

ROLE OF UNDERGROUNDING IN RESILIENCE

PUF
Energy Research

A PUBLIC UTILITIES FORTNIGHTLY SPECIAL REPORT

The Role of Undergrounding in Electricity System Resilience

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Executive Summary

- Notwithstanding long-held beliefs by many in the utilities industry, a growing number of utilities are now undergrounding. It is increasingly understood across the industry that these beliefs have been dispelled by proven innovations.
- With a more compelling life-cycle cost-benefit calculation, undergrounding has emerged as an evolving trend. Though one that has not yet been well reported.
- Undergrounding costs have come down substantially. On a life-cycle basis, including comparative operating costs throughout an underground cable's extended service life, such as savings in vegetation management and pole inspections, moving a line from overhead to underground has become competitive for a broad range of circumstances.
- Demands by the public for undergrounding have further risen. Which is impressive considering how passionate these demands were ten, fifteen and twenty years ago.
- To what extent have these changes remade the cost-benefit calculus for undergrounding? How widespread really is the movement to underground across the industry?
- Public Utilities Fortnightly, wishing to address these questions, undertook a targeted survey of utilities. The study team interviewed leaders at a dozen investor-owned companies, from all regions of the country, as well as two independent and highly respected technical experts.
- It became clear that a new consensus has developed. Undergrounding some proportion of utilities' electric distribution lines in the twenty twenties and beyond has become as practical an option as it has become a customer-demanded and driven one.

John Boston, a Director of Engineering at Alliant Energy, told us:

“The whole derecho experience [in Iowa in August 2020] really validated our underground strategy.

We had areas, subdivisions, where everything was underground. And those folks didn't really even see a single utility truck. They lost power because we lost [the power] source.

I think it really confirmed that what we're doing, in terms of trying to underground as much as we can, is the right direction to go.”

Table of Contents

I. Introduction	1
II. Why This Study	4
III. How We Did This Study	6
IV. Not Your Grandfather’s Undergrounding	8
V. Public Acceptance Considerations	14
VI. Cost Considerations	16
VII. Prioritizing Lines to Underground.	21
VIII. Conclusions and Need for Further Study.	23
About the Study’s Principal Investigators.	24
About PUF Energy Research	25

I. Introduction

A. Overview

After prolonged electric service outages, a particular question is often asked. Why can't electric utilities underground their overhead power lines?

The answer as often given is, to do so would be extraordinarily expensive. And that, while undergrounding would sidestep some outages, it would precipitate others. And that, undergrounding would complicate the restoration of electric service when outages do occur.

Notwithstanding these long-held beliefs by many in the utilities industry, a growing number of utilities are now undergrounding. It is increasingly understood across the industry that these beliefs have been dispelled by proven innovations.

With a more compelling life-cycle cost-benefit calculation than heretofore, undergrounding has emerged as an evolving trend. Though one that has not yet been well reported.

The Electric Power Research Institute's Dr. Andrew Phillips, its Vice President for Transmission and Distribution Infrastructure, told our study team:

“We started UDIG, the Undergrounding Distribution Interest Group, to enable utilities to share with one another different approaches, new technologies, and potential applications. So far, we've had ninety-five utilities participate and four hundred and forty individuals. That just gives you the depth of interest.”

Frank Morrissey, Managing Director at Burns & McDonnell for Underground and Submarine Cables, told us:

“Almost every utility we interface with is looking at [undergrounding] in some capacity.”

Alliant Energy's John Boston said this:

“The utilities in the Midwest are seeing more and more of the benefits of undergrounding. It goes beyond weather events. Whether it's reducing the exposure to squirrel outages, the racoons, cars hitting poles. And reduction in our maintenance cost, to reduce those tree trimming costs. There's just a multitude of benefits.”

Why is this tidal wave of undergrounding happening? And why is this happening now?

The study team found it to be largely because of dramatic scientific and engineering developments in undergrounding. But just as much because of equally dramatic developments in the role of electricity in our society – how dependent we have become and are further becoming on its uninterrupted supply – and consequently on the absolute necessity of raising electricity system resilience.

In recent years undergrounding costs have come down substantially. On a life-cycle basis, including

comparative operating costs throughout an underground cable's extended service life, such as savings in vegetation management and pole inspections, moving a line from overhead to underground has become competitive for a broad range of circumstances.

The undergrounding technologies we are now deploying have revolutionized how lines are placed under our streets, fields, and yards. With, for example, factory-comparable quality control testing during installation to avoid future faults. And also, with better materials, advanced cables perform for as long as a hundred years after they are put in place under the ground.

Demands by the public for undergrounding, additionally, have further risen. Which by itself is impressive considering how passionate these demands were ten, fifteen and twenty years ago.

To what extent have these changes remade the cost-benefit calculus for undergrounding? And how widespread really is the movement to underground across the industry?

Public Utilities Fortnightly, wishing to address these questions, undertook a targeted survey of utilities. The study team interviewed leaders at a dozen investor-owned companies, from all regions of the country, as well as two independent and highly respected technical experts.

We summarize our findings and conclusions herein, in this special report.

B. Findings and Conclusions

The survey of utility leaders and technical experts led the study team here at PUF to two principal findings.

First, undergrounding has emerged in recent years as a proven method for decreasing the incidence directly and duration indirectly of electric service outages. The days are now past when companies consider undergrounding to be no more than a marginal or niche strategy to raise their system's resilience and reliability.

Second, several remarkable innovations in undergrounding technologies, installation and processes have significantly driven down the expense of undergrounding and quite significantly driven up its own resilience (that is, of the lines themselves that have been placed under the ground).

C. Undergrounding is a Long-Term Strategy

Some have long predicted that it was merely a matter of time before undergrounding entered the mainstream as one of the most trusted ways to improve the resilience of the electricity system. The old idea seemed unsustainable that whole distribution systems will forever remain overhead, even including utilities' lines most vulnerable to storms, while the public increasingly becomes ever more dependent upon never-interrupted electric service.

Now that innovation has dramatically improved undergrounding as an option, utilities across the industry are rethinking whether those lines that are most susceptible to falling from increasingly fierce winds, snow, ice, and fire should be overhead or underground in the decades ahead. Especially since

the climate will become more challenging to our infrastructure. And since electricity will become even more critical, to not just customers' comfort and convenience, but also to their health and safety.

In his interview with the study team, Paul Gogan of WEC Energy Group told us:

“We have assets even going back to the nineteen twenties. I believe that we have a 1908 pole somewhere. So, you have some choices. Easiest thing to do is to just replace it in kind. For overhead systems, you have basically a pole and wire, and the easiest thing is to rebuild it with new wire and stronger poles. We do that in certain areas... But in our company, we take that step back and say, there's been a lot of changes in our system and our customers. This is a once in a lifetime opportunity to redesign the system for current and future needs.”

It became clear to the study team that a new consensus has come to the fore. Undergrounding some proportion of utilities' electric distribution lines in the twenty twenties and beyond has become as practical an option as it has become a customer-demanded and driven one.

II. Why This Study

A. Background

When Pacific Gas & Electric’s CEO said last year, on July 22, 2021, “We are committing to burying ten thousand miles of lines starting in our highest fire risk districts in our highest risk areas,” the electric utility industry’s historic view on undergrounding was shaken. The company’s COO added, “Undergrounding is tried and true. We’ve already done it in the past. What’s different about this situation, this scale and scope is truly unprecedented and extraordinary.”

For Public Utilities Fortnightly’s annual innovation issue that fall, published on October 25, 2021, we excerpted PG&E’s Request for Information. The RFI had been distributed on August 12, seeking ideas on how the company could achieve its undergrounding goal.

For the annual innovation issue, we also interviewed leaders at five other utilities – Dominion Energy, Florida Power & Light, Pepco, Southern California Edison, and Tampa Electric – about their own experiences in undergrounding. It became clear during these interviews that undergrounding was indeed taking place throughout the industry, at some companies quite vigorously.

B. We Had Questions About Undergrounding

Our questions afterwards were obvious. How widespread is undergrounding across the industry? How fast is this trend growing? And what does the future hold for this strategy to harden the grid?

The urgency of these questions has only increased as natural threats to the grid have increased (with oftentimes broader impact on growing population densities in harm’s way). Whether from storms of various kinds nationwide, or wildfires in the west particularly.

Making the nation’s electricity system more resilient for a climate that is evidently changing has become critical. So much so that the Electric Power Research Institute kicked off its Climate READi initiative in the spring of this year, on April 28, 2022.

Even President Joe Biden and Energy Secretary Jennifer Granholm have referred to undergrounding in public remarks. The President did this when he met with electric utility execs on October 21, 2021. And the Energy Secretary did this in a CNN Business op-ed two months after PG&E’s announcement, on September 17, 2021:

“To keep the American people safe, we need to increase resilience to these potent storms – which first requires more transmission lines... We also need to ensure that the new infrastructure we’re building can weather the mounting climate impacts we know are coming. That means, for example, switching wooden poles for steel poles [or] reinforced concrete, and, where it makes sense, putting lines underground. In response to wildfires, Pacific Gas & Electric is working to bury ten thousand miles of power lines. We can replicate that effort in key areas most vulnerable to extreme weather.”

There are several effective approaches that utilities are taking and planning to take to raise the grid’s

resilience. Such as insulating overhead lines, strengthening overhead poles, and elevating substations above flood levels. Among these now is quite apparently undergrounding.

It is increasingly considered a viable approach for a widening range of conditions and circumstances. Such as by the U.S. Department of Energy commencing an ARPA-E research program on undergrounding.

C. The Study's Goals

This study therefore aims to provide some insight, at this transitional point in time, about those obvious questions. And ultimately, on the bottom-line question of interest to Public Utilities Fortnightly and our readership. That is:

To what extent can a selective undergrounding strategy be deployed in the public interest, to harden the grid, and to improve its performance against the fierce storms and fires we shall inevitably face in the future.

D. New Line Undergrounding Versus Existing Line Undergrounding

It has been the practice of many utilities to place some of their new distribution lines under the ground. The study team found that some utilities – in the west at least – have placed many of their new lines under the ground.

The study's interviewee from PacifiCorp, Curt Mansfield, said this:

“A combination of customer desires, developer support and advanced underground material technology and installation process improvement drove movement to undergrounding. Additionally, the customers and developers were willing to bridge the financial impact from installation of overhead poles and wires to underground cable, vaults and switching equipment.”

The present study focused on existing line undergrounding. That is, relocating a line to underground when it has been overhead up until then.

Although we found substantial overlap between industry perspectives about new line undergrounding and existing line undergrounding. Especially since the experience of new line undergrounding has informed the industry and its vendors about the best approaches to existing line undergrounding.

Curt Mansfield of PacifiCorp added:

“We've had a considerable number of failures. But we also still have some of those assets that are performing just fine. If you've got a sandy area where you threw [underground cable] in, [that] made a whole lot of difference... Because the cable actually moves. So, you get scraping. You get the ability for water to get intrusion in there. And it fails the cable.

That's the seventies. But in the nineties and two thousands, the technology improved.”

III. How We Did This Study

A. Overall Study Methodology

Each month, Public Utilities Fortnightly provides our readers with as many as twenty interviews of utility industry regulatory and policy leaders and experts, and sometimes more than that number. We have conducted over two thousand such interviews since PUF transformed six years ago, in 2016, into an association of member organizations.

So, when PUF Energy Research undertakes a study on a particular trend or technology in the utilities industry, we naturally conduct interviews with industry leaders and experts as the basis for our analysis. Recordings of the interviews are discussed by the study team and the takeaways are synthesized into findings and conclusions.

B. Who We Interviewed

The study team sought to interview a diverse series of U.S. electric utility industry leaders that could represent their companies' perspectives on undergrounding. We reached out to companies that have well-known undergrounding programs as well as companies that don't. And even some that are at earlier stages of evaluating the role of undergrounding in their overall resilience investment portfolio. As well as industry experts at the Electric Power Research Institute and Burns & McDonnell.

Some of the interviews were conducted by Paul Kjellander, a Senior Advisor at PUF. Kjellander was formerly the longtime President of the Idaho Public Utilities Commission, and during November 2020 to November 2021, the President of the National Association of Regulatory Utility Commissioners as well. The remaining interviews were conducted by Steve Mitnick, PUF's Executive Editor.

Principal investigators Kjellander and Mitnick interviewed:

Les Carter, Strategic Advisor for Electric Distribution Underground, *Dominion Energy*

John Carmody, Director of Engineering and Planning, *NorthWestern Energy*

John Cornelius, Vice President, Power Delivery – Field Ops, *Georgia Power*

Josh DiLuciano, Vice President, Energy Delivery, *Avista*

Paul Gogan, Director of Electric Distribution Asset Management, *WEC Energy Group*

Michael Jarro, Company Vice President, Distribution Operations, *Florida Power & Light*, and Manny Miranda, Company Executive Vice President, Power Delivery

Aftab Khan, Senior Vice President, Engineering, *Eversource Energy*

Curt Mansfield, Senior Vice President, Power Delivery, *PacifiCorp*

Jamie Martin, Vice President, Undergrounding, *Pacific Gas & Electric*

Frank Morrissey, Managing Director for Underground and Submarine Cables, *Burns & McDonnell*

Dr. Andrew Phillips, Vice President, Transmission and Distribution Infrastructure, *Electric Power Research Institute*

Tim Tatum, Vice President, Regulatory Affairs, *Idaho Power*, and Mitch Coburn, Vice President, Planning, Engineering & Construction, and Connie Aschenbrenner, Senior Manager, Regulatory Affairs

Brian Weber, Vice President, Electric T&D Strategy and Engineering Services, *Black Hills Energy*, and Marc Eyre, Vice President for Operations in South Dakota

Jackie Winchester, Director of Engineering, *Alliant Energy*, and John Boston, Director of Engineering

Public Utilities Fortnightly is grateful for the participation in the study of these distinguished electricity industry leaders. Our findings and conclusions are, however, solely of the PUF study team and do not necessarily reflect the opinions of these interviewees and their companies.

C. What We Asked Interviewees

Questions that the principal investigators typically asked in these interviews were:

1. What has been your company's point of view and experience in undergrounding?
2. Which lines are being targeted for undergrounding and why?
3. How do you view undergrounding's costs and benefits?
4. What's been the role of technological innovations in undergrounding?
5. What are the impacts of supply chain limitations and inflation?

D. Completing the Study

Following the interviews, Kjellander and Mitnick were joined by Joe Paparello and Alex Revel of the PUF staff for in-depth discussions of the interviewee perspectives and experiences. A consensus was then developed among us about the most important learnings and overall conclusions.

Additionally, all the interviewees were provided the selected quotes chosen by the PUF team for this report. Per the "PUF Promise," interviewees were given the opportunity to review, tweak and approve these quotes.

Finally, the team prepared this report on our study.

IV. Not Your Grandfather's Undergrounding

A. Twenty Years Ago

An influential report on undergrounding by the Edison Electric Institute was published nearly twenty years ago. It found then that undergrounding was expensive, and that its reliability benefit was “uncertain.” The report concluded that “in most instances” the benefit was not apparently “sufficient to justify the high price tag.”

The report identified improved aesthetics as a primary benefit of undergrounding, if not the primary benefit. Though the report then added that undergrounding's aesthetics benefit was as difficult to quantify as its reliability benefit.

Much has changed since “Out of Sight, Out of Mind” was published back in January 2004. Nonetheless, its findings continue to influence perceptions to this day about undergrounding.

The 2004 report details the difficulty in locating an underground line's fault, as compared to an overhead line's fault. This was before electronic sensors were installed on underground lines.

The 2004 report discusses the shorter useful life of underground lines, that is, before the cables could become unreliable. This was before significantly enhanced cable technologies extending their useful life to as long as a hundred years.

And the 2004 report discusses undergrounding's problems with water and moisture infiltration. Again, this was before significant improvements in cable technologies that waterproofed the materials that are buried.

We heard this for example from Marc Eyre, one of the study team's interviewees from Black Hills Energy:

“Here in South Dakota, we're about a seventy-thirty split. A little under seventy percent of our distribution line miles are overhead, with the remaining thirty percent underground. That might be a little bit more in [our] Wyoming and Colorado area, probably closer to sixty-forty...

If it's underground right now, certainly we're not going to go back overhead. We would replace it underground.

I'd say the material has vastly improved since that time. That old plastic, the cross-linked poly, they call it, is really brittle and it cracks. That's where you get a lot of those underground faults over time as moisture and other contaminants get into those cracks... The material is just a lot better nowadays.”

Other changes like the adoption of smart meters, sensors throughout the distribution system, and far more precise weather forecasting and modeling mean that undergrounding's benefit generally, and for given circuits specifically, is better understood. All this too came well after that 2004 report was published.

Virginia's utility regulatory authority, the State Corporation Commission, published a report three years later, citing the 2004 report as well as contemporaneous studies in North Carolina and Maryland. Its executive summary states that:

“The cost associated with the placement of the currently existing overhead electric utility distribution facilities underground was estimated by utilities to be over \$80 billion.”

Two years later a commission of Virginia's legislature on undergrounding confirmed in its report the conclusions of the SCC report.

B. Turning Point Eight Years Ago

A decade passed when the Massachusetts' Department of Energy Resources published a report in December 2014 on undergrounding. Typical of the many such reports over the years, it was put together in response to a prolonged electric service outage and the subsequent public outcry, including demands for undergrounding. In this case, the precipitating events were Nor'easters on Halloween 2011 and in February 2013.

The Massachusetts report marked a turning point in perceptions about undergrounding. The idea of selective undergrounding or strategic undergrounding took hold. The report's executive summary states that:

“The cost of converting the entire existing overhead electric distribution system underground would likely be borne by the rate payers and could be prohibitively expensive... However, converting a targeted selection of circuits may be part of a successful storm resiliency program and worth the investment.”

That same year, in May 2014, following the local utility's broadly criticized performance that resulted in prolonged electric service outages, following storms, the District of Columbia's legislature approved a billion-dollar undergrounding project. Pepco's goal was to selectively underground up to sixty of the worst performing feeder distribution lines.

Hurricane Irma slammed into the Florida peninsula in September 2017. Its severity and impact were a game changer for thinking about electricity system resilience. Florida Power & Light's Company Executive Vice President of Power Delivery, Manny Miranda, in his interview with the study team, looked back at this experience and looked forward too:

“Hurricane Irma took us ten days [for restoration]. The average time our customers were out of service... was only a little bit over two days...”

The only problem we ran into, which we knew was our Achilles heel... a lot of our neighborhood lines... they're in people's backyards. We had a lot of trees that fell over into those lines. It was hand to hand combat.

We did a deep analysis and determined that there was no real good way to harden those overhead lines. So, we intend to underground all our neighborhood lines where it's technically feasible over the next twenty to twenty-five years.”

C. Undergrounding Now Mainstream

Dominion Energy was one of the first utilities to embrace an extensive undergrounding program. Notably in Virginia, where years earlier the regulatory authority and legislature had expressed their skepticism about its cost and efficacy in published reports.

The study team's interviewee from Dominion Energy, Les Carter, told us this:

“Modern underground cable is not like underground cable that was put in the ground twenty or thirty years ago...

We've now converted almost nineteen hundred miles from overhead to underground. We've built a sustainable program. We started this in the summer of 2014.”

A few other utilities began undergrounding programs later in the decade of the twenty-teens. These programs were usually undertaken in a low-key manner. Investor-owned utilities in Virginia, Florida, and Wisconsin were all undergrounding by 2020 and all with little publicity.

The industry's relatively tentative approach to undergrounding was shattered in July 2021. PG&E announced quite openly that it plans to bury ten thousand miles of its lines. Since then, the company has continued to explain quite transparently why and how they are proceeding.

The study team naturally included PG&E in its interviews. Jamie Martin of PG&E told us this:

“We will do one hundred and seventy-five miles [of undergrounding] this year... We will peak at twelve hundred miles to thirteen hundred miles a year. With a declining unit cost.”

It seems as if the publicity surrounding the PG&E project has given license to any utility pursuing undergrounding to discuss it openly and vigorously. The word is out. Undergrounding is now a major trend.

Most investor-owned utilities are pursuing some kind of undergrounding strategy. A few have very aggressive and ambitious programs meant to materially cut their customers' exposure to the risk of outages. At the other end of the spectrum, a number of utilities are taking their first preliminary steps, considering or undertaking small pilot programs.

Paul Gogan of WEC Energy Group told the study team that his company has already completed two thousand miles of undergrounding in its WPS service territory. The result is a ninety-three percent improvement in WPS's reliability.

D. Where We Are Now

As we write this report in 2022, perspectives on undergrounding have transformed and are radically different than twenty years ago. Or even ten years ago.

As just one example, the Federal Emergency Management Agency now proudly tells the story on its website of Dakota Energy Cooperative applying federal “hazard mitigation” funds to bury lines following a severe ice storm back in 1996. FEMA writes:

“After the power line was buried, storms continued with events that were severe enough to result in presidential disaster declarations for Beadle County in 2001, 2005, and 2007. But with the power lines buried four feet below the ground, neither these events nor others caused significant damage to the lines.

‘Obviously, a tornado can’t get a line that’s underground,’ [Manager of Operations Lynn] Kruse said. After a 2008 heavy snow, the only damage was on an overhead line that was fed by the underground line... the underground line would have paid for itself in just two damaging weather events. If the overhead line had been in place and damaged during all the weather events after 1996, the cumulative cost of replacing it after each storm would have been far greater than the cost of burying it once.”

The innovation in undergrounding materials, processes and planning has been remarkable over the past two decades. For instance, it had been feared that underground cables were vulnerable to flooding and coastline inundation. But the industry transitioned from standard crosslinked polyethylene cable to water resistant XLPE and ethylene propylene rubber.

This concern about flooding was addressed by Florida Power & Light Company Vice President of Distribution Operations Michael Jarro, a utility with considerable coastline exposure:

“A lot of our equipment is insulated and submersible as well. We have a lot of our equipment that is exposed to those conditions... Our experience has been that undergrounding is a much better and more resilient infrastructure. During Hurricane Irma in fact our underground grid performed eighty-five percent better than our overhead grid.

Irma was not as wet of a storm as sometimes they can be. But most recently PTC1 or tropical storm Alex... was a very wet storm for us. We did have some areas that were impacted by flood conditions. But again, the infrastructure held up extremely well.”

Aftab Khan of Eversource added:

“The cable itself is watertight. The splices would be our main concern but if the splices are done right, they hold up as well underwater. If the workmanship is right, and you use the proper termination equipment, the cable system should hold up well underwater.”

E. The Resilience Mission

It can be said that the electricity industry’s era of reliability has come to an end. Or rather that it is giving way to a new era, the era of resilience and reliability. Where the industry’s focus has turned from keeping electric service outage frequency and duration within generally acceptable limits. And turned equally to lessening the extent and duration of prolonged outages particularly and ultimately to significantly reducing the occurrence of outages of all kinds.

According to a March 2018 report by the Pacific Northwest National Laboratory, “Electric Grid Resilience and Reliability for Grid Architecture:”

“Resilience is an intrinsic characteristic of a grid or a portion of a grid. A perfectly resilient grid would not experience outages... Resilience applies to the grid under stress: how it resists losing capabilities or gracefully degrades... Resilience is in large part about what does not happen.”

The study team’s interviewee from WEC Energy Group, Paul Gogan, put it this way:

“It’s increasing customer expectations, leading to less leniency and tolerance for outages. We’ve got people working from home. Or going to school at home. Or homeschooling. Zoom meetings and all those types of things. So even momentary outages, which used to have more tolerance by the customers are no longer acceptable. In addition, there’s less acceptance from customers experiencing multiple interruptions in a year and definitely very long duration outages after storm events.”

It is now apparently well understood that, putting aside cost and some technical considerations, undergrounding can be a potent tool in making electricity systems more resilient. Particularly for lines most susceptible to environmental conditions.

The study team spoke with Les Carter, Dominion Energy’s Strategic Advisor for Electric Distribution Underground. He told us this about his experience with the impact on resilience:

“You have so many more faults in overhead versus underground. In our storms, ninety-five to ninety-nine percent of outages are in overhead devices. Those with underground generally involve the terminal poles for underground facilities.”

The study team heard this from John Carmody, our NorthWestern Energy interviewee:

“In those high beetle kill areas [leaving many dead trees], we converted a number of lines from overhead lines to underground lines. Just because it was the cheapest from a reliability standpoint... Vegetation management was one of the strategies. But as [the crews] got out there and started looking, they’d come back and go ‘why don’t we bury this single-phase line?’”

He added this about a unique environmental condition:

“We got one [five hundred-foot] segment... They actually buried it. Because there’s a bunch of turkeys there. It was causing lots of problems.”

Les Carter, the study team’s interviewee from Dominion Energy, told us:

“This [undergrounding] project is about reducing the length of time for restoration from catastrophic events. We like to be able to take what would potentially be an eight- or nine-day storm [outage] and make it a five- or six-day storm outage, or even less than that... What we’re seeing right now is reductions in storm [restoration] length, anything in between about twenty and thirty percent.

Because [outage] events are cost, events are time... You want to drive down the number of events that you have. Right now, we’ve driven about twenty-eight hundred or twenty-nine hundred events a year

off our system with the miles that we've [undergrounded] already. We're going to get to a much higher number than that when we finish."

The study team interviewed Florida Power & Light's Michael Jarro who brought up another benefit of undergrounding:

"A lot of our overhead laterals are in the rear of a customer's property. Accessibility really matters when you're trying to restore service [from a storm event]. The undergrounding program will bring all of those facilities to the front of the property. Making it that much easier to restore service."

E. Climate Changes

With climate changes, the local distribution companies are coping with increasingly adverse conditions for the existing fleet of overhead lines. Here's Paul Gogan again, from WEC Energy Group, discussing just one of the challenges facing utilities, and how that drives undergrounding decisionmaking:

"What we're seeing was just a lot more vegetation contact. And it is vegetation contact issues that we have little or no control over. Our historical legal rights to trim trees are limited to ten feet on either side of the wires. The trees that are falling are thirty, forty feet outside our right of way. These are sixty, seventy-foot tall trees that are within the strike zone of our facilities. Other than encouraging the customers to be proactive in removing these dead trees, there is just absolutely nothing we can do as a utility.

We urge customers to trim their trees. But they're not our trees. Customers love their trees until they're dead and failing.

Based on the type of vegetation, the area, whether it's coniferous or deciduous trees. Whether it's single phase or three phase, or if its cross-arm construction or armless construction. We take all of this into account in our predictive reliability planning model for design of the electric system. This model is calibrated based on historical performance (outage frequency and duration) and then we can predict what [we'll see] in the future."

V. Public Acceptance Considerations

A. Customers are Central to Undergrounding

How the public views undergrounding is central to whether utilities can and should underground. More than other resilience strategies, undergrounding captures the public's imagination.

Utility customers figure in the decision to underground or not to underground in these three ways:

First, after prolonged outages that were induced by overhead lines falling, many ask why those lines must still be suspended on wooden poles rather than be buried.

Second, when utilities announce undergrounding programs, the popularity of these programs is critical, given the cost and disruption characteristics of them.

Third, once these programs proceed, the willingness of customers to allow the disruption in their communities is necessary for undergrounding to be as extensive and efficient as it can be.

B. Invisible and Visible

It is somewhat ironic. Undergrounding obviously makes a power line invisible. However, an undergrounding strategy is typically high profile and highly visible.

This is best demonstrated by the program announced by Pacific Gas & Electric in the summer of 2021, to underground ten thousand miles of lines. The announcement has been the subject of many media reports, and political and regulatory leaders' comments. And the proposed plan has apparently been largely embraced by PG&E's customers.

C. Strategies to Embrace Customer Preferences

The companies interviewed by the PUF team have found some differences in public reaction to the disruption of undergrounding and have taken some different approaches accordingly. In a couple of utility service territories, such as those of Florida Power & Light and Pacific Gas & Electric, customers have been remarkably accepting of undergrounding disruption. This isn't surprising given the experiences of customers in these areas from prolonged electric service outages.

In some other service territories, not all their communities have equally welcomed undergrounding disruption. Dominion Energy for instance has adopted the approach that if a given community has significant opposition to the disruption, the company refocuses its undergrounding elsewhere.

Les Carter of Dominion told the study team this:

“We recognized very early on how important customer communication and customer service was to [the

undergrounding] program... We have people who are dedicated to the function of customer relations and customer communications throughout the project.”

Michael Jarro of Florida Power & Light also talked at length with the study team about customers and the undergrounding process:

“One of the things that we’ve tweaked is placing those underground lines, the cables themselves, in public right of ways. We have to work with the municipality and cities to get approval. But there’s a longstanding process to do that.

Where we do need to get with customers is the placement of the transformer and any switching equipment... You can essentially take the customer’s property with an iPad, show them what their property currently looks like and then what it will look like with this green box...”

And here’s what Paul Gogan of WEC Energy Group said on this aspect of undergrounding:

“This is the best part of the whole story. Going to the [undergrounding] program that is what our customers told us what they wanted... We surveyed customers before we did the project... Forty-seven percent of customers that were surveyed were willing to pay more on their electric bill. The increase was four dollars and thirty cents per month at the peak for this project.

This included not only customers that were directly impacted in the project areas but customers that were hundreds of miles away also were willing to pay for it. The real reason is they all benefit.

If I’m in Green Bay and my lines aren’t getting undergrounded but there’s a project one hundred and fifty miles away in Minocqua, when a storm comes through, we are no longer sending our Green Bay crews to Minocqua to repair the overhead system. They’re available in Green Bay if anything else goes wrong there. The durations of any outages including extraordinary storm events will be much less.”

VI. Cost Considerations

A. Appropriately Framing the Cost Analysis

That 2004 report, that labeled undergrounding's costs as enormous, compared constructing a new overhead line to constructing a new underground line. This one methodological misstep has led to a generation of misunderstanding about the economics of undergrounding.

The first reason that this comparison is misleading is that most of the industry's interest in undergrounding is in relocating an existing overhead line to under the ground. It is not in putting in entirely new lines (where there have been none heretofore) and then deciding to place the entirely new lines under the ground rather than overhead.

The prime example of this type of undergrounding, which is not a subject of this study, is a new line to new housing developments and subdivisions. Many utilities, we found during the study, have fully or almost fully transitioned to an underground company for new developments, such as Dominion Energy. But the question as to whether the new line should be overhead or underground isn't the central problem at hand herein.

From an economics standpoint, for the problem before us of whether to relocate an already existing overhead line to under the ground, the original cost of constructing the existing overhead line is a sunk cost (no pun intended). So, it is irrelevant, as sunk costs are always in decision analysis.

The status quo in this problem is leaving the line alone, and overhead (and not relocating it under the ground). If that is what is done, there is no incremental cost.

The alternative to the status quo is to relocate the already existing overhead line to under the ground. If that is what is done, now there is an incremental cost.

It does not matter if the cost of relocating an already existing overhead line to under the ground is three times that of constructing an entirely new overhead line, or five times, or even ten times. Because building a new overhead is not a branch of this particular decision tree. It's not one of the two options under consideration.

The only two relevant options are sticking with the status quo – maintaining the overhead as is – versus departing from the status quo – relocating the line to under the ground. That's it.

There's a second reason that the 2004 report's cost comparison is inapplicable to the subject of this study. When a long-lived asset is being considered for the electricity system, the evaluation must take into account all of the asset's life cycle costs. To not do so is misleading. How?

By only counting the upfront construction costs. And thereby neglecting the costs that will be incurred over the decades of service life of the status quo (keeping the line overhead) or of the status quo departure (relocating that line to under the ground).

For some assets, the present value of an asset's operations, maintenance, necessary capital additions over its lifetime, direct benefits, and externalities (positive and negative) are quite significant relative to initial construction cost. This is most certainly the case for undergrounding.

Mitch Coburn, one of the study team's interviewees from Idaho Power said this:

"We are looking at that tradeoff between the upfront cost and the ongoing cost... Is it worth it to spend more upfront to save money over the long run. The evaluation may be changing given the cost escalation we are seeing for vegetation management efforts."

Perhaps Michael Jarro of Florida Power & Light summed it up best:

"The cost for undergrounding has decreased over the last decade or so. It's much more in line with what is required to overhead-harden the system... You think about an underground system. It's not as exposed to tree conditions and flying debris. There's not a lot of poles you have to inspect... Those are two elements of our maintenance programs that we have that essentially go away..."

The long-term view, at least from our perspective, is that undergrounding is truly going to cause us to revisit a lot of things that we do. And it's going to be a big change for the way we operate the system."

B. What Drives Costs Up and Down

Undergrounding total installed costs vary. In his interview, Les Carter of Dominion Energy said this about costs:

"We thought we would be about five hundred thousand dollars per mile. We are doing mostly single phase. We do have some rocky areas. You will usually add two hundred and fifty thousand dollars per mile plus or minus to your costs.

We're saying we want to do about four thousand miles [of undergrounding]. We're a little bit shy of halfway through... How expensive is it for our customer base? Right now, after doing roughly nineteen hundred miles, each customer in our service territory is paying on average about two dollars and fifty cents a month for the program. That's the rider amount that's on the bill.

When I'm looking at six hundred and fifty thousand dollar a mile projects. We do have some that individually are over a million. But it's pretty rare to have that. And we have plenty at the other end of the scale too. When I'm looking at that six hundred and fifty, I'm also looking at customer densities that are more like sixty customers per mile"

A key principle of PG&E's large undergrounding program is local collaboration, including early customer and stakeholder engagement, which drives down costs. Jamie Martin of PG&E told the study team:

"When you have your designers, engineers, estimators with your construction leads, and your land and your environmental, with a project manager, and local customer experience person. All together, focused on specific geographies. You unlock an awful lot. Cost efficiencies. Local relationships. The ability for construction to influence design. Design to influence construction. There are huge efficiency

gains. Which is good for our customers and the hometowns we serve.”

In the interviews conducted by the study team, we heard again and again, that the main drivers of undergrounding costs are rocks in the ground and customer density. One of our interviewees from Black Hills Energy, Marc Eyre, said this:

“For us, it’s all about terrain. We operate in some very challenging environments with the National Forest Service and very rocky conditions... It depends on the area. If it’s somewhere where we can trench pretty easily and we can get the right of way, I would say there’s a lot of benefits to undergrounding.”

What the surrounding area is like can be key to the undergrounding decision. This is what the study team heard from Josh DiLuciano of Avista:

“Our company came up with a memo several years ago and said, it’s generally cost positive to go and underground it. If you’re doing a line rebuild in our rural areas, run the numbers and if it’s within the percentage, please underground it... We didn’t have wildfire as a risk... back then.

So, ten years ago it was something we were proposing as a positive thing to do. I think it just looks more positive in those areas.”

As supply chain constraints have affected the economy across all its sectors so too has it impacted undergrounding. Here is what Marc Eyre of Black Hills Energy, who was quoted earlier, said:

“We’re continuing with our strategy to underground where it adds value. It just requires a lot more planning and foresight. As an example, we’ve already ordered our 2023 transformer pad mounts for underground months and months ago. And we’re in the process of planning for 2024. Gone are the days of just-in-time material management.”

Josh DiLuciano of Avista said this:

“If we had one of those rural locations where we know [undergrounding is] the right thing to do. But if we don’t have enough spare stock of transformers, we don’t always do it right now.”

Michael Jarro of Florida Power & Light discussed, in his interview, cost trends in undergrounding installation:

“The cost for directional boring has decreased over the years. I think the technology has just developed. It’s something that’s being used not only in the electric industry but also gas and water. I think it continues to be perfected over time.”

C. Further Efficiencies Ahead?

While undergrounding costs have been falling, several of the interviewees expect there will be some further efficiencies to be realized in the next few years. Because of scale economies. And because of further innovations in, for example, both plowing and directional drilling.

Jamie Martin of PG&E told us this:

“In 2022, our target cost per mile is about three and three quarter million. But by 2026, we forecasted that cost to be two and a half million dollars per mile... There is work... that we are doing today that is well below three and three quarter million a mile.

We’ve done that, in part, by introducing different types of construction equipment... Things like rock wheels and ploughs and chainsaw trenchers. Not necessarily equipment that is new to the world. But equipment that is new to the undergrounding program that can be deployed at scale...

The other thing is the ability to take advantage of the scale of this program. The grouping of circuits into larger project bundles, going from projects that are about a mile to projects that are five, ten, twenty-five, thirty miles. Bigger projects and long-term visibility into the project portfolio provide clarity and certainty...

Our standards and specifications had the opportunity to evolve, given what we’ve learned. So, we’ve done things like changing the standard for trench depth in certain areas.

There’re certain areas where perhaps you don’t need to have a thirty-six-inch trench. You could have a thirty-inch trench. Or even a twenty-four-inch trench.

That’s a very specific example. But what it unlocks is a few things. One, you’re digging less. So, you could do more. You can get more feet per day. You’re moving less dirt. It’s less material and less waste. Less time constructing...

Another thing we’re thinking about and interacting on is when we look at our standard, how far apart do boxes need to be? It might make sense to have a box every eight hundred feet. But in other areas, does it make sense to have a box every five hundred feet or sixteen hundred feet? How can you think differently about the design of the work and the materials associated with that?”

Dr. Andrew Phillips of the Electric Power Research Institute looked ahead during his interview with the study team. He identified key trends in undergrounding:

“As we move lines from overhead to underground, maintaining a high level of reliability over the long term remains important. Installing underground assets requires a different set of skills than overhead lines and a high level of workmanship. Transforming the workforce will be key...

Prioritizing the undergrounding lines that serve disadvantaged communities is an important consideration, as these communities are often more impacted during [outage] events.”

And as PG&E is doing, Phillips added:

“Having a long-term commitment to undergrounding may enable companies to invest in new technology and commit resources. This may impact the cost of undergrounding.”

One can be skeptical about further innovation. Yet there’s every evidence that there shall be as much in undergrounding over the next twenty years as there was in the last twenty years. As Michael Jarro of

Florida Power & Light told the study team:

“We’re always looking to evolve the way we’re executing the program. So new tunneling methods, longer lasting materials, injecting smarter grid technology into the underground system.”

An Alliant Energy Director of Engineering, Jackie Winchester, told the study team:

“Just by having a greater volume of lines underground, that helps to reduce cost across the system for our customers. And ultimately executes on our plan for a safer, more reliable energy system.

Our crews are learning and getting better. At the beginning of this journey, we were contracting out the install of the underground. Now, we have set up crews within Alliant Energy and bought equipment for our crews to install and complete the work.

Employees can see that. ‘Hey, this work is transitioning to us and we’re learning this work, developing new skills and making the grid more reliable.’ They’re buying in and developing their careers – all while seeing the system benefit.”

Georgia Power’s Vice President of Power Delivery-Field Ops, John Cornelius, said this:

“Whether it’s five years, ten years, or multiple decades from now, undergrounding will continue to be a very effective solution for improving customer reliability. But also balancing that with cost and ability to give the customer what they expect is so critical...”

I think you’re going to see us continue to make decisions about undergrounding. We’re going to get even better at it, and the industry as a whole too. We’re consistently evaluating what we learn along the way to give our customers the level of service they deserve.”

VII. Prioritizing Lines to Underground

A. Nothing Less Than a Revolution in the Science

Paul Gogan of WEC Energy Group summarized best across the study team’s interviews the radical change that has taken place in undergrounding overall strategy:

“When I first started in distribution engineering in the early two thousands, the thought process was to harden and underground your main line, which is the three-phase large conductor, and put sectionalizing devices such as reclosers or resettable cutouts on your radial. Therefore, when a storm comes through, you’ve got that main line available and energized.

[Our approach now] is just the opposite. When we look at CMI [customer minutes of interruption] avoided per dollar, [the main line is the] most expensive stuff to underground. Due to the cost and associated benefit, it’s now what we try to avoid undergrounding.

When you look at least cost installation, the two-hundred-amp radial loops have the least cost per customer minutes of interruption avoided and it also helps in reducing future tree trimming maintenance costs. I would estimate that seventy percent of our system falls into this area. We have thousands of miles of this. Whereas the main line is significantly less.”

Some utilities like WEC Energy Group have been extensively undergrounding for years now. While other utilities are embarking on their undergrounding programs, such as Eversource Energy. Aftab Khan from Eversource said this:

“A lot of our distribution infrastructure is overhead along roadsides and exposed to a lot of trees. The northeast is a heavily treed part of the country and tree problems are the leading cause of outages during storms. The conversation of undergrounding comes up a lot...

We’re at an early stage in evaluating overhead lines to underground lines. But we’re going to do it where it makes sense. We’re going to prioritize according to circuit performance, customers impacted, and where alternatives like vegetation management are extremely difficult. Cost considerations are another important factor, but we are committed to overhead to underground conversion where it makes sense.”

B. How Selective

The terms selective undergrounding and strategic undergrounding came up in several of the interviews conducted by the study team. A few utilities have committed to undergrounding all or a majority of their distribution system. But more of them that have undertaken an undergrounding program believe in being selective about what to underground and what to leave as overhead. And they are innovating their data analysis and models to make those decisions line-by-line.

The old notions about undergrounding and its turn-of-the-century materials, installation and processes are now fading. Michael Jarro of Florida Power & Light talked with the study team about how selective

undergrounding is planned in the twenty-twenties:

“We’re attacking the worst of the worst. Customers might say, you’re not undergrounding my lateral. How am I benefitting from it?”

The more that we can underground, even if it is not specifically your infrastructure, the infrastructure that serves your house, you’re going to benefit. Because overall outage times and restoration costs will be reduced.”

Alliant Energy’s Jackie Winchester added:

“In Wisconsin, thirty percent of our lines are underground. In Iowa, we have approximately twenty percent of our system buried underground. Which means about twenty-five percent of our total system is underground across our service territory.

We aren’t attempting to underground everything. We’re undergrounding as a line comes up for its life cycle replacement. Or for example if we need to move facilities due to a road relocation. Within each project, we are balancing the costs with the benefits before moving forward. Our facilities have a fifty to sixty-year life span. So, it’s going to be a while before we are completely underground. Currently, we are progressing at a rate of about one to two percent of the system per year that gets transitioned to underground.”

John Cornelius of Georgia Power said this:

“Let’s face it – moving existing overhead lines underground in established neighborhoods can be disruptive and we had some challenges that made us better along the way... We’ve been able to work closely with local entities and learn ways to make it easier for them to process some of those work activities and traffic control requests.

Despite these challenges, we are now better able to determine the subset of lines where undergrounding is the most effective solution to address the root causes of outages and improve reliability, while minimizing the total cost to customers. [Georgia Power] will apply these lessons learned to continue implementing undergrounding through the Grid Investment Plan, in the best economic interests of customers.”

VIII. Conclusions and Need for Further Study

A. Study Conclusions

Based upon the nearly twenty interviews and the study team's findings from them, we came to these four conclusions:

1. Undergrounding of existing overhead distribution lines has become a mainstream method for enhancing the resilience of electricity systems.
2. A number of utilities are undergrounding extensively, and many more are embarking on selective programs, and all the companies are seeing substantial resilience results.
3. Innovation has driven down undergrounding costs and driven up the reliability and resilience of underground cables, including in flood conditions. And has substantially prolonged the service life of cables. Because its costs are still significant, utilities are also innovating to more accurately select which lines are most cost-beneficial to underground.
4. The customer is central to undergrounding. Customers generally embrace these programs that can slash electric service outages. But working closely with them before, during and after installation is key.

B. Need for Further Study

Even after this study, there remain outstanding and important questions about undergrounding. These are the questions that the study team still has:

1. How far has each major utility progressed in its undergrounding program or in its plan to proceed with some undergrounding?
2. For those major utilities who have not yet undertaken an undergrounding program, what do they see as the main concerns?
3. What is the potential for further innovation in undergrounding materials, installation and processes, and consequently the expected range of cost per mile, by later this decade?

About the Study's Principal Investigators

Paul Kjellander

Paul Kjellander is a Senior Advisor to Public Utilities Fortnightly. He was a member of the three-member Idaho Public Utilities Commission from 1999 to 2007, and from 2011 to 2021, and was its President in recent years. He also served as the President of the National Association of Regulatory Utility Commissioners from November 2020 to November 2021. He led Idaho's Office of Energy Resources between his terms as a member of the Public Utilities Commission.

Steve Mitnick

Steve Mitnick is the Executive Editor of Public Utilities Fortnightly and President of the firm that publishes PUF, Lines Up, Inc. He has authored four books on the economics and people of the electric utilities industry, testified as an expert witness on utility matters before nine different regulatory commissions, helped lead the utility consulting practices at McKinsey & Co., Marsh & McLennan/Oliver Wyman, and Bates White Economic Consulting, was the chief energy advisor to New York's Governor, and taught economics and statistics at Georgetown University.

Relevant to this study, he was also the CEO of a transmission development company that was broadly supported in its efforts to construct an underground transmission line from upstate New York to New York City. And his first book published in 2013, "Lines Down," was on the value of electricity and its uninterrupted supply to customers. His next book to be published this fall, "Heroes of the Storms," will be on the dedicated men and women who respond to electric service outages and restore service, and again the value of outage shortening and elimination.

About PUF Energy Research

PUF Energy Research, an arm of Public Utilities Fortnightly, aims to deeply dive into a single issue of importance in utility regulation and policy in each of our focused studies. Doing what Public Utilities Fortnightly does best, we engage in conversations with utility industry leaders and experts as the basis for assessing where a particular technology or issue stands across our broad community.

This report represents the independent findings and conclusions of PUF Energy Research. It reflects the study team's and Public Utilities Fortnightly's views solely.

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