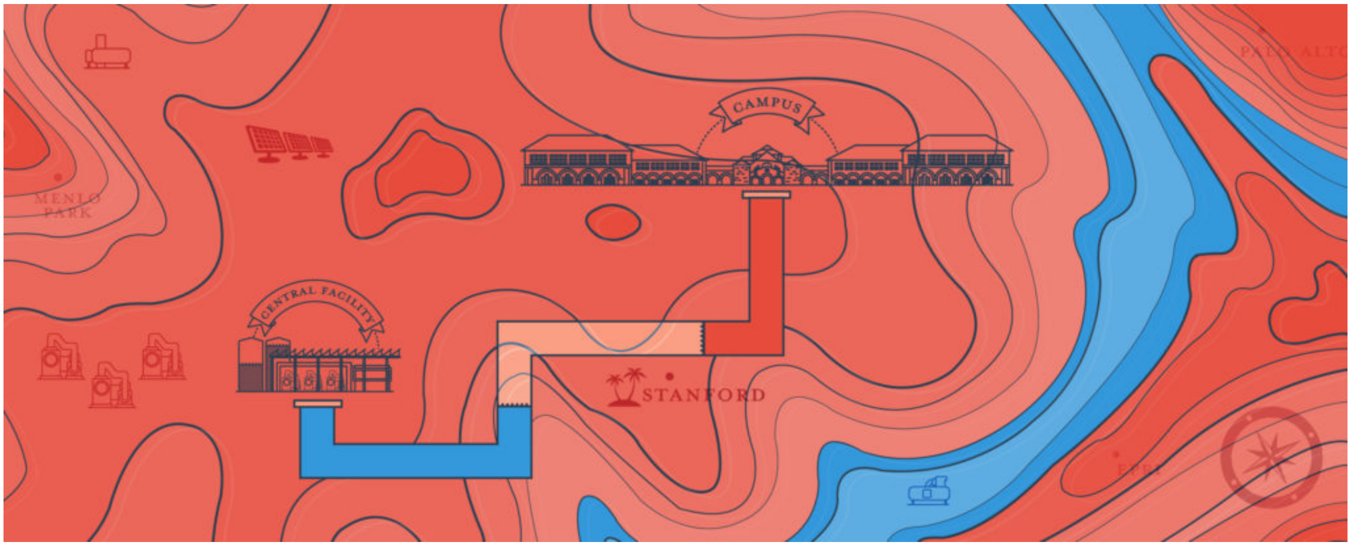
First Person—Electric University



Stanford Electrifies Its Campus, Cuts Greenhouse Gas Emissions by 65%

The Story in Brief

"Buildings are a big chunk of the challenge to develop sustainable, affordable energy for the world," says Joe Stagner, executive director for sustainability and energy management at Stanford University. Stagner speaks with *EPRI Journal* about how Stanford's new energy system works, the environmental and financial benefits, and its applicability in other settings, including his own house.

EJ: Describe Stanford's energy supply system.

Joe Stagner. Photo courtesy of Linda Cicero.

Stagner: Stanford previously powered its campus with a natural-gas-fired cogeneration plant. It heated buildings through a network of underground steam pipes and cooled buildings with cold water pipes. In 2015, we decommissioned the plant and converted the campus to a mostly electric energy supply system. An innovative aspect of the system is heat recovery to meet overlapping heating and cooling needs. Cooling the campus involves collecting waste heat from buildings and transporting it via underground chilled water pipes to a central energy facility. There, devices known as heat recovery chillers (also called heat pumps) transfer the waste heat to a new network of underground hot water pipes to heat buildings.

The central facility houses several large hot and cold water tanks that serve as thermal storage, enabling the system to time-shift cooling and heating. For example, if it's hot in the daytime, you could save the extra heat and use it at night when it's cold. When waste heat recovery from cooling processes is not sufficient to meet campus heating needs in winter, late fall, and early spring, the same heat recovery chillers can fill those gaps by extracting heat from the ground or Stanford's lake water irrigation system. Control software operates all these components efficiently. For backup heating and cooling and to meet thermal loads not covered by the heat recovery process, we have conventional electric-powered chillers and natural-gas-fueled hot water generators.

Another important aspect of our energy system is clean electricity. Stanford signed 25-year power purchase agreements for new on- and off-campus solar projects to supply 53% of our electricity. The remainder comes from the California grid.

Stanford's central energy facility. Photo courtesy of Matt Anderson.

Heat recovery chillers in Stanford's central energy facility. Photo courtesy of Robert Canfield.

Aerial view of Stanford's central energy facility. The large cylinders are thermal storage tanks. Photo courtesy of Steve Proehl.

An operator uses the control software for Stanford's energy system. Photo courtesy of Linda Cicero.

EJ: Why did Stanford electrify?

Stagner: According to the International Energy Agency, heating, cooling, and power in buildings consume about 40% of the developed world's energy. So, buildings are a big chunk of the challenge to develop sustainable, affordable energy for the world. That's the context for our energy system.

Many scientists believe that over the next few decades the only practical path to more sustainable energy is electrification across all sectors and supplying the electricity with a clean, economic, reliable, resilient, and open-access grid. That's not just the finding of Stanford and why we built our system. It's been verified by the International Energy Agency, United Nations Environment Program, and the national laboratories. Southern California Edison has arrived at a similar conclusion as well. In buildings—whether it's the Stanford campus or a house—this means electrifying the power, heating, and cooling, each of which represents about a third of building energy use. The power component is already electric, and cooling is primarily electric.

"The new system's heat recovery increased overall energy efficiency by 50%, which translates into a 50% reduction in campus greenhouse gas emissions. When factoring in the solar power purchase agreements that help power the system, our greenhouse gas reduction grows to 65%."

The challenge is the heating and hot water components. Electric resistance heating is very inefficient, which is why many have moved to natural gas for heat. The key for heating and hot water in buildings is electric heat recovery chillers. They are five to six times more efficient than electric resistance heating and twice as efficient as using natural gas.

With heat recovery chillers as part of the building energy system, you can recover and reuse your waste heat from cooling and extract heat out of the ground or a water body. During summer in all climates across America, there's a surplus of environmental heat, so there's no reason to burn fossil fuel to generate more heat. You can use heat recovery chillers to provide 100% of heat and hot water needs. That may be only 4 or 5 months in Boston or 10 months in Phoenix.

By the Numbers: The Stanford Energy System Innovations Project

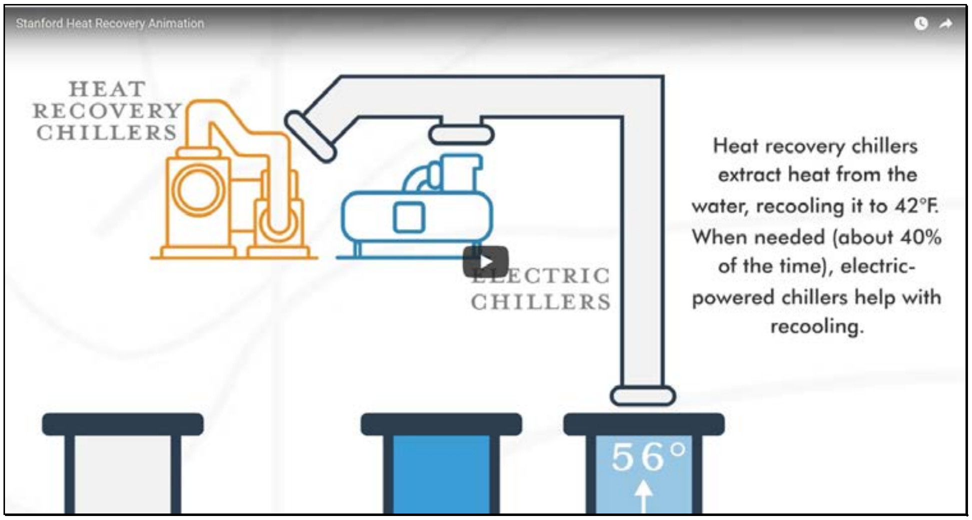
- Miles of underground steam pipes converted to hot water pipes: 22
- Number of buildings upgraded to hot water pipes: 155
- Percentage of time during which campus heating and cooling demands overlap: 70%
- Percentage of waste heat recovered from cooling: 53% (Stanford's previous natural-gas cogeneration system lost 100% of its waste heat)
- Percentage of campus heat load met by recovery of waste heat: 88%
- Percentage of Stanford's electricity supplied by on- and off-campus solar projects: 53%
- Increase in overall energy efficiency relative to Stanford's previous cogeneration system: 50%
- Reduction in greenhouse gas emissions relative to the previous cogeneration system: 65%
- Reduction in water use relative to the previous cogeneration system: 18%
- Increase in system efficiency as a result of the automated control software: 15%
- Capital cost: $485 million
- Projected savings relative to the costs of the previous cogeneration system: $420 million over 35 years

Source: Stanford University

In winter, particularly in northern areas like Boston, you hear people say, 'It's too cold for waste heat recovery.' What they don't understand is that even in cold regions there's a small amount of waste heat available from cooling and humidity control in complex buildings. Our data shows that more than 50% of annual heating and hot water needs at two large universities in Illinois and Massachusetts can be met by deploying heat recovery chillers and recovering waste heat from existing cooling processes. Those same heat recovery chillers can also extract the other 50% of needed heat from the ground, lake, or ocean. We can therefore fully electrify heating and hot water supply for buildings.

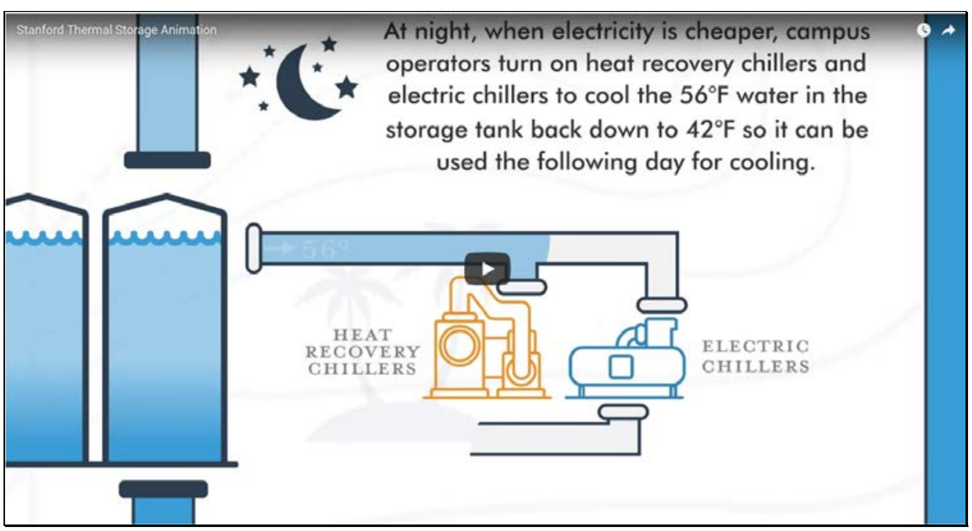
EJ: How do the heat recovery and thermal storage work?

Stagner: We have a chilled water loop that cycles around campus continuously. The central energy facility delivers 42°F water to campus buildings through cold water pipes. At each building, heat exchangers use this cold water to provide cooling, and 56°F water is returned to the central facility. There, a heat recovery chiller cools it back down to 42°F and transfers the heat to a separate hot water circulating system. This continuously cycling loop delivers 160°F water to buildings to provide heat for space heating and hot water and returns 130°F water to the central energy facility where the heat recovery chiller reheats it to 160°F (see animation below).



Watch an animation about how Stanford's heat recovery system works.

The thermal energy storage system consists of 70-foot-tall tanks of hot and cold water. The cold water tank has a pipe coming out the bottom to supply 42°F water to campus for cooling, simultaneously replacing it with 56°F water from campus through a pipe at the top. The hot water tank has a pipe coming out the top to deliver 160°F water to campus for heating and receives 130°F water back at the bottom. The large temperature difference between the top and bottom of the tanks creates a 'thermocline' that separates the warmer and colder water. Temperature probes placed every 1 foot from top to bottom indicate how much cold and hot water is available for campus heating and cooling (see animation below).



Watch an animation about how Stanford's thermal storage system works.

Cold water storage saves money in three ways: It allows you to shift cooling to off-peak hours when electricity is cheaper; it's less capital-intensive than deploying extra heat recovery chillers or regular electric chillers to meet peak loads; and its operations and maintenance costs are lower than heat pumps and chillers. Imagine that the daytime cooling load for a campus is 30,000 units, and the night cooling load is 10,000 units. Without cold water storage, you need to deploy and turn on 30,000 units of heat recovery chillers or regular electric chillers in the daytime and run 10,000 units at night. With cold water storage, you can install and run 20,000 units of heat recovery chillers or chillers 24 hours a day and store the 10,000 units of cooling not needed at night. In the day, when you need 30,000 units of chilling, you can borrow 10,000 units from storage to complement the 20,000 units of heat recovery chillers or chillers. A hot water storage system offers those same cost benefits for heating.

EJ: How does the control software work?

Stagner: Stanford developed a software program called the Central Energy Plant Optimization Model to prove the heat recovery concept and help with system design. Stanford commissioned Johnson Controls to develop an industrial version of this software that can be used for real-time operations and planning. The operational function is like an airplane autopilot, constantly seeking the best path forward, given constantly changing weather, heating and cooling loads, grid electricity prices, thermal energy storage balances, and many other factors. Every 15 minutes, it interrogates the thermal storage tanks to see how much usable hot and cold water they contain; determines which heat recovery chillers, chillers, and hot water generators are available and which are down for maintenance; and fetches the campus-area weather forecast from the National Weather Service. Based on all this information, it reforecasts the heating, cooling, and power loads and optimizes the use of heat recovery and thermal storage to meet loads and reduce electrical peaks. We've found that the software makes the entire system 15% more efficient than it would be if operated by humans.

We can use the software's planning function to simulate operations in future years with differing loads. For example, if loads grow as a result of campus expansion, the software may tell us that we need to change or add more equipment.

> "Even though Stanford has a district energy system with complex buildings, the insights are applicable in many types of buildings all the way down to the residential level."

EJ: What have been the environmental benefits?

Stagner: With our previous natural-gas cogeneration system, 100% of the waste heat from cooling the campus was thrown away in evaporative cooling towers. The new system's heat recovery increased overall energy efficiency by 50%, which translates into a 50% reduction in campus greenhouse gas emissions. When factoring in the solar power purchase agreements that help power the system, our greenhouse gas reduction grows to 65%.

If we power campus with 100% clean electricity, we could achieve an 85% greenhouse gas reduction. The remaining 15% is a result of scattered natural gas and liquid fuel use in vehicles, emergency generators, and other campus equipment not served by our new energy system yet. While we want to be powered by 100% renewables eventually, for now we want to see how electricity markets and technologies evolve. For example, we may determine that we need more load-following generation or baseload renewables such as geothermal energy.

The new system also uses 18% less water than the cogeneration system, which consumed significant water as it rejected waste heat via evaporative cooling.

"Utilities and regulators need to set in motion a long-term plan to electrify everything by enabling widespread use of local and grid-scale renewable energy and by providing grid infrastructure including robust transmission systems, thermal and electricity storage, grid-scale system management software, and regulatory rules and electricity tariffs to incentivize electrification."

EJ: How about the financial benefits?

Stagner: The new system had a capital cost of $485 million. At the outset of the project, we calculated that it would save us about $420 million over 35 years, relative to the costs of our previous system.

The control software and thermal energy storage helped us to reduce our peak load and increase our load factor on the grid. This is contrary to conventional expectations when electrifying a load previously served by natural-gas-fired cogeneration. For example, when the cogeneration plant was offline for maintenance, we'd pull a peak of 46 megawatts from the grid to run our campus. Now that we're electric, our peak is down to 38 megawatts.

A recent audit found that we're 10% under the original cost estimates for the system. This is mainly a result of two factors: our low-cost solar power purchase agreements and our ability to purchase California grid electricity through 'direct access.'

EJ: To what extent can Stanford's approach be applied in residential and commercial buildings?

Stagner: Even though Stanford has a district energy system with complex buildings, the insights are applicable in many types of buildings all the way down to the residential level. Heat recovery and heat recovery chillers can be used at many scales. I am considering doing what we did at Stanford at the next house I design when I retire and move. I said, 'If I'm going to design a house, would it be practical to have both hot and cold thermal storage and model the system with predictive software?' Instead of burning natural gas, I could use the waste heat from the air conditioning to produce the hot water that my kid's using in the shower or my wife's using in the washer. It turns out the answer is, 'Yes, this can be done.'

Many houses have hot water tanks, which can serve as hot thermal storage. Cold water storage tanks may or may not be needed depending on the house's load profile. Heat recovery chillers like the ones we installed at Stanford are commercially available for houses. They're called 'triple-function geothermal heat pumps' and 'reverse cycle chillers,' depending on whether they extract heat from the ground or air. They can recover waste heat from your air conditioning in summer to make 140°F hot water for your house. They also can extract heat from the air or ground whenever you are not running the air conditioning. Control software similar to Stanford's can be used to optimize heat storage and use.

"With heat recovery chillers as part of the building energy system, you can recover and reuse your waste heat from cooling and extract heat out of the ground or a water body. During summer in all climates across America, there's a surplus of environmental heat, so there's no reason to burn fossil fuel to generate more heat."

However, research is needed to apply this solution and develop software at different scales. Residential and commercial demonstrations would be great, and several building projects in North America are considering this approach. EPRI could model what an electrified America would look like and cost over the next 50 or 100 years. We also need more education to inform the public of these new opportunities, as well as development and dissemination of heat pump and other technologies. Research on new cooling fluids or compression methods to increase the efficiency of heat pumps and heat recovery chillers could lower the costs of electrification even further.

EJ: Stanford's campus is similar to a small city. What lessons can cities draw?

Stagner: While you can apply this approach in individual homes and commercial buildings, it's enhanced if you apply it in district energy systems. Any time you collect a series of buildings together you get more efficiencies. You get better thermal balance and more ways to recover waste heat from buildings for use in other buildings. In Europe, there are many good examples of cities that use district heating. Hot and cold water for district heating and cooling can be part of the basic city infrastructure just like natural gas, water, sewer, storm drainage, and communications.

EJ: What can utilities and regulators do to facilitate electrification?

Stagner: To make electrification work, you need clean power. Once you have that, natural gas is no longer a greenhouse gas reduction strategy. Is a clean grid economically competitive with natural gas distributed to buildings? It probably will be long term. We modeled a new cogeneration plant powered by cheap natural gas for the next 30 years and compared it to an all-electric scenario with electricity at more than 10 cents per kilowatt-hour, and electric won out. With our power purchase agreements, we locked in solar power for 5 cents per kilowatt-hour for 25 years, helping our system outcompete cogeneration by an even wider margin.

Utilities and regulators need to set in motion a long-term plan to electrify everything by enabling widespread use of local and grid-scale renewable energy and by providing grid infrastructure including robust transmission systems, thermal and electricity storage, grid-scale system management software, and regulatory rules and electricity tariffs to incentivize electrification.

In Development

Solar Storm Preparedness

EPRI Collaborative Research Aims to Protect Society from a Worst-Case Scenario Solar Storm

By Chris Warren

On March 13, 1989, a geomagnetic disturbance triggered a 9-hour blackout in and around Montreal, shutting down schools, businesses, and the city's airport and underground transit system. While memories of that day have likely faded for most Quebecois, the event has had an enduring impact on the electric power industry.

It set in motion a series of efforts by regulators, policymakers, and electric utilities to protect the bulk power system against geomagnetic disturbances, also known as solar storms. Most recently, in 2016, the Federal Energy Regulatory Commission (FERC) approved the North American Electric Reliability Corporation's (NERC) reliability standard for geomagnetic disturbances. As part of its approval, FERC required owners and operators of bulk power systems to develop action plans and mitigation measures to address the threat of geomagnetic disturbances.

The FERC order also mandates that system owners and operators assess potential impacts of a 100-year solar storm. It requires NERC to modify the new standard and develop tools to better protect against these impacts. At NERC's request, EPRI spearheaded a three-year, multi-million-dollar research initiative to advance understanding of worst-case scenario solar storms, with participation from national research laboratories, the National Aeronautics and Space Administration (NASA), and electric utilities.

"With a better understanding of what a 100-year solar storm looks like, we can build tools that help planners identify system weaknesses," said EPRI Senior Technical Executive Bob Arritt, who leads the work.

FERC mandated research to improve the science behind NERC's projection of a 100-year solar storm's severity, which is based on an average of worldwide geoelectric field amplitude measurements made between 1993 and 2013. While NERC reasoned that this "spatial averaging" approach would best reflect the effects of a severe solar storm over a wide area, FERC expressed concern that such estimates "could be weighted by local effects and suggest unduly pessimistic conditions…."

A bulk power transformer.

EPRI and its collaborators are examining spatial averaging and its implications for how grid operators prepare for a severe geomagnetic disturbance. "We need to advance the science behind our definition of a 100-year storm," said Arritt. "For example, we know that the geoelectric field is not uniform across a large area, and it is made up of small peaking areas. Better defining the characteristics of an extremely rare, severe solar storm will help us understand its impact on the bulk power system."

A primary concern outlined in the FERC order is the overheating of transformers, which could potentially lead to failures. Transformers are extremely expensive and take a long time to build, transport, and install. If widespread failures were to occur, they could result in long-term blackouts. To fulfill the requirements of FERC's order, EPRI's research initiative must analyze the current approach used to estimate transformer heating limits. If deemed inadequate, researchers are tasked with developing alternative methods.

"We will use data from lab testing and transformer monitoring in the field to improve the transformer response models used to estimate how equipment reacts to a solar storm," said Arritt.

Researchers also will focus on harmonics generated by solar storms, developing tools to analyze impacts on transformers. "It's important that bulk system operators understand harmonics, which can cause additional heating and equipment to trip off when it is needed most," said Arritt.

Arritt believes the next two years of research will provide a more scientifically rigorous foundation for NERC's reliability standard. Equally important, he emphasizes that EPRI's research will result in better tools that grid operators can use to prepare for the worst possible impacts of a solar storm.

"This research is where science meets practice," he said. "The results will inform solar storm vulnerability assessments and potential mitigation actions. It's where the rubber meets the road."

Key EPRI Technical Experts

Bob Arritt

Shaping the Future

EPRI Takes the Lead at Incubatenergy

By Scott Sowers

This June, EPRI takes the reins of Incubatenergy, a network of technology incubators and accelerators that supports more than 500 startup companies. Incubatenergy was launched in 2014 through a partnership among EPRI, the U.S. Department of Energy (DOE), and the National Renewable Energy Laboratory (NREL). When DOE funding ends this year, EPRI will continue to support the network.

Incubators in the network include more than a dozen organizations such as Greentown Labs in Boston and the Los Angeles Cleantech Incubator. The startups have received about $1.5 billion in funding from various sources, generate $440 million in revenue, and employ more than 3,300 people. They have access to hundreds of technology experts and business development mentors across the incubators, NREL, and EPRI's utility members.

"We have seen great value in connecting our utility members with the innovative entrepreneurs supported by members of the network," said EPRI Project Manager Beth Hartman. "EPRI is continuing to support the network as integral to our innovation scouting."

Incubators and accelerators play a critical role in supporting new energy technologies along the challenging journey from concept to commercialization. While incubators typically work with entrepreneurs for longer, more flexible periods, accelerators offer shorter, more standardized programs. Incubators and accelerators often aggregate themselves into networks for sharing best practices and new methods. EPRI is linking with other incubators and accelerators.

Going Global

Incubatenergy has expanded its reach internationally through a partnership launched in 2016 with InnoEnergy, a Netherlands-based accelerator for sustainable energy startups in Europe. The two organizations share company referrals between Europe and North America to facilitate and expand global coordination among technology developers, incubators, and accelerators—and to help startups break into new markets. For example, as a result of the Incubatenergy/InnoEnergy partnership, San Francisco–based accelerator Powerhouse is hosting Barcelona-based energy forecasting firm Nnergix.

In 2017, Incubatenergy—in collaboration with the California Clean Energy Fund, the World Bank, the World Wildlife Foundation, and the Asia Development Bank—organized the Accelerate Energy Summit in Shanghai. The summit convened 66 organizations from 21 countries to consider strategies for supporting entrepreneurs.

"At the Shanghai summit, Incubatenergy continued to develop important connections with groups that can help expand our international reach," said Hartman. "We plan to host similar gatherings to expand connections among energy incubators and accelerators around the world." For example, the upcoming Electrification 2018 conference hosted by EPRI will include stakeholders such as global energy entrepreneurs as well as incubators, accelerators, utilities, investors, government staff, and corporate partners.

The State of Innovation in Electric Power

According to Hartman, particularly active areas of technology innovation in the electric power sector include electric vehicle charging systems, data analytics and artificial intelligence applications, and indoor agriculture that uses electricity to run fans, lights, and other equipment. "Several new startups are using shipping container–sized structures to grow everything from tomatoes and lettuce to flowers," she said.

Another hotbed of innovation is end-use technologies. For example, Pick My Solar, supported by Los Angeles Cleantech Incubator, helps residential customers find the best bids for rooftop solar projects. More companies offer home energy storage that can be paired with solar panels and serve as backup power or a grid resource.

Indoor agriculture is an active area of technology innovation in the electric power sector.

“There are more and more ‘prosumers’—people who both produce and consume energy,” said Hartman. “As utilities adapt their business model for the future, they are thinking of innovative ways to work with prosumers.”

Hartman points to technology innovation in small modular nuclear reactors as an important trend. “Nuclear is an established carbon-free energy technology, and there are several interesting startups working in that space such as Transatomic and TerraPower,” said Hartman.

Hartman also sees utilities expanding collaboration with incubators and accelerators. “Increasingly, utilities are realizing the importance of partnering with innovation groups as disruption in the industry is happening faster and more frequently,” she said. For example, Ameren recently launched its own accelerator, and a consortium of international utilities supported the Free Electrons program last year. Other utilities are working more closely with incubators in their areas, such as Duke Energy with Joules Accelerator in Charlotte, North Carolina, and National Grid with the ACRE incubator in New York.

Key EPRI Technical Experts

Beth Hartman

Technology At Work

Helping Grid Components "Fail Gracefully"

EPRI Investigates More Resilient Designs, Controlled Failure Points, Inspection, and Maintenance

By Tom Shiel

What do automobile designs and electric grid designs have in common?

Both incorporate features that minimize damage during major accidents. When a car crashes, "crumple zones" in the vehicle's outer parts absorb the energy of the impact, reducing damage to the passenger cabin and preventing or reducing injury. Similarly, when a tree falls on a distribution power line during a major storm, certain design features can minimize damage to poles and overhead structures.

For several years, EPRI research has worked to better understand how overhead line components and structures fail. In 2018, it is now identifying resilient overhead structure designs and providing utilities with a tool for prioritizing resiliency investment.

"Broken poles need to be replaced and require expensive repairs," said EPRI Technical Executive John Tripolitis. "The key is to minimize the number of poles that break, whether it be from a falling tree, ice accumulation, or high winds. We want to design these components so that they fail gracefully, or in a known manner. If we can preserve the poles and contain damage to the pole-top components, this can result in easier and quicker repairs."

Prior EPRI stress tests on poles have shown that a pole's strength is correlated with its top circumference. In 2018, EPRI is testing distribution poles and pole-top components to determine the structures most resistant to pole breaks.

EPRI is exploring how designing controlled failure points into the system can reduce damage. For example, when struck by trees, conductors can slip through conductor ties, minimizing the forces on poles and pole-top components and reducing repair costs.

An additional challenge is that structures must meet National Electric Safety Code. "We're not weakening the structure," said EPRI Engineer/Scientist Joe Potvin. "We're designing it so that it breaks in a specific way when a significant force is applied."

"Our research is showing quite a bit of promise," Tripolitis said. "Several companies have sent us pole-top designs so we can test them."

EPRI also is looking at inspection and maintenance practices. "In field studies where we dropped trees on lines, we learned that the forces on the system tend to seek out weak spots—places with deteriorated components such as rotted crossarms," said Tripolitis. "Weak spots can cause unpredictable failures." In 2018, EPRI plans to identify inspection and maintenance approaches that can pinpoint and strengthen weak spots.

Getting the Most 'Bang for the Buck' out of Resiliency Efforts

Hardening poles and overhead structures is one of numerous strategies for making the grid more resilient. Other strategies include vegetation management, burying lines, and enhanced technologies such as advanced meters, stronger poles and components, and automated switches.

For utility planners, a primary challenge is to determine the best strategies for a particular distribution system.

“When I’m looking at a set of circuits that I want to harden, I could choose among various options—move the circuits underground, upgrade the poles, use larger wire, apply automation technologies, and others,” Tripolitis said. “So how do I choose?”

To inform such decisions, EPRI is developing a tool for estimating the reduction in outage risk per dollar spent for a given resiliency strategy. It evaluates circuits’ risk factors with respect to the likelihood of outages. For example, dense tree stands can increase risk.

“If tree density data is not available, a utility could assess risk using historical data on outages caused by trees and other vegetation,” said Tripolitis.

Circuit age is another risk factor, with older circuits posing a greater risk. Most utilities have good information on the age of wood poles but not small pole-top components.

“You can use the age of the poles on a circuit as a proxy for circuit age,” Tripolitis explained.

Users input the set of circuits to be evaluated, the resiliency strategies to be compared, their costs, the circuit risk factors, and the anticipated change to the risk factors associated with each strategy.

“The tool produces a ranking of resiliency strategies based on their expected ability to reduce circuit risk—their relative ‘bang for the buck,’” said Tripolitis.

Key EPRI Technical Experts

John Tripolitis

In the Field

Data-Driven Insights for Electricity Customers

How the Energy Management Circuit Breaker Can Benefit Utilities and Customers

By Chris Warren

In the near future, it may be common for utilities to send texts to homeowners or businesses alerting them that their compressor isn't functioning properly or that the filter on their air conditioning unit needs to be replaced. Avoiding a compressor failure and keeping an AC unit at peak efficiency can save utility customers a lot of money and prevent headaches.

Such preventive maintenance is possible only when utilities and customers have accurate, real-time views of how specific devices are consuming electricity, made possible through 'signature analysis.' "When a unit runs properly, it exhibits certain operating characteristics," said Tom Reddoch, an EPRI senior technical executive. "When you start seeing deviations from the normal characteristics, you can quickly realize that something is not right."

Historically, such detailed measurements have been unavailable: electric meters measure aggregate watt-hours for billing. But that may soon change with a device called the energy management circuit breaker (EMCB). Developed by Eaton Corporation, the EMCB is installed in a residential or commercial circuit breaker where it can continuously monitor voltage, current, and real and reactive power consumed by the appliances and devices for that circuit. This monitoring also can be used in real time to help with voltage control, power management during system restoration or peak load, and other aspects of distribution system management.

When the EMCB is combined with secure WiFi communication for data transmission, both utilities and their customers can monitor and control electricity use. For instance, smartphones can be used to open and close a circuit breaker to save energy or to address concern about an end-use device failing. The EMCB can also enable more cost-effective electric vehicle charging.

EPRI and member utilities are field-testing the performance of the energy management circuit breaker in more than 20 applications, including electric vehicle charging.

"Today, if you want to charge an electric vehicle at 240 volts, the National Electric Code requires you to spend at least $500 on special equipment that can include a three-prong wall outlet connector, a power supply cable, and a vehicle connector cable," said Reddoch. "The EMCB eliminates the need for both this equipment and the charger itself. All you need is a charging cable to connect the power source to the vehicle and the EMCB."

For utilities, more precise measurement of devices and electric services can enhance demand response, inform more equitable rate design, and help integrate distributed energy resources.

The EMCB has shown promise in EPRI laboratory tests and in preliminary field deployments. Now, EPRI is working with 12 member utilities to test its performance in diverse applications at residences, businesses, and government sites across the United States. So far, 280 devices have been installed at 80 sites.

The utilities have opted to use the EMCBs to monitor more than 20 end-use loads, including HVAC equipment, hot water heaters, EV charging stations, photovoltaic systems, pool pumps, street lights, batteries, and even an aquarium.

“We want to see if the device performs per its specifications, what its weak spots are, whether it fails in conditions of extreme heat and cold,” said Reddoch. The project will also provide feedback to improve user interfaces and identify new applications.

The initial field results are encouraging. The EMCB hardware and WiFi communication have worked exactly as expected. The testing has also revealed the need for improvements in certain software systems—one (developed by Eaton) that sends commands to and retrieves data from the devices, and another (developed by EPRI) that presents the data in a usable format.

“In the field, we have observed some flaws, but they are manageable and are being corrected,” said Reddoch.

EPRI continues to gather data and examine the power profiles of water heaters, HVAC systems, and other devices in homes and businesses outfitted with EMCBs. Those will be included in EPRI’s electric load shape library, which utilities can access to improve their operations and efficiency. “The profiles can help utilities more easily execute load control or manage end uses,” said Reddoch. “If you have three electric vehicles being charged on one transformer, you could manage them so that they won’t overwhelm the transformer.”

When the first round of field tests ends in August 2018, participants will have the option to continue for another two years. Another possibility is for EPRI to help utilities design programs that encourage customers to incorporate EMCBs into their homes or businesses. Utilities that did not participate in the first round of field tests can still join this second phase of activities.

“This device gives us a viewing port into the operation of the electric system. It makes it highly visible,” said Reddoch. “It allows for a wide range of actions that can provide benefits to both utilities and customers.”

Key EPRI Technical Experts

Tom Reddoch

In the Field

Miniature Monitoring

EPRI Investigates the Potential of Environmental Microsensors in Utility Applications

By Brent Barker

Advances in electronics manufacturing are driving the proliferation of small, portable, inexpensive environmental sensors. These microsensors are far less expensive than the larger monitoring equipment used today by the electric power industry for compliance with environmental regulations. However, the number of parameters that they can measure is limited, and the measurement quality is not regulatory-grade. Nevertheless, as their performance improves and costs come down, the future role of environmental microsensors is likely to expand.

"Monitoring equipment is being miniaturized," said EPRI Principal Technical Leader Stephanie Shaw. "Although microsensors don't include the complex analyzers and extra calibrations needed for regulatory compliance, they have the potential to provide utilities with screening data in unmonitored areas and supplement existing monitoring programs. They can run on batteries or small solar panels and are light enough to be carried by technicians, whereas regulatory-grade instruments are very bulky and often must be stored in climate-controlled cabinets."

To date, the quality of microsensor measurements has not been consistently high, though the U.S. Environmental Protection Agency (EPA), the California South Coast Air Quality Management District, and other industry stakeholders are working to improve measurement quality through thorough testing and comparison against reference instruments.

Microsensors may also put environmental monitoring in the hands of the public. Today it's feasible as part of emerging "citizen science" for the public to use smartphone-powered sensors to measure air quality near industrial facilities. This has spurred some utilities to work with EPRI to test these devices.

EPRI's SENTINEL project is investigating the potential of new microsensors, and electric utilities in the United States have hosted field studies of three applications: measuring airborne particulate matter near a coal-fired plant, measuring indicators of groundwater quality near a coal ash impoundment, and real-time monitoring of ground movement at a coal ash impoundment.

"We're trying to answer two questions," said EPRI Senior Technical Leader Bruce Hensel. "First, since there has been insufficient verification of the quality of these sensors, we want to find out what they can and cannot measure in the field and assess the accuracy of the data they capture. Second, if they work well, do they represent an opportunity for utilities to expand their environmental monitoring networks and save on monitoring costs?"

A microsensor for groundwater monitoring.

Environmental applications for microsensors potentially relevant to utilities include:

- Provide environmental data to help identify the best locations for regulatory-grade monitoring instruments
- Detect pollutants at power generation facilities
- Create early warning/detection systems
- Monitor worker exposure
- Educate local communities and other stakeholders about environmental conditions and other issues

Particulate Matter at Coal Piles

The utility hosting the study of particulate matter measurements wanted to know if microsensors could detect a dust plume coming from the power plant's on-site coal stockpiles. Those in long-term storage, typically a year or more, are coated with a sealant, while those being moved and conveyed into the plant are subject to wind and other weather.

Downwind of the coal piles, EPRI and the utility tested microsensors that measure various sizes of airborne particulate matter (1, 2.5, and 10 microns). Their accuracy was gauged relative to measurements from equipment whose precision is accepted by the U.S. federal government.

The nine-month test yielded mixed results for the microsensors. Comparisons to the reference monitor showed numerous false positives when the temperature fell below 0°C. The sensors didn't perform well in winter cold or summer humidity but did pick up the dust plume under more moderate conditions.

"The sensors are not perfect, but they are useful for screening. They can fairly reliably detect the presence of windblown dust and, when placed in multiple locations, give utilities a tool to inform action," said Shaw.

Measuring Ground Movement

Another utility's network of ground movement microsensors monitors the stability of berms (man-made embankments) at a coal ash impoundment. The utility has shared its real-time data with the SENTINEL team, which in turn will share with other industry stakeholders.

Sensors known as piezometers measure pore water pressure. In-place inclinometers measure the lateral displacement of a berm. Settlement plates characterize the interface between native soil and fill material, and other sensors measure soil settlement at various depths.

"The ground movement tests revealed that these are very sensitive instruments and provide a powerful data set capable of showing early stages of ground movement. This provides an early warning system for potential failure of berms, dikes, or impoundments at coal ash facilities, giving utilities time to take action to shore-up these structures before a catastrophic failure occurs," said Hensel.

Measuring Groundwater Quality

EPRI is also testing microsensors in a groundwater monitoring project at a coal ash management facility. At present, there is no suite of microsensors that can replace a comprehensive groundwater monitoring program, which relies on laboratory measurement of pH, total dissolved solids, sulfate, chloride, calcium, and boron as well as various trace elements, such as molybdenum and arsenic. Microsensors are available only for measuring pH, chloride, and electrical conductance (which provides a close parallel to total dissolved solids).

“Whereas the ground movement sensors are reliable and provide very useful information, sensors for groundwater monitoring are not as advanced,” said Hensel. “For the most part, the groundwater sensors we need are not available. The ones that are available are not cost-effective yet; they are not always reliable and require routine maintenance.”

That said, new microsensors can supplement traditional groundwater monitoring in a few applications. “Strategically positioned sensors can provide additional data between manual sampling events, particularly in karst and other groundwater systems with rapid flow,” said Hensel.

“Wide Open” Future

“We wanted to give these new microsensors a solid test in practical applications at utility facilities, comparing them with the more expensive, sophisticated monitoring systems used by utilities today,” said Shaw. “They are at an early stage of development, and we see promise if not perfection. Because of their portability and lower cost relative to other monitoring equipment, they are ready for some specific applications now—detecting a coal dust plume, characterizing water flow underground, providing early warning of dike instability. The future possibilities are wide open. EPRI will continue to track microsensor technologies with potential to provide more detailed environmental data and lower utilities’ monitoring costs.”

Key EPRI Technical Experts

Stephanie Shaw, Bruce Hensel

Innovation

Solar for the Long Haul

As Solar Goes Mainstream, EPRI Expands Research Portfolio to Address Long-Term Issues

By Sarah Stankorb

Solar photovoltaic (PV) energy is fast approaching a tipping point. Nationally, 29 states have renewable energy standards. Solar is a low-cost power source in a growing number of regions. These trends are driving utilities and corporate and retail customers to invest in, own, and operate solar plants.

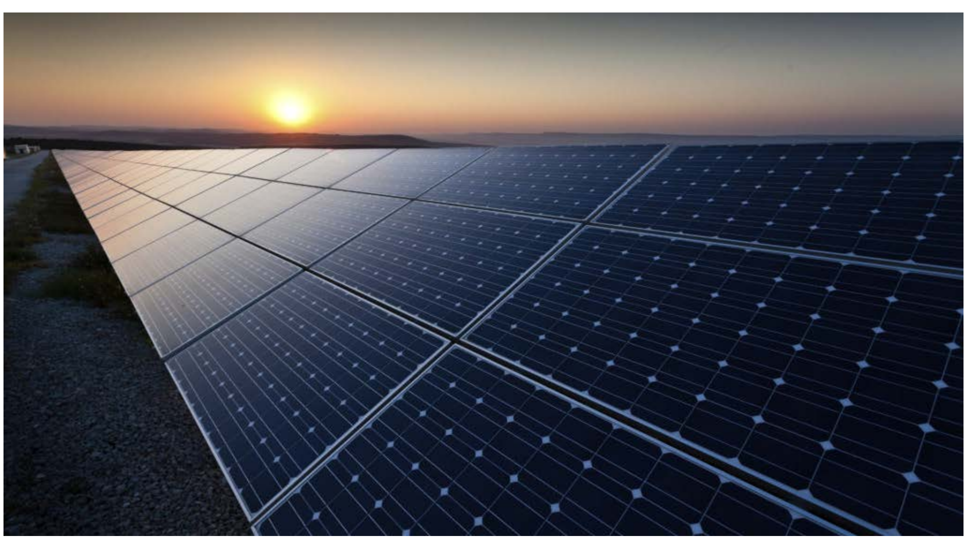
To inform solar plant owners and operators in their efforts to reduce costs and enhance reliability, EPRI has broadened its solar generation research portfolio, including technology assessments, technical assistance for solar plants, demonstration projects, and best practices for a plant's life cycle.

Short-Term Design, Long-Term Thinking

Companies seeking to purchase existing large-scale solar plants face a challenge. In the United States, independent power producers own about 90% of these facilities, and some were built as short-term investments—driven in part by federal tax credits requiring plants to be owned by a single entity for six years.

"Plants are expected to have lifetimes of more than 20 years. However, if the initial owners expect to sell the plants after 6 years, their design and procurement decisions might not consider the full lifetime of the plant," said EPRI Senior Project Manager Michael Bolen. "EPRI recognizes the need to better understand the impacts of upfront decisions on long-term operations and maintenance."

EPRI is developing best practices for PV plant specifications and commissioning, drawing on existing guidelines and input from subject matter experts and other stakeholders. For example, a recent EPRI study examined trade-offs associated with plant wiring. Power cable buried without conduit is cheaper but more prone to damage from animals, water infiltration, and other causes—and it costs more to diagnose problems, repair, and replace.



A large-scale solar power plant.

Monitoring and Maintenance

Upfront equipment choices, such as the type and quantity of sensors and inverters, impact plant monitoring and diagnosis capabilities. Advanced pattern recognition and other real-time monitoring systems often trigger alarms without adequate information about the causes of an excursion. There can be many false alarms. For technicians requiring hours to reach plants, it is necessary to dispatch them with the right information and equipment. EPRI is investigating the potential of advanced data analytics for solar plants. According to Bolen, emerging technologies may offer enhanced diagnostics, such as the ability to identify fault signatures and account for a plant's power degradation over time.

For decades, EPRI has studied and fine-tuned maintenance practices for fossil plants and is now evaluating ways to apply tried-and-true practices at solar facilities. For example, the Equipment Reliability Framework directs fossil plant operators to identify critical equipment as the focus of preventive maintenance. Using this framework, EPRI identified the inverter as the most critical component in PV plants.

At an EPRI workshop later this year, participants will conduct a comprehensive analysis of potential component and system failures in PV plants along with causes and effects. EPRI will incorporate this information in its Preventive Maintenance Basis Database, a web-based tool that utilities and other solar plant owners can use to develop maintenance strategies for various components.

EPRI researchers are investigating other long-term considerations for large-scale solar plants, such as whether and when to replace old equipment with new technology, and decommissioning. Considering end-of-life issues during plant design is important for environmentally responsible electricity generation.

"To the greatest extent possible, PV modules and other solar equipment should be reused or recycled," said Bolen. "When designing new plants or purchasing existing ones, it is important to think long-term and comprehensively."

Understanding DC Arc Flashes

At solar power plants, arc flashes in high-power direct current (DC) equipment can present safety concerns and damage equipment. There is a safety standard for assessing arc flash hazards in alternating current (AC) equipment (IEEE 1584), but not one for DC systems—which include PV plants. As more PV plants, utility-scale batteries, electric vehicle charging stations, and other DC systems come online, there is an increasing need for such a standard. In a three-year, $1.1 million cooperative agreement with the U.S. Department of Energy, EPRI is researching arc flash mechanics in PV systems to quantify the hazards and develop safety recommendations for the electric power industry.

Key EPRI Technical Experts

Michael Bolen

R&D Quick Hits

EPRI Demonstrates Laser Sensors to Optimize Coal Plant Combustion

Precise measurements of combustion gases in power plants can potentially save operators hundreds of thousands of dollars each year, an EPRI study finds.

To tune boilers and optimize combustion in coal-fired power plants, plant operators periodically extract combustion gases to measure oxygen distribution, which can then be adjusted to be more uniform. Plant operators today need even more precise combustion control as they face greater competitive pressures, flexible operations, more stringent nitrogen oxide emission mandates, and the potential for carbon dioxide emission limits. This can be achieved through real-time monitoring of oxygen and carbon monoxide levels in numerous areas of the flue gas duct, which is typically 50–90 feet wide.

EPRI demonstrated a device that can be inserted to measure oxygen and carbon monoxide from a single point in the flue gas flow, using laser-based sensors. Over several months at an 805-megawatt coal-fired boiler, the device collected continuous measurements with high accuracy and limited maintenance needs.

The measurement device used in the EPRI demonstration was mounted on a flue gas duct.

While the prototype measured only at a single point, results suggest that a similar device designed for multiple-point monitoring can enable operators to fine-tune burners, reduce excess oxygen, and maintain acceptable carbon monoxide levels. This can help enhance plant efficiency and reduce CO_2 and other emissions. Researchers estimate that using this approach, operators could potentially reduce annual operating costs by hundreds of thousands of dollars, based on factors such as improved boiler efficiency and reduced nitrogen oxide levels.

The study's authors report that refinements are needed to define multi-point approaches with capital costs acceptable for commercial application. EPRI is conducting a cost-benefit analysis of potential approaches.

R&D Quick Hits

From Refrigerators to Hot Dog Rollers: Making Convenience Stores More Efficient

Per square foot, convenience stores are among the biggest energy users in the commercial building sector because of considerable refrigeration, lighting, and space conditioning, coupled with long operating hours. According to the 2012 Commercial Buildings Energy Consumption Survey, the 131,000 convenience stores in the United States consumed 27 billion kilowatt-hours—roughly comparable to annual electricity sales in Connecticut.

While many utility efficiency programs already include offerings for convenience stores, an EPRI assessment of equipment in 24 Tennessee stores revealed further opportunities for energy savings:

- **Heating and cooling:** For space heating, replace electric resistance heat with more efficient heat pump technology. Improve heating and cooling through better ventilation systems, blowers, and variable-speed compressors. Install whole-building controls to coordinate multiple units.
- **Refrigeration:** Adjust units' temperature setpoints, use evaporative cooling, and improve defrost control.
- **Lighting:** Replace old 24/7 indoor lighting with a configuration that uses daylighting coupled with photosensors and dimmable LEDs. Stores already using LEDs in some applications can make additional gains through a full conversion to LEDs. In some stores, 24/7 outdoor lighting can be optimized.

EPRI's next step is detailed monitoring of two Texas convenience stores, determining load shapes for all equipment—even the hot dog rollers. From this, researchers can quantify savings achievable through central control systems and estimate loads that can be shifted or shed without disrupting store operation.

R&D Quick Hits

Street Lights: Not Just for Lighting Anymore

In the city of the future, could street lights help meteorologists forecast the weather? Could they identify open parking spaces for drivers circling the neighborhood? Quite possibly, according to an EPRI study on "smart city" lighting.

A growing number of commercially available technologies can be mounted on or in street poles and street lights to provide new city services, data streams, and revenue. Potential applications and opportunities include:

- **Environmental sensors:** The data could potentially be sold to weather providers, emergency services, and other parties.
- **Communication networks:** Antennas and routers could expand cellular and WiFi networks.
- **Grid services:** These include electricity metering, fault detection, and distribution automation.
- **Cameras and microphones:** Audio and video data could be used for security, accident reporting, and parking optimization.
- **Charging:** Electricity is already delivered to street lights and could be routed to electric vehicle chargers or inductive chargers for drones (used for city and safety services).
- **LED billboards:** These could be used for advertising.

Other examples include traffic monitoring, gunshot detection, and air quality monitoring. Utilities could potentially invest in a single communication infrastructure that integrates street lights, smart meters, and many other smart city technologies. Questions about these technologies remain, and EPRI is examining their deployment, technical requirements, performance, payback, costs, and benefits.

R&D Quick Hits

The Key to Success with Drones for Environmental Applications: Diligence

For utilities interested in operating drones along transmission and distribution rights-of-way, an EPRI study offers this insight: A full-fledged drone program can significantly bolster wildlife, vegetation management, resource mapping, and an ever-expanding list of other environmental programs, but success depends on careful planning and evaluation of costs, risks, and limitations.

Drones can be used for numerous environmental applications along rights-of-way. Examples include marking power lines to reduce bird collisions, surveying bird nests prior to line work, counting wildlife, tracking marked animals, and documenting vegetation health and intrusions into rights-of-way. Small, high-resolution cameras, infrared cameras, software for generating three-dimensional models, and numerous other sensors are expanding drones' capabilities.

Among best practices recommended by EPRI:

- **Hardware, software, and firmware:** These require careful selection and regular maintenance and updates.
- **Mission planning:** The flight operators, data analysis team, and end users of the data need to agree on mission parameters and deliverables. Preflight checklists can minimize forgotten tasks.
- **Data storage and management:** Selecting the right solution requires consideration of many factors such as the frequency and scope of missions, camera resolution, and types of sensor measurements.
- **Insurance:** Traditional insurance plans may not adequately cover drone missions, so utilities may need to evaluate alternatives.
- **Privacy:** Because drones operating in rights-of-way will inevitably collect images of the public and adjacent properties, utilities should adhere to the National Telecommunications and Information Administration's voluntary privacy guidelines.
- **Flight logs:** These can be used to document training, maintenance, firmware updates, flight locations and durations, mission goals, and unexpected incidents.
- **Electrical impacts:** The electrical environment around high-voltage lines can potentially impact drone operations. Utility staff need to understand and account for these impacts in planning missions.
- **Training:** Sufficient training in the use of drones should be provided to utility staff.

The results of the study can help utilities decide whether to start their own drone program or contract for these services—and formulate appropriate requirements if they choose the latter.

R&D Quick Hits

Solar Module Recyclers: On a Mission to Recover More Materials with Less Energy

A survey of recycling companies points to a critical trade-off in recycling of solar photovoltaic (PV) modules. On one hand, greater recovery of valuable trace constituents such as silver can reduce lifetime environmental impacts of solar generation and make module recycling more economically viable. On the other hand, it also requires more process steps and energy consumption. To be successful, the nascent PV recycling industry will need to strike a happy medium. That said, as processes and technologies for PV module recycling advance, it may be possible to increase recovery of materials while reducing energy use.

While the massive growth in solar energy has clear environmental benefits, solar panels have a finite lifetime and could end up in the waste stream. Landfilling is not an option. Some panels contain heavy metals such as cadmium and lead that can potentially leach into the environment. Disposal of other panels could contribute to the depletion of rare elements such as gallium and indium. Recycling is not easy because panels are assembled from numerous different materials.

Most experience with PV recycling is in Europe where it is mandatory. In the United States, there are no federal regulations for PV recycling, though several states are considering or developing policies and initiatives. Because volumes of PV waste are still low, dedicated recycling facilities are not yet economically justified. Today, glass, metal, and e-waste facilities perform most PV recycling, running only periodically to process batches of modules.

The National Renewable Energy Laboratory, Wambach Consulting, and EPRI surveyed five European recycling companies about their commercial and pilot-scale PV recycling processes and examined their data on consumption of energy and recovery of materials. Four companies incorporated module recycling in their existing glass and metal lines with only minor modifications, using crushing, sieving, and other mechanical processes to separate materials. The fifth company is demonstrating a new, dedicated PV recycling system that uses mechanical, thermal, and chemical processes. Relative to the other facilities, it recovers a greater proportion of materials, particularly metals and silicon. It consumes less energy than the metal recycler and more than the glass recyclers.

As more companies develop dedicated PV recycling facilities, R&D can help them recover materials more efficiently, enhance worker safety, and reduce the toxicity of residual materials.

EPRI JOURNAL

The **Electric Power Research Institute, Inc.** (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electric utility revenue in the United States with international participation in 35 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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