2050 Transmission Study

Results from Additional Analysis on Offshore Wind Relocation

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Overview

- Background on 2050 Transmission Study
- Review of Scope for Offshore Wind Relocation Analysis
- Results of Offshore Wind Relocation Analysis
- Conclusion
- Feedback and Next Steps

BACKGROUND ON 2050 TRANSMISSION STUDY

Background

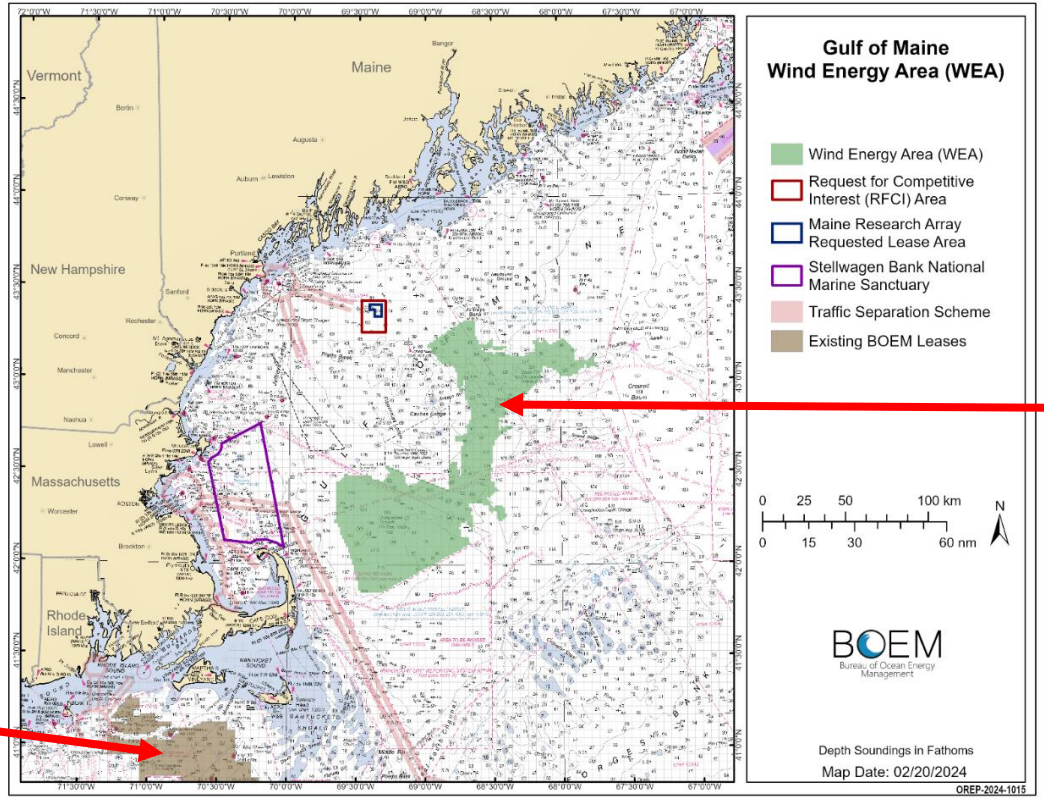
- In accordance with a recommendation from NESCOE's October 2020 "New England States' Vision for a Clean, Affordable, and Reliable 21st Century Regional Electric Grid," ISO-NE conducted the 2050 Transmission Study, posting a final report in February 2024
  - Links to other materials on the 2050 Transmission Study, including PAC presentations, can be found in the appendix to this presentation
- ISO-NE received a variety of stakeholder questions and feedback on the study, including two areas that merit further analysis in order to respond:
  - Large amounts of offshore wind interconnecting to northern New England led to severe overloads across the North-South interface; connecting this wind further south may help to mitigate these overloads
    - **Today's presentation will focus on presenting results for this piece of analysis**
  - Analysis of offshore wind points of interconnection (POIs) could provide high-level screening information on the interconnection and operation of offshore wind
    - **Work is still ongoing for this analysis; results will be presented at a future PAC meeting**

REVIEW OF SCOPE FOR OFFSHORE WIND RELOCATION ANALYSIS

Additional Offshore Wind POI Changes

- Original assumptions for the 2050 Transmission Study were taken from the Massachusetts-commissioned "Energy Pathways to Deep Decarbonization" study, including state-by-state total amounts of interconnected offshore wind
  - As this study was conducted, the exact location of the Gulf of Maine offshore wind lease area was not fully defined
- The Gulf of Maine lease area was finalized in March 2024, and reaches fairly far south
  - Much of the lease area is as close, or closer, to Boston as it is to Maine
  - North-South overloads may be mitigated by interconnecting some Gulf of Maine offshore wind to Massachusetts rather than Maine

Offshore Wind Energy Areas (WEAs)



Gulf of Maine
Wind Energy Area

Massachusetts &
Rhode Island
Wind Energy Area

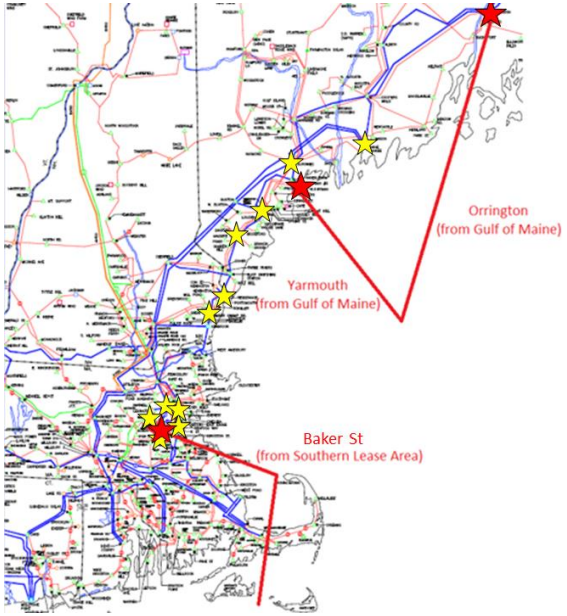
[Gulf of Maine | Bureau of Ocean Energy Management (boem.gov)]

Proposed Offshore Wind POI Changes

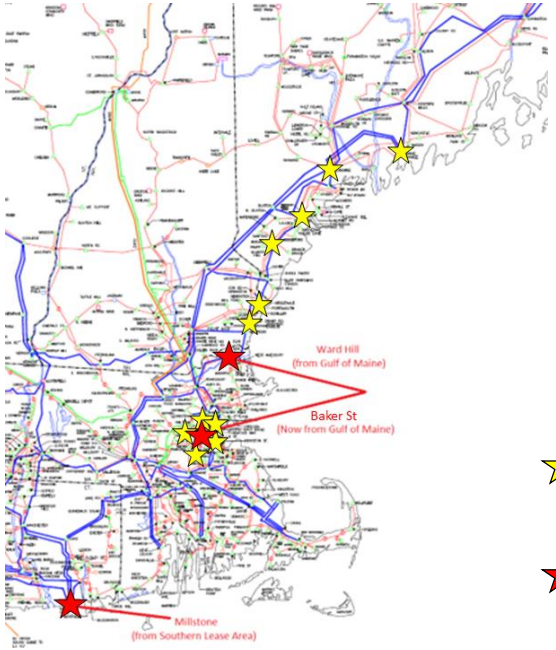
- ISO-NE proposed to study the effect of the following changes to the 2050 Transmission Study's offshore wind POIs:
  - Move one Gulf of Maine WEA wind farm's POI from Yarmouth, ME to West Roxbury, MA
  - Move one Gulf of Maine WEA wind farm's POI from Orrington, ME to Ward Hill, MA
  - Move one MA/RI WEA wind farm's POI from West Roxbury, MA to Millstone, CT
- All other wind farms were kept at their original POI
- This relocation proposal is not a recommendation or a requirement; it is a what-if scenario to study the effects of different choices of wind farm POIs
- These changes result in very little change in the mileage of offshore cables, but significantly reduce stress on the Maine-New Hampshire and North-South interfaces

Offshore Wind POI Relocations: Visualization

Originally Studied in 2050 Study



Proposed POI Relocations



= Wind Farm POI Did Not Move

= Wind Farm POI Moved

Wind farm POIs in the ME, NH, and Boston area are shown with stars. Not all wind farms included in the 2050 Transmission Study are represented in these images.

Scope of Offshore Wind Relocation Analysis

- All 13 snapshots from the 2050 Transmission Study were considered
  - The analysis was similar to that of the original 2050 Transmission Study, meaning only DC steady-state N-1 and N-1-1 contingency analysis was performed and only thermal violations on PTF elements are being reported
- All four North – South roadmaps were analyzed for each of these 13 snapshots:
  - AC roadmap
  - DC roadmap
  - AC roadmap, minimizing construction of new lines
  - Offshore grid roadmap

Summary of Offshore Wind Relocation

- POIs for 2,400 MW of wind (nameplate) moved from northern New England to southern New England
  - 1,200 MW from Orrington
  - 1,200 MW from Yarmouth
- 1,879 MW actual output shifted in Winter 2050 (57 GW Winter Peak snapshot, Wind and Shortfall Generation)
  - 960 MW attributed to Wind
  - 919 MW attributed to Shortfall Generation
- 120 MW actual wind output shifted in Summer 2050 (No Shortfall Generation at these POIs)

Interface Flow Changes

	Pre-Relocation		Post-Relocation	
	Winter (MW)	Summer (MW)	Winter (MW)	Summer (MW)
Maine-NH	6,090	1,848	3,988	1,750
North-South	5,714	5,187	3,778	5,098

- Wind relocation had little impact on the summer numbers
  - Wind output was 5% in the summer and no northern shortfall generation
- Wind relocation had more impact in the winter
  - Wind output was 40% in the winter and there was northern shortfall generation
- For the summer case, there is a large amount of solar generation assumed in NH
  - This meant ME-NH flows were typically lower than N-S flows for Summer cases

Note: The interface flow numbers are the maximum seen in any of the 13 snapshots

RESULTS OF OFFSHORE WIND RELOCATION ANALYSIS

AC Roadmap – Original

Summary of Upgrades Required to Serve 51 GW Load
Build new overhead 345 kV line from Surowiec – Timber Swamp – Ward Hill, 110 miles
Build a new partially-overhead/partially-underground 345 kV line from Ward Hill - Wakefield Junction – Mystic, 22.4 miles overhead and 12.8 miles underground
Build third Stoughton - K St 345 kV Underground Cable, 17.5 miles underground
Rebuild 1,071 miles of overhead 115 kV lines
Rebuild 132 miles of overhead 345 kV lines
Additional Upgrades Required to Serve 57 GW Load
Build a second Timber Swamp – Ward Hill line as described above, 30 miles
Rebuild an additional 634 miles of overhead 115 kV lines
Rebuild an additional 413 miles of overhead 345 kV lines

Map is for illustrative purposes only, and does not define a route for any transmission project.

- This solution option increases transfer capability on Maine-New Hampshire, North-South, and the Boston Import interfaces, bringing energy from northern New England resources to southern New England load centers
- Fully underground/submarine AC transmission lines are likely infeasible due to the long distances involved and lower capacity than overhead transmission lines

Note: Rebuild mileage describes total New England rebuilds, not just North-South related upgrades.

AC Roadmap – After Relocation

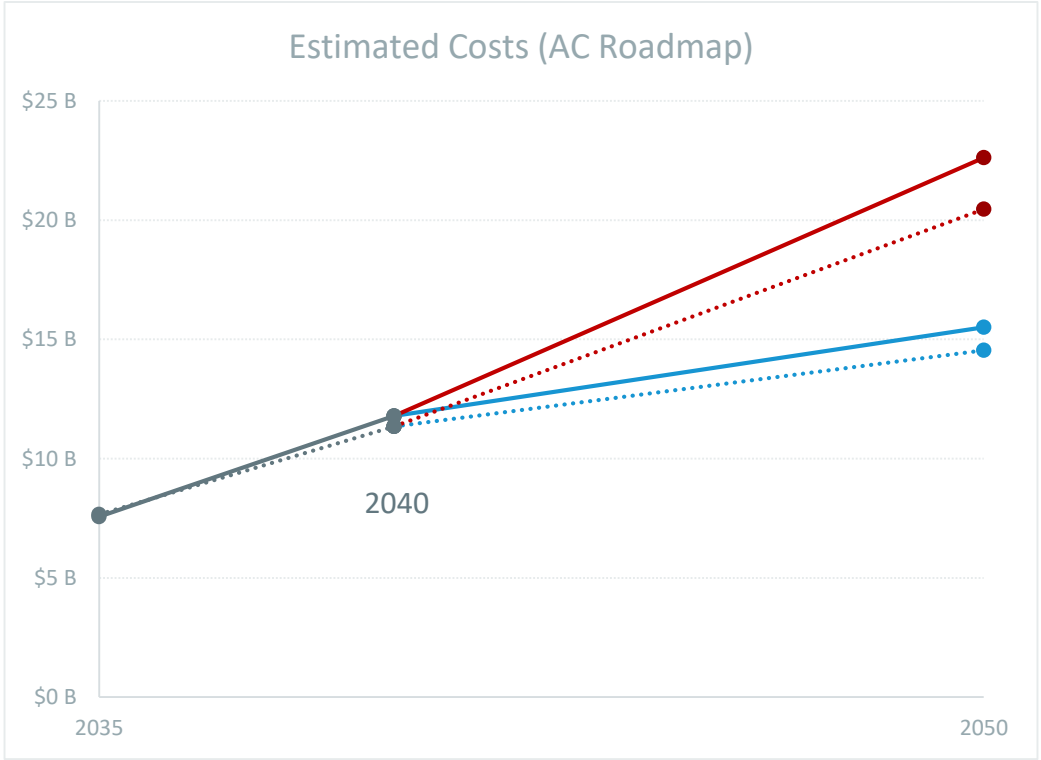
Summary of Upgrades Required to Serve 51 GW Load
Build new overhead 345 kV line from Surowiec – Timber Swamp – Ward Hill, 110 miles
Build a new partially-overhead/partially-underground 345 kV line from Ward Hill - Wakefield Junction – Mystic, 22.4 miles overhead and 12.8 miles underground
Build third Stoughton - K St 345 kV Underground Cable, 17.5 miles underground
Rebuild ~~1,071~~ 990 miles of overhead 115 kV lines
Rebuild ~~132~~ 39 miles of overhead 345 kV lines
Additional Upgrades Required to Serve 57 GW Load
~~Build a second Timber Swamp – Ward Hill line as described above, 30 miles~~
Rebuild an additional ~~634~~ 603 miles of overhead 115 kV lines
Rebuild an additional ~~413~~ 318 miles of overhead 345 kV lines

Red-lined modifications in the table above show changes in upgrades due to wind POI relocations.

Map is for illustrative purposes only, and does not define a route for any transmission project.

Note: Rebuild mileage describes total New England rebuilds, not just North-South related upgrades.

AC Roadmap – Cost Estimates



Note: Estimated costs are New England-wide totals

DC Roadmap – Original

Summary of Upgrades Required to Serve 51 GW Load
Build new HVDC line from Surowiec – Mystic (assumed to be underwater cable)
Build third Stoughton - K St 345 kV Underground Cable, 17.5 miles underground
Rebuild 1029 miles of overhead 115 kV lines
Rebuild 132 miles of overhead 345 kV lines
Additional Upgrades Required to Serve 57 GW Load
Build new HVDC line from South Gorham – Tewksbury
Rebuild an additional 621 miles of overhead 115 kV lines
Rebuild an additional 436 miles of overhead 345 kV lines

Map is for illustrative purposes only, and does not define a route for any transmission project.

- Large portions of the HVDC lines could feasibly be placed overhead, underground, or submarine, leading to more siting flexibility than with AC
- Onshore AC/DC converters at each terminal will add cost, but may bring voltage control and stability benefits to the grid

Note: Rebuild mileage describes total New England rebuilds, not just North-South related upgrades.

DC Roadmap – After Relocation

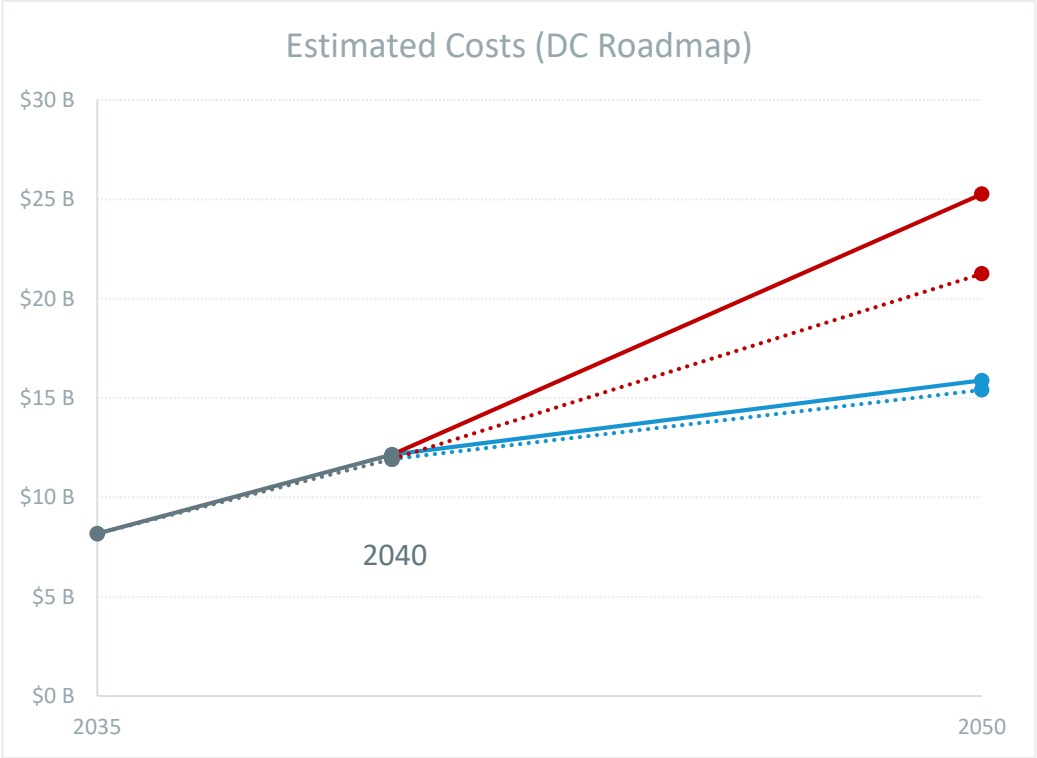
Summary of Upgrades Required to Serve 51 GW Load
Build new HVDC line from Surowiec – Mystic (assumed to be underwater cable)
Build third Stoughton - K St 345 kV Underground Cable, 17.5 miles underground
Rebuild ~~1029~~ 1006 miles of overhead 115 kV lines
Rebuild ~~132~~ 73 miles of overhead 345 kV lines
Additional Upgrades Required to Serve 57 GW Load
~~Build new HVDC line from South Gorham – Tewksbury~~
Rebuild an additional ~~621~~ 594 miles of overhead 115 kV lines
Rebuild an additional ~~436~~ 311 miles of overhead 345 kV lines

Red-lined modifications in the table above show changes in upgrades due to wind POI relocations.

Map is for illustrative purposes only, and does not define a route for any transmission project.

Note: Rebuild mileage describes total New England rebuilds, not just North-South related upgrades.

DC Roadmap

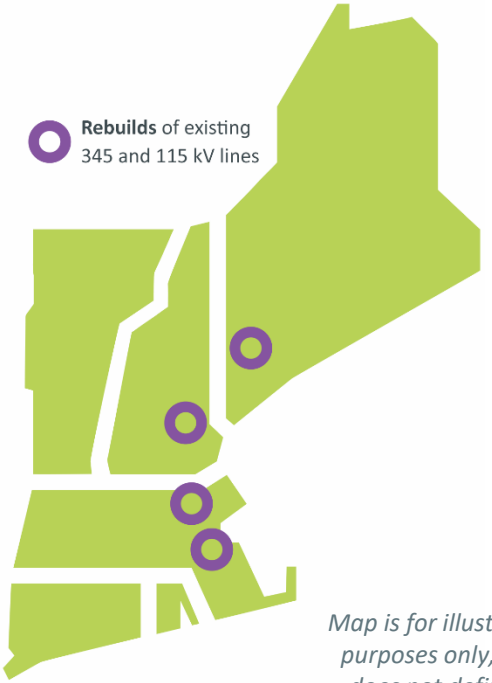


Note: Estimated costs are New England-wide totals

Minimization of New Lines Roadmap – Original

Summary of Upgrades Required to Serve 51 GW Load
Build a new partially-overhead/partially-underground 345 kV line from Ward Hill - Wakefield Junction – Mystic, 22.4 miles overhead and 12.8 miles underground
Build third Stoughton - K St 345 kV Underground Cable, 17.5 miles underground
Rebuild 1150 miles of overhead 115 kV lines
Rebuild 402 miles of overhead 345 kV lines
Additional Upgrades Required to Serve 57 GW Load
A 57 GW peak cannot be served for this roadmap without building additional new transmission

- Two new lines/cables are still required for this option due to a significant number of underground cable overloads in Boston
- Rebuilds alone cannot successfully serve a 57 GW winter peak load along the North-South and Boston Import interfaces
- This roadmap is more likely to require extra upgrades for voltage/stability concerns since fewer new lines are being added



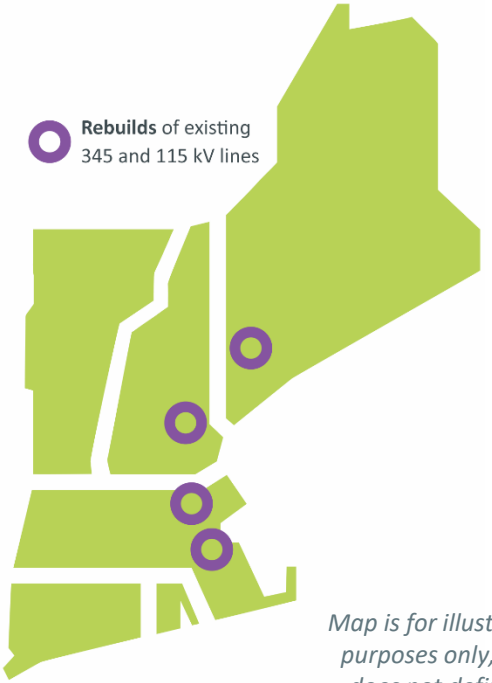
Map is for illustrative purposes only, and does not define a route for any transmission project.

Note: Rebuild mileage describes total New England rebuilds, not just North-South related upgrades.

Minimization of New Lines Roadmap – After Relocation

Summary of Upgrades Required to Serve 51 GW Load
Build a new partially-overhead/partially-underground 345 kV line from Ward Hill - Wakefield Junction – Mystic, 22.4 miles overhead and 12.8 miles underground
Build third Stoughton - K St 345 kV Underground Cable, 17.5 miles underground
Rebuild ~~1150~~ 1064 miles of overhead 115 kV lines
Rebuild ~~402~~ 198 miles of overhead 345 kV lines
Additional Upgrades Required to Serve 57 GW Load
~~A 57 GW peak cannot be served for this roadmap without building additional new transmission~~
57 GW peak is now able to be served
Rebuild an additional 565 miles of overhead 115 kV lines
Rebuild an additional 342 miles of overhead 345 kV lines

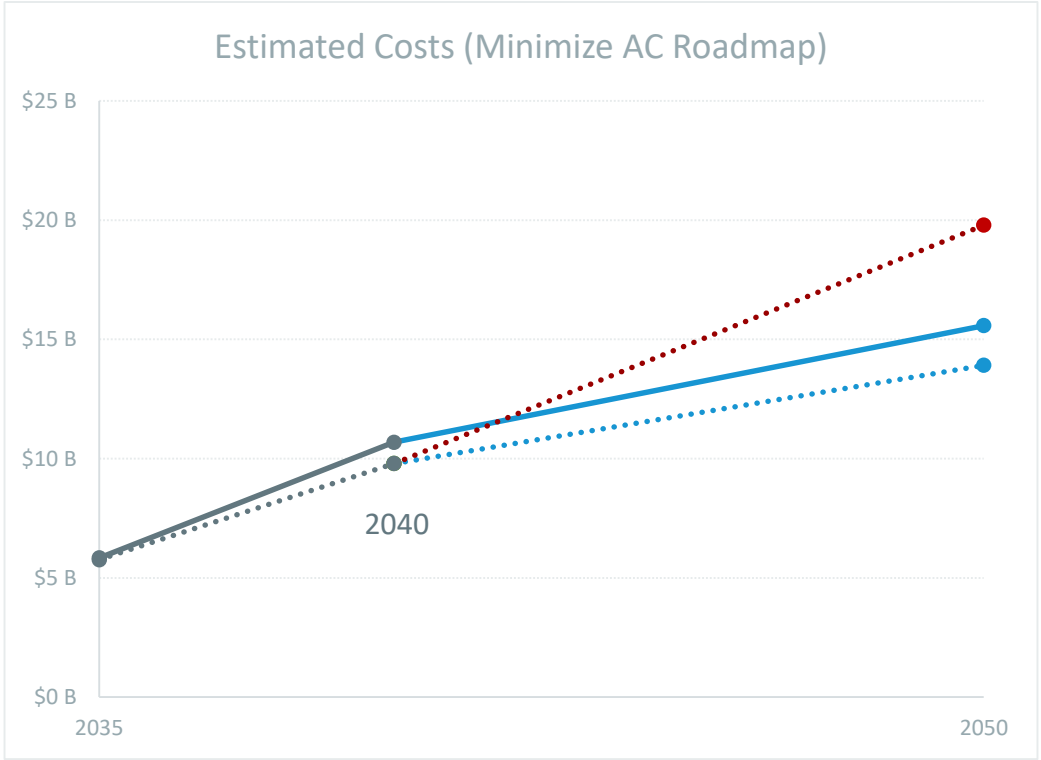
Red-lined modifications in the table above show changes in upgrades due to wind POI relocations.



Map is for illustrative purposes only, and does not define a route for any transmission project.

Note: Rebuild mileage describes total New England rebuilds, not just North-South related upgrades.

Minimization of New Lines Roadmap

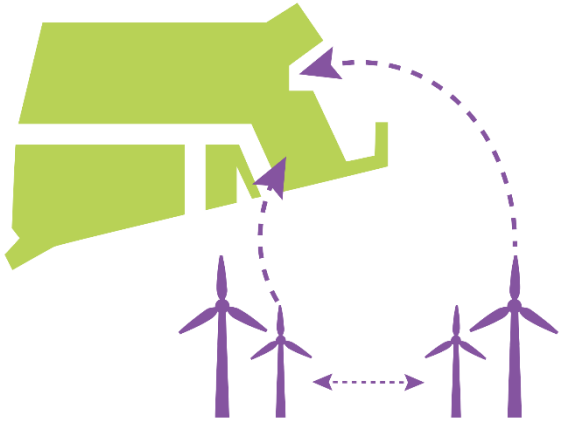


Note 1: Estimated costs are New England-wide totals

Note 2: No cost shown for 57 GW original scenario because it could not be reached without new transmission

Offshore Grid Roadmap – Changes

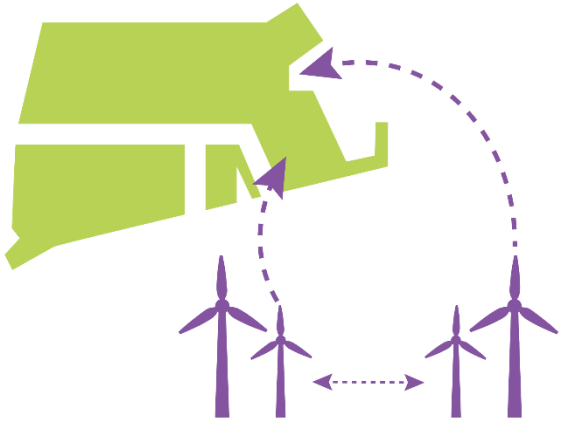
- Originally, an offshore grid was able to resolve import issues into Boston but was not sufficient to resolve the overloads seen on the Maine – New Hampshire and North – South interfaces
  - Due to this, the new AC lines from the AC Roadmap were used to resolve these northern issues, while the offshore grid was used to resolve the southern issues
- After wind relocation, the northern area of New England was able to follow the Minimization of New Lines AC Roadmap all the way through 57 GWs by rebuilding existing lines rather than building new lines, while the southern portion still utilized the offshore grid



Map is for illustrative purposes only, and does not define a route for any transmission project.

Offshore Grid Roadmap – Original

Summary of Upgrades Required to Serve 51 GW Load
Build new overhead 345 kV line from Surowiec – Timber Swamp – Ward Hill, 110 miles
345 kV line reconfiguration with the 375 and 3038
Build 3-terminal offshore network by building one HVDC link from Brayton Point Wind – K St Wind and another from K St Wind – Mystic Wind
Build 2-terminal offshore connection with an HVDC link between Montville Wind and Woburn Wind
Build 2-terminal offshore connection with an HVDC link between West Farnum Wind and Brighton Wind
Rebuild 1008 miles of overhead 115 kV lines
Rebuild 97 miles of overhead 345 kV lines
Additional Upgrades Required to Serve 57 GW Load
Build a second Timber Swamp – Ward Hill line as described above, 30 miles
Rebuild an additional 642 miles of overhead 115 kV lines
Rebuild an additional 499 miles of overhead 345 kV lines



Map is for illustrative purposes only, and does not define a route for any transmission project.

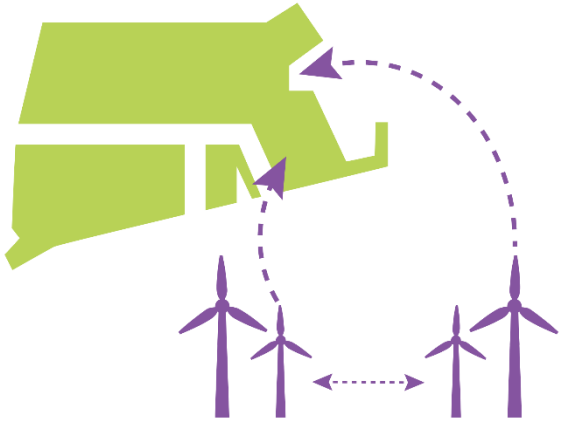
- Primary components are new HVDC connections between offshore wind farms
  - It is assumed that the links from wind farm to shore are already built as part of the generator interconnection
- Each offshore – offshore link was assumed to be 20 miles in length
- During periods of low wind availability, these connections would allow utilization of offshore wind transmission leads for power transfer between points onshore
- Beyond what is modeled in the 2050 Transmission Study, these grids could be expanded to include connections to New York, PJM, or other neighboring areas

Note: Rebuild mileage describes total New England rebuilds, not just North-South related upgrades.

Offshore Grid Roadmap – After Relocation

Summary of Upgrades Required to Serve 51 GW Load
~~Build new overhead 345 kV line from Surowiec – Timber Swamp – Ward Hill, 110 miles~~
~~345 kV line reconfiguration with the 375 and 3038~~
Build 3-terminal offshore network by building one HVDC link from Brayton Point Wind – K St Wind and another from K St Wind – Mystic Wind
Build 2-terminal offshore connection with an HVDC link between Montville Wind and Woburn Wind
Build 2-terminal offshore connection with an HVDC link between West Farnum Wind and Brighton Wind
Rebuild ~~1008~~ 973 miles of overhead 115 kV lines
Rebuild ~~97~~ 88 miles of overhead 345 kV lines
Additional Upgrades Required to Serve 57 GW Load
~~Build a second Timber Swamp – Ward Hill line as described above, 30 miles~~
Rebuild an additional ~~642~~ 638 miles of overhead 115 kV lines
Rebuild an additional ~~499~~ 495 miles of overhead 345 kV lines

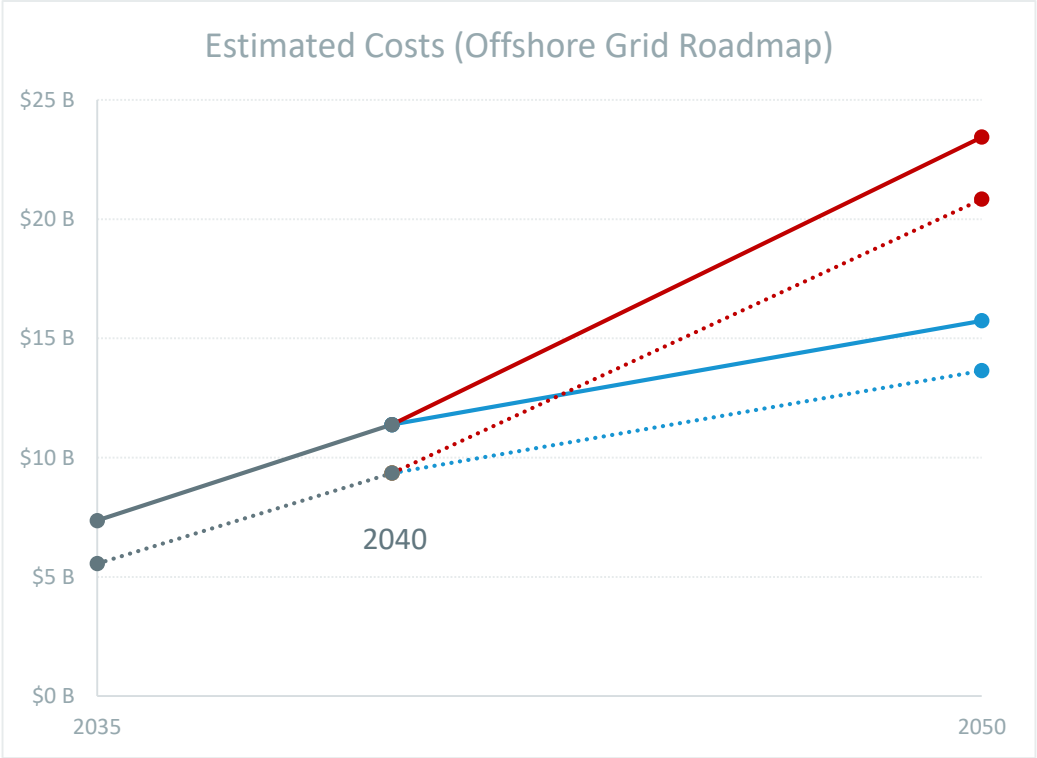
Red-lined modifications in the table above show changes in upgrades due to wind POI relocations.



Map is for illustrative purposes only, and does not define a route for any transmission project.

Note: Rebuild mileage describes total New England rebuilds, not just North-South related upgrades.

Offshore Grid Roadmap



Note: Estimated costs are New England-wide totals

Summary of Final Costs

Year/Load Level	Maximum Load Served (MW)	Original Total Cost Range ($)	After Relocation Total Cost Range ($)	Roadmap	Original Scenario -Total Cost ($B)	After Relocation – Total Cost ($B)	Cost Savings ($B)	Cost Savings (%)
2035	35,000	**$6-9 Billion**	**$5-9 Billion**	**AC**	$7.6	$7.7	-$0.1	-1.32%
				DC	$8.2	$8.2	$0	0.12%
				Minimize AC	$5.8	$5.8	$0.1	1.32%
				Offshore Grid	$7.4	$5.6	$1.8	24.54%
2040	43,000	**$10-13 Billion**	**$9-12 Billion**	**AC**	$11.8	$11.4	$0.4	3.69%
				DC	$12.1	$11.9	$0.2	1.81%
				Minimize AC	$10.7	$9.8	$0.9	8.38%
				Offshore Grid	$11.4	$9.4	$2	17.86%
2050 51 GW	51,000	**$15-17 Billion**	**$13-16 Billion**	**AC**	$15.5	$14.5	$1	6.21%
				DC	$15.9	$15.4	$0.5	2.95%
				Minimize AC	$15.6	$13.9	$1.7	10.62%
				Offshore Grid	$15.7	$13.6	$2.1	13.29%
2050 57 GW	57,000	**$22-26 Billion**	**$19-22 Billion**	**AC**	$22.6	$20.5	$2.2	9.55%
				DC	$25.3	$21.2	$4	15.86%
				Minimize AC	N/A	$19.8	N/A	N/A
				Offshore Grid	$23.4	$20.8	$2.6	11.13%

Note: Estimated costs are New England-wide totals and they are rounded to the nearest tenth billion. More details are available in the appendix.

CONCLUSION

Conclusion

- Moving some wind POIs out of northern New England and closer to load in southern New England can lead to transmission cost savings
- Even with the wind relocation, upgrades are still needed on the North-South and Maine-New Hampshire interfaces
- Location of offshore wind POIs are important, and results can vary significantly based on these locational choices
  - The offshore wind POI screening analysis will be one important step towards refining assumptions around offshore wind POIs
  - Optimizing these POIs across states can have significant benefits

FEEDBACK AND NEXT STEPS

Feedback and Next Steps

- Feedback on this portion of ISO-NE's analysis is welcome
  - Please submit feedback to pacmatters@iso-ne.com by May 3rd, 2024
- Next Steps:
  - Perform Offshore Wind POI Screening and Constraint Identification analysis
  - Publish a summary of results in Q3 2024

Questions

APPENDIX

Previous 2050 Study Presentations & Reports

- November 2021: Preliminary Assumptions & Methodology
- March 2022: Preliminary N-1 and N-1-1 Thermal Results
- April 2022: Sensitivity Results and Solution Development Plans
- July 2022: Updated Results and Approximate Frequency of Overloads
- December 2022: Solution Development Update
- April 2023: Solution Development Update
- July 2023: Key Takeaways and Transmission Development Roadmaps
- October 2023: Final Results and Estimated Costs
- February 2024: Final Report, Fact Sheet, and Technical Appendix (CEII access required)
- March 2024: Further Analysis to Address Comments on Study

AC Roadmap – Cost Estimates

	Original				After Relocation			
	2035	2040	2050 51GW	2050 57GW	2035	2040	2050 51GW	2050 57GW
Miles of 115kV Rebuild	216	631	1071	1705	236	628	990	1593
Miles of 345kV Rebuild	0	76	132	545	0	6	39	357
Total Cost of Rebuilds (Millions)	$1,080	$3,611	$6,147	$11,795	$1,180	$3,176	$5,184	$10,107
Total Cost of Projects (Millions)	$6,480	$8,178	$9,361	$10,831	$6,480	$8,178	$9,361	$10,358
Total Cost (Millions)	$7,560	$11,789	$15,508	$22,626	$7,660	$11,354	$14,545	$20,465
Cost Savings (Millions)					**-$100**	**$435**	**$963**	**$2,161**

- Project costs are associated with projects related to the AC Roadmap
- Rebuild mileage is across the system
- After relocation, the following project was avoided:
  - Second 345kV Timber Swamp – Ward Hill Line ($472.86M)

Note: See the October PAC Presentation for specific cost estimate information.

DC Roadmap

	Original				After Relocation			
	2035	2040	2050 51GW	2050 57GW	2035	2040	2050 51GW	2050 57GW
Miles of 115kV Rebuild	223	586	1029	1650	221	590	1006	1600
Miles of 345kV Rebuild	0	76	132	568	0	36	73	384
Total Cost of Rebuilds (Millions)	$1,115	$3,386	$5,937	$11,658	$1,105	$3,166	$5,468	$10,304
Total Cost of Projects (Millions)	$7,064	$8,762	$9,945	$13,594	$7,064	$8,762	$9,945	$10,942
Total Cost (Millions)	$8,179	$12,148	$15,882	$25,252	$8,169	$11,928	$15,413	$21,246
Cost Savings (Millions)					**$10**	**$220**	**$469**	**$4,005**

- Project costs are associated with projects related to the DC Roadmap
- Rebuild mileage is across the system
- After relocation, the following project was avoided:
  - South Gorham – Tewksbury DC Line ($2,651M)

Note: See the October PAC Presentation for specific cost estimate information.

Minimization of New Lines Roadmap

	Original				After Relocation			
	2035	2040	2050 51GW	2050 57GW	2035	2040	2050 51GW	2050 57GW
Miles of 115kV Rebuild	237	678	1150	N/A	236	620	1064	1629
Miles of 345kV Rebuild	31	179	402	N/A	19	78	198	540
Total Cost of Rebuilds (Millions)	$1,371	$4,464	$8,162	N/A	$1,294	$3,568	$6,508	$11,385
Total Cost of Projects (Millions)	$4,470	$6,227	$7,410	N/A	$4,470	$6,227	$7,410	$8,407
Total Cost (Millions)	$5,841	$10,691	$15,572	N/A	$5,764	$9,795	$13,918	$19,792
Cost Savings (Millions)					**$77**	**$896**	**$1,654**	**N/A**

- Project costs are associated with projects related to the Minimization of New Lines Roadmap
- After relocation, serving a 57 GW load was achievable
- The ISO is unable to make cost comparisons for the 2050 57 GW case because it was not previously attainable

Note: See the October PAC Presentation for specific cost estimate information.

Offshore Grid Roadmap

	Original				After Relocation			
	2035	2040	2050 51GW	2050 57GW	2035	2040	2050 51GW	2050 57GW
Miles of 115kV Rebuild	237	647	1008	1650	211	602	973	1611
Miles of 345kV Rebuild	0	46	97	596	31	55	88	583
Total Cost of Rebuilds (Millions)	$1,185	$3,511	$5,622	$11,826	$1,241	$3,340	$5,393	$11,553
Total Cost of Projects (Millions)	$6,178	$7,876	$10,119	$11,612	$4,315	$6,013	$8,256	$9,276
Total Cost (Millions)	$7,363	$11,387	$15,741	$23,438	$5,556	$9,353	$13,649	$20,829
Cost Savings (Millions)					**$1,807**	**$2,034**	**$2,092**	**$2,609**

- Project costs are associated with projects related to the Offshore Grid Roadmap
- After relocation, the following projects were avoided:
  - Surowiec – Timber Swamp – Ward Hill 345kV Line + ME Yankee – Buxton 345kV Line Reconfiguration ($1,863M)
  - Doubling Timber Swamp – Ward Hill 345kV ($473M)

Note: See the October PAC Presentation for specific cost estimate information.