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Offshore Transmission in New England:

The Benefits of a Better-Planned Grid

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Prepared for

ANBARIC®

THE Brattle GROUP

Project Scope and Approach

Anbaric retained Brattle to compare the potential costs of various offshore transmission options and recommend the most competitive and cost-effective options to enable offshore wind development in New England

We qualitatively and quantitatively examined two approaches to developing offshore transmission and associated onshore upgrades to reach New England's offshore wind (OSW) development goals

1. The **current approach** wherein OSW developers compete primarily on cost to develop incremental amounts of offshore generation and associated project-specific generator lead lines (GLLs)
2. An **alternative "planned" approach** wherein transmission is developed independently from generation. Offshore transmission and onshore upgrades are planned to minimize overall risks and costs.

We conduct analyses of potential OSW-interconnection configurations for two levels of future offshore wind development. While other transmission configurations are possible, those captured here are representative of likely outcomes

- The analyses reflect current trends in how and where developers cite generator lead lines
- We highlight an alternative outcome that is unlikely to occur without a planning process

Executive Summary

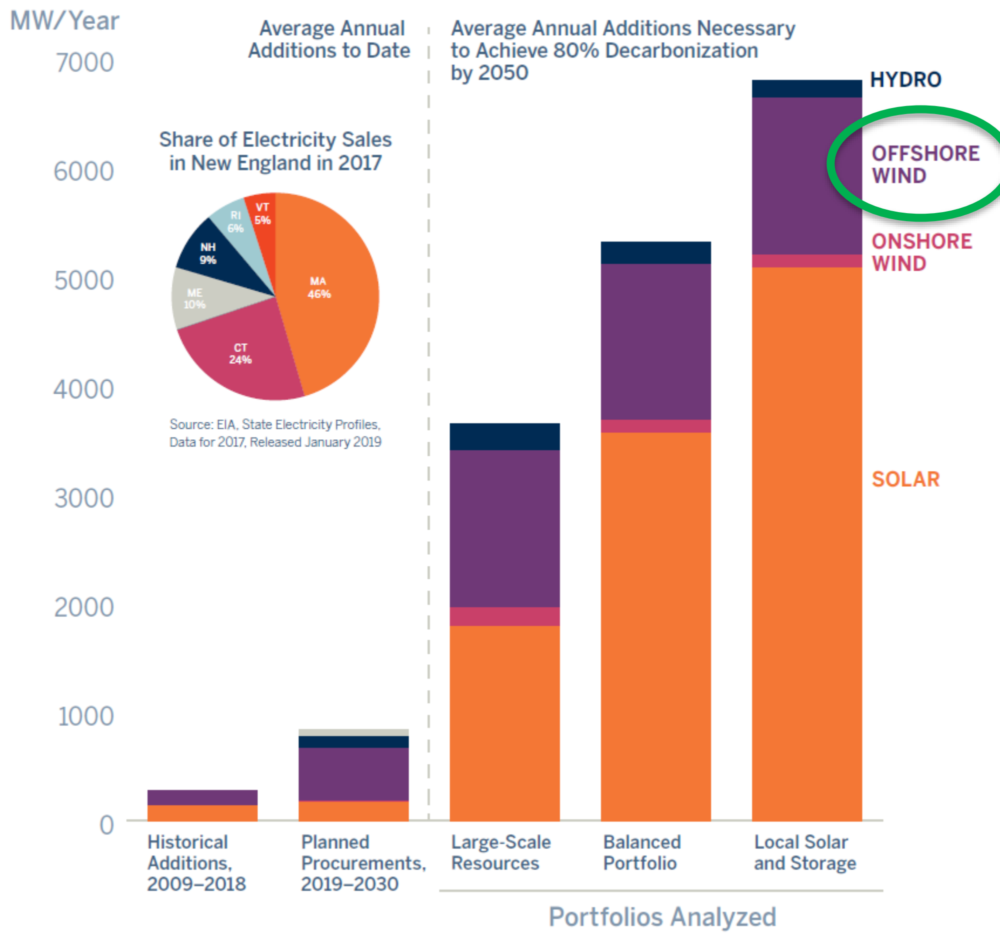
Motivation and policy goals

Thousands of MW of new clean resources would need to be built every year to meet decarbonization goals in New England – **possibly over 40,000 MW of OSW by 2050**

Developing these resources and associated transmission efficiently is essential for controlling customer costs

A key policy challenge is ensuring a pathway to enable the lowest-cost solutions for delivering new clean energy from source to population centers

New England Likely Needs 1,500 MW+ of OSW Additions Every Year to Achieve "80% by 2050" Decarbonization Goals



Source: Brattle Study by Jurgen Weiss and Michael Hagerty, "Achieving 80% GHG Reduction in New England by 2050," September 2019.

The current approach to offshore transmission will incur high costs

New England has already contracted for 3,112 MW of OSW. The next 3,600 MW* of OSW could still be developed under the status quo: with each developer constructing a GLL to an onshore point of interconnection (POI)

- To date, OSW developers have focused on identifying landing sites with the closest access to onshore grid

However, **this existing approach is likely to lead to substantial onshore upgrade needs far sooner than assumed**: already selected projects connecting to Cape Cod face up to $787 million in onshore transmission upgrades and continuing this approach in the next procurements could lead to an additional $1.7 billion in onshore upgrades**

Given the high cost and difficulty of building onshore transmission, **a planned approach to developing the offshore grid can significantly reduce the need and costs for onshore upgrades**, where there is a history of delays and budget overruns in New England

- Since 2002 major onshore transmission projects in New England have on average exceeded budgets by 79% with project duration exceeding five years***

A planned approach is likely to result in lower costs in both the near- and longer-term, by lowering risks and costs of onshore upgrades and increasing competition for both offshore transmission and generation

Estimated Offshore Transmission and Onshore Upgrade Costs Under Current Approach

* Corresponds to currently-authorized procurement authority in MA and CT and potential demand from other states and 3rd parties, beyond the OSW that has already been procured in New England.
**See slides 15-17
*** New Hampshire Transmission, "Greater Boston Cost Comparison," January 2015

Anticipatory planning will lead to lower and more predictable costs

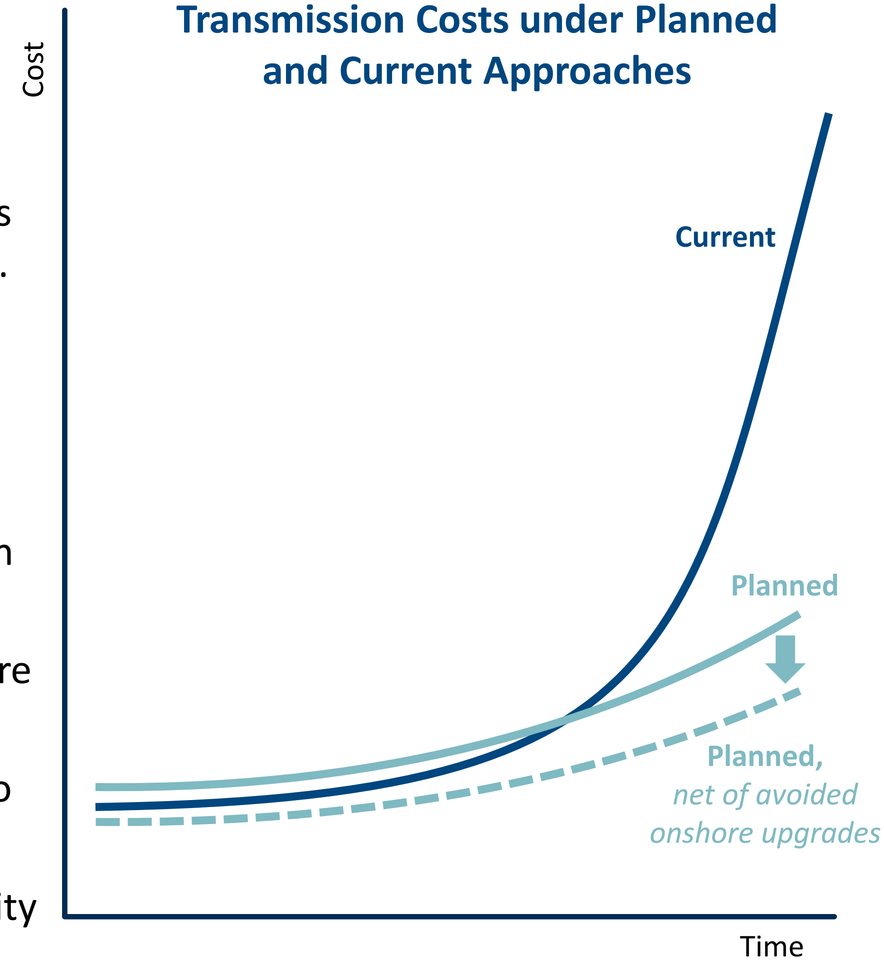
With a well-planned offshore grid, the overall transmission costs can be more closely estimated and phased-in over time

The current GLL approach may appear to have low initial costs but those will likely increase substantially after the "low hanging fruit" is picked, when real costs are revealed through costly onshore system upgrades.

Lack of well-planned transmission to achieve states' objectives has already created barriers for the deployment of clean energy in New England:

- Less than half of the 2,000 MW target Maine established for onshore wind resources have been built, largely due to transmission constraints
- While major new transmission projects for onshore wind were proposed, none have been built
- Five wind projects in Maine were cancelled due to prohibitive transmission upgrade costs
- Lack of a regional plan also imperils hydroelectricity imports from Canada

***Illustration* of Potential Incremental Transmission Costs under Planned and Current Approaches**



Source: Maine Governor's Office of Energy Independence and Security, "Maine Wind Energy Development Assessment," 2012.

Role of public policy in informing regional transmission planning

The growth in offshore wind in New England is driven by state public policy goals and will be achieved through policy mechanisms.

When considering the transmission network needed to support offshore wind deployment, system planning for New England should consider current cumulative goals and a high-OSW future.

Individual states or groups of states can proactively plan for and procure portions of the needed transmission network; such a state-led procurement framework is provided in later slides.

Broader regional coordination among New England states and ISO-NE could help meet the policy objectives of the participating states, including planning and procurement of offshore and onshore transmission systems.

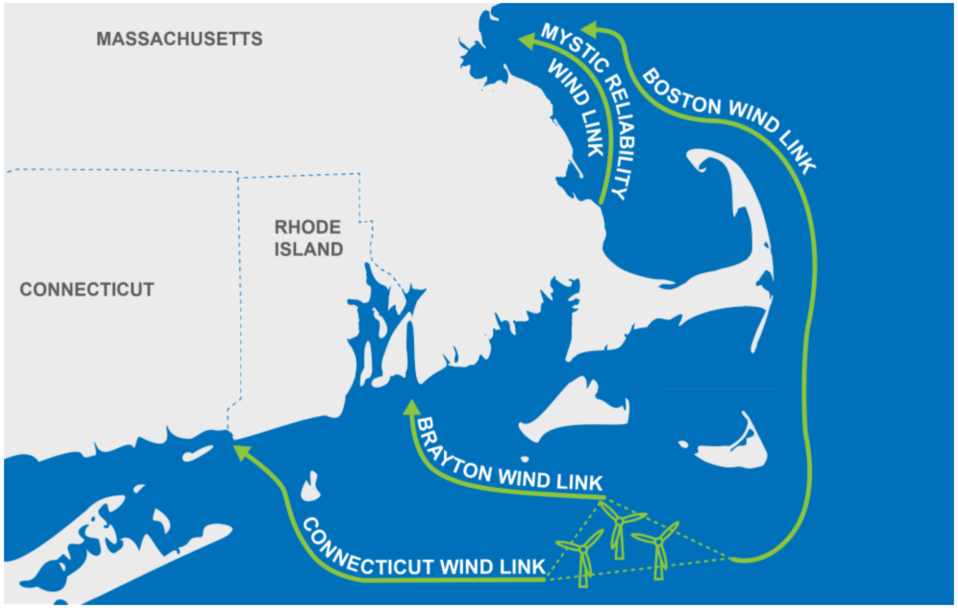
There is precedent for planned development of offshore transmission

Other U.S. jurisdictions have planned transmission infrastructure to develop large-scale onshore renewables. Examples include Texas (CREZ), California (Tehachapi Wind), MISO (Regional Multi-Value Projects), and several European countries. **New England could adopt a similar approach to planning transmission infrastructure to support offshore wind.**

As an example, Anbaric has proposed developing a southern New England OceanGrid that includes a vision to:

- Connect offshore wind directly to load centers and robust grid connections
- Meet needs identified by ISO-NE for new paths for offshore wind to integrate with existing system
- **Avoid more than $1 billion in onshore transmission upgrades**

Schematic of Anbaric OceanGrid Proposal



Source: Anbaric, "Southern New England OceanGrid."

Benefits of a planned offshore transmission approach

A planned transmission approach that jointly coordinates onshore and offshore transmission investments to serve New England's offshore wind needs provides significant benefits for the growing industry and electric customers.

Elements we examine	Our analysis indicates…	*Slides*
Total onshore + offshore transmission costs • Onshore transmission upgrade costs (more risk) • Offshore transmission costs (less risk)	10% lower under planned approach • 65% lower under planned approach • 22% higher under planned approach	*16 & 17*
Losses over offshore transmission	40% lower under planned approach	*12*
Impact to fisheries and environment	49% less marine cable under planned approach	*22*
Generation-related production costs	Reach ~$1 million/yr lower for 3,600 MW of OSW under planned approach	*19*
Customer costs of energy, excluding transmission	Reach $20 million/yr lower for 3,600 MW of OSW under planned approach	*19*
Effect on generation and transmission competition	Increased competition under planned approach	*18 & 20*
Utilization of constrained landing points	Improved under planned approach	*21*
Utilization of existing lease areas	Improved under planned approach	*23*
Enabling third-party customers	Improved under planned approach	*24*

Analytical Approach

We compare transmission configurations for two additional OSW expansion phases

	Current GLL approach	Planned offshore-grid approach
We compare two transmission scenarios representative of configurations achievable under the “current” and “planned” approaches		
We assume **3,112 MW of projects already procured** in New England proceed as currently planned with GLLs under both scenarios	Gen-ties to interconnect Vineyard Wind, Mayflower Wind, Revolution Wind, and Park City Wind	
We first look at a **Phase 1** to interconnect an additional **3,600 MW** of OSW, corresponding to currently-authorized procurement authority for MA (1,600 MW), CT (1,200 MW), and 800 MW of assumed procurements from other states and third-parties. We necessarily make assumptions about transmission routing and points of interconnection under the planned vs. current approach.	Continue GLL approach	Begin planned procurements
We then look at a **Phase 2** to add a total of **8,000+ MW** of OSW beyond the amount already procured. The total Phase 2 represents the remaining estimated OSW capacity of existing New England lease areas (beyond those already-committed for projects in New England and New York + one additional 1,100MW project to NY)*	Continue GLL approach	Build on Phase 1 planned transmission configuration with additional planned transmission procurements

* 14.5GW assumed total capacity of New England lease areas based on Anbaric analysis of public announcements from BOEM and leaseholders

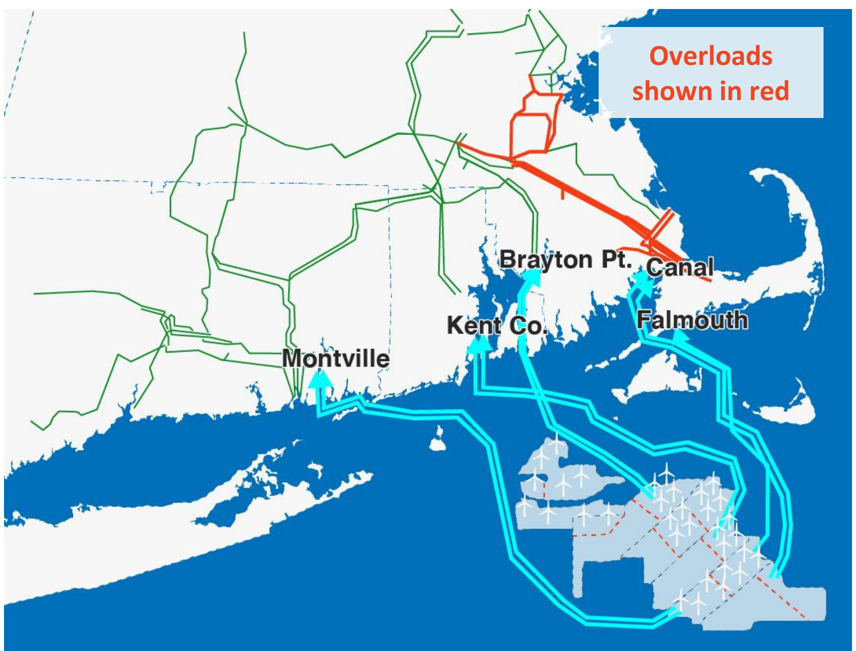
Phase 1 (add 3,600 MW): Summary of the two transmission approaches

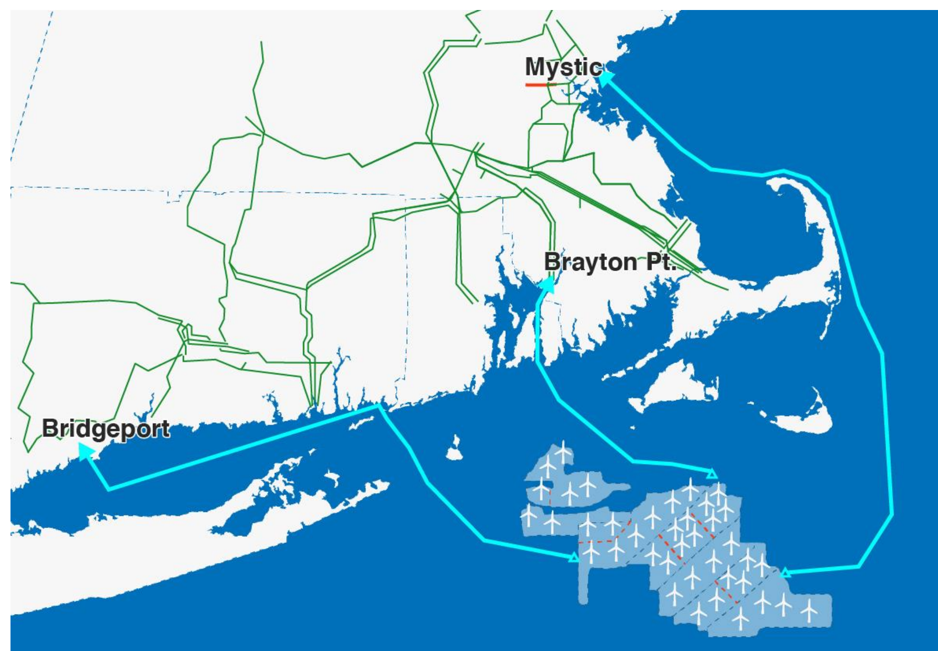
Current GLL Approach

- 9 x 400 MW High Voltage Alternating Current (HVAC) cable bundles:
  - 800 MW each at Montville, Kent Co. Brayton Pt. & Canal
  - 400 MW at Falmouth
- 694 miles of marine cabling
- 4.0% losses
- Significant onshore transmission overloads

Planned Offshore-Grid Approach

- 3 x 1,200 MW High Voltage Direct Current (HVDC) cable bundles
  - 1,200 MW each at Bridgeport, Brayton Pt. & Mystic
- 356 miles of marine cabling
- 2.4% losses
- Minimal onshore transmission overloads





Sources: Overloads based on GE analysis for Anbaric (Appendix B), which identified numerous within-zone overloads not identified in ISO-NE zonal analysis. Loss estimates based on vendor specifications and third-party sources

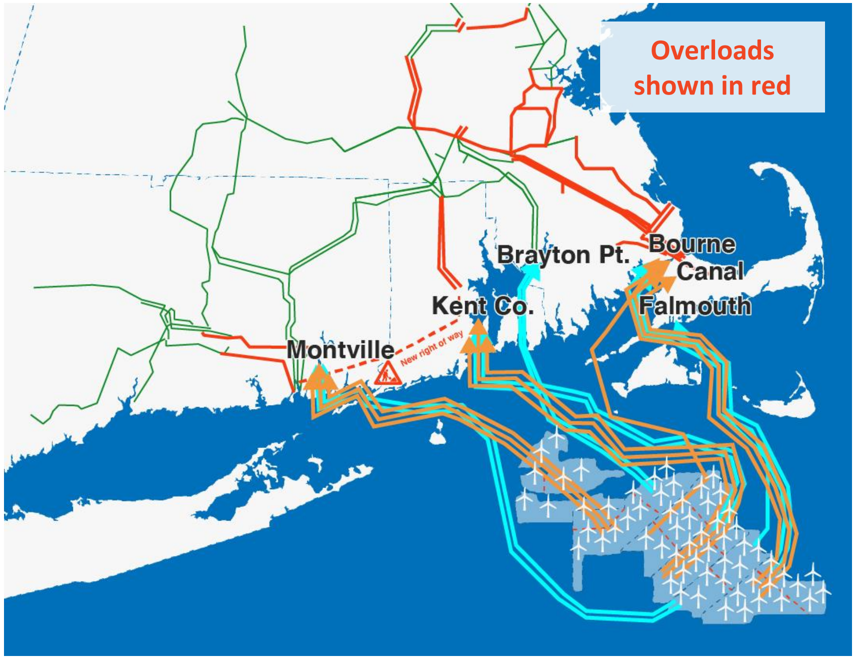
Phase 2 (add 8,000+ MW): Summary of the two transmission approaches

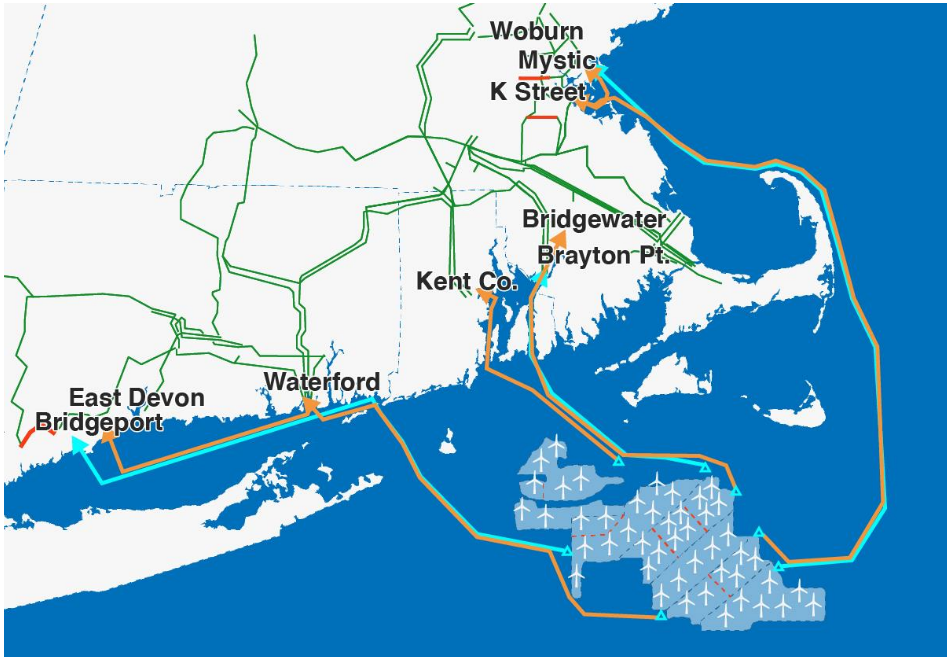
Phase 2, Current Approach (add 8,200 MW)

- 9 x 466 MW HVAC cable bundles
  - 1,400 MW each at Montville, Kent Co., & Canal
- 1 x 400 MW HVAC project
  - 400 MW at Bourne
- 926 miles of marine cabling *(1,620 total Phase 1+2)*
- Major onshore transmission overloads

Phase 2, Planned Approach (add 8,600 MW)

- 3 x multiterminal HVDC projects
  - 2,000 MW to Waterford (1200 MW) & East Devon (800 MW)*
  - 1,600 MW to K St. (800 MW) & Woburn (800 MW)*
  - 1,000 MW to Bridgewater
  - 400 MW HVAC project to Kent Co. RI
- 474 miles of marine cabling *(831 total Phase 1+2)*



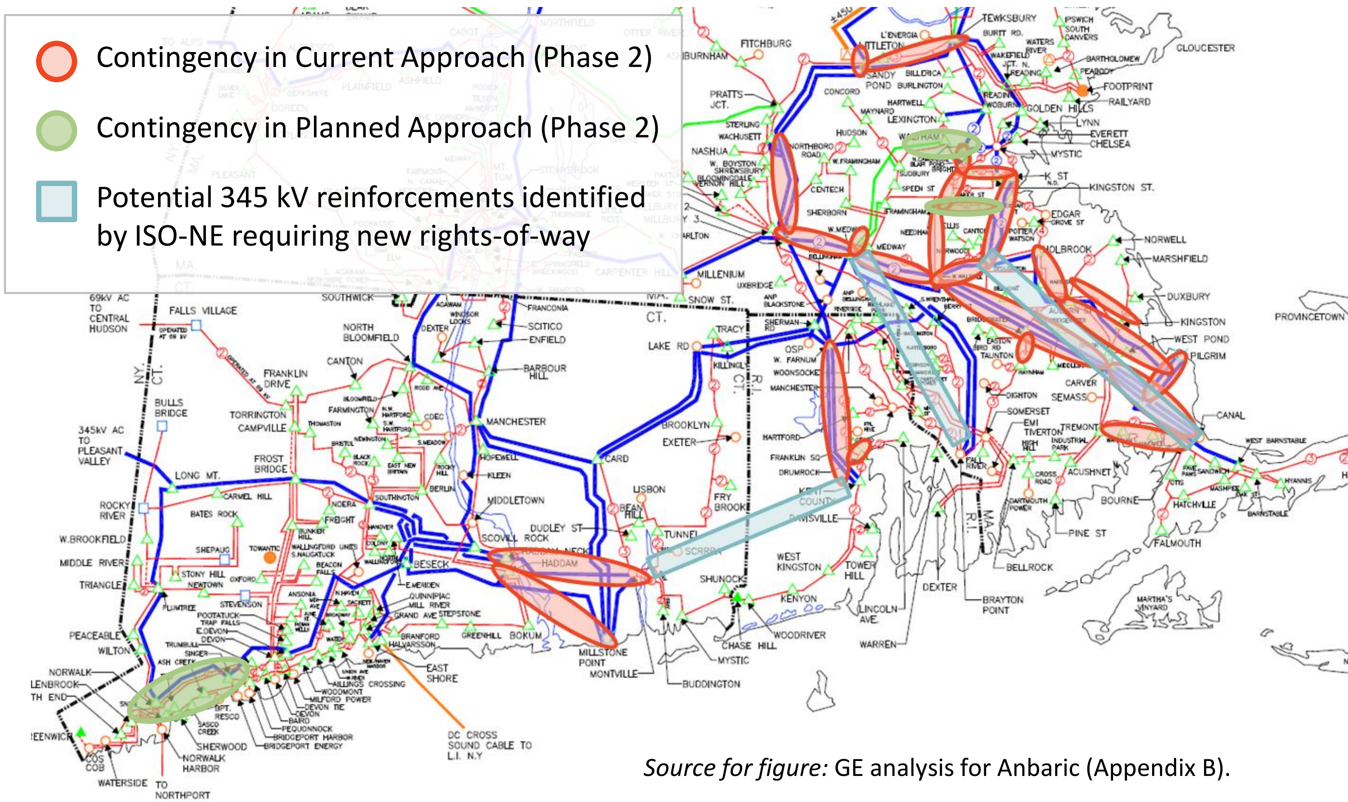


*Multiterminal HVDC injecting at two locations

Benefits of Planned Offshore Transmission

Avoid major overloads of the onshore grid resulting from current gen-tie approach

- To date, OSW developers have focused on landing sites with the closest access to onshore grid
- Already-procured projects connecting to Cape Cod face up to $787 million in onshore upgrades*
- Regional procurement targets exceed available near-shore landing sites**
- Onshore upgrade costs should be included in a generator's bid, but we anticipate that costs are underestimated, in which case the additional costs could lead to problems completing the projects or increased costs for customers



Source for figure: GE analysis for Anbaric (Appendix B).

* ISO-NE's Feasibility Study for interconnecting three projects totaling 2,400 MW to Cape Cod (QP 828) identifies $227M in upgrade costs with a -50% to +200% range ($113M to $681M). Interconnecting an additional 400 MW associated with one of these projects (QP829) is estimated to cost an additional $36M with a -50% to +200% range ($18M to $106M).

** ISO-NE has identified 5,800 MW of injection capability in SEMA, RI, and SECT, and existing state procurement targets already equal 5,900 MW

Planning ahead avoids onshore transmission upgrades that otherwise would be needed

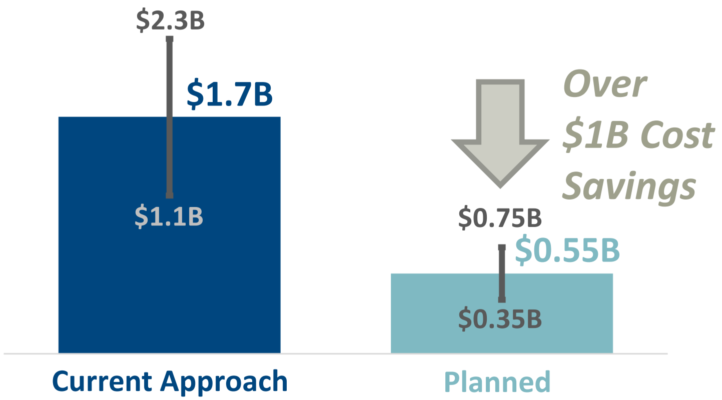
Given the high cost and difficulty of building onshore transmission, a planned offshore grid can significantly reduce need and costs for onshore upgrades, where there is a history of delays and budget overruns in New England

- Major transmission projects in New England since 2002 have averaged budget overruns of 79% with average development times of over five years*
- One recent project in Southern New England – the New England East-West Solution Interstate Reliability Project – took 9 years to complete

Customers benefit from better-planned off-shore transmission through reduced cost and risk of onshore transmission upgrades

- Previous analysis indicates that delays of even one or two years could cost ratepayers $350 to $700 million*
- These uncertainties add substantial risks to the feasibility of the current approach; potentially adding $1.1 billion in costs

The Current GLL Approach Would Require Onshore Upgrade Costs $1.1B Higher Than a Planned Approach in Phase 1
(3,600 MW additional OSW)



Sources: CHA analysis of "Phase 1" transmission upgrade costs for Anbaric included in Appendix C.
*New Hampshire Transmission, "Greater Boston Cost Comparison," January 2015.

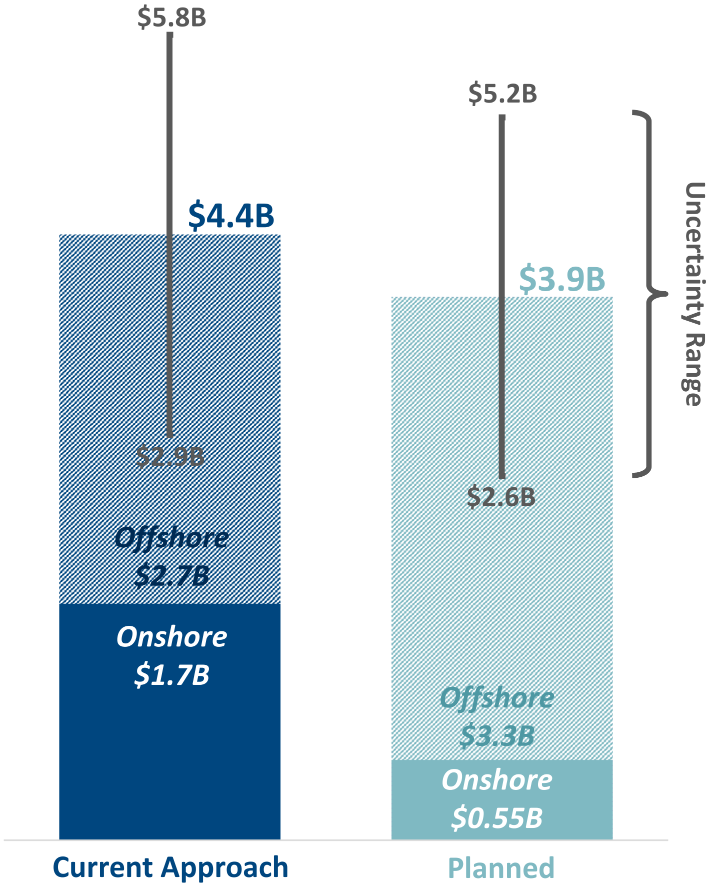
Total costs of transmission are expected to be lower under a planned approach

Even including the more costly offshore transmission equipment ($3.3B vs $2.7B for Phase 1), total costs of onshore upgrades plus offshore transmission to enable the next 3,600 MW of OSW are estimated to be lower under a planned than the current gen-tie approach

- Onshore upgrade costs of $0.55B under planned approach vs $1.7B under current approach)

The planned approach to building offshore transmission can enable significant long-term cost savings and avoid some of the higher risks associated with onshore upgrades

Comparison of Total Onshore Plus Offshore Transmission Costs in Phase 1
(3,600 MW additional OSW)



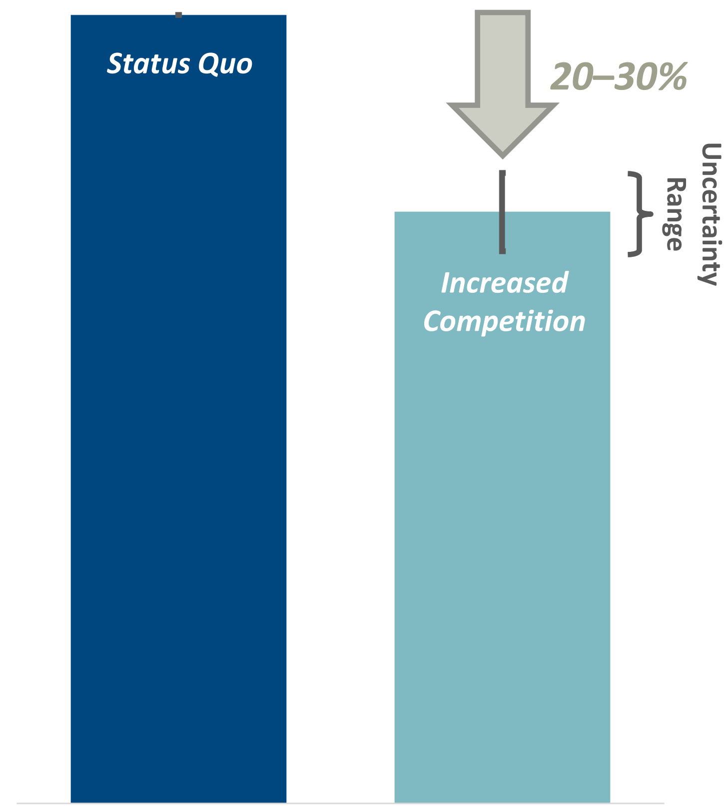
Source for cost data: Onshore upgrade cost estimates based on GE and CHA analysis of "Phase 1" scenarios for Anbaric included in Appendices B and C. Estimate for offshore transmission equipment based on proprietary supplier information provided to Anbaric.

Increased competition among offshore transmission developers

Offshore transmission developers would compete to build planned transmission. This direct competition would put downward pressure on costs to ratepayers (further lowering costs beyond that described on previous slides)

- Studies of onshore transmission indicate that competitive procurement enables "significant innovation and cost savings of 20–30%" relative to the costs incurred by incumbent transmission companies; the costs of conducting the competitive processes are small compared to the savings*
- Studies of offshore transmission costs in the U.K. similarly indicate that competition across independent offshore transmission owners reduced costs 20–30% compared to generator-owned transmission (driven by lower operating costs and financing costs from improved allocation of risk and reduced risk premium)**

Anticipated Cost Impact of Competition to Develop Offshore Transmission



Sources: * The Brattle Group, "Cost Savings Offered by Competition in Electric Transmission: Experience to Date and the Potential for Additional Customer Value," April 2019, Produced for LSP Transmission.
** Cambridge Energy Policy Associates, "Evaluation of OFTO Tender Round 2 and 3 Benefits," March 2016, Produced for Ofgem.

Lower total system-wide generation costs and savings to customers

Based on analyses conducted by GE, the planned approach will yield system-wide generation cost savings, primarily from reduced transmission losses and reduced offshore wind curtailments

- After Phase 2 with an additional 8 GW of OSW in service, curtailments would be reduced from 13% in the current approach to 4% in the planned: equivalent to ~700 MW
- This yields generation cost savings that reach **$55 million** per year-under the planned approach relative to the current approach for Phase 2

The planned approach would inject more of the OSW into higher-priced locations on the grid, further reducing customer costs

- GE's estimated customer savings of the planned approach reach ~$20 million per year in Phase 1 and over **$300 million** per year in Phase 2 in 2028
- Part of this is a value transfer from conventional generators to customers, not necessarily a reduction in total system costs (so is not shown in the chart)

One Year System-wide Generation Cost Savings of Planned Approach Compared to Current Approach

Source: GE analysis for Anbaric included in Appendix B

Increased competition among OSW generation developers

Competition among developers of OSW generation would be enhanced, yielding a range of potential cost savings

Minimum savings → **Higher potential savings**

The planned, competitive approach would simplify a major strategic decision for developers

Today, developers must bid before they have accurate information about their transmission upgrade costs. Removing these risks from the offshore generation procurement should lead to lower bids because of the reduced risk premium alone

Ultimately, it could increase participation and competition in OSW solicitations.

In Europe, planned transmission approaches have enhanced head-to-head competition leading to **zero-subsidy bids** in recent procurements (see case study details in appendix)

We anticipate more willing bidders and more competition with increased access to transmission (though overall still limited by number of leaseholders)

More efficient use of constrained "cable-approach" routes

There are a limited number of landing sites for offshore wind transmission lines in New England

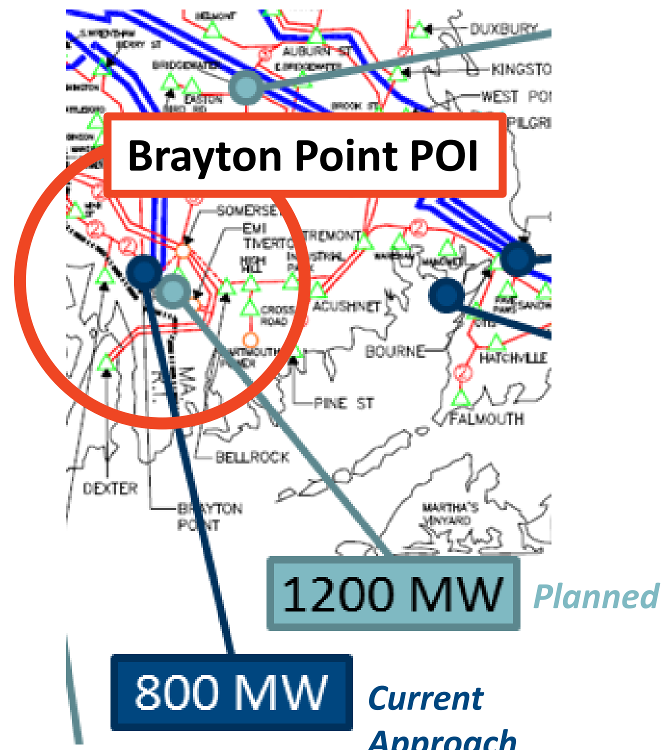
In the longer term, if each OSW project requires a separate cable connection to the onshore transmission system, viable cabling routes become constrained

A planned transmission approach can make better use of limited landing sites.

For example:

- Anbaric's analysis indicates that access routes to Brayton Point have space for only 2 physical cable bundles. Under the current gen-tie approach this would accommodate 2 x 400 MW HVAC interconnection cable bundles
- A planned approach utilizing HVDC cable bundles can deliver 1,200MW to Brayton Point with room for an additional HVDC cable bundle before reaching spacing constraints

Example: Interconnection Capacity under the Current and Planned Approaches



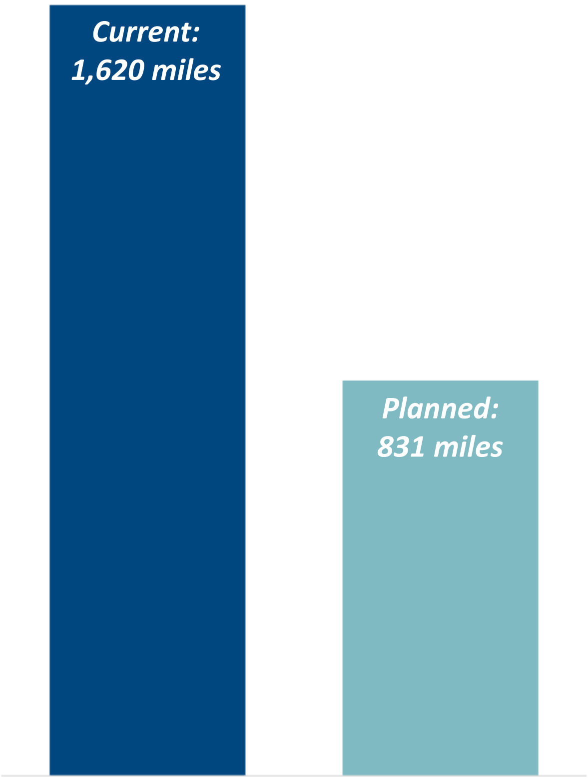
Reduced impacts to fisheries and the environment

Better planning can reduce the cumulative effects of offshore transmission on fisheries and the environment

- Under a planned off-shore-grid approach, marine trenching can be reduced by almost 50% (based on Anbaric proposed cable routing)
- Offshore cables can be grouped in transmission corridors to minimize impact; this is not possible to enforce under the current (one-off, unplanned) approach

Minimizing the number of offshore platforms, cabling, and seabed disturbance reduces impacts on existing ocean uses and marine environments to the greatest practical extent

Comparison of Total Length of Undersea Transmission Under Current and Planned Approaches by Phase 2
(8,000 MW + additional OSW)



Source: Slide 13.

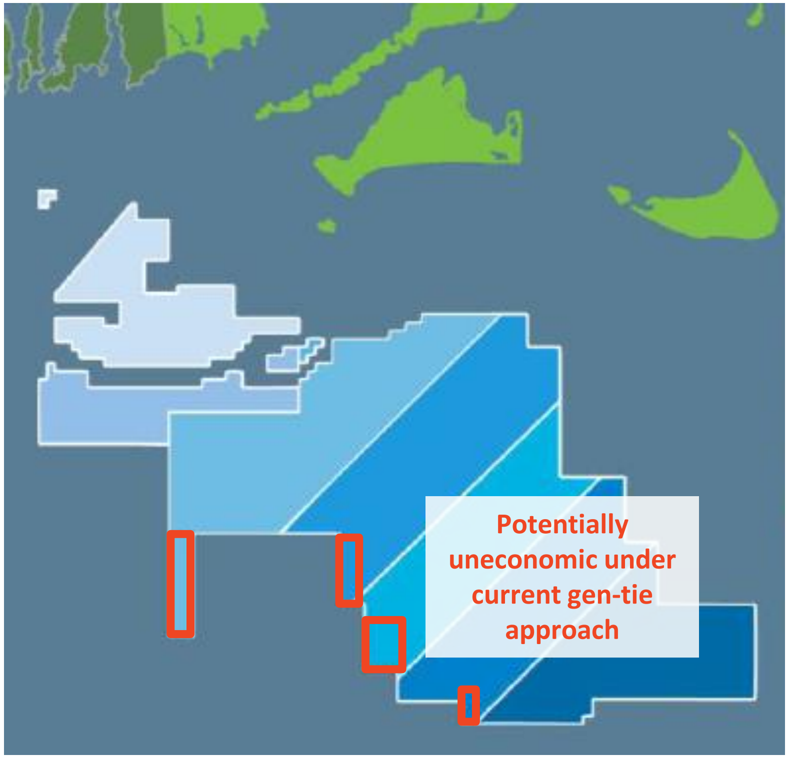
Realize the full potential of existing lease areas

Without a well-planned offshore grid, some of the existing offshore lease sites may not be economic to develop

- After developers interconnect the bulk of their lease sites, it may be cost prohibitive to interconnect the residual areas (of perhaps 50 MW to 250 MW each) using AC generator lead lines sized to carry ~400 MW each
- This increases the risk of inefficient use of lease sites and stranded assets

An offshore grid with well-located offshore collector stations would increase the likelihood that residual lease areas could be developed cost-effectively, and that the full potential of all lease areas can be realized

Developers May Find Residual Areas Uneconomic to Interconnect With Generator Lead Lines



Map Source: Massachusetts CEC, "Massachusetts Offshore Wind Initiatives," EBC Sixth Annual Offshore Wind Conference.

Improved reliability and reduced OSW curtailments

Designing and building the offshore grid with networking capability preserves the option to create a meshed configuration to improve reliability and reduce curtailments in case of transmission outages

- For example: If three 1,200 MW HVDC converter stations were networked offshore, an outage of one line would still allow flowing full power in all hours when the total generation is less than 2,400 MW, resulting in only 4% of energy curtailed relative to no outages
- Under the current (non-meshed) gen-tie approach, an outage in any one of three lines would results in 33% reduction in delivered energy to the onshore system, causing significantly more curtailments than under a meshed configuration

Source: Anbaric analysis.
Notes: Several European countries are studying meshed DC configurations for use interconnecting OSW in the North Sea. Reference materials compiled by Curis et al., "Synthesis of available studies on offshore meshed HVDC grids," 2016.

Enabling third-party customers

An independent, open-access offshore grid can create opportunities for additional (non-mandated) OSW resources to be built at lower cost

- As OSW generation costs decrease, third-party customers have expressed interest in purchasing offshore wind, but even large individual customers are unlikely to purchase sufficient OSW to fully utilize an export cable sized to carry 400 MW of offshore wind. Developing smaller projects with larger export cables would be uneconomical
- An open access transmission system could serve as a platform for individual offshore-wind procurements of smaller sizes, enabling OSW development without state-sponsored contracts
- A generation developer could build surplus transmission capacity into a project but would then likely have market power in selling to third parties, whereas independent transmission would require OSW generators to compete against each other to utilize independent transmission.

Case examples:

Microsoft and Google purchased 90 MW and 92 MW of OSW over independent transmission in the Netherlands and Belgium

The Texas CREZ served as a platform for third-party power purchase agreements (PPAs), enabling over 2 GW of onshore wind PPAs from 22 corporate buyers

In the Southwest Power Pool, ISO-planned transmission investment enabled 2.5 GW of corporate PPAs

Sources: Wind Solar Alliance, "Corporate Renewable Procurement and Transmission Planning," October 2018.

Procurement Approach

We recommend a planned approach to offshore transmission

A planned approach leverages competition among transmission developers to build out a New England offshore transmission grid in a staged manner, enhances competition between off-shore wind generators, and leads to lowest costs

Utilizing GLLs has distinct disadvantages over planned offshore transmission. While the GLL approach may appear to offer* lower costs in the short run, it is not aligned with the public interest in the long run, leading to:

- Poorer use of limited onshore POIs
- Increased seabed disturbance
- Reduced competition for transmission and off-shore wind generation
- Higher onshore transmission upgrade costs and higher overall costs in the long run

Under the planned approach, OSW generation developers still will be able to participate in transmission procurements,** but must be willing to develop open-access transmission for other leaseholders when participating in the transmission procurement (even if their generation bid is unsuccessful in the generation procurement)

* Costs of transmission in bundled generation + transmission bids could also appear artificially low if bidders can shift costs from transmission to generation within projects

** This would require functional or physical business separation

Implementing planned transmission procurements

The planned approach can be implemented through joint procurement of transmission and generation. The solicitation can build on prior New England state procurements of transmission for renewable energy, including the 2015 "Three State RFP" issued by MA, CT and RI, which included a Transmission Service Agreement model. The procurement can be initiated immediately, with selection of winning projects by 2021.

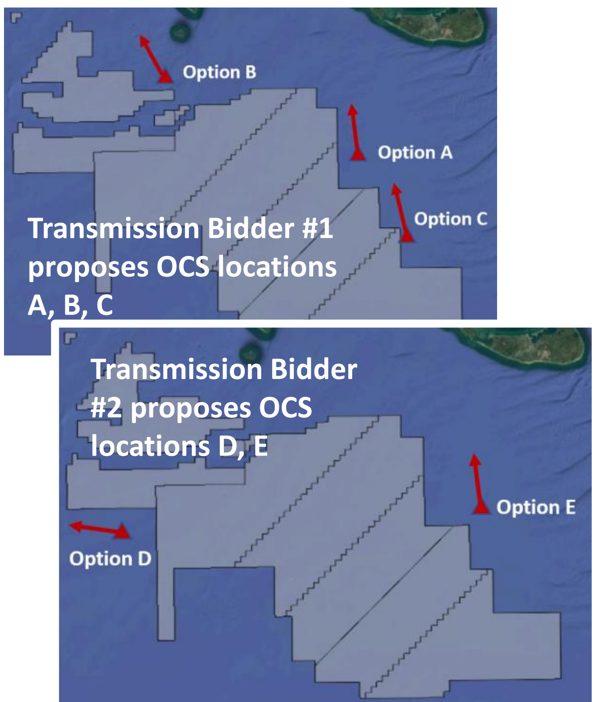
Example Implementation of Transmission and Generation Procurement

1. **Identify preferred onshore POIs** based on long-term plan
2. **Solicit transmission** developers to propose multiple fixed-price options for (bidder-determined) offshore collector station (OCS) locations and POIs
3. Evaluate transmission (Tx) bids considering cost, accessibility to lease areas, impacts on fisheries & environment and select a single winning bidder – but do not yet select final OCS location or POI
4. **Solicit generation** developers to bid to interconnect to any of the OCS locations provided by winning Tx bidder
5. Evaluate OSW generation bids, considering total cost (generation + transmission) and other factors to select generation developer and OCS location

Example of transmission and generation procurement

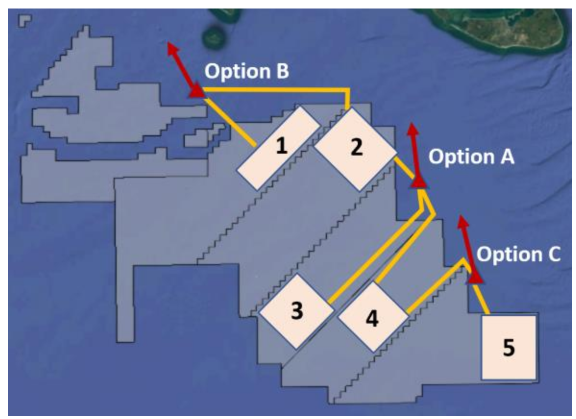
<u>Transmission</u> developers propose collector station locations A - E

Each transmission developer bids a fixed price for one or more collector station locations



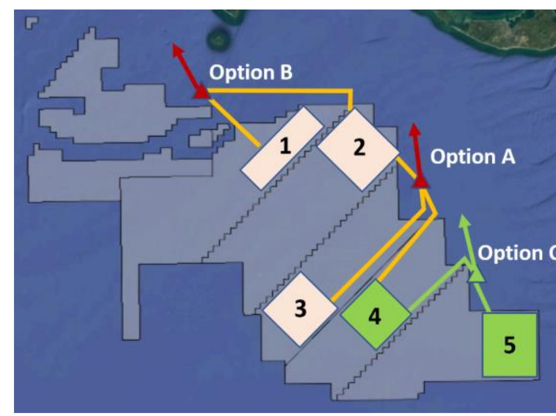
Transmission developer #1 selected; leaseholders bid <u>wind generation</u> 1-5 to collector stations A, B, C

Each generation developer bids a fixed price for one or more collector station locations



Selection of winning configuration

Wind farms 4 and 5 connecting to collector station C minimize costs of procuring specified MW quantity of offshore wind



Mitigating risk with separate generation and transmission procurements

The current GLL approach places development of generation and offshore transmission under a single developer, but leaves onshore upgrades with incumbent (onshore) transmission owners

- This approach reduces coordination risk between OSW and offshore transmission, but there remains project-on-project risk related to the completion of onshore upgrades
- Furthermore, the misalignment between generation developer incentives and public policy objectives increase risks to the overall offshore wind development effort (significant onshore upgrades, higher curtailment risk, less competition, and higher long-term costs)

The planned offshore grid model reduces risks that could inhibit achievement of overall OSW development goals, and can also address individual project-on-project risk through:

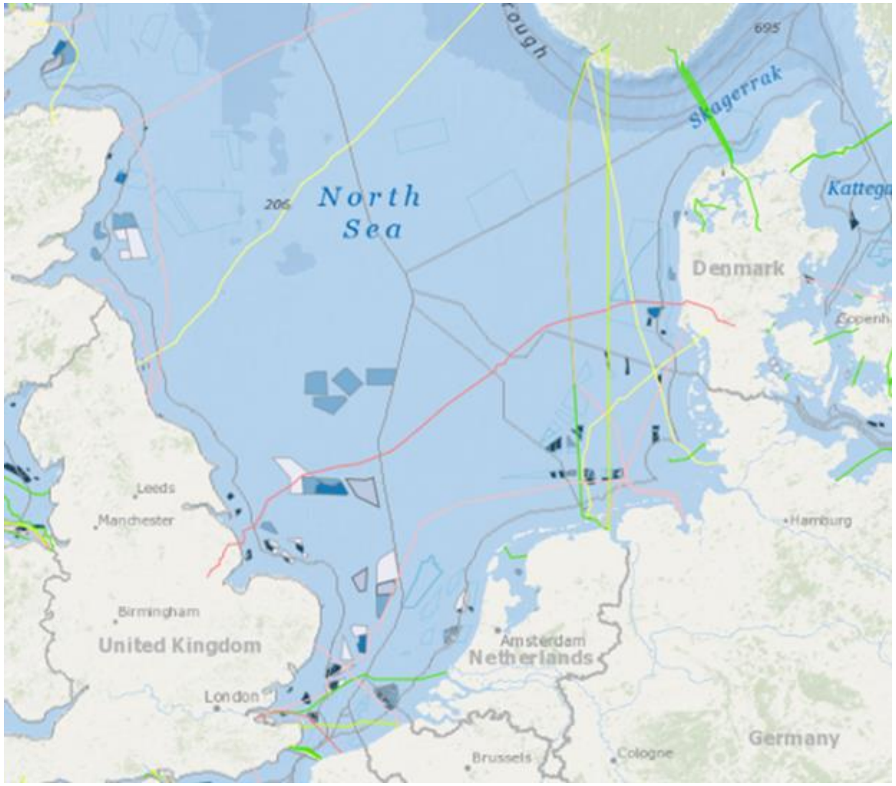
- Strong performance and completion incentives (rewards or penalties) for both transmission and generation developers to meet project deadlines
- Allowing generation developer to participate in transmission procurement, with the condition that the transmission will be open access
- Staggered transmission and generation project completion timelines (e.g., scheduling transmission project completion before generation)

Appendix A: Case Studies

Offshore transmission network in Europe

- Both Germany and the Netherlands have implemented a planned transmission approach, with offshore transmission developed separately and in anticipation of new OSW generation
- Offshore transmission developed by TSO and paid for by electric ratepayers (as with other transmission infrastructure)
- This approach has already enabled 8,600 MW of OSW connected to Germany and the Netherlands to date
- Approach has increased competition among OSW developers. Project costs have declined by over 50% in the last five years, leading to "subsidy free" PPAs for recent OSW in both Germany and the Netherlands

Existing Offshore Transmission Development in the North Sea

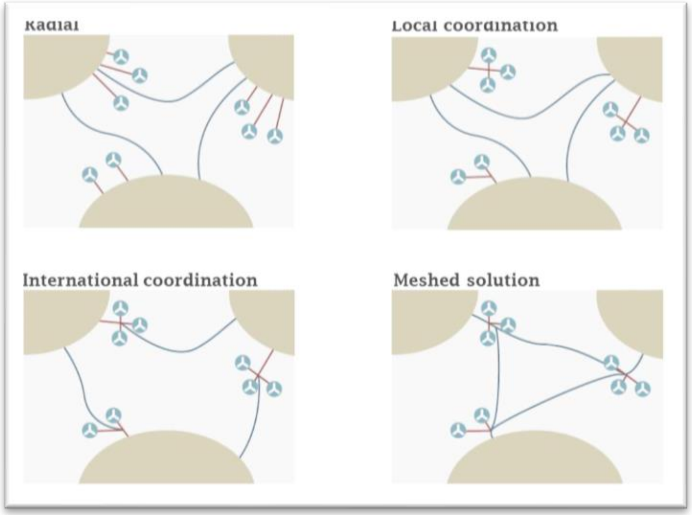


Source: NY Power Authority, "Offshore Wind: A European Perspective," August 2019.
Wind Europe, "Offshore Wind in Europe," February 2020.

Planning in the North Sea of Europe

- Planning ahead in the North Sea included analyses of "Radial" versus "Meshed" offshore grid
  - The North Seas Countries' Offshore Grid initiative (NSCOGI), formed in 2010, evaluated and facilitated coordinated development of a possible offshore grid that maximizes the efficient and economic use of renewable resources and infrastructure investments
  - Ten countries were represented by their energy ministries, supported by their Transmission System Operators, their regulators and the European Commission.
- A scenario-based planning approach was initiated in 2012; analysis then already showed benefits of having a planned meshed offshore system*
- More recent 2019 planning and analysis of very high OSW penetration in the North Seas (380 GW by 2050) indicates substantial benefits of meshed offshore grids: lowering the environmental burden, using infrastructure more efficiently, and reducing costs*

Models of Offshore Grid Development Considered



Sources: * The North Seas Offshore Grid Initiative, "Initial Findings," November 2012.
** Wind Europe, "Our energy, our future," November 2019.

Offshore transmission network in the U.K.

- To date, all OSW transmission in the UK has a radial design, with the transmission developed by the OSW developer and then sold to a separate transmission owner
- However, this approach is reaching its limits, as ad-hoc onshore interconnections are pushed further inland with increasing community impacts.
- Ofgem is currently studying and strongly considering implementing an offshore transmission network.

Ofgem Study of Possible Offshore Grid Design

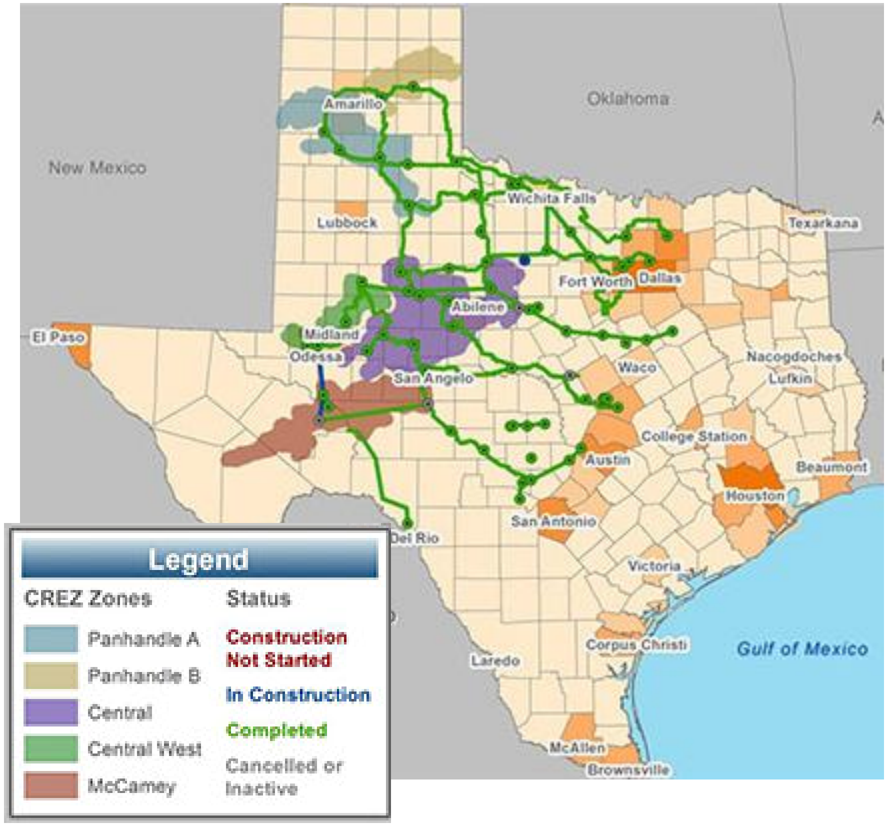
- Various studies conducted by Ofgem, utilities, and industry groups show that such a coordinated design could lower overall transmission costs by 9 to 15 percent.
- An offshore grid to support 34 GW of capacity would cost £24.2 billion ($31.5 billion), equivalent to a transmission cost of £5.36/$6.98 per MWh

Source: NewEnergyUpdate, Reuters Events, February 19, 2020.

Competitive Renewable Energy Zones (CREZ) in Texas

- $7 billion transmission-first program
- Phased development of transmission enabled 18.5 GW wind from five "competitive renewable energy zones" to rest of state
- Allowed rapid merchant development of wind in W. Texas, reducing electricity costs by $1.7 billion annually
- Process: ERCOT designed transmission system configurations to integrate each renewable energy zone through a staged, expandable approach. Desired configurations selected by PUC and developed by competitive transmission developers and incumbents

Texas CREZ Transmission Projects



Source: EIA, "Fewer wind curtailments and negative power prices seen in Texas after major grid expansion," June 2014.

Tehachapi Renewable Transmission Project (TRTP) in California

- Tehachapi was identified as a high wind potential region in southern California almost 20 years ago
- California policy makers solicited interest in building wind in Tehachapi
- California ISO developed a transmission plan for the region
- The transmission enabled 4,500 MW renewable power development
- 250 circuit miles, $2.1 billion cost
- Built by transmission developer, with costs allocated using existing CAISO transmission cost allocation system

CAISO TRTP Transmission Projects

Seg	Description
1	New 500kV line between Antelope and Pardee Substations and Antelope Substation Expansion
2	New 500kV line between Antelope and Vincent Substations
3A	New Windhub Substation and new 500kV line between Windhub and Antelope Substations
3B	New Highwind Substation and New 220kV line between Windhub and Highwind Substations
3C	Upgrades to Antelope, Vincent, Windhub Substations
4	Single-circuit 500kV transmission line between Whirlwind and Antelope Substations
5	Replacement of two 220kV lines with one 500kV line between Antelope and Vincent Substations
6	32 miles of 500kV line from Vincent Substation through the Angeles National Forest
7	Replacement of 220kV line with 500kV line between Angeles National Forest and Mesa Substation
8	Replacement of 220kV line with 500kV line between Mesa and Mira Loma Substations. New and replacement double-circuit 220 kV lines between Chino and Mira Loma Substations
9	New Whirlwind Substation and upgrades to Antelope, Vincent, Windhub, Mesa, Gould, Mira Loma Substations
10	New 500kV line between Windhub and Whirlwind Substations
11	Replacement 500kV line between Vincent and Gould Substations. New 220kV circuit on existing structures between Gould and Mesa Substations

Source: SCE, "Tehachapi Renewable Transmission Project."

Support from Other Stakeholders

"Separating transmission from generation procurement, while complex, has the potential to deliver optimal outcomes for consumers and the environment."

*- Environmental Stakeholders**

"A separate contingent solicitation for structure installation offshore could result in greatly fewer impacts to fisheries, and must have the primary goal of developing a more efficient (less cable used) and better-sited structure in the water."

- Responsible Offshore Development Alliance

"By allowing for more options for consideration and fostering greater competition, a planned transmission system benefits the offshore wind industry, states, taxpayers, local communities, the environment, local businesses, and other stakeholders. To maximize benefits and the opportunities for scaling an offshore wind industry that can create thousands of good sustainable jobs, BOEM should facilitate making open access, planned transmission available as an option [...]"

- International Brotherhood of Electrical Workers

"[…] the size and speed of OSW installations could overwhelm and congest our current land-based coastal grid, damaging the industry's reputation and shortchanging its growth potential."

- Tufts Power Systems and Power Research Group

* Environmental Stakeholders include the National Wildlife Federation, Conservation Law Foundation, Sierra Club (Mass. Chapter), and Acadia Center

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Offshore Transmission in New England: Benefits of a Better Planned Grid

Appendix B

Transmission Security Analysis & Economic Production Cost Simulation

May 13, 2020

Overview of Planning Study Process & Methodology

Transmission Security Analysis

Purpose: Model and Evaluate Costs of Current vs. Planned Transmission Development for ISONE Offshore Wind

Modify ISONE Cases to Create OSW Buildout Base Cases(PSSE)

- Scenario 1: Current HVAC Transmission Buildout
- Scenario 2: Planned HVDC Transmission Buildout + Mystic Reliability Wind Link Project

Perform Transmission Security Analysis (TARA)

- NERC Transmission Planning Performance Requirements TPL-001-4
- NPPC Directory #1: Design and Operation of Bulk Power System

Economic Study Process & Methodology

Purpose: Compare Economic Production Cost Metrics in Current vs. Planned Transmission

Build[1] GE EC MAPS 4-Pool Database Model (PJM/NYISO/IESO/ISONE)

- Base Case: Install 3.1 GW of Baseline OSW in ISONE
- Scenario 1: Current HVAC Transmission Buildout (8.1 GW OSW)
- Scenario 2: Planned HVDC Transmission Buildout (8.6 GW OSW) + Mystic Reliability Wind Link Project

Base Case Assumption: Six Transmission Upgrades

- Upgrades assumed as necessary to address 44% curtailment resulting from Base Case injections

Scenario 1 & 2 Include Reliability Upgrades from Base Case Injections

- Necessary transmission upgrades to meet NERC TPL Standards / NPCC Directory 1 Requirements

Key Production Cost Simulation Metrics for ISONE

- Offshore Wind Curtailment (%)
- Annual Average LMP ($/MWh)
- Annual Production Cost Savings ($M)
- Load Payment Savings ($M)

[1] https://www.iso-ne.com/static-assets/documents/2019/05/a2_2019_economic_study_draft_scope_of_work_and_high_level_assumptions.pptx

Overview of Economic Study Process & Methodology

Comparison to ISONE Economic Study Methodology[1]

GE EC Anbaric Study

More granular and closely mirrors modeling new transmission overloads needed to be addressed to interconnect offshore wind

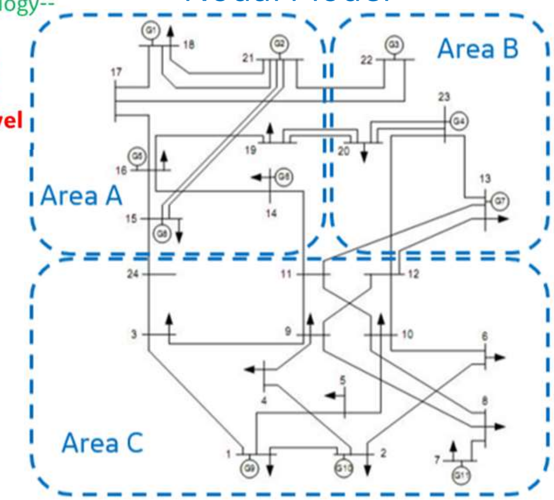
» Network Topology – Nodal model allows detailed specific N-1 transmission contingency constraints

» Transmission Constraints (Current) – Interface transfer limits *and* specific transmission element constraints (N-0 and N-1)

» Transmission Constraints (Offshore Wind Buildout) – Model additional constraints (N-0 and N-1) based on updated power flow analysis to more accurately capture future congestion patterns

- ISO Commitment & Dispatch Operations Modeling Methodology--Uses AC Powerflow Data
- Monitor and Secures Flows on Individual Lines and Interfaces
- **Different Prices at Nodal Level**

Nodal Model



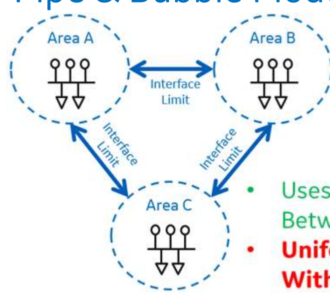
ISONE Economic Study

» Network Topology – Pipe and bubble model

» Transmission Constraints (Current) – Model interface transfer limits only

» Transmission Constraints (Offshore Wind Buildout) – None, only models existing interfaces

Pipe & Bubble Model



- Uses Interface Limits Between Areas
- **Uniform Price Within an Area**

[1] https://www.iso-ne.com/static-assets/documents/2020/02/a6_nescoe_2019_Econ_8000.pdf

Offshore Wind Point-of-Interconnection List

Scenario 1 AC vs Scenario 2 HVDC Buildout

**Baseline 800 MW at Bourne 345 kV POI modeled at Canal 345 kV & Bourne 115 kV			Additional MWs Added to Baseline			
POI Substation Name	**Bus Number**	**Baseline Offshore Wind**	**Scenario 1: Current - Radial AC**		**Scenario 2: Planned - Offshore HVDC Grid**	
			Phased 2024	**Full 2028**	**Phased 2024**	**Full 2028**
Footprint (Salem Harbor 115kV)	114417					
Woburn 345 kV	110756					800
Mystic 345 kV	110759				1200	1200
K Street 345 kV	110790					800
Bridgewater 345 kV	115446					970
Pilgrim (alternate to Footprint) 115 kV	110783					
Canal 345 kV	111193	600**	1100	2500		
West Barnstable 345 kV	111134	1600				
Bourne 115 kV	111217	200**	100	445		
Brayton Point 345 kV	114734		800	800	1200	1200
Kent County 345 kV	117301	704	800	2200		418
Montville 345 kV	119180		800	2200		
Millstone/WaterfordCT 345 kV	119194					1200
New Haven (alternate to Kent Co)						
East Devon 345 kV	119389					800
Singer/BridgeportCT 345 kV	123626				1200	1200
Incremental MW Total to Onshore POIs		**3104**	**3600**	**8145**	**3600**	**8588**
POIs		2	5	5	3	9

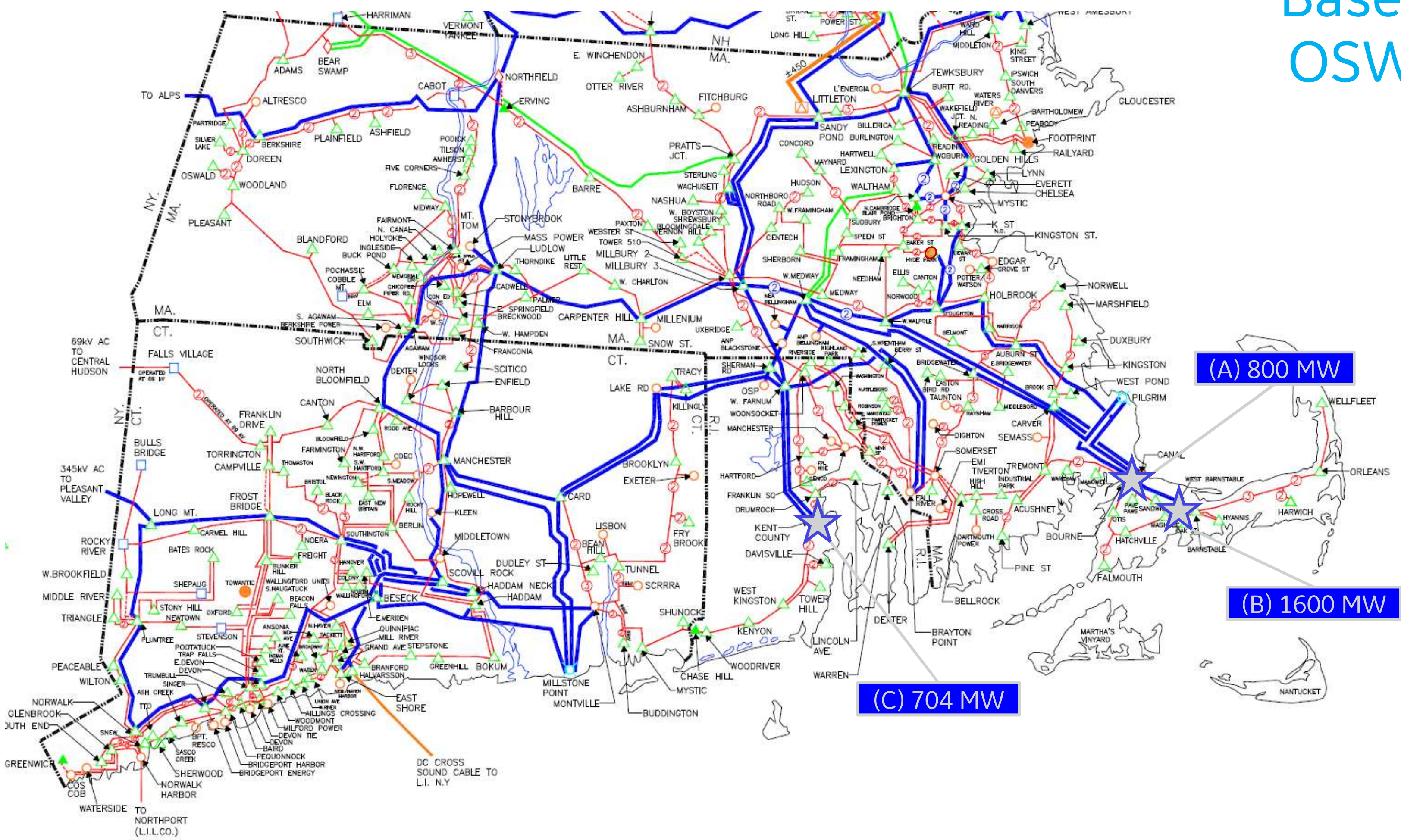
POWER INJECTION AT POI (MW)

Millstone 1200 MW assumes continuing operation of Millstone Nuclear Plant in 2030, retirement of Unit 2 or 3 could enable additional offshore wind injection

Phased 2024 reflects next procurement round based on existing authorizations for MA (1600 MW), CT (1200 MW) and additional demand from other New England states and third parties

Full 2028 reflects development of full 14.5 GW estimated capacity of ISONE offshore lease areas. 2028 was chosen to remain within ISONE projections. Injection volumes in 2028 were based on assumed losses of 8% for Scenario 1 and 3% for Scenario 2. Subsequent revision of assumed losses to 4% for Scenario 1 and 2.4% for Scenario 2 would increase total 2028 injections to 8,499MW for Scenario 1 and 8,641MW for Scenario 2. Larger additional injections in Scenario 1 are not anticipated to change results significantly, as marginal injections at constrained POIs would have minimal system-wide impacts.

Base Case Baseline OSW Buildout Map



☆ Baseline POI

» 3.104 GW

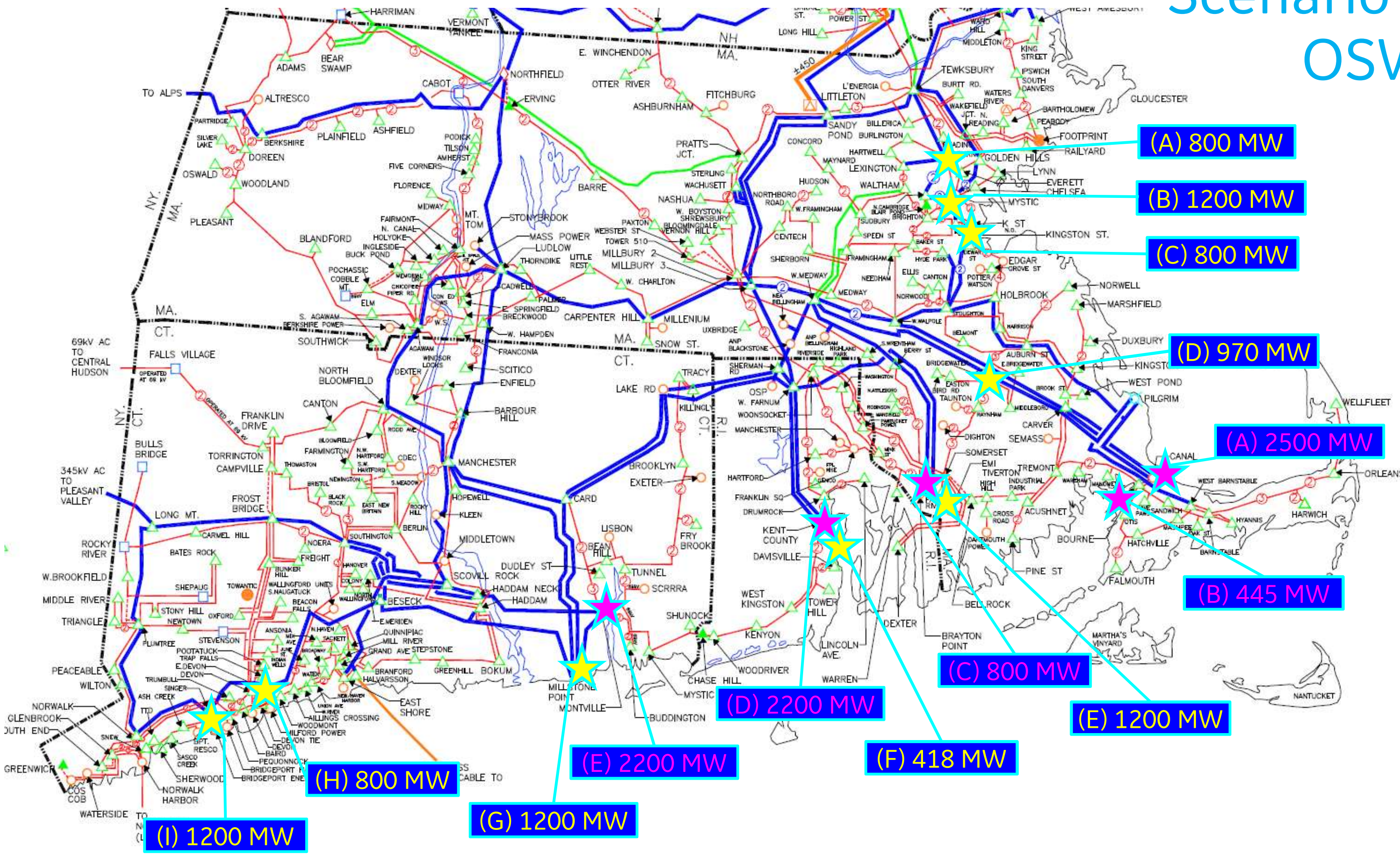
» 3 POIs:

A. Bourne 345 kV

B. W. Barnstable 345 kV

C. Kent County 345 kV

Scenario 1 vs Scenario 2 OSW Buildout Map



Scenario 1 POI

» 8.145 GW

» 5 POI

A. Canal 345 kV
B. Bourne 345 kV
C. Brayton Point 345 kV
D. Kent County 345 kV
E. Montville 345 kV

Scenario 2 POI

» 8.588 GW

» 9 POI

A. Woburn 345 kV
B. Mystic 345 kV
C. K Street 345 kV
D. Bridgewater 345 kV
E. Brayton Point 345 kV
F. Kent County 345 kV
G. Millstone 345 kV
H. East Devon 345 kV
I. Singer 345 kV

Transmission Security Results

TARA Analysis

N-1 Results

TARA Analysis

Overloaded Monitored Elements in Scenario 1 *Phased* OSW Buildout (2024)

Overloaded Transmission Elements (27)

- New Overloads (10)
- Overloaded in Base Case AND OSW (13)
- Overloaded in Base Case, Worse in OSW (4)

Overloaded Transmission Elements by kV:

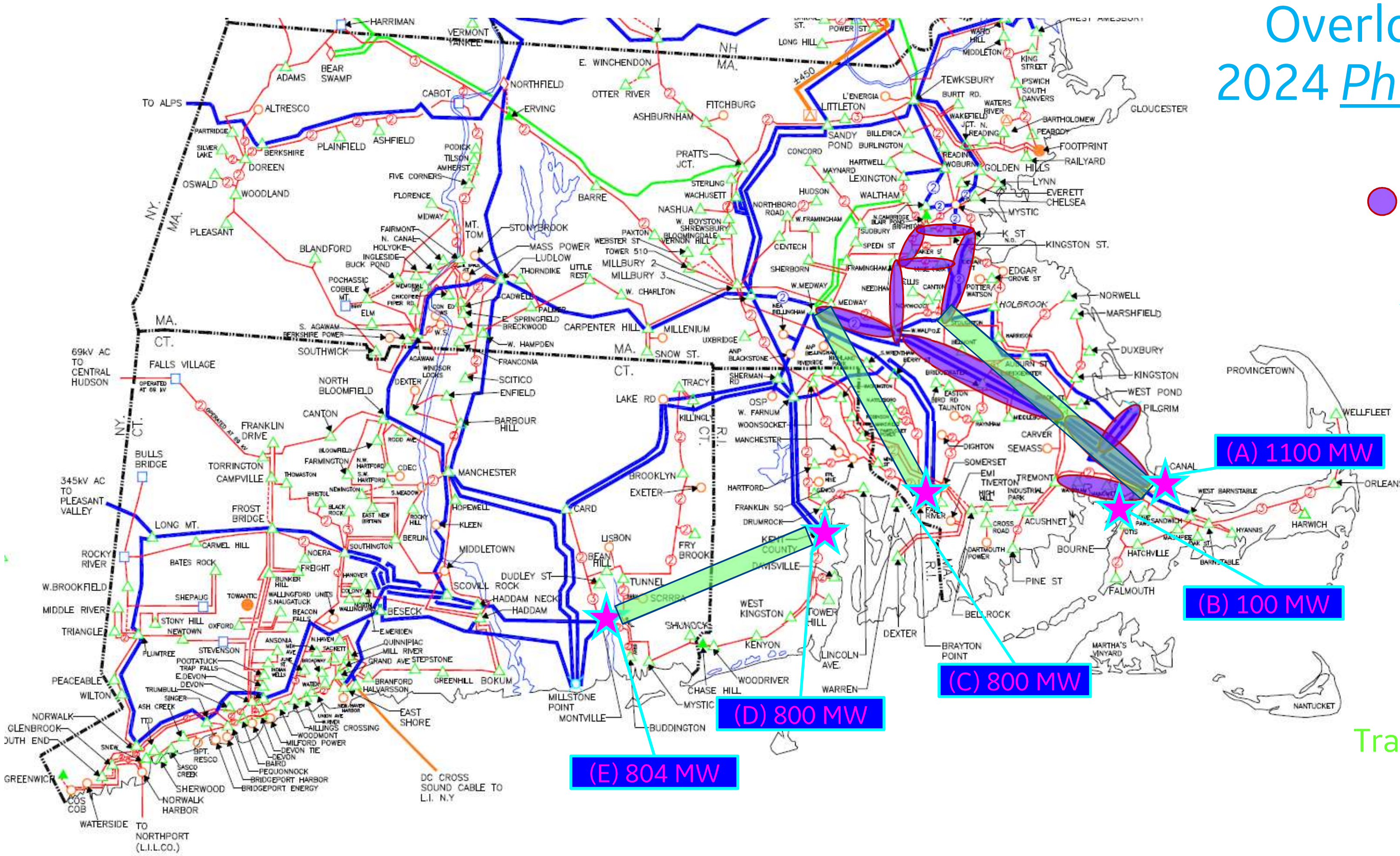
- 345 kV Branches (11)
- 115 kV Branches (29)

Monitored Facility	kV	2024 OSW Buildout AC Loading %	Scenario 2 Base Case AC Loading %	Rating (MVA)	Frequency	Mitigated by Transmission Project
111133 CARVER 345 111193 CANAL 345 1	345	143	< 85%	1221	5	A
110814 BRIGHTON B 115 110855 WASH_TAP 511 115 1	115	129	< 85%	150	251	NONE
110813 BRIGHTON A 115 110854 WASH_TAP 510 115 1	115	129	< 85%	150	251	NONE
110782 JORDAN ROAD 345 111193 CANAL 345 1	345	128	< 85%	1446	5	A
110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	115	123	< 85%	150	386	NONE
110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	115	123	< 85%	150	386	NONE
111133 CARVER 345 111134 W BARNSTABLE 345 1	345	118	< 85%	1016	259	NONE
110853 COLBURN 511 115 110855 WASH_TAP 511 115 1	115	118	99	140	1	NONE
110852 COLBURN 510 115 110854 WASH_TAP 510 115 1	115	118	99	140	1	NONE
110887 BAKER ST PS2 115 110889 BAKER ST B 115 1	115	114	95	205	9	NONE
110886 BAKER ST PS1 115 110888 BAKER ST A 115 1	115	114	95	205	9	NONE
111133 CARVER 345 115013 NGR_356_NST 345 1	345	112	< 85%	1410	8	A
110786 STOUGHTON 345 110790 K STREET 1 345 2	345	111	< 85%	675	9	NONE
110786 STOUGHTON 345 110790 K STREET 1 345 1	345	110	91	675	5	NONE
111149 HORSEPDTP108 115 111156 VALLEYNB 108 115 1	115	109	< 85%	246	3	A
111133 CARVER 345 115036 NGR_331_NST 345 1	345	104	< 85%	1156	4	A
110780 WEST WALPOLE 345 115008 NST_331_NGR 345 1	345	104	< 85%	1156	4	A
111142 VALLEYNB 113 115 111158 HORSEPDTP113 115 1	115	103	< 85%	246	2	A
111158 HORSEPDTP113 115 111217 BOURNE 115 1	115	103	< 85%	246	2	A
111155 WAREHAM 108 115 111156 VALLEYNB 108 115 1	115	101	< 85%	246	2	A
111152 WAREHAM 113 115 111318 TREMONT 113 115 1	115	100	< 85%	246	2	A
111142 VALLEYNB 113 115 111152 WAREHAM 113 115 1	115	100	< 85%	246	2	A
111149 HORSEPDTP108 115 111217 BOURNE 115 1	115	101	88	354	1	A
110888 BAKER ST A 115 110892 HYDE PARK B 115 1	115	137	118	235	1	NONE
110889 BAKER ST B 115 110891 HYDE PARK A 115 1	115	136	116	235	1	NONE
110893 NEEDHAM 115 110894 DOVER MA 115 1	115	115	108	385	5	NONE
111137 TREMONT S 115 111155 WAREHAM 108 115 1	115	119	102	246	1	A

Transmission Project Code:

A) Canal - Stoughton 345 kV
B) Brayton Point - West Medway 345 kV
C) Monvale - Kent County 345 kV

Overloaded Elements
2024 *Phased* Scenario 1



Design Contingency

Scenario 1 POI
3.6 GW

» 5 POI

A. Canal 345 kV
B. Bourne 345 kV
C. Brayton Point 345 kV
D. Kent County 345 kV
E. Montville 345 kV

Potential 345kV Transmission Reinforcements Identified by ISONE

Overloaded Monitored Elements in Scenario 1 *Full* OSW Buildout (2028)

Overloaded Transmission Elements (60)

- New Overloads (42)
- Overloaded in Base Case AND OSW (17)
- Overloaded in Base Case, Worse in OSW (1)

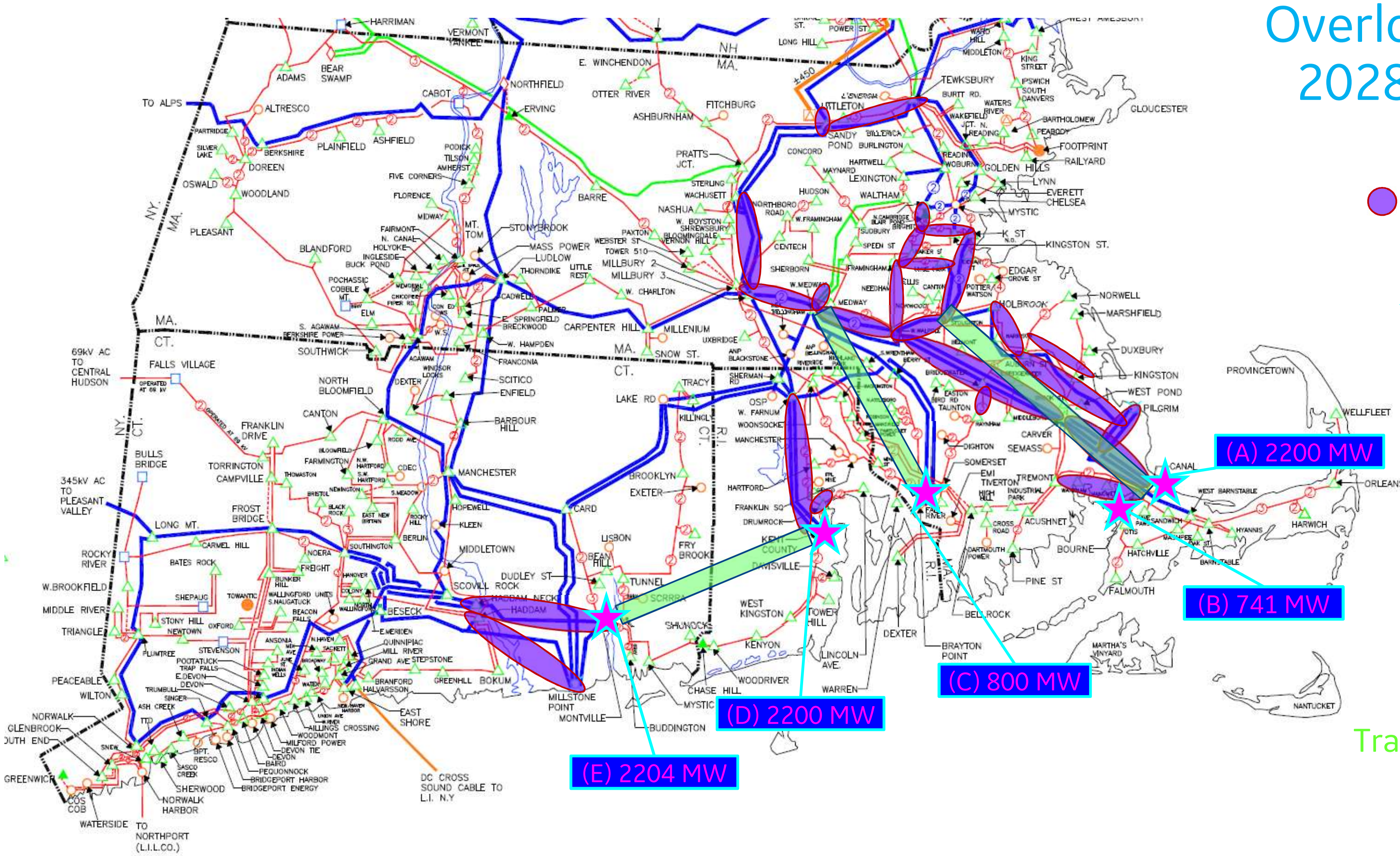
Overloaded Transmission Elements by kV:

- 345 kV Branches (22)
- 115 kV Branches (32)
- Transformers (6)

Transmission Project Code:
A) Canal - Stoughton 345 kV
B) Brayton Point - West Medway 345 kV
C) Monvale - Kent County 345 kV

Monitored Facility	kV	2028 OSW Buildout AC Loading %	Scenario 2 Base Case AC Loading %	Rating (MVA)	Frequency	Mitigated by Transmission Project
111133 CARVER 345 111193 CANAL 345 1	345	217	< 85%	1221	33	A
110782 JORDAN ROAD 345 111193 CANAL 345 1	345	192	< 85%	1446	888	A
110814 BRIGHTON B 115 110855 WASH_TAP 511 115 1	115	171	< 85%	150	372	NONE
110813 BRIGHTON A 115 110854 WASH_TAP 510 115 1	115	170	< 85%	150	371	NONE
111149 HORSEPDTP108 115 111156 VALLEYNB 108 115 1	115	165	< 85%	246	58	A
111142 VALLEYNB 113 115 111158 HORSEPDTP113 115 1	115	158	< 85%	246	11	A
111158 HORSEPDTP113 115 111217 BOURNE 115 1	115	158	< 85%	246	11	A
111155 WAREHAM 108 115 111156 VALLEYNB 108 115 1	115	157	< 85%	246	8	A
111133 CARVER 345 115013 NGR_356_NST 345 1	345	156	< 85%	1410	847	A
111142 VALLEYNB 113 115 111152 WAREHAM 113 115 1	115	156	< 85%	246	9	A
111152 WAREHAM 113 115 111318 TREMONT 113 115 1	115	156	< 85%	246	9	A
110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	115	152	< 85%	150	303	NONE
110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	115	152	< 85%	150	303	NONE
111137 TREMONT S 115 111155 WAREHAM 108 115 1	115	148	< 85%	246	5	A
111133 CARVER 345 115036 NGR_331_NST 345 1	345	144	< 85%	1156	22	A
110780 WEST WALPOLE 345 115008 NST_331_NGR 345 1	345	144	< 85%	1156	22	A
110852 COLBURN 510 115 110854 WASH_TAP 510 115 1	115	141	99	140	1	NONE
110853 COLBURN 511 115 110855 WASH_TAP 511 115 1	115	141	99	140	1	NONE
110781 HOLBROOK 345 115009 NGR_335_NST 345 1	345	139	< 85%	1410	35	A
110786 STOUGHTON 345 110790 K STREET 1 345 2	345	138	< 85%	675	893	NONE
110786 STOUGHTON 345 110790 K STREET 1 345 1	345	137	< 85%	675	17	NONE
110886 BAKER ST PS1 115 110888 BAKER ST A 115 1	115	136	< 85%	205	359	NONE
110887 BAKER ST PS2 115 110889 BAKER ST B 115 1	115	136	< 85%	205	359	NONE
110782 JORDAN ROAD 345 115011 NGR_342_NST 345 1	345	132	< 85%	1855	11	A
110834 HIGH ST 510 115 110836 K STREET 1 115 1	115	130	< 85%	190	45	NONE
110835 HIGH ST 511 115 110837 K STREET 2 115 1	115	129	< 85%	190	48	NONE
111133 CARVER 345 111134 W BARNSTABLE 345 1	345	129	< 85%	1016	100	NONE
110830 KINGSTN ST W 115 110836 K STREET 1 115 2	115	125	< 85%	190	29	NONE
111136 KINGSTON 115 115006 NGR_191_NST 115 1	115	124	< 85%	165	2	NONE
110830 KINGSTN ST W 115 110836 K STREET 1 115 1	115	124	< 85%	190	29	NONE
115446 BRIDGEWATER 345 115451 BRIDGEWATER 115 2	345	122	< 85%	472	1	A
111149 HORSEPDTP108 115 111217 BOURNE 115 1	115	121	< 85%	354	4	A
110772 W MEDWAY B 345 115014 NGR_357_NST 345 2	345	118	< 85%	1315	1	NONE
119168 HADDAM NECK 345 119180 MONTVILE_364 345 1	345	118	< 85%	1884	8	C
110836 K STREET 1 115 110790 K STREET 1 345 1	345	117	< 85%	750	7	NONE
110837 K STREET 2 115 110790 K STREET 1 345 1	345	117	< 85%	750	8	NONE
115011 NGR_342_NST 345 115447 AUBURN ST 345 1	345	116	< 85%	2108	5	A
110814 BRIGHTON B 115 110815 N. CAMBRIDGE 115 1	115	114	< 85%	231	4	NONE
115008 NST_331_NGR 345 115036 NGR_331_NST 345 1	345	113	< 85%	1466	8	A
115446 BRIDGEWATER 345 115451 BRIDGEWATER 115 1	345	112	< 85%	515	1	A
110813 BRIGHTON A 115 110989 BLAIR POND 115 1	115	111	< 85%	231	1	NONE
113950 SANDY POND 345 114027 SANDY PD T1 99.0 1	345	111	86	572	1	NONE
110888 BAKER ST A 115 110892 HYDE PARK B 115 1	115	110	< 85%	235	3	NONE
110889 BAKER ST B 115 110891 HYDE PARK A 115 1	115	110	< 85%	235	3	NONE
113264 MILLBURY 345 113265 WACHUSETT 345 1	345	108	< 85%	1609	1	NONE
110900 HOLBROOK 115 110908 E.HOLBRK TAP 115 1	115	107	< 85%	548	2	A
119194 MILLSTONE 345 119209 HADDAM 345 1	345	107	< 85%	1884	6	C
110791 HYDE PARK 115 110788 HYDE PARK 345 1	345	107	89	600	8	NONE
117001 WEST FARNUM 345 117301 KENT COUNTY 345 2	345	107	< 85%	1918	4	C
113950 SANDY POND 345 113951 TEWKSBURY 345 1	345	107	< 85%	1918	6	NONE
110770 W MEDWAY A 345 110794 W MEDWAY A 230 1	345	107	< 85%	585	9	NONE
117330 JOHNSTON_171 115 117334 RISE 171_TAP 115 1	115	106	< 85%	446	2	B
117001 WEST FARNUM 345 117301 KENT COUNTY 345 1	345	106	< 85%	1918	4	C
110832 KINGSTN ST A 115 110835 HIGH ST 511 115 1	115	106	< 85%	190	4	NONE
110833 KINGSTN ST B 115 110834 HIGH ST 510 115 1	115	105	< 85%	190	4	NONE
110781 HOLBROOK 345 110786 STOUGHTON 345 1	345	105	< 85%	1649	1	A
115013 NGR_356_NST 345 115446 BRIDGEWATER 345 1	345	104	< 85%	2108	4	A
110908 E.HOLBRK TAP 115 115020 NG451-536NST 115 1	115	102	< 85%	588	1	A
110893 NEEDHAM 115 110894 DOVER MA 115 1	115	101	< 85%	385	1	NONE
117327 DRUMROCK 115 117379 DRUMROCK T5 99.0 1	115	116	113	107	1	C

Overloaded Elements 2028 *Full* Scenario 1



Design Contingency

Scenario 1 POI
8.145 GW

» 5 POI

A. Canal 345 kV
B. Bourne 345 kV
C. Brayton Point 345 kV
D. Kent County 345 kV
E. Montville 345 kV

Potential 345kV Transmission Reinforcements Identified by ISONE

Overloaded Monitored Elements in Scenario 2 *Phased* & *Full* OSW Buildout (2024 & 2028)

Overloaded Transmission Elements (1 & 4)

- New Overloads (1 in 2024 & 4 in 2028)
- No Pre-existing Overloads Worse with OSW

2024

Monitored Facility	kV	2024 OSW Buildout AC Loading %	Scenario 2 Base Case AC Loading %	Rating (MVA)	Frequency
110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 1	345	113	< 85%	596	2

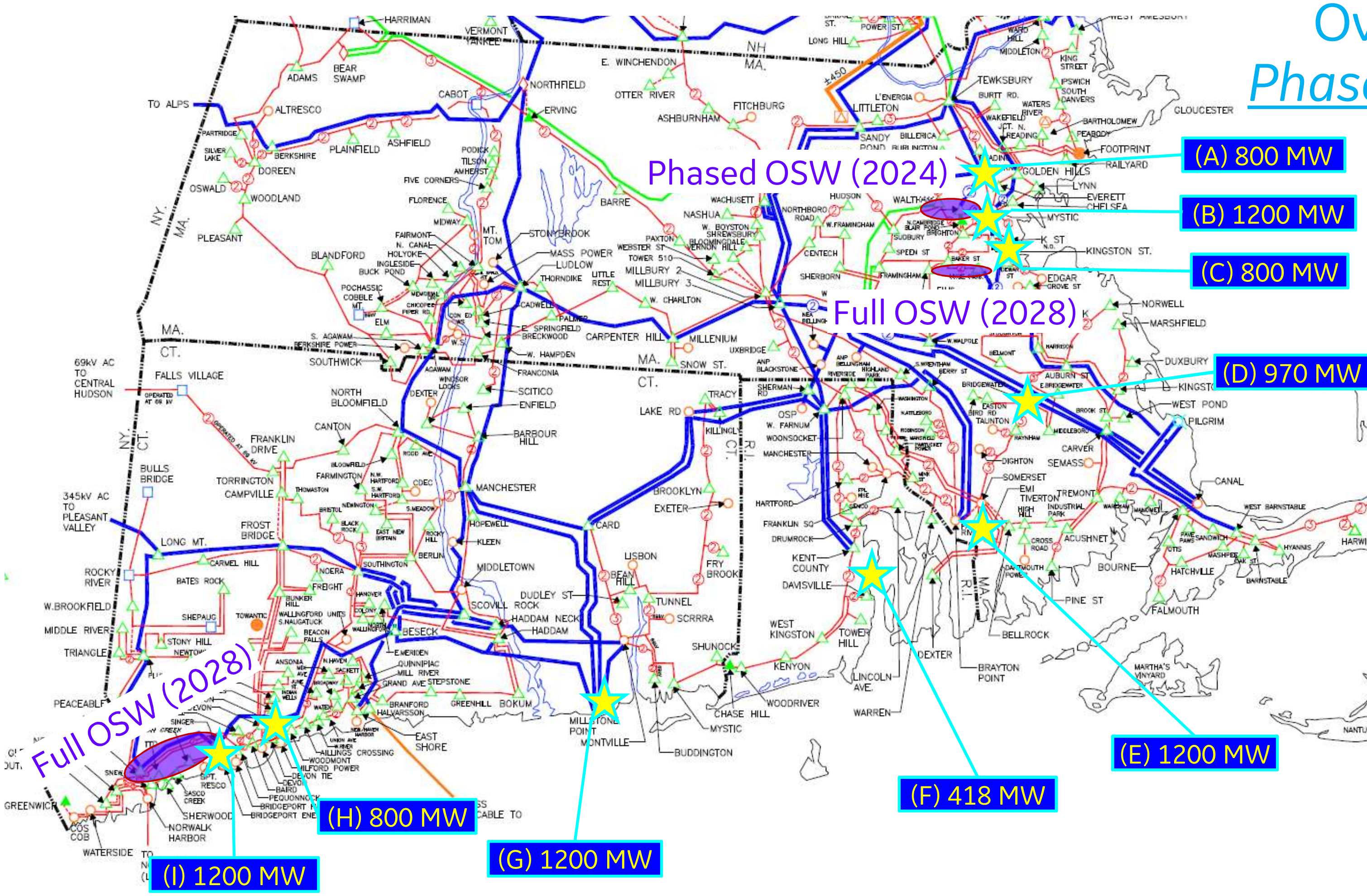
Overloaded Transmission Elements by kV:

- 345 kV Branches (1 in 2024 & 2 in 2028)
- 115 kV Branches (0 in 2024 & 2 in 2028)

2028

Monitored Facility	kV	2028 OSW Buildout AC Loading %	Scenario 2 Base Case AC Loading %	Rating (MVA)	Frequency
110888 BAKER ST A 115 110892 HYDE PARK B 115 1	115	115	100	235	1
110889 BAKER ST B 115 110891 HYDE PARK A 115 1	115	113	97	235	1
119441 NU_3921_UI 345 119480 NORWALK 345 1	345	107	< 85%	1133	3
119428 NU_3280_UI 345 119480 NORWALK 345 1	345	107	< 85%	1133	3

Overloaded Elements
Phased & *Full* Scenario 2



Design Contingency

Scenario 2 POI
8.588 GW

» 9 POI

A. Woburn 345 kV
B. Mystic 345 kV
C. K Street 345 kV
D. Bridgewater 345 kV
E. Brayton Point 345 kV
F. Kent County 345 kV
G. Millstone 345 kV
H. East Devon 345 kV
I. Singer 345 kV

N-1-1 Results

TARA Analysis

Overview of N-1-1 Methodology

Relevant Notes for TARA Analysis

N-1-1 analysis focuses on the next 3.6 GW offshore wind injection most immediately relevant

N-1-1 analysis for the full 8+ GW build out was beyond the scope of this analysis

NERC

» Allows Non-Consequential Load-Shedding for non-generator first contingency loss in N-1-1

NPCC

» For simplicity, Bulk Power System (BPS) Assumption for ISONE: 200kV+

» Actual ISONE BPS list contains many elements below 200kV

Overloaded Monitored Elements in Scenario 1

NPCC Criteria

Overloaded Monitored Element	OSW Buildout AC %Loading	Rating (MVA)	Total N-1-1 Contingency Combinations	Base Case AC %Loading	New Overload or Makes Existing Overload Worse
111133 CARVER 345 111193 CANAL 345 1	194.5	1221	3305	less than 85%	New Overloads Due to Scenario 1 OSW Buildout, NOT Overloaded in Base Case
110786 STOUGHTON 345 110790 K STREET 1 345 2	176.8	675	10474	100	
110786 STOUGHTON 345 110790 K STREET 1 345 1	174.6	675	4117	100	
110782 JORDAN ROAD 345 111193 CANAL 345 1	165.6	1446	1734	less than 85%	
111133 CARVER 345 115036 NGR_331_NST 345 1	144.1	1156	16	less than 85%	
110780 WEST WALPOLE 345 115008 NST_331_NGR 345 1	143.8	1156	16	less than 85%	
119168 HADDAM NECK 345 119180 MONTVILE_364 345 1	135.2	1884	3832	less than 85%	
111133 CARVER 345 115013 NGR_356_NST 345 1	130.3	1410	13	less than 85%	
119272 NE_398_NY 345 126294 PLTVLLEY 345 1	125.9	1382	7	less than 85%	
119194 MILLSTONE 345 119209 HADDAM 345 1	124.8	1884	104	less than 85%	
121408 NE_601_NY 138 129343 NRTHPT P 138 1	124.4	191	1	less than 85%	
121409 NE_602_NY 138 129343 NRTHPT P 138 2	124.0	191	1	less than 85%	
121410 NE_603_NY 138 129343 NRTHPT P 138 3	123.2	191	1	less than 85%	
113950 SANDY POND 345 113951 TEWKSBURY 345 1	121.8	1918	97	less than 85%	
119259 LONG MTN 345 119272 NE_398_NY 345 1	121.8	1428	6	less than 85%	
113264 MILLBURY 345 113265 WACHUSETT 345 1	118.9	1609	16	less than 85%	
110770 W MEDWAY A 345 110794 W MEDWAY A 230 1	117.6	585	327	91	
119181 MONTVILE_371 345 119194 MILLSTONE 345 1	114.7	1884	18	less than 85%	
104191 NU_381_VEL 345 107040 VERNON VT 345 1	114.6	1491	41	88	
115008 NST_331_NGR 345 115036 NGR_331_NST 345 1	113.6	1466	12	less than 85%	
119129 KLEEN 345 119142 SCOVILLE RCK 345 1	112.8	1912	15	less than 85%	
104191 NU_381_VEL 345 104195 NU_381_NU 345 1	109.6	1626	6	less than 85%	
113265 WACHUSETT 345 113950 SANDY POND 345 1	109.2	1611	3	less than 85%	
104159 NU_326_NGR 345 113950 SANDY POND 345 1	108.0	1635	13	less than 85%	
119142 SCOVILLE RCK 345 119168 HADDAM NECK 345 1	107.3	1697	11	less than 85%	
123637 ESHORE 9X 345 123638 ESHORE TELEM 345 1	107.1	617	7	less than 85%	
119168 HADDAM NECK 345 119220 BESECK 345 1	107.1	1884	8	less than 85%	
119142 SCOVILLE RCK 345 119233 SOUTHINGTON 345 1	107.0	1884	8	less than 85%	
110781 HOLBROOK 345 115009 NGR_335_NST 345 1	105.9	1410	14	less than 85%	
110785 ANP BLACKSTN 345 115015 NGR_3361_NST 345 1	105.8	1685	16	less than 85%	
110780 WEST WALPOLE 345 110786 STOUGHTON 345 1	105.8	1649	4	less than 85%	
119077 MANCHESTER 345 119194 MILLSTONE 345 1	104.6	1797	15	less than 85%	
119402 NU_3165_UI 345 123626 SINGER 345 1	104.2	1074	9	87	
119415 NU_3619_UI 345 123626 SINGER 345 1	104.2	1074	9	87	
119209 HADDAM 345 119220 BESECK 345 1	103.9	1884	11	less than 85%	
123636 ESHORE 8X 345 123638 ESHORE TELEM 345 1	102.9	642	2	less than 85%	
110782 JORDAN ROAD 345 115011 NGR_342_NST 345 1	102.6	1855	4	less than 85%	
119389 EAST DEVON 345 119402 NU_3165_UI 345 1	101.7	1106	2	less than 85%	
119389 EAST DEVON 345 119415 NU_3619_UI 345 1	101.7	1106	2	less than 85%	
104151 LAWRENCE RD 345 104159 NU_326_NGR 345 1	101.1	1747	1	less than 85%	
110786 STOUGHTON 345 110788 HYDE PARK 345 1	100.6	676	1	less than 85%	
110786 STOUGHTON 345 110790 K STREET 1 345 2	196.0	675	82	115	Overloaded in Base Case, Worse with Scenario 1 OSW Buildout
110786 STOUGHTON 345 110790 K STREET 1 345 1	193.7	675	46	114	
119389 EAST DEVON 345 119415 NU_3619_UI 345 1	143.0	1106	1	121	
119389 EAST DEVON 345 119402 NU_3165_UI 345 1	143.0	1106	1	121	
119415 NU_3619_UI 345 123626 SINGER 345 1	142.2	1074	1	121	
119402 NU_3165_UI 345 123626 SINGER 345 1	142.2	1074	1	121	
119428 NU_3280_UI 345 119480 NORWALK 345 1	109.6	1133	1	103	
119441 NU_3921_UI 345 119480 NORWALK 345 1	109.2	1133	1	103	

NERC Criteria

Overloaded Monitored Element	OSW Buildout AC %Loading	Rating (MVA)	Total N-1-1 Contingency Combinations	Base Case AC %Loading	New Overload or Makes Existing Overload Worse
110814 BRIGHTON B 115 110855 WASH_TAP 511 115 1	174.2	150	7814	91	New Overloads Due to Scenario 1 OSW Buildout, NOT Overloaded in Base Case
110813 BRIGHTON A 115 110854 WASH_TAP 510 115 1	174.1	150	7806	91	
110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	166.0	150	7851	100	
110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	166.0	150	7848	100	
110786 STOUGHTON 345 110790 K STREET 1 345 2	160.4	675	588	100	
111133 CARVER 345 111193 CANAL 345 1	159.9	1221	63	less than 85%	
110786 STOUGHTON 345 110790 K STREET 1 345 1	158.3	675	164	99	
110888 BAKER ST A 115 110892 HYDE PARK B 115 1	142.4	235	59	98	
110782 JORDAN ROAD 345 111193 CANAL 345 1	141.9	1446	83	less than 85%	
110889 BAKER ST B 115 110891 HYDE PARK A 115 1	140.7	235	61	96	
110886 BAKER ST PS1 115 110888 BAKER ST A 115 1	137.5	205	952	89	
110887 BAKER ST PS2 115 110889 BAKER ST B 115 1	137.5	205	951	89	
104900 NORTH KEENE 115 104902 KEENE 115 1	121.9	135	2	less than 85%	
110835 HIGH ST 511 115 110837 K STREET 2 115 1	121.6	190	8	less than 85%	
110834 HIGH ST 510 115 110836 K STREET 1 115 1	121.1	190	8	less than 85%	
104935 CHESTNUT HIL 115 104946 VERNONROAD_T 115 1	120.0	234	1	less than 85%	
113950 SANDY POND 345 113951 TEWKSBURY 345 1	118.1	1918	4	less than 85%	
110830 KINGSTN ST W 115 110836 K STREET 1 115 1	117.7	190	5	less than 85%	
110830 KINGSTN ST W 115 110836 K STREET 1 115 2	117.7	190	5	less than 85%	
110893 NEEDHAM 115 110894 DOVER MA 115 1	116.9	385	185	100	
111149 HORSEPDTP108 115 111156 VALLEYNB 108 115 1	115.2	246	15	less than 85%	
104913 A152_T 115 104924 WESTPORT 115 1	113.5	234	1	less than 85%	
104924 WESTPORT 115 104935 CHESTNUT HIL 115 1	113.5	234	1	less than 85%	
104895 TUTTLE HILL 115 104900 NORTH KEENE 115 1	111.6	135	2	less than 85%	
104891 JACKMAN 115 104895 TUTTLE HILL 115 1	111.3	135	2	less than 85%	
110836 K STREET 1 115 110790 K STREET 1 345 1	110.4	750	1	less than 85%	
110837 K STREET 2 115 110790 K STREET 1 345 1	110.4	750	1	less than 85%	
119718 MONTVILLE 115 119181 MONTVILE_371 345 2	110.3	527	254	less than 85%	
104191 NU_381_VEL 345 104195 NU_381_NU 345 1	109.6	1626	1	less than 85%	
111142 VALLEYNB 113 115 111158 HORSEPDTP113 115 1	109.4	246	15	less than 85%	
111158 HORSEPDTP113 115 111217 BOURNE 115 1	109.4	246	15	less than 85%	
117330 JOHNSTON_171 115 117334 RISE 171_TAP 115 1	108.8	446	53	less than 85%	
104191 NU_381_VEL 345 107040 VERNON VT 345 1	108.1	1491	7	88	
111155 WAREHAM 108 115 111156 VALLEYNB 108 115 1	107.9	246	14	less than 85%	
119168 HADDAM NECK 345 119180 MONTVILE_364 345 1	107.5	1884	216	less than 85%	
111142 VALLEYNB 113 115 111152 WAREHAM 113 115 1	107.0	246	14	less than 85%	
111152 WAREHAM 113 115 111318 TREMONT 113 115 1	107.0	246	14	less than 85%	
113264 MILLBURY 345 113265 WACHUSETT 345 1	106.3	1609	1	less than 85%	
110770 W MEDWAY A 345 110794 W MEDWAY A 230 1	105.9	585	3	less than 85%	
117331 JOHNSTON_172 115 117360 RISE 172_TAP 115 1	103.6	446	3	less than 85%	
104159 NU_326_NGR 345 113950 SANDY POND 345 1	102.2	1635	1	less than 85%	
110814 BRIGHTON B 115 110815 N. CAMBRIDGE 115 1	102.2	231	2	less than 85%	
110785 ANP BLACKSTN 345 115015 NGR_3361_NST 345 1	101.0	1685	1	less than 85%	
110791 HYDE PARK 115 110788 HYDE PARK 345 1	100.3	600	1	less than 85%	
110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	187.5	150	60	119	Overloaded in Base Case, Worse with Scenario 1 OSW Buildout
110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	187.5	150	60	119	
110786 STOUGHTON 345 110790 K STREET 1 345 2	178.5	675	3	108	
110786 STOUGHTON 345 110790 K STREET 1 345 1	176.7	675	3	107	
110893 NEEDHAM 115 110894 DOVER MA 115 1	124.5	385	55	109	

Overloaded Monitored Elements in Scenario 2

NPCC Criteria

Overloaded Monitored Element	OSW Buildout AC %Loading	Rating (MVA)	Total N-1-1 Contingency Combinations	Base Case AC %Loading	New Overload or Makes Existing Overload Worse
110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 1	174.1	596	22	less than 85%	New Overloads Due to Scenario 2 OSW Buildout, NOT Overloaded in Base Case
110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 2	147.6	705	10	less than 85%	
110786 STOUGHTON 345 110790 K STREET 1 345 2	120.7	675	1	less than 85%	
110786 STOUGHTON 345 110790 K STREET 1 345 1	120.1	675	1	less than 85%	
119428 NU_3280_UI 345 119480 NORWALK 345 1	111.1	1133	52	less than 85%	
119441 NU_3921_UI 345 119480 NORWALK 345 1	111.1	1133	52	less than 85%	
119181 MONTVILE_371 345 119194 MILLSTONE 345 1	106.7	1884	14	less than 85%	
114734 BRAYTN POINT 345 114900 BERRY STREET 345 1	104.4	1157	2	less than 85%	
119428 NU_3280_UI 345 119480 NORWALK 345 1	177.5	1133	1	102	Overloaded in Base Case, Worse with Scenario 2 OSW
119441 NU_3921_UI 345 119480 NORWALK 345 1	177.5	1133	1	102	

NERC Criteria

Overloaded Monitored Element	OSW Buildout AC %Loading	Rating (MVA)	Total N-1-1 Contingency Combinations	Base Case AC %Loading	New Overload or Makes Existing Overload Worse
115743 GRAND ARMY 115 115744 Z1_TAP 115 1	117.9	446	1	less than 85%	New Overloads Due to Scenario 2 OSW Buildout, NOT Overloaded in Base Case
115743 GRAND ARMY 115 115745 Y2_TAP 115 1	117.9	446	1	less than 85%	
115711 SOMERSET 115 115744 Z1_TAP 115 1	108.0	446	1	less than 85%	
115711 SOMERSET 115 115745 Y2_TAP 115 1	108.0	446	1	less than 85%	

Economic Production Cost Results

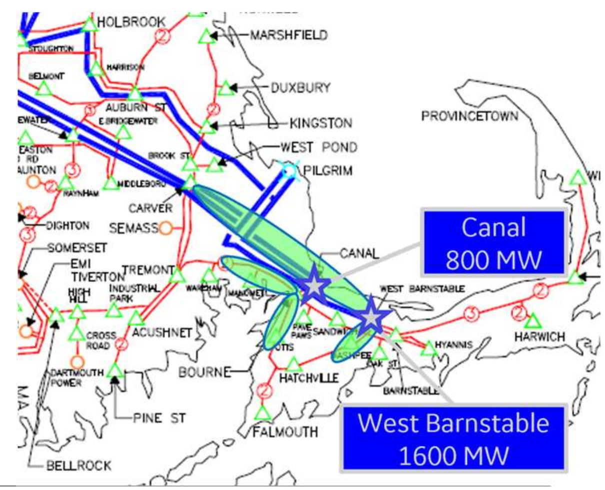
GE-MAPS Analysis

Much More Consistent LMP Change in Scenario 2

Necessary Transmission Upgrades Assumption

What happens with no transmission upgrades in the Base Case with 3.1 GW OSW?
- Initial MAPS simulation showed 44% OSW curtailment at West Barnstable POI
- Curtailment is way too high and not a realistic starting point

<u>Six transmission segments where upgrades necessary for reasonable starting point in **Base Case,** which are similar to the upgrades proposed in the QP828 Feasibility Study:</u>
- Carver – West Barnstable 345 kV Line (399)
- West Barnstable – Mashpee 115 kV (137) and Otis – Bourne 115 kV Line (107)
- West Barnstable 345/115 kV Transformer
- Bourne – Horse Depot – Valley NB 115 kV Line (108)



Transmission Upgrades Assumed in Base Case

Powerflow					Ratings		
From Bus Number & Name		To Bus Number & Name		Ckt	Initial	Upgrade	Upgrade Description
111134	W BARNSTABLE345.00	111135	W BARNSTABLE115.00	1	604	1585	2nd Larger Parallel Transformer
111133	CARVER 345.00	111134	W BARNSTABLE345.00	1	1016	1585	Reconductor Line
111214	OTIS 115.00	111217	BOURNE 115.00	1	407	431	Reconductor Line
111135	W BARNSTABLE115.00	111215	MASHPEE 137 115.00	1	244	488	Parallel or Reconductor Line
111149	HORSEPDTP108115.00	111156	VALLEYNB 108115.00	1	246	291	Reconductor Line
111149	HORSEPDTP108115.00	111217	BOURNE 115.00	1	246	291	Reconductor Line

Transmission Upgrades for Reliability (NERC/NPCC)

Transmission upgrades modeled in respective offshore wind buildout scenarios required to mitigate N-1-1 transmission security violations according to NERC TPL Standards and NPCC Directory 1 Criteria

Scenario 1

- West Barnstable – K Street 345 kV
- West Barnstable – Mashpee – Hatchville – Fallmouth Tap 115 kV
- West Barnstable – Bourne – Canal – Valley – Wareham – Tremont 115 kV
- Johnson – Rise 115 kV

Scenario 2

- Mystic – North Cambridge – Woburn 345 kV
- Norwalk – Singer 345 kV

Annual Offshore Wind Generation Curtailment

Occurs when transmission constraints cause reduced generation output below full capability

Average ISONE Curtailment

- Base Case: 3% in 2024 & 2028*
- Scenario 1: 0.5% in 2024; 12.9% in 2028
- Scenario 2: 1.4% in 2024; 3.7% in 2028

Max Offshore Wind Generation Curtailment:

- Base Case: 6% (West Barnstable 1600MW)
- In 2024, Scenario 1 & 2 have relatively low curtailment % of OSW POIs, all OSW curtailment is located in SEMA
- In 2028, Scenario 1 top OSW POI curtailment is significantly higher (Scenario 1: ***34%*** *vs* Scenario 2: ***14%***)
- In 2028, Scenario 1 showed curtailment > 5% in multiple areas: SEMA and CT; only SWCT for Scenario 2
- Scenario 2 OSW buildout does not result in any additional West Barnstable POI curtailment compared to Base Case

		Average ISO-NE Curtailment			
Year	Technology Type	Base_S1	Base_S2	OSW_S1	OSW_S2
2024	Offshore	3.0%	3.0%	0.5%	1.4%
	Onshore	0.1%	0.1%	0.1%	0.1%
2028	Offshore	2.9%	3.0%	12.9%	3.7%
	Onshore	0.1%	0.1%	0.2%	0.8%

Percent Curtailment by ISO-NE Offshore Site						
Simulation Year	POI	MAPS Area	Base_S1	Base_S2	OSW_S1	OSW_S2
2024	Bourne	SEMAA	0%	0%	0%	0%
	Brayton Point	SEMAA			0%	0%
	Canal	SEMAA	0%	0%	0%	0%
	Kent County	RIA	0%	0%	0%	0%
	Montville	CTA			0%	
	Mystic	BOSTONA				0%
	Singer Bridgeport	SWCTA				
	West Barnstable	SEMAA	6%	6%	1%	6%
2028	Bourne	SEMAA	0%	0%	0%	0%
	Brayton Point	SEMAA			0%	2%
	Bridgewater	SEMAA				1%
	Canal	SEMAA	0%	0%	34%	1%
	East Devon	SWCTA				6%
	K Street	BOSTONA				1%
	Kent County	RIA	0%	0%	1%	1%
	Millstone	CTA				3%
	Montville	CTA			13%	
	Mystic	BOSTONA				0%
	Singer Bridgeport	SWCTA				14%
	West Barnstable	SEMAA	6%	6%	6%	6%
	Woburn	BOSTONA				2%

*2018 ISONE averaged 2% onshore wind curtailment

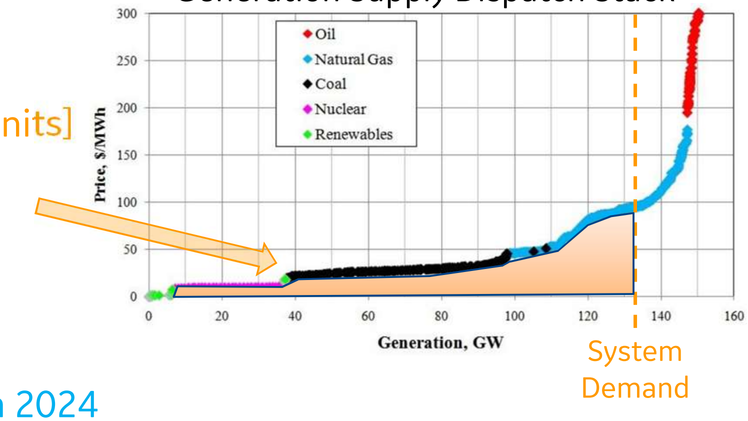
Annual ISONE Production Cost Savings

Electric energy production cost reflects variable operating costs

System Production Cost = Σ [Variable O&M Costs of Dispatched Units]

Area Under the Dispatch Curve

Generation Supply Dispatch Stack



Production Cost Saving Comparison

- Production cost savings for both Scenario 1 & 2 are similar in 2024
- In 2028, Scenario 2 shows more production cost savings than Scenario 1 (difference of **$55M**)

	ISO-NE Production Cost ($M)			
Year	Base_Case	Base_S2	OSW_S1	OSW_S2
2024	$1,774	$1,776	$1,489	$1,492
2028	$2,064	$2,062	$1,500	$1,443

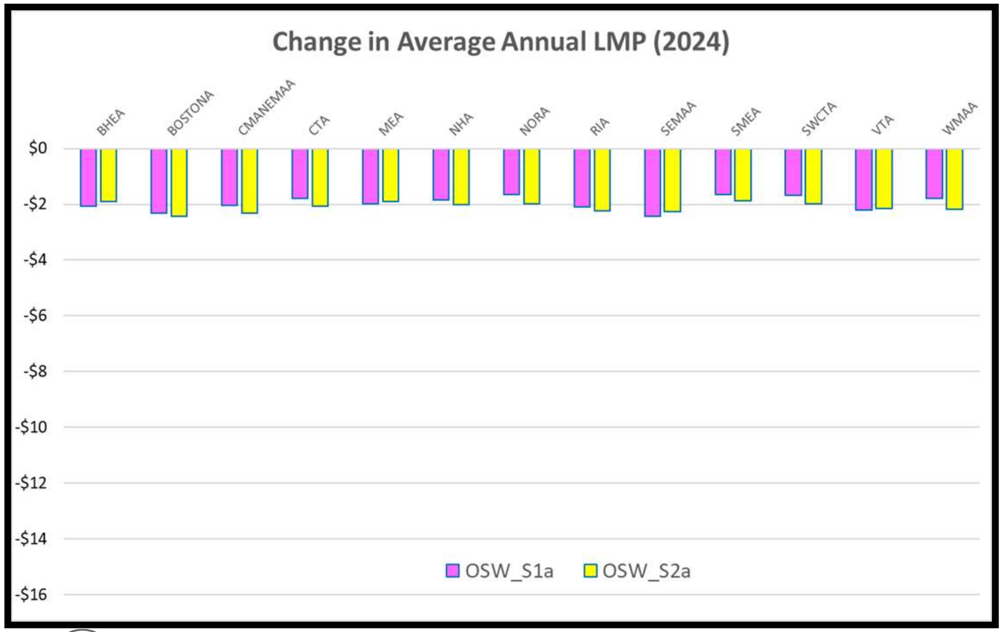
	Production Cost Savings ($M)	
Year	OSW_S1	OSW_S2
2024	$285	$284
2028	$564	$619

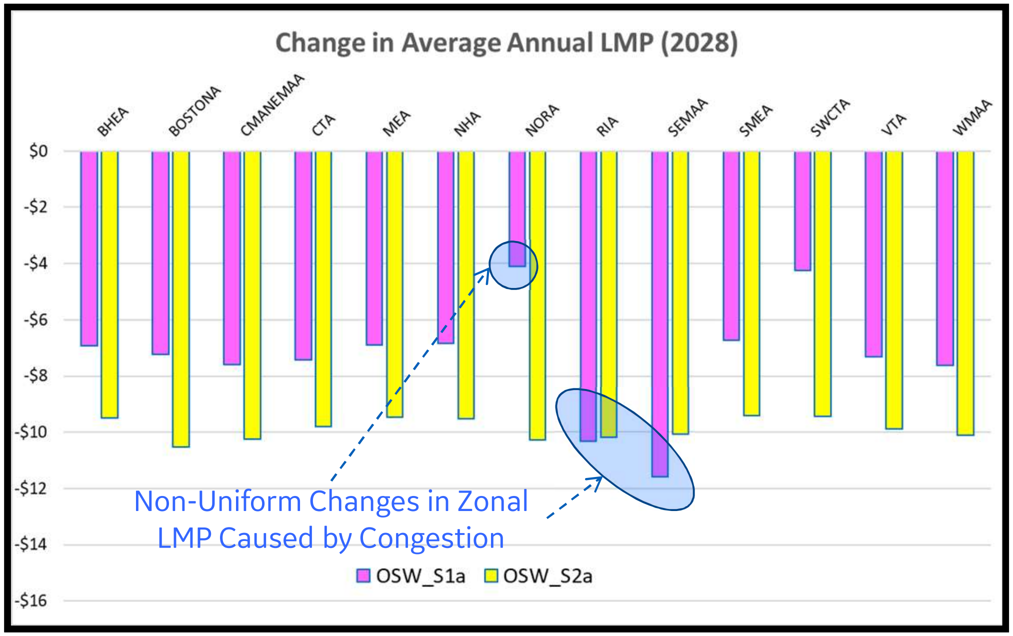
Annual ISONE Zonal LMP Change

Locational Marginal Price (LMP) = Marginal Cost of Electricity + Transmission Congestion Cost + Cost of Losses

In 2028, More Uniform Zonal LMP Decrease in Scenario 2 than Scenario 1 is an indication of:

- More efficient and cost-effective use of added cheap energy from OSW
- Less transmission congestion moving cheap OSW energy
- More load payment savings





Load Payment Savings

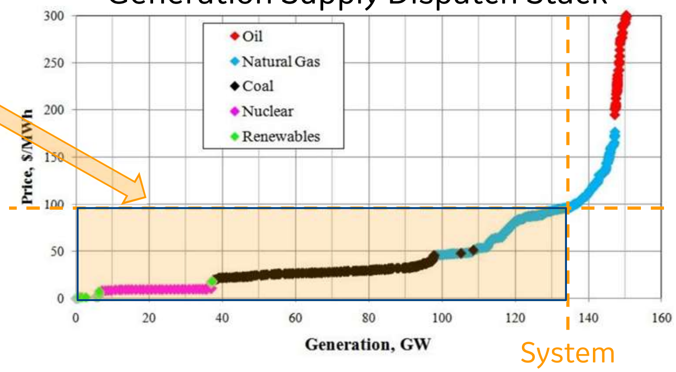
Electricity Load Payment = Marginal Cost of Electricity ($/MWh) x System Demand (MWh)

Load payment is the amount the rate payers ultimately pay to serve the load in their area

Rectangle area bound by Marginal Price and Demand

Marginal Cost of Electricity

Generation Supply Dispatch Stack



System Demand

Load Payment Comparison

- In 2024, similar annual load payment savings occur in Scenario 1 ($259M) vs. Scenario 2 ($281M), reflecting in a modest difference between the two OSW transmission scenarios (**$22M or 0.5%**).
- In 2028, the load payment savings between the two begin to diverge between Scenario 1 ($1,000M) vs. Scenario 2 ($1,306M) and the resulting annual difference is significant (**$306M or 5.2%**).

Annual ISO-NE Load Payment ($M)				
Year	Base_S1	Base_S2	OSW_S1	OSW_S2
2024	$4,815	$4,808	$4,557	$4,527
2028	$5,921	$5,897	$4,921	$4,591

	Load Payment Savings ($M)	
Year	OSW_S1	OSW_S2
2024	$259	$281
2028	$1,000	$1,306

Offshore Transmission in New England: Benefits of a Better Planned Grid

Appendix C: System Upgrades Required for 2024 Offshore Wind Connection

Dwayne Basler, PE
CHA Consulting
May 7, 2020

CHA

System Upgrades Required for 2024 Offshore Wind Connection – *Unplanned* vs *Planned* Transmission

1. Summary of Results
2. Analysis Details
3. Overload Maps
   A. *Unplanned* interconnection
   B. *Planned* interconnection
4. System Upgrade Costs
   A. Unit Costs
   B. *Unplanned* interconnection
   C. *Planned* interconnection
5. Transmission Overload Tables

Dwayne Basler, PE
CHA Consulting
May 7, 2020

CHA

Summary of Results

Phase 1 (2024) of the *Unplanned* (also referred to in this study as the *current approach*) offshore wind interconnection described in General Electric's 'Anbaric Offshore Wind POI Transmission Security Analysis' would create approximately four times as many facility overloads as a *Planned* interconnection resulting in significantly higher interconnection costs.

Extensive transmission system siting and construction to mitigate overloads for an *Unplanned* Offshore Wind interconnection in New England would be challenging and could require ten or more years to complete based on similar projects in the region.

	Planned Transmission	Unplanned Transmission
Overloaded Lines (>110%)	6	47
Overloaded Substation Equipment (>110%)	4	17
Overloaded Lines (<110%)	11	44
Overloaded Substation Equipment (<110%)	3	6
(**Note**: overloads <110% are not included on the New England maps.)		
Total Overloaded Facilities	24	114

***Unplanned** scenario overlaods:*

- West Barnstable to the North (to K-Street)
- Boston area
- West Barnstable to the West (Tremont and Falmouth Tap paths)
- Connecticut and Rhode Island

Planned scenario overloads:

- Mystic - North Cambridge - Woburn
- Connecticut

The cost of transmission system upgrades are estimated to be:

		Midpoint
Unplanned transmission system	\$1.2B - \$2.3B	\$1.7B
Planned transmission system	\$390M - \$710M	\$550M

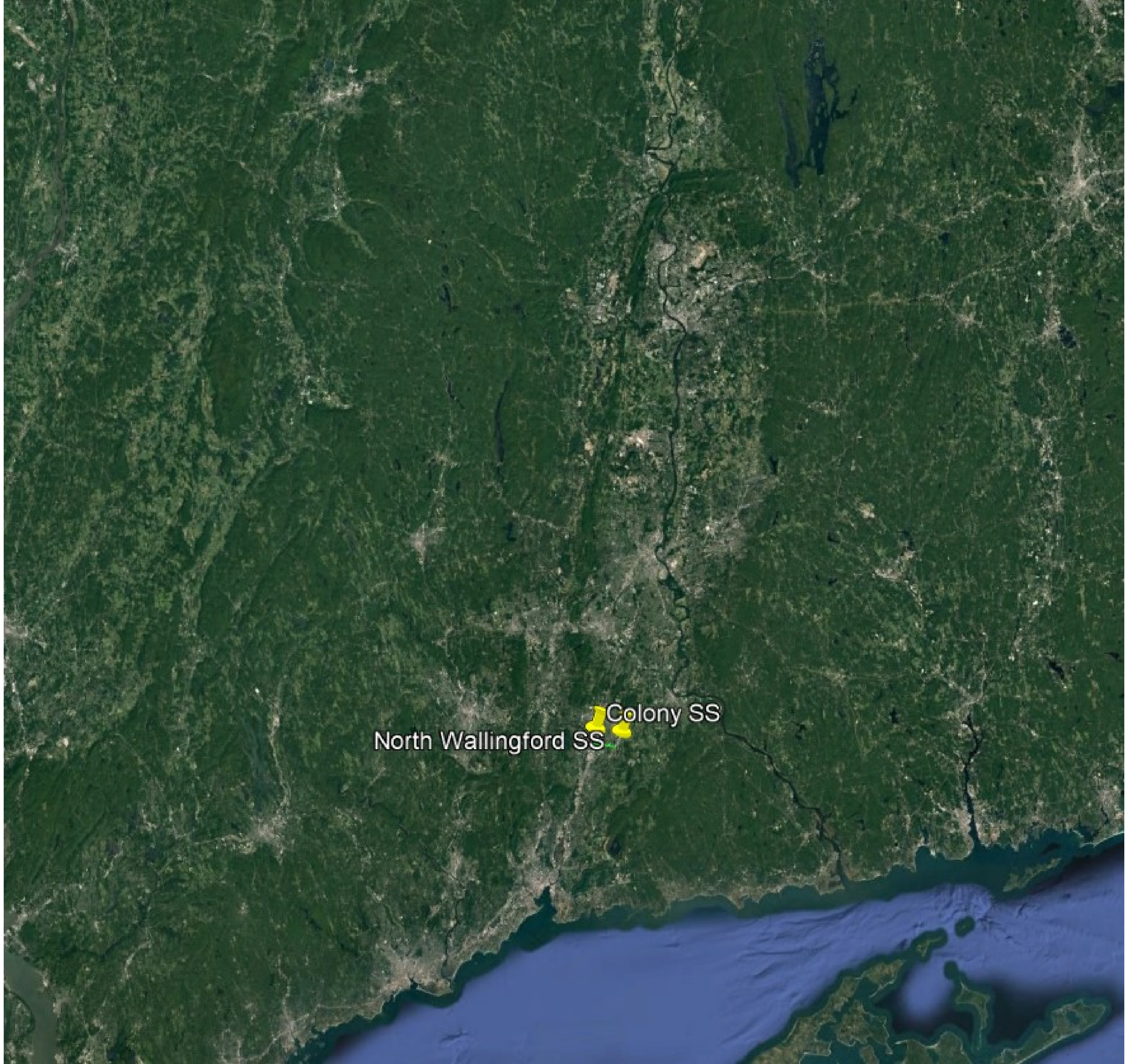
- Costs are order of magnitude to illustrate the differences between an ***Unplanned*** and ***Planned*** transmission interconnection only. Mitigation options have not been verified by power flow analysis, routing assessment, or detailed engineering.
- Ranges have been established for illustrative purposes only and not to imply a level of precision. For example, ±25% was applied to the project averages in the *Greater Boston Cost Comparison, NHT Analysis using New England Comparables January 2015;* however, that analysis identified a larger variability in project costs.

Analysis Details

- General Electric Power Flow studies using NERC and NPCC N-1-1 criteria identified transmission overloads for a Phase 1 (2024) ***Planned*** and ***Unplanned*** interconnection of offshore wind projects.
- NERC N-1-1 overloads were verified to be a subset of the NPCC N-1-1 overloads. The overload percentages in this analysis are NPCC criteria overloads.
- Transmission line lengths were estimated to be 1.2 times the straight line distances between substations.
- Pre-existing overloads were not included. For example, the West Barnstable to Carver transmission line was overloaded in the Base Case and therefore is not included in either the *Planned* or *Unplanned* interconnection scenarios.
- Overloads less than 110% are listed separately to simplify the mitigation cost analysis.
- Transmission system upgrades required for the *Unplanned* scenario being approximately four times more extensive would result in a much longer time to complete which could result in increased costs. These increased costs have *not* been included in this analysis.
- Extreme Event analysis (NPCC Directory 1) such as Loss of ROW contingencies would require some new transmission lines to be on new ROWs rather than constructed on existing ROWs. This would result in increased costs and time to complete. This is consistent with ISO-NE conclusions in **2019 Economic Study Offshore Wind Transmission Interconnection Analysis**, March 18, 2020. A 50% factor was included for the West Barnstable to Stoughton 345kV overhead transmission line to account for construction in a new ROW.

New England Overloads – Unplanned Transmission System (2024) – slide 1 of 2

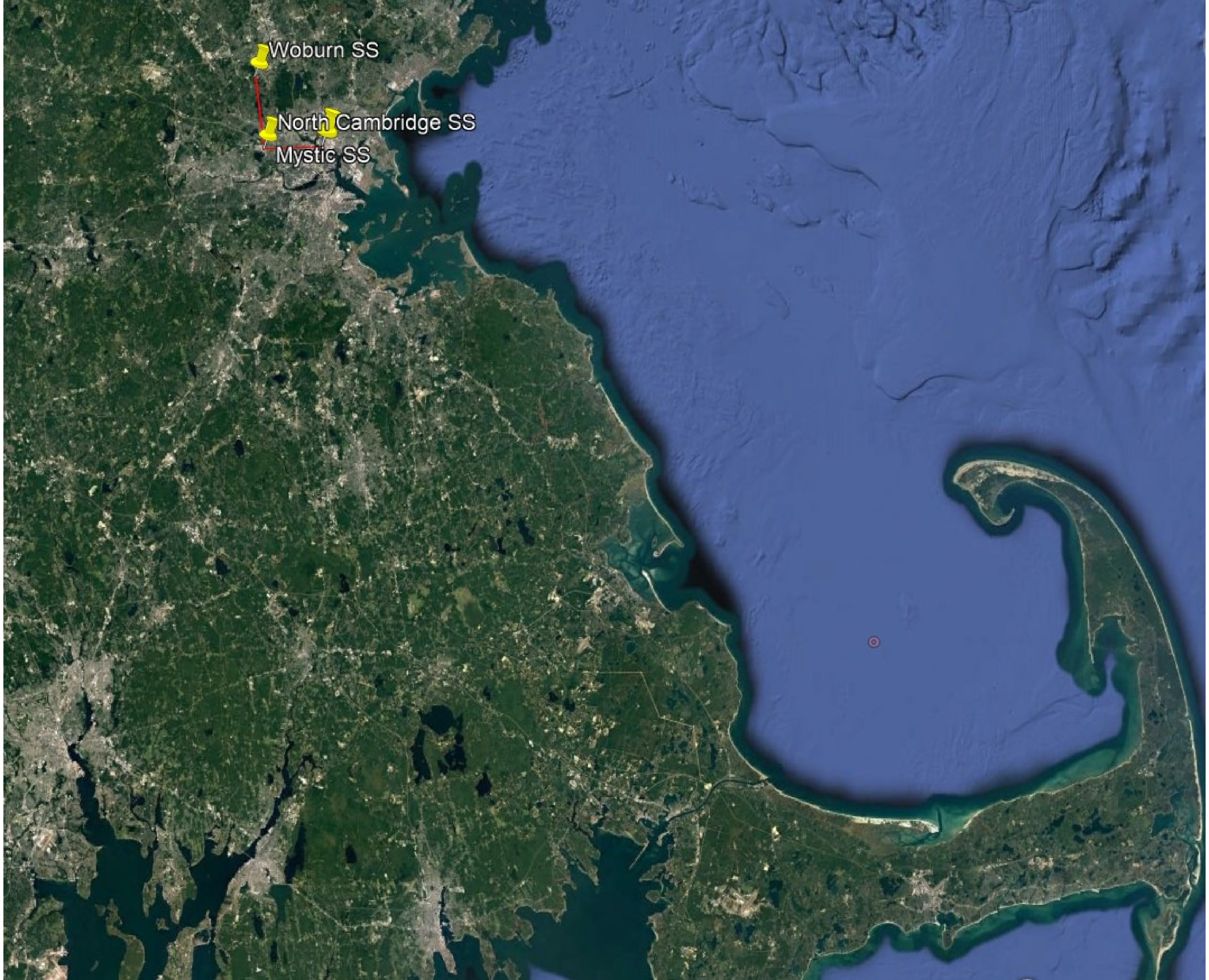
50 overloads less than 110% not shown



New England Overloads – Unplanned Transmission System (2024) – slide 2 of 2

50 overloads less than 110% not shown

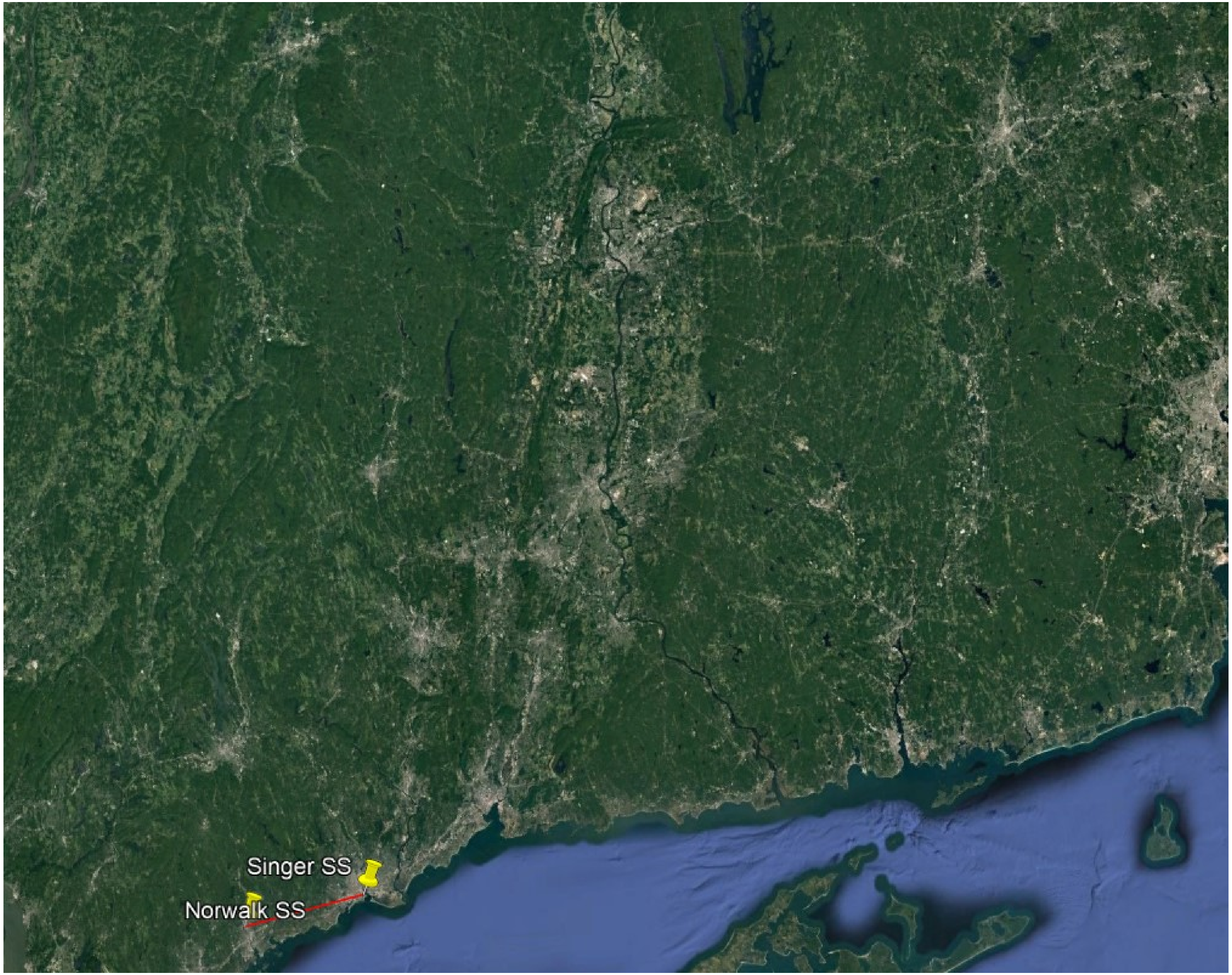
115kV overhead transmission line
115kV underground transmission line
345kV overhead transmission line
345kV underground transmission line



New England Overloads – Planned Transmission System (2024) – slide 1 of 2

14 overloads less than 110% not shown

115kV overhead transmission line
115kV underground transmission line
345kV overhead transmission line
345kV underground transmission line



New England Overloads – Planned Transmission System (2024) – slide 2 of 2

14 overloads less than 110% not shown

115kV overhead transmission line
115kV underground transmission line
345kV overhead transmission line
345kV underground transmission line

System Upgrade Costs – Unit Costs

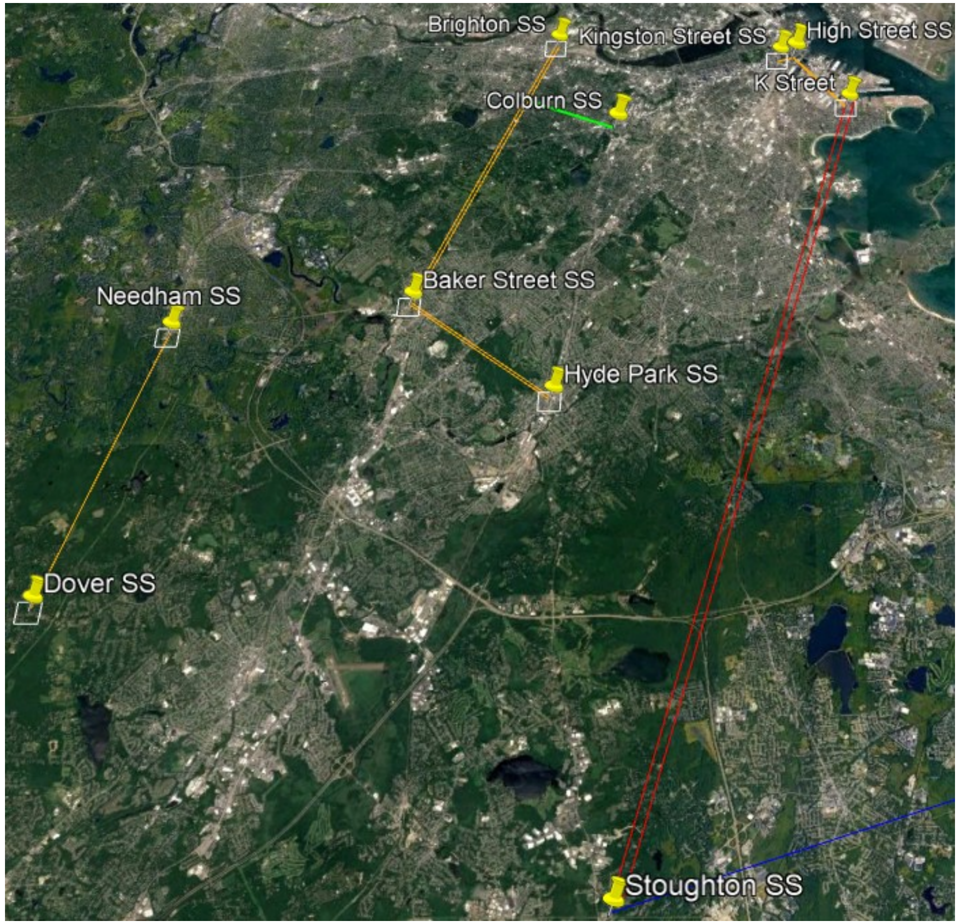
- ***New transmission lines -*** costs were determined using the *Greater Boston Cost Comparison, NHT Analysis using New England Comparables January 2015* (https://www.iso-ne.com/static-assets/documents/2015/02/a2_nht_greater_boston_cost_analysis_public.pdf). The 115kV per mile overhead line costs were not included in the 2015 New England analysis so a 45% cost ratio (115kV to 345kV) was used; $5.4M/mile (basis: Transmission Cost Estimation Guide MTEP19, Section 4, https://cdn.misoenergy.org/20190212%20PSC%20Item%2005a%20Transmission%20Cost%20Estimation%20Guide%20for%20MTEP%202019_for%20review317692.pdf).
- ***Transmission reconductoring*** (overhead lines only) – costs were determined using 30% - 70% of the new line average construction cost (this assumes some new structures would be required for the larger conductors and to meet current NESC design criteria)
- ***Transmission lines overloaded to less than 110%*** - a mitigation cost range of $200K - $500K was applied to each line. Thermal ratings could be limited by smaller conductors on some spans, sag limiting spans, encroachments, conservative ratings methodology inconsistent with ISONE PP7, or limiting substation equipment (breakers, switches, connectors, system protection, …). Transmission lines could be rerated a variety of ways to achieve sufficient ratings. While mitigation for some transmission lines would exceed this cost, the assumed cost range is conservative. Precise mitigation costs would likely *increase* the cost differential between the *Planned* and *Unplanned* scenarios.
- ***Overloaded substation equipment*** – costs for overloaded equipment could vary considerably; an overloaded auto transformer or phase shifter could cost $10M while overloaded substation breakers and disconnect switches would cost much less. Costs were determined using a cost range of $200K-$10M per overload. Note that many of the overloads are transformers or phase shifters.

Unit Costs (per mile) - New Lines

Overhead	
345	$12M
115 / 69	$5.4M
Underground	
345	$19.5M
115	$16.9M

System Upgrade Costs - *Unplanned*

- The ***Unplanned*** scenario overloads are in the following areas:
  - West Barnstable to the North (to K-Street)
  - Boston area
  - West Barnstable to the West (Tremont and Falmouth Tap paths)
  - Connecticut and Rhode Island
- Analysis Assumptions:
  - A new transmission line from West Barnstable to Stoughton to K-street will resolve other overloads in the Boston area (several overloaded lines and substation facilities). If this is *not* the case, significant additional costs will result since many of the transmission lines in the Boston area are underground. Refer to the first diagram on the next slide.
  - The *High Street to K-street* and *Kingston St to K-street* overloads would be mitigated by a new 115kV underground line from *Kingston St to K-street*.
  - Overhead transmission line overloads could be mitigated by reconductoring.



Overloads from West Barnstable to the West

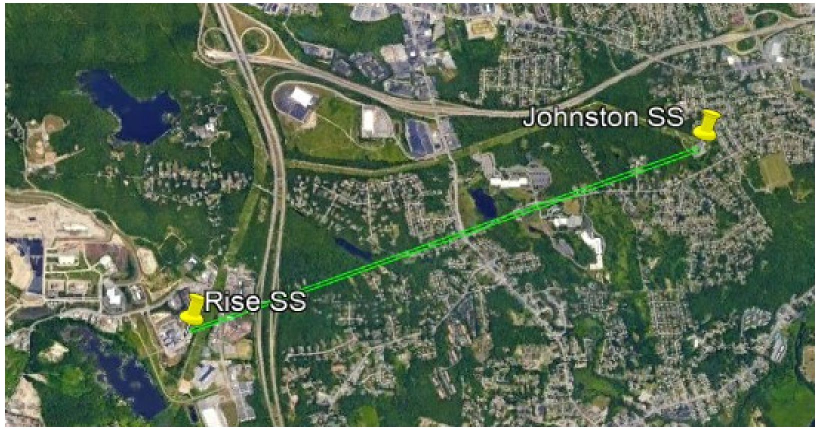
Boston Area Overloads

Overloaded Lines (>110%)	OL %	Voltage
110786 STOUGHTON 345 110790 K STREET 1 345 2	160.4	345kV UG
110786 STOUGHTON 345 110790 K STREET 1 345 1	158.4	345kV UG
110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	161.9	115kV UG
110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	161.9	115kV UG
110814 BRIGHTON B 115 110855 WASH_TAP 511 115 1	154.8	115kV UG
110813 BRIGHTON A 115 110854 WASH_TAP 510 115 1	154.8	115kV UG
110888 BAKER ST A 115 110892 HYDE PARK B 115 1	144.3	115kV UG
110834 HIGH ST 510 115 110836 K STREET 1 115 1	142.6	115kV UG
110889 BAKER ST B 115 110891 HYDE PARK A 115 1	140.4	115kV UG
110893 NEEDHAM 115 110894 DOVER MA 115 1	128.4	115kV UG
110835 HIGH ST 511 115 110837 K STREET 2 115 1	126.9	115kV UG
110830 KINGSTN ST W 115 110836 K STREET 1 115 2	122.6	115kV UG
110830 KINGSTN ST W 115 110836 K STREET 1 115 1	122.6	115kV UG
110853 COLBURN 511 115 110855 WASH_TAP 511 115 1	121.7	115kV OH
110852 COLBURN 510 115 110854 WASH_TAP 510 115 1	121.7	115kV OH

Overloaded Lines (>110%)	OL %	Voltage
111217 BOURNE 115 111226 CANAL 126 115 1	157.9	115kV OH
111217 BOURNE 115 111222 CANAL 121 115 1	157.0	115kV OH
111158 HORSEPDTP113 115 111217 BOURNE 115 1	143.2	115kV OH
111142 VALLEYNB 113 115 111158 HORSEPDTP113 115 1	143.1	115kV OH
111155 WAREHAM 108 115 111156 VALLEYNB 108 115 1	141.2	115kV OH
111142 VALLEYNB 113 115 111152 WAREHAM 113 115 1	141.1	115kV OH
111152 WAREHAM 113 115 111318 TREMONT 113 115 1	139.9	115kV OH
111149 HORSEPDTP108 115 111156 VALLEYNB 108 115 1	138.9	115kV OH
111137 TREMONT S 115 111155 WAREHAM 108 115 1	137.9	115kV OH
111135 W BARNSTABLE 115 111215 MASHPEE 137 115 1	136.0	115kV OH
111217 BOURNE 115 111219 CANAL 120 115 1	132.1	115kV OH
111135 W BARNSTABLE 115 111217 BOURNE 115 1	122.9	115kV OH
111209 HATCHVILLE 115 111212 MASHPEE 136 115 1	122.1	115kV OH
111149 HORSEPDTP108 115 111217 BOURNE 115 1	116.6	115kV OH

Connecticut Overload

120587 NU_1588_CMEC 115 120596 CMEC_1588_NU 115 1	127.7	115kV OH



Rhode Island Overloads

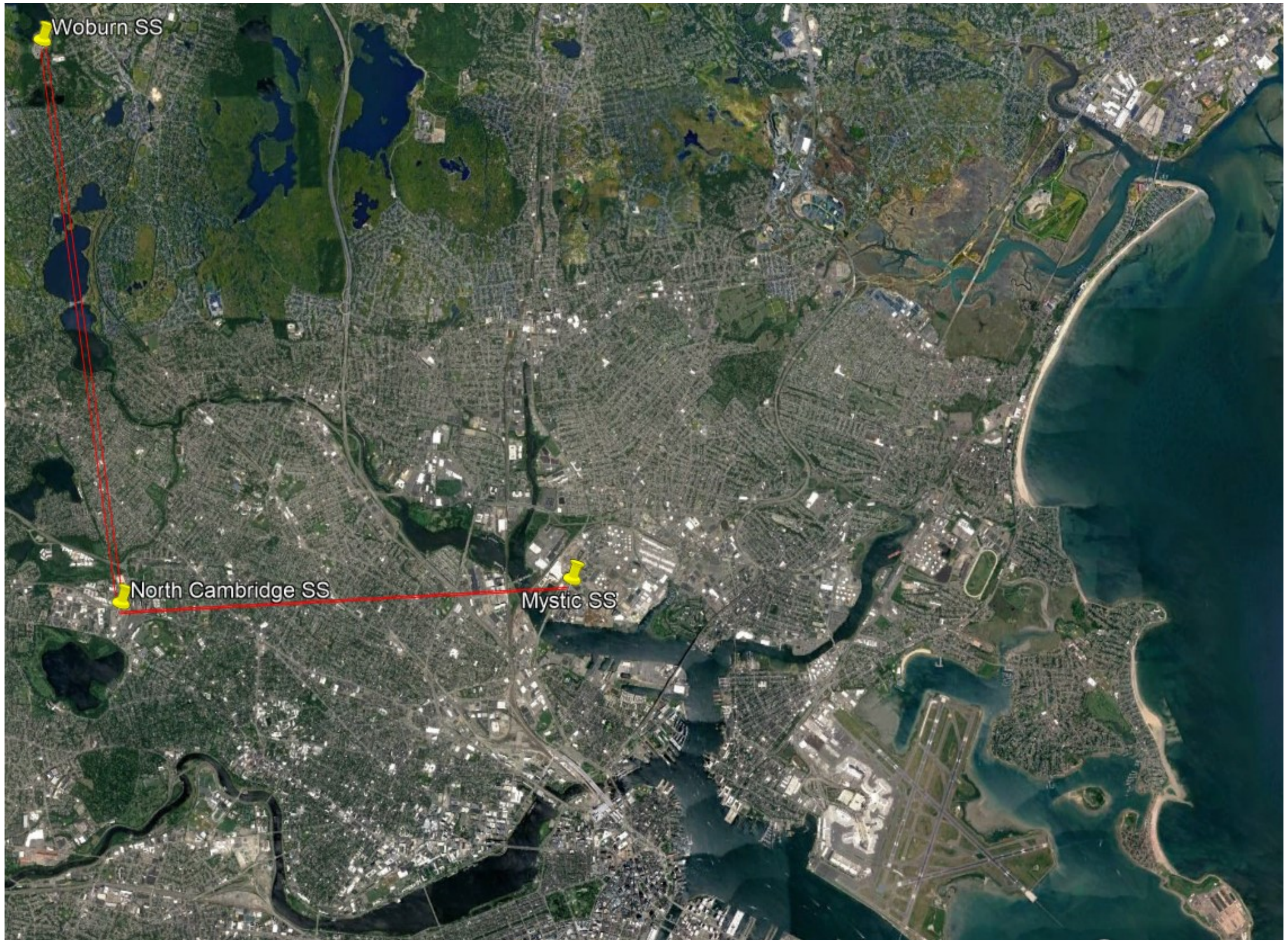
117330 JOHNSTON_171 115 117334 RISE 171_TAP 115 1	124.4	115kV OH
117331 JOHNSTON_172 115 117360 RISE 172_TAP 115 1	122.1	115kV OH

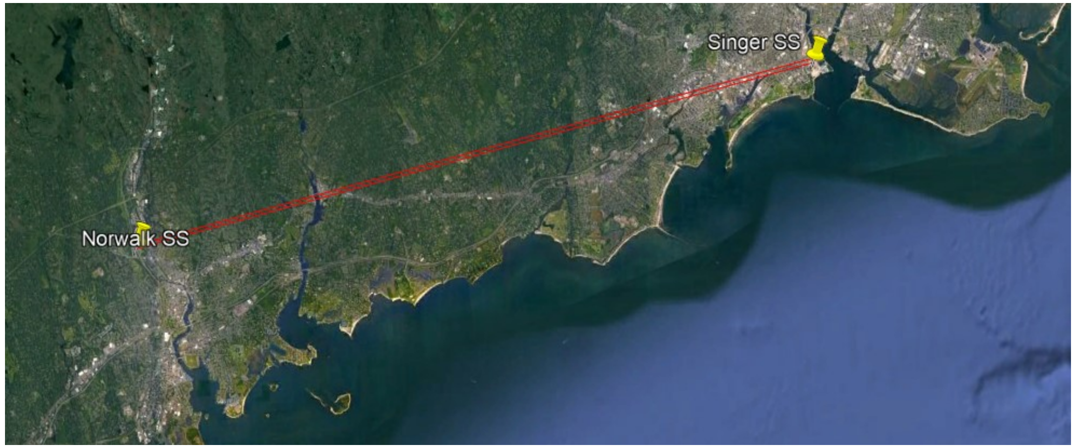
System Upgrade Costs - *Unplanned*

		Voltage	Miles or Units	Cost/Mile (Low)	Cost/Mile (High)	Cost/Mile (Midpoint)	Cost (Low)	Cost (High)	Cost (Midpoint)
1	**West Barnstable to Stoughton to K-Street - New Line**								
	Overhead portion (on new ROW)	345kV OH	60	$ 13,500,000.00	$ 22,500,000.00	$ 18,000,000.00	$ 810,000,000.00	$ 1,350,000,000.00	$ 1,080,000,000.00
	Underground portion	345kV UG	16.8	$ 14,625,000.00	$ 24,375,000.00	$ 19,500,000.00	$ 245,700,000.00	$ 409,500,000.00	$ 327,600,000.00
2	**Kingston St to K-street - New Line**								
	Underground	115KV UG	1.8	$ 12,675,000.00	$ 21,125,000.00	$ 16,900,000.00	$ 22,815,000.00	$ 38,025,000.00	$ 30,420,000.00
3	**Eastern Massachusetts - Reconductoring**								
	West Barnstable to Mashpee	115kV OH	9	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 14,580,000.00	$ 34,020,000.00	$ 24,300,000.00
	Mashpee to Hatchville	115kV OH	5.16	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 8,359,200.00	$ 19,504,800.00	$ 13,932,000.00
	Hatchville to Falmouth Tap	115kV OH	2.28	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 3,693,600.00	$ 8,618,400.00	$ 6,156,000.00
	West Barnstable to Bourne	115kV OH	14.58	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 23,619,600.00	$ 55,112,400.00	$ 39,366,000.00
	Bourne to Canal	115kV OH	3	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 4,860,000.00	$ 11,340,000.00	$ 8,100,000.00
	Bourne to Valley	115kV OH	3.12	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 5,054,400.00	$ 11,793,600.00	$ 8,424,000.00
	Valley to Wareham	115kV OH	5.52	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 8,942,400.00	$ 20,865,600.00	$ 14,904,000.00
	Wareham to Tremont	115kV OH	4.56	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 7,387,200.00	$ 17,236,800.00	$ 12,312,000.00
4	**Rhode Island - Reconductoring**								
	Johnston to Rise	115kV OH	2.76	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 4,471,200.00	$ 10,432,800.00	$ 7,452,000.00
5	**Connecticut - Reconductoring**								
	Colony to North Wallingford	115kV OH	3.12	$ 1,620,000.00	$ 3,780,000.00	$ 2,700,000.00	$ 5,054,400.00	$ 11,793,600.00	$ 8,424,000.00
7	**Overloaded lines {less than 110%}**	345/115kV	46	$ 200,000.00	$ 500,000.00	$ 350,000.00	$ 9,200,000.00	$ 23,000,000.00	$ 16,100,000.00
8	**Substation Overloads**	345/115kV	23	$ 200,000.00	$ 10,000,000.00	$ 5,100,000.00	$ 4,600,000.00	$ 230,000,000.00	$ 117,300,000.00
	Total Cost Estimate Range						**$ 1,178,337,000**	**$ 2,251,243,000.00**	**$ 1,714,790,000.00**

System Upgrade Costs - *Planned*

- The ***Planned*** scenario overloads are in the following areas:
  - Mystic - North Cambridge - Woburn
  - Connecticut
- Analysis Assumptions:
  - A new underground transmission line from Mystic to North Cambridge to Woburn would be required to resolve overloads out of Mystic.
  - Overhead transmission line overloads could be mitigated by reconductoring.
  - Underground transmission line overloads (Norwalk to Singer) would require a new 345kV underground transmission line.





Connecticut Overloads

119441 NU_3921_UI	345	119480 NORWALK	345	1	160.3	345kV UG
119428 NU_3280_UI	345	119480 NORWALK	345	1	160.4	345kV UG

Boston Area Overloads

Overloaded Lines (>110%)	OL %	Voltage
110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 1	190.2	345kV UG
110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 2	160.6	345kV UG
110756 WOBURN 345 110758 N. CAMBRIDGE 345 2	117.4	345kV UG
110756 WOBURN 345 110758 N. CAMBRIDGE 345 1	117.4	345kV UG

System Upgrade Costs - *Planned*

		Voltage	Miles or Units	Cost/Mile (Low)	Cost/Mile (High)	Cost/Mile (Midpoint)	Cost (Low)	Cost (High)	Cost (Midpoint)
1	**Boston Area - New Lines**								
	Mystic to North Cambridge to Woburn	345kV UG	10.56	$ 14,625,000.00	$ 24,375,000.00	$ 19,500,000.00	$ 154,440,000.00	$ 257,400,000.00	$ 205,920,000.00
2	**Norwalk to Singer - New UG Line**	345kV UG	15.54	$ 14,625,000.00	$ 24,375,000.00	$ 19,500,000.00	$ 227,272,500.00	$ 378,787,500.00	$ 303,030,000.00
3	**Overloaded lines {less than 110%}**	345/115kV	15	$ 200,000.00	$ 500,000.00	$ 350,000.00	$ 3,000,000.00	$ 7,500,000.00	$ 5,250,000.00
4	**Substation Overloads**	345/115kV	7	$ 200,000.00	$ 10,000,000.00	$ 5,100,000.00	$ 1,400,000.00	$ 70,000,000.00	$ 35,700,000.00
	Total Cost Estimate Range						**$ 386,112,500.00**	**$713,687,500.00**	**$ 549,900,000.00**

Unplanned Transmission Overloads (>110%)

	Overloaded Lines (>110%)	OL %	Voltage
1	110786 STOUGHTON 345 110790 K STREET 1 345 2	160.4	345kV UG
2	110786 STOUGHTON 345 110790 K STREET 1 345 1	158.4	345kV UG
3	111133 CARVER 345 111193 CANAL 345 1	152.8	345kV OH
4	110782 JORDAN ROAD 345 111193 CANAL 345 1	148.8	345kV OH
5	111133 CARVER 345 115036 NGR_331_NST 345 1	139.4	345kV OH
6	110780 WEST WALPOLE 345 115008 NST_331_NGR 345 1	138.6	345kV OH
7	110772 W MEDWAY B 345 115012 NGR_344_NST 345 1	136.4	345kV OH
8	110781 HOLBROOK 345 115009 NGR_335_NST 345 1	133.2	345kV OH
9	110782 JORDAN ROAD 345 115011 NGR_342_NST 345 1	131.6	345kV OH
10	115008 NST_331_NGR 345 115036 NGR_331_NST 345 1	127.7	345kV OH
11	111133 CARVER 345 115013 NGR_356_NST 345 1	124.9	345kV OH
12	115013 NGR_356_NST 345 115446 BRIDGEWATER 345 1	124.1	345kV OH
13	110781 HOLBROOK 345 110786 STOUGHTON 345 1	115.8	345kV OH
14	115011 NGR_342_NST 345 115447 AUBURN ST 345 1	115.8	345kV OH
15	110888 BAKER ST A 115 110892 HYDE PARK B 115 1	144.3	115kV UG
16	110834 HIGH ST 510 115 110836 K STREET 1 115 1	142.6	115kV UG
17	110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	161.9	115kV UG
18	110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	161.9	115kV UG
19	110814 BRIGHTON B 115 110855 WASH_TAP 511 115 1	154.8	115kV UG
20	110813 BRIGHTON A 115 110854 WASH_TAP 510 115 1	154.8	115kV UG
21	110889 BAKER ST B 115 110891 HYDE PARK A 115 1	140.4	115kV UG
22	110830 KINGSTN ST W 115 110836 K STREET 1 115 2	122.6	115kV UG
23	110830 KINGSTN ST W 115 110836 K STREET 1 115 1	122.6	115kV UG
24	110893 NEEDHAM 115 110894 DOVER MA 115 1	128.4	115kV UG
25	110835 HIGH ST 511 115 110837 K STREET 2 115 1	126.9	115kV UG

	Overloaded Lines (>110%)	OL %	Voltage
26	111142 VALLEYNB 113 115 111158 HORSEPDTP113 115 1	143.1	115kV OH
27	111158 HORSEPDTP113 115 111217 BOURNE 115 1	143.2	115kV OH
28	111155 WAREHAM 108 115 111156 VALLEYNB 108 115 1	141.2	115kV OH
29	117330 JOHNSTON_171 115 117334 RISE 171_TAP 115 1	124.4	115kV OH
30	111217 BOURNE 115 111219 CANAL 120 115 1	132.1	115kV OH
31	110853 COLBURN 511 115 110855 WASH_TAP 511 115 1	121.7	115kV OH
32	110852 COLBURN 510 115 110854 WASH_TAP 510 115 1	121.7	115kV OH
33	117331 JOHNSTON_172 115 117360 RISE 172_TAP 115 1	122.1	115kV OH
34	111136 KINGSTON 115 111144 BROOK STREET 115 1	118.6	115kV OH
35	111149 HORSEPDTP108 115 111217 BOURNE 115 1	116.6	115kV OH
36	120587 NU_1588_CMEC 115 120596 CMEC_1588_NU 115 1	127.7	115kV OH
37	111217 BOURNE 115 111226 CANAL 126 115 1	157.9	115kV OH
38	111217 BOURNE 115 111222 CANAL 121 115 1	157.0	115kV OH
39	115449 DUPONT 115 115452 AUBURN ST 115 1	113.3	115kV OH
40	111209 HATCHVILLE 115 111212 MASHPEE 136 115 1	122.1	115kV OH
41	111135 W BARNSTABLE 115 111217 BOURNE 115 1	122.9	115kV OH
42	111135 W BARNSTABLE 115 111215 MASHPEE 137 115 1	136.0	115kV OH
43	111142 VALLEYNB 113 115 111152 WAREHAM 113 115 1	141.1	115kV OH
44	111152 WAREHAM 113 115 111318 TREMONT 113 115 1	139.9	115kV OH
45	111149 HORSEPDTP108 115 111156 VALLEYNB 108 115 1	138.9	115kV OH
46	111137 TREMONT S 115 111155 WAREHAM 108 115 1	137.9	115kV OH
47	111136 KINGSTON 115 115006 NGR_191_NST 115 1	130.6	115kV OH

	Overloaded Substation Equipment (>110%)	OL %
1	111226 CANAL 126 115 111193 CANAL 345 1	160.5
2	119718 MONTVILLE 115 119181 MONTVILE_371 345 2	153.0
3	119718 MONTVILLE 115 119180 MONTVILE_364 345 1	148.8
4	111222 CANAL 121 115 111193 CANAL 345 1	139.0
5	117301 KENT COUNTY 345 117332 KENT COUNTY 115 8	124.4
6	117301 KENT COUNTY 345 117332 KENT COUNTY 115 4	122.1
7	114734 BRAYTN POINT 345 114742 BRAYTN POINT 115 1	132.3
8	115447 AUBURN ST 345 115452 AUBURN ST 115 1	130.8
9	110887 BAKER ST PS2 115 110889 BAKER ST B 115 1	125.3
10	110886 BAKER ST PS1 115 110888 BAKER ST A 115 1	125.3
11	115450 E BRGWTR_E20 115 115451 BRIDGEWATER 115 1	117.4
12	110836 K STREET 1 115 110790 K STREET 1 345 1	116.4
13	110837 K STREET 2 115 110790 K STREET 1 345 1	116.4
14	111269 IND PRK 112T 115 111319 INDUST_PK112 115 1	113.0
15	114742 BRAYTN POINT 115 114907 BP XFMR 115 115 1	113.9
16	110791 HYDE PARK 115 110788 HYDE PARK 345 1	110.0
17	111134 W BARNSTABLE 345 111135 W BARNSTABLE 115 1	262.4

Unplanned Transmission Overloads (<110%)

	Overloaded Lines (<110%)	OL %
1	110866 MEDWAY 115 110879 HOLLISTON 115 1	109.7
2	110870 FRAMINGHAM 115 110871 SPEEN STREET 115 1	110.6
3	115450 E BRGWTR_E20 115 115452 AUBURN ST 115 1	108.9
4	115448 BELMONT_F19 115 115451 BRIDGEWATER 115 1	108.7
5	110894 DOVER MA 115 110895 WEST WALPOLE 115 1	108.5
6	110868 SHERBORN 115 110879 HOLLISTON 115 1	108.2
7	110832 KINGSTN ST A 115 110835 HIGH ST 511 115 1	107.6
8	110889 BAKER ST B 115 110893 NEEDHAM 115 1	106.8
9	110833 KINGSTN ST B 115 110834 HIGH ST 510 115 1	106.6
10	110900 HOLBROOK 115 114764 S RANDLPH509 115 1	107.4
11	119718 MONTVILLE 115 119957 NU_1090_CMEC 115 1	109.0
12	123163 GRAND AVENUE 115 123782 WEST RIVER B 115 2	108.2
13	123163 GRAND AVENUE 115 123780 WEST RIVER A 115 1	107.9
14	111139 CARVER 115 111144 BROOK STREET 115 1	105.6
15	110811 WATERTWN 520 115 110987 WALT PS-D 115 1	105.5
16	110812 WATERTWN 521 115 110988 WALT PS-E 115 1	105.5
17	110811 WATERTWN 520 115 110926 ELECTRIC AVE 115 1	104.7
18	110812 WATERTWN 521 115 110926 ELECTRIC AVE 115 1	104.7
19	115448 BELMONT_F19 115 115452 AUBURN ST 115 1	104.6
20	113271 WYMNGRDN57_T 115 113909 CENTECH_E157 115 1	104.2
21	113271 WYMNGRDN57_T 115 113286 MILLBURY 115 1	104.2

	Overloaded Lines (<110%)	OL %
24	113950 SANDY POND 345 113951 TEWKSBURY 345 1	104.4
25	111257 HIGH_HL_111 115 111268 INDUSTRL PRK 115 1	102.4
26	110922 CANTON 509_T 115 114764 S RANDLPH509 115 1	103.0
27	120434 BRISTOL CT 115 120444 FORESTVIL 25 115 1	103.9
28	110900 HOLBROOK 115 110908 E.HOLBRK TAP 115 1	101.9
29	123221 ELM WEST A 115 123780 WEST RIVER A 115 1	103.0
30	123222 ELM WEST B 115 123782 WEST RIVER B 115 1	103.0
31	110830 KINGSTN ST W 115 110849 CARVER ST 13 115 1	102.2
32	110830 KINGSTN ST W 115 110848 CARVER ST 12 115 1	102.2
33	110849 CARVER ST 13 115 110851 SCOTIA ST513 115 1	101.5
34	110920 CANTON 508_T 115 114765 S RANDLPH508 115 1	103.1
35	110848 CARVER ST 12 115 110850 SCOTIA ST512 115 1	101.4
36	110900 HOLBROOK 115 114765 S RANDLPH508 115 1	102.4
37	110786 STOUGHTON 345 110788 HYDE PARK 345 1	101.0
38	100150 SECT 83C TAP 115 100212 HEYWOOD ROAD 115 1	100.9
39	117351 HARTFORD AVE 115 117353 PUTNAM PK_71 115 1	103.1
40	117333 PHILLIP 83_T 115 117336 FRANKLIN SQ 115 1	103.0
41	120470 SOTHNGTN50_R 115 120938 CANAL CT 115 1	102.2
42	120227 DOOLEY 115 120236 WEST SIDE 115 1	101.7
43	113924 HUDSON 115 115040 NGR_H160_HLP 115 1	100.2
44	111209 HATCHVILLE 115 111407 FAL TAP 136 115 1	104.7

	Overloaded Substation Equipment (<110%)	OL %
1	115446 BRIDGEWATER 345 115451 BRIDGEWATER 115 2	104.4
2	110770 W MEDWAY A 345 110794 W MEDWAY A 230 1	102.4
3	111219 CANAL 120 115 111193 CANAL 345 1	103.0
4	115447 AUBURN ST 345 115452 AUBURN ST 115 2	103.9
5	110900 HOLBROOK 115 110781 HOLBROOK 345 1	101.9
6	115446 BRIDGEWATER 345 115451 BRIDGEWATER 115 1	103.0

Planned Transmission Overloads (>110%)

	Overloaded Lines (>110%)	OL %	Voltage
1	110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 1	190.2	345kV UG
2	110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 2	160.6	345kV UG
3	119441 NU_3921_UI 345 119480 NORWALK 345 1	160.3	345kV UG
4	119428 NU_3280_UI 345 119480 NORWALK 345 1	160.4	345kV UG
5	110756 WOBURN 345 110758 N. CAMBRIDGE 345 2	117.4	345kV UG
6	110756 WOBURN 345 110758 N. CAMBRIDGE 345 1	117.4	345kV UG

	Overloaded Substation Equipment (>110%)	OL %
1	114734 BRAYTN POINT 345 114742 BRAYTN POINT 115 1	200.4
2	114742 BRAYTN POINT 115 114907 BP XFMR 115 115 1	170.9
3	114734 BRAYTN POINT 345 114907 BP XFMR 115 115 3	119.4
4	114734 BRAYTN POINT 345 114907 BP XFMR 115 115 2	116.6

Planned Transmission Overloads (<110%)

	Overloaded Lines (<110%)	OL %		Overloaded Substation Equipment (<110%)	OL %
1	116360 PLEASANT 115 116364 BLANDFORD 115 1	105.2	1	110759 MYSTIC MA 345 110818 MYSTIC MA 115 1	106.2
2	121337 NORWALK 115 121457 GLENBROOK 115 1	103.2	2	110759 MYSTIC MA 345 110818 MYSTIC MA 115 2	105.0
3	121337 NORWALK 115 121457 GLENBROOK 115 2	103.2	3	110799 WOBURN 115 110756 WOBURN 345 1	102.3
4	116356 WOODLAND 115 116360 PLEASANT 115 1	104.0			
5	100150 SECT 83C TAP 115 100212 HEYWOOD ROAD 115 1	100.9			
6	110813 BRIGHTON A 115 110926 ELECTRIC AVE 115 1	100.7			
7	110814 BRIGHTON B 115 110926 ELECTRIC AVE 115 1	100.7			
8	110888 BAKER ST A 115 110892 HYDE PARK B 115 1	100.5			
9	114734 BRAYTN POINT 345 114900 BERRY STREET 345 1	103.7			
10	110833 KINGSTN ST B 115 110834 HIGH ST 510 115 1	104.7			
11	110832 KINGSTN ST A 115 110835 HIGH ST 511 115 1	104.6			