Undergrounding Assessment Phase 1 Final Report:

Literature Review and Analysis of Electric Distribution Overhead to Underground Conversion

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Executive Summary

The conversion of overhead electric power distribution facilities to underground has been a topic of discussion in Florida for more than twenty years. The topic has been studied, discussed, and debated many times at the state, municipal, and local levels. Overhead construction is the standard in Florida, but all investor-owned utilities are required to have a process where customers can opt to underground existing overhead service by paying the incremental cost. For municipals and cooperatives, the decision to underground is left to local citizen boards.

This report presents the results of a review of relevant previous undergrounding studies done in Florida as well as literature on the subject from throughout the US and around the world. This review finds that the conversion of overhead electric distribution systems to underground is costly, and these costs are far in excess of the quantifiable benefits presented in existing studies, except in rare cases where the facilities provide particularly high reliability gains or otherwise have a higher than average impact on community goals.

This conclusion is reached consistently in many reports, which almost universally compare the initial cost of undergrounding to the expected quantifiable benefits. No prior cost benefit study recommends broad-based undergrounding, but several recommend targeted undergrounding to achieve specific community goals.

All numbers quoted throughout this report appear in one or more of the reports cited.[1]

Undergrounding is Expensive

As a rough estimate, the cost of converting existing overhead electric distribution lines and equipments to underground is expected to average about $1 million per mile. In addition there are costs required to convert individual home and business owner electric service and meter facilities so they will be compatible with the new underground system now providing them with electricity. Further, there are separate, additional costs associated with site restoration and placing third-party attachments underground.

When only considering the direct utility cost of a conversion from overhead to underground, studies find that undergrounding distribution facilities in residential neighborhoods served by investor-owned utilities in Florida would cost an average of about $2,500 per residential customer affected. Undergrounding residential main-trunk feeders (those lines leading to residential neighborhoods) throughout Florida would cost an average of about $11,000 per residential customer affected. Undergrounding all main trunk commercial feeders (those feeding business and office areas, etc.) in Florida would cost an average of about $37,000 per commercial customer affected.

Costs in any particular situation could vary widely from these estimates depending upon electric system design, construction standards, customer density, local terrain, construction access issues, building type, and service type. Existing studies estimate the wholesale conversion of overhead electric distribution system to underground would require that electricity rates increase to approximately double their current level, or possibly more in areas with a particularly low customer density.

[1] References are intentionally left out of this Executive Summary. They are included throughout the main body of the report.

Further Costs Must Be Incurred to Obtain Complete Aesthetic Benefits

Nearly every study and examination of overhead to underground conversion notes in some manner that removing the poles, overhead lines and equipment, and in some cases above-ground facilities required for the overhead utilities will improve the visual appeal – the aesthetics – of an area, be it residential or commercial property. Opinions and analytical studies of the value of this aesthetic improvement differ widely as to results, but no studies examined in this report conclude that aesthetics had a *quantifiable* monetary benefit that substantially affected the overall benefit-to-cost ratio for the conversion.

Regardless, there is no doubt that some municipal governments, developers, businesses, and homeowners value the aesthetic improvement brought about by undergrounding of utilities very highly. This is evident because some choose pay the cost differential for underground service themselves (for new construction).

The electric system conversion costs discussed above would *not* always provide aesthetic improvement without additional expenses to convert third-party utilities such as telephone and cable television to underground. The costs necessary to relocate all remaining utilities underground is most often estimated at somewhere between 10% and 30% beyond the cost of the electric conversion.

Undergrounding Provides a Number of Benefits

In return for the considerable expense, electric customers can receive a number of potential benefits from the undergrounding of their overhead systems. The following is a list of benefits most often mentioned in undergrounding reports and studies:

Potential Benefits of Underground Electric Facilities

- Improved aesthetics;
- Lower tree trimming cost;
- Lower storm damage and restoration cost;
- Fewer motor vehicle accidents;
- Reduced live-wire contact;
- Fewer outages during normal weather;
- Far fewer momentary interruptions;
- Improved utility relations regarding tree trimming;
- Fewer structures impacting sidewalks.

Underground Has a Number of Potential Disadvantages

There are a number of potential disadvantages which need to be considered whenever the conversion of overhead facilities to underground is evaluated. The following is a list of potential disadvantages most often mentioned in undergrounding reports and studies:

Potential Disadvantages of Underground Electric Facilities

- Stranded asset cost for existing overhead facilities;
- Environmental damage including soil erosion, and disruption of ecologically-sensitive habitat;
- Utility employee work hazards during vault and manhole inspections;
- Increased exposure to dig-ins;
- Longer duration interruptions and more customers impacted per outage;
- Susceptibility to flooding, storm surges, and damage during post-storm cleanup;
- Reduced flexibility for both operations and system expansion;
- Reduced life expectancy
- Higher maintenance and operating costs;
- Higher cost for new data bandwidth.

Financing Options

The reports and references reviewed in this report all conclude that undergrounding incurs a very substantial additional cost compared to that for overhead distribution, even as they differed on what that cost was and how much of it was justified based on the benefits obtained. Ultimately, those undergrounding costs must be paid if the conversion is to be done. There are many funding options to cover these costs, and selecting the most appropriate financing approach is a critical part of the overall undergrounding process. The following are methods of financing that are most often cited in reports and studies (combinations of these options can be used as well):

Basic Financing Options

- Customer funded;
- Higher electricity rates;
- Higher taxes;
- Special tax districts;
- Utility set-asides;
- Federal funding;
- Private sector funded.

Overall Conclusion

The Florida Public Service Commission as well as many municipalities and electric customers in Florida are interested in undergrounding electric distribution systems in order to improve aesthetics, improve reliability of service, and reduce vulnerability to hurricane damage. The benefits associated with improved aesthetics are not quantifiable. Without considering aesthetics, no study reviewed in this report concludes that wholesale conversion of overhead electric distribution lines to underground can be fully cost justified.

In summary, a review of the body of public knowledge on the undergrounding of electric distribution facilities reveals the following:

Summary of Literature Review on Electric Distribution Underground Conversion

- No state is requiring extensive undergrounding of existing distribution facilities;
- Conversion of overhead facilities to underground is rarely 100% justified on the basis of costs and quantifiable benefits;
- *Ex post* analyses on actual underground conversion projects have not been done;
- Few studies address the potential negative impacts of undergrounding;
- Few studies consider strengthening existing overhead systems as a potential cost-effective alternative to underground conversion;
- There are almost no academic or industry publications that address storm reliability modeling of electric distribution systems;
- Until last year, there was no academic or industry literature that addressed failure rates during hurricanes as a function of hurricane strength;
- Existing research on mitigating the impacts of major storms on electric distribution systems is not sufficient for use in a detailed study.

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1 Introduction

This report is the Phase 1 deliverable of a project awarded in response to RFP #U-1 issued by the Florida Electric Utilities. The scope of the overall project is to investigate the implications of converting overhead electric distribution systems in Florida to underground (referred to as undergrounding). The primary focus of the project is the impact of undergrounding on hurricane performance, which is the ability of the local power system to withstand high winds and other damage from hurricanes and to minimize the number and duration of customer interruptions. This study also considers benefits and issues with regard to performance during non-storm situations.

RFP #U-1 was a result of Florida Public Service Commission Order No. PSC-06-0351-PAA-EI, which directs each investor-owned electric utility in Florida to establish a plan that increases collaborative research to further the development of storm-resilient electric utility infrastructure and technologies that reduce storm restoration costs and interruptions to customers. Municipal electric and cooperative electric utilities are participating voluntarily. In an effort to comply with this order, the following utilities are joint sponsors and are coordinating their efforts through the Public Utility Research Center (PURC) based out of the University of Florida:

Investor-Owned Utilities

- Florida Power & Light Company;
- Progress Energy Florida, Inc.;
- Tampa Electric Company;
- Gulf Power Company;
- Florida Public Utilities Company;

Publicly-Owned Entities

- Florida Municipal Electric Association;
- Florida Electric Cooperatives Association;
- Lee County Electric Cooperative, Inc.

The scope of work for the overall project is divided into three phases. Phase 1 is a meta-analysis of existing research, reports, methodologies, and case studies. Phase 2 examines specific undergrounding project case studies in Florida. Phase 3 develops and tests a methodology to identify and evaluate the costs and benefits of undergrounding specific facilities in Florida. This report presents the results of Phase 1.

The goal of Phase 1 is to provide a comprehensive survey of published and unpublished research, case studies, and other reports on the costs and benefits of undergrounding. Benefits to be considered include, but are not limited to, reliability impacts, private and public benefits, reduced outages and changes in restoration times, reduced operating and maintenance costs, and reduced vegetation management costs. The survey also searched for a uniform, defensible methodology that could be used widely to evaluate the pros, cons, costs and benefits of overhead to underground conversions.

A list of references examined in Phase 1 is provided in Appendix A. A corresponding annotated list is provided in Appendix B. Each list contains an initial set of studies and reports compiled by the Florida Public Service Commission and the project sponsors [1-37], additional references subsequently provided by project sponsors [38-45], and additional references identified by Quanta Technology [46-61].

The meta analysis of Phase 1 is primarily concerned with the following: (1) prior study results, (2) comments on the conversion of overhead electrical facilities (as opposed to other utilities, such telephone or cable TV) to underground, (3) facts and findings both qualitative and quantitative, (4) cited costs and benefits (including who bears the costs and who receives the benefits), (5) conclusions reached by the existing work, and (6) methodological features of the existing work that can be carried over or improved upon for the Florida-specific studies and methodology development for predictive cost-to-benefit analysis.

To the extent possible, this report also considers (1) results in the existing studies that inform about the implications of regulatory treatment and other government policies of undergrounding costs and benefits, and (2) content in existing studies about how electric undergrounding affects costs and benefits for other utilities, such as telecommunications and cable television.

This report begins with a summary of the literature search with a focus on identifying key references and key findings. Next, the report summarizes the existing situation in Florida. The report continues by providing separate sections on costs, benefits, and financing options of undergrounding. The report ends with conclusions.

2 Literature Review

The conversion of overhead electric distribution systems to underground is expensive and, except in occasional targeted situations, cannot be fully justified based upon quantifiable benefits.

The above statement summarizes the conclusions of large body of literature surrounding the topic of underground conversion of electric distribution systems (referred to hereafter as undergrounding), which is listed in Appendix A. This literature set includes studies and reports provided to Quanta by the Florida Public Service Commission and the project sponsors [1-37], additional references subsequently provided by project sponsors [38-45], and additional referenced identified by Quanta [46-61]. Appendix B provides a corresponding list that includes a brief summary of each reference as it relates to the topic of undergrounding.

2.1 Summary of Literature

The undergrounding references examined in this report and listed in Appendix A generally fall into the following categories: consultant reports, state regulatory reports, municipal reports, international reports, system reliability modeling, failure rate modeling, and property value studies. A brief discussion of each of these categories is now provided.

Consultant Reports. The purpose of a consultant report is typically to provide a comprehensive overview of undergrounding issues with regards to costs, benefits, regulatory issues, previous work, case studies, and implementation issues. If done well, these reports are valuable for use as a starting point when considering issues related to undergrounding. The two primary consultant reports on undergrounding are (1) the EEI report titled *Out of Sight, Out of Mind? A study on the costs and benefits of undergrounding overhead power lines* [14], and (2) the Navigant report titled *A Review of Electric Utility Undergrounding Policies and Practices* [24]. These reports are both good references, but have a high overlap in content.

State Regulatory Reports. Several state regulatory commissions have performed investigations on the costs and benefits of undergrounding all electric utilities in their corresponding state (sometimes limited to investor-owned utilities). Examples include Virginia [11], North Carolina [28], Maine [27], Maryland [3], and Florida [15]. Often times these reports include large overview sections on topics such as the electric delivery system, natural disasters relevant to the state, and previous undergrounding investigations. Each current state regulatory report either does not make a recommendation on undergrounding or recommends not pursuing undergrounding in the state.

Municipal Reports. A number of towns, cities, and local authorities have either hired consultants or assigned municipal staff to produce studies of the cost and benefits of undergrounding utilities in their franchise area. Examples include: Fort Pierce, Florida [16]; Palm Beach, Florida [43, 44, 45]; Tallahassee, Florida [49]; Davis Island, Florida [38]; Tahoe Donner Subdivision in Truckee, California [35]; Honolulu, Hawaii [41]; Long Island, New York [24]; and Washington, D.C. (PEPCO service territory) [19]. Most of these reports focus on the cost implications of undergrounding, rather than making a specific recommendation on whether undergrounding should be undertaken. In Florida, there was a study done for a group of municipalities [39], but this report analyzes undergrounding costs and benefits in general and is not intended to address specific municipalities.

International Reports. Undergrounding of utilities, particularly of electric facilities, has been studied in many other parts of the developed world. One report addresses electric transmission undergrounding issues in the European Commission countries [12]. Electric distribution systems throughout Europe are significantly different in design and operation from those in the US, so results specific to European distribution systems have not been considered in detail here, although [57] points out that undergrounding is also expensive in a European distribution design. While slightly different, electric distribution designs in the UK and Australia are much closer to American practice and a number of reports and their results are included here [17, 46, 48, 50, 51, 53, 54].

System Reliability Modeling. System reliability models are able to predict expected customer interruption statistics from component reliability data, system topology, and operational assumptions. Many of the references listed in Appendix A address system reliability modeling [1, 7, 8, 9, 23, 26, 30, 31, 33, 36, 37, 58, 59, 60], but basic functionality already exists in most commercially available feeder analysis packages. These tools are sufficient to compute the expected reliability differences of overhead versus underground in non-storm conditions. However, these tools are not appropriate to assess reliability under severe storm conditions. There are almost no publications that address storm reliability modeling of electric distribution system. One suggests the use of a non-storm algorithm with different failure rate and repair times [59]. This approach is not suitable for hurricane simulations. One paper presents a simulation methodology to compute expected performance during major wind storms [60]. This includes the prediction of storm severity, restoration efforts during the storm, and post-storm restoration. Data used in this paper is not based on hurricanes, but the basic approach could be used as a basis for a hurricane simulation.

Failure Rate Modeling. Accurate prediction of system reliability requires accurate estimates of equipment failure rates. For example, non-storm benefits of undergrounding require information on overhead line and underground cable failure rates. There is a host of data on average equipment failure rates in a variety of publications [5, 18, 22, 34, 56, 57, 59], most of which are summarized in [58]. These are sufficient to do a basic examination of non-storm reliability, but utility-specific data often varies substantially from industry averages. Other papers discuss the relationship of equipment condition to failure rate [4, 29, 32, 33]. These references are helpful guides when considering the different effects of undergrounding overhead systems in good versus poor condition. There are not useful references with regard to failure rates during hurricanes as a function of hurricane strength (the exception is [61], which discusses FPL statistics). Rough inferences can be made in certain cases from damage statistic provided by consultant reports and state regulatory reports.

Property Value. There are two major categories of interaction of property values with undergrounding of utilities as addressed in the examined reports. The first concerns the risk to property value from exposure to major storms [2, 6, 20]. It is generally noted that there is a short lived but measurable drop in property value after a major storm due to damage it causes, and that longer-term property value interactions are based the perception of risk of future damage. The second category of property-value interaction concerns the improved aesthetics due to removal of above-ground utilities, and its impact on property value [40, 41]. A literature review performed for [40] found no references in either *The Appraisal Journal* or the *Journal of Real Estate Research* that specifically consider the impact of overhead electricity lines on property values. The results in [40] also references a 1992 review of relevant literature on *transmission lines* by EEI that, "the effect, especially for single family homes, is generally small (from zero to ten percent), but has been estimated to be greater than fifteen percent in some specialized cases in rural areas." It is not clear if estimates for transmission can be used to estimate the impact of distribution, especially since some of the negative impact of transmission lines is attributed to a perceived risk associated with high-voltage electromagnetism. A study done in Hawaii [41] notes that data on changes in property value due to undergrounded utilities are inconclusive as to whether there is actually a measurable impact, with one local study showing no impact while another assumed there would be improved property values.

2.2 Primary Issues

A review of the literature indicates that there are four primary issues related to the undergrounding of distribution systems, each with common misconceptions. These issues are related to initial cost, positive effects, negative effects, and funding. A brief discussion of each primary issue is now provided.

Cost. The literature is consistent in its recognition that undergrounding is expensive relative to the embedded cost of existing overhead systems. However, it is often not emphasized that there are three initial costs related to undergrounding. The cost most commonly considered is the cost for a utility to remove the existing overhead electrical facilities in easements and rights-of-way and install equivalent underground facilities. The second is the cost of converting or modifying each individual customer's "private" service equipment (service drops and entrance, meter box, etc.) to accommodate new underground electric service. This second cost can be substantial and is almost always born directly by the associated customer. The third cost is for undergrounding other utilities such as telephone, cable television, and broadband fiber. There is an offset for this third cost since the third-party utilities will no longer have to pay an attachment fee to the electric utility. Virtually all undergrounding projects place all overhead utilities underground. However, many undergrounding studies do not consider the cost of undergrounding third-party attachments.

Positive Effects. The literature most commonly attributes to underground distribution systems the following improvements as compared to overhead distribution systems: (1) more reliable electric service with fewer failures (2) more economical to maintain and service, (3) safer, (4) positive value to nearby property, and (5) more desirable during adverse weather. These and other positive effects are discussed in detail in Section 5.

Negative Effects. Potential negative effects of undergrounding include: (1) possible negative impacts on sensitive environmental areas, (2) higher costs (and therefore prices) for local businesses, (3) lower life expectancy of underground system equipment, (4) reduced operational flexibility and higher costs for some types of maintenance. These and other negative effects are discussed in detail in Section 6.

Financing Options. Ultimately, the cost of any undergrounding project has to be paid. Selecting the most appropriate financing option and setting the cost allocation policy (who pays what portion of the cost) is a critical part of the overall undergrounding process. Most commonly, funding for initial construction comes from one or more of the following: increased taxes, increased electricity rates, and direct contributions from customers. Funding must also be considered for other undergrounded utilities such as telephone, cable television, and broadband fiber. Most commonly, undergrounding plans involve a specific group of customers such as a municipality or a "special assessment district." In addition, most studies recognize that individual customers must absorb the cost of converting their own service facilities to take underground service. This can be a financial burden to the individual customer with implications of its own. These issues are discussed in detail in Section 7.

The fundamental question of undergrounding is whether customers are willing to pay for the costs in anticipation of the benefits. The Virginia analysis in [11] shows that undergrounding would require an additional $3,000 per year per customer, but customer willingness to pay is estimated to be about $180 per year. This means that customers are only willing to pay 6% of the cost of undergrounding in anticipation of the benefits. If undergrounding costs are offset by expected utility benefits (in this case an estimated offset of 37%), customer willingness to pay corresponds to 10% of net cost. In Australia, customer surveys indicate that only 20% to 30% of customers are willing to pay for undergrounding [42]. In the case of Tahoe Donner subdivision, residents viewed the costs of undergrounding as being too high and not being justified by the aesthetic benefits.

The discrepancy between cost and customer willingness to pay is why nearly all undergrounding initiatives are limited and targeted in nature. This will be discussed in more detail in sections 5 – 7.

3 The Situation in Florida

In 1989, the Florida Legislature directed the Florida Public Service Commission (FPSC) to conduct a study on the cost-effectiveness of undergrounding. That study was completed in December 1991, and examined the total life-cycle costs for six distribution subsystems for both overhead and underground for the following construction scenarios: new, relocation, replacement, and conversion.[2] Non-utility cost data was developed for storm outage costs, non-storm outage costs, surge/sag costs, pole accident costs, electric contact accident costs, and direct customer costs. This report found that undergrounding electric distribution facilities in Florida was not cost effective for any of the scenarios that were examined.

Since 1991, the undergrounding discussion in Florida has continued. This section reviews the major activities that have occurred since 1991 including FPSC rules related to undergrounding, a subsequent FPSC report [15], and a variety of municipal undergrounding studies.

3.1 FPSC Rules

The main FPSC rules related to undergrounding are the following [15]:

Florida Administrative Code Rule 25-6.078. This rule requires each investor-owned utility to file with the FPSC a written policy that will become a part of the utility's tariff rules and regulations regarding underground service in new residential subdivisions. This requires an estimate of the cost differential between overhead and underground and a method to recover up to the cost difference from the developer. This rule does not directly apply to undergrounding, but sets a precedent that customers can pay directly for an underground distribution system.

Florida Administrative Code Rule 25-6.115. This rule requires each investor-owned utility to file a tariff addressing the conversion of existing overhead to underground facilities not covered by Rule 25-6.078. The tariff must include the general provisions and terms under which the investor-owned utility and applicant may enter into a contract for the purpose of conversion of existing overhead electric facilities to underground electric facilities. This rule effectively allows municipalities and neighborhoods to underground their existing distribution systems as long as they pay the incremental cost.

[2] Report on Cost-Effectiveness of Underground Electric Distribution Facilities, Florida Public Service Commission, December, 1991.

3.2 FPSC 2005 Report

In March of 2005 the FPSC issued the following report: *Preliminary Analysis of Placing Investor-Owned Electric Utility Transmission and Distribution Facilities Underground in Florida* [15]. This report cites the following cost estimates:

- The total cost to convert existing Investor-owned utility (IOU) residential subdivision and neighborhood overhead facilities to underground: $6.7 billion. This corresponds to $2,475 per residential customer affected.
- The total cost to convert all existing IOU residential feeders to underground: $65.5 billion. This corresponds to $11,288 per residential customer affected.
- The total cost to convert all IOU mainline urban commercial feeders to underground: $12.4 billion. This corresponds to an initial cost of $36,737 per commercial customer affected.

The above cost estimates do not include any costs related to the removal of service masts or any costs typically incurred by customers, such as those modifying meter sockets, service panels, or internal wiring. The above costs do not consider any offsetting cost savings.

The 2005 FPSC report estimates that complete distribution undergrounding by investor-owned utilities in Florida would result in an 81% rate increase for ten years if costs were allocated over all customers, and a 141.5% increase if costs were allocated over just residential customers. These increases only pay for direct utility costs and do not consider the cost of undergrounding other facilities such as telephone and cable television. This report is careful not to make any value judgments; its purpose is "to develop a ballpark estimate of the cost for investor-owned electric utilities to place existing electric transmission and distribution facilities in Florida underground."

3.3 Reports and Studies Specific to Florida

Among the references given in Appendix A (annotated listing in Appendix B) are a number of studies and reports that are specific to Florida, having been requested by communities or municipalities in the state.

3.3.1 Davis Island

There has been a significant investigation into the feasibility of undergrounding the distribution system on Davis Island [38]. This is being performed by a utilities task force that includes the Davis Island Civic Association, the City of Tampa, the University of South Florida, Tampa Electric, and Verizon. A first phase based on cost data from the 1991 FPSC report was completed in 1999, and a second phase was completed in 2002. The second phase concludes that undergrounding would cost $3,200 per electrical connection for a 3,000 customer project. This estimate does not include the costs to replace street surfaces, sidewalks, shrubbery, grass, or other property disturbed by the construction efforts. In addition, this estimate does not include any costs related to the removal of service masts or any costs necessary to modify meter sockets, service panels, or internal customer wiring.

3.3.2 Fort Pierce

The Fort Pierce Utilities Authority issued a draft report in 2005 titled *Qualitative Advantages and Disadvantages of Converting Overhead Distribution Facilities to Underground Facilities within the Service Territory of the Fort Pierce Utilities Authority* [16]. This report presents detailed cost comparisons of underground versus overhead distribution, and looks at a wide range of issues that are involved in comparing underground and overhead distribution. It concludes that wholesale undergrounding of overhead distribution facilities is not economically justifiable, but that conversion of selected portions may be desirable, and that new single-phase tap lines in neighborhoods should be undergrounded as standard practice. This report is discussed in more detail in Section 3.4.

3.3.3 Jacksonville

Estimates were given by JEA to its board in November 2004 on the cost to convert its existing overhead distribution system to underground in Jacksonville [15]. There is no formal report containing this information. The JEA staff estimates that undergrounding costs would range from $3,103 per house to $7,080 per house. On a neighborhood basis, average costs per customer range from $3,649 to $4,761.

3.3.4 Tallahassee

In 2003, the City of Tallahassee issued a report titled *Comparison of Impacts of Overhead versus Underground Transmission Line Construction* [49]. This report highlights only one point, that underground lines require trenching and therefore have an environmental impact on streams, wetlands, and "sensitive species" locations that they cross, whereas overhead lines can hang from poles and not disturb the same areas. The report does note that there are potential reliability impacts of underground lines but states that the Tallahassee transmission system has been out of service only 30 minutes due to hurricane winds in the past 17 years, and that "the economic benefits associated with underground electric facilities are, in most cases, minimal compared to the difference in the cost of installation."

3.3.5 Municipal Underground Utilities Consortium

Following the intense Florida hurricane seasons of 2004 and 2005, a group of cities and towns in the state formed the Municipal Underground Utilities Consortium (MUUC) to "support a substantial study of the cost-effectiveness of undergrounding electric distribution facilities considered on a life-cycle basis." This effort resulted in a report titled *Cost Effectiveness of Undergrounding Electric Distribution Facilities in Florida* [39]. This report addresses the direct, quantifiable costs and benefits of installing, operating, and maintaining underground power lines in lieu of overhead electric lines. It concludes that the incremental cost of new underground service versus construction to hardened overhead standards is an estimated average of $835, 314, and that avoided costs from various sources due to the benefits accruing from undergrounding should lead to a significant reduction in the Contribution In Aid of Construction (CIAC) required of municipalities or property owners desiring the undergrounding. This report is discussed in more detail in Section 3.4.

3.3.6 Palm Beach

Three reports were prepared for the Town of Palm Beach including the *State Road Utility Study* in 2002 [43], the *Undergrounding Utilities Staff Report* in 2004 [44], and the *Conversion of Aerial to Underground Utilities Analysis* [45]. The first two reports conclude that conversion to all-underground electric lines along state and town roads within Palm Beach would cost $54.27 million. In [45], the town commission staff then recommends that only about 40% of that work be done, which it deems sufficient to address aesthetic and public safety issues associated with evacuation and post disaster response following a hurricane. The town commission staff goes on to note the following major issue; undergrounding would require that home and business owners in affected areas pay for conversion of their own service entrance equipment to underground. Section 3.4 discusses [44] and [45] in more detail.

3.3.7 Summary

Undergrounding of overhead utilities lines has been a topic of discussion in Florida for more than twenty years, and the costs, benefits, and other issues involved have been examined many times at both the state and local level. IOUs are not required to underground service at their own cost, but all IOUs must have a process where municipalities and individual customers who want their local facilities put underground can have it done if they pay the incremental or differential cost.

The most recent FPSC study indicates that undergrounding residential neighborhoods costs about $2,500 per residential customer, undergrounding residential main-trunk feeders costs about $11,000 per residential customer, and undergrounding all main trunk commercial feeders costs about $37,000 per commercial customer. These studies are based on the service territories of investor-owned utilities and could be much higher for rural areas of low customer density served by some cooperatives. No study recommends broad-based undergrounding, but several recognize that targeted undergrounding to specific sites and situations which provide particularly high value can help achieve community and customer goals.

3.4 Detailed Observations on Several Florida Reports

The project team found four of the Florida-specific reports reviewed in this phase of the study to be particularly relevant to the scope and purpose of this project. This includes the Fort Pierce report [16], the Municipal Underground Utilities Consortium report [39], and two Palm Beach reports [44, 45]. These reports are discussed further in the following sections.

3.4.1 Fort Pierce Utilities Authority

In 2005, the Fort Pierce Utilities Authority issued a draft report titled *Qualitative Advantages and Disadvantages of Converting Overhead Distribution Facilities to Underground Facilities within the Service Territory of the Fort Pierce Utilities Authority* [16]. This report looks at cost differences between overhead and underground distribution, utility operating and maintenance differences, and a wide range of other issues of public, community, and property-owner interactions and impacts that could be positively or negatively affected by a decision to underground electric utilities. This report is very comprehensive in its treatment of these issues among all references examined in this phase of the project. All of this analysis is specific to Fort Pierce but representative of the situations faced in many Florida suburban and urban areas.

With respect to cost, the report presents detailed comparisons of underground versus overhead distribution materials and equipment costs for various elements of a distribution system, noting that underground equipment costs from 6% to 340% more than equivalent overhead equipment. It notes that "The cost of construction is probably the single most important factor when deciding to convert an overhead system to an underground system. Traditionally, the cost to construct an underground system is a least double that of an overhead based system." Tables given with this analysis show cost differentials of 3.9:1 for underground versus overhead main trunk (three phase) lines, and slightly less than 2:1 for single-phase lines that tap off main feeders. The report also notes that underground systems are generally less flexible in both expansion possibilities as new load develops, and operational switching and protection, and that this difference will have a noticeable impact on cost.

The report looks at a wide range of operational and maintenance issues between underground and overhead distribution systems, including the complexity of inventory and spare parts management when great amounts of both underground and overhead equipment must be maintained, underground utilities congestion and coordination of under-the-street space with other utilities, electrical power losses and how those differ between overhead and underground systems, power factor correction differences, load cycles and their different impacts on underground and overhead equipment and lines, differences in underground and overhead equipment lifetimes in typical service, easement availability and the different approaches and results the Fort Pierce Utility Authority could expect when working with customers during construction of overhead or underground lines, employee safety practice differences with respect to overhead and underground work, and others.

Finally, underground versus overhead distribution is examined from the standpoint of different impacts on a number of "non-utility" or public and community issues, for both positive and negative effects. These include public safety, construction time, disruption of traffic and routine business flow during initial construction and during repairs later on, soil conditions, de-watering, handling underground congestion in property owner's easements, access and working on private property, power interruption restoration, and interaction with other utilities like telephone and cable television.

This report is particularly noteworthy in that it recognizes and compares *three* options for distribution, not just two. In addition to the design of existing overhead construction and conversion to underground construction, the report looks at "hardening" of overhead construction, which it defines as building overhead lines to stronger NESC grade B standards, or other "extreme wind loading factors" for all normal rather than just special situations as done now (like crossing over railroad tracks).

The overall conclusion of the Fort Pierce Utility Authority's report is concisely given in its Executive Summary as, "The wholesale conversion of overhead distribution facilities cannot be supported based on research and economic issues and benefits."

The report goes on to note that while wholesale conversion of Fort Pierce's distribution system is not justifiable based on the benefits, selected portions of the system such as double-circuit portions near an interstate highway and those in high-profile tourist areas might be considered for underground conversion where reliability or aesthetic benefits are much higher than average. It recommends that a standard practice be to build new single-phase taps from main feeder lines as underground lines within the town limits, and that this has a cost differential of less than $1,000 more per utility customer.

With respect to reliability, storm restoration, and the system's ability to withstand high winds and hurricane damage the report's summary of conclusions notes that for main feeder lines, a combination of hardened construction and loop design is "more economical and prudent." It concludes that, "The strengthening of overhead main feeder lines may be a better alternative to placing facilities underground," and, "The hardening of new and existing main line feeders will provide an economical solution with minimal tradeoffs."

3.4.2 Municipal Underground Utilities Consortium

In 2006, a group of Florida cities and towns (none owns or operates a municipal electric utility) came together to form the Municipal Underground Utilities Consortium (MUUC). The stated primary purpose of the MUUC is to "support a substantial study of the cost-effectiveness of undergrounding electric distribution facilities considered on a life-cycle basis." To this end, the MUUC commissioned a study to the consulting firm PowerServices, who submitted in 2006 a report titled *Cost Effectiveness of Undergrounding Electric Distribution Facilities in Florida* [39]. This report does not address a specific municipality.

The MUUC report addresses the direct, quantifiable costs and benefits of installing, operating, and maintaining underground power lines in lieu of overhead lines, which it notes does not include social and long-term economic benefits. The report compares the cost of underground lines only to the cost of hardened overhead lines on the basis of initial costs, O&M costs, and other utility costs, and it quantifies a wide range of utility, customer, and societal benefits and savings in order to compute the monetary benefit and costs. It cites and uses data based on experience and results from several previous utility undergrounding projects including two in North Carolina that show that the reliability, customer, and societal benefits to undergrounding for hurricane damage mitigation extend inland far from the coast. This report's overall conclusion is that the cost differential between new underground and new hardened overhead construction is $835,314 per mile. The report states that avoided utility costs from various sources such as reduced costs from outage restoration, reduced O&M and vegetation management costs, and reduced revenue losses could amount to $422,158 per mile.

Observations about the analytical approach taken in the MUUC report methodology, and its overall conclusion of $422,158 per mile in avoided utility costs include the following items:

1. The "base conversion cost differential" of $835,314 per mile the report uses is the difference between converting existing overhead facilities to "hardened" overhead design and the cost of converting those facilities to underground design. The assumed cost of converting existing overhead lines to hardened overhead lines is substantial, as it would involve a substantial cost in materials and labor. If calculations used the cost of standard overhead construction, the cost differential would be higher and result in higher cost obligations for the consumer. Therefore the effect of this step is to reduce the cost of undergrounding paid by the consumer used throughout the MUUC report.
2. Although the cost analysis is based upon the difference between conversion to hardened overhead and conversion to underground, the utility benefits assumed for underground are determined by comparing the historical reliability of existing underground lines to that of existing overhead lines, most of which are not hardened. Since the operational cost of hardened overhead may be expected to be less due to higher storm resilience, the net effect of this is to determine a very optimistic benefit-to-cost ratio (i.e., the cost paid by the consumers) for underground conversion.

3. The report assumes that underground systems will result in reduced utility operations and maintenance (O&M) spending, even though Florida-specific historical data provided for the report on actual utility O&M costs indicated that underground systems cost more per mile that overhead systems to operate and maintain. The authors of the report state that they disregarded this data and instead substituted data from other sources because they assume that those O&M cost data included substantial additional costs for "improved technology." However, other undergrounding investigations show that underground O&M costs are often similar to overhead (e.g., direct-buried cables), and are often much higher for some underground systems (e.g., ductbank systems) [11, 28].
4. The report allocates total storm restoration cost in proportion to the ratio of overhead interruptions per mile to underground interruptions per mile. Quanta does not believe this is the most appropriate metric. An interruption refers to an interrupted customer. A more appropriate measure for cost calculations is faults per mile weighted by the repair cost ratio.
5. The report does not distinguish between small-scale and large-scale conversion scenarios. A large percentage of storm restoration costs are fixed and semi-variable (e.g., staging areas). Small-scale conversions will typically not affect these fixed and semi-variable costs, making the major event outage restoration reduction assumptions in the report optimistic for small-scale conversions.
6. This report assumes that an underground system will result in lower lost revenues during non-storm conditions. Lost revenue is proportional to customer interruption minutes. Other studies [14, 24, 28] state that underground systems have fewer failures but longer restorations times, resulting in roughly an equivalent number of customer interruption minutes.
7. The utility benefit for reduced accidents assumes that all current accidents are related to overhead lines and that undergrounding will eliminate all accidents. Industry experience does not support this conclusion. No state commission analysis attributes any economic benefit to reduced accidents [3, 11, 27, 28]. A study for Honolulu [41] cites statistics describing car accidents involving utility poles, but does not make any claims regarding reduced accident rates with regards to undergrounding.
8. The report does not address *any* of the negative effects of undergrounding except for high initial cost.

3.4.3 Palm Beach

Several reports were prepared for the Town of Palm Beach over the period 2002 – 2006 including the *Undergrounding Utilities Staff Report* in 2004 [44], and *Conversion of Aerial to Underground Utilities Analysis* in 2006 [45]. These reports differ slightly in how they evaluate costs and the scope considered, with the estimated cost of undergrounding all overhead utilities (electric, phone, and cable) within the Town running between $53 million and $62 million.

Undergrounding Utilities Staff Report [44]

This report, by the Assistant Town Manager, reviews the results of two earlier consulting studies done for the town which estimate that the total cost for conversion of all overhead utilities to underground at $54.3 million. The Assistant Town Manager recommended converting only a portion of utilities – those along all State roads and those on major roads leading north and south out of Palm Beach – at an estimated cost of $20.9 million. Undergrounding along these roads, it was felt, would address most “aesthetic and public safety issues associated with evacuation and post disaster response capabilities following a direct hit of the island by a hurricane.” It was expected that such a plan would take ten years to complete.

The report addresses two additional issues the town must address before proceeding. The “most significant financial policy decision” is identified as who will pay the estimated cost of $5,000 per property for converting home and business service entrances and secondary service wiring to underground. If the city would decide to pay these expenses it would be an additional $15.7 million.

The second issue that the report identifies as important is the mechanism that would be used to pay for the undergrounding. This report looks at six possible funding mechanisms and notes they may differ with respect to policy implications and voter satisfaction. These are: pay-as-you-go with the city paying for the conversion over a period of years from general revenues; the sale of general revenue or revenue bonds; non-ad valorem assessments; a special taxing district; a utility bill tariff; and federal grants. The report makes no firm conclusions or recommendation with respect to funding other than that financing must be resolved before conversion can proceed, and that financial issues might control the rate at which the town could do the conversion in a “pay as it goes” scenario. The ten-year time frame envisioned for any conversion is partly a function of this concern.

***Conversion of Aerial to Underground Utilities Analysis* [45]**

This most recent undergrounding report for the Town of Palm Beach applies a particularly comprehensive assessment of cost for conversion of all overhead utility facilities, including electric, phone, and cable TV. It concludes that the lowest expected initial cost for undergrounding of all utilities would be $59.9 million. This is the total estimated CAIC (Contribution In Aid of Construction) for all three utilities. Of this, undergrounding of electric distribution is 83% of the total ($51.9 million), phone $6.0 million (10%), and cable television $4.0 million (7%). Estimated conversion costs per mile of line developed in the study and used to determine these numbers are $1.5 million (electric), $134,000 (phone), and $162,000 (cable).

One interesting conclusion of the report is that coordination of the undergrounding work by the three utilities (joint trenching) would be slightly *more* expensive (by about 0.8%) than if each utility were permitted to independently schedule and perform its undergrounding work. The authors of the report believe that the cost of coordinating the undergrounding work is greater than the savings joint trenching would produce. In spite of this, the report recommends that if wholesale utility undergrounding were to be done, joint trenching should be adopted throughout the town, which would cost $60.3 million. The major reason for joint trenching is that coordination would greatly reduce the amount of time the public would be exposed to construction and its associated traffic disruption.

4 Costs of Undergrounding Existing Overhead Facilities

The initial cost of converting existing overhead distribution systems to underground is very high. This conclusion has been reinforced time and again as states and utilities examine the costs of undergrounding their systems. Recent studies include one by the Florida Public Service Commission in 2004 [15], one by the Virginia State Corporation Commission in 2003 [11], one by Long Island Power Authority in 2004 [24], and one by the Tahoe Donner Association (Truckee, CA) in 2006 [35]. A summary of these and other studies is shown in Table 4-1 [14]. These costs do not include the costs of converting or modifying each individual customer's private service equipment or the cost for undergrounding third party utilities such as telephone, cable television, and broadband fiber.

Table 4-1. Estimate of Initial Utility Costs for Underground Conversion [14]

Scope of Estimate	Total Initial Cost ($B)	Miles of UG Conversion	$ / Mile
State of Florida	94.5	115,961	814,929
Virginia Investor Owned Utilities	75.09	62,830	1,195,050
Long Island Power Authority	28.55	10,075	1,578,976
Tahoe-Donner, California	0.12	102	1,191,176
Allegheny Power			764,655
Baltimore Gas & electric			952,066
PEPCO			1,826,415
Conectiv			728,190
Virginia Power			950,000
California			500,000
Georgia Power			950,400
Puget Sound Energy			1,100,000

The costs cited in Table 4-1 provide a rough estimate of undergrounding costs of about one million dollars per mile. However, it should be noted the cost of each specific mile of undergrounding can vary widely, and most undergrounding projects will be small and targeted and have costs that may have no relationship to costs cited in Table 4-1. Regardless, examining broad-based estimates are useful in a broad-based undergrounding discussion.

The general range of estimates of initial costs for undergrounding is from a low of $500,000 per mile to a high of $1.8 million per mile. These differences in estimates stem from three primary factors: (1) differences in construction standards, (2) differences in geography, and (3) differences in accounting methods for recording and allocating costs. Each of these factors is now discussed.

Construction Standards. There are many standards-related issues affecting cost such as voltage level, number of phases, and circuit ampere capacity. There are also certain engineering standards (such as the requirement to operate underground systems in loops) that can have a large impact on cost. However, the largest impact of standards with regards to cost is whether the underground system will be directly buried (less expensive) or be placed in a system of manholes and conduit (much more expensive).

Geography. It is much cheaper per mile to underground a feeder following a rural country road than to underground a feeder in a central business district. However, the cost per customer could be substantially higher because of the lower customer density. In addition, installing underground facilities in underdeveloped areas can be problematic when the area is later developed. Other potentially expensive areas to underground are through rocky terrain, inaccessible mountains, swampland, and other difficult terrains. These geographic issues are often correlated with customer classes such as urban, suburban, and rural. A study by Dominion Virginia Power [14] breaks down cost by both customer class and construction type is shown in Table 4-2.

Table 4-2. Dominion Virginia Power Undergrounding Estimates for Initial Cost [14]

Construction Type	Heavy Commercial/ Urban Residential	Suburban	Rural	Units
3-phase bulk feeder	3.1	2.5	2.7	$ million per mile
3-phase tap	3.1	2	2.1	$ million per mile
1-phase tap	1.4	1.4	1	$ million per mile
Service drop	4,269	4,269	7,092	$ per service

Table 4-2 shows that there is a large initial cost difference when undergrounding single phase verses three phase parts of the system. This is due to both the increased cable cost associated with three-phase construction as well as the need for increased trenching, manholes, and concrete duct banks. Table 4-2 also shows a smaller but still significant difference related to customer class.

Accounting. The Dominion Virginia Power study states that only 34% of undergrounding costs are associated with material cost. The remaining 66% is associated with labor, equipment, and overhead costs. Different companies account for and allocate these non-material costs in different ways. For example, some utilities may include equipment depreciation costs in overall construction costs, while others may have a separate vehicle account that does not impact construction cost accounts. Differences in accounting treatment can easily vary per-mile undergrounding cost estimates by 100% or more, for precisely the same construction activities. Therefore, care must be taken when comparing undergrounding costs across utilities.

The appropriate measure of utility cost for analyzing a project such as converting facilities from overhead to underground is the overall change that the expected project causes to the utility's costs. A project might affect cost associated investment and maintenance in distribution materials, but might also affect costs associated with reduced damage during hurricanes. In Florida the estimated $94.5 billion cost for undergrounding the entire state results in an annual incremental revenue requirement of $10.6 billion [15]. This is an additional $10.6 billion that customers would have to pay utilities each year (assuming that vehicles, labor, and the costs of undergrounding would be borne initially by the utility and then recovered through rate increases).

One-time Undergrounding Cost versus Continual Restoration of Overhead Facilities. Much of the Florida undergrounding discussion is based on reduced damage during hurricanes. The logic is as follows: "it is better to pay once for a more expensive underground system than to keep rebuilding overhead systems after each hurricane." In Florida, the estimated annual incremental revenue requirement of $10.6 billion for undergrounding compares to a total restoration cost of $1.5 billion for Florida investor-owned utilities during the intense hurricane season of 2004 including both transmission and distribution [15]. In 2004, Hurricanes impacting Florida included Charley, Frances, Ivan, and Jeanne.

Another important issue related to large undergrounding initiatives is the extensive amount of resources required for state-wide undergrounding initiatives. The Florida study [15] concludes that state-wide undergrounding would require a workforce of 35,950 individuals working full-time for ten years.

Effects on Rates. One way to measure the cost of undergrounding is to determine the impact on rates if all undergrounding costs were funded through rate increases. Such an analysis has been done for several large regions including Florida, North Carolina, Long Island, and Virginia [14]. Results of that study are summarized in Table 4-3.

Table 4-3. Estimated Rate Impact of Undergrounding

Area to Underground	Estimated Rate Increase
Florida	81%
North Carolina	125%
Long Island	126%
Virginia	$3,577 per customer per year

It is beyond the scope of this report to discuss why the estimated Florida rate increase is lower than North Carolina and Long Island, and none of the literature addresses this issue. Possible factors [presented by the authors of this report] include differences in the following areas: initial percentages of underground distribution, percentages of rates allocated to distribution costs, customer density, amount of overhead distribution in urban areas, terrain, book value of existing overhead distribution assets, and many others.

Table 4-3 implies that broad undergrounding initiatives will roughly require a doubling of electricity rates. This has a direct cost on utility bills, and indirectly results in higher retail prices due to increased business costs.

Costs for Undergrounding Non-Electric Pole Attachments. Electric lines are typically not the only equipment installed on utility poles. Also commonly found are cables for telephone, cable television, and broadband fiber. Since it is almost never acceptable to just underground the electric facilities, costs for undergrounding these “third-party attachments” must also be considered. This has been done for an undergrounding assessment for the Tahoe Donner development in California [35]. Results are shown in Table 4-4.

Table 4-4. Tahoe Donner Cost Estimates for Undergrounding All Utilities

	Initial Cost	% of Total Undergrounding Cost
General Contractor	76,881,639	65.75%
Electric	11,207,828	9.59%
Cost for Electric Only	88,089,467	75.34%
Telephone	11,858,615	10.14%
Cable television	9,697,150	8.29%
Broadband Fiber	7,276,709	6.22%
Adder for Third Party Attachments	28,832,474	24.66%
Total	$ 116,921,941	100.00%

In the Tahoe-Donner case, electric distribution-related costs account for only 75% of the total initial undergrounding cost. The remaining 25% would have to be spent to underground the other overhead utilities (telephone, cable, etc.). Assuming that all of these components would be paid for by the converting customers, the total cost impact in this case for all utilities is estimated at $1,924 per customer per year.

Costs of Undergrounding Service Drops. There is yet another cost of undergrounding that customers will typically have to pay. This includes all costs required to prepare customer-owned facilities to accept underground service. For example, meter sockets designed to accept overhead service are typically not suitable for underground service. Since these devices are the property of the customer and not the utility, the customer will typically have to directly pay for the new socket and installation cost. For example, the North Carolina study [28] estimates an average service drop cost of $1,481 per suburban customer and $2,346 per rural customer. The Dominion Virginia Power study [14] estimates an average service drop cost of $4,269 per suburban customer and $7,092 per rural customer.

Summary. Undergrounding cost issues can be succinctly summarized as follows: (1) undergrounding is expensive; (2) broad undergrounding initiatives would have a significant impact on rates; and (3) many undergrounding cost estimates do not include the cost of undergrounding other utilities or the cost of customer-related work.

Actual total cost will vary from case to case, but typical underground conversion will have an initial cost of about $1 million per mile which would require electricity rates to approximately double if paid for through electric rates. Further, undergrounding all other utilities and third-party attachments will add an estimated additional 25% to that cost, and each residential customer will bear yet another additional initial cost of $3,000 for service conversion work to their private property.

5 Positive Effects of Undergrounding

There are many potential benefits that may result from undergrounding existing overhead electrical facilities. These can generally be grouped into economic benefits for utilities, aesthetic benefits, health and safety benefits, and reliability benefits. In the reviewed literature, economic benefits for utilities are most commonly quantified, while aesthetic benefits are never quantified. The treatment of safety and reliability ranges from qualitative to quantitative with significant qualifications and caveats. Benefits for each of these categories are discussed further in Sections 5.1 through 5.4.

5.1 Economic Benefits for Utilities

Undergrounding can potentially result in a savings to the electric utility operating the system, due to reduced O&M costs, reduced vegetation management costs, reduced storm restoration costs, and reduced lost revenue due to customer interruptions. A brief discussion of each of these potential benefits is provided below.

Operations & Maintenance (O&M). Contrary to common perception, depending on the type of specifications and design, underground distribution is somewhere between slightly more expensive to much more expensive to operate and maintain than equivalent overhead facilities. Table 5-1 presents the results of a cost comparison study done in North Carolina [28]. It shows that overhead and direct buried underground have about the same O&M cost. However, underground duct bank systems, the type required in urban areas or where sub-surface conditions may damage direct-buried lines, are from two to five times more expensive to operate and maintain as compared to overhead. The higher cost for duct-bank systems is due to the requirement of manhole and vault inspections and the difficulties associated with manhole and vault access (e.g., traffic diversion, manhole flooding) in the areas where they are typically installed.

Table 5-1. O&M Costs Per Mile in North Carolina

	Overhead	Direct Buried Underground	Duct Bank Urban Underground
High	$1,064	$1,160	$6,404
Low	$757	$614	$1,700
Average	$917	$920	$4,052

Vegetation Management. Tree trimming is one of the most expensive activities related to overhead distribution systems. Actual tree trimming costs can range from $7,000 to $70,000 per mile depending on the size and height of trees, the climate and annual rate of growth, the number of trees removed per mile, accessibility by necessary equipment, and whether the work is being done in rural or urban locations [28]. In an extreme situation a utility would need to spend $70,000 per mile every two years on vegetation management for a portion of its system. This results in $35,000 per mile per year for tree trimming as compared to about $1 million per mile in capital cost to underground, which has a corresponding carrying cost of about $110,000 per year (assuming the 11% carrying charge rate implied by the calculations in [15]). In this extreme situation, reduced tree trimming costs will offset about 30% of the cost of undergrounding. In less extreme cases, the offset will be less.

Storm Restoration. One of the primary motivations for undergrounding electric facilities is the potential for far less damage and interruption of electric service during major storms. Less damage translates directly into lower restoration cost and faster restoration time. The Virginia study [11] concludes that the economic benefits for Virginia utilities would be about $40 million per year. This assumes the elimination of all storm damage, one "100-year storm" every 50 years (one hurricane and one ice storm over a 100-year period), and an expected underground system life of 30 years. This $40 million per year in savings compares to an estimated initial capital outlay of $75 billion, which would have an associated carrying cost of about $8.3 billion per year (assuming the 11% carrying charge rate implied by the calculations in [15]). These types of calculations obviously require important assumptions about future weather events that have a strong impact on the estimated benefits of reduced storm damage.

Lost Revenue. An electric utility can make no sale of electricity when its electric system is out of service. Thus, if undergrounding results in fewer customer hours of interruption, utilities will lose less revenue. This will occur during hurricanes, and lost revenue during storms is a factor in most underground cost benefit analysis. It is debatable whether lost revenue will lessen during normal weather. In non-storm conditions, underground systems tend to fail less often but take longer to restore and are more difficult to reconfigure. Despite this, the Virginia study [11] calculates that if 80% of all non-storm outage hours could be eliminated via undergrounding, annual saving would be about $12 million per year (compared to initial capital outlay of $75 billion). Even with the extremely high assumption of an 80% reduction, savings due to avoided lost revenue are close-to-negligible.

5.2 Aesthetic Benefits and Property Values

One of the most often-cited benefits of undergrounding utilities is an improvement in aesthetics. This includes the elimination of unsightly distribution poles and overhead wires, and the possibility of more aesthetically-pleasing tree locations, types, and pruning methods.

Improved Aesthetics. One of the most commonly cited improvements from undergrounding is the removal of unsightly poles and wires [14]. Such aesthetic benefits are extremely difficult to quantify with any degree of accuracy, but they are almost always an important part of any justification for an actual undergrounding projects. Improved aesthetics are commonly expected to result in improved property values, and anecdotal evidence suggests this is the case because almost all developers commonly pay premiums to put distribution systems in new neighborhoods and in new business parks underground. Although there are no studies demonstrating the effect of underground distribution on property values, such studies do exist for overhead transmission. The Virginia General Assembly Staff report [40] has a section reviewing the impact that nearby *transmission* lines have on property values due to unsightliness and concerns over electromagnetic fields. The estimates in this report of negative impact on property values are all heavily qualified, but generally range from a 0% to 10% reduction, with special cases warranting a 15% reduction.

By contrast, a Hawaii study [41] notes that there have been conflicting results with regard to undergrounding and property values in Hawaii. It observes that one recent 138-kV project report stated that property values were unaffected, whereas recent legislation on utilities was based on other reports that determined property values would increase when nearby lines were undergrounded. The Hawaiian study [41] also mentions an increased *business* value to tourism and recreational enterprises in areas where aesthetics were improved due to undergrounding, amounting to an estimated $1 to $10 per tourist per day.

No similar quantitative results are given among the references reviewed with respect to the impact of underground *distribution* facilities. Generally, the common expectation seems to be that undergrounding of distribution lines will have a benign or positive benefit on property value (no report states or implies that underground lines *lower* property value), but no report gives any estimates of the change and several do not list an improvement in property value as a benefit of *distribution* undergrounding.

In addition to increased property values, undergrounding is often seen by municipalities as a "strategic" move by an area to improve desirability in terms of attracting new residents, businesses, and visitors. For example, the Hawaii study [41] cites the Hawaii constitution as potential justification for undergrounding: "for the benefit of future generations, the State and its political subdivisions shall conserve and protect Hawaii's natural beauty."

Improved tree canopies. The preservation of existing trees can be considered an extension of improved aesthetics; the interaction of undergrounding with the tree canopy is often discussed separately, too. When overhead power lines have been removed, existing trees no longer have to be trimmed frequently and can thus grow into more pleasing, full shapes. This also creates an opportunity to replace every pole with a new tree, to have taller trees, and to plant faster growing types of trees, without worry of any risk to them through trimming [24, 49].

Improved utility-customer relations due to reduced tree trimming. Many utility customers do not appreciate the trimming of trees on or in sight of their property, regardless of the need to remove trees that pose a potential hazard to electric lines and that may affect their service reliability. These issues of customer dissatisfaction are largely eliminated when overhead systems are placed underground [11].

Potentially fewer structures impacting sidewalks. Overhead feeders that run along streets often require poles to be set in the sidewalk. This creates obstructions for pedestrians that are generally considered undesirable [11].

5.3 Health and Safety Benefits

Undergrounding of electric lines is recognized as having some public health and safety benefits. This includes a reduced risk of motor vehicle collisions with utility facilities, and a reduced risk of live wire contact.

Reduced motor vehicle accidents. Undergrounding completely eliminates the risk of vehicular pole collisions if all equipment is relocated to the sub-surface (although streetlight poles are still often required). Pad-mounted equipment is still subject to vehicle collisions, but there are typically fewer pieces of pad-mounted equipment on underground systems, though this is mitigated by their larger footprint. In general, pad-mounted equipment tends to be located farther from traffic areas where collisions can be less likely. A Hawaii study [41] finds that about 5% of all traffic accidents involve a utility pole. This study does not attempt to quantify the value of fewer collisions, nor do any of the consultant reports [14, 24] or other state reports [3, 11, 27, 28]. The MUUC study [39] quantifies expected reduction in accident litigation and award payments amounting to $87,109 per mile of conversion, but there are not enough details in the report and Quanta does not have any actual claims values to validate this number.

Reduced electrical contact injuries. Overhead lines will occasionally "burn down" and fall to the ground. Though infrequent, a protection device under certain conditions may not open and the conductor lying on the ground may remain energized. Human contact with such a line can result in electrical contact injury. Undergrounding minimizes this type of incident, but replaces it with the risk of electrical contact injury due to dig-in contact with the underground facilities. Detailed analyses of public health cost differences between overhead and underground distribution are not available. Overhead lines are also subject to contact from tall objects such as mobile cranes and boat masts. Undergrounding eliminates these events, but detailed economic analyses are not available, nor again does Quanta have any actual incidence data.

5.4 Reliability Benefits

Underground distribution systems are recognized as having reliability advantages when compared to overhead distribution systems [11, 48, 54, 56, 57]. During major wind storms, less damage is experienced, fewer customers are interrupted, and total restoration efforts will be completed quicker. During non-storm situations, service outages will occur less frequently and momentary interruptions will be reduced. Specific observations with regards to the reliability benefits of undergrounding are discussed below.

Increased reliability during severe weather. Underground systems are not immune from hurricane damage; flooding and storm surges can cause equipment failures and outages. However, underground equipment will typically not fail due to high winds alone. This means that wind-related hurricane damage will be greatly reduced for an underground system, and areas not subjected to flooding and storm surges will experience minimal damage and interruption of electric service [11, 54].

Fewer outages during normal weather. The failure rates of overhead lines and underground cables vary widely, but typically underground cable outage rates are about half that of their equivalent overhead line types [48, 56, 57]. This will generally result in fewer faults per mile for underground systems.

Potentially far fewer momentary interruptions. Momentary interruptions are those lasting only a very short time. The most common cause of momentary interruptions on power systems are lightning, animals, and tree branches falling on wires. These events cause an interrupting device, such as a circuit breaker or recloser, to de-energize the circuit and then automatically re-energize the circuit a moment later. These temporary faults occur far less frequently on underground equipment when compared to overhead equipment, thus the practice of reclosing is rarely used on pure underground distribution systems, and therefore momentary interruptions will typically be far fewer [56, 57].

5.5 Summary

There are a number of potential benefits associated with underground systems as compared to overhead systems. Benefits often cited include potentially reduced maintenance and operating costs, improved reliability, improved public safety, improved property values, and others. Some of these benefits are quantifiable in economic terms, such as reductions in tree trimming cost. Many of these benefits are difficult to quantify, such as aesthetic value. Some are disputable based on available data (e.g., maintenance cost savings). Regardless, all of the studies reviewed that attempt to quantify the costs and benefits of undergrounding agree that, except in rare cases, quantifiable benefits cannot fully justify the high cost of undergrounding.

6 Negative Effects of Undergrounding

Converting overhead systems to underground is not without some negative consequences. A review of the literature reveals a number of potential negative effects. These negative effects can be broadly grouped into economic, environmental, health and safety, reliability and technical, and miscellaneous. Essentially none of the literature attempt to quantify the negative effects of undergrounding.

6.1 Economic Problems for Utilities and Governments

A viable electric utility, regardless of ownership structure, must recover its costs to remain viable. An IOU in the long term must be allowed the opportunity to earn a fair rate of return through its regulated rates. Cooperative and municipally-owned utilities must similarly recover all of their costs to remain viable, but sometimes have other cost recovery options available, such as federal funds to recover from storms. If electricity rates and other funding mechanisms do not support cost recovery, a utility will not have sufficient resources or incentive to properly maintain and operate its electric system. In this sense, any sound investment in infrastructure is not an economic problem for a utility as long as regulators and legislators allow for a fair cost recovery. However, large increases in spending can present potential problems with regard to regulatory policy, rate structure, public image, and customer relations.

Regulatory Affairs and Changing Capital Structure. The initial cost of undergrounding is discussed in detail in Section 3, including the possibility of a significant rate increase. Section 3 does not address additional problems a utility might have with handling the increased spending requests or capital structure. When a utility proposes large spending increases, interested parties typically use any means available to challenge the overall economic efficiency of the requesting utility and any of its initiatives, forthcoming projects, or policies, even if only tangentially associated with the current request. Dealing with these issues can be expensive and distracting for the utility, government agencies, and municipal franchise authorities involved in the hearings.

If and when the increased spending is approved, cost increases must be funded. Financing through large amounts of new debt can potentially increase the utility's cost of borrowing money. Financing through equity can result in either reduced stock prices or dilution in the case of IOUs or increased rates for cooperative customer-owners or public power customers. Finally, there is often a contentious issue of how the additional cost is to be divided among customers by area or type through rate increases, based on benefits and other associated issues. All of this means that in addition to the very real cost of broad-based conversion of overhead to underground, there are many other costs which must be borne by the utility, regulatory commission, and other governmental authorities.

Stranded Assets. The recovery of undepreciated assets is an undergrounding issue listed in [11]. Undergrounding requires the removal of an overhead system that is currently being financed. This is akin to tearing down a house that still has an existing mortgage. Not only will the owner have to pay the new mortgage for the newly constructed house, but will have to pay the old mortgage for the old house that no longer exists. For regulated utilities, FASB (Financial Accounting Standards Board) Statement 71 allows the stranded costs associated with prudent investments to remain capitalized, resulting in the potential for rates to reflect simultaneous cost recovery for both the original overhead system and the new underground system.

6.2 Environmental Problems

Although underground systems have improved aesthetics when compared to overhead, there are often negative environmental impacts including the following:

Tree Root Damage. The trenching or boring required for undergrounding can damage tree roots which can kill trees directly, structurally weaken trees, and make trees more susceptible to disease [49].

Erosion. Open trenching techniques are commonly used in underground construction. This process destroys surface vegetation and can result in an increased susceptibility to soil erosion [49].

Disruption of ecologically-sensitive land. Distribution systems will sometimes have to traverse ecologically-sensitive land such as wetlands, streams, and rivers. Overhead systems in these areas will typically place poles so as to minimize impact and may use wide spans to traverse particularly sensitive terrain such as the wetlands along a stream. In contrast, trenching and placing an underground cable in such areas has the potential to disrupt the local ecosystem, especially during construction [49].

6.3 Safety Problems

Although underground systems are typically safer than overhead systems, there are several safety concerns that are associated with underground systems.

Vault inspections. When underground systems are installed in conduit, manholes, and vaults, regular equipment inspection and maintenance must be done in the manholes and vaults. This exposes workers to potential electric contacts, arc flash burns, and vault explosions, to a higher degree than when similar equipment is examined on overhead facilities.

Dig-ins. Underground systems are susceptible to damage from digging activities from backhoes and excavators and even hand-operated equipment like powered post-hole diggers [57]. Underground service drops are also subject to damage from shovels and pickaxes. Not only do dig-in events constitute a reliability problem, but they also pose the risk of electric contact to the workers involved.

6.4 Reliability and Technical Problems

It is common perception that underground systems are more reliable than overhead systems. This perception is oversimplified. In fact, there are many reliability and other technical problems associated with underground systems. The most important are now described.

Susceptibility to dig-ins. As mentioned above, underground cables and facilities are susceptible to dig-ins. Beyond any safety impacts, a dig-in on underground electrical facilities causes a fault that normally results in interruption of electric service to customers. Thus, not only do dig-in events constitute a safety problem, but they also pose a noticeable service reliability problem [57].

Longer duration interruptions. It is relatively difficult to locate and fix an underground fault [57]. Repair times are system specific, but as a general rule an underground fault will take at least twice as long to locate and repair when compared to an overhead fault.

More customers impacted per outage. Due to the nature of cable and underground equipment, it is much more expensive and difficult to install fuses, circuit interrupters, and sectionalizing switches in underground systems as compared to overhead systems [57]. As a result, underground systems tend to have less protection selectivity, which means that a fault or failure in an underground system will interrupt service to more customers than an equivalent problem in an overhead system.

Constrained post-fault reconfiguration. After a fault or failure occurs on a distribution system, it is desirable to reconfigure the system so that service is quickly restored to as many customers as possible while repairs are taking place. As mentioned in the paragraph above, underground systems typically have fewer switching locations. In addition, in order to avoid "three way splices" and other weakness, they tend to utilize mostly loop configurations instead of branching as in overhead circuits. The result is less flexibility in field-reconfiguration for restoration while awaiting repairs [58].

Limited Emergency Overload Capability. For a variety of reasons related to how different types of conductor, cable, and equipment respond to high levels of loading, underground equipment and systems are somewhat less tolerant of short periods of heavy overloads than equivalent overhead equipment. Thus, where overhead equipment can be loaded from 20% to 50% above its normal peak rating for up to several hours to maintain service after a storm or major failure, underground equipment cannot be loaded to these levels without risking damage [55].

Flooding. Underground systems, especially those in manholes and ductbanks, are susceptible to flooding. Flooding can cause interruption of and damage to non-waterproof equipment, and leave contamination residue on equipment that increases the risk of future failures. Water exposure can also increase the rate of electrochemical treeing (a major failure mode) in underground cable insulation. Flooding can slow restoration activities since flooded manholes and vaults must be pumped out before being entered [15].

Storm Surges. When a hurricane approaches a coastline, winds push a wall of water ashore called a storm surge. A storm surge will pick up debris push it inland in a wall of wreckage that can batter padmounted equipment and bury equipment in sand. A receding storm surge can also severely erode topsoil and sand and leave previously undergrounded equipment exposed [15].

Bulldozer Damage during Cleanup. After a hurricane, there are often large piles of debris that must be cleaned up with heavy machinery such as bulldozers and front-end loaders. Padmounted utility equipment near or under these piles of debris have proven susceptible to damage from this cleanup activity [verbal discussions by Quanta with Gulf Power].

Reduced Flexibility for Upgrading and Reconfiguring Circuits. It is much easier to modify, extend, and add equipment to an overhead circuit when compared to an underground circuit [57]. In this sense, operational and planning flexibility is more limited for underground systems. This is especially relevant in rural and underdeveloped areas that are subject to future development.

Reduced life expectancy. The life expectancy for overhead distribution equipment is typically assumed to be fifty years or more while the life expectancy for underground distribution equipment is typically assumed to be on the order of thirty years [57]. Equipment lifetimes vary for a variety of reasons, but in general industry experience supports this general ratio: overhead facilities tolerate the wear and tear of normal service for roughly 60% longer than their equivalent underground equipment. The replacement of underground equipment due to old age in an underground system, in the long run, will occur at something only slightly less than twice the rate of an overhead system [11].

6.5 Other Potential Disadvantages of Underground Circuits

There are a host of other potential disadvantages of undergrounding utilities that do not fit into the above categories. These are:

New Data Bandwidth. It is relatively cheap and easy for a communications company to install new cables on existing utility poles. On underground systems, new telecommunications cables must also be buried. This may be a disincentive for phone companies, cable television companies, and broadband companies to add new bandwidth [11].

Disruptions during Initial Construction. In many cases, undergrounding requires digging up existing streets and sidewalks, which can disrupt both vehicular and pedestrian traffic [43].

Scarcity of Journeyman Cable Skills. The availability of utility craft workers with underground cable expertise is limited. These work skills simply may not be available for large undergrounding initiatives [11].

Increased Business Costs. Large undergrounding initiatives will likely result in higher electricity rates, and higher electricity rates will result in higher local business costs due to higher electricity bills. These higher business costs will result in lower competitiveness for electricity-intensive businesses. They will also result in increased prices (or lower profits) for all local businesses [50].

6.6 Summary

There are a number of potential negative effects which must be weighed against the benefits when investigating the possibility of undergrounding. None is necessarily reason enough to not consider the possibility of undergrounding, but all demonstrate the very complicated nature of any decision to underground overhead electric circuits.

7 Financing Options

The most exhaustive list of potential financing options for undergrounding was developed for the Commonwealth of Australia in 1997 in response to legislation to study the feasibility of undergrounding [46]. This report lists forty eight funding options, including approaches such as Internet taxes and other specific fees and levies. Another study [41] devotes a good deal of attention to policy issues related to financing and finance oversight and discusses numerous mechanisms. It is beyond the scope of this section to address financing options in these levels of detail. Instead, seven basic methods for financing as described in the Florida Report [15] will be summarized with the understanding that these methods can be combined and modified in a variety of ways. That report, as well as [41] and [46], provides more detail in studies of policy and other impacts.

Higher Electricity Rates. Perhaps the simplest way (in an administrative sense) of funding is through higher rates paid by all electricity customers. A disadvantage of this option is that many customers who receive less value from undergrounding, or who have already paid for the undergrounding of their own neighborhood, may be forced to pay the same amount as those who receive higher benefits.

Higher Taxes. A general tax could be applied at the state, county, or local level. Funds from these taxes could then be used to pay for undergrounding activities. This method has a similar disadvantage to that of higher electricity rates; all customers are forced to pay the tax, but certain people enjoy much higher benefits than others.

Customer Funding. A customer or a group of customers (such as a subdivision) can fund an undergrounding project. Payments could be made to the government or directly to the utility, or in some cases to a special billing district or authority set up for that purpose. Advantages of this method are simplicity while targeting the funding so that those who benefit also pay for the undergrounding. However, this method can be expensive on a per-customer basis and 100% of affected customers must typically agree to pursue the undergrounding project. An example of this type of initiative is the proposed undergrounding of the neighborhood represented by the Tahoe Donner Association, which is in Truckee, California [35].

Special Tax Districts. Special tax districts can be set up by a county or municipality. Each electricity customer within the special taxing district is taxed a small amount on each electricity bill. These funds are collected by the electric utility and are put into a special undergrounding fund that the utility uses for underground conversion in that special tax district. An example is Dare County, NC, which can levy up to $1 per month on residential electric bills and $5 per month on commercial electric bills. A concern is that this level of taxation will only fund an extremely small amount of undergrounding activity.

Utility Set Asides. In this method, a state or local fee is placed on utilities which is set aside and allowed to accrue over a period of time to cover the cost of undergrounding projects. This is similar in effect to special tax districts, except that the funds are controlled by the government, and the utility must separately pursue rate recovery to compensate for these fees. The fees are typically low, and this method therefore will usually have very little effect on utility rates. Because fees are low, a long time must elapse before sufficient funds are collected to initiate undergrounding. California has been using utility set asides for roughly thirty years; utilities are required to set aside between one and two percent of gross revenues annually for use by counties in undergrounding projects. The counties are responsible for identifying areas eligible for undergrounding.

Federal Funding. The Department of Transportation (DOT) uses federal funds for undergrounding when eligible highways are being constructed. The federal Transportation Enhancements Program, under the Transportation Equity Act for the 21st Century allows communities to apply for funds for utility burial or relocation under the categories of landscaping, scenic beautification, or scenic/historic highway programs and welcome centers. Federal Community Development Block Grants have also been used to fund utility relocation projects. The Federal Emergency Management Agency (FEMA) makes funding available for qualified projects through its Hazard Mitigation Program. Guam Power Authority presently has an undergrounding initiative that is 90% funded through this program.

Private Sector Funded. This method creates a marketable security similar to bonds, which are sold to private investors to fund undergrounding. Almost always, investor payments for these securities are guaranteed by state regulators, resulting in a low borrowing cost. Utilities still have to recover the cost of payments, typically through rate increases or bill surcharges through the maturity period of the investment vehicle.

A hybrid method of funding presently being proposed by Florida Power and Light (FPL) is to have local governmental entities requesting underground conversion to pay 75% of the initial cost while FPL pays the remaining 25%. The cost of the FPL contribution would be recoverable in rates from the general body of customers, but FPL anticipates that this cost would be offset by avoided storm restoration costs.

8 Conclusions

Undergrounding has been a topic of discussion in Florida for more than twenty years, and has been examined multiple times at both the state and local level. Except in special circumstances, overhead construction is the standard for electric distribution due to least cost. Therefore electric utilities may not be required, choose or be able to underground service at their own cost. There have been many municipal studies to investigate undergrounding. No study recommends broad-based undergrounding, but several recommend targeted undergrounding to achieve specific community goals.

A review of relevant previous undergrounding studies done in Florida as well as literature on the subject from throughout the U.S. and around the world shows clearly that the conversion of overhead electric distribution systems to underground is expensive and, except in targeted situations (such as undergrounding as part of a road widening), cannot be 100% justified based quantifiable benefits. Therefore, justification almost always must rely on qualitative and often intangible aesthetic benefits. This conclusion is reached consistently throughout many reports.

Undergrounding Involves Considerable Additional Expenses

As rough estimate, the cost of undergrounding overhead electric distribution lines and equipment is expected to average about $1 million per mile of line. In addition, individual customers would face a separate cost to convert their service and meter facilities so they are compatible with the newly undergrounded system providing them power. Further, there are separate costs associated with placing third-party attachments underground.

When only considering the direct utility cost of undergrounding, the most recent FPSC study estimated that undergrounding residential neighborhoods in Florida will cost an average of about $2,500 per residential customer affected. Undergrounding residential main-trunk feeders in Florida will cost an average of about $11,000 per residential customer affected. Undergrounding all main trunk commercial feeders in Florida will cost an average of about $37,000 per commercial customer affected. These studies are based on the service territories of investor-owned utilities and could be much higher for rural areas of low customer density served by some cooperatives.

It is important to keep in mind that costs in any particular situation could vary widely from these estimates depending upon electric system design and standards, customer density, local terrain and construction access issues, and building and service type. But overall, working with these average costs, one can estimate that wholesale conversion of overhead electric distribution system to underground would require that electricity rates increase to approximately double their current level for typical investor owned utilities, and increase even more for cooperatives serving areas of low customer density.

Undergrounding Provides a Number of Benefits

In return for this considerable increase in electric cost, Florida electric ratepayers would receive a number of benefits from the underground conversion of overhead systems. The following is a list of benefits most often mentioned in undergrounding reports and studies:

Potential Benefits of Underground Electric Facilities

- Improved aesthetics;
- Lower tree trimming cost;
- Lower storm restoration cost;
- Fewer motor vehicle accidents;
- Reduced live-wire contact;
- Less damage during severe weather;
- Fewer outages during normal weather;
- Far fewer momentary interruptions;
- Improved utility relations regarding tree trimming;
- Fewer structures impacting sidewalks.

Further Costs Needed to Obtain Complete Aesthetic Benefits

Nearly every study and examination of overhead to underground conversion notes in some manner that removing the poles, overhead lines and equipment, and in some cases above-ground facilities required for the overhead utilities will improve the visual appeal – the aesthetics – of an area, be it residential or commercial property. Opinions and analytical studies of the value of this aesthetic improvement differ widely as to results, but no studies examined in the meta-analysis reported here concluded that aesthetics had a *quantifiable* monetary benefit that substantially affected the overall benefit/cost ratio for the conversion.

Regardless, there is no doubt that some municipal governments, developers, businessmen, and homeowners value aesthetic improvement highly, because some pay the very considerable differential for underground service themselves.

Electric system conversion by itself will *not* always result in aesthetic improvement. The electric service reliability improvements, utility cost changes, and hurricane-hardening improvements sought by the FSPC and other stakeholders in Florida and discussed here are obtained by converting *only the overhead electric system* to underground. In many cases, the remaining utilities would still be overhead, and no substantial improvement in aesthetics would be gained. It is vital to keep this point in mind because an unmeasured or intangible benefit attributed to underground conversion in many studies, and no doubt expected by many municipalities and electric customers, is precisely this type of desired aesthetic improvement.

There is a further cost to obtain aesthetics benefits beyond just the cost of undergrounding electric utilities. This is the cost necessary to relocate all remaining utilities underground such as telephone, cable television, and broadband fiber. Most often this additional cost is estimated at somewhere between 10% and 30% beyond the cost of the electric underground conversion.

Potential Disadvantages of Undergrounding

There are a number of potential disadvantages that need to be considered whenever the conversion of overhead facilities to underground is evaluated. The following is a list of potential disadvantages most often mentioned in undergrounding reports and studies:

Negative Aspects

- Stranded asset cost for existing overhead facilities;
- Environmental damage including soil erosion, and disruption of ecologically-sensitive habitat;
- Utility employee work hazards during vault and manhole inspections;
- Increased exposure to dig-ins;
- Longer duration interruptions and more customers impacted per outage;
- Susceptibility to flooding, storm surges, and damage in post-storm cleanup;
- Reduced flexibility for both operations and system expansion;
- Reduced life expectancy;
- Higher maintenance and operating costs;
- Higher cost for new data bandwidth.

Financing Options

All the reports and references reviewed in the meta-analysis conclude that undergrounding incurs a very substantial additional cost, even if they differed substantially on what that cost was and how much of it was justified based on benefits obtained. Ultimately, these undergrounding costs must be paid if the conversion is to be done. There are many funding options to cover these costs, and selecting the most appropriate financing approach is a critical part of the overall undergrounding process. The following are methods of financing that are most often cited in reports and studies:

Basic Financing Options

- Higher electricity rates;
- Higher taxes;
- Customer funded;
- Special tax districts;
- Utility set asides;
- Federal funding;
- Private sector funded.

Overall Conclusion

The Florida Public Service Commission as well as many municipalities and electric customers in Florida are interested in undergrounding electric distribution systems in order to improve aesthetics, improve reliability of service, and reduce vulnerability to hurricane damage. The benefits associated with improved aesthetics are not quantifiable. Without considering aesthetics, no study reviewed in this report concludes that wholesale conversion of overhead electric distribution lines to underground can be fully cost justified.

In summary, a review of the body of public knowledge on the undergrounding of electric distribution facilities reveals the following:

Summary of Literature Review on Electric Distribution Underground Conversion

- No state is requiring extensive undergrounding of existing distribution facilities;
- Conversion of overhead facilities to underground is rarely justified on the basis of costs and quantifiable benefits presented in existing studies;
- *Ex post* analyses on actual underground conversion projects have not been done;
- Few studies address the negative impacts of undergrounding;
- Few studies consider strengthening existing overhead systems as a potential cost-effective alternative to underground conversion;
- There are almost no academic or industry publications that address storm reliability modeling of electric distribution systems;
- Until last year, there was no academic or industry literature that addressed failure rates during hurricanes as a function of hurricane strength;
- Existing research on mitigating the impacts of major storms on electric distribution systems is not sufficient for use in a detailed study.

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This paper is essentially the same as 7, but presented at a different conference.

9. Chowdhury, A. A., and D. E. Custer. 2004. "A Value-Based Probabilistic Approach to Designing Urban Distribution Systems." Proceedings of the 8th International Conference on Probabilistic Methods Applied to Power Systems, 939-946, Sept. 12- 16. Ames, Iowa: Iowa State University.

The overall outcome of this analysis is that capital costs can be directed towards system improvements that will have the most societal benefits. This paper presents a value-based urban distribution system planning model for the determination of items such as effective section length for switch placement on the main distribution feeder lines, the number and optimal placement of switches on the main feeder, and transformer loadings. Customer cost numbers are based on surveys specifically done for MidAmerican Energy.

10. Commonwealth of Virginia State Corporation Commission. 2004. Special Report of the Division of Energy Regulation, Preparation for and Response to Hurricane Isabel by Virginia's Electric Utilities. Richmond, Virginia.

This report presents the results of on analysis by the Virginia State Corporation Commission Staff of the preparedness and responsiveness of the state's electric utilities relative to power outages and service restoration following Hurricane Isabel. The report specifically states that it does not address issues of undergrounding, which was studied under a separate House Joint Resolution (see 11). The report concludes that that overall preplanning and restoration efforts were satisfactory.

11. Commonwealth of Virginia State Corporation Commission. 2005. Placement of Utility Distribution Lines Underground, Report to the Governor and the General Assembly of Virginia. Richmond, Virginia.

This comprehensive report examines the costs and benefits of undergrounding the distribution system in Virginia. It has a good breakdown of undergrounding impacts including costs and benefits, and looks at the expected levelized dollars associated with each cost and impact (cost and reliability are shown to be the most important impacts). The analysis shows that undergrounding would require an additional $3,000 per year per customer, but customer willingness to pay is estimated to be about $180 per year. When tallying itemized benefits instead of customer willingness to pay, total societal benefits are estimates at $3.9 billion per year as compared to costs of $10.6 billion per year. These benefits include an estimated $40 million per year in storm restoration cost reduction. Some interesting finding of this report include the following: (1) overhead systems have more flexibility with respect to post-fault circuit reconfiguration, (2) overhead systems can more readily withstand overloads, and (3) O&M costs are similar for overhead and underground systems. The report includes a case study of Ocean View which concludes that the primary benefit of undergrounding is improved aesthetics. The report also summarizes the conclusions of previous studies including the EEI undergrounding report (14), the North Carolina undergrounding report (28), an undergrounding task force report in Maryland, and the Australian undergrounding working group report (55).

12. DG TREN/European Commission. 2003. Overview of the Potential for Undergrounding the Electricity Networks in Europe, Final Report. By ICF Consulting Ltd. London.

This report is primarily focused on new transmission lines in Europe. As such, its relevance to the undergrounding of existing distribution lines in Florida is minimal. The report does address the cost and benefit of undergrounding distribution, but does so by referencing Australian studies (49, 52, 54). Of interest is its analysis of electromagnetic fields. Research shows that underground cables eliminate electric fields, but produce higher magnetic fields (at ground level) when compared to overhead lines.

13. Edison Electric Institute. 2004. Utility Storm Restoration. By Bradley W. Johnson. Washington, D.C.

This report examines utility responses to 44 major storms that occurred between 1989 and 2003 (including 11 hurricanes). Data comes from survey responses from 6 utilities. The report also presents 2 case studies: (1) the 2002 North Carolina ice storm with data from Progress Energy and Duke, and (2) the Baltimore Gas & Electric response to Hurricane Isabel in 2003. The report shows that the re-

sponding utilities have improved their ability to quickly repair significant damage done by major storms. They are deploying workers more efficiently, power is being restored quicker and the overall duration of storm outages is decreasing. A lack of data precludes general conclusions on a nation-wide or industry-wide basis. This report does not discuss undergrounding.

14. Edison Electric Institute, Out of Sight, Out of Mind? A Study on the Costs and Benefits of Undergrounding Overhead Power Lines, by Bradley W. Johnson, July 2006.

    This is perhaps the best known resource on undergrounding, and is an important reference for nearly all recent undergrounding investigations. It was originally written in January 2004, but was updated in July 2006 to include references to recent documents such as the Navigant study for LIPA (24). Readers should be aware that these documents effectively reference each other, potentially creating a false sense of industry consensus on certain undergrounding issues. The report discusses issues related to reliability, cost, benefits, customer willingness-to-pay, and payment alternative. The contents of this report are discussed in detail in the body of this document, but the general conclusions are that (1) many residential customers are interested in undergrounding, but are not aware that this will involve an approximate upfront cost of about $5,000, a doubling of electricity rates, and an increase in telephone and cable bills, (2) the reliability advantages of underground systems are not as great as commonly thought, and (3) the biggest benefit is aesthetics, which is difficult to quantify but has been large enough in certain cases to justify the cost.

15. Florida Public Service Commission. 2005. Preliminary Analysis of Placing Investor-Owned Electric Utility Transmission and Distribution Facilities Underground in Florida. Tallahassee, Florida.

    This is must reading for everyone involved in Florida undergrounding, and builds upon a 1991 commission study on undergrounding. It estimates that complete distribution undergrounding in Florida would result in an 81% rate increase for ten years if costs were allocated over all customers, and a 141.5% increase if costs were allocated over just residential customers. These increases only pay for direct utility costs and do not consider the cost of undergrounding other facilities such as telephone and cable television. The report has extensive sections on general overviews of the Florida distribution infrastructure and on the 2004 hurricane season. It then discusses (1) cost assumptions behind the aforementioned rate increases, (2) financing options, (3) hardening overhead systems as an alternative to undergrounding, and (4) other studies, reports, and state regulation. This report is careful not to make any value judgments; its purpose is "to develop a ballpark estimate of the cost for investor-owned electric utilities to place existing electric transmission and distribution facilities in Florida underground."

16. Fort Pierce Utilities Authority. 2005. Draft Report of Qualitative Advantages and Disadvantages of Converting Overhead Distribution Facilities to Underground Facilities within the Service Territory of the Fort Pierce Utilities Authority. By Hi-Line Engineering LLC. Fort Pierce, Florida.

    This report, prepared for the Fort Pierce Utilities Authority by Hi-Line Engineering, LLC, presents an analysis of issues related to converting overhead electric power distribution facilities in the city of Fort Pierce and portions of St. Lucie county served by the Port Pierce Utilities Authority to underground facilities. The report's scope is limited to electric distribution. It does not address transmission or substation facilities. It presents numerous detailed cost comparisons of underground versus

overhead distribution materials costs for various elements of distribution (specific to Fort Pierce only). It itemizes and addresses a wide range of operational and practical issues that are involved in comparing underground and overhead distribution, such as equipment inventory complexity, underground utilities congestions, electrical losses, power factor correction, load cycles, equipment lifetime, easement availability, and others. The report concludes that wholesale conversion of overhead distribution facilities cannot be supported based on research and economic issues and benefits. However, it notes that conversion of selected portions of the Fort Pierce Utilities' distribution system should be considered for underground conversion and that a case can be made for undergrounding overhead single phase taps in residential areas. In addition, it notes that hardening of existing overhead facilities for higher wind loading, while having a higher material cost, may provide benefits that outweigh the costs.

17. Friends of the Lake District. 2002. The Scope for Undergrounding Overhead Electricity Lines. By Richard Cowell, UK Centre for Economic and Environmental Development. Peterborough, United Kingdom.

This report was prepared for the Friends of the Lake District, a charity that states it "works to protect and enhance the landscape of the Lake District and Cumbria" in the UK, by the UK Centre for Economic and Environmental Development, a group that provides "practicable sustainable development solutions." A good deal of this report centers on aesthetic and land-value benefits of underground lines as compared to the benefits or advantages of overhead lines. It is mostly concerned with public policy issues with regard to overhead versus underground conversion.

18. Gustavsen, Bjørn, and Lars Rolfseng. 2004. "Asset Management of Wood Pole Utility Structures." Proceedings of the 8th International Conference on Probabilistic Methods Applied to Power Systems, 975-979, Sept. 12- 16. Ames, Iowa: Iowa State University.

This paper describes two probabilistic approaches for evaluating the economic impacts of alternative maintenance strategies, design strategies, and compensation fees for undelivered energy.

19. James Lee Witt Associates, LLC. PEPCO Holdings, Inc., Hurricane Isabel Response Assessment. May 2004.

This report looks at whether undergrounding would avoid system outages resulting from future storms. Although it recognized that underground systems will perform better during major storms, it may never be cost-effective to underground already built systems except in certain situations such as community redevelopment projects. This report also notes that the destruction of vegetation while undergrounding could cause erosion due to lost vegetation.

20. Hallstrom, Daniel G., and V. Kerry Smith. 2005. "Market Responses to Hurricanes." Journal of Environmental Economics and Management, 50(3): 541–561.

This paper uses one of the strongest hurricanes to hit the US, Andrew in 1992, to define a random experiment that permits estimation of the responses of housing values to information about new hurricanes.

21. Levi, V., G. Strbac, and R. Allan. 2005. "Assessment of Performance-Driven Investment Strategies of Distribution Systems Using Reference Networks." Proceedings of Generation, Transmission and Distribution, Vol. 152, Issue 1, 1- 10. New York: IEEE.

This paper discusses the functions of the Office of Gas and Electricity Markets in the UK which addresses the trend towards performance-based regulation. To achieve this, a methodology is needed that enables the reliability performance associated with alternative investment strategies to be compared with the investment cost of these strategies. The approach, its implementation in conjunction with a number of distribution companies, and its effectiveness when approached using the underground part of a real system are described in this paper.

22. Li, Wenyuan.2002. "Incorporating Aging Failures in Power System Reliability Evaluation." IEEE Transactions on Power Systems, 17(3): 918-923.

The paper presents a method to incorporate aging failures in power system reliability assessment .It includes development of a calculation approach with two possible probability distribution models for unavailability of aging failures and implementation in reliability assessment. The results indicate that aging failures have significant impact on system reliability, particularly for an aged system. The paper concluded that if aging failures in reliability assessment of an aged power system is ignored, could result in an overly underestimation of system risk and maybe a misleading result in system planning.

23. Lim, Tae-Jin, and Chang H. Lie. 2000. "Analysis of System Reliability with Dependent Repair Modes." IEEE Transactions on Reliability, 49(2): 153-162.

This paper proposes an imperfect-repair model for repairable systems where two repair modes, perfect and minimal, occur in accordance with a Markov chain. This paper most addresses mathematical modeling issues with respect to valid analysis methods for power system reliability, but presents no useful practical results with respect to undergrounding cost or benefits.

24. Long Island Power Authority. 2005. A Review of Electric Utility Undergrounding Policies and Practices. By Navigant Consulting Inc. Long Island, New York.

In addition to discussing the specific situation at LIPA, this study presents a comprehensive review of undergrounding literature, and is one of the best current references on the subject. Topics covered include the following: industry trends, policies in New York State, the EEI report (14), California Rule 20 (47), Colorado System Improvement Fund, Florida Underground Assessment Areas, Maryland undergrounding studies, Maine undergrounding studies, North Carolina Undergrounding Study (28), Oklahoma underground studies, and the Oregon City of Portland undergrounding study. The contents of this report are discussed in detail in the body of this document, but the general conclusions are that (1) the costs and resources required for undergrounding rarely justify the benefits except in targeted situations, (2) the reliability advantages of underground systems are not as great as commonly thought, and (3) undergrounding programs can realize the greatest potential when coordinated with governmental programs.

25. Maney, C. Thomas. 1996. "Benefits of Urban Underground Power Delivery." IEEE Technology and Society Magazine, 15(1): 12 – 22.

This paper talks about the benefit of placing distribution power delivery underground. The paper seems to be in contrary to most papers on the topic, in that it approaches the benefits of under grounding from a societal point of view. In doing so, the paper mentions the high cost to the public due to electrocution and vehicle-pole accidents. The paper states that as per the National Safety Council "the cost to the public for loss of life due to electrocution and vehicle-pole accidents can be as much as $3 to $5 million per life. In addition to that, the paper mentions that in Florida between the years 1981-1993 there were 57.73 times more fatalities associated with overhead contact than with underground contact on a per-mile basis. The author talks about the possible linkage between proximity to electric power lines and cancer, mentioning that this public fear or concern causes a corresponding reduction in property values. The paper talks about how utilities perhaps do not properly consider new reliable and affordable technologies for undergrounding, and implies that utilities tend to use the higher cost of undergrounding materials or technologies when conducting a benefit-cost analysis.

26. Moon, Jong-Fil, Jae-Chul Kim, Hee-Tae Lee, Chang-Ho Park, Sang-Yun Yun, and Sang-Seung Lee. 2004. "Reliability Evaluation of Distribution System through the Analysis of Time-Varying Failure Rate." Power Engineering Society General Meeting. Vol. 1, 668- 673, June 6-10. New York: IEEE.

This paper compares the reliability of a distribution system using the mean failure rate (MFR) and the time varying failure rate (TFR), which is extracted from real failure data obtained from the Korean Electric Power Corporation (KEPCO).The TFR is approximated to a bathtub curve using the Weibull distribution function. The paper states that reliability assessments using TFR is more accurate than using MFR.

27. Docket No. 98-026. State of Maine Public Utilities Commission. Inquiry into the Response by Public Utilities in Maine to the January 1998 Ice Storm. Dec. 1998.

This report concludes that although undergrounding would have some positive effects (e.g., aesthetics, fewer outages, less susceptible to weather events), it would also have noticeable negative effects (e.g., longer outages, high susceptibility to flooding, problematic winter access). It cites Central Main Power estimates that undergrounding would increase average monthly bills by $95. The conclusion of the report is that the benefits of undergrounding do not justify the costs, but that utilities should continue to monitor the cost of undergrounding projects and related new technologies.

28. North Carolina Natural Disaster Preparedness Task Force. 2003. The Feasibility of Placing Electric Distribution Facilities Underground. By the North Carolina Public Staff Utilities Commission. Raleigh, North Carolina.

This report was a result of the December 2002 ice storm, which resulted in interruptions to about two million North Carolina customers. The report examines both the cost and man-hours required for undergrounding the North Carolina distribution systems of Progress Energy, Duke, and Dominion. It concludes that rates would increase by about 125%, and would take approximately 25 years to complete with a dedicated workforce of 5,000 people. This report has some interesting observations such *as: (1) O&M costs for urban underground systems are 4 times larger than urban overhead systems, and (2) a typical new underground system has an expected life of 30 years while a typical new overhead system has an expected life of 50 years.*

29. Pahwa, Anil. 2004. "Effect of Environmental Factors on Failure Rate of Overhead Distribution Feeders." Power Engineering Society General Meeting. Vol. 1, 691- 692, June 6-10. New York: IEEE.

    This is a summary paper of a presentation, and does not contain any data. The topic of the paper is how to compute site-specific failure rates for overhead lines considering factors such as tree density and wind exposure.

30. Pérez, Duque O., Martin F.J. Bueno, and Del Alamo y Del Sarmiento. 1996. "Inclusion of Preventive Maintenance and Weather Conditions Influence in Reliability Analysis of Distribution Networks Using Minimal Cut Set - Markov Processes Mixed Techniques." Proceedings of the 8th Mediterranean Electrotechnical Conference on Industrial Applications in Power Systems, Computer Science and Telecommunications. Vol. 3, 1649–1652, May 13-16. New York: IEEE.

    This paper presents a method for the reliability evaluation of distribution networks, including the influence of the weather on the failure rates of the components, and the possibility of preventive maintenance. This paper describes a mixed technique combining the use of the minimal cut set method with a model based on Markov homogeneous processes of a discrete state-space. This technique has been applied to several examples of distribution networks, including open-air, underground and mixed networks.

31. Pylvänäinen, Jouni, Jussi Järvinen, Pekka Verho, Susanna Kunttu, and Janne Sarsama. 2004. "Advanced Reliability Analysis for Distribution Network." Proceedings of the 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies, Vol. 2, 457–462, April 5-8. New York: IEEE.

    This paper presents a reliability analysis methodology for a distribution network in order for utilities to manage costs and improve reliability simultaneously. Failure rate models and customer outage times in different fault situations have been analyzed in this paper to help determine financial impacts and results.

32. Radmer, Duane T., Paul A. Kuntz, Richard D. Christie, Subrahmanyam S. Venkata, and Robert H. Fletcher. 2002. "Predicting Vegetation-Related Failure Rates for Overhead Distribution Feeders." IEEE Transactions on Power Delivery, 17(4): 1170-1175.

    This paper presents models that could be used to predict the time-varying, vegetation-related failure rates of overhead distribution power lines. Several direct failure-rate models based on vegetation growth parameters were developed and evaluated using historical data, because existing vegetation growth models were found to be unsuitable for this purpose, as they were not developed for the vegetation encountered along distribution feeders. The models evaluated were the linear, exponential, multivariable and artificial neural network (ANN). The multivariable linear model proved to be the most accurate in predicting unknown failures, but the ANN model fits the data well. The paper states *that the inclusion of additional climate and environmental inputs such as tree density, soil characteristics, and sunlight exposure maybe useful to enhance the accuracy of the failure-rate models. The paper states that, "For a utility in the northwest US, the annual cost of the clearance maintenance is approximately 30% of the total distribution system maintenance cost and 8% of the total distribution system operations and maintenance cost." This paper methodology applies only to situations requiring reliability assessments of different tree trimming cycles and does not cover other costs and benefits.*

33. Retterath, Brad, S. S. Venkata, and Ali A. Chowdhury. 2004. "Impact of Time-Varying Failure Rates on Distribution Reliability." Proceedings of the 8th International Conference on Probabilistic Methods Applied to Power Systems, 953-958, Sept. 12- 16. Ames, Iowa: Iowa State University.

    This paper examines the impact of components with time-varying failure rates on distribution reliability by comparing the reliability of a distribution system using time varying failure rates to a distribution system using constant failure rates. The study used exponentially distributed models for modeling the component failure rates along with time-sequential Monte Carlo simulation to demonstrate the effect of time varying failure rates. The paper examines how the reliability of a system at different points in time changes depending on the state of the components. The paper concludes by stating that when a system experiences conditions such as weather related events, time -varying repair rates and maintenance times may result in a more accurate representation of actual system reliability. In addition, the paper states that time varying failure rates are important for estimating the cost of interruption to the customer.

34. Stillman, R. H. 2000. "Modeling Failure Data of Overhead Distribution Systems." IEEE Transactions on Power Delivery, 15(4): 1238-1242.

    This paper presents a methodology in which a distribution system is modeled as a repairable system. It mainly talks about using the homogeneous poison process (HPP) and the non homogeneous Poison process (NHPP) as the stochastic process models applied to repairable systems.

35. Tahoe Donner Association. 2006. Undergrounding Feasibility Study, Final Report. By CVO Electrical Systems. Truckee, California.

    This report was prepared by CVO Electrical Systems for the home and business owners in the Tahoe Donner subdivision in Truckee California, which includes approximately 6500 homes and commercial structures. The report looks at the conversion of all overhead utilities, including electric, telephone, cable TV, and fiber broadband, to underground throughout the entire subdivision. It presents a comprehensive evaluation of equipment, labor, and inter-utility and permitting as well as other issues expected to be encountered during conversion, and gives a construction sequence and schedule of work over a seven year period. Estimated cost of the conversion of public utilities is $25,000 per home or business owner, which would be paid for through creation of a "special district" that would borrow money for the conversion and then assess owners $2,586 per year over a 15-year period to pay off the debt. Home and business owners would also have to pay separately for conversion of their overhead utilities service facilities (e.g., for electric, the service drops, service entrance/meter box, etc.) which is estimated at between $5,000 and $12,000 per customer depending on type and location. A majority of this cost is related to electrical service facilities.

36. Wang, Peng, and Roy Billinton. 2002. “Reliability Cost/Worth Assessment of Distribution Systems Incorporating Time-Varying Weather Conditions and Restoration Resources.” IEEE Transactions on Power Delivery, 17(1): 260-265.

This paper incorporates the effects of variable weather conditions and restoration resources into the reliability evaluation of distribution system by using the concept of time-varying failure rates(TVFR) and restoration times (TVRT). It considers chronological issues and system random behavior. Time sequential simulation techniques are presented. The paper states that in general, time-varying failure rates result in a large increase in the unreliability cost indices for frequency sensitive load and a slight increase for the others. The paper also states that time varying restoration times have significant impact on the unreliability cost indices. This paper introduces the Reliability Worth of Disconnect Switches (RWSA) and the Reliability Worth of Alternative Supply (RWAA).The results shows that some load points benefit considerably from the installation of disconnect switches and some do not. The results also show the RWAA for some load points increasing significantly. The paper concludes by stating that to replace the manual switch device with automatic devise and to cut restoration times is a very important measure to reduce customer interruption costs.

37. Zhang, Pei, Stephen T. Lee, and Dejan Sobajic. 2004. “Moving Toward Probabilistic Reliability Assessment Methods.” Proceedings of the 8th International Conference on Probabilistic Methods Applied to Power Systems, 906-913, Sept. 12- 16. Ames, Iowa: Iowa State University.

This paper describes how the probabilistic reliability method can be used in assessing transmission system reliability. This method offers greater insight into potential failure modes by including interaction, situation, root cause, weak point, and probabilistic margin analysis. However, this paper is not directly applicable to distribution systems.

<u>Additional References Supplied by Project Sponsors</u>

38. University of South Florida College of Engineering. A Citizen’s Initiative: Evaluating the Benefits of Underground Utility Distribution. Final Report submitted to the Florida Department of Community Affairs. July 31, 1999.

This research project was initiated to re-evaluate results from the 1991 Florida Public Service Commission report on undergrounding considering new cost data and new benefit data. The focus of the research is on undergrounding benefits due to reduced storm damage, fewer electrocutions, and increased property values. The initial report concludes that conversion to underground would be cost effective due to lower external, operation, and maintenance costs, and because of increased real estate values. However, this conclusion was not based on cost estimates derived from engineering design studies. Follow-on activities from this initiative appear to have ceased without any definitive recommendations and the official website, http://ee.eng.usf.edu/DavisIslands-UCRP, seems to be last updated in 2002.

39. Florida Municipal Underground Utilities Consortium. 2006. "Cost Effectiveness of Undergrounding Electric Distribution Facilities in Florida." By Power Services Consultants, Wake Forest, NC.

This report on undergrounding of overhead power distribution facilities addresses the direct, quantifiable costs and benefits of installing, operating, and maintaining underground power lines in lieu of overhead lines, which it notes does not include social and long-term economic benefits. The report compares the cost of underground lines only to the cost of hardened overhead lines on the basis of initial, O&M, and other utility costs, and quantifies a wide range of utility, customer, and societal benefits and savings in order to compute the monetary benefit and costs. It cites and uses data based on experience and results from several previous utility undergrounding projects including two in North Carolina that show that the reliability, customer, and societal benefits to undergrounding for hurricane damage mitigation extend inland far from the coast. This report's overall conclusion is that overhead to underground conversion should have a 50.54% base Contribution In Aid of Construction (CIAC) adjustment; a $1,000,000 overhead to underground cost differential would be reduced to $494,600 that had to be paid by the customer requesting the lines be placed underground. The rest of the cost would be borne by the general body of customers and offset by the realized expected future savings.

40. Joint Legislative Audit and Review Commission of the Virginia General Assembly. 2006. "SCC Review of Underground Electric Transmission Lines." Staff report.

This report by the Virginia General Assembly Joint Legislative Audit and Review Commission details the results of a study of criteria and policies used by the State Corporation Commission in evaluating the feasibility of underground transmission lines. It includes the cost considerations and the impact on property values. The study shows that technologies exist for undergrounding transmission lines but the costs ranged from 4 to 10 times more than overhead lines. Reliability may not be much different between the two and at best is only slightly better with underground although this may be offset by the much longer repair times. The issue of reliability under hurricane or extreme weather conditions was not mentioned. Undergrounding is generally considered for aesthetic reasons and those can be address by altering routes or modifying the types of towers used. There were limited cases where it was financially advantageous to place the lines underground for new construction. These were in locations where right of way costs were excessive and with the underground option they could be reduced. The impact of overhead transmission lines on property values is debatable but it is generally accepted to be less than 5%. Aesthetics and EMF concerns tend to drive away potential buyers but, in a "sellers market" there are usually enough buyers to keep the selling prices consistent with areas where no lines exist.

41. Martin, Pamela. 1999. "Undergrounding Public Utility Lines" Honolulu, HI: Legislative Reference Bureau.

This report on undergrounding, including both electrical transmission and distribution, was prepared for the Hawaiian State Senate by the State's Legislative Reference Bureau of the State of Hawaii. The report is based on research of data and results from other undergrounding studies, and acknowledges heavy use of prior work by the California Public Utility Commission. Over half of the report deals solely with policy and legal issues and proceedings that would need to be managed before undergrounding could proceed. Cost for conversion of overhead utilities to underground is estimated as

$1,000,000 per mile for electric lines and about one quarter of that for either telecom or cable television lines. Potential benefits of undergrounding are identified as safety and liability (fewer traffic hazards from poles), better hurricane preparedness, improved public due to changes in EMF (under some circumstances) and reduction of vegetation-management pesticide use, and particularly from aesthetics, which it notes is in keeping with a concern in the state constitutional "to preserve the natural beauty of the islands." The report notes that there are conflicting published reports and evaluations about property value increases when all utilities are undergrounded. It cites sources of data and method that had been used elsewhere to value the aesthetic improvement for tourism and natural beauty reasons and recommends they could be used in more detailed studies of the cost/benefit to the state of undergrounding utilities.

42. New South Wales, Australia Ministry of Energy and Utilities. 2002. "Undergrounding Electricity Cables"

This report was prepared in response to calls for the undergrounding of all power lines in the Sydney Basin. Its stated purpose is to examine current undergrounding programs in Australia, consider programs in New Zealand, and "canvass issues and implications for an undergrounding policy and a long term program." Of particular interest is the estimated cost per lot of undergrounding, which ranges from $3,000 to $8,000 depending on certain factors such as soil condition and average lot frontage. At these cost levels, a survey of Eastern Energy and Powercor customers showed that between 20% and 30% of customers are willing to pay for undergrounding. This report also discusses the possibility of replacing bare overhead conductor with aerial bundled cable, which would provide much of the reliability and safety benefits of undergrounding at a much lower cost. This report does not reference US or European reports on undergrounding.

43. Town of Palm Beach, FL. 2002. "State Road Utility Study." By JLSD Consulting.

This report was prepared by Johnson, Levinson, Slider, Davilia, Inc. for the Town of Palm Beach Florida, on the feasibility of relocating existing overhead distribution lines for power, telephone, and cable TV to an underground duct distribution system. The study is specific to only those facilities running along state roads in the Town, an estimated 42,900 feet of electric and TV cable lines, 60 road crossings, 52 pole mounted transformers, and 169 transitions from underground to overhead. The report is of the opinion that conversion would improve both reliability and aesthetics, and that the conversion would cost an estimated at $13.37 million. The report highlights the inconvenience and problems that the conversion might cause for local home and business owners due to traffic congestion, scheduled utility outages needed, and disruption of private paving and landscaping during construction. This report references a "Town Roads Utility Study," also prepared by JLSD, which addresses utilities running along town-owned roads as opposed to state-owned roads. The "Town Roads Utility Study," is not included as a reference in this report.

44. Town of Palm Beach, FL. 2004. "Undergrounding Utilities Staff Report." Submitted by Thomas G. Bradford, Assistant Town Manager.

This report, prepared by the Assistant Town Manager of the Town of Palm Beach, Florida, was meant to address undergrounding the State Road Utility Study (43) as well as studies done for conversion of overhead utilities on Town (as opposed to State) roads. The reports estimates that the total cost of conversion of all underground facilities along state and town roads within the Town would re-

quire $54.27 million. However, it recommends that only about $21 million of the work —that on state roads as well as north-south Town roads – be done, because this would convert "all major routes of ingress and egress within the Town . . . addressing both aesthetic and public safety issues associated with evacuation and post disaster response capabilities following a direct hit of the island by a hurricane." The report notes that this cost does not include the cost of converting utilities service equipment (service drops, service entrance and meter box, etc.) on affected properties to underground service, at an estimated $5,000 per home and $8,750 per business in those affected properties. It identifies the question of who pays for these costs as a policy issue the city would have to resolve in advance of the conversion.

45. Town of Palm Beach, FL. 2006. "Conversion of Aerial to Underground Utilities Analysis". By R. W. Beck, Goodlettsville, TN.

This report was prepared R. W. Beck for the Town of Palm Beach Florida, on the feasibility of relocating existing overhead utility to an underground system. It makes use of information from previous studies (43-44) as well as other sources and estimates the total cost to convert overhead and underground utilities at $60.3 million, affecting service to the Town's entire utility customer base, given as 2,851 homes and businesses. $32 million of that total is for electric utility conversion. The report notes that trenching represents the vast majority of total cost (over 83%) and that joint trenching would save about $1.5 million. The report notes that the cost for converting utilities service equipment (service drops, service entrance and meter box, etc.) on affected properties to underground service would not be high, because most homes and businesses have underground service already, due to existing town ordinances.

<u>Additional References Supplied by Quanta</u>

46. Allen Consulting Group. 1997. "Putting Cables Underground: Applicable Principles of Public Finance." Report to PCU Working Group, Melbourne, Australia.

This report examines the costs and benefits of undergrounding distribution systems in Australia. It is one of several reports related to a more comprehensive study for a state sponsored working group on putting cables underground (PCU Working Group). It focuses on principles of public finance for the evaluation of funding options for undergrounding. It contains information related to two case studies to illustrate the way in which the principles might be applied to other cases. The case studies contain average costs for 2,731 residential lots. They indicate an average cost of $5,500 (converted to USD in 1997) per lot to convert to underground. Actual lot charges varied widely ranging from $1,000 to $38,000. The report does not indicate whether or not this included all costs associated with undergrounding each area or if it is just the facilities associated with each customer. It makes the point that a community should receive the level of undergrounding for which it is willing to pay. Funding options considered include charging each ratepayer a fixed contribution irrespective of property value, charging according to property value and charging according to property frontage. Responses to surveys conducted in the case study areas indicated between 80 and 85% of the customers were in favor of the conversion and 70% were willing to pay a part of the cost. It should be noted that less than 40% of the customers responded to the surveys. The conversion was being justified based on visual impact, reliability impact, and maintenance savings. It contains an extensive summary of benefits to undergrounding. No firm conclusions are drawn from the report regarding the most efficient and equitable solutions.

47. California Public Utilities Commission Tariff Rule 20. 2002. "Replacement of Overhead with Underground Electric Facilities.”

This document explains the policy of Pacific Gas & Electric (PG&E) for conversion of overhead to underground. For a city or municipality to initiate an active undergrounding program it first requires a proof of need related to excessively heavy concentration of overhead lines, susceptibility to vehicular issues, proximity to areas of scenic interest, or lines along major thoroughfares. It references a PG&E budgeted amount for undergrounding within a city that has an active undergrounding program but does not contain any specific cost information. There are also allowances for other situations such as individual customers or small groups of customers which generally requires a non refundable up-front payment equal to the conversion cost along with written agreements to make the necessary wiring changes to the meters to accept underground service from all property owners.

48. Commonwealth Department of Transport and Regional Development. 1997. “Measuring the Benefits of Putting Cables Underground.” PCU Working Group report, Melbourne, Australia.

This report was part of the PCU Working group previously mentioned in the Allen Group report (46). To identify benefits, the report draws extensively on the available literature and on consultations with representative stakeholders. It cautions that considerable care should be taken to avoid the possibility of double counting benefits (i.e., ensure that different manifestations of the same benefit are not counted as separate benefits). In assessing the importance of each benefit, the report considers its likely magnitude and significance to the issue of undergrounding aerial cables. It states that the value of most benefits is highly subjective and difficult to quantify. For each identified benefit, the report also considers the availability of data likely to lend themselves to the derivation of direct or indirect estimates of the value of the benefit. Where direct measurement of a benefit is not possible, the report considers the feasibility of applying indirect valuation techniques to derive an estimate. The benefits and costs identified in the report fall into three broad categories in terms of their significance to the issue of undergrounding aerial cables: significant, moderate and low. For each benefit it shows whether or not a methodology and data exist to quantify it, the relative difficulty in measuring it, and the significance of the benefit. The report contains no specific cost data. It also references a report by the Florida Public Service Commission in 1991, titled “Report on Effectiveness of Underground Electric Distribution Facilities, Volume I and II, Miami.”

49. City of Tallahassee, FL. 2003. “Comparison of Impacts of Overhead versus Underground Transmission Line Construction.” Summary of consultant report related to Eastern Transmission Line Project.

This is a summary of a consultant report done for the City of Tallahassee on impacts of overhead versus underground transmission line construction. It highlights only one point, that underground lines require trenching and therefore have a environmental impact on streams, wetlands, and “sensitive species” locations that they cross, whereas overhead lines can hang from poles overhead and not disturb the same areas. The report does note that there are potential reliability impacts of underground lines but states that the Tallahassee transmission system has been out of service only 30 minutes due to hurricane winds in the past 17 years, and that “the economic benefits associated with underground electric facilities are, in most cases, minimal compared to the difference in the cost of installation.”

50. Economic Subcommittee of the Putting Cables Underground Working Group. 1997

This is a report outlining a preliminary assessment of the funding options previously presented in Ref. 46 to the Putting Cables Underground Working Group in Australia. For each option discussed the public pays everything minus any savings due to avoided costs (such as reduced maintenance) by the utilities. It also details principles to assist in considering whether any program of putting cables underground should proceed, who should decide whether it should proceed, and the equity and efficiency of different options for funding such a program. The principles do not in themselves provide a definitive answer but rather serve as an analytical framework to assist decision-making about funding options. The benefits accruing from reductions in tree trimming, pole inspections, pole replacement, reductions in transmission losses and maintenance resulting from putting overhead cable underground are quantified at a high level. Other benefits such as increased property value are discussed in concept only. Costs are broken down into relative categories, including the various equipment versus labor and other factors. One point of interest is the discussion as to what level the decision to underground should be made. Making decisions at too low a level, such as individual property-owners or streets, risks significant diseconomies of scale and create free-rider effects. Their conclusion is the smallest most efficient area would be about 1,000 houses, less than a local government area. They also address upstream and downstream impacts but do not attempt to quantify them, only recognizing that they should be minimized. For example, if the price of electricity is forced up by the costs of undergrounding, this will have negative effects on downstream industries which are large users of electricity (and their customers) and negative effects on upstream industries which provide inputs into electricity production.

51. First Report on Benefits and Costs. PCU Working Group, Melbourne, Australia.

This is a follow-on report to [50]. In it the Sub-Committee finds that the main benefits are urban amenity benefits, the significant elements of which are: improved visual amenity, improved urban streetscape aesthetics and less-pruned trees. They conclude a credible national valuation of these intangible benefits cannot be achieved. In lieu of that it suggests that total costs be quantified as well as all significant benefits other than urban amenity. All funding options proposed by the Sub-Committee's First Report on Funding Options involve contributions to the total cost in relation to benefits received. After seeking contributions from all other beneficiaries this leaves a gap to be funded related to the remaining urban amenity benefits. It will then be a decision for those funding that share of the costs to decide whether to proceed and determine whether the local urban amenity benefits are valuable enough to them to justify funding the related share of the costs. The overall local area benefits and costs model will include maintenance benefits, benefits from reduced interruptions to supply, possible benefits from reduced transmission losses and benefits from reduced tree-trimming costs. In addition external benefits from reduced motor vehicle/pole accidents and reduced electrocutions are to be considered.

52. Hydro Quebec. 2004. "Power Line Undergrounding (PL UNDERGROUND) Program." Local utility rules and regulations for undergrounding facilities.

This document is made to be given to the public and describes Hydro Quebec's Power Line Undergrounding (PLUG) program. There are three options considered: underground extensions in new residential developments, undergrounding of existing power systems in municipalities, and under-

grounding of existing power systems in heritage sites. The only benefits mentioned are aesthetics and increased value to the home (no explanation is given). Underground versus overhead differential costs are shown as $1,700 USD per house. There is mention of new concepts and technologies that make the process more affordable but no details are given. They have US$85 million available for undergrounding programs in selected municipalities and sites of interest. For municipalities the city pays 100% of the withdrawal costs of the overhead equipment and 70% of the new underground system while Hydro Quebec absorbs 30% of the new system cost.

53. Sinclair Knight Merz. 1998. "Consultancy to Investigate Potential Benefits from Putting Cables Underground." Report given to PCU Working Group, Melbourne, Australia

    The Putting Cables Underground working group in Australia commissioned this study to examine and report on the avoided costs of putting existing overhead electricity distribution assets underground. In the funding options examined by the working group avoided costs provide the basis for determining the contribution of each stakeholder to the overall cost of an undergrounding program. A model for calculating avoided costs was developed. This model uses mathematical formula relating avoided costs of reactive maintenance and preventive maintenance activities. The model was developed using data on preventive and reactive maintenance activities supplied by Australian utilities. The costs and savings or avoided costs are quantified in terms of $/km of overhead facilities. The model is useful for calculating benefits, costs and savings for overhead main line sections but does not do a detailed accounting for secondaries and services.

54. Putting Cables Underground Working Group. 1998. "Putting Cables Underground Working Group - Discussion Paper." Commonwealth Department of Communications and the Arts, Melbourne, Australia.

    This discussion paper summarizes the work conducted by the Putting Cables Underground working group, which covers technical, economic and regulatory issues. Everything in it is commented on elsewhere in References 46, 48, 50, 51, and 53.

55. T. A. Short, *Electric Power Distribution*, CRC Press, 2004.

    This excellent book has an entire chapter on underground distribution. For new construction, cost-per-foot values are given for various utilities and for various construction scenarios. Typical cost ratios for underground-to-overhead costs are also provided, as well as expected life differences and maintenance cost differences. Specific treatment of underground conversion is limited, with implications that the cost is justified only in certain instances (e.g., circuit relocation due to road widening).

56. J. J. Burke, *Power Distribution Engineering: Fundamentals and Applications*, Marcel Dekker, 1994.

    This time-tested book has a short section titled "Overhead versus Underground." It describes that the historical motivation for underground distribution was aesthetics, but that underground systems tend to have fewer sustained interruptions and can virtually eliminate momentary interruptions. Comparative failure rate data is provided, but no specific discussion on underground conversion is provided. This book is a good reference with regards to lightning protection issues.

57. H. L. Willis, *Power Distribution Planning Reference Book*, Second Edition, Marcel Dekker, 2004.

This comprehensive tome addresses undergrounding in a multitude of sections; mostly describing issues relating to aesthetics and reliability. There is a helpful section on "The Economics of Underground Cable" that discusses the implications of the high initial cost of underground systems on planning calculations such as the optimal conductor size for various load densities. No specific discussion on underground conversion is provided.

58. R. E. Brown, *Electric Power Distribution Reliability,* Marcel Dekker, 2002.

This book discusses both overhead distribution and underground distribution from a reliability perspective. It is a good reference for comparative failure rate values, and has extensive data relating to customer-cost survey data. Since undergrounding is so rarely used to improve reliability, this book only gives the topic cursory treatment in its section on "improving reliability." The book does show how overhead-versus-underground can be considered in minimizing the total cost of reliability including utility cost and customer cost.

59. R.N. Allen, R. Billinton, I. Sjarief, L. Goel, and K.S. So, "A Reliability Test System for Educational Purposes - Basic Distribution System Data and Results," IEEE Transactions on Power Systems, Vol. 6, No. 2, May 1991.

This paper presents a test distribution system for predictive reliability models. This includes separate failure rate and reliability component data for normal and storm conditions. No specific comments on normal versus storm algorithms are provided.

60. R. E. Brown, S. Gupta, R. D. Christie, S. S. Venkata, and R. D. Fletcher, "Distribution System Reliability: Momentary Interruptions and Storms," IEEE Transactions on Power Delivery, Vol. 12, No. 4, October 1997, pp. 1569-1575.

This paper presents a simulation methodology to compute expected performance during major wind storms. This includes the prediction of storm severity, restoration efforts during the storm, and post-storm restoration. Data used in this paper is not based on hurricanes, but the basic approach could be used as a basis for a hurricane simulation.

61. Final technical report prepared by KEMA for Florida Power & Light. Post Hurricane Wilma Engineering Assessment. January 12th 2006.

This report examines the performance of FPL facilities during Wilma in an attempt to better understand whether transmission and distribution structures performed appropriately. The investigation concludes that the transmission, substation, and distribution systems of FPL are designed to meet or exceed all required safety standards, and, during Wilma, performed as expected and in accordance with FPL standards. These results are based on an extensive assessment including standards, quality systems, maintenance practices, transmission performance, substation performance, and distribution performance. These results are further supported by an industry benchmark survey covering these topics, and a review on the strength of Wilma by an independent hurricane expert. Analyses in this report show detailed failure rate analyses for wood poles, including wood pole failure rates as a function of hurricane strength.