and which sites need to be “unwatered” before installing them – was a difficult task. “I didn’t even know ‘unwatering’ was a word,” said Stockton, referring to the process of deploying heavy pumps to remove water from buildings, electrical substations and tunnels. The logistical challenges piled up.

“Understanding those priorities when operating in that environment was very difficult,” said Stockton. “It remained a challenge throughout the event, and it’s an area for further progress to be made.”

In the days and weeks after the storm, President Obama praised the Defense Department for its “heroic” role in the largest coordinated power restoration effort in history. The Air Force, Army, Coast Guard, Navy and Marines were all active in getting equipment and personnel to where it was needed. Millions of gallons of fuel were delivered; hundreds of backup generators were installed; and dozens of engineering teams were deployed to assist utilities in restoring power.

But Stockton knew that much of the electrification effort was impromptu – a result of traditionally limited interaction between federal disaster response teams and power restoration crews on the ground. “Hurricane Sandy showed that we are poorly integrated thus far in most states,” said Stockton.

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The New Jersey coastline that JCP&L’s Pat Mullin had known was gone. The one she saw on Tuesday morning looked like it had been ravaged by war.

Virtually all of JCP&L’s 1.2 million customers in New Jersey were without power. Transmission lines were cut; substations were flooded; and thousands of downed trees had severed 3,400 sections of distribution wire and nearly 1,000 poles. Along the beach in Mullin’s territory, entire blocks were completely torn apart. Splintered poles and limp wires littered the crumbling coastal streets, creating potential shock hazards for residents.

As helicopters surveyed the damage across the entire state, the utility estimated it had incurred around a half-billion dollars in damage. And JCP&L’s parent company, FirstEnergy, was looking at $1 billion in repair costs across New Jersey, Ohio and Pennsylvania. It was the worst disaster in the company’s history.

Grid infrastructure, while crucial to the response effort, was rendered meaningless along stretches of New Jersey's coastline where Mullin rallied her crews. In Ortley Beach, a small coastal neighborhood in her hometown of Toms River, the streets had been swept into the ocean. In some neighborhoods, there were simply no homes left to receive electricity. Thousands of people would need to put their crumbling houses back together before the grid meant anything to them again.

That included Mullin herself. While on a conference call with response teams the morning after Sandy, she received multiple texts from her husband. A neighbor had gone back to the block and found their houses had been consumed by the bay. Cars were completely underwater, mailboxes were no longer visible and remnants of the homes were floating in the street. “It was a pretty horrific moment for me,” said Mullin.

But there wasn't much she could do aside from the job in front of her. She couldn't get near the house. After going to see her family, she settled back into her trailer on the side of the highway, preparing the triage effort.

Up in Trenton, Tony Hurley was working with federal officials to get crews and equipment from the West Coast into New Jersey as quickly as possible. It was, remarkably, easier than he imagined. The president had just declared all utility workers “first responders,” giving them immediate access to federal resources through a 100 percent cost share. In his 34 years in the utility industry, Hurley had never worked with the Pentagon or FEMA after a storm. Sandy represented a whole new level of coordination between utilities and the Defense Department that neither had ever experienced. “In that environment, issues that might take several days got resolved in almost hours,” said Hurley. Within five days, JCP&L had restored 900,000 of its 1.2 million customers who had been without electricity.

Destroyed neighborhoods in Ortley Beach make electricity restoration difficult.

Source: FirstEnergy Corp.

That battlefield-like coordination, while extremely challenging for the Pentagon due to its unique demands, helped get resources to power companies in the hardest-hit areas of the East Coast faster. Utilities and other responders agreed that power restoration efforts would have taken days longer without the help. And it showed: Sandy caused more outages than Katrina nine years earlier; however, after Sandy, electricity was restored to 95 percent of customers two weeks faster than after Katrina.

Turning the power back on for hundreds of thousands or even millions of customers after an event like Sandy isn't as simple as putting a bunch of new poles in the ground and flipping a switch. Crews must

"It was a pretty horrific moment for me."

first take damage assessment and input information into a central database called an outage management system, which is often still a somewhat manual process. If a utility owns power plants, it must pump water and fix structural damage to get them back on-line, which can take days or even weeks. Transmission lines running from the power plants must be repaired. Substations and circuits connecting the high-voltage transmission system to the distribution system must be cleaned and dried out. And finally, the wires to homes and businesses have to be reenergized.

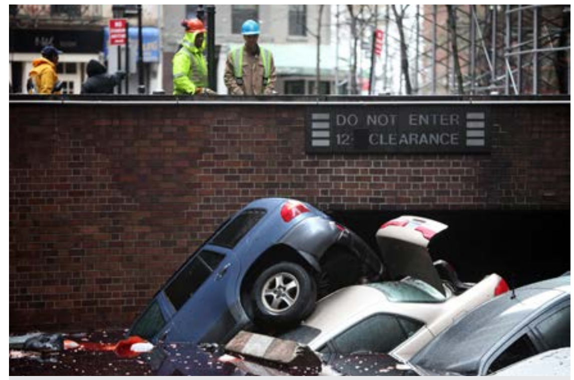
Utilities also must prioritize who gets power. First, they'll look at critical loads like hospitals, police stations and schools. Next, they'll look at networks with the most outages to bring the maximum number of customers on-line with the least amount of effort. For the last 10 percent or 20 percent of customers – often people living in rural areas without a heavily used circuit – the power may not come on for many days after the first customers have begun to have their power restored.

For Con Edison, the recovery efforts after Sandy were more logistically difficult than those that were carried out in the aftermath of the 9/11 terrorist attacks, when more than 1,900 workers were deployed to provide backup power and fix underground equipment. The cumulative outages after Sandy – which left a total of 1.1 million people without power – were five times bigger than any previous blackout the utility had experienced. "This wasn't just a little bit bigger than what we had seen before – it was unprecedented," said Burke.

On the morning of Tuesday, October 30, Con Edison engineers were dealing with two sets of outages: flooded equipment underground and collapsed poles, wires and transformers above ground. Many of the underground lines had to be completely disconnected to avoid electrocuting flooded customers. The large pipes housing underground lines were pumped full of dielectric fluid to prevent arcing. Electric motors that had been inundated with salt water were brought to the Bronx and put in ovens to dry. Working above ground, crews helped restore feeders serving networks of thousands of customers – a process that could take a group of linemen 15 hours to complete.

One of Con Edison's biggest problems was getting mutual aid from other utilities. In the first days, only 170 of the 2,500 line workers requested were available. That slowed down efforts to reconnect the system above ground. Eventually, military cargo planes brought in loads of utility trucks from around the country, and 5,600 mutual aid workers were deployed. Within eight days, 90 percent of customers were back in service. "Considering all the problems, I think people got back in service relatively quickly," said Burke.

Sandy was unique for PSE&G because it knocked out equipment further upstream. Nearly 90 percent of power outages stemming from weather in the U.S. occur on the distribution system. But as with Con Edison, PSE&G's substations were inundated by 12-foot storm surges. The utility saw one-third of its transmission circuits damaged by water, and power plants were also shut down. Engineers couldn't even think about turning power back on until major switching stations were back up and running.



A Con Edison crew takes a break from pumping out a flooded substation to look at flooding in Manhattan.

Michael Kamber, Con Edison

"It was the flood driven by wind that had the biggest impact. It's important to understand how quickly it occurred," said PSEG's Ralph Izzo. The storm surge inundated stations and damaged equipment that had never been wet before. Much of the machinery had to be cleaned with toothbrushes.

By November 3, PSE&G's sixteen damaged substations were back in working order. Four of its inundated power plants were also preparing to come back into operation. And with help from an influx of 2,800 mutual aid workers, 65 percent of customers had power back by this juncture. By the following week, 98 percent of the 1.7 million people who had lost electricity were back on the grid – the biggest and fastest restoration in the history of the company's history.

"Given the massive extent of the storm, I think this one was easier for customers to understand what we were up against," said Izzo.

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Sandy represented a "strategic surprise" for all utilities involved. Every company executive and representative interviewed for this book described the storm as an unprecedented event that far surpassed expectations. Given the scope of the damage and the complicated nature of the electric grid, utilities are understandably defensive about their responses to the storm.

"As a thought exercise, I sometimes ask people, 'Why couldn't you drive to work an hour faster this morning?'" said Ron Morano, a spokesperson for JCP&L, which was targeted by New Jersey regulators for failing to properly upgrade equipment before the storm.

"You have traffic, stoplights, speed limits and pedestrians. There's a limit to how quickly you can get there. That's exactly what it's like getting the power back on during such a big event – you have limits to how quickly you can restore electricity."

Indeed, data did show that restoration times were faster than average compared to all other major hurricanes that have hit the U.S. since 2004. Those working within utilities believed that initial complaints after the storm ignored the scope of damage to the system.

"Hurricane Sandy illustrated that utilities are woefully unprepared to manage the growing threat posed to New York state by catastrophic storms."

The public reaction to that utility defensiveness has been conflicted. Some who are close to the power industry praised power companies for executing a fast turnaround by historical standards. However, many public officials warned that the storm revealed deep problems with aging equipment and utility preparedness to handle an event even worse than Sandy. And customers don't care if utilities performed slightly better on average compared to past storms – in the age of instantaneous, always-on connectivity, going without power for a week or more is almost inconceivable for most people.

Even though PSE&G was credited with a relatively fast response – and was even ranked the most reliable utility in 2012 – it was criticized for failing to address longstanding equipment vulnerabilities. Some of the same substations damaged by Sandy had been damaged after Hurricane Irene in 2011 due to storm surges – a consequence of having critical infrastructure sited in flood-prone areas.

"For years, they have known that our substations and other key components of the grid were in the wrong places, and instead of moving them, we kept paying to fix them," lamented Jeff Tittel, president of the New Jersey Sierra Club chapter, months after the storm when the utility presented its grid hardening plan.

After promising to fix its communication efforts in the wake of Hurricane Irene, JCP&L still had severe problems in its outreach to customers and government officials. "Unfortunately, we have found that communication with JCP&L regarding timing and location has been unreliable and inaccurate," said the mayor of Colts Neck, New Jersey, six days after the storm, echoing the complaints of officials throughout the state.

Con Edison's Kevin Burke was chastised by customers for giving conflicting information about when the power would come back after the storm. "We didn't know the answers," admitted Burke ten days after

Sandy in a public forum, explaining the difficulties in surveying the scope of the damage. The utility was also singled out for failing to fully inspect equipment before the storm and failing to pull in enough workers to help with the response, as well as for spotty coordination with city officials and other utilities.

In June 2013, a commission in New York summed up what many customers that had gone without power for days and weeks were feeling: "Hurricane Sandy illustrated that utilities are woefully unprepared to manage the growing threat posed to New York state by catastrophic storms."

By far, the worst prepared was the Long Island Power Authority (LIPA), a public utility created by the New York legislature in 1985. The previous private utility did a poor job of keeping rates low and infrastructure up to date, so LIPA was formed to take over operations – becoming the largest municipal utility in the country. But Sandy revealed the worst possible set of problems within LIPA that only got worse over the years: an inability to maintain equipment, lack of leadership, substandard financial practices, old computer systems, and poor storm response plans that left customers in the dark about response times. The utility's response to Sandy was considered a total failure.

Con Edison crews work in darkness to bring underground equipment back in service.

Source: Robert Francis.

"Resources came late. When they came, there was no management to utilize those resources effectively. And it took ten days for them to get their act together," explained a former FEMA official to the New York Times two weeks after the storm. Six months later, New York stripped management of LIPA's assets away from National Grid and handed them to PSEG in an effort to get the system functioning properly.

Utilities have seemingly taken these criticisms to heart. Since 2012, there has been a significant change to the way they prepare for a Sandy-like storm. Regulators in Connecticut, the District of Columbia, Illinois, Indiana, Massachusetts, Maryland, New Jersey, Ohio, New York, and Pennsylvania have approved billions of dollars' worth of grid-hardening and modernization packages. Under pressure from regulators, utilities have started adopting federal standards for emergency response. And under pressure from customers, response plans have included improvements to calling systems and social media outreach, upgrades to outage mapping and better software to streamline internal operations.

"I've been doing this for 34 years. The things that are taking place right now – because of Irene, because of Sandy – it's like nothing I've ever seen," said JCP&L's Hurley. Although no storms with the destructive power of Irene and Sandy have swept through the region since, Hurley said the utility used its new command structure more than a dozen times in 2013 to manage storm response and is a "much better organization" as a result of the internal changes.

But some have voiced the opinion that an even more comprehensive overhaul is needed. After PSEG took over operations and maintenance of LIPA's assets in 2013, New York commissioners ordered a completely new business model for the Long Island company, now called PSEG Long Island. Calling for a "utility 2.0" model, regulators said that simply replacing substations and wires wouldn't be enough. By July, PSEG will submit a plan to integrate battery storage systems, distributed generation and energy efficiency to make the grid more dynamic – and hopefully more resilient by diversifying backup sources and isolating problems.

"It will be a heavy emphasis beyond the meter," said PSEG's Izzo. "I think we have a really exciting opportunity out on Long Island to reinvent the utility."

That forward-looking philosophy, while still limited to a handful of utilities, is arguably one of the most significant changes coming out of Sandy. In the past, conversation around post-storm planning was about whether it should be done differently. This time around, it's about how it should be done differently.

"Simply relying on the status quo of utility response isn't acceptable any longer. To me, that's the dramatic change," said Lew Milford, founder of the Clean Energy Group, a clean energy advocacy nonprofit. "States in the Northeast have made the collective decision that things have to change."

Those changes are emerging because of three factors: recognition of climate change, the improving economics of distributed energy and advances in IT on the grid.

Closing the Intelligent Infrastructure Gap

Almost exactly three years before Sandy, on October 27, 2009, President Obama stood in front of a 25-megawatt solar farm in southern Florida to deliver his vision for a 21st-century grid. The speech was one of many on a cross-country tour to highlight the newly passed stimulus package, which set aside $90 billion to support renewable energy projects and smart grid technologies.

Joined by Lew Hay, CEO of the Florida utility FPL, President Obama was in Arcadia, Fla. to announce a $3.4 billion package of investments for smart grid projects – mostly advanced meter deployments – to build a "smarter, stronger, and more secure electric grid."

For 15 minutes, the president spoke about the economic and efficiency benefits of the smart grid, occasionally mentioning the need to reduce power outages. The word "resilient" never came up.

Fast forward to October 2012. Working off a $200 million grant through the stimulus package, Maryland utility Baltimore Gas & Electric (BGE) had just deployed 100,000 smart meters, reaching 10 percent of its goal to digitally connect 1 million gas and electric meters. Like the president, BGE officials weren't thinking much about resiliency. The meters were mostly for improving energy efficiency and demand response, not outage management. And then Sandy swept through Maryland, knocking out the power for nearly 200,000 of its customers.

BGE smart meters saved 6,000 truck rolls like this one, reducing labor costs during Superstorm Sandy by $1 million.

Source: BGE

Even though the meters were not fully integrated into the utility's centralized outage system, BGE had a new way to monitor where the power was out in its territory. By sending messages to the meters to see if they responded, the utility was able to locate where to send crews in the field or verify if power had been turned back on. It was a huge leap from BGE's previous callback system, which required staff to make phone calls to customers in order to determine whether the electricity was back on.

Within 48 hours, 90 percent of BGE's customers had their power restored. The utility calculated it had saved more than $1 million in labor costs by more efficiently deploying line workers and eliminating the need for 6,000 truck deployments.

"That was really when we saw an opportunity to later leverage the project," said Chris Burton, vice president of BGE's smart grid business. "Resiliency and reliability were not the biggest tickets at the time the project was first announced, but we saw their value." The utility now has 650,000 smart meters installed.

Neighboring utility Pepco, which operates in Maryland and Washington, D.C., saw the exact same benefits. Sandy caused more than 100,000 outages in Pepco's territory. By leveraging its newly built smart meter infrastructure, the utility was able to restore power for 95 percent of customers within 48 hours. That was a major improvement over its performance during the June derecho, which took the utility by surprise and left hundreds of thousands of customers without power in the sweltering heat for nearly a week. In the days before Sandy, Pepco's president assured the public that thousands of new smart meters would help the utility better prepare for the storm. And they did.

There was one glaring problem, however. In nearly every other Northeastern state struck hardest by Sandy – Connecticut, New Jersey, New York and Massachusetts – there were virtually no networks of smart meters deployed. Utilities had developed plans over the years, but regulators worried about cost and security had delayed the projects. That left big gaps in how utilities alerted customers and managed repair jobs during the storm. It's an issue faced by many power companies across the country that still depend on manual processes to verify and fix outages.

PSE&G had many situations in New Jersey where it could have saved manual visits or phone calls to verify power restoration if it had had smarter meters in place. Without the technology, the utility couldn't tell if individual houses were receiving electricity after repairing circuits. "That's an infrastructure gap that, candidly, is a policy debate where the regulators say they don't want to spend the money," said Izzo.

"What we've learned from Hurricane Sandy and other disasters is that we've got to build smarter, more resilient infrastructure that can protect our homes and businesses, and withstand more powerful storms."

The lack of intelligence in its technology frustrated Izzo. So while New Jersey regulators delayed large-scale smart meter rollouts, PSE&G focused further out on its distribution system and proposed one of the most comprehensive deployments of intelligent technologies on the grid.

As part of Energy Strong, PSE&G's $1 billion post-Sandy hardening plan, the utility plans to spend $100 million on fault location, isolation and service restoration (FLISR) – an application gaining traction in the U.S. that can help better detect faults and isolate problems on distribution circuits. That investment in FLISR rivals what any other utility has made thus far.

The utility will also spend another $100 million on remote controls for substations and a distribution management system (DMS) that can pull together maps, outage reports, information from field crews, SCADA data, customer information and data from equipment in the field into one system. Even after getting whittled down by regulators from its original $3.9 billion spending target, it will be one of the biggest rounds of spending on distribution grid intelligence since Sandy.

A PSE&G employee manages a job through the outage management system. The company's grid monitoring capabilities are going to get a big boost in the coming years.

Source: PSEG

With $200 million in assistance from the stimulus package, Con Edison is also investing quite heavily in distribution management capabilities that will give it a better view of its grid network in New York City. When completed, it will network SCADA systems, FLISR and smart meters into one system – potentially helping link together buildings with intelligent control systems and electric vehicles. The ambitious project was initially announced in 2009 on the same day the president was visiting Florida touting his smart grid plan. However, it was not in place during Sandy – and parts of the system still have not been finished.

When Con Edison's $1 billion grid hardening plan is completed and its distribution management system fully integrated, executives are confident that company will be very different than it was before Sandy. "When all is said and done, a Sandy-like event will have a much smaller impact on the system," said Con Edison's John Miksad.

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In June 2013, President Obama stood in front of hundreds of students at Georgetown University. Instead of talking about green jobs and new investments in the clean energy economy – topics that had faded somewhat from his speeches at that point – the president was there to talk about climate change.

When the topic of infrastructure came up, Obama struck a different tone than in past speeches: "What we've learned from Hurricane Sandy and other disasters is that we've got to build smarter, more resilient infrastructure that can protect our homes and businesses, and withstand more powerful storms."

Manmade climate change, he said, had "contributed to the destruction that left large parts of our mightiest city dark and under water."

The speech was a pivotal moment for the White House, which was trying to show it was serious about addressing the climate. It was also part of a broader shift in the power sector, where utilities were starting to think differently about infrastructure development. In 2009, the buzzword within the industry – and thus the political realm – was "smart grid." After Sandy, it was largely about "resiliency."

A 2013 survey from the consulting services company Accenture backed that up. When U.S. utilities were asked their top reason for integrating IT on the grid to make it smarter, 97 percent identified reliability and outage management as top concerns. In Europe, where grid reliability historically has been much higher than in the U.S., every single utility surveyed said the top priority was distributed energy integration.

When American power companies were asked if recent extreme weather events had driven smart grid investments, 83 percent responded in the affirmative. "It is a top priority. Utilities believe they've got a lot of work to do in that space, and they are now planning to invest," said Jack Azagury, the global managing director of Accenture's smart grid services unit.

It hasn't been a top priority in recent decades. Throughout the 1990s, satisfied with reliability improvements, U.S. utilities significantly reduced spending on distribution infrastructure from 5.7 percent of revenues in the 1980s to 3.5 percent in the 1990s. The result: a $57 billion gap in spending that the American Society of Civil Engineers has said needs to be filled by the end of the decade to replace outdated, aging equipment.

The stimulus package provided a needed surge. As of March 2014, the $4.5 billion spent by the government on grid modernization resulted in more than $5 billion in private investment to install 14 million smart meters, nearly 350 advanced grid sensors, the digitization of 6,500 distribution circuits and development of more than a dozen storage projects. But even the Department of Energy, which oversaw the stimulus grid program, admitted those projects were "a relatively small down payment" on the hundreds of billions of dollars needed to bring the distribution and transmission system up to modern standards.

"I don't think that utilities have been doing a poor job. I think they've been doing as well as they typically could, given restrictions around the technology they were using."

Anecdotally, utilities have reported numerous benefits from the stimulus: thousands of fewer truck rolls; millions in operational savings; and hours in saved outages. But with limited nationwide data after 2011, it has been difficult to determine how far those benefits have spread since Sandy.

The most recent data from ABB showed a lack of progress in the industry as of 2011. When the Associated Press looked at information provided by the software company, it found that the average power outage was 15 percent longer in 2011 than it was in 2002. Throughout that same decade, spending per customer on distribution equipment and maintenance – not including power plants or transmission lines – rose by one-third; however, the number of nationwide outages stayed virtually the same. Those statistics didn't take into consideration any of the big extreme weather events like Hurricane Irene or the October snowstorm in 2011.

"I don't think that utilities have been doing a poor job. I think they've been doing as well as they typically could, given restrictions around the technology they were using," said Rick Nicholson, head of product management and marketing at ABB's Enterprise Software product group.

Conversely, ABB and the Associated Press found one mildly positive statistic that mentioned previously: power restoration after Sandy was faster on average than any other hurricane since 2004, even though it caused the largest number of outages in U.S. history. Although many utilities are still feeling the impact of the long period of lagging investment, Nicholson said that power providers are slowly starting to change. The post-Sandy recovery was a sign that smarter OT and IT is making its way onto the grid.

"Clearly, the availability of more advanced technology like smart meters and distribution SCADA systems are having an impact. It's also because utilities are putting more emphasis on [technology] as the number of storms increases," said Nicholson.

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With stimulus funds dried up, resiliency has become a more important driver of grid modernization, even for utilities outside of Sandy's path. This has a direct impact on how technologies are integrated as companies try to build on the technological foundation laid by recent government investments.

There are five major technology areas that can provide utilities a better sense of what's happening on the grid, and some of them have been given a boost by the stimulus. The first are smart meters and the communications systems that link the meters, known as automated metering infrastructure.

The second are the geographic information systems and SCADA that can analyze locational data and provide remote control capabilities. The third are the outage management systems (OMS) and distribution management systems (DMS) to track issues on the grid. The fourth are the mobile workforce management systems, which all utilities use to track jobs out in the field. And the fifth are business analytics tools that help utilities make sense of the large amounts of information across the grid.

“We’re starting to see a much greater emphasis on integrating these systems,” said Nicholson.

Utility systems for addressing outages, managing calls during emergencies and mobilizing the workforce are starting to converge.

Source: FirstEnergy Corp.

Utilities are making an effort to bring these disparate elements together in ways that improve operations and the customer experience. After Sandy, for example, JCP&L invested tens of millions of dollars in new mobile capabilities for its outage management system to help deliver information to lineworkers in the field, track mutual assistance crews and give customers an up-to-date view on outages. That system was developed as a direct response to criticism that the utility wasn’t keeping customers adequately informed.

“That information is readily available, not just during storms, but during blue-sky days as well,” said JCP&L’s Tony Hurley. “We are much better off with these changes.”

Scott Olson, who was deputy mayor of Byram Township, New Jersey during Hurricanes Irene and Sandy, witnessed those integration problems within JCP&L. From late 2011 through 2012, his town experienced an aggregate total of more than 30 days of outages –and he was getting frustrated.

On daily conference calls with company executives to get updates, Olson heard conflicting reports about when power would be restored. “They just didn’t have the information,” he said. When talking to crews on the street, Olson saw that they had paper maps of the grid that didn’t show streets. The line workers would go up to the pole, look at the number imprinted on it, and compare it to the map – while simultaneously using a compass to figure out which direction they were facing. And when JCP&L set up an online map to track outages, the display was consistently incorrect.

“They were clearly trying to do their best, but they were trying to get information for us and they just couldn’t find it,” said Olson. “The situation seemed pretty ridiculous in modern America.”

While its new outage system is an important step for JCP&L, that level of communications integration is still a baby step compared to the type of integration that is possible. The sixth – and most nascent – technology area is the advanced distribution management system (ADMS). It's the holy grail of resiliency, which is why a lot of the big grid automation companies are chasing it.

To understand the potential of ADMS, it's helpful to understand how the other response systems at a utility work.

Outage management systems have been the core of utility control centers since the 1980s, when direct digital controls became common. Those systems relied mostly on analyzing patterns of phone calls and comparing them to outages in the field. They were much better than the completely manual systems used before, but early outage management capabilities were unable to reliably provide situational awareness. Newer systems have integrated digital mapping tools. As illustrated in the case of BGE and Pepco during Sandy, smart meters and other sensors have also enhanced monitoring capabilities.

Utilities also use a mobile workforce system to dispatch crews and update work orders. Traditionally, outage systems and workforce systems were separate. But over the years, they have been merged, usually through custom integration. Newer platforms now offer the two in the same package and have expanded beyond laptop computers to handheld devices – sometimes benefiting mutual assistance crews visiting from other utilities. That's what JCP&L has done.

Finally, the traditional DMS brings together SCADA systems, mapping and demand modeling tools together on one platform. Sometimes, the outage and workforce platforms are fully integrated with the DMS, but it often runs separately.

An ADMS combines all of these systems together, while also bringing in all the new information from meters and sensors that have recently been deployed in the field. In theory, a utility engineer or CEO could have access to any combination of data in one place: damaged circuits, location of crews, status of jobs, maps of the service territory, damage estimates, and even social media feeds from customers locating outages. And outside of a crisis situation, the utility would be able to monitor voltage levels, demand on the grid, and performance of distributed systems like solar and batteries.

At a time when consumers expect everything to be connected, it may seem surprising that these capabilities are only now coming together. Part of the issue has been the availability of technology: many of the enabling devices in the field were only deployed as a result of funding from the stimulus package. Part of the issue has also been culture; operations and IT teams within utilities have historically operated in silos. And there's also cost; spending tens or hundreds of millions of dollars on new equipment and the overlaying software can be a tough sell to some regulators.

"They were trying to get information for us, but they just couldn't find it. The situation seemed pretty ridiculous in modern America."

"It's all about a question of priorities and budgets. Even when a technology is there and the business case is strong, utilities may not go for it," said John McDonald, director of technical strategy at GE Digital Energy.

That's not stopping companies from trying. In the last few years, major grid software and hardware providers – Alstom, GE, Oracle, Schneider Electric, Siemens and ABB – have beefed up their ADMS offerings and used recent extreme weather events as a way to pitch utilities on the benefits. Utility adoption is increasing around the country, but traditionally conservative power companies are still somewhat slow to integrate such advanced systems.

However, if there's anything that could accelerate ADMS adoption, it might be another potential "threat" to the way utilities have historically managed infrastructure: distributed generation.

Accenture's 2013 industry survey found that utilities in America were far more interested in using information technology for outage management, while utilities in Europe were mostly interested in using it for integrating distributed energy. But as the U.S. starts to catch up with Europe in renewable energy – and states like California, Hawaii and New Jersey put enough distributed resources like solar on-line to start challenging circuits and cutting demand – an integrated approach to grid management may appeal to more utilities.

"I think that's how the U.S. market is moving forward. There's a lot of attention around reliability, but I think the next big wave of investment is going to be around distributed energy resources and how they're being incorporated into the grid," said Gary Rackliffe, the vice president of smart grid development for ABB. "We're seeing a lot more attention in this area."

Pockets of Distributed Resilience

For many who lived through the aftermath of Superstorm Sandy without power, the experience will forever be an example of how the centralized electricity system failed them. But the system didn't fail for everyone. Scattered throughout the ruin, tiny pockets of resiliency formed – proving that smaller, cleaner, distributed technologies can be a powerful defense against crises on the grid.

In Bayonne, New Jersey, 75 residents settled into the Midtown Community School in the days after the storm. The elementary school was operating as an emergency shelter, providing a place to stay dry for some people stuck in the severely flooded town. But the school was much more than a shelter – it was an experiment in hybrid solar photovoltaics (PV).

Four years earlier, the local school district approached Lyle Rawlings, the president of New Jersey-based solar installer Advanced Solar Products, to talk backup power. The company had already developed a 272-kilowatt system for the Midtown school. District officials wanted to go further and figure out how to allow the solar PV to operate during power outages when other systems were required to shut off.

As the second-biggest solar market in the U.S., New Jersey had 20,000 solar systems on roofs throughout the state. But the vast majority of those systems were tied to the grid, which meant they could not function if the electricity system blacked out. Without batteries or a backup generator – technologies that were often prohibitively expensive for the average system owner – the panels turned into useless bricks of silicon and glass during an outage.

"I think Sandy taught us a lesson about the need for a more distributed approach to resiliency."

The Midtown school already had a diesel generator. So rather than install an expensive bank of batteries, Rawlings figured he could just pair the solar with the generator and the emergency lighting system. The only problem: there weren't any inverters on the market that could support switching between the systems safely and efficiently.

Advanced Solar Products turned to engineers at the world's largest inverter manufacturer, SMA, and worked for months to adapt the power electronics so that electricity produced from the solar system could be directed into the backup lighting system, thus allowing the generator to idle at low levels when the sun was shining. It didn't mean that the entire building was powered by solar in the days after Sandy. But the hybrid system allowed for a steep drop in fuel consumption at a time when it was nearly impossible to deliver diesel to flood-stricken areas.

"The solar did what it was supposed to do. It worked exactly as planned," said Rawlings. He imagined the possibility of doing the same for thousands of other systems throughout the state.

The Midtown solar system was an isolated case. The thousands of diesel and gasoline generators deployed in areas hit by Sandy were the true emergency power workhorses, providing important backup to homes and businesses. However, within just a few days, fuel supply shortages became a serious challenge. People lined up for hours at gas stations to find the fuel supplies completely depleted. In New York and New Jersey, half of all gas stations ran out of fuel within three days. Diesel climbed to $35 per gallon at some stations. Panic and anger grew.

Two SMA Sunny Central commercial inverters help create a solar/diesel microgrid for an emergency shelter in Bayonne, New Jersey.

Source: SMA

Finally, in early November, the military delivered 24 million gallons of gasoline and diesel to the hardest-hit areas, bringing in trucks to help those desperate for fuel. Relief may have come, but vulnerabilities were exposed: in a prolonged outage, generators are limited by the top-down logistics of supplying fuel. Problems with fires, failed units at critical facilities, carbon monoxide poisoning and noise pollution were also issues in Sandy's wake.

IMAGE 18: A line forms at a gas station in New York, where gasoline and diesel was hard to come by in the days after Sandy.

Source: Anton Oparin/Shutterstock

Solar is not a panacea, nor will it fully replace conventional generators anytime soon. But after Sandy, the technology was taken more seriously as a supplemental outage solution providing a clean, safe and abundant supply of energy. "I think Sandy taught us a lesson about the need for a more distributed approach to resiliency," said Rawlings. "There's a perception after the hurricane that we need new types of emergency power capabilities like this."

It's not just perception that's changed – it's the technology itself. Solar, storage and power electronics are undergoing a steady transformation. Since 2008, the cost to manufacture a lithium-ion battery has fallen by half, and could potentially drop another 50 percent within the decade. Meanwhile, the average all-in price to install a solar system has fallen by 61 percent in the U.S. over the last four years, making it far more affordable for both residential and commercial customers. One recent study from the Rocky Mountain Institute estimated that solar paired with storage could be cost-effective for more than a million utility customers in East Coast markets within ten years.

The markets have also evolved alongside the technology. Since Sandy, electricity markets in California, the Mid-Atlantic and the Northeast have adopted new federal rules that value grid services provided by battery storage. While important during times of crisis, tying a solar system to batteries or a generator for emergency backup alone is cost-prohibitive for most customers. System owners must find consistent revenue streams in order to pay back the thousands of dollars in extra investment. Now that owners of fast-responding storage systems can get paid for balancing out the grid in real time, the economics of adding backup are improving. Businesses can also use storage to reduce the demand charges imposed by utilities during peak times when energy supply is limited.

These factors – resiliency planning, improving economics and market recognition of storage – are coming together to make solar a more viable backup technology. By 2020, commercial building owners could install 700 megawatts of distributed storage around the country, with solar partnerships a major factor in the growth. America's largest solar installer, SolarCity, has partnered with EV manufacturer Tesla to provide solar-battery offerings in the last two years. And Solar Grid Storage, a company with offices around the East Coast, has added storage to commercial solar systems and microgrids in Maryland, New Jersey and Pennsylvania.

"Taking advantage of the tens of thousands of solar projects already installed over the last several years and accelerating support for new installations – this time with storage – should be a key component of plans for rebuilding," wrote Solar Grid Storage CEO Tom Leyden in an op-ed a year after Sandy. He and others have sought to educate the public about the resiliency potential of the technology combination.

Rawlings took the experience of the Midtown school to heart. Advanced Solar Products has since started offering lithium-ion batteries with solar, and plans to make solar-storage systems a bigger part of the business going forward. In one case, one of Rawlings' customers was able to pay for a commercial storage system and inverter through frequency regulation payments -- actually making the cost of a hybrid solar-storage system lower than solar alone.

“People are approaching this in a much more sophisticated way,” he said. “It told us we could provide this service for a low cost.”

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Daniel Soto was a digital refugee. He’d known plenty of them in Africa – people who had to trek to far-away villages just to charge their mobile phones. But he’d never been one himself, at least not on Long Island.

When Sandy hit New York, Soto was living with his wife’s parents in the upper-middle-class hamlet of Oceanside, Long Island. He was finishing up a two-year post-doctorate fellowship at Columbia University with a focus on distributed energy access in developing countries. The fellowship brought him to Mali, where he helped work on solar-powered microgrids and other small-scale energy projects. Oceanside was a dramatically different world from the villages he’d visited in Africa where kerosene lights and candles were the norm and reliable grid-based electricity was a luxury.

But Long Island Power Authority, the utility widely considered to have been the worst prepared for Sandy, was, in its customers eyes, running a third-world grid that didn’t work. For nearly two weeks, Oceanside and neighboring communities went without power, desperately waiting for updates from LIPA that came infrequently. Soto and his neighbors wanted normalcy. And at the very least, that meant being able to use their cell phones and tablets.

Two days into the outage with no update from LIPA, word spread throughout the neighborhood that the nearby village of Rockville Centre had power. Rockville was only a couple of miles away, but the two communities seemed worlds apart. The town owned its own grid, which made electricity rates there 50 percent lower than LIPA’s. It also made turning on the electricity for the town’s 23,000 residents a faster, far less complicated process.

Soto and his neighbors took full advantage of the situation. Each day, hundreds of people from nearby towns flocked to Rockville to power their electronic devices and buy supplies. Soto rode his bike to the library, charged his laptop and cell phone, and went back home. As the days wore on and thousands of New Yorkers performed a similar daily ritual across the city, Soto realized he was witnessing the same pattern of behavior he saw in developing countries.

“It was a really interesting opportunity for me, personally and as a researcher, to see that this behavior is universal,” he said. “To see it play out miles away from the most powerful and well-known city on the planet was really humbling for me.”

Soto felt lucky to have a power source nearby. Finding a source of electricity was far more difficult for tens of thousands of other LIPA customers. On Rockaway Peninsula in Queens, there were still 27,000 people without power a full two weeks after the storm. But a small bit of relief eventually came for some in those cut-off communities: off-grid solar generators.

FEMA and the military were spending millions of dollars on fuel convoys to supply generators. However, they paid virtually no attention to the sun's abundant fuel supply spilling into the region every day. In early November, with relief efforts in New York slowed by lack of power and fuel shortages for generators, a collection of solar advocates banded together to take advantage of that solar resource.

Chris Mejia, president of Consolidated Solar, a company that sells mobile solar units, had a lot of equipment on hand to help people access electricity via portable devices. He was eager to get them in the field – he just needed some help on logistics. But the government didn't seem interested in solar. After numerous attempts to reach local and federal disaster coordinators, Mejia couldn't find anyone who wanted to help deploy his systems.

"Without the solar, we wouldn't be able to have a generator."

He finally connected with a local clean energy education nonprofit called Solar One, which put out a public call for help on Facebook. Some employees at SolarCity saw the post and quickly moved to contact utilities. Over the next month, the informal coalition, dubbed the Solar Sandy Project, hauled seventeen 10-kilowatt generators mounted on trailers to Long Island, Staten Island, the Rockaways and Red Hook. It was a small but meaningful effort to get energy to places where fuel convoys and the centralized grid had failed to reach. "Without it, we wouldn't be running at all," said Kelli Donahue, director of a local relief agency in Rockaway, in an interview. "Without the solar panel, we wouldn't be able to have a generator" because of gas shortages, she said.

Chris Mejia of Consolidated Solar and Shaun Chapman of SolarCity help set up a 10-kilowatt solar generator on Staten Island.

Source: The Solar Sandy Project.

Meanwhile, a husband-and-wife team of landscape architects living in Brooklyn had the same idea. Walter Meyer and Jennifer Bolstad reached out to David Gibbs, an engineer-turned-furniture maker who had worked in Alaska for four years designing off-grid energy systems. They wanted to bring solar to the Rockaways too. Using spare solar panels and batteries that Gibbs had lying around, they installed a small charging station near the Rockaway Surf

Club, which was serving as a community center near the beach. The Power Rockaways Resilience Project was born, and a dozen more systems were soon deployed.

Diane Cardwell, an energy reporter for the New York Times, was one of the many residents of Rockaway Beach flooded out by Sandy and essentially left homeless after the storm. As a journalist, her neighbors looked to her for information on relief and power restoration. Many didn't know where else to turn.

In mid-November, a solar charging station came to Cardwell's neighborhood. The project was a collaboration between the Solar Sandy Project and the Power Rockaways Resiliency Project, which together raised tens of thousands of dollars from corporate donors and crowdfunding. It changed the mood in the neighborhood immediately.

Cardwell was filing stories via her phone, and she was happy to have a place to charge her equipment without fighting hordes of people for an outlet. But more importantly, the solar stations gave her neighbors a better connection to the world. Using mobile devices was not just about convenience – it was about figuring out how to start the process of putting their lives back together.

According to one industry survey, more than 75 percent of people who experienced extended outages relied primarily on cell phones to get updates from utilities. "We were desperate for that connection. I was knocking on doors telling people what to do because there were no other means of communication," said Cardwell. "It was clear that it would have been very helpful if we'd already had solar generators."

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Herb Freedman liked the idea of solar. He liked the idea of a lot of different technologies. But his mission was keeping housing costs as low as possible, and Freedman wasn't convinced that solar was the right answer.

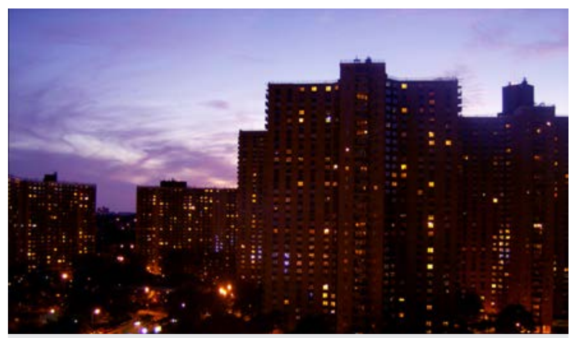
Besides, the city his company maintained had something else keeping residents insulated from problems on the grid: a 40-megawatt combined heat and power (CHP) plant providing electricity, steam, heating and cooling to 60,000 people all in one package. And it worked flawlessly during Sandy.

Technically, the area served by the power plant wasn't a city. It was an affordable housing development in the Bronx called Co-Op City, with more than 15,000 apartment units, 35 high-rise buildings and three shopping complexes on 330 acres of land. It was, officially, the largest residential complex ever built. If it were designated a city, it would be the tenth largest in the state of New York.

Freedman was a principal at Marion Real Estate, the company managing Co-Op City. And he took pride in the community's energy self-sufficiency. "One dollar of fuel gets used three times. There's a level of comfort knowing you supply your own energy needs."

The steam and gas turbines at Co-Op City were replaced in 2011 after the original steam plant and 6-megawatt backup generator built decades ago had fallen into disrepair. The new plant generated electricity along with steam, giving the co-op an ability to island itself from Con Edison's electric grid during emergencies. The original motivator for building the $60 million CHP plant wasn't just resiliency during blackouts – it was straight economics. The co-op immediately saved $15 million a year in energy costs, helping to keep housing affordable as electricity prices in New York increased.

For a year, the power plant chugged along mostly unnoticed – cooling apartments, heating showers and electrifying appliances with virtually no one in the city knowing where the resources came from. And then came Sandy, which caused 45,000 power outages in the Bronx. During it all, Co-Op City was business as usual. "We were watching what was going on around the city, but we were fine. We had no outage," said Freedman.



Co-Op City's 40-megawatt cogeneration unit kept the lights on during and after Sandy when the power went out in the Bronx.

Source: Jules Antonio

Most of the Co-Op City residents still had no idea that a local power and steam system had saved them from a possible extended power outage. But others took notice. "All of a sudden, the value of CHP really hit home," said Jessica Lubetsky, a clean energy policy expert with the Pew Charitable Trusts.

Across Connecticut, New Jersey and New York, more than a dozen CHP plants at colleges, hospitals, data centers and corporate campuses reliably provided energy during and after Sandy. According to a report from ICF International, all twenty-four CHP systems in New York that were designed to operate independently from the grid during a power outage performed flawlessly. By comparison, during the major Northeast blackout of 2003, half of the 58 emergency generators serving hospitals failed to operate.

"This notion of using combined heat and power for resiliency really materialized after Sandy."

When LIPA struggled for two weeks to get electricity back, the 1.25-megawatt natural gas CHP system at South Oaks Hospital kept medicine refrigerated and patients comfortable. When the grid failed in Princeton, New Jersey, Princeton University's 15-megawatt system supplied all of the campus' energy for three days. And when cascading power outages hit Manhattan, Public Interest Network Services kept its data center and internet services humming thanks to a 65-kilowatt CHP unit.

Just three months earlier, President Obama had signed an executive order that set a national target of 40,000 megawatts of new CHP capacity and established a technical assistance program at the Department of Energy. The order was framed entirely in an efficiency context, with no mention of the resiliency benefits. Then Sandy showed how reliable cogeneration could be during extreme events. The push to develop CHP took on a whole new meaning.

"This notion of using combined heat and power for resiliency really materialized after Sandy," said Lubetsky. "Before, 'resiliency' just sort of came up in passing." Suddenly, cogeneration was a central piece of post-Sandy recovery spending.

When announced, some worried that President Obama's 2012 executive order to double CHP deployment would fall flat without funding. But East Coast states created funding momentum after Sandy. In May 2013, following recommendations from a state commission, New York Governor Andrew Cuomo boosted spending on CHP by $40 million – adding to the $100 million recently allocated for the technology. New Jersey quickly followed suit with another $100 million in funding for its existing CHP program. Two months later, Connecticut allocated $18 million for microgrid projects, many based on cogeneration units.

"Superstorm Sandy demonstrated the need for resilient power generation when critical facilities like hospitals lose electricity," said Gov. Cuomo in a funding announcement. "CHP technology is a clean energy, commonsense solution that keeps the lights on and systems running during emergencies."

In recent months, Freedman has been talking with Siemens and the New York mayor's office about turning Co-Op City into a laboratory for networking other distributed energy technologies into its microgrid. That could include solar, battery storage, or a more sophisticated software system for controlling energy across buildings. "We're like a city. We're a perfect laboratory for testing because of our size," said Freedman.

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The use of clean, distributed energy was not widespread during Superstorm Sandy. These examples were outliers at the time of the storm. But in the nearly two years since the disaster, much work has been done to turn them into the norm – and tie these technologies together into a more complete resiliency framework.

Across Connecticut, Massachusetts, New Jersey and New York, more than $300 million has been spent or committed to develop distributed energy systems specifically to address events like Superstorm Sandy. Utilities, regulators and lawmakers have made a real effort to learn from the success of localized energy production during the storm.

"There is a serious commitment to begin to fund distributed power solutions for more resilient solutions. That, to me, is really a fundamental change," said Lew Milford of the Clean Energy Group. Indeed, there has never been a coordinated multi-state effort to build distributed energy systems like the one that took shape after Sandy.

On a summer day in late July 2013, Connecticut Governor Dannel Malloy joined local officials in downtown Bridgeport to announce state funding for nine microgrid projects. It just was one of many similar announcements from state officials in the months since the storm passed. But this one was personally significant for Malloy. "This is close to my heart," he proclaimed.

Before becoming governor, Malloy had been mayor of Stamford, Connecticut from 1995 to 2009. He took a special interest in localized energy throughout his mayoral terms, both because he believed in renewables and because he was concerned about power reliability for his city. With electricity prices in Connecticut nearly 60 percent higher than the U.S. average, it was getting harder to attract financial businesses to the city from New York. Power reliability problems made the situation worse. A heat wave in 2006 caused power lines to catch fire and left 9,000 people in Stamford without power, exposing problems with an aging system.

In 2007, Malloy ushered through an ordinance in Stamford that created an energy improvement district that allowed property owners to collectively fund and implement onsite energy systems. He was particularly interested in building a downtown microgrid. To prove the concept, Malloy worked with his economic development team and a project developer in 2009 to build a CHP microgrid for a 250,000-square-foot government building using a gas turbine and a fuel-cell unit. But the project languished. Concerns grew about the financing agreement, and when a new mayor came in a year later, the project was terminated.

Three years on, Malloy had witnessed the statewide consequences of not having resilient backup systems like microgrids. The destructive combination of Hurricane Irene and the Halloween nor'easter in 2011 caused more than 800,000 outages across the state that took 12 days to restore. Malloy knew it was time to take another stab at power reliability. In the summer of 2012, he worked with the legislature to pass an emergency preparedness act that, among many other things, established the first statewide loan program for microgrids.

"There is a serious commitment to begin to fund distributed power solutions for more resilient solutions. That, to me, is really a fundamental change."

When Sandy swept through Connecticut, it brought another crippling round of outages and $400 million in damages. The government swiftly set aside millions to build out distributed energy projects for critical facilities. "Today marks another step forward in how we deal with extreme weather," said Malloy proudly as he announced the first nine projects in the summer of 2013.

In March 2014, the first microgrid at Wesleyan University in Hartford went on-line. The school invested in a 676-kilowatt CHP unit featuring a reciprocating natural gas engine that will keep nearly 90 percent of the campus running for weeks during an outage. Other microgrids around Connecticut are in development and will be finished within the year. Most will be based on natural gas; others may feature more renewable energy sources. After an initial $18 million commitment to the loan program, Malloy proposed another $15 million to build more microgrids across the state.

Since New York's initial commitment to spend $40 million on CHP, Con Edison has stepped up with a $66 million program to support the technology. In January, New York set aside another $40 million for at least ten communities looking to develop local microgrids that can integrate clean energy and provide crucial backup power by islanding from the centralized grid. That includes a potential project on Rockaway Peninsula, where the power didn't come back on for weeks after Sandy.

New Jersey and Massachusetts have responded in kind, together setting aside $50 million to develop microgrid projects in those states. "These states, in particular, have not wasted the opportunity to move forward," said Pew's Lubetsky. Adding to the funding, the Department of Energy also jumped in with an additional $7 million for innovative microgrid designs in communities around the country.

There is no doubt these programs spurred by Sandy are catalyzing the nascent market for microgrid development. But simply setting aside money for projects doesn't solve the complex legal and technical challenges facing project owners and utilities.

The pitfalls are numerous, and have yet to be sorted out in a comprehensive way. What if wires from a local microgrid intersect into the public domain? A utility may be able to sue for infringing on franchise rights, or could opt to raise its interconnection rates. What if a project is sized too large? The project owner can be taxed as a steam corporation if using CHP. What if the host wants to island from the grid during an emergency? In some cases, the utility may argue for shutting down the microgrid for reliability or safety reasons.

Tax policy is an issue as well. Currently, the federal Investment Tax Credit for CHP is only at 10 percent. And like other clean energy technologies, CHP can't qualify for publicly traded infrastructure funds like master limited partnerships. Those federal limitations – combined with local conflicts with utilities – present enormous challenges for microgrids. "While the movement is underway, there's also kind of a bigger-picture issue in that the markets aren't quite right," said Lubetsky.

There are also limitations in the way these projects are being developed after Sandy. Building a CHP-based microgrid strictly for emergency power is much different from building a self-healing microgrid – sometimes called a virtual power plant – that uses advanced software, renewable energy and battery storage to react in real time. Taking the leap to the next generation of microgrid technology is still a risky proposition for many customers that are worried mostly about emergency backup, rather than becoming a smart-grid vanguard. That's why people like Herb Freedman of Co-Op City are much more comfortable with proven, cost-effective CHP systems: "It's got to make sense for us. We can't just do it because it sounds like a good idea," said Freedman.

Then there are the technical issues associated with controlling these distributed assets on the grid. Utilities without advanced monitoring and control technologies may be hesitant to support a large number of islandable microgrids as the market grows. A slew of software and power automation companies are attempting to solve these challenges, and post-Sandy activity has led to a boost in business for many.

"With all these programs starting up or in pilot stage, we are looking more and more at the concept of virtual power plants," said ABB's Gary Rackliffe. "It has to be one system with a multitude of applications based on a single model."

The military is boosting the development of microgrid projects that utilize solar, storage and other renewables.

Source: Lockheed Martin.

The Defense Department has also jumped deeper into microgrids, both for in-field emergency solutions and to prove more advanced virtual power plant applications. For many years, the military has been looking at ways to reduce energy consumption at bases and in the battlefield, while also protecting itself from cybersecurity and extreme weather threats that can cause blackouts. Since Sandy, various branches of the military have accelerated microgrid development. According to GTM Research, the Army, Navy and Marine Corps are developing thirteen new projects in the U.S. – more than a quarter of all the microgrid projects underway in the U.S.

These aren't your traditional backup systems seen at universities and hospitals. In May 2013, the Army's first grid-connected project was completed: an islanding system that features 120 kilowatts of solar, a 300-kilowatt battery and an advanced control system from Lockheed Martin. The Navy is also in the process of connecting three separate solar-storage microgrids together in San Diego to create the "first centrally managed cluster of multiple cybersecure military microgrids" in the U.S. that features an early-warning system for monitoring threats. "This is a very important realm [in terms of] helping to scale up situational awareness and reduce threats," said Paul Stockton.

Sandy proved that networked, distributed generation could have a real impact during the most severe events. It also proved how rare those systems were compared to the ubiquity of the problems within the broader electricity system. But the storm undoubtedly created a new catalyst for investment with a lasting impact – not just for individual technologies, but also for networks of technologies with the ability to change how the grid functions over the long term.

Managing Uncertainty at the Grid Edge

In late February 2014, sixteen months after Sandy, Paul Stockton sat at a large table with twenty electricity regulators in a dimly lit, windowless ballroom in the basement of a downtown Washington, D.C. hotel. He was there to deliver a presentation about grid resilience to a national meeting of utility commissioners.

Stockton was no longer at the Department of Defense. The previous April, he had taken a position with the Washington-based analysis firm Sonecon to lead its work assessing cyberthreats and extreme weather threats on infrastructure. After witnessing the complexities inherent in the response to Sandy – a storm that wasn't even close to a worst-case scenario – grid resiliency had taken on a new meaning in his work.

Stockton's voice boomed throughout the oversized room. "Start thinking about 'black sky' days," he warned, letting the term linger for a few seconds. The commissioners around the table were silent.

"It's not going to look like Sandy. It's not going to look like the derecho. It's going to be far more intense," he said. "We're talking about an extremely hazardous event much worse than Sandy. It's going to go above and beyond anything ever experienced."

Stockton's concerns about industry preparedness came from direct experience. Up until Sandy, integrated planning between utilities, federal emergency responders and the military was in its infancy. When Stockton traveled to New York City the week before the superstorm to discuss complex catastrophe scenarios, the conversation was still rooted largely in theory. It consisted mostly of planning documents and small exercises – not real-world practice. There were "silos of excellence" in preparedness. The leaders of federal agencies understood their traditional support roles, and had made many improvements since Katrina. But adding power restoration and grid resiliency into the mix created new demands that still had not been fully institutionalized.

"We're talking about an extremely hazardous event much worse than Sandy. It's going to go above and beyond anything ever experienced."

The organization hosting the conference, the National Association of Regulatory Utility Commissioners (NARUC), was very interested in Stockton's experience. So they hired him to write a report about what utilities and regulators could do better. Presenting his findings, Stockton listed off some of the potential answers for regulators in the room: adopt standards created by the Department of Homeland

Security for infrastructure restoration; establish new metrics for utilities that distinguish between standard performance and extraordinary events; create better risk assessment systems; and support a "shopping cart of resilience" for utilities that goes beyond equipment hardening to include more sophisticated IT-based intelligence on the grid.

"Take an additional rock in your backpack," said Stockton sternly to the commissioners seated around the table. "We need to take high-consequence events worse than Sandy more seriously."

As soon as Stockton finished and thanked the twenty commissioners around him, a question immediately came up. It was the question that every utility and regulator impacted by Sandy had been asking since the storm cleared: "It's going to cost money to do all this. How do we analyze the cost to make sure it's useful and something that we can justify?"

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Ralph Izzo understood the difficulties of justifying spending. Despite the buzz about resiliency and the eagerness within the industry to make the grid more adaptable to extreme events, PSE&G's post-Sandy plan was only approved in May 2014 – nearly fourteen months after it was originally proposed.

Izzo believed that the original $3.9 billion plan, called Energy Strong, covered all the areas where PSE&G was most vulnerable. The biggest expense, $1.7 billion, would have gone toward moving or protecting 29 substations in flood-prone areas. Nearly half a billion dollars would have been spent on communications technologies that could help PSE&G identify local problems on circuits faster. Hundreds of millions more would be spent to bury power lines and to make aboveground utility poles stronger. The remaining billion dollars would focus on overhauling old gas mains and metering stations.

Energy Strong was by far the most ambitious post-Sandy modernization effort. But it was the scope of that ambition that worried New Jersey regulators.

The nearly $4 billion price tag troubled ratepayer advocates, commissioners and outside groups, who worried PSE&G was using Sandy to enrich shareholders through a spending "bonanza" – rather than choosing the most prudent projects to protect the grid at the lowest cost. One lawyer representing large energy users in the industrial sector called Energy Strong "the regulatory equivalent of a well-funded ATM machine" that would earn PSE&G shareholders billions in profits and drive up rates. The state's ratepayer advocate claimed Energy Strong would increase rates by 20 percent; PSE&G claimed it would only raise rates by 4 percent.

Regulators were particularly concerned about the way PSE&G wanted to earn back its investment. Rather than undertake a traditional rate case and pay for the plan over a five- or ten-year period of time, the utility called for an immediate reimbursement from ratepayers. Izzo worried that waiting years to earn back the investment would put his company in a precarious financial position if more storms like Sandy didn't materialize. "The last thing I'm going to do is spend $3.9 billion and in five years risk [having] the regulator telling us we didn't need to do all this," he said.

Throughout the process, Izzo didn't hide his feelings. In a conversation with reporters after an April shareholder meeting, Izzo responded to a question about his frustration level: "On a scale of one to ten, I would say eleven," he quipped.

Opponents didn't hold back either. New Jersey's ratepayer advocate Stefanie Brand warned that the plan was poorly thought out, and if passed in full would "squander resources that our state simply cannot afford."

And so, with no agreement on how to pay for the plan – or even what the plan should have been – the largest grid-hardening effort in the country was stuck in regulatory limbo for over a year. "We've been away from Sandy for a long time, so folks are not feeling the same kind of urgency in the commissions that they felt then," said Izzo. "I'm worried about short memories."

A PSE&G lineworker prepares to install a new 69 kV line. The utility's plans to upgrade infrastructure after Sandy have been scaled back due to concerns about cost.

Source: PSEG

Finally, in May, Izzo ended the standoff with regulators and ratepayer advocates by agreeing to cut spending down to $1.2 billion, shedding some spending on smart grid technologies and equipment hardening.

As a result of the delay, none of the improvements made by PSE&G since Sandy have gone beyond ordinary maintenance work. There have been virtually no grid-hardening efforts and no new investments in intelligent systems to monitor the grid. The one thing that did change, said Izzo, was better coordination between utilities for mutual aid deployment.

"Everybody's trying to wrap their arms around [resiliency], while at the same time, a lot of other things in the industry are changing rapidly and demanding attention."

The conflict over Energy Strong proved the difficulty in agreeing on the benefits of resiliency planning. The series of extreme weather events in 2011 and 2012 undoubtedly changed the dialogue around storm preparedness, climate change and grid modernization within the power sector. But it did not change the same basic requirement that utility commissioners are required to uphold: investments must be financially prudent and in the public interest.

Peter Fox-Penner, the utility expert with the Brattle Group, doesn't think regulators have completely grasped what that means in the new era of extreme weather, distributed generation and evolving business models. "It's not so much that memories have faded," he said. "It's that everybody's trying to wrap their arms around it, while at the same time, a lot of other things in the industry are changing rapidly and demanding attention."

In February, the day after Paul Stockton spoke about black-sky threats at the NARUC conference in Washington, D.C., Fox-Penner attended a similar session on severe weather risks. The same questions kept coming up from regulators who admitted they were still trying to figure out how to think about resiliency – which meant they were having trouble analyzing its benefits. "These are very intelligent people. But it's just so new," he said.

It was also new for Fox-Penner, who conducted a cost-benefit analysis of PSE&G's Energy Strong program in October 2013 as the regulatory debate in New Jersey intensified. The study, based on a break-even analysis, looked at how many hours of outages the Energy Strong hardening plan would need to prevent before it paid for itself. The answer: only 3.1 days of prevented outages could make up for $2 billion in electricity investments proposed by PSE&G. Six days of prevented outages could pay for the entire $3.9 billion package that included upgrades to the natural gas system. Together, Hurricane Irene, Superstorm Sandy and the October 2012 nor'easter caused 5.3 days of outages on average.

The results seemed to vindicate PSE&G. But some regulators and groups opposed to the plan remained skeptical, saying the study assumed that all investments through Energy Strong would prevent outages. They also questioned the assumption that an extreme weather event of similar size to Sandy might hit New Jersey in the coming years. When Fox-Penner presented the findings to New Jersey commissioners, he was asked about whether his assessment of extreme weather risk was accurate.

"I'm not a climate scientist; I'm an economic analyst," he responded. "But based on everything I've read, it seems reasonably likely that we're going to get that much cumulative severe weather."

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Of course, it's impossible to predict when the next major extreme weather event will occur. The best scientists in the world can't bring that level of long-term certainty about individual events. But the basic science about human-caused planetary warming is unambiguous.

A March report from the United Nations Intergovernmental Panel on Climate Change described the risk succinctly: "recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of...human systems to current climate variability." In other words, the world's scientists have "very high confidence" that those extreme weather threats are increasing and are being caused by human activity.

The science of how hybrid storms like Sandy are impacted by a warming planet is not as clear. For example, there is still much scientific debate about whether the melting Arctic sea ice – a process which is accelerating because of climate change – created a disturbance in the jet stream that caused Sandy to veer further west. However, scientists agree that warmer-than-average ocean temperatures in the Atlantic, combined with sea level rise, made the storm far more destructive. Even though it's difficult to pinpoint how those factors may converge in the future, climate experts don't view those scientific unknowns as an excuse to avoid addressing the problem.

"Uncertainty should never, ever be an excuse for a lack of planning. I think it's just the opposite. It's the uncertainty that should be goading us into action," said Kerry Emanuel, a professor of atmospheric science at the Massachusetts Institute of Technology. And that's what Emanuel told officials in New York as they started the process of evaluating those climate risks for utilities.

While regulators in New Jersey were engaged in a contentious debate over the value of PSE&G's plan and the future of storms, the New York Public Service Commission approved a measure in February the likes of which had never before been passed in the history of the U.S. electricity sector: a requirement that Con Edison factor climate science into future planning efforts.

The official proceedings started in December 2012, when the Columbia Law School Center for Climate Change banded together with the Environmental Defense Fund, the Natural Resources Defense Council and the Pace Energy and Climate Center to demand that climate science be considered in all utility plans approved by regulators. While there was a lot of talk about climate change after Sandy, most utilities were not using the latest science as a legal guide for their post-storm investments.

In January 2013, Con Edison filed its $1 billion plan to harden the grid. When Michael Gerrard, professor and director of Columbia University's Center for Climate Change Law, looked at Con Edison's plan, he noticed it was aimed at protecting the utility's equipment against heavy winds and storm surges like those from Sandy. That was an important start, but it didn't account for other kinds of weather events like extreme heat or inland flooding. The coalition decided to formally intervene in the rate case throughout 2013 and use it as a platform to force climate change front and center in the discussion.

As Con Edison plans to upgrade equipment on the grid, it will be required to take climate change risks into account.

Source: Con Edison

The process was surprisingly smooth. Unlike in New Jersey, where debate around PSE&G's plan has been contentious and time-consuming, passing a new climate-based definition of resiliency didn't meet with much resistance in New York. It helped that a state commission established by Governor Cuomo had recently lambasted New York regulators for their "reactive" approach to storm preparation. Even more importantly, Con Edison didn't resist the idea.

"Con Edison is run by engineers, and they got the math," said Gerrard. "They understood the nature of the threats to their system."

MIT's Emanuel, who is often asked to deliver scientific findings to various industry groups, agreed that utility officials are generally aware of the risks: "They understand how to digest probabilistic information. They have to do it every day. If they couldn't do that, they wouldn't be able to run their business. These are smart people."

In February 2014, after a year of slogging through the details of rate design, climate science and proposed resiliency strategies, the New York Public Service Commission approved the $1 billion plan, along with a mandate to consider a wider range of extreme weather risks. It was the first time that a regulatory body had so clearly factored in climate science to utility planning.

Throughout the rest of 2014, Con Edison will work with legal experts and environmental groups to develop a long-term climate strategy. In theory, Con Edison won't be planning equipment deployment through 2020 – it will be thinking about how that equipment will be operating in 2075 when climate conditions could be dramatically different than they are now. It is a fundamentally new approach to power sector planning. "We think that it can and should be a model for the rest of the country," said Gerrard.

The ruling has implications for New York's grid that go far beyond building taller walls and protecting equipment from the elements. Con Edison will also be required to think about demand-side services and technologies that can reduce consumption during heat waves. That includes distributed battery storage, demand response and electric-vehicle charging to shift load. The utility will also need to develop a stronger plan for procuring CHP, solar paired with storage, and islanding microgrids as "alternative resiliency strategies" during extreme events.

"Uncertainty should never, ever be an excuse for a lack of planning. I think it's just the opposite. It's the uncertainty that should be goading us into action."

Since Sandy, New York has embraced these technologies like no other state impacted by the storm. In February, Con Edison partnered with the state's clean energy planning authority, NYSERDA, to issue a 100-megawatt procurement for grid-scale energy storage and demand response services. The utility is also partnering with storage providers to test new technologies in buildings to see how they interact with renewable energy systems and the grid.

Topping off these groundbreaking changes, the state's Public Service Commission proposed another truly groundbreaking change in April: an overhaul to the state's distribution utilities to make them into "distributed system platform providers" with a mandate to integrate customer-sited energy systems. The plan would change how regulators compensate utilities – switching from the traditional rate-of-return model to a structure that would pay utilities for their ability to reduce energy consumption and serve more distributed energy. The process could completely change the way utilities in the state operate.

"Technological innovation and increasing competitiveness of renewable energy resources, combined with aging infrastructure, extreme weather events, and system security and resiliency needs, are all leading to significant changes in how electric energy is produced, managed and consumed," concluded state regulators in their report. "New York state must lead the way."

Superstorm Sandy was clearly a wakeup call for regulators, state lawmakers and utilities in New York.

These actions, directly and indirectly influenced by Sandy, have focused on making the state's electricity infrastructure more resilient. More importantly, they go well beyond the traditional hardening techniques that other states have considered – setting in motion major changes for how the grid operates.

"New York has made it clear that distributed generation is very important," said Gerrard. "It serves a dual purpose to reduce greenhouse gas emissions and add resilience."

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Lew Milford had been working on grid resiliency strategies for fifteen years, with little success. In 1998, when Milford founded the Clean Energy Group, a renewable energy advocacy organization, he made distributed technologies a core focus in his work on strengthening the grid.

A year later, a major blackout swept through upper Manhattan. In response, Milford wrote policy pieces on the need to integrate fuel cells and CHP into hospitals and other critical facilities. He saw little response. Four summers later, in August 2003, cascading equipment failures caused a blackout for 55 million people in the U.S. and Canada. Milford kept writing about the need for distributed energy but got little traction. Two years later, after Hurricane Katrina ravaged the Gulf Coast, Milford hoped that policymakers and utilities would start listening to the calls for distributed resiliency. But even then, he saw virtually no policy response or changes within the industry.

"We continued to write about the need for more resilient power, more distributed power to address power outages from severe weather events, but I'd say we probably didn't make much progress," said Milford.

When Sandy hit – coming soon after a series of other powerful storms – the change started. Worried that Sandy was a "new normal," state officials set aside tens of millions of dollars to fund low-carbon, distributed energy technologies. Milford had never seen a state respond to a severe weather event in the way that Northeastern states were. "For the first time, there's a serious commitment to fund distributed power solutions. That's the first turnaround I've seen in fifteen years," said Milford.

The turnaround didn't happen because policymakers and utility executives decided suddenly that clean energy advocates like Milford were right all along. Rather, it was a number of forces coming together that made the post-Sandy environment unique from events in the past.

New York regulators laid out those elements in their April report on changing utility business models: the urgent need to replace aging infrastructure; the recognition that increasingly severe climate

"Increasing competitiveness of renewable energy resources, combined with aging infrastructure, extreme weather events, and system security and resiliency needs, are all leading to significant changes in how electric energy is produced, managed and consumed."

events are the "new normal"; and the rapidly falling cost of distributed energy and IT systems on the grid. These factors now have the potential to "challenge incumbent systems and present opportunities for transformation of those systems," concluded the report.

In 1999, when Milford first started pushing for more distributed energy, the median price of installing a residential solar system was around $12 per watt, the cost of a lithium-ion battery was between $1,000 and $2,000 per kilowatt-hour, and the cost to store a gigabyte of data was $100. Today, the median price of a residential system is less than $5 per watt, lithium-ion batteries are being developed for $500 per kilowatt-hour, and the cost to store 1 gigabyte of data is 5 cents.

These cost trends have enabled a boom in distributed generation and set the foundation for a networked grid in ways that were not possible fifteen years ago. In the last 2.5 years, more solar has been installed in the U.S. than in the previous 50 years combined. And tens of billions of new data points are being generated through sensors and smart meters every day – opening up new applications for managing demand on the grid. "Up until now, there hasn't been a market to support investments in resilient power," said Milford.

That new market is what Greentech Media calls the "grid edge" – the place where distributed energy, grid modernization and digital technologies collide to create entirely new business opportunities.

Distributed energy technologies like solar are gaining traction on the grid. They could soon come to be seen as a resiliency strategy as well.

Source: PSEG

At the grid edge, solar paired with storage, electric vehicles, building energy management systems, advanced power electronics and microgrids are becoming potential enablers of resiliency. Once-separate communication networks are getting increasingly integrated and moving closer to the customer, where renewable energy and efficiency are increasing priorities. And layered on top of all these assets are more advanced distribution management systems with the capability to link disparate systems, analyze their impact and better predict what's happening on the grid.

The technologies are available today to make this possible. Enabling the shift in a big way is just a matter of time, policy and market construct. Growing concerns about extreme weather have started influencing both policies and market rules to make applications at the grid edge more prominent.

"There's a more sophisticated conversation going on in the industry around resiliency than in the past. It's everyone: the utilities, the regulators, the policymakers, the customers and the technology vendors," said ABB's Rick Nicholson. "Worlds are coming together."

It would be a mistake to overstate the influence of Sandy on the grid edge, or to overstate the influence of the grid edge on current resiliency efforts. Many utilities are still wary of using distributed energy as a grid resilience strategy. Even executives at Con Edison, who have been generally supportive of the regulatory push to factor storage, solar, efficiency and microgrids into extreme weather preparedness, consider distributed energy to be a "relatively small" part of the resiliency mix in the near future. Meanwhile, adoption of new information technologies, while certainly on an upward trajectory, is moving at a modest pace after the surge from stimulus funding.

As a consequence, storm preparation strategies in the utility sector have been largely focused on hardening the grid and improving operations, not on enabling dramatic changes to the centralized system. But change is afoot. PSE&G's Energy Strong plan contains one of the most comprehensive grid communications investments ever proposed, and its takeover of LIPA will be focused on building a "utility 2.0" model.

For the first time, a group of states has collectively looked to distributed energy beyond fossil-fueled generators as a solution to storm preparedness. And in New York, regulators are looking to redesign the entire utility business model, in part to integrate clean energy for "system security and resiliency needs."

"There is no question that the existence of distributed resources and demand-side measures has influenced the whole utility industry and its future immeasurably – while also playing a very real role in [influencing] the thinking about resilience," said Fox-Penner.

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In the year and a half since Sandy, much has been written about the need for a more resilient grid. It appears that these words are starting to be translated into action.

Utilities are working closer with government agencies to coordinate mutual assistance crews and emergency response efforts; aging, vulnerable equipment is finally getting replaced or moved; utilities heavily criticized for their inability to communicate have implemented better outage mapping tools; and vendors are reporting that utilities all around the country are taking resiliency seriously when considering investments in grid networking technologies.

As the dispute over PSE&G's post-Sandy plan showed, regulators are still figuring out how to value and prioritize resiliency. One of the fundamental challenges that planners face is how to balance the need to harden infrastructure with distributed resources, while also keeping rates low. Historically, distributed technologies have been cost-prohibitive, and have therefore not been treated with the same respect as grid-hardening efforts. But as the economics improve rapidly, regulators are confronting more complex challenges when thinking about the health of the grid.

However that plays out in individual states, there's a sense among many watching the power sector that the game is truly changing – that climate change, distributed energy, a networked grid and the slow erosion of the traditional utility business model are coming together to create a new framework for how the industry defines resiliency.

"Everyone's watching. There is a very heightened awareness in the industry as we see more frequent and intense storms. We're all paying attention to what's happening out there," said Con Edison's Miksad.

However, like many of their customers who have not yet been able to totally rebuild their lives, utilities are still in the process of putting all the pieces together in Sandy's wake.

Last June, JCP&L's Pat Mullin was finally able to return to her coastal New Jersey home. Every month, another family returns to the neighborhood. But there are many who haven't yet returned. The empty houses in the communities around her are a reminder of the scope of the storm's devastation.

In order to stay, Mullin and her husband must raise their house to prepare for future floods that scientists say are likely only to get worse. "There are still so many people who have tough decisions to make," said Mullin. "There's a lot of work still to be done."

The same is true for utilities. The electricity system may have been back up and running within weeks after Sandy, but the hard work of enabling the grid to withstand future events even more powerful than Sandy has only just begun.

Stephen Lacey

ABOUT THE AUTHOR

Stephen Lacey is a Senior Editor at Greentech Media, where he reports on energy efficiency, solar and grid modernization. He is also host of the Energy Gang podcast, a weekly audio digest of cleantech news. He has extensive experience reporting on the business and politics of the clean energy industry. Lacey was formerly Deputy Editor of Climate Progress, a climate and energy blog based at the Center for American Progress. He was also an editor/ producer with Renewable Energy World. He received his B.A. in journalism from Franklin Pierce University.

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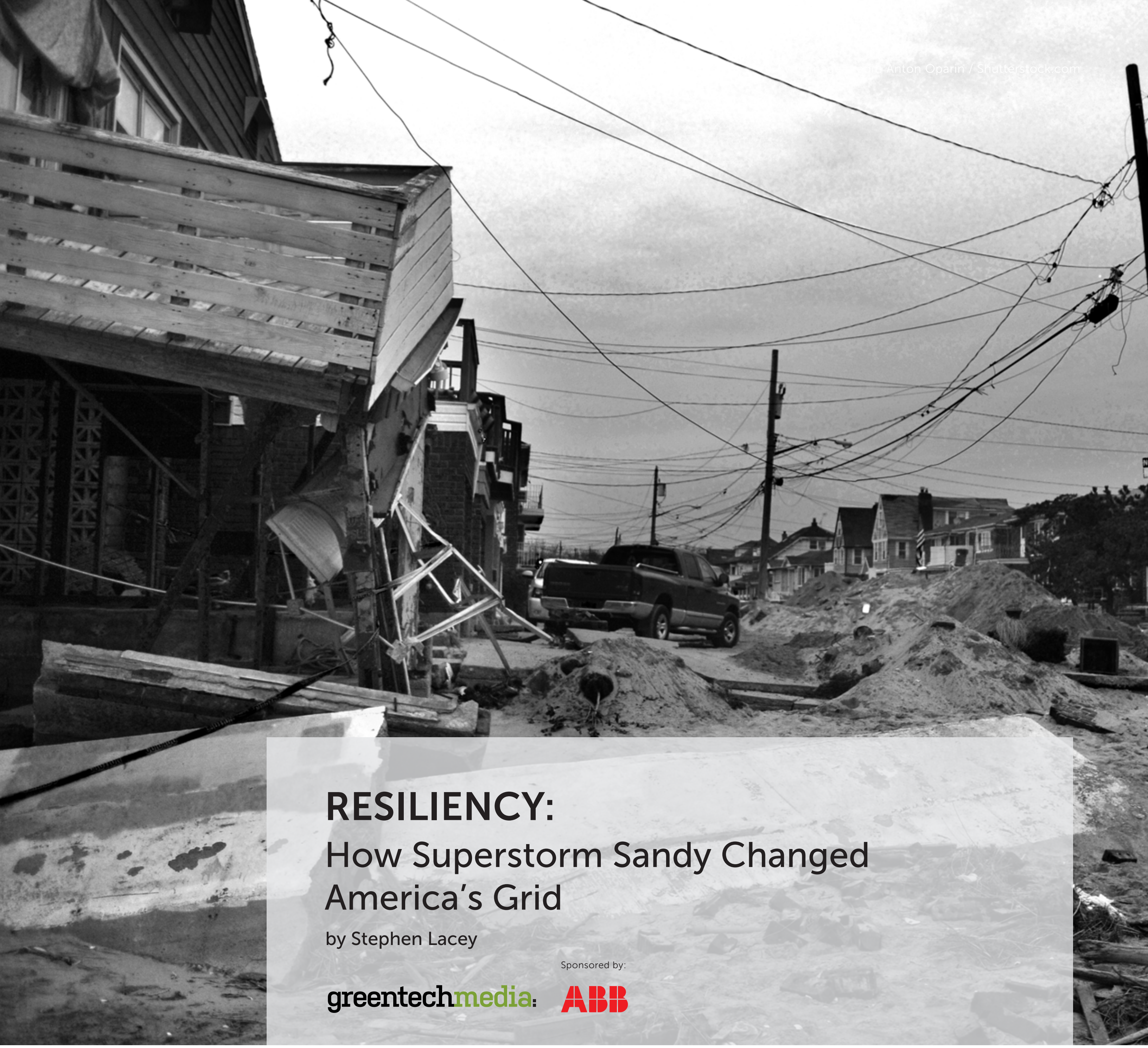

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RESILIENCY:
How Superstorm Sandy Changed America's Grid

by Stephen Lacey

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