DEAR READER

The age of "Strategic" undergrounding, as a source of the lowest life-cycle cost and achievement of resiliency and reliability targets, is here. There are multiple examples of "strategic" undergrounding efforts across North America where the compiling evidence is that the upfront investment in "strategic" undergrounding yields the lowest maintenance cost, vegetation management cost, and outage minutes, along with higher resiliency, reliability, and customer satisfaction. In addition, this type of long-term, lower-cost investment is highly aligned with the original utility industry "regulatory compact" where the utility provides reliable, nondiscriminatory (available to everyone) power at the lowest long-term cost.

The Utility Undergrounding Life-Cycle Cost Guide (Guide), developed by the Power Delivery Intelligence Initiative (PDI^2), is designed to help utilities assess and choose narrowly defined line segments where "strategic" undergrounding is the lowest life-cycle cost and will achieve resiliency and reliability targets. This Guide is designed for electric investor-owned, municipal, and cooperative utilities throughout the U.S. and Canada searching for a logical and structured approach to capture the lowest life-cycle cost for critical line segments. Topics each utility should consider and that are explored in this Guide include the following:

1. **Executive Summary** – Inform and educate industry executives on the application and use of "Strategic" undergrounding.
2. **Myth-Busting** – Remove misconceptions about the nature, performance, and cost of undergrounding.
3. **The Current State of Undergrounding** – Who is Doing What and Where.
4. **Emerging Undergrounding Materials, Practices, Techniques, and Costs** – "True Lifetime Costs" definition, performance, and implication that demonstrates that "Strategic" undergrounding is the lowest long-term cost for selected line segments.
5. **True Cost of Undergrounding…Taking the Long View** – Which "quantitative" and "qualitative" factors are driving the superior cost, reliability, and resiliency performance of "Strategic" undergrounding on selected segments?
6. **Generating Boardroom and Regulatory Support for Undergrounding** – How to position and obtain approval of boards, councils, legislators, and regulators for "Strategic Undergrounding" efforts?

The reader can use this Guide to inform and educate their investigation into the application of "Strategic" undergrounding, as a tool to achieve the lowest life-cycle cost and pursue resiliency and reliability targets.

PDi^2 trusts you will find the Guide a useful tool as you explore the development and implementation of "Strategic" undergrounding programs that deliver superior cost, reliability, and resiliency performance on selected line segments.

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UTILITY UNDERGROUNDING LIFE-CYCLE COST GUIDE

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1. EXECUTIVE SUMMARY

The age of "Strategic" undergrounding, as a source of the lowest cost life-cycle cost and tool to achieve resiliency and reliability targets, is here. Whether driven by low-cost performance pursuit, aesthetic desires, maintenance efficiency, vegetation management reduction, reliability targets, resiliency speed improvement, or customer satisfaction intentions, for critical line segments, "Strategic" undergrounding is aligned with the "regulatory compact" where the utility provides reliable, nondiscriminatory (available to everyone) power at the lowest long-term cost.

In the following pages of the Utility Undergrounding Life-Cycle Cost Guide (Guide), a series of 10 industry myths are debunked, and a logical and structured approach to capture the lowest life-cycle cost and achieve resiliency and reliability targets from critical segments is described in the following areas.

The Current State of Undergrounding
Highlighting the multiple Investor-Owned Utilities (IOU), Cooperatives (Co-Op), and municipal system operators embracing "Strategic" undergrounding, in every part of North America, for every reason. IOU examples include Dominion's Strategic Undergrounding Program (SUP), Florida Power & Light Company's (FPL) two programs including Storm Secure Underground Program (SSUP) and Municipality/community-initiated underground conversions, Georgia Power's Grid Investment Program (GIP), San Diego Gas & Electric's (SDG&E) Strategic Undergrounding Program, PEPCO's DC PLUG (District of Columbia Powerline Undergrounding Initiative), and WEC Energy Group among others.

Emerging Undergrounding Materials, Practices, Techniques, and Costs
"True Lifetime Costs" definition, performance, and implication demonstrate that "Strategic" undergrounding is the lowest long-term cost for selected segments. Driver examples include the potential for 100+ year cable life, 3-7x maintenance reduction, longer pulling length technology, and upfront cost differential of only 2-3x, **not the 10-15x industry myth**.

True Cost of Undergrounding…Taking the Long View
Which "quantitative" and "qualitative" factors are driving superior cost performance of "Strategic" undergrounding on selected segments? Avoided costs or risks associated with "Strategic" undergrounding include among others: Lost local Gross Domestic Product (GDP) from an outage; Annual tree trimming; and Outage truck rolls. Captured gains and benefits associated with "Strategic" undergrounding include among others: Improved Environmental, Social, and Governance (ESG) performance; Utility staff and public safety risk exposure reduction; Streetscape beautification; Improved quality of life for utility customers; and Improved customer service perspectives.

Generating Boardroom and Regulatory Support for Undergrounding
How to position and obtain approval of boards, councils, legislators, and regulators for "Strategic Undergrounding" efforts? "Strategic" undergrounding is a path to achieve low-cost performance, aesthetic desires, maintenance efficiency, vegetation management reduction, reliability targets, resiliency speed improvement, or superior customer satisfaction on critical line segments…which of these benefits is the driver for your governing body?

The reader can use this Guide to inform and educate their consideration of applying "Strategic" undergrounding, as a tool to achieve the lowest cost life-cycle cost and achievement of resiliency and reliability targets.

PDi² trusts you will find the Guide a useful tool as you explore the development and implementation of "Strategic" undergrounding programs that deliver superior cost, reliability, and resiliency performance on selected line segments.

1.A. MYTH-BUSTING

Exhibit 1.1

Myth-Busting

Remove misconceptions of the nature, performance, and cost of "Strategic" undergrounding

Myth	Myth-Busted
1. Undergrounding is 10-15x the cost of overhead installation.[51, 560]	The real cost differential in upfront cost is 2-3x for "Strategic" undergrounding efforts where the intention is to capture the lowest cost life-cycle cost and achieve resiliency and reliability targets for critical line segments. Multiple successful and PUC-approved "Strategic" underground programs, including Dominion, are coming in at the 2-3x benchmark. Dominion's Phase II SUP completed 249 miles undergrounded at an average cost of $422,496 per mile – significantly below the legislatively required maximum of $750,000.[251] Nearly every utility system will have line segments that exhibit similar cost/benefit.
2. Underground maintenance cost far exceeds overhead maintenance cost.	The cost of underground distribution maintenance per mile is 3 to 7 times **lower** than overhead distribution maintenance.[559, 603] This reduction in maintenance is also a direct reduction in "truck rolls" yielding both a safer environment and a focus on critical/emergency needs addressed by first or second responders.
3. Underground cable fails at a faster rate than overhead cable.[531]	Innovation and problem-solving where 100-year+ cable life, submerged and directly buried, is now possible.[255, 602] Specifically, materials, manufacturing, and factory comparable quality control (QC) field testing are greatly improved allowing cable systems to live 2 to 3 times longer than wood pole-supported assets.[615] In one study, underground assets exhibit 12x fewer System Average Interruption Frequency Index (SAIFI) customer interruptions than overhead assets.[610]
4. Overhead to underground conversion programs are cost-prohibitive.[51]	Undergrounding transformations are driving costs down and performance up via materials science; construction techniques; maintenance practices; regulatory policy; and financial engineering. What is truly cost-prohibitive is the lost GDP incurred by a weather-impacted region or state while overhead line segments are down a day or days longer than necessary – Hurricane Irma estimates of $1 billion per day lost[612] in regions impacted are consistent with FL's daily GDP of $3.8 billion and by comparison, VA's daily GDP of $1.7 billion.[611]
5. Boards, councils, legislators, and regulators will not support "Strategic" undergrounding.	Approximately 90% of new subdivisions are undergrounded[549,591]; "Strategic" undergrounding programs are underway in multiple states (AL, CA, DC, FL, GA, PA, WI, and VA among others) with implementation approval from boards, councils, legislators, and regulators. An "…increase in % share of T&D lines that are underground has a statistically significant correlation with improved reliability…"[501] WEC Energy is on track to achieve a 16% improvement in customer minutes interrupted (CMI) attributed to strategic undergrounding.[533]
6. "Strategic" undergrounding is not for Investor-Owned Utilities (IOUs).	"Strategic" undergrounding programs are underway by multiple IOUs (Alabama Power, Dominion, Georgia Power, PECO, PEPCO, PG&E, SDG&E, and WEC Energy Group as examples) with approvals achieved from boards, councils, legislators, and regulators.
7. Underground faults are hard to find, expensive to repair, and take longer to resolve.[107]	The quality, performance, and field testing of modern materials are allowing cable systems to live 2 to 3 times longer than overhead assets and reducing the number of faults below that of overhead lines[610, 615] This high-quality performance married with technology to accurately and rapidly locate faults,[608] when they do occur, and specialized keyhole or vacuum excavation technology dramatically speeds up and lowers the cost of finding and repairing any fault.

Myth	Myth-Busted
8. “Strategic” undergrounding is not for municipal or Co-Op utilities.	“Strategic” undergrounding programs are underway by multiple municipalities (Anaheim, Austin, Ft. Collins, Salt River Project, and Seattle among others) and Co-Op[501, 581] (Cordova Electric Cooperative, Dakota Energy Cooperative, and Lane Electric Cooperative) utilities with approvals achieved from boards and councils.
9. Undergrounding offers very limited intangible benefits.	Municipalities, developers, communities, and homeowners demand that new distribution and service lines be placed underground where nationwide, approximately 90% of new subdivisions are undergrounded.[549, 591] Other, non-monetary benefits include raptor protection, public safety, customer satisfaction, reduced traffic incidents, and community and customer satisfaction ratings, etc. “Fewer than 15% of selected underground projects have been canceled due to the inability to secure easements.”[601]
10. The present value of underground vs. overhead cost to install, maintain, and repair is **not** compelling.	Dramatically reduce outage duration both modeled and achieved. • “Strategic” undergrounding modeling, the Total Length of Restoration (TLR) will be reduced by up to 40-50% and this accomplishment is achieved despite spending less than 3% of the cost of more extensive undergrounding described in the VA SCC report on undergrounding post-Hurricane Isabel.[252] • “…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 of 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.”[581]

2. THE CURRENT STATE OF UNDERGROUNDING - WHO IS DOING WHAT AND WHERE

The age of "Strategic" undergrounding is here. In the early 2000s and into the 2003-2007 housing boom, service drops and distribution feeders, within developer neighborhoods, were placed underground in a single or joint trench with increasing frequency for aesthetic reasons and because developers rolled the cost incurred into a home's price. In parallel, the underperformance of a previous era's undergrounding work, particularly distribution mainline and feeder lines, clearly presented material performance issues related to direct bury installation techniques. The 2004 Edison Electric Institute (EEI) study, *Out of Sight, Out of Mind?* brought this history of underperformance to a head. The undergrounding of service drops and distribution feeders, within developer neighborhoods, however, continued unabated across the country, again primarily for aesthetic reasons and because developers rolled the cost incurred into a home's price.

Today, the application of "Strategic" undergrounding as a source of the lowest cost life-cycle cost for selected distribution feeder and mainline line segments is accelerating. The upfront cost is where much of the discussion and singular emphasis is placed and the range of cost is wide and highly dependent on permitting, line type, voltage, soil conditions, urbanization, and a host of other factors. Two examples of this range are provided in Exhibit 2.1. This singular emphasis on upfront cost is misplaced. A strong argument is made in this Guide that what really matters is how converting "strategic" segments targeted for overhead to underground drives out and down the risks and costs of the overhead infrastructure failing and falling in extreme weather, as well as resolving the resultant disruption to the life and well-being of the local community.[607]

Exhibit 2.1

"Strategic" Undergrounding Program Upfront Cost Range Examples

Utility	Undergrounding Actual/Forecast Cost Range	Undergrounding Characteristics
Dominion	Achieving $650,000 per mile average[506]	Single phase, diggable; add $250,000 per mile for routine rock for service drops and distribution feeders[506]
PG&E	Target $3,750,000 per mile maximum, falling to $2,500,000 per mile with efficiency, experience, and innovation[506]	Rough terrain and rock anticipated for distribution mainline and feeders[506]

Source: [506] PUF Energy Research, *Role Of Undergrounding In Resilience*, A Public Utilities Fortnightly Special Report, September 29, 2022.
Interpretative Note: A broader sample of cost ranges is available in Table 2.5 and 2.6, pg. 21-23 in Bohman, Angelena D. (2022).[536]

Three myths relating to who is doing what, where, in "Strategic" undergrounding are detailed in Exhibit 2.2. The expansion of "Strategic" undergrounding as described in Exhibit 2.3, is driven by value achieved. Two examples include:

- San Diego Gas & Electric (Sempra Energy) highlighted areas of high value achieved:[559]
  1. Less frequent outages caused by exposed equipment;
  2. Beautification in the case of franchise agreements;
  3. Reduced risk of downed wires that could cause ignition in the high fire threat districts.
- Utility highlighted the areas of high value achieved:[601]
  1. Achieved a 99% improvement in both SAIDI (duration) and SAIFI (frequency) indices when they were calculated for the geographies targeted as part of the Strategic Undergrounding Program (SUP).
  2. A forecast reduction in Total Length of Restoration (TLR) by up to 40-50% which impacts and generates benefits for all customers in the event of an outage.
  3. Ratepayer bill impact of $1.98 based on usage of 1,000 kWh - well below legislative maximum.
  4. Fewer events per mile and shorter duration of an event were achieved.

Exhibit 2.2

Selected Myth-Busting – Myth 6, 8, and 9

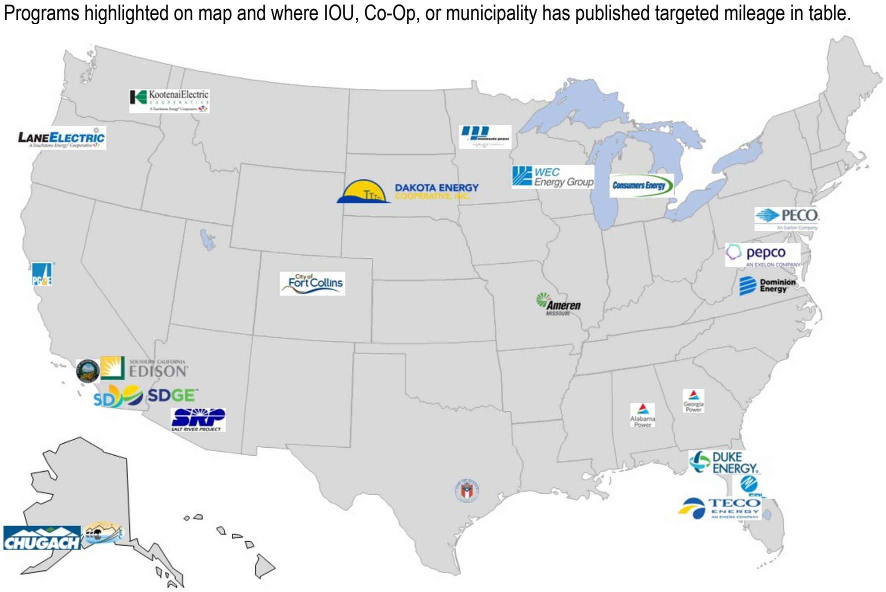
Myth	Myth-Busted
6. "Strategic" undergrounding is not for Investor-Owned Utilities (IOUs).	"Strategic" undergrounding programs are underway by multiple IOUs (Alabama Power, Dominion, Georgia Power, PECO, PEPCO, PG&E, SDG&E, and WEC Energy Group as examples) with approvals achieved from boards, councils, legislators, and regulators.
8. "Strategic" undergrounding is not for municipal or Co-Op utilities.	"Strategic" undergrounding programs are underway by multiple municipalities (Anaheim, Austin, Ft. Collins, Salt River Project, and Seattle among others) and Co-Op[501, 581] (Cordova Electric Cooperative, Dakota Energy Cooperative, and Lane Electric Cooperative) utilities with approvals achieved from boards and councils.
9. Undergrounding offers very limited intangible benefits.	Municipalities, developers, communities, and homeowners demand that new distribution and service lines are placed underground where nationwide, approximately 90% of new subdivisions are undergrounded.[549, 591] Other, non-monetary benefits include raptor protection, public safety, customer satisfaction, reduced traffic incidents, and community and customer satisfaction ratings, etc. "Fewer than 15% of selected underground projects have been canceled due to the inability to secure easements."[601]

Source: [501] Hoffman, Patricia and Larsen Peter, Resilient Power Grids: Strategically Undergrounding Powerlines, U.S. Department of Energy – Office of Electricity, March 22, 2022.;
[549] Mara, Kevin J., Cost-Effectiveness of Undergrounding Power Lines, HiLine Engineering, a GDS Company.;
[581] From Overhead to Underground: It Pays to Bury Power Lines, Federal Emergency Management Administration (FEMA), February 11, 2021.;
[591] Underground Power Line Conversions, FPL (Downloaded: https://www.fpl.com/reliability/underground-conversions.html).;
[601] Utility Infrastructure Resiliency Playbook, Power Delivery Intelligence Initiative (PDi2) Playbook, Mid-Atlantic Utilities Undergrounding Program Case Study.

Exhibit 2.3

"Strategic" Undergrounding Programs

Programs highlighted on map and where IOU, Co-Op, or municipality has published targeted mileage in table.



Strategic Undergrounding Programs	
Utility	**Program Miles**
PG&E	10,000
FPL	~ 5,000
Dominion	4,000
WEC	2,200
TECO	~ 1,000
PECO	1,000
Duke, FL	~ 500
Ameren	400
PEPCO	150
SDGE	~150 per year
Georgia Power	~100 per year
AL Power	~50 per year
San Diego, CA	1,500
Anaheim, CA	240
CO	99% Complete
Austin, TX	Study

Source: Continuum propriety research, compiled from public sources.

Other efforts at "Strategic" undergrounding are profiled in Exhibit 2.3 and touch multiple IOUs, Co-Op, and municipal system operators embracing "Strategic" undergrounding, in every part of North America, for every reason. Named and high-profile examples include Dominion's Strategic Undergrounding Program (SUP), Florida Power & Light Company's (FPL) two programs including Storm Secure Underground Program (SSUP) and Municipality/community-initiated underground conversions, Georgia Power's Grid Investment Program (GIP), San Diego Gas & Electric's (SDG&E) Strategic Undergrounding Program, PEPCO's DC PLUG (District of Columbia Powerline Undergrounding Initiative) among others.

The Michael Lewis book, Moneyball, and follow-up movie starring Brad Pitt is perhaps known to many readers. This book and movie, explore the transformation of baseball team recruiting, formation, and management based upon data that reflects a statistical correlation and probability to the pursuit of the ultimate goal, winning. There is an analogy from this book and movie that is applicable here.

- "The statistics were not merely inadequate; they lied" – Michael Lewis, Chapter 4
  - This speaks to the belief that traditional baseball stats (read utility metrics on undergrounding) were preventing the formation of good decisions and strategies. The analogy here is that reliance on upfront cost solely and a lack of focus on perhaps what really matters - the lowest cost life-cycle cost for selected distribution feeder and mainline line segments. This approach drives out and down the risks and costs of the overhead infrastructure failing and falling in extreme weather, as well as resolving the resultant disruption to the life and well-being of the local community.[607]
- "Conventional opinions about baseball…had acquired the authority of fact" – Michael Lewis, Chapter 4
  - This speaks to the fact that historic myths about the cost, performance, and acceptability of undergrounding pervade the industry as fact and don't stand up when challenged with today's superior materials performance, installation innovation, risks that assets are subject to, and a host of other factors, all pushing toward the demonstration that the lowest life-cycle cost for selected distribution feeder and mainline line segments can be achieved via undergrounding.

3. EMERGING UNDERGROUNDING MATERIALS, PRACTICES, TECHNIQUES, AND COSTS

The age of "Strategic" undergrounding is here. Innovations in materials science, construction techniques, maintenance practices, and regulatory policy each are significant contributors to "Strategic" undergrounding as a source of the lowest cost life-cycle cost for selected line segments. Four myths explored relating to cost and innovation in "Strategic" undergrounding are described in Exhibit 3.1.

Undergrounding is not a new concept. Thomas Edison directed his Edison Illuminating Company to bury wires in conduit, which he referred to as "subways," when serving parts of New York City.[609] Mary Cable, author of The Blizzard of '88 described how, post the devastating blizzard with its lingering impact on power availability, telegraph communications, and electrocution hazard, the New York City Mayor at the time, Abram Hewitt, demanded that all telegraph and electric utilities serving NYC, not just Edison, place their lines underground.[609]

Exhibit 3.1

Selected Myth-Busting – Myth 2, 3, 4, and 7

Myth	Myth-Busted
2. Underground maintenance cost far exceeds overhead maintenance cost.	The cost of underground distribution maintenance per mile is 3 to 7 times **lower** than overhead distribution maintenance.[559, 603] This reduction in maintenance is also a direct reduction in "truck rolls" yielding both a safer environment and a focus on critical/emergency needs addressed by first or second responders.
3. Underground cable fails at a faster rate than overhead cable.[531]	Innovation and problem-solving where 100-year+ cable life, submerged and directly buried, is now possible.[255, 602] Specifically, materials, manufacturing, and factory comparable quality control (QC) field testing are greatly improved allowing cable systems to live 2 to 3 times longer than wood pole-supported assets.[615] In one study, underground assets exhibit 12x fewer System Average Interruption Frequency Index (SAIFI) customer interruptions than overhead assets.[610]
4. Overhead to underground conversion programs are cost-prohibitive.[51]	Undergrounding transformations are driving costs down and performance up via materials science; construction techniques; maintenance practices; regulatory policy; and financial engineering. What is truly cost-prohibitive is the lost GDP incurred by a weather-impacted region or state while overhead line segments are down a day or days longer than necessary – Hurricane Irma estimates of $1 billion per day lost[612] in regions impacted are consistent with FL's daily GDP of $3.8 billion and by comparison, VA's daily GDP of $1.7 billion.[611]
7. Underground faults are hard to find, expensive to repair, and take longer to resolve.	The quality, performance, and field testing of modern materials are allowing cable systems to live 2 to 3 times longer than overhead assets and reducing the number of faults below that of overhead lines.[610, 615] This high-quality performance married with technology to accurately and rapidly locate faults,[608] when they do occur, and specialized keyhole or vacuum excavation technology dramatically speeds up and lowers the cost of finding and repairing any fault.

Many recent innovations cause "Strategic" undergrounding to outperform overhead lines subject to wind, snow, ice, trees or vines, and wildfires. These innovations reinforce that it doesn't matter that the installation costs of undergrounding are x number of times more costly than "overheading." What matters is how the installation costs of converting overhead to underground compare with the risks and costs of the overhead infrastructure failing and falling in extreme weather. Including the resultant disruption to the life and well-being of the local community.[607]

In Exhibit 3.2, we highlight a subset of the undergrounding innovations available to the reader today.

3.A. UTILITY UNDERGROUNDING INNOVATION & TRANSFORMATION TOOLS

Exhibit 3.2

Utility Undergrounding Innovation & Transformation Tools

Innovation in materials science, construction techniques, maintenance practices, regulatory policy, and financial engineering driving the lowest life-cycle cost path to achieve resiliency and reliability targets via "Strategic" undergrounding

Innovation	Description/Definition	Impact
Materials Science		
Semiconducting shield materials with smooth surface[559]	Specialty materials designed specifically for underground applications.	**Increased Life & Reduced Maintenance Costs**: Reduced material stress and continuous grounding to dissipate overvoltage conditions more quickly.[559]
Enhanced insulation materials	Increased cable life under both normal and adverse conditions.	**Increased Life & Reduced Maintenance Costs**: Materials testing shows significantly longer life under accelerated wet-aging conditions where cables can last 100 years,[255, 602] far beyond a 50-year wood pole life.[559]
Cable strength and material packaging	Stronger cable designs on larger reels.	**Increased Life, Reduced Maintenance Costs & Reduced Installation Cost**: "Stronger cable designs on larger reels cut civil design and construction costs by reducing the number of manholes needed, traffic control and public disruption, the number of splices and terminations, and cable handling costs."[559]
Cable joints and separable connectors	Fully submersible components.	**Increased Life & Reduced Maintenance Costs**: Fully submersible components that enable uninterrupted power distribution during storm surges and flooding – ideal for coastal and high-water table environments.[559]
Heat management	Reducing the amount of copper used with application of cross-linked polyethylene (XLPE).	**Increased Life**: Reduced copper in medium voltage, three-phase cable with concentric wire neutrals, paired with cross-linked polyethylene (XLPE) increases the maximum cable jacket temperature rating without concern that a fault on the system will overheat and damage the jacket. [559]
Extra-thick cable insulation (133% or higher)	Reducing the choice or need for extra-thick cable insulation (133% or higher).	**Material Cost**: 100% insulation levels proven to perform at over-insulated cable level with overvoltage protection via surge arresters, properly installed at transitions from overhead to underground, at multiway (three-plus) intersections, and circuit endpoints.[559]

Innovation	Description/Definition	Impact
Construction Techniques		
Specialty Installation (Shallow Trench, Direct Bury Cable)	Design/permit modifications for shallow/narrow trench; Direct bury due to high-performance materials.	**Reduced Installation Cost**: Achieved by reducing civil work, labor cost (pulling), and material cost (conduit).
Increased Horizontal Direction Drilling (Directional Boring) Use	Equipment improvement, utility locating improvement, GPS technology application on drill head, etc.	**Reduced Installation Cost**: Achieved by reducing the excavation costs associated with open trench and hand-digging excavation requirements.
High Energy (Natural Gas or Plasma fueled) Boring[604, 605] (Petra & EarthGrid)	Specialized boring techniques to place conduit in hard rock, including a tight turning radius to remain within a narrow right of way or easement.	**Reduced Installation Cost**: Achieved via more sites where underground cable can be laid without challenge or risk of blasting or breaking hard rock.
Longer Bore Run & Longer Cable Pull Back	Traditional 300 ft bore runs increased to 800, and potentially 1,500+ feet, due to equipment capability, pull tonnage, design criteria, conduit lubricants, and tension calibration.	**Reduced Installation Cost**: Achieved by reducing the number of access pits and conduit fusion/solvent or cable splicing requirements.
Straight Conduit Installation	Reduces the internal friction that limits the length of underground cable pulls.	**Reduced Installation Cost**: Achieved by reducing friction in pulling cable through a serpentine conduit run and reduces labor cost, crew time spent in the field, and equipment expenditure.
Prefabrication	Factory-made components tested in a controlled setting (precast manholes, equipment pads, duct banks, etc.).	**Reduced Installation Cost**: Prefab components reduce installation time, work rigor, simplify on-site work, and reduce highly skilled trade requirement. Savings on thermal backfill or concrete curing requirements, conduit fusion/ solvent requirements, no formwork or steel reinforcement needed, etc.[559, 607]
3D Design paired with site visualization and mapping	Dimensionally accurate 3D standards for equipment applied to geographically positioned mapping visualization using geographic information system (GIS) or similar tool.	**Reduced Installation Cost**: Allows for higher accuracy between design and site conditions where knowledge of the road, right of way, and other obstacles are defined and results in reduced installation time and cost.[559]
Range-taking shear-bolt conductor connectors	Application of range-taking shear-bolt conductor connectors versus traditional compression connectors.	**Reduced Maintenance Costs & Reduced Installation Cost**: Reduces the likelihood of common installation mistakes, especially in highly loaded circuit applications.[559]
Improved accuracy, reliability, and speed of commissioning tests	Early identification, location, and repair of performance issues via factory comparable QC test or Offline 50/60Hz PD tests with 5pC sensitivity.[615]	**Reduced Maintenance Costs & Reduced Installation Cost**: Immediate feedback to crews enables use of lower-cost, higher-risk installation techniques with confidence.

Innovation	Description/Definition	Impact
Maintenance Practices		
Advanced Sensors and Monitoring Systems[606, 607]	State-of-the-art and emerging sensors are used to monitor and locate faults underground. Examples: Power Quality Monitors, Fault Indicators, High Voltage Current Sensors, Underground Cable Fault Passage Indicators, Radar, etc.	**Reduced Maintenance Cost**: Achieved through fewer truck rolls and technician time in the field to monitor and locate a fault. Reduced risk of damaging cable performance with "thumping" fault-finding technique.
Historic performance & weather analytics for targeted segment undergrounding[607]	Use historic data (potentially 100 years in some locations) to develop in-depth models to determine where targeted undergrounding will yield the most beneficial impact on customers.[607]	**Reduced Maintenance Cost**: Achieved by analyzing historic outage data and removing at-risk segments from the potential of damage and the need for repair.
Fault finding and repair	Technology applications to accelerate fault finding and repair.	**Reduced Maintenance Cost**: The use of factory comparable QC field testing of cable-condition to extend the life by identifying weakened cable system components and directing lean work practices to only repair or replace what is necessary – in the CenterPoint Energy Inc. case study, a 98% reduction in outages was achieved.[608]
Fault avoidance or reduction	Lower the frequency of waste-producing maintenance work orders through the application of underground technologies.	**Reduced Maintenance Cost**: Federal Energy Regulatory Commission (FERC) Form 1 and U.S. Securities and Exchange Commission (SEC) 10-K filings for five geographically diverse investor-owned utilities the cost of underground distribution maintenance per mile is 3 times to 7 times lower than overhead.[559]
Regulatory Policy & Financial Engineering		
Cost treatment through a progressive rate structure	Accelerated cost recovery and long-duration cost recovery – capitalized.	**Reduced Maintenance Cost**: Multi-decade program capitalized to smooth impact on customer rates and facilitate regulatory oversight of the work (same concept applied to the modernization of electric distribution networks).[607]
Government and stakeholder-supported funding	Specialized funding sources (Federal Emergency Management Agency (FEMA) Grant, Legislative driven funding, etc.).	**Reduced Installation Cost**: Alternate sources of funding to achieve the lowest life-cycle cost and achievement of resiliency and reliability targets.[546, 599]
Restoration standards post-storm/event	Relaxation of post-storm/event standards that require repair to "original design standards" effectively precluding undergrounding.	**Reduced Maintenance Cost**: Opportunistically update assets to drive down long-term maintenance.

4. TRUE COST OF UNDERGROUNDING…TAKING THE LONG VIEW

Before addressing the true cost of undergrounding, ask the question, "Which 'quantitative' and 'qualitative' factors are driving superior cost performance of "Strategic" undergrounding on selected segments?" To simplify the question, think of the potential targeted line segments into three buckets:

1. High Undergrounding Potential: Critical customer location, areas of repetitive and historic storm-related damage and/or long restoration time, areas of increasing storm or fire-related risk, etc.
2. Undergrounding Requested/Preferred: Areas where undergrounding is "almost" economically competitive and a decision to underground is driven by qualitative factors - aesthetics, customer satisfaction, community reputation, or public relations marketing, etc.
3. Low/No Undergrounding Potential: Areas of low customer density and/or areas where repetitive weather or fire damage is not and/or will not be present.

It Is obvious that there are certain segments in which the cost of undergrounding once is clearly less than the cost of building or even maintaining overhead infrastructure given the frequency and severity of storm damage. Similarly, there are overhead segments that will remain overhead because the construction, replacement, and overall maintenance costs of undergrounding these segments will never be competitive. But there is a middle ground between where undergrounding is competitive and where undergrounding is not economically competitive yet qualitative factors may drive the decision making. To ignore or exclude these qualitative modifiers from the calculation of the true cost of undergrounding is a mistake. In short, these modifiers must be recognized and included when deciding where and when undergrounding is appropriate.

Avoided costs or risks associated with "Strategic" undergrounding include among others: lost local gross domestic product (GDP) from an outage; annual tree trimming; and outage truck rolls. Captured gains and benefits associated with "Strategic" undergrounding include among others: improved Environmental, Social, and Governance (ESG) performance; utility staff and public safety risk exposure reduction; streetscape beautification; improved quality of life for utility customers; and improved customer service perspectives. At the end of the day, however, IOU, Co-Op, or municipalities with large service territories where larger "Strategic" undergrounding programs or spend will take place, require some amount of financial justification.

Every IOU, Co-Op, or municipality is unique and their modeling of the financial justification is by definition specific to their situation, regulatory body, customers, soil conditions…the list goes on. While it is not possible to generalize in a single way in financial modeling for all IOU, Co-Op, or municipal organizations, two of the myths explored relating to how to take the long view of lowest life-cycle cost and achievement of resiliency and reliability targets where "Strategic" undergrounding is applied are detailed in Exhibit 4.1.

The first myth speaks to upfront cost and the second myth speaks to a financial justification of undergrounding. In any financial modeling based on payback, cash flow, present value, or internal rate of return, the upfront investment will be a primary driver of this modeling. This singular emphasis on upfront cost is misplaced, however, and a strong argument is made in this paper that this upfront cost is frequently overestimated and the resulting future savings and risk reduction are underestimated. There are multiple examples of investors achieving reduced upfront costs and increased improvement in reliability and resiliency. One example: "10% increase in the percentage share of underground line miles is correlated with a 14% reduction in the total annual duration of interruptions."[548] Another example that originates from Angelena D. Bohman's 2022 Ph.D. thesis[536] is focused on how to make effective investments in system resilience. A casual comparison of data presented in this paper demonstrates that FPL has implemented the most aggressive undergrounding programs in Florida ("…which increased its underground lines from 28% to 40%" [from 2006 and 2020] ...) and has achieved superior Customer Average Interruption Duration Index (CAIDI) values ("…FPL has a statistically significant CAIDI value that is on average 33.6% less…" [than other Florida utilities]).[536]

Exhibit 4.1

Selected Myth-Busting – Myth 1 and 10

Myth	Myth-Busted
1. Undergrounding is 10-15x the cost of overhead installation.[51,560]	The real cost differential in upfront cost is 2-3x for "Strategic" undergrounding efforts where the intention is to capture the lowest cost life-cycle cost and achieve resiliency and reliability targets for critical line segments. Multiple successful and PUC approved strategic underground programs, including Dominion, are coming in at the 2-3x benchmark. Dominion's Phase II SUP completed 249 miles undergrounded at an average cost of $422,496 per mile – significantly below the legislatively required maximum of $750,000.[251] Nearly every utility system will have line segments that exhibit similar cost/benefit.
10. The present value of underground vs. overhead cost to install, maintain, and repair is **not** compelling.	Dramatically reduce outage duration both modeled and achieved. • "Strategic" undergrounding modeling, the Total Length of Restoration (TLR) will be reduced by up to 40-50% and this accomplishment is achieved despite spending less than 3% of the cost of more extensive undergrounding described in the VA SCC report on undergrounding post-Hurricane Isabel.[252] • "…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 of 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."[581]

Source:
[51] Johnson, Brad, *Out of Sight, Out of Mind? A study on the costs and benefits of undergrounding overhead power lines*, Edison Electric Institute, January 2004.
[251] Commonwealth of Virginia, State Corporation Commission, Application of Virginia Electric and Power Company, Report of Deborah V. Ellenburg – Chief Hearing Examiner, November 8, 2018.
[252] Commonwealth of Virginia State Corporation Commission, Special Report of the Division of Energy Regulation, Preparation for and Response to Hurricane Isabel by Virginia's Electric Utilities, September 20, 2004.
[560] Underground Electric Transmission Lines, Public Service Commission of Wisconsin, May 2011.
[581] From Overhead to Underground: It Pays to Bury Power Lines, Federal Emergency Management Administration (FEMA), February 11, 2021.

There are a host of factors that are incorporated into establishing the "lifetime" superior performance of "Strategic" undergrounding for targeted line segments. Less traditional characteristics that are relevant to this analysis include the following:[505]

- 10x reliability and resiliency
- Capital investment - a consistent rate of return
- Stable rate base growth
- Minimal vegetation management
- 10x O&M elimination
- 6-9x safety improvement
- Technology improvement and long-life cable
- State or regional GDP/tax revenue protection
- Reinvestment of avoided maintenance and repair costs as capitalized spend

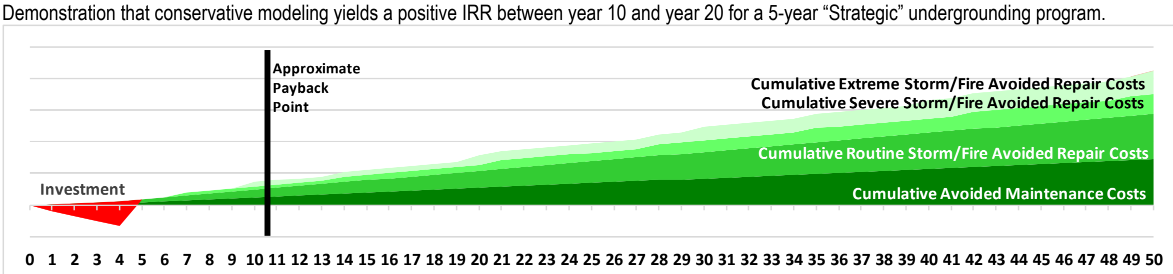
In a simplified internal rate of return (IRR) analysis looking at the avoided future costs as returns, integrating avoided annual maintenance impact, [559, 603] demonstrating accelerated recovery, repair, and replacement after routine storms, [610] and avoidance of the frequency and severity of system impact due to severe or extreme weather or fire risks [616] can yield a positive IRR over a 10-20 year timeline without the incorporation of multiple factors that will further augment and demonstrate that "Strategic" undergrounding is the source of the lowest life-cycle cost and is the path to achievement of resiliency and reliability targets. Qualitative benefits including improved ESG performance; utility staff and public safety risk exposure reduction; streetscape beautification; improved quality of life for utility customers; and improved customer service perspectives are not incorporated. Other quantitative financial factors not modeled in Exhibit 4.2 include:

- No incorporation of adjustment in rates - or return on invested capital
- No incorporation of societal benefits including GDP impact
- No incorporation of safety savings associated with lower maintenance activity
- No incorporation of inflation
- No reinvestment of maintenance savings as capital spend
- No anticipation of cable life beyond 50 years

Exhibit 4.2

Simplified IRR Analysis of Life-Time Performance of Undergrounding

Demonstration that conservative modeling yields a positive IRR between year 10 and year 20 for a 5-year "Strategic" undergrounding program.



Source: Continuum modeling of a "Strategic" undergrounding program and the resulting avoided annual maintenance impact, demonstrating accelerated recovery, repair, and replacement after routine storms, and avoidance of the frequency and severity of system impact due to severe or extreme weather or fire risks.

5. GENERATING BOARDROOM AND REGULATORY SUPPORT FOR UNDERGROUNDING

The age of "Strategic" undergrounding is here. An increasing number of stakeholder groups, councils, boards, legislators, and regulators are recognizing that "Strategic" undergrounding is a path to achieve low-cost performance (Exhibit 5.1). In addition, aesthetic desires, maintenance efficiency, vegetation management reduction, reducing outage truck rolls, reliability targets, resiliency speed improvement, or superior customer satisfaction on critical line segments are all of high value. Not mentioned previously among these traditional perspectives is the general impact on local economic conditions, which is often overlooked, yet perhaps the largest contributor to both positive and negative impact. A two-state example for Florida and Virginia demonstrates a daily GDP of $3.8 billion and $1.7 billion respectively.[611] An outage and storm recovery in specific counties and towns will rack up tens of millions, hundreds of millions, and perhaps billions in lost economic value.[612] Shaving hours or days off of this recovery due to underground assets not being impacted recaptures this potential lost benefit. An emerging factor is improved Environmental, Social, and Governance (ESG) performance that yields a utility staff and public safety risk exposure reduction, beautifies the streetscape in historically disadvantaged neighborhoods, improves the quality of life for utility customers, and can improve customer service perspectives.

In any individual utility, cooperative, or municipal setting, the challenge is determining which of these benefits is the driver for your governing body.

Exhibit 5.1

Selected Myth-Busting – Myth 5

Myth	Myth-Busted
5. Boards, councils, legislators, and regulators will not support "Strategic" undergrounding.	Approximately 90% of new subdivisions are undergrounded[549,591]; "Strategic" undergrounding programs are underway in multiple states (AL, CA, DC, FL, GA, PA, WI, and VA among others) with implementation approval from boards, councils, legislators, and regulators. An "…increase in % share of T&D lines that are underground has a statistically significant correlation with improved reliability…"[501] WEC Energy is on track to achieve 16% improvement in customer minutes interrupted (CMI) attributed to strategic undergrounding.[533]

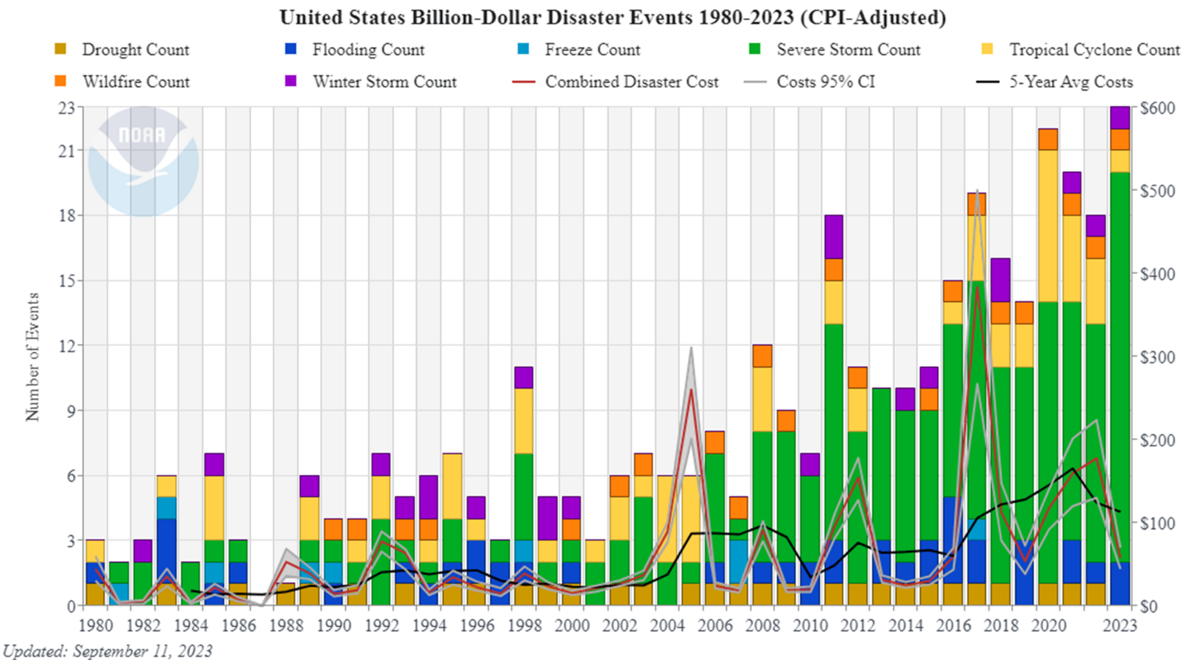
Source: [501] Hoffman, Patricia, et al, Resilient Power Grids: Strategically Undergrounding Powerlines; [533] Smalley, Michael, et al, System Modernization and Reliability Project (SMRP); [549] Mara, Kevin J., Cost-Effectiveness of Undergrounding Power Lines; [591] Underground Power Line Conversions, FPL.

While there are many reasons an IOU, Co-Op, or municipality might choose a "Strategic" undergrounding effort, the underlying driver is the avoidance of increasing frequency of highly damaging wind, snow, and ice storms in combination with increasing wildfire risk. Today, many utilities might pull potentially 100 years of historical data to develop in-depth models to determine where targeted undergrounding will yield the most beneficial impact on customers.[607] These modeling techniques, by definition, rely on linear regression, which in turn relies on a statistical assumption that history is a good predictor of the future. One researcher, the National Oceanic and Atmospheric Administration (NOAA), collected and published records going back 40 years showing how the frequency, severity, and societal cost impact of extreme weather events across the U.S. have increased over the past four decades (Exhibit 5.2). Engineers and statisticians will recognize this type of shift in the frequency and severity displayed in Exhibit 5.2 is what is euphemistically referred to as the "horn of doom" indicating that the variability in the dataset is destroying confidence that the historical data will accurately predict the future. Said another way, we can't simply use history as a guide.

Exhibit 5.2

Billion-Dollar Disaster Event Types by Year

CPI Adjusted



Source: [616] National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2023)

Obtaining approval to implement a "Strategic" undergrounding program must be built on the underlying root cause, as well as increasing frequency and severity of system damage, the financial modeling that demonstrates a reasonable investment will generate a return, and other more subjective preferences like aesthetics. Choosing the right presentation and securing approval is the most challenging undertaking, and success is not guaranteed. Crafting a clear objective and establishing the financial or ratepayer benefit from the program is critical. Traditionally, for IOUs, the path is to seek Public Utilities Commission (PUC) support. There are, however, multiple examples in Virginia, Florida, Indiana, and other states of a non-traditional approach where IOUs help to craft a legislative route to support resilience programs including both hardening and undergrounding strategies. Even more non-traditional approaches are seeking grants or funding sources through FEMA, and other governmental agencies at the federal or state level.

Public Utilities Commission (PUC)

Resiliency programs that rely on undergrounding strategies have and will continue to receive significant and inappropriate pushback, largely due to perceived high upfront cost. As pointed out previously, this focus on upfront cost is misplaced where a focus on life-cycle cost is most appropriate. Ultimately, a utility wanting to pursue these types of programs for the ratepayer benefits in satisfaction and reliability will have to pick a traditional rate case, rider/surcharge, or related approach through the PUC. Regardless, a champion of this concept at the regulatory body, in addition to city, local, or regional government support, and ratepayer communications are also required.

Legislative Path to Approval

In the case of a legislative approach, the development of preliminary legislation will require at least one, and preferably a bi-partisan group as a formal sponsor to develop and push the bill. There are examples in Florida[232], Indiana (see 2013 Senate Bill 560, and 2013 Public Law 133) and Virginia[50, 188] where a traditional PUC approach was attempted, and then legislative action was ultimately implemented.

Federal, FEMA, and State Grants

Multiple grant funding types are potentially available and applicable to undergrounding:

- Transportation Enhancements Program (Transportation Equity Act)
- Community Development Block Grants
- Federal Emergency Management Agency (FEMA) Hazard Mitigation Program[546]
- Federal Emergency Management Agency (FEMA) Building Resilient Infrastructure and Communities (BRIC)[599]
- Grid Hardening State/Tribal Formula Grant Program

PUC and Legislative Approval Process Steps

The basic steps to successfully pursue approval include the following:

1. Clarify and document a resiliency program objective, how a resiliency program can support the pursuit of the objective, and a preliminary resiliency program plan, including a description of hardening, undergrounding, or other strategies anticipated.
2. Select a preliminary path to pursue approval – PUC versus Legislative.
3. Capture and describe outage history and performance.
4. Capture and describe national weather history and demonstrate an increase in severe storm frequency and severity in your service territory.
5. Work with public affairs, rates, and communications groups within the utility to build a community outreach program to describe and position the resiliency program.
6. Identify and/or recruit champions within the PUC or legislature depending on the path chosen.
7. Build a regulatory or legislative approval approach in order to gain approval for the program and cost recovery approach. Cost recovery approaches might include:
    a. Traditional Rate Recovery
    b. Accelerated Rate Recovery
    c. Customer/Geography Specific Funding
    d. Special Tax District
    e. Utility Set Aside
    f. Federal Funding Options
        - Transportation Enhancements Program (Transportation Equity Act)
        - Community Development Block Grants
        - Federal Emergency Management Agency (FEMA) Hazard Mitigation Program
    g. Private Sector Funding
8. Clearly document and incorporate anticipated performance improvement and ratepayer benefits.
9. Clearly forecast ratepayer impacts.

The collection and display of metrics to demonstrate implementation performance and results achieved for the benefit of ratepayers is critical.

CASE STUDY – PROGRAM APPROVAL PERSEVERANCE, PEPCO[9] describes a nearly 15-year process to secure approval for a PEPCO resiliency effort structured and approved in Washington, DC. Ultimately, a severe series of storms over a 10-year period served as a catalyst to drive municipal authorities and the community to work with the utility to structure a resiliency program. Communicating why a resiliency program was appropriate, and that the costs were reasonable and prudent to the Washington, DC community was critical and part of a well-designed process.

The age of "Strategic" undergrounding, as a source of the lowest cost life-cycle cost and tool to achieve resiliency and reliability targets, is here.

CASE STUDY – PROGRAM APPROVAL PERSEVERANCE

PEPCO – (DC PLUG) What caused the delay of program approval initially in DC? Lessons learned and new approach resulting in approval.

CHALLENGE

- In 2003, PEPCO and the DC Commission first investigated the concept of undergrounding all or part of the overhead electric system. The initial 2004 study estimated approximately $4 billion to place all of its remaining above-ground lines and cables underground. The next eight years saw additional studies, including a significant 2010 study by Shaw Consulting Group, various assessments, and extended discussion on the topic, but little action. Then the 2012 derecho experienced by the Mid-Atlantic changed the focus and discussion with a more intense focus on how to structure an undergrounding program that would have a substantial impact on reliability.

SOLUTION

- After the 2012 derecho, the political machine was positively engaged when Vincent C. Gray, Mayor of DC sponsored the Power Line Undergrounding Task Force to more aggressively develop a reliability and resilience solution in collaboration with PEPCO. This focus on finding a solution was further accelerated by the January 2016 blizzard.
- In 2017, the Undergrounding Act that amended the Electric Company Infrastructure Improvement Financing Act of 2014 allowed the effort to move forward.
- By 2018, the DC PLUG program was developed, over seven years, and was designed to migrate up to 30 of the District's most vulnerable overhead distribution lines underground. Financial contributors for approximately $500 million include $250 million from PEPCO, $187.5 million from DC taxpayers, and $62.5 million from the District's Department of Transportation (DDOT).

RESULT

- After 14 years of assessments, study, discussion, and the experience of three major storm-related outages in Washington, DC over a decade, consensus was reached to move forward on a resilience, hardening, and undergrounding program to improve reliability. It took another two years for the June 2019 groundbreaking and actual construction to start.
- The DC PLUG program, a $500 million joint undertaking by the District and PEPCO, is expected to improve reliability by 95% on targeted segments against wind, ice, and snowstorms as well as falling trees.

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- William "Bill" Gausman, (Retired) SVP Strategic Initiatives, PEPCO Holdings
- Bill Sullivan, Vice President, Electric and Gas Operations, PEPCO Holdings

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