

**POSITIONING FOR A
SUSTAINABLE, RELIABLE, AND
AFFORDABLE T&D FUTURE**

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Michael E. Beehler



The U.S. electric utility industry faces a pivotal moment.

The demand for cleaner electric energy grows each year with the electrification of transportation, space conditioning, vertical agriculture, industrial processes, and hyper-scalers. Some say that America will double its current peak demand requirements by 2050. If that is half right, it's a huge effort.

In addition, we need to replace aging assets, support the integration of distributed energy resources (DERs), provide resilience against high-impact storms and wildfires, and employ emerging technologies like robots, advanced conductors, super-conductors and artificial intelligence (AI) to build and expand a robust electric transmission and distribution (T&D) grid. These challenges and opportunities have a compounded impact on the current planning, design, operations, and maintenance of our complex grid that needs to deliver sustainable, reliable and affordable energy to more and more large and sophisticated loads coming from, in some cases, new and unique customer classes. Making large investments like these requires a careful and consistent evaluation of the total cost of ownership because, according to Warren Buffet:

“Price is what you pay. Value is what you get.”

To extract the maximum, long-term value of these investments, our industry must adopt a comprehensive, long-term grid strategy built on three interdependent pillars: **sustainability**, **reliability**, and **affordability**.

These are not competing priorities but mutually reinforcing elements—advancing one strengthens the others. Neglecting any of the three will appropriately result in valid questions from regulators, shareholders, and customers, starting with **“why not?”**



Reducing truck rolls is an important consideration for sustainability and resilience.

SUSTAINABILITY

Sustainability requires a grid capable of supporting the clean energy transition while responsibly accommodating substantial load growth. Electrification in transportation, buildings, and manufacturing when combined with the explosive rise of data centers and AI infrastructure is dramatically driving electricity consumption upward. However, this growth coincides with national ambitions to cut emissions through expanded renewables, like solar and wind, paired with advanced storage, grid-enhancing technologies, and efficient integration of DERs.

A sustainable approach emphasizes long-lived, low-emission assets, and full lifecycle responsibility from material sourcing and manufacturing to operation, maintenance, and recycling. It will include innovations that maximize clean energy while minimizing environmental harm or consequences. A sustainable T&D system positions the U.S. to achieve climate goals without sacrificing economic strength or energy independence. Within T&D infrastructure, sustainability extends across the

entire asset lifecycle, prioritizing durable components from responsible suppliers to reduce waste and emissions, again.... over the life of the asset. Stakeholders from customers and investors to regulators and employees value these sustainable practices for their contributions to performance, compliance, and trust.

A good example of owners adopting more sustainable business practice is the large growth of strategic undergrounding programs across the country. Strategic undergrounding is increasingly popular amongst utilities and their regulators delivering multiple advantages and uniting sustainability with other advantages or goals such as:

- Optimized capital and reduced operations and maintenance (O&M) costs through fewer truck rolls, inspections, and vegetation management, resulting in lower fuel and labor costs, and reduced regulatory burdens.
- Enhanced reliability and customer and crew safety by eliminating risks from storms, vehicle collisions, downed lines, or chemical (treatment) hazards.
- Extended asset life, reduced waste, and no wildlife/aviation impacts, like woodpecker damage or bird electrocutions.
- Faster storm recovery with minimal debris and no post-event landfilling.
- Elimination of herbicide use, supporting biodiversity and water quality.
- Near-total wildfire ignition prevention (98-99% reductions in high-risk areas per utility studies), averting smoke, ash, and ecosystem damage.
- Improved community aesthetics and goodwill, boosting property values and acceptance.



This 500kV cable at SCE should last 50-100 years if operated within design specifications.

By embracing lifecycle principles through smart material choices, life extension methods, and programs like strategic undergrounding, the T&D industry can forge a greener, more reliable and resilient grid that starts to meet societal expectations for responsible environmental stewardship and true sustainability.

RELIABILITY

Complemented by sustainability, reliability forms an unshakeable core value of the T&D grid. Many utilities and regional reliability organizations see demand soaring while high-impact, low-probability (HILP) events like intense storms, wildfires, heat waves, and winter extremes become more common. The T&D system must safely deliver uninterrupted power under all conditions. Modernization replaces aging assets with hardened assets that integrate variable renewables, maintain capacity via dispatchable resources and storage, and incorporate smart controls. Faster interconnection, regional planning, and data-driven upgrades prevent shortfalls and outages that threaten safety, critical services, and economic vitality. Reliability is measured in minutes, but resiliency is measured in days.



Wildfires challenge electric utilities. Most major utilities, and their regulators have developed comprehensive, multi-year fire prevention plans to improve system resiliency and, ultimately, sustainability.

Resilience, as defined by organizations like the Electric Power Research Institute (EPRI), the North American Electric Reliability Corporation (NERC), and the North American Transmission Forum (NATF), means preparing for, absorbing, adapting to, and recovering from disruptions swiftly. In the future, targeted strategies that leverage vast amounts of data from GIS, AMI, SCADA, ubiquitous sensors, and AI—will outperform physical hardening of overhead systems. AI analyzes patterns to guide decisions such as timing conductor upgrades for higher capacity, deploying covered conductors in fire-prone areas, preempting underground conflicts with other utilities, or when and where to strategically underground laterals and circuits. Resilience focuses on protecting critical loads (hospitals, emergency services, water systems) first, enabling triage and rapid restoration to minimize broader impacts. Microgrids for critical infrastructure, when considered, are built around resilient T&D assets.

Strategic undergrounding provides balanced resilience that eliminates the threat damage from wind, ice, trees, and fires while enhancing sustainability and proving to be cost-effective over the life of the T&D asset through reduced outages and recovery expenses and lost customer gross domestic product (GDP). As threats such as cyberattacks, sabotage, and geomagnetic disturbances potentially increase, a comprehensive all-hazards planning policy, powered by AI for risk modeling and redundancy, can also measurably improve system performance. Intelligent investments will support a T&D grid that withstands today's challenges and affordably adapts to and positions for tomorrow's load growth and opportunities.

AFFORDABILITY

Affordability ensures that electricity remains accessible to each income class of customer amid rising costs and inflationary pressures. Recent US Energy Information Administration (EIA) data shows average residential prices at about 17.78 cents per kWh in late 2025, with monthly bills around \$153-\$165 (based on ~863 kWh usage), varying by region and season. For many households juggling other essential living expenses, even modest increases can be challenging, especially as load demand from commercial and industrial customers can tend to push rates upward. Bills may stabilize at some progressive utilities due to energy efficiency programs and deployment of technology, but rates per kilowatt hour will go up.

True affordability considers the total cost of ownership (TCO) over asset lifecycles, factoring capital costs, O&M, outage impacts, storm recovery, and replacement cycles. Overhead systems may appear less expensive upfront but, over the life of the asset, accrue higher TCO from weather vulnerabilities, frequent vegetation management, wildfires, system outages, and lost GDP. Strategic undergrounding of high-outage circuits, cable life extension methods, the use of new and more durable conduits and cables can potentially flip this dynamic. Upfront capital costs may be higher, but long-term TCO savings emerge from:

- Dramatically fewer outages (4-14 times lower during severe weather per utility analyses), reducing household losses (e.g., \$50-\$200 per event from spoilage) and regional and national economic damages (tens of billions of dollars annually in lost Gross Domestic Product).
- Sharp O&M reductions (75 to 80% lower in many cases) by eliminating tree trimming and emergency repairs of storm damaged overhead poles and wires.

- Faster restoration times that can help to stabilize recovery charges.

Analyzing and prioritizing high value circuits for sustainability and reliability improvements can maximize early benefits as regulators thoughtfully support prudent cost recovery. Over the coming years, system-wide savings will postpone or indefinitely delay the need for traditional incremental T&D investments. The result will be more predictable electric bills and customers that are protected from the price volatility tied to massive electrification and data center growth.

Central to everything in this pivotal time of unprecedented growth is a new age of emerging technologies lead by artificial intelligence built on high-quality data from ubiquitous sensors on everything.

ARTIFICIAL INTELLIGENCE

Artificial intelligence is the “new electricity,” and data is the fuel, said Kai-Fu Lee in his provocative book *AI Superpowers, China, Silicon Valley and the New World Order*. It is ironic that Lee uses the electricity metaphor for AI. The electric grid was declared the greatest engineering achievement of the 20th Century by the National Academy of Engineering in 2000—greater than the airplanes, plastics, fertilizers, antibiotics, the assembly line, and more. The electric grid changed the world. Now, powered by the very T&D grid it serves, AI is poised to change the world.



Artificial intelligence, like the human brain, functions around “pattern recognition.” As a child, we learn by using our five senses to communicate to our brain. Over time, our brain recognizes the look, feel, smell, sound, or taste of an infinite number of people, places, and things. With today’s advanced computing technology and massive amounts of data storage, a computer can do the same thing. Artificial intelligence is defined by *Webster’s Dictionary* as “a branch of computer science dealing

with the simulation of intelligent behavior in computers: the capability of a machine to imitate intelligent human behavior.” There are different

types of AI, ranging from simple rule-based systems to more complex machine learning algorithms that can learn and adapt over time.

Some general applications of AI include:

- 1) Image and speech recognition: AI can analyze and interpret images or audio recordings, allowing machines to “see,” “hear,” and understand their surroundings.
- 2) Natural language processing: AI can process and understand human language, allowing machines to communicate with humans in a more natural way.
- 3) Decision-making: AI can analyze data and make decisions based on that data, allowing machines to act autonomously or assist humans in decision-making.
- 4) Predictive analytics: AI can analyze data and make predictions about future outcomes, such as demand for a product or the likelihood of an equipment failure.

There are several ways in which AI can specifically benefit the T&D industry, including:

- 1) Predictive maintenance: AI-powered systems can analyze data from sensors on T&D equipment to predict when maintenance or repairs are needed before an outage.
- 2) Fault detection and classification: AI algorithms can analyze data from sensors on T&D equipment to detect and classify faults, such as short circuits, downed conductors, or broken insulators. This can help utilities respond more quickly to wild-fires and weather-related events to improve system reliability and resiliency.



California wildfires rage out of control and require new, proactive solutions

- 3) Demand forecasting: AI can be used to analyze data on past electricity consumption patterns, forecast future demand, and simulate DER integration, allowing utilities to better plan and manage their T&D systems.
- 4) Energy management: AI can optimize the use of electricity by households and businesses by analyzing customer data on energy use, data from a ubiquitous sensor network on secondary and tertiary sources, and the current or proposed grid configurations to make the decisions for efficient energy usage.

Among many other sources of data, AI will be complemented by robots gathering valuable data and working in the field and the office.

ROBOTS

A robot is a machine that duplicates certain human movements and functionality. Robots are made in a human or creature-like form or simply look like a large machine with multiple appendages. Robots generally perform unsafe, hazardous, highly repetitive, and unpleasant tasks. However, they can take the form of scanners and kiosks at your local grocery store, fast food restaurant, or airport to replace costly human employees that are hard to recruit, train, and retain. While robots are more pervasive in our daily lives, the electric T&D industry is discovering useful applications for robots such as security, inspection and maintenance, construction, and even mail delivery.

The new security robot in the T&D industry is Spot the “robotic dog” by Boston Dynamics. Robots, like Spot, can be used in confined and hazardous spaces to provide eyes and ears to the user for security and inspection.



Spot the “robotic dog” by Boston Dynamics.

Other forms of robotic inspection can be conducted by drones or unmanned aerial vehicles (UAVs) that reduce the need for manned aircraft inspection and deliver vast amounts of asset condition data to be used for maintenance decisions. Drones can also be used to laser scan entire project sites to accurately map asset location, material quantities, work progress, and more. Construction and maintenance can be performed with robotic arms that keep human personnel a safe distance from energized electrical lines. The LineMaster Robotic Arm by Quanta Services is a proprietary live-line tool that allows for the safe capture, control, and movement of energized conductors without the need for temporary provisions. New advancements in robotics for the industry can be expected by other entrepreneurs and the Electric Power Research Institute (EPRI) as the pressure on skilled labor cost and availability grows. Watch for developments in tree trimming and vegetation management, simple substation switching, and safe and rapid installation of millions of sensory devices in hard-to-access and hazardous locations. The use of robots in electric transmission and distribution systems will increase in the coming years as utilities seek to improve the efficiency, safety, and reliability of their systems and personnel and seek to have a better understanding of their assets via tools like the digital twin.



Drones or unmanned aircraft systems (UAS) are changing the nature of data collection today. Drones are inexpensive and ubiquitous.

DIGITAL TWINS

The digital twin is a multi-dimensional model or representation of a physical asset, infrastructure system, or city that provides valuable information about asset location, cost, condition, and performance. The digital twin is constantly updated from multiple human, robotic, and sensory data sources. It is more than a static three-dimensional (x, y, z) model and can include dimensions for schedule (4D), cost (5D), ESG scoring (6D), and more. The digital twin of the overhead and underground electric transmission and distribution system is a virtual replica of the physical system. It is a computer-based model that incorporates data from various sources, such as sensors, meters, robots, and other monitoring equipment, to provide a detailed and accurate representation of the electric system. The digital twin can simulate various design scenarios, such as the integration of distributed resources like renewables, storage, electric vehicles (EVs), or fuel cells. The digital twin can assist operators with condition assessment and predictive analyses of asset condition as part of an asset management program or asset health center. This can help utilities optimize their asset management strategies and sustainably extend the life of their equipment. Further, the digital twin can simulate asset performance and resilience during high impact-low probability (HILP) events such as wildfires, ice storms, tornadoes, or even cyberattacks.



Asset mapping and subsurface engineering are advancing rapidly. Digital twins of the underground infrastructure are deliverable today.

The digital twin of the electric T&D system provides utilities with a powerful tool for optimizing their operations, improving the reliability and resiliency of the grid, and lowering the cost of the asset over its useful life. This leverage allows utilities to apply other advanced technologies to benefit their safe, reliable, and resilient operation. One such technology is 3D printing and construction.

3D PRINTING AND CONSTRUCTION

3D printing construction has the potential to impact the electric transmission and distribution industry in several ways, such as printing concrete walls and some foundations in substations. 3D printing can produce structures with less waste material, reducing the environmental impact of construction and supporting sustainability objectives of the owners. 3D printing can be used to create durable replacement parts on the jobsite for some T&D equipment and potentially reduce downtime and repair costs. Plastic parts, panels, or enclosures in substations or in manholes will be the starting point.

As print feedstock metallurgy advances, this opportunity will grow significantly and improve the ability to solve some critical path supply chain issues with a printed part rather than a long-lead-time part from a far-away factory. The possible schedule impacts of 3D printing will be hard to quantify, but real.



Colorado Springs overhead transmission line with underground distribution

ADVANCED CONDUCTORS

Advanced electric transmission conductors such as those with composite cores are significantly improving the transmission grid by boosting sustainability, reliability, and affordability. These high-performance conductors can carry more power than traditional lines, operate at higher temperatures with minimal sag, and significantly reduce energy losses. Sustainability is enhanced by enabling faster integration of renewables by unlocking additional electrical capacity in existing right of way corridors, and cutting transmission losses. Reliability and resilience are improved by lowering wildfire risks from reduced high temperature line sagging, handling ampacity surges during extreme weather or outages, and physically strengthening lines against extreme wind and ice loads. Re-conductoring existing lines with high ampacity advanced composite core conductors can cost significantly less than building new lines. Reduced transmission line losses will theoretically lower the long-term energy costs for consumers over the life of the asset. Overhead T&D systems have many new technologies emerging to enhance performance. Likewise, super conductors and other underground system design philosophies and construction methods have advanced dramatically.

SUPER CONDUCTORS FOR THE FUTURE

Integrating underground high-temperature superconducting (HTS) cables into the electric grid represents a transformative step toward a

more sustainable, reliable, and affordable power system of the future. Superconducting cables have zero resistive losses thereby eliminating 5–10% of the energy waste typical of conventional copper or aluminum cables while carrying five to ten times more power. Increased power capacity to dense urban areas or to large data centers might be a good application for superconductors in the future.

Cooled by readily available liquid nitrogen, cables can potentially be installed in legacy underground conduits making today's investment in underground a tremendous asset for future superconductors. Refrigeration systems for the liquid Nitrogen must be further developed or advancements in material science must give us new materials with low or zero resistivity. Again, installing underground conduits today positions us for the future.



Liquid Nitrogen refrigeration for superconducting cables is a perfect insulator. This refrigeration plant at ComEd's Northwest Substation uses older technology on a closed loop system and requires regular maintenance. Newer technologies have improved dramatically.

ComEd has installed a short segment of 12kV 3000A superconducting tri-axial (all phases in one cable) cable at their Northwest Substation in the greater Chicago area. The cable links transformers on one side of the substation to the opposite side and, to date, performance has been "spectacular" according ComEd operators. The Cryogenic closed loop cooling system is the challenge. Temperature, pressure, and flow rates of the cooling system are carefully monitored and evaluated and hundreds of other sensors are deployed by engineers and operators throughout the system to measure "everything." ComEd is operating, maintaining and learning on behalf of the industry.



Installed in 2021, these 3000 A super conductors terminate into cables that lead to transformers on the opposite side of Northwest Substation providing a redundancy and improved reliability. Cables can be side by side because there is NO thermal heating or derating.

The reliability of the refrigeration system for superconducting cables has yet to be proven at scale except for the inherent reliability of underground assets. Solid dielectric and fluid filled underground systems today are much less expensive than ComEd's piloted super conductors. However, ComEd planners and engineers understand that superconductors may have a unique and very specific role on the ComEd grid in the years to come replacing traditional overhead lines and substations in areas that new lines are simply impossible to permit and build.

In the future, affordability and value will come from huge capacity increases in limited space and drastically reduced transmission and distribution losses. Loads are growing, technology is advancing, and our industry is responding.

UNDERGROUND

Today, the electric distribution system in America is approximately 20% underground. Some public power utilities like Ft. Collins, Colorado

Springs, and Anaheim have had underground ordinances for years. They have beautified their cities and improved the performance of their systems. Fort Collins is 99% underground and is 99.9% reliable. Colorado Springs started in the 1970s, and today is 77% underground with 99.9% reliability.



The District of Columbia Power Line Undergrounding (DC PLUG) initiative is a partnership between the District and Pepco to improve the reliability and resiliency of the Washington, D.C., electric system by placing select systems underground.

Anaheim has been engaged in their Home Underground Program (HUG) since 1990 with excellent results. And the phone and cable TV utilities in Anaheim paid to go underground as well. Investor-owned utilities (IOUs) have put new neighborhoods underground for years, and now, many large IOUs like PG&E, FP&L, WEC Energy Group, PHI, and Dominion are engaged in multi-year, multi-billion-dollar programs to “strategically” underground laterals and other key parts of their systems. These municipalities and IOUs are starting to understand the total value of undergrounding over the life of the asset. The data support it: data on capital cost; data on reduced O&M cost, time, and safety exposure; data on customer satisfaction; data on reliability measured in minutes; and data on resiliency measured by total time of line restoration (TLR).

Technological and material advances now make underground electric distribution more safe, reliable, and resilient. The benefits of undergrounding have been clearly documented in several industry reports, and construction costs are coming down. These utilities and their regulators and public power boards are leading the way with strategic undergrounding programs. More system and cost data will come from these projects in the coming years. Some have suggested that we could achieve 50% underground by 2040; could we? It is a dramatic and very progressive goal. It is a goal that will provide a 21st Century “decarbonized” grid of the future that will be capable of concurrently delivering the equally

progressive renewable, net zero, and carbon-free generation goals of that same future. Underground innovation will be the key to extracting the value of a 50% future.



Underground cables greatly improve system resiliency and sustainability and are very affordable when evaluated over the life of the asset.

JOINT TRENCH UTILITIES

Many design and construction innovations and methods are improving the overall installed cost of undergrounding. One design that shows great promise is the concept of joint trenching for utilities in a single, common excavation (or trench). Entities in other countries, and some North American electric utilities, have collaborated and used joint trenches for decades, providing improved safety, resilience, and affordability.

JOINT TRENCH

SAFE • RESILIENT • AFFORDABLE

FOR BID ONLY NOT FOR CONSTRUCTION

+ 2 m

Optimal Pavement

Compacted Aggregate Base Course Fill

Select Native Backfill

Aggregate Base Course Fill

Flowable Thermal Backfill

Aggregate Base Course Fill

Aggregate Base Course Fill

Original In-Situ Soil

+ 1.5 m

WATER GAS COMMUNICATIONS ELECTRIC SEWER

COLLABORATION IS A GIFT

Learn More

Power Delivery
Intelligence Initiative

www.pdi2.org

Many utilities around the world have successfully used joint utility trenches. In America, it may take regulatory leadership to get all of our utility infrastructure into a common excavation. Let's start now.

The safety of our electric grid is paramount. Joint trenching provides improved safety and improved performance, leading to fewer truck rolls for maintenance and repair, reduced fire threat, fewer cars hitting poles, and reduced lightning strikes, animal/avian-related outages, and downed wire accidents. This is more sustainable as well.

Resilience is the ability of an electric, gas, water, or communications utility asset to withstand a high-impact low-probability event with little or no customer outages. Joint trenching can eliminate extended outages measured in days due to fire, wind, ice, or other storms, and it can help eliminate dig-ins. Imagine one central corridor or alignment for ALL utilities that can be accurately identified and adequately protected.

Affordability is an increasingly serious challenge in our civil and electrical infrastructure industries. Some case studies suggest that each utility in a joint trench may save up to 40 percent of their “individually installed” capital cost. Less cost for each utility merits strong consideration.

Better reliability, better aesthetics, better maintenance of property values, and better run communities are all possible with joint trenching. Another underground innovation that plans for all utilities in a common excavation is tunneling.

PLASMA TUNNEL BORING

Building more underground T&D for a dramatically more sustainable and decarbonized future will require more human and material resources and technological advancements to deliver this infrastructure at scale. One advancement that shows great promise is the concept of plasma boring, drilling, and cutting. A new venture capital startup is developing the world’s first way to tunnel, trench, and excavate using a patented plasma tunnel-boring technology. Compared to traditional tunneling, trenching, and excavation methods, this technology has the potential to excavate rock much faster and save dramatically on civil construction costs. Plasma boring is a technique that uses a plasma torch to bore, drill, and cut holes through rock and soil. The process involves directing a high-powered plasma arc at the rock and soil material, causing it to melt and vaporize into “cornflake” sized chaff, leaving a hole or trench that can be used to install conduits or cables for underground electric lines, and more.

Plasma boring is energy intensive and generates much waste heat in the excavation. If developments are successful at scale, they will deliver faster underground installation times, reduced utility and environmental disturbance, and increased locational accuracy. Plasma boring, drilling, and cutting may be fundamental to the industry’s ability to deliver the changes needed to meet the goals stated. The 21st Century grid will still need to be sustainable, reliable, resilient, and affordable

while it is massively overhauled to accommodate electrification and distributed energy resources like local generation, storage, and EV charging. Building underground is a big part of the new “decarbonized” grid. So too are redefined microgrids.

MICROGRIDS

Microgrids are stand-alone clusters of electric customers served by onsite generation that can seamlessly connect and disconnect from the legacy grid. They will provide critical electric service to strategic areas throughout a community during times of high impact, low probability (HILP) events with little or no customer outages. Microgrids are an excellent solution for much-needed resiliency but are expensive and very difficult to permit when using carbon-based stored fuels. As a result, we do not build many microgrids. Therefore, the industry needs to redefine a microgrid. A microgrid should be redefined and “reimagined” without onsite carbon-fueled generators and with the development of resilient electric infrastructure, such as a dedicated, hardened overhead or underground feeder(s) or transmission lines.



Microgrids support critical infrastructure and services with high resilience.

Imagine a select portion of the grid remaining in service after a wide-area catastrophic event. The surviving partial system would provide service to multiple small portions of communities across a large metro area. Homes may be out of power, but potable water would still be available. The toilets could be flushed, and sanitary systems could still operate.

Mobile phones could still operate, and customers would still have access to news and emergency information. Phone charging stations could be available, and a limited number of grocery stores and gas stations could still operate. Community centers could be available for heating or cooling in extreme weather as well as providing food, water, and shelter.



EV charging stations can offer two-way charging in the years to come, becoming a minor generational resource for a microgrid.

Reimagined microgrids will survive HILP catastrophic events, remain operational, and provide electric service to multiple small areas (microgrids) of communities across large service territories. In time, clean, carbon-free hydrogen or other sustainable resources may be applied to microgrids.

HYDROGEN

Hydrogen is produced from methane or water using energy-intensive processes to separate the chemical elements. Hydrogen is an exciting area of development for the energy industry and has the potential to transform the delivery and use of electricity. It can support electric system operations and microgrids in several ways.

Hydrogen can be used as a form of energy storage for electric systems. Excess renewable energy, such as from wind or solar, can be used to produce hydrogen through electrolysis. The hydrogen can then be stored and used to generate electricity during times when renewable energy production is low. Hydrogen fuel cells can be used to generate electricity, providing a clean and efficient alternative to traditional combustion-based power generation. In addition, fuel cells can be used to power electric vehicles, homes, microgrids, and even entire communities.

Hydrogen can be used to balance the electric grid by providing a flexible source of power that can respond quickly to changes in demand or supply. Hydrogen fuel cells can be used to provide backup power during times of peak demand, reducing the need for fossil fuel-based peaker plants. And hydrogen can be used to power remote sensors and monitoring equipment on the T&D system. Finally, hydrogen fuel cells can be part of a portfolio of generation, storage, and demand-side management tools used to successfully operate and maintain net zero energy buildings.

NET ZERO ENERGY BUILDINGS

Commercial buildings consume 40% of energy and emit 40% of all carbon dioxide in America. Net zero buildings can help us start to achieve our environmental goals and provide unique and valuable new business opportunities at the same time.



Urbanova is 770 acres of living laboratory for scalable, replicable, and innovative projects in Spokane's downtown University District—a true “innovation neighborhood.” Photo courtesy of Gonzaga University

Net zero can be defined several ways. The best definition for early applications is “the net energy or water used for an asset over the course of a one-year period is produced onsite.” Buildings, facilities, and plants experience peak periods of energy and water use as temperature, humidity, consumer use, and production levels vary. During these peak periods, the facility will need to be connected to the electric, gas, or water distribution systems of the local utility.

One progressive idea is to design and build a direct current (DC), net zero energy (annualized) microgrid at a greenfield industrial or data center site powered by 1) onsite wind and solar plus storage, 2) onsite natural gas converted to hydrogen with renewables for microgrid system support, AND 3) a highly resilient, dedicated underground HVDC and back-up AC transmission line built and connected to an existing regional transmission system. The microgrid will use demand side management (DSM) and demand response (DR) to control the specially designed DC loads and some AC loads in the state-of-the-art plant, facilities, and supporting infrastructure. The end-use customer will be able to arbitrage the plant electrical output with the regional price of power and need for ancillary services, buying and selling both when most profitable. Challenging? Yes, but any way you define it, net zero energy is hard to deliver, especially year over year.



Is this Tesla Energy truck in your neighborhood yet?

However, the world-changing technologies featured herein will synergistically work to make net zero more achievable. In order to achieve this, the T&D industry will need to gather more data on just about everything. Utilities and their customers will need to deploy sensing technology to help plan, design, construct, operate, and maintain a sustainable, reliable, and affordable grid of the future.

DATA SENSORS

Ubiquitous data sensors can be used on the T&D grid and on customer premises in several ways to maintain and improve the safety, reliability, and resiliency of the decarbonized grid.

Data sensors can be used to monitor the electric T&D system in real time, providing utilities with instant data that can be turned into information on the condition and performance of their infrastructure. This can help utilities predict and identify potential issues or problems before they become serious and take proactive measures to maintain the system's health and reliability.

Data sensors can be used to discover wildfires, downed conductors, failing cables, voltage anomalies, and faults in the T&D system. This can help utilities respond more quickly to these issues and restore power more efficiently. Data sensors can be used during wildfires, extreme

weather events, or other emergencies like car-hit poles, plane impacts, etc., to plan for and respond to these hazardous events more effectively in the future. Finally, data sensors as part of a utility-provided or proprietary building management system can lead to better and more sustainable use of energy and water resources for customers.

Overall, ubiquitous data sensors can provide utilities with the raw data that are turned into valuable information that they can use to plan and optimize the performance of the decarbonized grid and maintain a safe, reliable, and resilient electric system. By leveraging the power of data, utilities can improve their T&D system planning, asset performance and day to day operations. This ubiquitous data fuels the digital solutions and AI that support and deliver a T&D grid that continues to meet the changing needs of old and new consumers, regulators and communities.



Wind energy from this Montana billboard is a distributed energy resource.

ASSET MAPPING

Civil and electrical infrastructure owners will learn a lot in the coming years as emerging technologies advance their understanding of the location, condition, and performance of their assets. They will model various high impact, low probability events such as hurricanes, tornadoes, wildfires, and ice storms. They will extrapolate various growth rates of customer usage. They will calculate the optimal times for vegetation management, road closures, line outages, and system repairs. They will know the amount of moisture in the soil, depth of the water table, and

the location of natural springs, etc. They will know the soil conditions and the extent and hardness of rock or expansive nature of the clay. Much progress is being made. Overhead and underground asset identification and locating will look different in 2035. It will be:

- Autonomous, with minimal manual labor,
- Highly accurate, using rich, multi-sensor data,
- Integrated, part of a seamless construction and infrastructure ecosystem, and
- Predictive and preventive, not just reactive.



Underground cables greatly improve system resiliency and sustainability and are very affordable when evaluated over the life of the asset.

CONCLUSION

The path forward demands bold, integrated action. The U.S. electric grid stands at a crossroads and faithfully clinging to outdated ideas about sustainability, reliability, and affordability risks environmental setbacks, reduced reliability and affordability crises amid unprecedented load demand and business opportunity.

We must embrace a holistic T&D strategy using cutting edge technologies anchored in lifecycle sustainability, targeted reliability and resilience, and TCO-optimized affordability. Strategic undergrounding, advanced

asset mapping, AI-driven decisions, and innovative tools like robots, digital twins and plasma boring can deliver a decarbonized, high-performance grid that supports clean energy integration, withstands extreme events, and keeps electricity reliable and affordably accessible as we position for the future.

Positioning for sustainable, reliable and affordable T&D future will require a foundational T&D investment. By aligning customers, regulators, innovators, and communities around this investment, the electric utility industry can and will build a 21st Century grid that delivers the value needed for the next 250 years of America's future.



ABOUT MIKE BEEHLER



Mike started his career designing and building transmission lines and substations for Tucson Electric Power and the Hawaiian Electric Company and then spent over twenty years designing T&D infrastructure and consulting on emerging trends at Burns & McDonnell, a large, international architectural/engineering/construction firm. He has written, presented, and consulted on reliability-centered maintenance, critical infrastructure protection, and program management. In addition, he

is a well-known industry writer and speaker on the early definition of the smart grid, 3D/BIM applications in T&D, and development plans for smart cities. Most recently, he is sought for his strategic leadership and vision on the application of emerging technologies in changing business models to include the integration of distributed energy resources, augmented/virtual reality, and artificial intelligence. He is the founding member and Chief Opportunity Officer of Mike Beehler & Associates, LLC <https://mikebeehler.com/about-mike/> and serves as the National Spokesperson for the Power Delivery Intelligence Initiative <https://www.pdi2.org/>

Mike is a registered Professional Engineer in AL, AZ, CO, FL, GA, HI, KS, TX. He is a Fellow and Life Member in ASCE and a Member of CIGRE and IEEE. Mike has been married for over 40 years, has four adult children and some delightful grandchildren, and lives on Singer Island, Florida.

Find more at

MikeBeehler.com