LIFE-CYCLE 2017

Connecticut Siting Council Investigation into the Life-cycle Costs of Electric Transmission Lines

Final Report

October 11, 2018

LIFE-CYCLE ANALYSIS 2017

I. INTRODUCTION

Electric transmission is used to efficiently move bulk power long distances. To provide balanced power, alternating current (AC) transmission uses three phases that work together as one to serve loads. The potential difference[1] between any two of the phases is called the "line to line voltage" or simply "line voltage." All else being equal, a transmission line with a higher line voltage is a higher capacity line. Higher voltages also reduce losses because, generally, less current[2] would be required to serve a given load, and losses are a function of the current. Under Connecticut General Statutes (CGS) §16-50i, an electrical transmission line facility has a design capacity (or line voltage) of at least 69,000 Volts or 69 kilovolts (kV). Power lines with line voltages under 69-kV would be considered distribution and thus would be outside the scope of this report.

On land in Connecticut[3], existing electric transmission has three different AC line voltages: 69-kV, 115-kV and 345-kV. However, 69-kV lines will not be considered in this report because it is not likely that Connecticut utilities will construct new (limited capacity) 69-kV lines in the future. Specifically, The United Illuminating Company (UI) does not consider 69-kV construction to be appropriate for new construction in Connecticut due to dense load characteristics and proximity to the stronger 115-kV and 345-kV transmission networks[4]. Similarly, The Connecticut Light and Power Company d/b/a Eversource Energy (Eversource) does not see any opportunities in the immediate planning horizon for the addition of new 69-kV transmission lines in Connecticut[5].

High voltage direct current (HVDC) lines will also not be considered in this report. Specifically, HVDC systems are appropriate when there is a need to transmit power over long distances or when interconnecting two systems that require isolation to preserve system reliability. UI notes that the cost of HVDC becomes competitive to AC transmission only when applied for very long distances due to the initial cost of the AC-DC converter stations[6]. Eversource further notes that, in order to provide a solution to a transmission reliability need in the State of Connecticut, HVDC lines would offer fewer system benefits than most AC options, and the HVDC option would have greater cost[7]. Thus, this report will focus exclusively on high voltage AC 115-kV transmission and extra-high voltage AC 345-kV transmission.

Transmission lines can be overhead, underground, or a combination of the two (i.e. a hybrid line). The total cost of ownership of a transmission line from its inception to the end of its useful life, including but not limited to, design, engineering, construction, operation (e.g. losses), maintenance and repair is referred to as the life cycle cost of such transmission line. Life cycle costs also provide a meaningful, objective way to compare various transmission alternative configurations over the life of the transmission line, rather than simply comparing the initial costs (known as first costs, to be discussed later).

Accordingly, CGS §16-50r(b) requires that "not less than once every five years…, the council shall establish a proceeding to investigate and determine life-cycle costs for both overhead and underground transmission line alternatives. ...The scope of the investigation shall include, but not be limited to, an inquiry of all relevant life-cycle costs, relative reliability, constraints concerning access and construction, potential damage to the environment and compatibility with the existing electric supply system." This statute requires the Connecticut Siting Council (Council) to investigate and determine life cycle costs of overhead and underground transmission line alternatives. The investigation shall include, but not be limited to, the following:

a) Life cycle costs;
b) Relative reliability;
c) Constraints concerning access and construction;
d) Potential damage to the environment; and
e) Compatibility with existing electric supply system.

On November 15, 2012, the Council issued its LIFE-CYCLE 2012 Report (LC 2012 Report). On March 30, 2017, the Council established a proceeding for the LIFE-CYCLE 2017 report. CGS §16-50r(b) also requires the Council to hold a public hearings to afford all interested persons an opportunity to be heard. At least one public hearing shall be held after 6:30 p.m. Accordingly, after providing due notice, the Council held a public comment session on May 9, 2017[8].

Two electric transmission utilities serve much of Connecticut. These are Eversource and UI. UI serves the municipalities of Ansonia, Bridgeport, Derby, East Haven, Easton, Fairfield, Hamden, Milford, New Haven, North Branford, North Haven, Orange, Shelton, Trumbull, West Haven, and Woodbridge. Eversource serves the remainder of Connecticut, except for certain municipally-served areas. Specifically, the Town of Wallingford has its own municipal utility. Other areas such as Bozrah, Groton, Norwich, Jewett City, South Norwalk, the Third Taxing District of Norwalk, and the Mohegan Tribal Utility Authority area are under The Connecticut Municipal Electric Energy Cooperative.

A. **Life Cycle Costs:** total costs of ownership of an asset or facility from its inception to the end of its useful life that include design, engineering, construction, operation, maintenance and repair of the asset.

1. 115-kV and 345-kV Overhead Transmission Lines

a. Costs incurred to design, permit and build a line – First Costs

The costs to design, permit and build a line are referred to as "First Costs." First Costs are composed of the following cost categories: poles and foundations; conductor and hardware; site work; construction; engineering, sales tax; and project management. Costs are highly project-specific, and thus, such cost data are limited to the utilities recent experience in constructing such lines in Connecticut. Land costs (or right-of-way easement acquisition costs) are not included in this report because they are highly variable and very project-specific[9]. Thus, such costs cannot be readily generalized for transmission projects across the entire State of Connecticut.

The costs in each category vary depending on the overhead transmission line configuration. In general, there are four common configurations in Connecticut for which data were readily available: 115-kV horizontal H-frame; 115-kV delta; 345-kV horizontal H-frame; and 345-kV delta[10].

The H-frame design uses vertical poles with horizontal cross-arms to make an H-pattern. The three phases are arranged at the same height above ground level, to provide what is known as a horizontal configuration. The H-frame poles and cross arms may be made of wood, or wood pole equivalent (WPE) steell[11].

Steel transmission structures can have a galvanized steel finish or a weathering steel finish. Weathering steel is designed to oxidize to a roughly red/brown finish, so it would have more of a "rustic" or "wood" look than a galvanized gray steel. Thus, weathering steel can be used as a replacement for wood structures for aesthetic reasons.

The delta design uses one pole, and the three phases are arranged in a triangular configuration. The Council has included first cost data that were provided by Eversource because Eversource has more recent data on new line construction. UI has had several recent overhead transmission line rebuild projects along the Metro-North Railroad right-of-way (ROW)[12], but a rebuild project would have slightly different cost data than a brand new line construction project, particularly for construction/engineering.

First costs provided by Eversource are noted below for new single-circuit lines on a $/mile basis as follows[13]:

Cost Category	115-kV H Frame - Wood or WPE Steel	115-kV Delta - Steel Monopole	345-kV H Frame - Wood or WPE Steel	345-kV Delta - Steel Monopole
Poles & Foundations	$401,388	$389,178	$552,417	$647,972
Conductor & Hardware	$284,831	$284,920	$936,212	$950,212
Site Work	$1,251,722	$1,138,647	$1,485,238	$1,370,938
Construction	$1,498,192	$1,401,242	$1,741,367	$1,781,478
Engineering	$343,613	$321,399	$471,523	$475,060
Sales Tax	$0	$0	$0	$0
Project Management	$171,807	$160,699	$235,762	$237,530
Totals	**$3,951,553**	**$3,696,086**	**$5,422,517**	**$5,463,190**

b. Costs of operating and maintaining the line over its useful life – Operations and Maintenance Costs

Operations and maintenance (O&M) costs for overhead transmission lines are provided by the utilities in the Federal Energy Regulatory Commission (FERC) Form 1 and listed below[14].

Eversource Energy Operation & Maintenance Costs
CT Only - FERC Form 1, years 2012-2016

	O&M Cost Per Circuit Mile - Overhead Transmission					
560 / 568	Supervision Costs (line 1+4)	10,430,708	8,871,751	9,030,452	7,171,820	5,304,180
	% of Overhead to Total (line 9)	92.38%	92.42%	92.34%	92.48%	92.48%
	Supervision % allocated to Overhead	9,635,595	8,199,230	8,339,158	6,632,716	4,905,466
563 / 571	Direct Overhead Costs (line 2+5)	13,020,003	10,217,848	9,231,462	7,215,430	18,727,334
	Total Overhead Costs	22,655,598	18,417,078	17,570,620	13,848,146	23,632,800
	Overhead Circuit Miles (line 7)	1636	1645.89	1645.89	1678.65	1678.65
	O&M Costs - Overhead Trans. Per Circuit Mile	$13,848	$11,190	$10,675	$8,250	$14,078
		12.12%	-19.20%	-4.60%	-22.72%	70.66%
				5 year O&M Cost Average - OH		$11,608

	2016	2015	2014	2013	2012
Costs per circuit mile for O&M of UI's existing overhead transmission lines	$60,867	$77,259	$78,933	$39,648	$33,638

O&M costs are provided based on the utility's experience with all of its overhead transmission, irrespective of pole types or conductor configuration. Based on data from years 2012 through 2016, Eversource estimates that the 5-year O&M cost average for overhead transmission in its service area is approximately $11,608 per circuit-mile. Based on data from years 2012 through 2016, UI estimates that the 5-year O&M cost average for overhead transmission in its service area is approximately $58,069. However, given that Eversource has significantly greater circuit-mileage than UI (because of its much larger service area), the Council has historically used a weighted average[15] rather than a simple average to determine an overall O&M cost average per circuit-mile. UI's overhead circuit mileage (as of May 2017) was approximately 109.2 circuit-miles[16]. Over the five year (2012 to 2016) time period, Eversource's overhead transmission circuit mileage ranged from 1636 circuit-miles to 1678.65 circuit-miles for an average over the five years of about 1657 circuit-miles. Thus, the approximate weighted average O&M cost is computed as follows:

Annual O&M Cost per Circuit-mile = [($11,608/circuit-mile)(1657 circuit-miles) +($58,069/circuit-mile)(109.2 circuit-miles)] / (1657 circuit-miles + 109.2 circuit-miles)

Annual Overhead Transmission O&M Cost per Circuit-mile ≈ $14,481 per circuit-mile

c. Costs of energy losses resulting from the line's use – Electrical Losses

Electric transmission line losses, known as "I-squared-R" losses, represent power lost as heat due to the resistance of the conductors. Accordingly, such power loss is proportional to the resistance of the conductors and proportional to the square of the current. Since line currents vary over time in response to changing load conditions, the power losses are also varying with time. A standard peak line current of 1,000 amps is assumed[17]. A loss factor of approximately 0.38 is applied to estimate the ratio of the average losses to peak losses, so that the average power losses can be estimated[17].

To convert average power loss to energy consumption (per year) and compute the cost of energy (due to losses) per year, additional data have been provided by the utilities. Based on recent data from the grid operator ISO-NE, Eversource estimates that loads (and therefore currents) would decline by about 0.07 percent per year during the life cycle study period[17]. Energy costs (also based on recent ISO-NE data) were estimated to be about $100 per megawatt-hour, or ten cents per kilowatt-hour at the beginning of the study period[17]. Energy costs are estimated to decline at a rate of four percent per year over the study period[17]. See Appendix A for a breakdown on loss costs for different overhead transmission configurations.

2. 115-kV and 345-kV Underground Transmission Lines

a. Costs incurred to design, permit and build a line – First Costs

The costs in each category vary depending on the underground transmission line configuration. In general, there are four common configurations in Connecticut for which data were readily available: 115-kV cross-linked polyethylene (XLPE); 115-kV high-pressure fluid-filled (HPFF); 345-kV XLPE; and 345-kV HPFF[18].

First costs provided by Eversource are noted below for new single-circuit underground lines on a $/mile basis as follows [18]:

Eversource Energy - Typical UG Transmission Types

Life-Cycle Cost Components - Estimated Underground Construction Costs/ Typical Mile

First Costs	XLPE 115-kV	HPFF 115-kV	XLPE 345-kV	HPFF 345-kV
	Single Circuit	Single Circuit	Single Circuit	Single Circuit
Ducts & Vaults	$ 5,050,285	$ 3,498,986	$ 5,400,873	$ 3,501,991
Cable & Hardware	$ 4,143,127	$ 3,421,151	$ 4,947,648	$ 3,936,850
Site Work	$ 1,549,416	$ 1,548,327	$ 1,549,449	$ 1,549,657
Construction	$ 2,506,270	$ 2,129,280	$ 2,564,069	$ 2,156,749
Engineering	$ 1,324,910	$ 1,059,774	$ 1,446,204	$ 1,114,524
Sales Tax (X%)	$ -	$ -	$ -	$ -
Project Management	$ 927,437	$ 794,831	$ 1,084,653	$ 891,620
Totals	**$ 15,501,445**	**$ 12,452,349**	**$ 16,992,896**	**$ 13,151,391**

b. Costs of operating and maintaining the line over its useful life

O&M costs for underground transmission lines are provided by the utilities in the FERC Form 1 and are listed below[19].

Eversource Energy Operation & Maintenance Costs

CT Only - FERC Form 1, years 2012-2016

	O&M Cost Per Circuit Mile - Underground Transmission					
560 / 568	Supervision Costs (line 1+4)	10,430,708	8,871,751	9,030,452	7,171,820	5,304,180
	% of Underground to Total (line 10)	7.62%	7.58%	7.66%	7.52%	7.52%
	Supervision % allocated to Underground	795,113	672,521	691,294	539,104	398,714
564 / 572	Direct Underground Costs (line 3+6)	116,508	1,152,626	1,097,409	1,736,822	1,340,279
	Total Underground Costs	911,621	1,825,147	1,788,703	2,275,926	1,738,993
	Underground Circuit Miles (line 8)	135	135	136.44	136.44	136.44
	O&M Costs - Underground Trans.Per Circuit Mile	$6,753	$13,520	$13,110	$16,681	$12,745
		-71.25%	100.21%	-3.03%	27.24%	-23.59%
				5 year O&M Cost Average - UG		$12,562

	2016	2015	2014	2013	2012
Costs per circuit mile for O&M of UI's existing underground transmission lines	$49,401	$48,667	$41,895	$29,534	$26,636

Based on data from years 2012 through 2016, Eversource estimates that the 5-year O&M cost average for underground transmission in its service area is approximately $12,562 per circuit-mile. Based on data from years 2012 through 2016, UI estimates that the 5-year O&M cost average for underground transmission in its service area is approximately $39,227. However, given that Eversource has significantly greater circuit-mileage than UI (because of its much larger service area), the Council has historically used a weighted average rather than a simple average to determine an overall O&M cost average per circuit-mile. UI's underground circuit mileage (as of May 2017) was approximately 28.9 circuit-miles[20]. Over the five year (2012 to 2016) time period, Eversource's underground transmission circuit mileage ranged from 135 circuit-miles to 136.44 circuit-miles for an average over the five years of about 135.86 circuit-miles. Thus, the approximate O&M cost is computed as follows:

Annual O&M Cost per Circuit-mile = [($12,562/circuit-mile)(135.86 circuit-miles) +($39,227/circuit-mile)(28.9 circuit-miles)] / (135.86 circuit-miles + 28.9 circuit-miles)

Annual Underground Transmission O&M Cost per Circuit-mile ≈ $17,239 per circuit-mile

c. Costs of energy losses resulting from the line's use – Electrical Losses

The assumptions and method of calculation regarding losses are similar for both underground and overhead lines. The only material difference is the resistance in ohms[21] per mile for the various underground cables versus the overhead conductors. All else being equal, loss costs increase as the resistance increases. See Appendix A for a breakdown on loss costs for different underground transmission configurations.

B. Costs of Relative Reliability

The Federal Energy Policy Act of 2005 required the FERC to designate an Electric Reliability Organization (ERO) to develop and enforce a system of mandatory reliability standards for planning and operations of the bulk power electric system. Compliance with the standards is mandatory under federal law and violations are punished by fines. FERC designated the North American Electric Reliability Corporation Inc. (NERC) to be the ERO. As the ERO, NERC is charged with improving the reliability of the bulk-power electric system (BES) by developing mandatory reliability standards for planning and operations.

1. 115-kV and 345-kV Overhead Transmission Lines

a. Reliability Standards

The Connecticut utilities have identified the following national and regional reliability standards for overhead transmission lines[22]:

a) North American Electric Reliability Corporation (NERC) TPL-001-4 Transmission Planning Performance Requirements;

b) Northeast Power Coordinating Council (NPCC) Regional Reliability Reference Directory #1 Design and Operation of the Bulk Power System;

c) Independent System Operator New England (ISO-NE) PP 03 Reliability Standards for the New England Area Pool Transmission Facilities.

*** For UI's service territory, Avangrid Planning Criteria is used in addition to the national and regional reliability standards for overhead transmission lines.

b. Security Standards

NERC has issued numerous standards for governing the protection of critical infrastructure of the bulk power transmission system, which includes transmission resources[22]. These standards are referred to as the Critical Infrastructure Protection (CIP) program. The CIP program coordinates all of NERC's efforts to improve the North American power system's security. These efforts include standards development, compliance enforcement, assessments of risk and preparedness, dissemination of critical information and raised awareness regarding key security issues. The following standards are currently subject to enforcement:

a) CIP-002-5.1a Cyber Security – Bulk Electric Power System (BES) Cyber System Categorization;

b) CIP-003-6 Cyber Security – Security Management Controls;

c) CIP-004-6 Cyber Security – Personnel & Training;

d) CIP-005-5 Cyber Security – Electronic Security Perimeter(s);

e) CIP-006-6 Cyber Security – Physical Security of BES Cyber Systems;

f) CIP-007-6 Cyber Security – System Security Management;

g) CIP-008-5 Cyber Security – Incident Reporting and Response Planning;

h) CIP-009-6 Cyber Security – Recovery Plans for BES Cyber Systems;

i) CIP-010-2 Cyber Security – Configuration Change Management and Vulnerability Assessments;

j) CIP-011-2 Cyber Security – Information Protection; and

k) CIP-014-2 Physical Security.

In addition to NERC standards, the National Electrical Safety Code (NESC) requires signage on all transmission structures as a security standard[23].

c. Transmission Vegetative Maintenance (TVM) Standards

The Connecticut utilities have identified the following national vegetative management standards for overhead transmission lines[22]:

a) North American Electric Reliability Corporation (NERC) Transmission Vegetation Management Standard FAC-003-4;

b) American National Standards Institute (ANSI) Z-133 Standards for Arboriculture Operations;

c) ANSI A-300 – Tree Care Practices; and

*** For UI's service territory, UI OP-170 – Transmission Vegetative Management Program -- is also used (for UI service territory)[22].

d. Storm Hardening

There are no known national standards for storm hardening for transmission line construction. However, Eversource has performed a review of structure capacity, at the recommendation of the <u>Final Report on Connecticut Light and Power's Emergency Preparedness and Response to Storm Irene and the October Nor'easter, February 27, 2012</u> (known as the Davies Report) in the analysis of structures for storm resiliency[22].

UI standards for storm hardening call for designing its overhead transmission facilities in accordance with the current NESC and to the level of a Category III hurricane and 1.5 inches of radial ice. This is applicable to all newer overhead transmission lines in UI's territory only, irrespective of whether they are 115-kV or 345-kV structures[22].

e. NESC and Building Codes

NESC is a national standard for the practical safeguarding of persons, utility facilities, and affected property during the installation, operation, and maintenance of electric supply and communication facilities, under specified conditions[23]. In the context of overhead electric transmission lines, among other considerations, NESC standards govern the spacing of conductors and clearances under conductors, which can affect structure heights. The 2017 NESC is the most up to date, and UI notes that recent revisions to the NESC appear to be minor and are not expected to significantly increase life-cycle costs of electric transmission[24].

Structural design considerations for overhead transmission structures, include, but are not limited to, utility-specific wind load design criteria and American Society of Civil Engineers (ASCE) standards. Furthermore, if a structure contains a wireless telecommunication facility on top, sometimes referred to as a "power-mount facility," then the TIA-222 "Structural Standards for Antenna Supporting Structures and Antennas" Version G would also apply. The Connecticut State Building Code (CSBC) is not applicable to transmission line construction[24]. Based on all applicable code considerations, the structure would have to be designed to the controlling standard.

2. 115-kV and 345-kV Underground Transmission Lines

a. Reliability Standards

See Section B1a, as the same standards are also applicable to underground transmission[22].

b. Security Standards

See Section B1b, as the same standards are applicable to underground transmission[22].

c. TVM Standards

See Section B1c, as the same standards are applicable to underground transmission[22].

d. Storm Hardening

Underground transmission generally does not have overhead "structures" to "storm harden" except, for example, transition structures which convert overhead to underground or vice versa. See Section B1d for storm hardening standards[22].

e. NESC and Building Codes

Underground electrical transmission is also subject to the NESC, which includes, but is not limited to, cable spacing and burial depths. The CSBC is not applicable to electric transmission lines.

C. Costs of Access and Construction Constraints

1. 115-kV and 345-kV Overhead Transmission Lines

a. Easement acquisition

The costs of acquiring temporary or permanent access easements is a private matter that is negotiated between the utility and the adjacent property owners. While it may be preferable to utilize existing utility property or ROW to the extent feasible, acquiring a new easement or additional easement is both an engineering and business decision.

b. Connecticut Department of Transportation (DOT) permits

Construction within State highway ROW generally requires a DOT Encroachment Permit.

c. United States Army Corps of Engineers (USACE) permits

The following USACE permits may be required for various types of overhead transmission projects[25]:

a) USACE 404 permit for dredge and fill activities (wetlands and watercourses);

b) USACE 408 permit for altering federal land public works projects, such as dams/levees;

c) USACE Self-Verification Form (SVF) for impacts to resource areas outlined under impact-specific General Permit(s) within Connecticut Programmatic General Permit;

d) USACE Pre-Construction Notification (PCN) for impacts to resource areas outlined under impact-specific General Permit(s) within Connecticut Programmatic General Permit; and

e) USACE Individual Permit for large-scale impacts not covered under SVF or PCN General Permits in Connecticut Programmatic General Permit.

d. Connecticut Department of Energy and Environmental Protection (DEEP) permits

The following DEEP permits may be required for various types of overhead transmission projects[25]:

a) Natural Diversity Database (NDDB) Project review for potential impacts to state-designated Threatened Species, Endangered Species or Species of Special Concern;

b) Section 401 Water Quality Certification (related to inland impacts and filters up to USACE SVF or PCN);

c) Registration under DEEP General Permit and submission of Stormwater Pollution Control Plan for projects with a construction disturbance area of greater than one acre;

d) Coastal Zone Consistency Review; and

e) Certification of Structures and Dredging Permit for coastal zone or tidally influenced areas from Office of Long Island Sound Programs.

e. United States Fish & Wildlife Service (USFWS) permits

Applicants may utilize the USFWS Information for Planning and Consultation (IPaC) tool to determine if any federally-listed species, critical habitat, migratory birds or cultural resources may be impacted by a proposed project.

Connecticut is within the range of the northern long-eared bat (NLEB), a federally-listed Threatened Species and State-listed Endangered Species. The submission of a NLEB Review Form to the USFWS is required for projects that would impact or potentially impact NLEB hibernacula and roosting trees[25].

f. Legal Costs

Under CGS § 4-183, a person who has exhausted all administrative remedies available within an administrative agency by participating as a party or intervenor in the proceedings held on a matter and who is aggrieved by a final decision of the Council may appeal to Superior Court. A Council decision to grant or deny a Certificate of Environmental Compatibility and Public Need for a new transmission line or a Declaratory Ruling for a modified/rebuilt transmission line is appealable. Such appeal must be filed within 45 days after mailing of the Council's final decision.

Under CGS §16-50z, a person engaged in transmission of electric power in the state may acquire real property, and exercise any right of eminent domain, for:

1. Relocation of a transmission facility or ROW required by a public highway project or other governmental action;
2. Acquisition of additional rights or title to property already subject to an easement or other rights for electric transmission lines; or
3. Widening a portion, not exceeding one mile in length, of a transmission ROW for reasons of safety or convenience of the public.

2. 115-kV and 345-kV Underground Transmission Lines

a. Easement Acquisition

See Section C1a.

b. Connecticut DOT permits

Construction within State highway ROW generally requires a DOT Encroachment Permit.

To the extent that the underground duct banks are to be located within state highway ROW, the burial depth of such underground transmission duct banks must be reviewed for compliance with the Connecticut Department of Transportation Utility Accommodation Manual.

See Section C1b.

c. USACE permits

See Section C1c, as similar USACE permitting may also be required for various underground transmission projects.

d. DEEP permits

See Section C1d, as similar DEEP permitting may also be required for various underground transmission projects.

e. USFWS permits

See Section C1e, as similar USFWS review/permitting may also be required for various underground transmission projects.

f. Legal costs

See Section C1f, as similar legal issues can result from various underground transmission as with overhead transmission.

D. Costs of Potential Impacts to the Environment

1. 115-kV and 345-kV Overhead Transmission Lines

a. Wildlife Habitat

Tree clearing, the use of construction vehicles, and project development may be disruptive to certain wildlife habit and/or result in the incidental take of certain state-listed or federally-listed species. Consultation with DEEP regarding the NDDB should be performed prior to construction to determine potential impacts to state-listed species. Consultation with USFWS regarding the NLEB, as well as any other federally-listed species that may be present in the project area may also be required, as noted in Section C1e. To the extent that known state or federally-listed species are located within a project area, a species-specific protection plan would have to be developed and may include, but not be limited to, third party environmental inspector(s), contractor education regarding the species, seasonal restrictions on tree clearing and/or other construction activities, and measures to isolate the construction area to prevent such species from entering.

b. Wetlands and Watercourses

In the design of a new transmission line, wetland and watercourse locations are an important consideration when selecting the locations of transmission structures and associated access roads. While utilities generally seek to avoid placing new structures in wetland locations when feasible, sometimes wetland and watercourse areas cannot be avoided due to limitations in the span (i.e. distance between structures), structural/design considerations that require turning structures or dead-end structures in certain locations and ROW constraints. In such situations, direct wetland and watercourse impacts may not be avoidable, but be minimized in area and subject to the appropriate permitting requirements.

Access to overhead transmission structures may require wetland and watercourse crossings. Temporary crossings typically utilize wood matting, known as "swamp mats," and temporary culverts to reduce impacts to wetlands and watercourses during construction. While temporary impacts to wetlands and watercourses may result from construction, the intent is to prevent and/or minimize permanent impacts to soils, drainage patterns and vegetation.

Proper erosion and sedimentation controls consistent with the 2002 Connecticut Guidelines for Erosion and Sedimentation Control are required to isolate construction areas and minimize the risk of downstream flow of silt into wetland and watercourse areas.

c. Leaks and Spills

Cable leaks are not applicable to overhead transmission. Overhead transmission generally uses the air around the conductors for cooling purposes, and thus, it does not require a dielectric fluid, used as an electrical coolant, like certain underground transmission, i.e. HPFF.

To protect against fuel spills or oil leakage from construction or maintenance vehicles, a DEEP Stormwater Pollution Control Plan (SWPCP), if required, incorporates best management practices to protect against accidental petroleum-based spills. If a SWPCP is not required for a project, a spill prevention plan serves to minimize such risks.

d. Vegetation

Vegetative maintenance could result in visual impacts as identified in the next sub-section. Depending on the location of the vegetative maintenance and seasonal timing of such activities, there may also be impacts to state or federally-listed wildlife species that would have to be considered and mitigated. Vegetative maintenance can also increase the risk of the spread of invasive species. An invasive species mitigation plan may be required particularly to protect sensitive areas, such as wetlands and watercourses.

The nature of the vegetative maintenance is also an important consideration in electric transmission projects. For example, in some areas, it may be possible to simply cut existing vegetation short and convert the maintained area to a "scrub-shrub" habitat. Such vegetative habitat would be low in height to minimize risk of contact with electric transmission, yet provide wildlife habitat value as opposed to full vegetative clearing to ground level that would be more disruptive to wildlife and susceptible to the risk of spread of invasive species.

e. Visibility

Concerns regarding visual impacts of overhead transmission are typically related to the heights of overhead structures. There are also visual considerations related to the arrangement of the conductors, which can affect the perceived "width" of the structures. For example, a delta configuration would also typically have a more narrow visual profile than a horizontal conductor configuration. The use of guy wires can also affect the visual profile of a transmission structure. While lattice transmission structures have a very different visual profile than monopole or H-frame structures, new lattice structures have rarely been used for new transmission construction in Connecticut in recent years[26].

There are also aesthetic considerations such as the finish of a transmission structure being, for example, galvanized steel or weathering steel or wood.

Tree clearing to create or expand a ROW (or accommodate access or construction work pads) is also a very important consideration in the context of visual impacts as this could result in the reduction (or elimination) of existing vegetative buffers between the transmission project and adjacent homes or sensitive visual receptors.

Finally, utilities review and apply the FERC Guidelines for the Protection of Natural, Historic, Scenic and Recreational Values in the Design and Location of Rights-of-Way and Transmission Facilities.

f. Parks, forests and recreation

One potentially adverse impact on parks and recreational resources resulting from a transmission project would be visual impacts. See prior sub-section on visibility. A new transmission line passing through a park or recreational resource area may also separate or isolate portions of that resource temporarily or permanently, and potentially impact the use of such resource.

Impacts to forest are typically related to tree clearing. See prior sub-section on vegetation. Of particular concern would be clearing in "core forest" areas. Under CGS §16a-3k, "core forest" means unfragmented forest land that is three hundred feet or greater from the boundary between forest land and nonforest land, as determined by the Commissioner of DEEP.

DEEP's Comprehensive Open Space Acquisition Strategy – 2016-2020 Green Plan (Green Plan) identifies the value of large-scale, intact forest areas as they provide "key habitat linkages" for wildlife species. Other benefits identified in the Green Plan include, but are not limited to, the forests' ability to absorb rainwater and slow runoff, filter pollutants and regulate air temperature.

g. Soils

Excavation may result in encountering subsurface rock or ledge. While mechanical/pneumatic chipping of such materials is preferable, there may be projects that require controlled blasting. A blasting plan, prepared in consultation with the state and local fire marshals, would have to be developed and approved.

Excavation to construct a transmission line facility could result in the removal and/or disturbance of contaminated soils. Such soils would need to be handled and disposed of in accordance with state and federal regulations. Dewatering for excavation could also result in having to remove potentially contaminated water from excavation holes, and such contaminated water would also have to be properly handled and disposed of.

Construction of a transmission line project could also potentially traverse prime farmland and disturb agricultural soils. Any impacts and possible mitigation would be a consideration. Under CGS §16a-3k, "prime farmland" means land that meets the criteria for prime farmland as described in 7 Code of Federal Regulations 657, as amended from time to time.

The statutory mission of the Governor's Council for Agricultural Development (GCAD) is to develop a statewide plan for Connecticut agriculture that includes the creation of an agriculture-friendly energy policy incorporating on-farm energy production to reduce costs and supplement farm income, agricultural net metering for power production and transmission, and qualification of agricultural anaerobic digestion projects for zero-emissions renewable energy credits (ZRECs). Agriculture in Connecticut is likely to be adversely impacted by climate change. It is most affected by changes in temperature and both the abundance and lack of precipitation. Adaptation strategies for climate change impacts to agriculture include promotion of policies to reduce energy use, conserve water and encourage sustainability.

2. 115-kV and 345-kV Underground Transmission Lines

a. Wildlife Habitat

See Section D1a regarding potential wildlife habitat impacts.

b. Wetlands and Watercourses

See Section D1b. With respect to wetland and watercourse impacts, one significant difference between underground transmission versus overhead transmission is that underground transmission would have buried duct banks that could span many feet in length, and also include buried splice vaults. Thus, an underground facility, depending on its specific route and location, could potentially have (for example) more wetland or watercourse impact area than multiple smaller excavations for overhead transmission structure foundations. Such potential impacts would have to be considered in the engineering phase of the project and mitigated as necessary.

c. Leaks and Spills

Solid dielectric cables such as XLPE do not have a fluid for cooling purposes, so there is no risk of leaks. However, HPFF lines have to be properly designed and monitored to minimize the potential leakage of dielectric fluid. Specifically, Eversource notes that leak prevention begins with a high-quality corrosion coating of the pipe, careful testing of the coating several times during construction and placing a high-quality backfill around the pipes. A cathodic protection system is also provided to protect the pipe. Measures to reduce fluid loss consist of containment volumes designed into foundations under the pump plant/fluid expansion tank enclosures. Eversource also includes a variety of pressure gauges and alarms to detect low fluid pressure or frequently operating pumps that might indicate a leak in the system and valves to isolate appropriate portions of the system[27]. Similarly, UI monitors fluid pressures, fluid flows and pump-run characteristics continuously. Such HPFF systems are monitored continuously by a Supervisory Control and Data Acquisition (SCADA) system[28].

d. Vegetation

See Section D1d regarding vegetative maintenance impacts, as activities to accommodate duct banks, splice vaults and transition structure foundations, could potentially result in similar types of impacts as overhead transmission.

e. Visibility

Post-construction visual impacts are generally much less of a concern for underground transmission lines than for overhead transmission lines because the post-construction underground lines cannot be seen. Splice vaults are also buried. Generally, the only visible above-ground structures would be the transition structures that convert the underground line to overhead or termination structures if located at a substation or switchyard. Visual impacts of such structures could be mitigated, for example, by limiting the height of such structures to be comparable with the heights of other adjacent overhead structures, to the extent allowable by codes. Visual consistency (as an aesthetics-improving measure) could also be achieved, for example, by utilizing a similar finish (e.g. galvanized or weathering steel) to any adjacent overhead transmission structures.

Also, tree clearing to accommodate underground transmission construction could have potential visual impacts on nearby homes or sensitive receptors if existing vegetative buffers are removed or reduced.

f. Parks, forests and recreation

While underground transmission lines may not necessarily have the potential post-construction visual impacts on parks and recreation associated with overhead transmission structures (except for transition structures), tree clearing to establish or modify an underground transmission line ROW may result in potential impacts to parks, forests and recreation as discussed in Section D1f.

g. Soils

See Section D1g, as excavations for underground duct banks, splice vaults, and transition structure foundations could result in potential soil impacts as already discussed.

E. Compatibility with Existing Electric Supply System

1. 115-kV and 345-kV Overhead Transmission Lines

a. ISO-NE Transmission Planning (Needs and Solutions Studies)

ISO-NE is the not-for-profit corporation responsible for the reliable and economical operation of New England's electric power system. It also administers the region's wholesale electricity markets and manages the comprehensive planning of the regional power system. The planning process includes the periodic preparation of a Regional System Plan (RSP) in accordance with the ISO's *Open Access Transmission Tariff* (OATT) and other parts of the *Transmission, Markets, and Services Tariff* (the ISO tariff), approved by the Federal Energy Regulatory Commission (FERC). Regional System Plans meet the tariff requirements by summarizing planning activities that include the following:

a) Forecasts of annual energy use and peak loads (i.e., the demand for electricity) for a 10-year planning horizon and the need for resources (i.e., capacity);

b) Information about the amounts, locations, and characteristics of market responses (e.g., generation or demand resources or elective transmission upgrades) that can meet the defined system needs—systemwide and in specific areas; and

c) Descriptions of transmission projects for the region that meet the identified needs, as summarized in an RSP Project List, which includes information on project status and cost estimates and is updated several times each year.

ISO-NE's RSP Project List updates include cost and other information on the following:

a) Transmission solutions in response to the needs identified in the RSP, a needs assessment, or a study of transmission need related to public policy requirements;
b) Elective transmission upgrades, which are transmission projects proposed and funded by private developers; and
c) Generator interconnection upgrades, which are transmission projects required to accommodate new generators.

ISO-NE also has an Asset Condition List update, which includes cost and other information on the upgrades or replacements of existing transmission facilities identified by the facility owner.

ISO-NE's Planning Advisory Committee (PAC) is an open stakeholder forum that provides input and feedback to ISO-NE on the regional system planning process, which involves the following:

a) Developing and reviewing needs assessments;
b) Identifying and prioritizing requests for economic studies to be performed by ISO-NE;
c) Developing solutions studies and competitive solutions;
d) Conducting the public-policy transmission study process; and
e) Developing the RSP and updates to RSP Project List and Asset Condition List.

ISO-NE's Reliability Committee (RC) is the standing technical committee of the New England Power Pool (NEPOOL). As one of NEPOOL's principle committees, the RC advises the Participants Committee and ISO-NE on the design and oversight of reliability standards for the New England power system.

b. Comparison to other New England utilities

The line voltages of 115-kV and 345-kV used in Connecticut are compatible (and consistent) with transmission used elsewhere in New England. Connecticut utilities, along with other New England utilities, are under the same regional ISO-NE grid and would also be subject to ISO-NE, NERC, NPCC, and NESC standards which would ensure compatibility. Furthermore, all of New England is part of the "Eastern Interconnection," a larger unified electric power grid that spans from the Rocky Mountains to the East Coast and Canadian Maritimes.

New England has 13 interconnections to neighboring electric grids in New York, Quebec and New Brunswick.

c. New large generator interconnections

For interconnection purposes, ISO-NE considers a "large generator" to be a generator larger than 20 megawatts (MW) in capacity. To interconnect a new "large generator" or modify an existing generator (e.g. a power up-rate), a "Large Generator Interconnection Request Form" has to be filed with ISO-NE for review and approval. For the construction of the interconnection from the new large generator to existing transmission line(s) or an existing substation, a Petition for a Declaratory Ruling or Application for a Certificate of Environmental Compatibility and Public Need, as applicable, would have to be filed with the Council.

2. 115-kV and 345-kV Underground Transmission Lines
a. ISO Transmission Planning (Needs and Solutions Studies)

Transmission planning for underground lines is similar to as noted in Section E1a for overhead lines. Existing land uses, cost and electrical considerations are factors in underground versus overhead line alternatives.

b. Compared to other New England utilities

See Section E1b, as comparisons of Connecticut utilities to New England utilities remain the same for underground transmission.

c. New large generator interconnections

See Section E1c, as large generator interconnection procedures apply to both overhead and underground connections.

F. CONCLUSION

The Council has investigated the life-cycle costs of electrical transmission lines in the State of Connecticut pursuant to CGS §16-50r(b) for specific transmission line configurations deemed likely to be constructed in the future. The Council also held a public comment session on May 9, 2017. No comments were received at the public comment session. The estimated first costs (to design, permit and build a line) for the various single-circuit transmission configurations are noted below:

a) 115-kV H-frame - $3,951,553 per mile
b) 115-kV Delta - $3,696,086 per mile
c) 345-kV H-frame - $5,422,517 per mile
d) 345-kV Delta - $5,463,190 per mile
e) 115-kV XLPE - $15,501,445 per mile
f) 115-kV HPFF - $12,452,349 per mile
g) 345-kV XLPE - $16,992,896 per mile
h) 345-kV HPFF - $13,151,391 per mile

An estimated initial weighted average O&M cost of $14,481 per circuit-mile for overhead transmission and $17,239 per circuit-mile for underground transmission was determined by the Council based on the utility data. With an estimated O&M cost escalation compound annual growth rate of about 2 percent, the O&M costs across the 40-year life-cycle study period for these various overhead and underground configurations were determined and are shown in Appendix A.

Lastly, besides first costs and O&M costs, the other component of life-cycle costs is the cost of electrical losses. With an estimated initial energy cost of $100 per MWh declining at 4 percent per year and loads declining by 0.07 percent per year, as well as the conductor resistances in ohms per mile and estimated loss factor of 0.38, the loss costs over the 40-year study period were also determined and are shown in Appendix A for the various transmission configurations.

With the three major components of first costs, O&M costs and electrical energy loss costs (and a discount rate of eight percent), the total net present value (NPV) life-cycle costs (LCCs) for the eight single-circuit transmission configurations over a 40-year study period are listed below:

i) 115-kV H-frame - $6,598,214 per mile
j) 115-kV Delta - $6,217,114 per mile
k) 345-kV H-frame - $8,503,618 per mile
l) 345-kV Delta - $8,564,290 per mile
m) 115-kV XLPE - $23,603,909 per mile
n) 115-kV HPFF - $19,095,808 per mile
o) 345-kV XLPE - $25,828,809 per mile
p) 345-kV HPFF - $20,138,637 per mile

End Notes

1. This would be roughly analogous to the pressure difference between two water pipes.

2. This would be the rate of net flow of charge (electrons) per unit of time or roughly analogous to gallons per minute flowing through a water pipe.

3. Submarine cables that connect Connecticut to Long Island are outside of the scope of this report.

4. UI response to Council interrogatory number 21, dated May 23, 2017.

5. Eversource response to Council interrogatory number 21, dated May 23, 2017.

6. UI response to Council interrogatory number 29, dated May 23, 2017.

7. Eversource response to Council interrogatory number 29, dated May 23, 2017.

8. There was no public comment at the May 9, 2017 public comment session.

9. LC 2012 Report, pp. 3-8 and 3-9.

10. Eversource response to Council interrogatory number 3, dated May 23, 2017.

11. Eversource response to Council interrogatory number 3, dated May 23, 2017. WPE steel is a light-duty steel that Eversource has increased in use in recent years due to its resiliency, longevity and cost-efficient qualities.

12. UI response to Council interrogatory number 3, dated May 23, 2017.

13. Eversource response to Council interrogatory number 3, dated May 23, 2017.

14. Eversource response to Council interrogatory number 10, dated May 23, 2017 and UI response to Council interrogatory number 11, dated May 23, 2017.

15. A weighted average O&M cost taking into account the circuit mileage of UI and Eversource was used in the LC 2012 Report. See Table 6-1 on page 6-10 of the LC 2012 Report.

16. UI response to Council interrogatories, Appendix 2, dated May 23, 2017.

17. Eversource response to Council interrogatory number 3, dated May 23, 2017.

18. Eversource response to Council interrogatory number 34, dated May 17, 2018.

19. Eversource response to Council interrogatory number 10, dated May 23, 2017 and UI response to Council interrogatory 11, dated May 23, 2017.

20. UI response to Council interrogatories, Appendix 2, dated May 23, 2017.

21. Ohms are the standard units of electrical resistance between two points on a conductor when a potential difference of one volt between them produces a current of one ampere.

22. Eversource response to Council interrogatory number 15, dated May 23, 2017 and UI response to Council interrogatory number 15, dated May 23, 2017.

23. NESC, p. 1.

24. UI response to Council interrogatory 16, dated May 23, 2017.

25. LC 2012 Report page 8-3, Eversource response to Council interrogatory number 18, dated May 23, 2017 and UI response to Council interrogatory 18, Appendix 3, dated May 23, 2018.

26. Eversource response to Council interrogatory 8a, dated Mary 23, 2017.

27. Eversource response to Council interrogatory 23, dated May 23, 2017.

28. UI response to Council interrogatory 23, dated May 23, 2017.

Appendix A – Life Cycle Cost Breakdown – 115-kV H-frame

First Costs			**Losses**			**O&M**		
Poles & Foundations	401388	Dollars	Conductor	1272 ACSS	54/19 Pheasant	Annual Cost per mile	14481	$/mi-year
Conductor & Hardware	284831	Dollars	Resistance	0.0741	ohm/mi	O&M Cost Escalation	0.02	decimal CAGR
Site Work	1251722	Dollars	Peak Line Current	1000	amps			
Construction	1498192	Dollars	Load Growth	-0.0007	decimal CAGR			
Engineering	343613	Dollars	Loss Factor	0.38	dimensionless			
Sales Tax	0	Dollars	Energy Cost	100	$/MWh			
Project Management	171807	Dollars	Energy Cost Escalation	-0.04	decimal CAGR			
Capital Recovery Factor	0.1251	dimensionless						
Year	**Carrying Costs**	**Losses**	**O&M**	**PV Factor**	**PV FC**	**PV O&M**	**PV Losses**	**PV Cost**
0								
1	494339	59552	14481	0.925925926	457722	13408	55140	526270
2	494339	57090	14770	0.85733882	423816	12663	48945	485424
3	494339	54729	15066	0.793832241	392422	11960	43446	447828
4	494339	52467	15367	0.735029853	363354	11295	38565	413214
5	494339	50297	15674	0.680583197	336439	10668	34232	381338
6	494339	48218	15988	0.630169627	311518	10075	30385	351978
7	494339	46224	16307	0.583490395	288442	9515	26972	324929
8	494339	44313	16634	0.540268885	267076	8987	23941	300004
9	494339	42481	16966	0.500248967	247293	8487	21251	277031
10	494339	40725	17306	0.463193488	228975	8016	18864	255854
11	494339	39041	17652	0.428882859	212014	7571	16744	236328
12	494339	37427	18005	0.397113759	196309	7150	14863	218322
13	494339	35880	18365	0.367697925	181768	6753	13193	201713
14	494339	34396	18732	0.340461041	168303	6378	11711	186391
15	494339	32974	19107	0.315241705	155836	6023	10395	172254
16	494339	31611	19489	0.291890468	144293	5689	9227	159209
17	494339	30304	19879	0.270268951	133605	5373	8190	147167
18	494339	29051	20276	0.250249029	123708	5074	7270	136052
19	494339	27850	20682	0.231712064	114544	4792	6453	125790
20	494339	26699	21095	0.214548207	106060	4526	5728	116314
21	494339	25595	21517	0.198655748	98203	4275	5085	107562
22	494339	24537	21948	0.183940507	90929	4037	4513	99479
23	494339	23522	22387	0.170315284	84194	3813	4006	92013
24	494339	22550	22834	0.157699337	77957	3601	3556	85114
25	494339	21618	23291	0.146017905	72182	3401	3157	78740
26	494339	20724	23757	0.135201764	66836	3212	2802	72849
27	494339	19867	24232	0.125186818	61885	3034	2487	67405
28	494339	19046	24717	0.115913721	57301	2865	2208	62373
29	494339	18258	25211	0.107327519	53056	2706	1960	57722
30	494339	17503	25715	0.099377333	49126	2556	1739	53421
31	494339	16780	26230	0.092016049	45487	2414	1544	49445
32	494339	16086	26754	0.085200045	42118	2279	1371	45768
33	494339	15421	27289	0.078888931	38998	2153	1217	42367
34	494339	14783	27835	0.073045306	36109	2033	1080	39222
35	494339	14172	28392	0.067634543	33434	1920	959	36313
36	494339	13586	28959	0.062624577	30958	1814	851	33622
37	494339	13025	29539	0.057985719	28665	1713	755	31133
38	494339	12486	30129	0.053690481	26541	1618	670	28829
39	494339	11970	30732	0.049713408	24575	1528	595	26698
40	494339	11475	31347	0.046030933	22755	1443	528	24726
				LCC Total	6598214			

Appendix A – Life Cycle Cost Breakdown – 115-kV Delta

First Costs			Losses			O&M		
Poles & Foundations	389178	Dollars	Conductor	1272 ACSS	54/19 Pheasant	Annual Cost per mile	14481	$/mi-year
Conductor & Hardware	284920	Dollars	Resistance	0.0741	ohm/mi	O&M Cost Escalation	0.02	decimal CAGR
Site Work	1138647	Dollars	Peak Line Current	1000	amps			
Construction	1401242	Dollars	Load Growth	-0.0007	decimal CAGR			
Engineering	321399	Dollars	Loss Factor	0.38	dimensionless			
Sales Tax	0	Dollars	Energy Cost	100	$/MWh			
Project Management	160699	Dollars	Energy Cost Escalation	-0.04	decimal CAGR			
Capital Recovery Factor	0.1251	dimensionless						
Year	**Carrying Costs**	**Losses**	**O&M**	**PV Factor**	**PV FC**	**PV O&M**	**PV Losses**	**PV Cost**
0								
1	462380	59552	14481	0.9259259	428130	13408	55140	496678
2	462380	57090	14770	0.8573388	396417	12663	48945	458025
3	462380	54729	15066	0.7938322	367052	11960	43446	422458
4	462380	52467	15367	0.7350299	339863	11295	38565	389723
5	462380	50297	15674	0.6805832	314688	10668	34232	359587
6	462380	48218	15988	0.6301696	291378	10075	30385	331838
7	462380	46224	16307	0.5834904	269794	9515	26972	306281
8	462380	44313	16634	0.5402689	249810	8987	23941	282737
9	462380	42481	16966	0.500249	231305	8487	21251	261044
10	462380	40725	17306	0.4631935	214172	8016	18864	241051
11	462380	39041	17652	0.4288829	198307	7571	16744	222622
12	462380	37427	18005	0.3971138	183618	7150	14863	205630
13	462380	35880	18365	0.3676979	170016	6753	13193	189962
14	462380	34396	18732	0.340461	157422	6378	11711	175511
15	462380	32974	19107	0.3152417	145762	6023	10395	162180
16	462380	31611	19489	0.2918905	134964	5689	9227	149880
17	462380	30304	19879	0.270269	124967	5373	8190	138530
18	462380	29051	20276	0.250249	115710	5074	7270	128054
19	462380	27850	20682	0.2317121	107139	4792	6453	118385
20	462380	26699	21095	0.2145482	99203	4526	5728	109457
21	462380	25595	21517	0.1986557	91854	4275	5085	101214
22	462380	24537	21948	0.1839405	85050	4037	4513	93601
23	462380	23522	22387	0.1703153	78750	3813	4006	86569
24	462380	22550	22834	0.1576993	72917	3601	3556	80074
25	462380	21618	23291	0.1460179	67516	3401	3157	74073
26	462380	20724	23757	0.1352018	62515	3212	2802	68528
27	462380	19867	24232	0.1251868	57884	3034	2487	63405
28	462380	19046	24717	0.1159137	53596	2865	2208	58669
29	462380	18258	25211	0.1073275	49626	2706	1960	54292
30	462380	17503	25715	0.0993773	45950	2556	1739	50245
31	462380	16780	26230	0.092016	42546	2414	1544	46504
32	462380	16086	26754	0.0852	39395	2279	1371	43045
33	462380	15421	27289	0.0788889	36477	2153	1217	39846
34	462380	14783	27835	0.0730453	33775	2033	1080	36888
35	462380	14172	28392	0.0676345	31273	1920	959	34152
36	462380	13586	28959	0.0626246	28956	1814	851	31621
37	462380	13025	29539	0.0579857	26811	1713	755	29280
38	462380	12486	30129	0.0536905	24825	1618	670	27113
39	462380	11970	30732	0.0497134	22986	1528	595	25109
40	462380	11475	31347	0.0460309	21284	1443	528	23255
				LCC Total	6217114			

Appendix A – Life Cycle Cost Breakdown – 345-kV H-frame

First Costs			Losses			O&M		
Poles & Foundations	552417	Dollars	Conductor	1590 ACSS	54/19 Falcon x2	Annual Cost per mile	14481	$/mi-year
Conductor & Hardware	936212	Dollars	Resistance	0.0301	ohm/mi	O&M Cost Escalation	0.02	decimal CAGR
Site Work	1485238	Dollars	Peak Line Current	1000	amps			
Construction	1741367	Dollars	Load Growth	-0.0007	decimal CAGR			
Engineering	471523	Dollars	Loss Factor	0.38	dimensionless			
Sales Tax	0	Dollars	Energy Cost	100	$/MWh			
Project Management	235762	Dollars	Energy Cost Escalation	-0.04	decimal CAGR			
Capital Recovery Factor	0.1251	dimensionless						
Year	**Carrying Costs**	**Losses**	**O&M**	**PV Factor**	**PV FC**	**PV O&M**	**PV Losses**	**PV Cost**
0								
1	678357	24190	14481	0.92592593	628108	13408	22398	663915
2	678357	23190	14770	0.85733882	581582	12663	19882	614127
3	678357	22231	15066	0.79383224	538502	11960	17648	568109
4	678357	21312	15367	0.73502985	498613	11295	15665	525573
5	678357	20431	15674	0.6805832	461678	10668	13905	486251
6	678357	19587	15988	0.63016963	427480	10075	12343	449898
7	678357	18777	16307	0.5834904	395815	9515	10956	416286
8	678357	18000	16634	0.54026888	366495	8987	9725	385207
9	678357	17256	16966	0.50024897	339347	8487	8632	356467
10	678357	16543	17306	0.46319349	314211	8016	7663	329889
11	678357	15859	17652	0.42888286	290936	7571	6802	305308
12	678357	15203	18005	0.39711376	269385	7150	6037	282572
13	678357	14575	18365	0.36769792	249431	6753	5359	261542
14	678357	13972	18732	0.34046104	230954	6378	4757	242089
15	678357	13394	19107	0.3152417	213846	6023	4222	224092
16	678357	12841	19489	0.29189047	198006	5689	3748	207443
17	678357	12310	19879	0.27026895	183339	5373	3327	192038
18	678357	11801	20276	0.25024903	169758	5074	2953	177785
19	678357	11313	20682	0.23171206	157184	4792	2621	164597
20	678357	10845	21095	0.21454821	145540	4526	2327	152393
21	678357	10397	21517	0.19865575	134760	4275	2065	141099
22	678357	9967	21948	0.18394051	124777	4037	1833	130648
23	678357	9555	22387	0.17031528	115535	3813	1627	120975
24	678357	9160	22834	0.15769934	106976	3601	1445	112022
25	678357	8781	23291	0.1460179	99052	3401	1282	103735
26	678357	8418	23757	0.13520176	91715	3212	1138	96065
27	678357	8070	24232	0.12518682	84921	3034	1010	88965
28	678357	7736	24717	0.11591372	78631	2865	897	82393
29	678357	7417	25211	0.10732752	72806	2706	796	76308
30	678357	7110	25715	0.09937733	67413	2556	707	70675
31	678357	6816	26230	0.09201605	62420	2414	627	65460
32	678357	6534	26754	0.08520005	57796	2279	557	60632
33	678357	6264	27289	0.07888893	53515	2153	494	56162
34	678357	6005	27835	0.07304531	49551	2033	439	52023
35	678357	5757	28392	0.06763454	45880	1920	389	48190
36	678357	5519	28959	0.06262458	42482	1814	346	44641
37	678357	5291	29539	0.05798572	39335	1713	307	41355
38	678357	5072	30129	0.05369048	36421	1618	272	38311
39	678357	4862	30732	0.04971341	33723	1528	242	35493
40	678357	4661	31347	0.04603093	31225	1443	215	32883
				LCC Total	8503618			

Appendix A – Life Cycle Cost Breakdown – 345-kV Delta

First Costs			Losses			O&M		
Poles & Foundations	647972	Dollars	Conductor	1590 ACSS	54/19 Falcon x2	Annual Cost per mile	14481	$/mi-year
Conductor & Hardware	950212	Dollars	Resistance	0.0301	ohm/mi	O&M Cost Escalation	0.02	decimal CAGR
Site Work	1370938	Dollars	Peak Line Current	1000	amps			
Construction	1781478	Dollars	Load Growth	-0.0007	decimal CAGR			
Engineering	475060	Dollars	Loss Factor	0.38	dimensionless			
Sales Tax	0	Dollars	Energy Cost	100	$/MWh			
Project Management	237530	Dollars	Energy Cost Escalation	-0.04	decimal CAGR			
Capital Recovery Factor	0.1251	dimensionless						
Year	**Carrying Costs**	**Losses**	**O&M**	**PV Factor**	**PV FC**	**PV O&M**	**PV Losses**	**PV Cost**
0								
1	683445	24190	14481	0.9259259	632820	13408	22398	668626
2	683445	23190	14770	0.8573388	585944	12663	19882	618489
3	683445	22231	15066	0.7938322	542541	11960	17648	572148
4	683445	21312	15367	0.7350299	502353	11295	15665	529313
5	683445	20431	15674	0.6805832	465141	10668	13905	489714
6	683445	19587	15988	0.6301696	430686	10075	12343	453104
7	683445	18777	16307	0.5834904	398784	9515	10956	419255
8	683445	18000	16634	0.5402689	369244	8987	9725	387956
9	683445	17256	16966	0.500249	341893	8487	8632	359012
10	683445	16543	17306	0.4631935	316567	8016	7663	332246
11	683445	15859	17652	0.4288829	293118	7571	6802	307490
12	683445	15203	18005	0.3971138	271405	7150	6037	284593
13	683445	14575	18365	0.3676979	251301	6753	5359	263413
14	683445	13972	18732	0.340461	232686	6378	4757	243821
15	683445	13394	19107	0.3152417	215450	6023	4222	225696
16	683445	12841	19489	0.2918905	199491	5689	3748	208928
17	683445	12310	19879	0.270269	184714	5373	3327	193414
18	683445	11801	20276	0.250249	171031	5074	2953	179059
19	683445	11313	20682	0.2317121	158362	4792	2621	165776
20	683445	10845	21095	0.2145482	146632	4526	2327	153485
21	683445	10397	21517	0.1986557	135770	4275	2065	142110
22	683445	9967	21948	0.1839405	125713	4037	1833	131584
23	683445	9555	22387	0.1703153	116401	3813	1627	121841
24	683445	9160	22834	0.1576993	107779	3601	1445	112824
25	683445	8781	23291	0.1460179	99795	3401	1282	104478
26	683445	8418	23757	0.1352018	92403	3212	1138	96753
27	683445	8070	24232	0.1251868	85558	3034	1010	89602
28	683445	7736	24717	0.1159137	79221	2865	897	82982
29	683445	7417	25211	0.1073275	73352	2706	796	76854
30	683445	7110	25715	0.0993773	67919	2556	707	71181
31	683445	6816	26230	0.092016	62888	2414	627	65929
32	683445	6534	26754	0.0852	58230	2279	557	61066
33	683445	6264	27289	0.0788889	53916	2153	494	56563
34	683445	6005	27835	0.0730453	49922	2033	439	52394
35	683445	5757	28392	0.0676345	46224	1920	389	48534
36	683445	5519	28959	0.0626246	42800	1814	346	44960
37	683445	5291	29539	0.0579857	39630	1713	307	41650
38	683445	5072	30129	0.0536905	36694	1618	272	38584
39	683445	4862	30732	0.0497134	33976	1528	242	35746
40	683445	4661	31347	0.0460309	31460	1443	215	33117
				LCC Total	8564290			

Appendix A – Life Cycle Cost Breakdown – 115-kV XLPE

First Costs			Losses			O&M		
Ducts & Vaults	5050285	Dollars	Conductor	3000 kcmil	XLPE	Annual Cost per mile	17239	$/mi-year
Conductor & Hardware	4143127	Dollars	Resistance	0.0268	ohm/mi	O&M Cost Escalation	0.02	decimal CAGR
Site Work	1549416	Dollars	Peak Line Current	1000	amps			
Construction	2506270	Dollars	Load Growth	-0.0007	decimal CAGR			
Engineering	1324910	Dollars	Loss Factor	0.38	dimensionless			
Sales Tax	0	Dollars	Energy Cost	100	$/MWh			
Project Management	927437	Dollars	Energy Cost Escalation	-0.04	decimal CAGR			
Capital Recovery Factor	0.1251	dimensionless						
Year	**Carrying Costs**	**Losses**	**O&M**	**PV Factor**	**PV FC**	**PV O&M**	**PV Losses**	**PV Cost**
0								
1	1939231	27073	17239	0.92592593	1795584	15962	25068	1836614
2	1939231	25954	17584	0.85733882	1662578	15075	22251	1699905
3	1939231	24881	17935	0.79383224	1539424	14238	19751	1573413
4	1939231	23852	18294	0.73502985	1425393	13447	17532	1456372
5	1939231	22866	18660	0.6805832	1319808	12700	15562	1348070
6	1939231	21921	19033	0.63016963	1222044	11994	13814	1247852
7	1939231	21015	19414	0.5834904	1131523	11328	12262	1155112
8	1939231	20146	19802	0.54026888	1047706	10699	10884	1069289
9	1939231	19313	20198	0.50024897	970098	10104	9661	989864
10	1939231	18514	20602	0.46319349	898239	9543	8576	916358
11	1939231	17749	21014	0.42888286	831703	9013	7612	848328
12	1939231	17015	21435	0.39711376	770095	8512	6757	785364
13	1939231	16312	21863	0.36769792	713051	8039	5998	727088
14	1939231	15637	22301	0.34046104	660233	7592	5324	673149
15	1939231	14991	22747	0.3152417	611326	7171	4726	623223
16	1939231	14371	23201	0.29189047	566043	6772	4195	577010
17	1939231	13777	23666	0.27026895	524114	6396	3723	534233
18	1939231	13207	24139	0.25024903	485291	6041	3305	494636
19	1939231	12661	24622	0.23171206	449343	5705	2934	457982
20	1939231	12138	25114	0.21454821	416058	5388	2604	424051
21	1939231	11636	25616	0.19865575	385239	5089	2312	392640
22	1939231	11155	26129	0.18394051	356703	4806	2052	363561
23	1939231	10694	26651	0.17031528	330281	4539	1821	336641
24	1939231	10252	27184	0.15769934	305815	4287	1617	311719
25	1939231	9828	27728	0.1460179	283162	4049	1435	288646
26	1939231	9421	28282	0.13520176	262187	3824	1274	267285
27	1939231	9032	28848	0.12518682	242766	3611	1131	247508
28	1939231	8659	29425	0.11591372	224783	3411	1004	229198
29	1939231	8301	30014	0.10732752	208133	3221	891	212245
30	1939231	7957	30614	0.09937733	192716	3042	791	196549
31	1939231	7628	31226	0.09201605	178440	2873	702	182016
32	1939231	7313	31851	0.08520005	165223	2714	623	168559
33	1939231	7011	32488	0.07888893	152984	2563	553	156100
34	1939231	6721	33137	0.07304531	141652	2421	491	144563
35	1939231	6443	33800	0.06763454	131159	2286	436	133881
36	1939231	6177	34476	0.06262458	121444	2159	387	123989
37	1939231	5921	35166	0.05798572	112448	2039	343	114830
38	1939231	5676	35869	0.05369048	104118	1926	305	106349
39	1939231	5442	36586	0.04971341	96406	1819	271	98495
40	1939231	5217	37318	0.04603093	89265	1718	240	91223
				LCC Total	23603909			

Appendix A – Life Cycle Cost Breakdown – 115-kV HPFF

First Costs			**Losses**			**O&M**		
Ducts & Vaults	3498986	Dollars	Conductor	2500 kcmil	HPFF	Annual Cost per mile	17239	$/mi-year
Cable & Hardware	3421151	Dollars	Resistance	0.0317	ohm/mi	O&M Cost Escalation	0.02	decimal CAGR
Site Work	1548327	Dollars	Peak Line Current	1000	amps			
Construction	2129280	Dollars	Load Growth	-0.0007	decimal CAGR			
Engineering	1059774	Dollars	Loss Factor	0.38	dimensionless			
Sales Tax	0	Dollars	Energy Cost	100	$/MWh			
Project Management	794831	Dollars	Energy Cost Escalation	-0.04	decimal CAGR			
Capital Recovery Factor	0.1251	dimensionless						
Year	**Carrying Costs**	**Losses**	**O&M**	**PV Factor**	**PV FC**	**PV O&M**	**PV Losses**	**PV Cost**
0								
1	1557789	32023	17239	0.925925926	1442397	15962	29651	1488010
2	1557789	30699	17584	0.85733882	1335553	15075	26320	1376948
3	1557789	29430	17935	0.793832241	1236623	14238	23363	1274223
4	1557789	28214	18294	0.735029853	1145021	13447	20738	1179206
5	1557789	27047	18660	0.680583197	1060205	12700	18408	1091312
6	1557789	25929	19033	0.630169627	981671	11994	16340	1010005
7	1557789	24857	19414	0.583490395	908955	11328	14504	934786
8	1557789	23829	19802	0.540268885	841625	10699	12874	865198
9	1557789	22844	20198	0.500248967	779282	10104	11428	800814
10	1557789	21900	20602	0.463193488	721558	9543	10144	741244
11	1557789	20994	21014	0.428882859	668109	9013	9004	686126
12	1557789	20126	21435	0.397113759	618619	8512	7992	635124
13	1557789	19294	21863	0.367697925	572796	8039	7094	587929
14	1557789	18496	22301	0.340461041	530366	7592	6297	544256
15	1557789	17732	22747	0.315241705	491080	7171	5590	503840
16	1557789	16999	23201	0.291890468	454704	6772	4962	466438
17	1557789	16296	23666	0.270268951	421022	6396	4404	431822
18	1557789	15622	24139	0.250249029	389835	6041	3909	399785
19	1557789	14976	24622	0.231712064	360958	5705	3470	370134
20	1557789	14357	25114	0.214548207	334221	5388	3080	342689
21	1557789	13763	25616	0.198655748	309464	5089	2734	317287
22	1557789	13194	26129	0.183940507	286540	4806	2427	293774
23	1557789	12649	26651	0.170315284	265315	4539	2154	272009
24	1557789	12126	27184	0.157699337	245662	4287	1912	251861
25	1557789	11625	27728	0.146017905	227465	4049	1697	233211
26	1557789	11144	28282	0.135201764	210616	3824	1507	215946
27	1557789	10683	28848	0.125186818	195015	3611	1337	199963
28	1557789	10242	29425	0.115913721	180569	3411	1187	185167
29	1557789	9818	30014	0.107327519	167194	3221	1054	171469
30	1557789	9412	30614	0.099377333	154809	3042	935	158787
31	1557789	9023	31226	0.092016049	143342	2873	830	147045
32	1557789	8650	31851	0.085200045	132724	2714	737	136174
33	1557789	8292	32488	0.078888931	122892	2563	654	126109
34	1557789	7950	33137	0.073045306	113789	2421	581	116790
35	1557789	7621	33800	0.067634543	105360	2286	515	108162
36	1557789	7306	34476	0.062624577	97556	2159	458	100172
37	1557789	7004	35166	0.057985719	90330	2039	406	92775
38	1557789	6714	35869	0.053690481	83638	1926	360	85925
39	1557789	6437	36586	0.049713408	77443	1819	320	79582
40	1557789	6171	37318	0.046030933	71706	1718	284	73708
				LCC Total	19095808			

Appendix A – Life Cycle Cost Breakdown – 345-kV XLPE

First Costs			**Losses**			**O&M**		
Ducts & Vaults	5400873	Dollars	Conductor	3000 kcmil	XLPE	Annual Cost per mile	17239	$/mi-year
Cable & Hardware	4947648	Dollars	Resistance	0.0268	ohm/mi	O&M Cost Escalation	0.02	decimal CAGR
Site Work	1549449	Dollars	Peak Line Current	1000	amps			
Construction	2564069	Dollars	Load Growth	-0.0007	decimal CAGR			
Engineering	1446204	Dollars	Loss Factor	0.38	dimensionless			
Sales Tax	0	Dollars	Energy Cost	100	$/MWh			
Project Management	1084653	Dollars	Energy Cost Escalation	-0.04	decimal CAGR			
Capital Recovery Factor	0.1251	dimensionless						
Year	**Carrying Costs**	**Losses**	**O&M**	**PV Factor**	**PV FC**	**PV O&M**	**PV Losses**	**PV Cost**
0								
1	2125811	27073	17239	0.92592593	1968344	15962	25068	2009374
2	2125811	25954	17584	0.85733882	1822541	15075	22251	1859867
3	2125811	24881	17935	0.79383224	1687538	14238	19751	1721527
4	2125811	23852	18294	0.73502985	1562535	13447	17532	1593514
5	2125811	22866	18660	0.6805832	1446791	12700	15562	1475054
6	2125811	21921	19033	0.63016963	1339622	11994	13814	1365430
7	2125811	21015	19414	0.5834904	1240390	11328	12262	1263980
8	2125811	20146	19802	0.54026888	1148510	10699	10884	1170092
9	2125811	19313	20198	0.50024897	1063435	10104	9661	1083200
10	2125811	18514	20602	0.46319349	984662	9543	8576	1002781
11	2125811	17749	21014	0.42888286	911724	9013	7612	928349
12	2125811	17015	21435	0.39711376	844189	8512	6757	859458
13	2125811	16312	21863	0.36769792	781656	8039	5998	795693
14	2125811	15637	22301	0.34046104	723756	7592	5324	736672
15	2125811	14991	22747	0.3152417	670144	7171	4726	682041
16	2125811	14371	23201	0.29189047	620504	6772	4195	631471
17	2125811	13777	23666	0.27026895	574541	6396	3723	584660
18	2125811	13207	24139	0.25024903	531982	6041	3305	541328
19	2125811	12661	24622	0.23171206	492576	5705	2934	501215
20	2125811	12138	25114	0.21454821	456089	5388	2604	464081
21	2125811	11636	25616	0.19865575	422305	5089	2312	429705
22	2125811	11155	26129	0.18394051	391023	4806	2052	397881
23	2125811	10694	26651	0.17031528	362058	4539	1821	368419
24	2125811	10252	27184	0.15769934	335239	4287	1617	341143
25	2125811	9828	27728	0.1460179	310407	4049	1435	315890
26	2125811	9421	28282	0.13520176	287413	3824	1274	292511
27	2125811	9032	28848	0.12518682	266124	3611	1131	270866
28	2125811	8659	29425	0.11591372	246411	3411	1004	250825
29	2125811	8301	30014	0.10732752	228158	3221	891	232270
30	2125811	7957	30614	0.09937733	211257	3042	791	215091
31	2125811	7628	31226	0.09201605	195609	2873	702	199184
32	2125811	7313	31851	0.08520005	181119	2714	623	184456
33	2125811	7011	32488	0.07888893	167703	2563	553	170819
34	2125811	6721	33137	0.07304531	155281	2421	491	158192
35	2125811	6443	33800	0.06763454	143778	2286	436	146500
36	2125811	6177	34476	0.06262458	133128	2159	387	135674
37	2125811	5921	35166	0.05798572	123267	2039	343	125649
38	2125811	5676	35869	0.05369048	114136	1926	305	116366
39	2125811	5442	36586	0.04971341	105681	1819	271	107771
40	2125811	5217	37318	0.04603093	97853	1718	240	99811
				LCC Total	25828809			

Appendix A – Life Cycle Cost Breakdown – 345-kV HPFF

First Costs			**Losses**			**O&M**		
Ducts & Vaults	3501991	Dollars	Conductor	2500 kcmil	HPFF	Annual Cost per mile	17239	$/mi-year
Cable & Hardware	3936850	Dollars	Resistance	0.0317	ohm/mi	O&M Cost Escalation	0.02	decimal CAGR
Site Work	1549657	Dollars	Peak Line Current	1000	amps			
Construction	2156749	Dollars	Load Growth	-0.0007	decimal CAGR			
Engineering	1114524	Dollars	Loss Factor	0.38	dimensionless			
Sales Tax	0	Dollars	Energy Cost	100	$/MWh			
Project Management	891620	Dollars	Energy Cost Escalation	-0.04	decimal CAGR			
Capital Recovery Factor	0.1251	dimensionless						
Year	**Carrying Costs**	**Losses**	**O&M**	**PV Factor**	**PV FC**	**PV O&M**	**PV Losses**	**PV Cost**
0								
1	1645239	32023	17239	0.92592593	1523369	15962	29651	1568983
2	1645239	30699	17584	0.85733882	1410527	15075	26320	1451922
3	1645239	29430	17935	0.79383224	1306044	14238	23363	1343644
4	1645239	28214	18294	0.73502985	1209300	13447	20738	1243484
5	1645239	27047	18660	0.6805832	1119722	12700	18408	1150830
6	1645239	25929	19033	0.63016963	1036780	11994	16340	1065113
7	1645239	24857	19414	0.5834904	959981	11328	14504	985813
8	1645239	23829	19802	0.54026888	888871	10699	12874	912444
9	1645239	22884	20198	0.50024897	823029	10104	11448	844581
10	1645239	21900	20602	0.46319349	762064	9543	10144	781751
11	1645239	20994	21014	0.42888286	705615	9013	9004	723632
12	1645239	20126	21435	0.39711376	653347	8512	7992	669851
13	1645239	19294	21863	0.36769792	604951	8039	7094	620084
14	1645239	18496	22301	0.34046104	560140	7592	6297	574030
15	1645239	17732	22747	0.3152417	518648	7171	5590	531408
16	1645239	16999	23201	0.29189047	480230	6772	4962	491964
17	1645239	16296	23666	0.27026895	444657	6396	4404	455457
18	1645239	15622	24139	0.25024903	411719	6041	3909	421670
19	1645239	14976	24622	0.23171206	381222	5705	3470	390397
20	1645239	14357	25114	0.21454821	352983	5388	3080	361452
21	1645239	13763	25616	0.19865575	326836	5089	2734	334659
22	1645239	13194	26129	0.18394051	302626	4806	2427	309859
23	1645239	12649	26651	0.17031528	280209	4539	2154	286903
24	1645239	12126	27184	0.15769934	259453	4287	1912	265652
25	1645239	11625	27728	0.1460179	240234	4049	1697	245981
26	1645239	11144	28282	0.13520176	222439	3824	1507	227770
27	1645239	10683	28848	0.12518682	205962	3611	1337	210911
28	1645239	10242	29425	0.11591372	190706	3411	1187	195304
29	1645239	9818	30014	0.10732752	176579	3221	1054	180854
30	1645239	9412	30614	0.09937733	163499	3042	935	167477
31	1645239	9023	31226	0.09201605	151388	2873	830	155092
32	1645239	8650	31851	0.08520005	140174	2714	737	143625
33	1645239	8292	32488	0.07888893	129791	2563	654	133008
34	1645239	7950	33137	0.07304531	120177	2421	581	123178
35	1645239	7621	33800	0.06763454	111275	2286	515	114076
36	1645239	7306	34476	0.06262458	103032	2159	458	105649
37	1645239	7004	35166	0.05798572	95400	2039	406	97846
38	1645239	6714	35869	0.05369048	88334	1926	360	90620
39	1645239	6437	36586	0.04971341	81790	1819	320	83929
40	1645239	6171	37318	0.04603093	75732	1718	284	77734
				LCC Total	20138637			