FEASIBILITY STUDY FOR UNDERGROUNDING ELECTRIC DISTRIBUTION LINES IN MASSACHUSETTS

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Acknowledgments: This report was prepared by staff at the Department of Energy Resources (DOER) with Joanna Troy serving as the primary researcher and author.

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1. Executive Summary

After the 2011 Halloween Nor'easter, many residents of Massachusetts suffered prolonged outages caused by falling trees and heavy ice and snow. The failure of the overhead electrical system caused some to question whether these sub-transmission and distribution lines should be buried underground, protected from the Massachusetts weather.[1] After the February Nor'easter of 2013, Governor Deval Patrick recognized both the high cost of underground electrical infrastructure but also the high cost of cleanup and restoration of major storms.[2] The Massachusetts Department of Energy Resources in consultation with the Department of Public Utilities was directed to complete a review of the feasibility of undergrounding the Massachusetts electrical distribution system for the investor owned utilities (IOUs) to improve reliability and storm resiliency. This report summarizes national, state, and municipal studies of undergrounding, including order of magnitude cost estimates. After a general overview of Massachusetts storm outages there is a summary of the benefits and limitations of undergrounding, which extend beyond increased reliability in storms and high cost of installation. The decision to underground an electrical line is complex, dependant on multiple site-specific factors. 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. Technological limitations may make such a large project infeasible. However, converting a targeted selection of circuits may be part of a successful storm resiliency program and worth the investment.

2. Overview of National, State, and City Investigations

Many states and municipalities have already investigated the costs and benefits of converting all or some of their overhead electrical distribution systems to underground lines. The following table includes the reports reviewed for this study. The studies are all either directly or indirectly a result of a major storm event that damaged an area's overhead electrical distribution system. Of particular interest are the reports from New York City following Superstorm Sandy, the comprehensive report "Out of Sight, Out of Mind" summarizing the national costs and benefits of undergrounding, and the reports about the planning and implementation of the current $1 billion undergrounding project in the District of Columbia.

<table>
<tr><td colspan="3">Mayor's Power Line Undergrounding Task Force</td></tr>
<tr><td>DC</td><td>2013</td><td>The final report and recommendations for a large investment in a selective undergrounding project in Washington, D.C. These findings are heavily based on the cost estimates and reliability statistics reported in the 2010 Pepco report below.</td></tr>
<tr><td colspan="3">Utilization of Underground and Overhead Power Lines in the City of New York</td></tr>
<tr><td>NYC</td><td>2013</td><td>After the Moreland report, the Mayor's Office of Long-Term Planning and Sustainability completed a more detailed analysis of the costs and benefits of undergrounding utility lines in New York City.</td></tr>
<tr><td colspan="3">Moreland Commission on Utility Storm Preparation and Response - Final Report</td></tr>
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[1] Connor Barry, "Power lines: To bury, or not to bury -- that's the question," MassLive, Nov. 22, 2011, http://www.masslive.com/news/index.ssf/2011/11/power_outage_in_hampden.html (last visited Dec. 5, 2014)

[2] "Mass. Gov. proposes underground power lines," WPRI, Feb 12, 2013, https://www.youtube.com/watch?v=EdaE9pERerE (last visited Dec. 5, 2014)

NYC	2013	This large report, completed by the Moreland Commission in response to the devastation caused by Sandy, analyzed the preparedness of utilities and municipal services.
Report of the Subcommittee on Burying Electric Utility Lines to the Chevy Chase Town Council		
Chevy Chase, MD	2013	This short report summarizes the general benefits of undergrounding to the city of Chevy Chase. A subcommittee of the Town Council completed this report and suggested engineers conduct a more in-depth study.
Out of Sight, Out of Mind 2012: An Updated Study on the Undergrounding Of Overhead Power Lines		
USA	2012	A comprehensive report done by the Edison Electric Institute (EEI, an association of all the investor owned utilities) surveying IOUs for undergrounding cost estimates and compiling publically available outage data.
Undergrounding Electric Lines		
CT	2011	A short review for the Office of Legislative Research about cost estimates and reliability of underground electric lines in response to the CT legislature reviewing an undergrounding project.
Underground Electric Transmission Lines by the Public Service Commission of Wisconsin		
WI	2011	A technical report summarizing the engineering requirements of different types of underground cables and underground cable installation.
Study of the Feasibility and Reliability of Undergrounding Electric Distribution Lines in the District of Columbia		
DC	2010	Shaw Consultants published this report detailing the cost estimates for undergrounding lines in Washington, DC.
Cost-Benefit Analysis of the Deployment of Utility Infrastructure Upgrades and Strom Hardening Programs		
TX	2009	Quanta Technology completed this report for the Public Utility Commission of Texas (PUCT), comparing the costs of undergrounding to pole and vegetation maintenance in light of recent major storm events, including Hurricane Ike.
Overhead to Underground Conversion		
NH	2008	This appendix report was included in the New Hampshire December 2008 Ice Storm Assessment Report published by NEI Electric Power Engineering which addresses the utility response to the major storm. The assessment makes a general cost estimate for undergrounding the overhead system.
Inquiry into Undergrounding Electric Facilities		
OK	2008	This report was prepared by the Oklahoma Corporation Commission Public Utility Division in response to the December 2007 Ice Storm. The Commission estimated the cost to underground their transmission and distribution systems based on the local utility's order of magnitude estimates.
Infrasource Study		
FL	2007-08	This multi-phase study included a literature review of existing undergrounding studies and case studies of undergrounding projects in Florida.
Cost-Effectiveness of Undergrounding Electric Distribution Facilities in Florida		
FL	2006	The Municipal Underground Utilities Consortium, an organization of Florida cities and towns, published this report to support undergrounding legislation.
Review of Undergrounding Policies and Practices		
NY	2005	Navigant Consulting prepared this report for the Long Island Power Authority reviewing the estimated rate impact to NY customers for an undergrounded distribution system.
Preliminary Analysis of Placing Investor-Owned Electric Utility Transmission and Distribution Facilities		
FL	2005	This report updates previous studies on the cost and benefits of undergrounding

		electrical systems as a response to an active 2004 Hurricane season.
Placement of Utility Distribution Lines Underground		
VA	2005	The Virginia General Assembly requested this report from the State Corporation Commission, which found that the cost to underground the entire distribution system to be prohibitive.
Maryland Task Force to Study Moving Overhead Utility Lines Underground		
MD	2003	The Maryland Task Force was created by law in 2002 and charged with facilitating converting the overhead lines to underground lines. The Task Force recommendations included increased storm preparedness, vegetation management, and selective undergrounding.
Statewide Undergrounding Study		
NC	2003	The North Carolina Public Utilities Commission staff completed this report to the Natural Disaster Preparedness Task Force, reviewing the engineering requirements of undergrounding and the comparative costs to an overhead system.

3. Current Massachusetts Law on Undergrounding

3.1 Chapter 166 Section 22D

Massachusetts General Law (MGL) Chapter 166 § 22D allows municipalities to pass an ordinance or by-law requiring their utility to bury existing overhead electric utility lines and the utility to recover costs by increasing rates. Although some municipalities have passed this legislation, few towns serviced by IOUs have utilized it. The rate increase, limited to 7%, does not cover the total cost of a large undergrounding project. The municipality is therefore left to cover the remainder of the upfront project cost and must work directly with the utility to coordinate construction. Some towns not served by the investor owned utilities, such as Holden and Concord, have completed undergrounding projects, likely due to the close project coordination associated with municipal electric utilities.[3]

3.2 Zoning Regulations

Without passing a by-law requiring the conversion of existing overhead electric distribution lines, many towns have met their goals for increased underground utility lines by requiring them for new construction through zoning by-laws. These regulations are usually associated either with specific zoning districts, such as a business or commercial district[4], or with a specific type of building, such as large condominiums.[5] These zoning regulations generally cover the secondary lines that connect buildings to the grid and exclude the higher voltage sub-transmission and distribution lines. There is therefore less of an impact on the overall reliability of the grid, and instead a focus on the building and neighborhood aesthetics.

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[3] http://www.massmunichoice.org/f.html

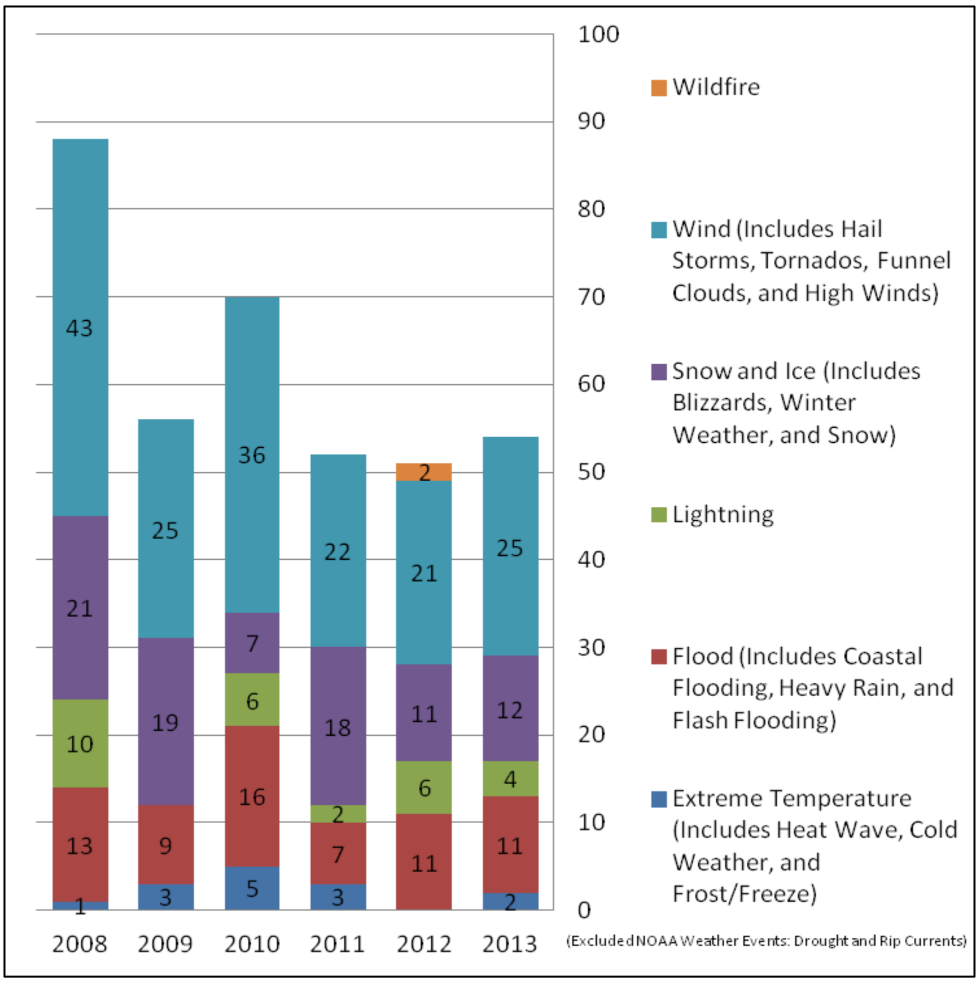
[4] For examples see Charlton zoning by-laws (http://www.townofcharlton.net/forms/ZoningBylaw2012.pdf) requiring underground on-site utilities for so-defined business enterprise districts (BED) or Leominster zoning by-laws (http://www.leominster-ma.gov/pdf/zoning-13/leominster-zoning-ordinance.pdf) requiring underground utilities on all new or redeveloped buildings in the Downtown Overlay District.

[5] For an example see Suttons zoning by-laws requiring new condominium complexes with more than 25 units be built with underground utility connections (http://www.suttonma.org/Pages/SuttonMA_Planning/Zbylaw, p. 68).

4. Storms and Adverse Weather

The Edison Electric Institute, a representative body of all the investor-owned utilities (IOUs) including those IOUs serving Massachusetts, completed a report in 2012 that surveyed utilities nationally and reviewed the benefits and costs of undergrounding utility lines.[6] Part of this report looked at storm events, which is one of the most commonly cited reasons for considering undergrounding. Using publically available data provided by the Energy Information Administration (EIA) from 2003 to 2011, the EEI found that the number of storm events causing "major system incidents" has been increasing nationally.[7] These major events are defined by major load-shedding, reduction in voltage, and other grid disturbances.

Figure 1: Days with Reported NOAA Weather Events in Massachusetts (2008-2013)



[6] Edison Electric Institute, Out of Sight, Out of Mind 2012: An Updated Study on the Undergrounding Of Overhead Power Lines, 2012
[7] *Id*. at p. 10

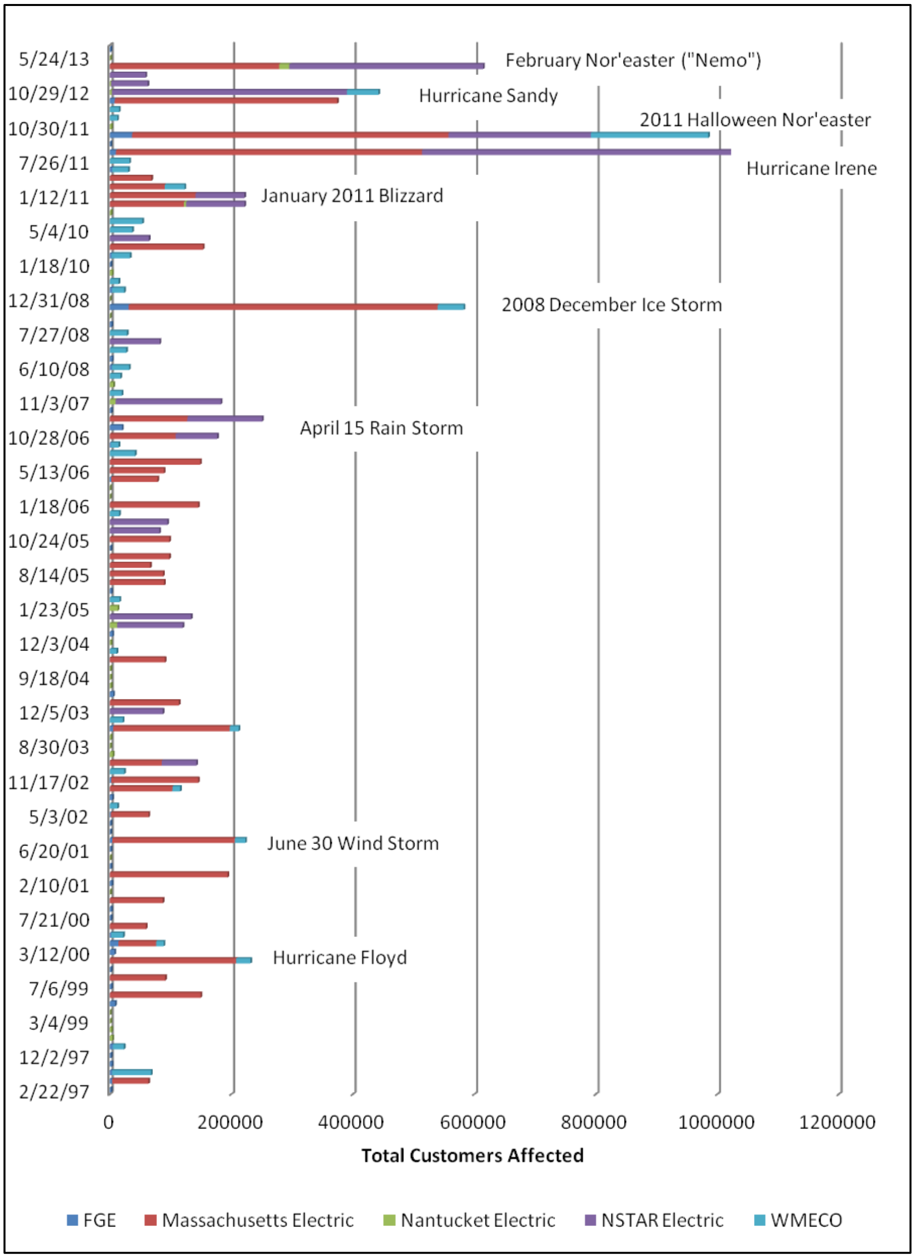


Figure 2: Major Outages in Massachusetts 1997-2012 Impacting 5% of More of Company's Service Area

Massachusetts follows a similar trend. The National Ocean and Atmospheric Administration (NOAA) publishes observed storm events through its Storm Events Database.[8] For Massachusetts, the number of days with weather events has decreased over the last 6 years from 2008-2013 as seen in Figure 1. But this count does not measure the severity of the storm event or its impact on the grid. In 2011, there were only 52 days with reported weather events, but 2011 was also one of the worst years for major outages starting with the January 2011 Blizzard, Hurricane Irene on August 28 and finishing with the 2011 Halloween Nor'easter. Figure 2, which shows outages from 1997-2013 that affected at least 5% of each IOU's service area, shows that within the last three years Massachusetts has seen a greater concentration of major storms with large customer outages. In addition to increased storm outages, Figure 3 shows that for most IOUs the percent of their customers that suffer outages for each major event has increased from 1997-2013. This means that the increase in the total number of customers seeing outages in these events cannot be attributed to an increase in population alone.

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[8] National Ocean and Atmospheric Administration Storm Events Database, http://www.ncdc.noaa.gov/stormevents/

With each major storm, regardless of the location, citizens question the reliability of overhead lines they can see breaking under the weight of fallen trees and heavy snow and ice. Most of the aforementioned reports were completed in response to specific storm events, such as Hurricane Ike and Sandy. But undergrounding a state's electrical distribution grid is a complex decision than cannot be made in response to a specific outage event. Overhead electrical lines can have lives of over 60 years and any decision to bury these lines underground requires understanding of undergrounding project construction and the implications in terms of both the frequency and duration of outages over the life of the electrical line.

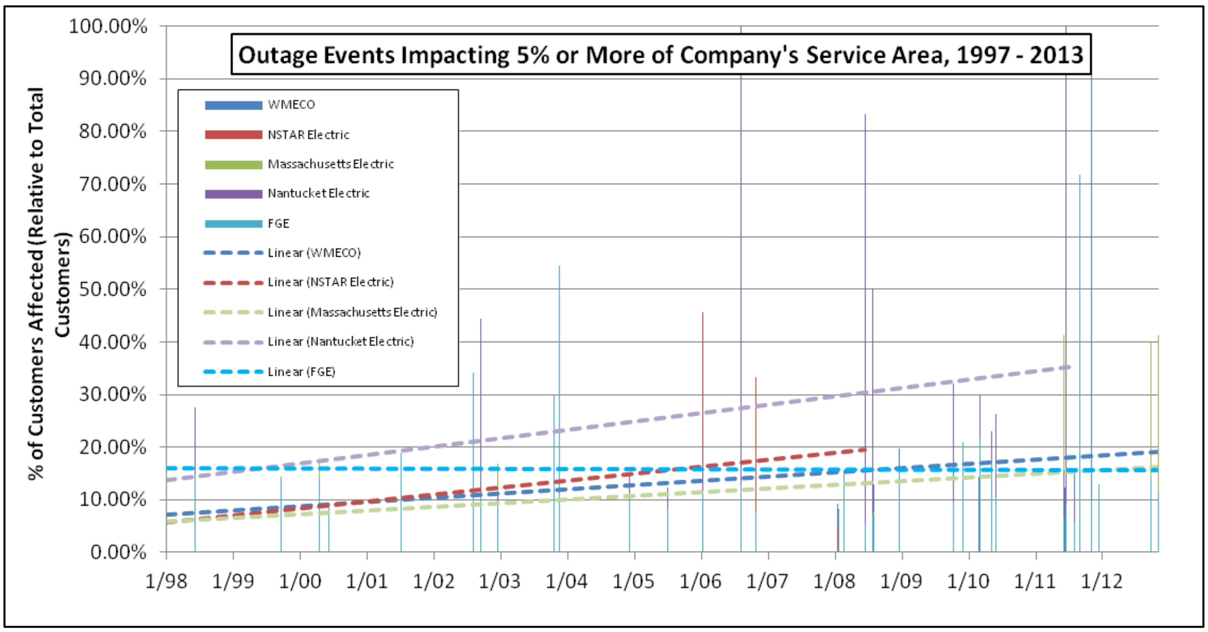


Figure 3: Major Outages in Massachusetts: Percent of Customers Affected.

From 1997 -2013, the percent of customers affected during each major outage has increased for almost all the utilities in Massachusetts

5. Benefits and Limitations of Undergrounding Electrical Lines

The following table summarizes some of the many aspects of an undergrounding project, many of which are dependent upon each other. The two most important factors, the cost of installation and the subsequent reliability improvement will be discussed in further detail below.

Benefits from Undergrounding	*Limitations to Undergrounding*
Improved reliability in wind and winter weather events	Increased cost of materials and labor
Aesthetics	Increased duration of outages because failures are difficult to locate and access[9]
Reduced vegetation management	Requires disruptive trenching
Increase in property values with underground utility connections[10]	Exposure to road salt and corrosive chemicals[11]
Can be paired with undergrounding cable and telecommunication lines[12]	Shortened line life as compared to overhead lines[13]
Can reduce cost of conversion through salvage	Increased thermal loading during heat waves and because of urban heat islands[14]
Reduced electro-magnetic fields (EMF) because steel pipe acts as shield[15]	Possible environmental damage from leaking cooling fluid[16]
Reduction in public safety risks from downed wires[17]	Higher maintenance costs[18]
Improved public relations	Susceptible to storm surges and flooding[19]
Fewer vehicle impacts with poles	Vegetation management still requires the removal of plants with possible disruptive roots
Can shorten outages duration after major storm damage	Heat buildup in above buildings and possible early seed germination[20]
Less lost commercial activity because of frequent outages	More complex and costly maintenance and repair

[9] Office of Long-Term Planning and Sustainability, Office of the Mayor. City of New York, Utilization of Underground and Overhead Power Lines in the City of New York, 2013, p. 11
[10] Al Lang and John Bickerman, Report of the Subcommittee on Burying Electric Utility Lines to the Chevy Chase Town Council ,2013, p. 4 (finding possible property increases up to $25,000)
[11] Utilization of Underground and Overhead Power Lines in the City of New York at 12
[12] Burying Electric Utility Lines to the Chevy Chase Town Council at 4
[13] Utilization of Underground and Overhead Power Lines in the City of New York at 12
[14] *Id*. at at 13
[15] Public Service of Wisconsin, Underground Electric Transmission Lines by the Public Service Commission of Wisconsin, 2011, p. 19
[16] *Id*. at at 3
[17] Oklahoma Corporation Commission Public Utility Division Staff, Inquiry into Undergrounding Electric Facilities, 2008, p. 8
[18] Underground Electric Transmission Lines by the Public Service Commission of Wisconsin at 17
[19] Utilization of Underground and Overhead Power Lines in the City of New York at 13
[20] Underground Electric Transmission Lines by the Public Service Commission of Wisconsin at 19

6. Basics of the Grid and Undergrounding Installation

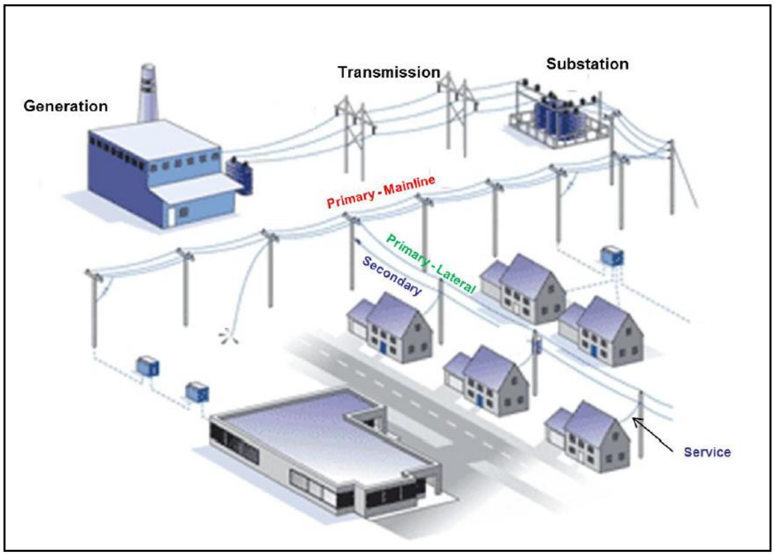


Figure 4: Transmission and Distribution Systems (from Mayor's Power Line Undergrounding Task Force, District of Columbia, p. 52)

The electric grid consists of generators, transmission lines, primary distribution circuits, secondary distribution feeders that connect the grid to buildings, and other associated infrastructure that converts voltage and maintains reliability. The high-voltage transmission lines that connect the power plants to the sub-transmission and distribution grid are often found overhead with large rights-of-way that are cleared of all trees and shrubs.[21] These high voltage lines then connect through substations to lower voltage transmission and distribution lines that may or may not be buried underground. Many people are familiar with the overhead lines often running along public streets on wooden poles but may be unfamiliar with the technology required to transmit electrical power underground.

6.1 Undergrounding Project Construction

A significant technological challenge with underground electric cables is the dissipation of the heat created by the electric circuits' thermal load.[22] Cables burdened from high loads can overheat and fail. Overhead lines are less susceptible to overheating because circulating air quickly dissipates heat. Underground lines, on the other hand, are surrounded by soil and rock, which insulates them capturing the heat. To counteract this, underground transmission and sub-transmission cables are

Figure 5: Example off Trench Construction: Massachusetts Ave, Cambridge, MA as part of NSTAR's Cambridge Reliability Project (http://nstar.watkinsstrategies.com/progress.htm)

[21] See the Occupational Health & Safety Administration (OSHA) Illustrated Glossary of Electric Power, https://www.osha.gov/SLTC/etools/electric_power/illustrated_glossary/transmission_lines.html

[22] Underground Electric Transmission Lines by the Public Service Commission of Wisconsin at 1

encased in pipe filed by pressured gas or pressured fluid that is circulated to help cool the cable.[23] Lower voltage cables, however, can rely on the thermal conductivity of the surrounding soil to dissipate their heat.

Figure 6: 138 kV Overhead to Underground Transition Structure (From Public Service Commission of Wisconsin Report, 6)

High voltage transmission lines, such as 138kV or higher, are generally not buried unless necessary (such as under water bodies or protected areas) because of the technological limitations with thermal load and line length. There are fewer of these important lines in the grid, allowing utilities to maintain more rigorous vegetation management. They are therefore significantly more reliable and likely would not benefit from undergrounding projects.

Lower voltage transmission lines can be buried along roadways, such as the 115 kV line buried in Cambridge, MA.[24] NSTAR recently completed a project installing new pipe and heat exchanger pumps along the existing line, which has three copper cables encased in a dielectric fluid filled steel pipe. These new pumps will help dissipate the thermal load and increase reliability to Cambridge customers.[25]

Figure 7: Pad-mounted residential transformers to reduce voltage from underground distribution line for end-user (from OSHA Illustrated Glossary of Electric Power)

Undergrounding project construction, such as the Cambridge Reliability Project described above, can create temporary community disruption. Most underground cables are installed by trenching. Sometimes, when there are obstructions that cannot be trenched, such as railways and water bodies, underground projects can only be completed by more complex boring or drilling.[26]

The depth and width of the trench depend on the size of the cable (which depends on the required voltage and ampacity), the substrate and its insulating properties, and obstructions (such as existing underground infrastructure). These complications vary the project's timing and cost. In addition to digging the trench in which the cables

[23] Underground Electric Transmission Lines by the Public Service Commission of Wisconsin at 2
[24] John A. Hawkinson. "The cause of MIT's major power loss," The Tech, Dec. 4, 2012, http://tech.mit.edu/V132/N58/power.html (last visited Dec.4, 2014)
[25] NSTAR, "Cambridge Cooling Line Reliability Project," http://www.nstar.com/system_improvements/cambridge.asp (last visited Dec. 4, 2014)
[26] Underground Electric Transmission Lines by the Public Service Commission of Wisconsin at 11

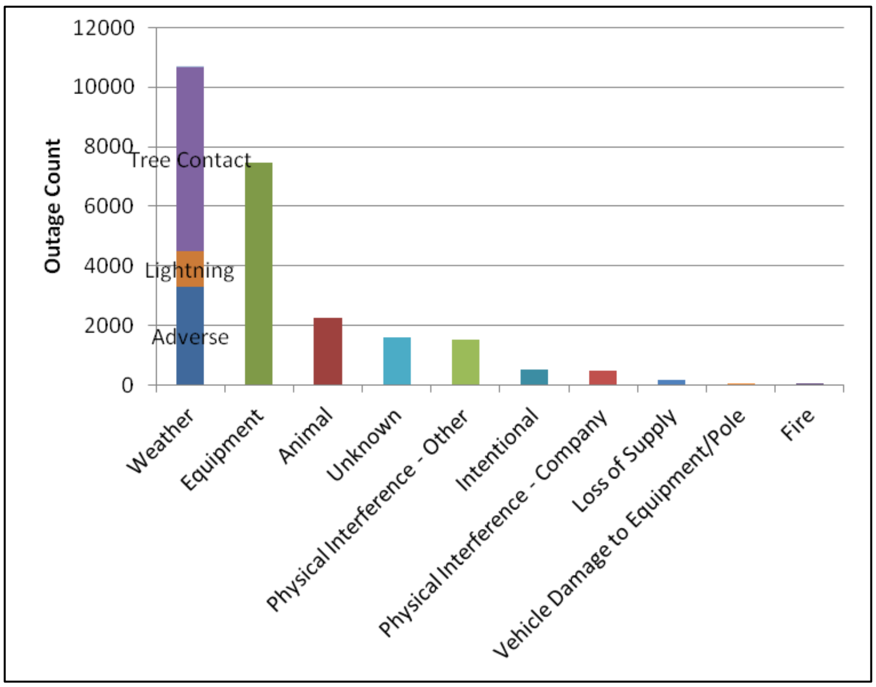
will be installed, vaults of sufficient size need to be built to allow maintenance workers to enter through manholes to inspect and repair cables.[27] At the end of an undergrounded line there are above-ground structures that connect to the overhead grid, such as transmission risers or transmission stations,[28] pumping stations, and pad-mounted transformers as needed to change voltage and connect to the rest of the distribution grid (Figure 7).

Because electrical lines are often buried along existing public streets and right-of-ways, undergrounding projects are best incorporated into plans for street improvement to reduce costs and community disturbance. This will reduce the project construction time and combine cost.

6.2 Undergrounding Reliability

Figure 8: Total Overhead and Underground Outages in Massachusetts, 2013, by Cause

From Massachusetts Department of Public Utilities Dockets 14-ERP-08 through 14-ERP-11



Reliability metrics not only measure how often a customer may experience an outage but how long it takes the utility to restore service. Common reliability metrics include the system average interruption frequency index (SAIFI, the average number of interruptions a customer can expect), the customer average interruption duration index (CAIDI, the average duration of a customer's outage in hours), and the system average interruption duration index (SAIDI, the average duration of an interruption divided by all the customers served, regardless if they experience an outage). Generally, these statistics support the assumption that underground lines reduce the frequency of outages.[29] This can be explained by Figure 8[30], which shows all the IOU reported outages, both underground and overhead, for Massachusetts in 2013. As depicted, 43% of all the outages were caused by weather, with the number one cause being tree contact, often associated with high winds. An underground line is protected from these conditions.

[27] Underground Electric Transmission Lines by the Public Service Commission of Wisconsin at 5
[28] *Id*. at 7
[29] Edison Electric Institute, Out of Sight, Out of Mind, 2012, p. 20
[30] See Massachusetts Department of Public Utilities Dockets 14-ERP-08 through 14-ERP-11 http://web1.env.state.ma.us/DPU/FileRoom/dockets/bynumber

Although reliability data shows that outages are less frequent with underground lines, burying a line does not eliminate the danger of an outage in general, or from adverse weather. While many of the outages in 2013 were caused by tree contact, 30% were caused by general equipment failure, unrelated to any weather events.

Figure 9: Massachusetts Outages 2013: Overhead Outages due to Adverse Weather

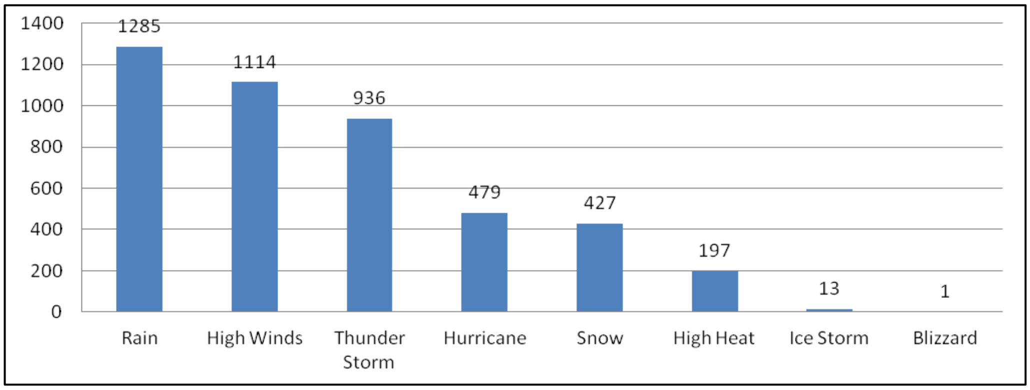
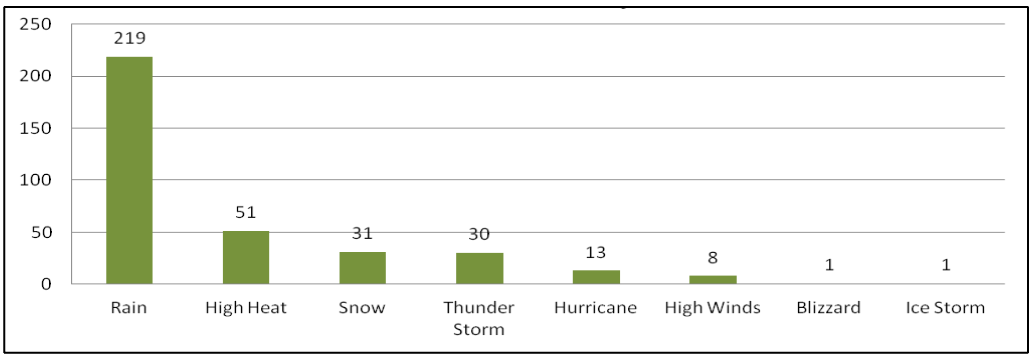


Figure 10: Massachusetts Outages 2013: Underground Outages due to Adverse Weather



Underground lines are still susceptible to equipment failure and, as discussed below, the complexity of their equipment can add to reliability issues.

Figures 9 and 10 show that both overhead and underground lines are most susceptible to rain events that can cause both downed trees and flooding.[31] Where overhead lines are susceptible to high winds, underground lines are susceptible to high heat, related to the difficulty cooling underground cable's thermal loads. While snow and ice may not weigh down underground cables, road salt and other chemicals used on overlying roads can seep into the ground and lead to equipment failure and shortened line life.[32] Because underground lines are connected to overhead transmission and feeders, failures in other parts of the grid can mean users supplied by functioning underground lines still experience outages. Undergrounding an electrical line may decrease the frequency of outages, especially during times of adverse weather, but it will not insulate a customer from all outages.

Although underground lines experience fewer outages, the duration of an outage may increase because of the difficulty locating and repairing faulted devices.[33] In order to repair an underground line, the utility must first locate the cause of the outage. Unlike with overhead lines that are completely visible,

[31] See Dockets 14-ERP-08 through 14-ERP-11
[32] Utilization of Underground and Overhead Power Lines in the City of New York at 12
[33] *Id*. at 11

locating an underground line failure can be technically difficult and requires more time. Additionally, if the issue is located with a substation, a maintenance worker must enter a vault through a man hole. If the issue is with the line itself, the maintenance worker must pull the cable out of the ground and its protective casing until the fault is found. Further, excessive snowfall can block access to underground vaults and increase the duration of an outage.

Table 1: Reliability Metrics Comparing the Primarily Underground Con-Edison System of New York City to Primarily Overhead New York State Systems

(does not include outages from major storm events)

	2012		5 Year Average	
	SAIFI	CAIDI	SAIFI	CAIDI
	Frequency	Duration	Frequency	Duration
Con Edison Non-Network (partial underground system)	0.36	2.02	0.4	1.93
Con Edison Network (predominately underground)	0.012	6.33	0.02	6.28
Con Edison System Wide (both network and non-network)	0.1	2.39	0.12	2.44
All NYS electric utilities except Con Edison (predominately overhead)	0.85	1.87	0.9	1.84

The best examples of studying underground utility reliability were those of Superstorm Sandy's aftermath in New York City. After Sandy, the Mayor's Office of Long Term Planning and Sustainability for New York City looked at the reliability statistics for both their overhead and underground utilities. New York City, with its dense population, has a predominately underground transmission and distribution

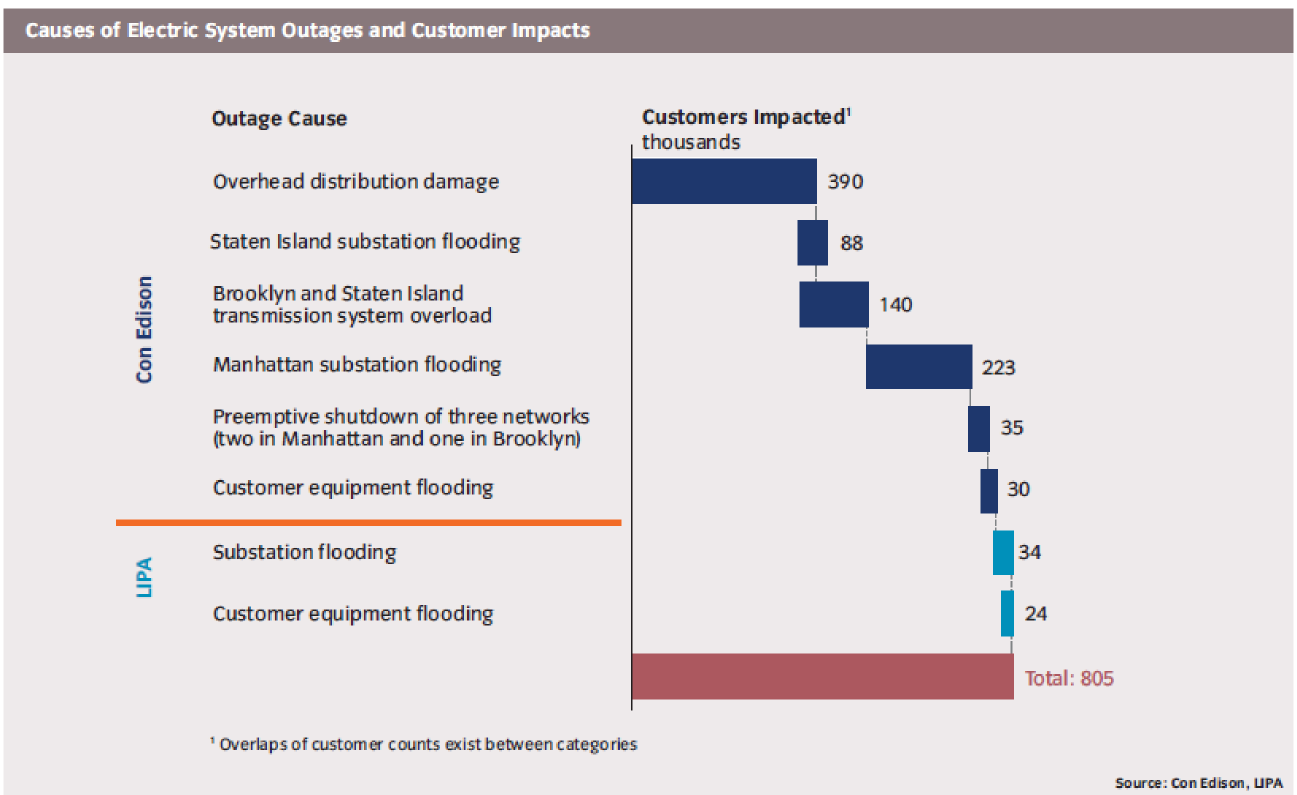


Figure 10: The total outages in New York City during Sandy, separated by causation. (from PlaNYC, "A Stronger, More Resilient New York, 2013, p. 115)

system, while the rest of New York State maintains an overhead grid. When comparing the reliability metrics in normal weather of the underground grid of the Con Edison network to all other New York State utilities, Con Edison network averaged over a 5-year period a SAIFI of .02 while New York State averaged .90 (Table 1).[34] Con Edison network customers average a significantly lower frequency of outages. But the Con Edison network averaged a CAIDI of 6.28 hours compared to New York State's 1.84 hours meaning that the average Con Edison network customer outage lasted almost three times longer. But these statistics represented the system reliability with storm events removed.[35] The performance of the grid was more complex during and following the devastation of Sandy.

A significant portion of the electrical system damage in New York City happened when underground substations connecting the transmission and distribution systems were flooded. Figure 10 shows the number of customers that suffered outages in NYC during Sandy and their causation.[36] While almost half of the outages were caused by overhead line failure, customers affected by unexpected substation flooding experienced more significant outage durations. Figure 11 shows the percent of customers still without power 1, 4, 9, 13, and 17 days after the super storm passed.[37] All those customers with overhead line damage had service returned by day 17 after the storm while those who had suffered outages caused by underground equipment flooding were still without power. Within the city of New York, the overhead outage duration was significantly shorter than across New York State. Sandy's devastation in the rest of the State to the overhead electrical system was so significant that it was not back in service until after New York City had regained service.[38] Understanding a system's reliability during a major storm event is harder to predict but is important to consider.

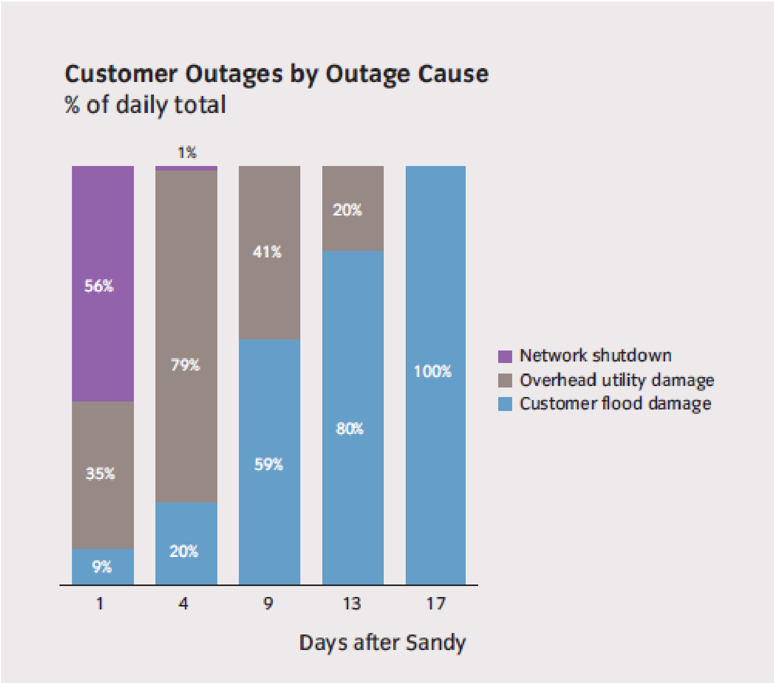


Figure 11: Days after Sandy Customer Outage Percents (from PlaNYC, A Stronger, More Resilient New York, 2013, p. 115)

[34] Utilization of Underground and Overhead Power Lines in the City of New York at 12
[35] *Id*. at 12
[36] PlaNYC, A Stronger, More Resilient New York, Office of the Mayor Michael Bloomberg, 2013, p. 115
[37] A Stronger, More Resilient New York at 115
[38] Utilization of Underground and Overhead Power Lines in the City of New York at 13

7. Costs of Undergrounding

7.1 Previous Review Estimates

The most significant limitation to large undergrounding projects is cost. The cost is much greater than a similar overhead project, sometimes by a factor of 5-10,[39] and can vary widely based on location. The following factors influence the cost of an undergrounding project:

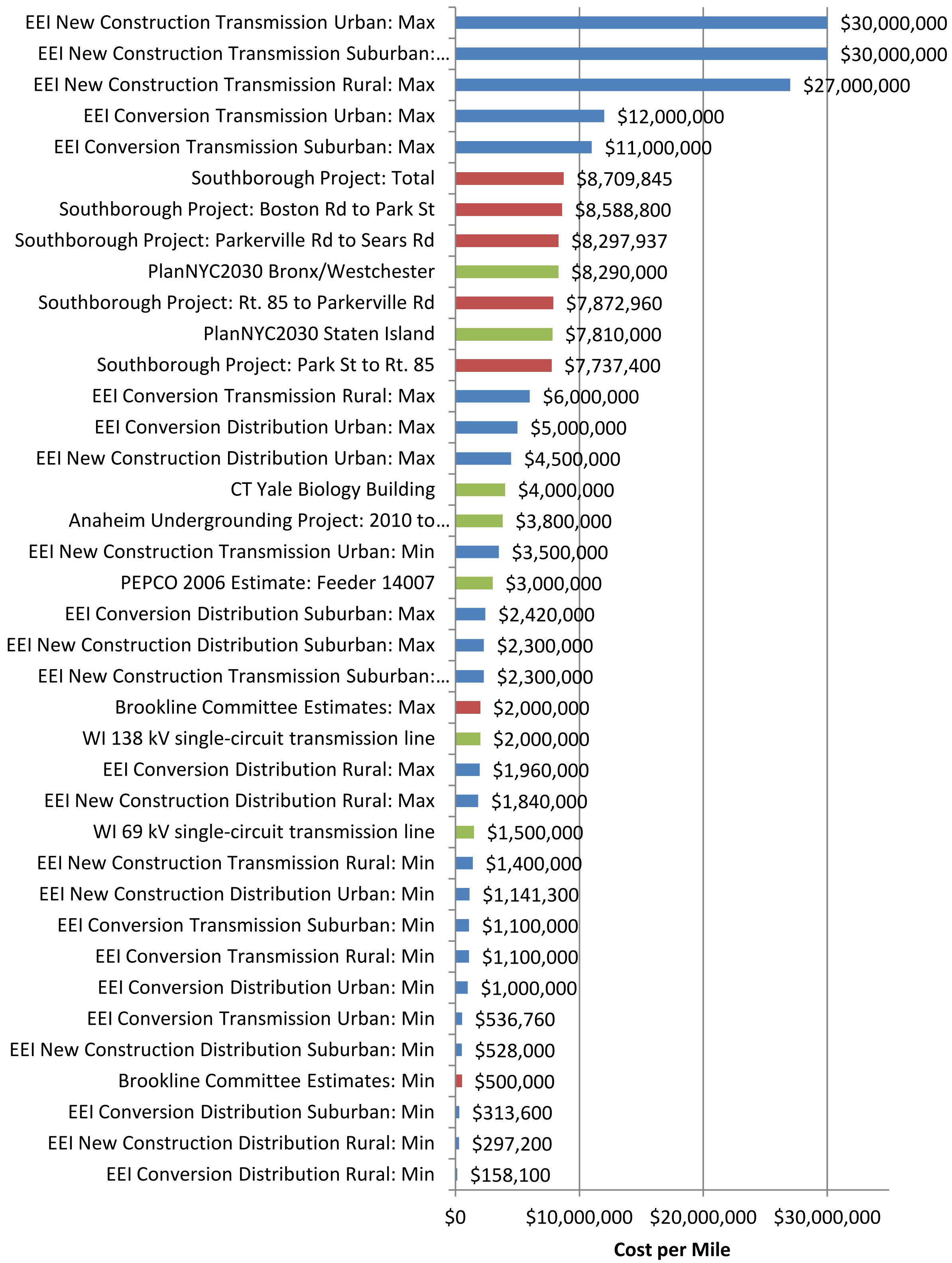
- Soil type
  - The heat insulating properties
  - The ease of excavating
- Frost line and groundwater depths
- Obstructions
  - Flat ground versus hills
  - Rivers and other water bodies
  - Existing infrastructure
  - Protected areas
- Population density and existing buildings
- Obtaining right-of-ways
- Disruption of commercial activities
- Line voltage
- Number and type of cables
- Project engineering plans
  - Spacing of vaults
  - Size of vault required to access cables
  - Equipment required to connect project to grid
  - Radial or loop system design
- Expected weather disturbances (e.g. coastal flooding)
- Construction costs and labor
- Materials
- Replacing meters in buildings
- Conversion from overhead versus new construction
- Concurrent road development
- Condition of existing infrastructure, including gas and water lines
- Drainage design
- Street Lights
- Telecommunication lines

This list is not comprehensive but meant to demonstrate how estimating the cost of an undergrounding project requires knowledge of the line locations and the engineering aspects of the projects. Many states and cities have attempted to estimate the cost per mile of an underground line. The following

[39] Out of Sight, Out of Mind at 31

table, “Underground Cost Estimates from Various Reports,” (Table 2) shows just some of the estimates that reports have developed. These estimates have not been altered for inflation, with most estimates from the 2012 EEI study but also including estimates from the 2010 D.C. report and the 2013 PlanNYC study. They represent both averages for states and specific projects, all presented by cost per mile. They also represent mainly conversion projects but also some new construction estimates. For conversion projects, there will be some reduction in cost based on salvaging the existing overhead line but there will also be stranded costs associated with lost investment from removing a line before the end of its life. For new construction projects, the cost estimates would need to be compared to overhead line estimates which are generally significantly less. These costs are the cost borne by the utility and do not include the cost to towns and other utilities, such as telecommunication companies.

Table 2: Underground Cost Estimates from Various Reports



7.2 Cost Allocation

One of the most challenging aspects of project costs is cost allocation. Utilities may be responsible for construction but they are not responsible for covering the entire project cost. Total project costs also include landowner costs to connect to the new updated system, town costs to replace lights and move water and sewage lines, and costs for other utilities, for example, telecommunications utilities, to underground their own lines. Electrical utilities recover their debt by increasing the rates of customers who benefited from the project. Which customers are required to pay the increased rate is determined by which customers are affected but can be decided by law. For example, with the current DC undergrounding project discussed below, low income customers are exempt from increased rates and commercial and residential customers have separate rate increases.[40]

In Massachusetts, MGL Chap. 166 § 22D allows for rate increases but only up to 7%, which would not be enough to cover the cost of a whole undergrounding project. In fact, covering the cost of these projects only through rate increases would be prohibitive for most customers. New Hampshire's report on the December 2008 Ice Storm included cost estimates for converting the entire overhead sub-transmission and distribution system and estimated an increase of between $434-907/month on the average customers electricity bill assuming 40 years to repay the cost of the project .[41] Assuming a conservative cost estimate of $3 million dollars per mile and assuming that only the primary distribution network for the Massachusetts IOUs would be placed underground, the average customer bill increase would be between $40-100 a month. This also assumes a 40-year payback period and does not include any inflation, additional costs to the homeowner, increased maintenance costs, or reduced line life. In this scenario, all transmission lines would remain overhead.

Table 3: Rough Estimate of a Monthly Bill Increase to Underground Primary Overhead Distribution Lines in Massachusetts. Calculation assumes all lines will require a $3 million per mile investment and the debt will be paid back over 40 years. Line length estimates provided by utilities.

	National Grid	NSTAR	WMECo	Unitil
Primary Overhead Distribution Circuits (miles)	13,210	8,000	3,416	410
Customers Served (2012)	1,277,574	1,163,135	212,728	29,000
Estimate cost per mile for Conversion	$ 3 Million	$ 3 Million	$ 3 Million	$ 3 Million
Total Cost of Conversion	$39.630 Billion	$24 Billion	$10.248 Billion	$1.230 Billion
Cost per Average Customer	$31,000	$21,000	$48,000	$42,000
Monthly Bill Increase for Average Massachusetts Customer for 40-Years	$65	$43	$100	$88

[40] Government of the District of Columbia, Mayor's Power Line Undergrounding Task Force, 2013, p. 12
[41] NEI Electric Power Engineering, Appendix B: Overhead to Underground Conversion, 2008, p. B-13

Part of the EEI 2012 study surveyed customers to determine how much they would be willing to pay as a rate increase for undergrounding their electric lines. The study separated their results based on region and whether the customer was located in a rural or urban area. For the northeast, the EEI found that over 35% of people would be willing to spend up to 10% more on their monthly bill, but less than 10% would pay more than 21%. In rural areas, 40% of people responded they would be unwilling to increase their monthly bill at all. Because the cost of undergrounding in rural areas is spread over so few, rural customers may be the ones to see the greatest monthly bill increase.

As part of a study investigating a large redevelopment project in Bridgewater, MA, consultants interviewed residents about paying for underground utilities. 34% of residents stated they would not want to pay for undergrounding while only 14% said they would.[42] Generally, when faced with a significant increase to their monthly electricity bill, customers are unwilling to fully support a total undergrounding project.

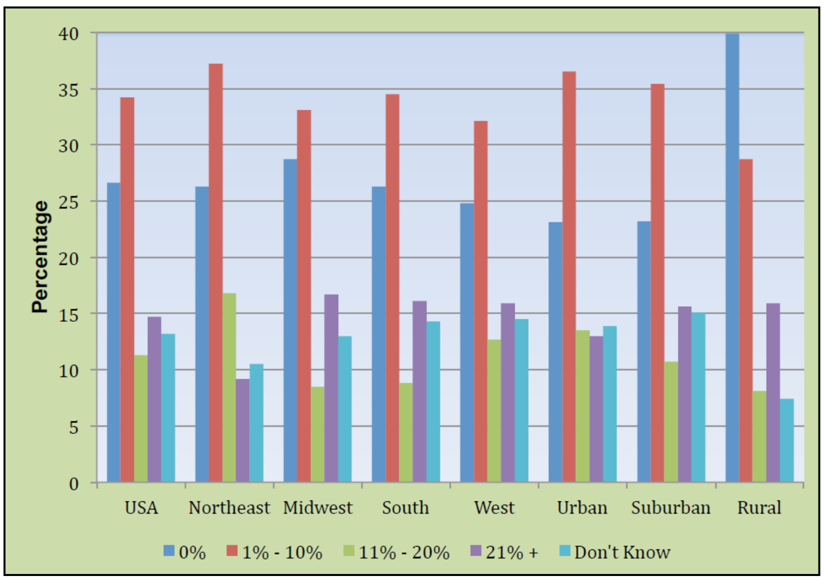


Figure 12: Percent of Survey Respondents (from Out of Sight, Out of Mind, p.3)

This survey asked each respondent to choose how much they were willing to allow their monthly electricity bill to increase in order to cover an undergrounding project. The results are separated by region and by rural/suburban/urban divisions.

7.3 PEPCO and DC P.L.U.G. – Undergrounding D.C.

Following the Mayor's Power Line Undergrounding Task Force report recommendations in 2013[43] the Council of the District of Columbia passed the Electric Company Infrastructure Improvement Financing Act of 2014.[44] This legislation allowed DC to secure $375 million in bonds, adding up to $125 million in Department of Transportation funding. PEPCO, the utility that services the D.C. customers, is also required to match D.C.'s $500 million investment and will recoup their investment with raised utility rates, with the average residential customer seeing a monthly increase of $3.25.[45] The Public Service Commission approved the financing plan on November 12, 2014 and the project, now called D.C. Power Line Undergrounding or DC PLUG, will move forward.

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[42] The Cecil Group and Nelson\Nygaard, Bridgewater Downtown Community Development Master Plan, 2014, p. 66

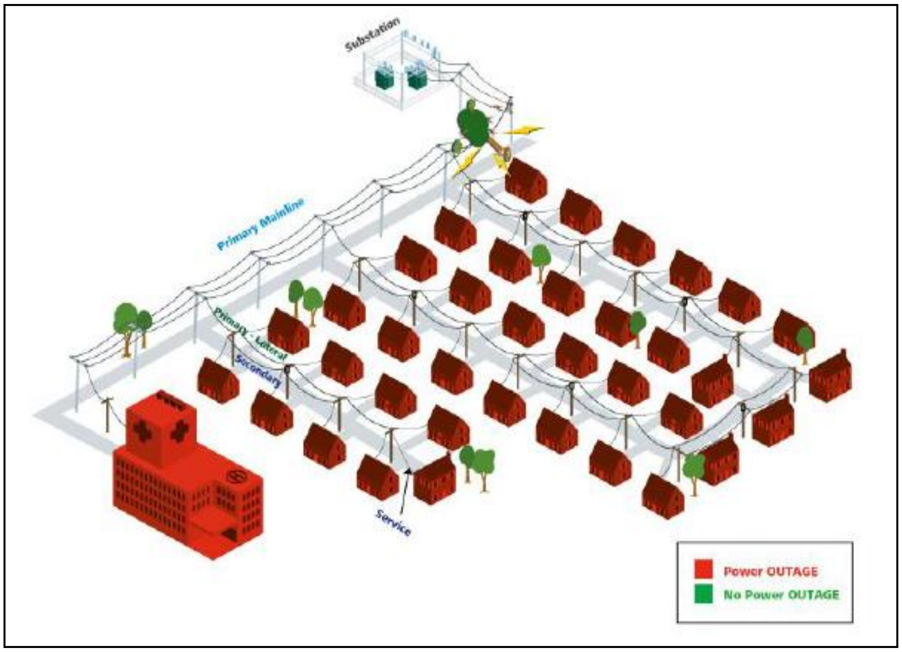
[43] Mayor's Power Line Undergrounding Task Force

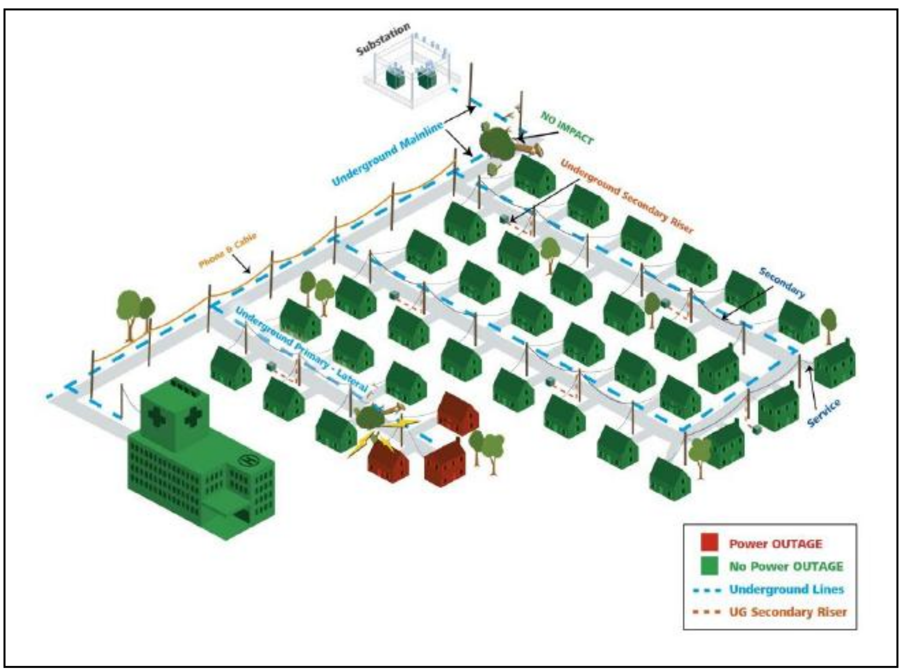
[44] See www.pepco.com/dcplug/

[45] Mayor's Power Line Undergrounding Task Force at 86

Figure 13: Existing and Proposed DC Distribution Grids (Mayor's Task Force Report, p. 57)

On the left, with overhead primary distribution lines, the tree contact at the entrance to the neighborhood caused outages at all the homes. On the right, after the proposed undergrounding of the primary distribution lines, the same tree falling does not cause any outages. Outages can still be caused by a tree falling on the secondary distribution lines connecting homes to the grid, which will remain overhead. Here though, only three homes will experience outages instead of the whole neighborhood.





The project closely follows the task force's recommendations and is based on PEPCO's findings in the Shaw Consultants' Underground Feasibility report.[46] Instead of starting with the cost estimate to bury all the electrical lines, the DC PLUG project has set aside a $1 billion investment and engineers have determined which would be the best lines to bury to have the greatest reliability impact. Engineers have looked at the 5 year reliability performance of the DC electrical grid and found that focusing work on the primary distribution lines would have the greatest impact on the greatest number of customers.[47] Undergrounding the electrical line would be the last resort when other reliability improvement measures, such as increased vegetation

[46] Study of the Feasibility and Reliability of Undergrounding Electric Distribution Lines in the District of Columbia
[47] Shaw report, 4

management and updating the lines with additional circuits or advanced technologies, do not work.[48] The targeted scenario proposed by the task force, undergrounding only the primary and lateral distribution lines, would require a $3 billion investment but would result in an expected reduction in outage frequency of 97%.[49] Because the investment has been limited to $1 billion, each overhead primary distribution feeder has been ranked based on multiple factors, including reliability statistics, customers served, and other possible reliability improvement measures.[50]

7.4 Massachusetts Project Estimates

Massachusetts communities have investigated the costs and benefits to underground some or all of the town's electrical systems. Peter Ditto, the town engineer for Brookline, Massachusetts, produced a report for Town Meeting in 2004 after a subcommittee had expressed a desire to bury the Brookline distribution grid. After a cost estimate of $500,000 - $2 million per line and the prospect of requiring an increase to customers' monthly bills, the town decided not to pursue any undergrounding projects.

The town of Southborough retained VBH Consultants in 2011 to investigate the specific costs with undergrounding a less than 1-mile stretch of overhead line by Main Street (Route 30).[51] The request coincided with the MassDOT Main Street (Route 30) Reconstruction Project, which was to include sidewalk reconstruction and minor street widening. The numbers VBH published and seen below (Table 4) are based on responses from some utilities for order of magnitude cost estimates. [52] These cost estimates are not meant to be actual project costs but demonstrate the many stakeholders of an undergrounding project.

An underground project involves more parties than just the town and the utilities. The below cost estimates are a great example of how many different costs are associated with an entire undergrounding project. While most of the cost estimates from the national and state reports are estimates about how much cost the utilities will incur, the VBH Southborough report shows how other parties may be affected by the project. The poles used to support the overhead electrical lines are sometimes owned by the telecommunication companies. If removing these poles is part of the project for aesthetic reasons, the telecommunication lines must also be buried. Many of the poles also support the town's street light system. For this Southborough project, the estimate includes the cost of installing new light poles and LED lights. The town is also responsible for moving any water and gas lines that might interfere with the required duct-bank construction and must pay for the project coordination.

Depending on how the project is funded, private landowner(s) may be required to pay to connect their homes and businesses to the grid. If a Massachusetts town passes a MGL Chap. 166 § 22D bylaw, the utilities are required to install service at least 50 feet into private property, but it is up to the private

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[48] Mayor's Power Line Undergrounding Task Force at 36
[49] *Id*. at 55
[50] *Id*. at 59
[51] VBH Consultants, Main Street/Route 30 Utility Undergrounding Feasibility Study, 2011, p. 1, http://www.southboroughtown.com/dpw/dpw/Underground%20Feasibility%20Study.pdf
[52] Main Street/Route 30 Utility Undergrounding Feasibility Study, at 7-9

land owner to cover the cost of any additional line required.[53] If the town does not choose to pass the bylaw, the cost of connecting to the distribution line will be the sole responsibility of the land owner.

Table 4: Cost Estimates from VBH Consultants to Underground a Nearly 1-Mile Section of Overhead Line in Southborough, Massachusetts

This table shows the many parties that contribute to the cost of an undergrounding project. The second table shows the cost to the town and landowners. The final column shows the total cost per mile for the whole project, not just for the electrical utility.

Cost to Utilities							
Roadway Segments	**Length (FT)**	**National Grid**	**Verizon**	**Charter**	**Lightower**	**Verizon Business**	**Total Cost**
Boston Rd to Park St	450	$437,000	$112,000	$112,000	N/A	N/A	*$661,000*
Park St to Rt. 85	1,200	$1,086,000	$245,000	$245,000	N/A	N/A	*$1,580,000*
Rt. 85 to Parkerville Rd	2,750	$2,488,000	$561,000	$561,000	$40,000	N/A	*$3,650,000*
Parkerville Rd to Sears Rd	950	$859,000	$194,000	$194,000	N/A	$25,000	*$1,280,000*
Total	*4,900*	*$4,870,000*	*$1,112,000*	*$1,112,000*	*$40,000*	*$25,000*	*$7,170,000*

Cost to Town and Landowners						Total Project Cost	
Roadway Segments	Lights	Water Line	Gas Line	Total	Landowner Cost	Total Project Cost	Cost per Mile
Boston Rd to Park St	$56,000	$5,000	$10,000	$71,000	$0	$732,000	*$8,588,800*
Park St to Rt. 85	$141,500	$10,000	$20,000	$171,500	$7,000	$1,758,500	*$7,737,400*
Rt. 85 to Parkerville Rd	$328,500	$15,000	$30,000	$373,500	$77,000	$4,100,500	*$7,872,960*
Parkerville Rd to Sears Rd	$113,000	$10,000	$20,000	$143,000	$70,000	$1,493,000	*$8,297,937*
Total	*$639,000*	*$40,000*	*$80,000*	*$759,000*	*$154,000*	*$8,083,000*	*$8,709,845*

8. Conclusions and Recommendations

Both general reviews and specific project estimates, such as the DC PLUG and Southborough Route 30 projects, show that undergrounding is a site specific choice. While undergrounding the entire grid may be cost prohibitive, as well as technically difficult and unnecessary to improve reliability, there may be specific lines that are good candidates for undergrounding. To determine which lines would be best buried, utilities should follow a ranking system similar to PEPCO DC PLUG project. These would be the lines that serve a significant amount of customers and have reliability issues that are not solved by cheaper measures such as increased vegetation management. Even when undergrounding would improve reliability, utilities should first try more aggressive tree trimming or advanced technologies to not increase customers' monthly electricity bills.

Understanding the benefits and limitations of undergrounding as a part of storm resiliency is a more complex issue, especially when considering the effects of the Sandy storm surge on New York City's

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[53] See MGL Chap. 166 §22H; Main Street/Route 30 Utility Undergrounding Feasibility Study at 9

underground substations. One of the most difficult aspects of predicting the benefit of an undergrounded line is determining the cost avoided. The cost of a failure, especially during a large weather event, is not limited to the cost of repair and replacement but loss of business and risk of public safety. There have been reports that attempted to determine the cost of a prolonged storm outage and the probability a major storm will damage a particular line.[55] This type of study exceeds the scope of this review but may prove beneficial to understanding where a large undergrounding investment may still be feasible.

Undergrounding should only be one part of a larger policy to improve storm resiliency. There are many alternative technologies and grid modifications that can help to prevent and reduce the frequency and duration of outages. The Department of Energy Resources (DOER) already considers many of these alternatives such as distributed generation using solar panels and storage, and micro grids connecting small communities.[56] DOER should continue to incentivize these alternatives as long as they remain a reasonable financial decision as compared to undergrounding.

[55] *See* Quanta Technology, Cost-Benefit Analysis of the Deployment of Utility Infrastructure Upgrades and Storm Hardening Programs, 2009.
[56] *See* "Community Clean Energy Resiliency, " http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/resiliency-initiative.html (last visited Dec 5, 2014)