2050 Transmission Study

Preliminary Assumptions and Methodology for the 2050 Transmission Study Scope of Work - Revision 2

Revision to the November 17, 2021 Presentation

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Overview

- Background
- Longer-Term Planning and 2050 Transmission Study
- Objectives
- Snapshots determination
- Assumptions
  - Transmission topology
  - Load modeling
  - Resource modeling
  - Energy storage
  - Inter-area ties
- Resource adequacy
- Study methodology and deliverables
- Schedule and next steps

BACKGROUND

Background

- In October 2020, the New England States Committee on Electricity (NESCOE) released the "*New England States' Vision for a Clean, Affordable, and Reliable 21st Century Regional Electric Grid*"
  - One of the recommendations in the vision statement was for ISO-NE to conduct a comprehensive long-term regional transmission planning study to inform all stakeholders of the amount and type of transmission infrastructure needed to cost-effectively integrate clean energy resources and DERs across the region to meet New England states' energy policy requirements and goals
- The ISO has coordinated with NESCOE to fulfill this recommendation and to develop objectives and assumptions for the 2050 Transmission Study presented today

Longer-Term Planning and 2050 Transmission Study

- The ISO is proposing to revise Attachment K of the ISO New England Open Access Transmission Tariff (OATT) to incorporate the Longer-Term Planning process primarily focused beyond the current ten-year planning horizon to produce information in connection with meeting New England states' energy policy requirements and goals

- The 2050 Transmission Study is the first effort undertaken in the Longer-Term Planning process

- The Longer-Term Planning process allows the ISO to implement a state-led, proactive scenario-based planning process for longer-term analysis of state mandates and policies as a routine planning practice

- As with all other studies presented to the PAC, stakeholder feedback is an integral part of the process
  - The ISO, through discussions with NESCOE given the study purpose and focus on state laws and policies, will consider PAC feedback and finalize scope of work

OBJECTIVES

Study Objectives

- Given the future load and resource scenarios described in the *"New England States' Vision for a Clean, Affordable, and Reliable 21st Century Regional Electric Grid,"* determine the following for the years 2035, 2040 and 2050:
  - Transmission needs in order to serve load while satisfying NERC, NPCC, and ISO-NE reliability criteria
  - Transmission upgrade "roadmaps" to satisfy those needs considering both constructability and cost
- The future load and resource assumptions will be based on the "All Options" pathway in the "*Energy Pathways to Deep Decarbonization*" report, which is also the basis for Scenario 3 in NEPOOL's 2021 Economic Study – Future Grid Reliability Study (FGRS) Phase I
  - This data shall be referred to as the "All Options Pathway" data in this presentation

Practical Considerations to Meet the Objectives

- The analysis will be restricted to thermal steady-state analysis
  - DC contingency analysis will be used to identify thermal constraints and develop transmission upgrades
    - This analysis is expected to identify potential major transmission line additions
  - Voltage and transient stability analysis may be considered as part of future assessments
    - Requires additional data and assumptions
    - Violations are typically solved with substation upgrades that require minimal siting

Practical Considerations to Meet the Objectives, cont.

- “Snapshots” of future scenarios for the study years will be developed to represent boundary conditions for the study years
  - A snapshot is a combination of load and resources from the All Options Pathway data for contingency analysis
  - The boundary conditions represent the worst expected cases, such as 90/10 Summer Peak in transmission planning studies
  - The snapshots capture the highest load periods with low renewable energy output
    - These conditions are expected to be the most severe for serving load
    - Additional criteria violations observed for other system snapshots that are combinations of high renewable energy output and/or lower load levels may be addressed through means other than new transmission lines, including substation upgrades and curtailment of resources

Focus of this Presentation

- The following slides discuss how the All Options Pathway data translates into specific snapshots
- This presentation also discusses other assumptions made in assembling the models for the 2050 Transmission Study

SNAPSHOT DETERMINATION

Snapshot Identification

- The snapshots were identified based on the All Options Pathway load levels for the study years
- The All Options Pathway load data was based on the 2012 weather year, and to be consistent with the FGRS,* the data was recast to the 2019 weather year data
- The hourly load profiles, available in the All Options Pathway load data, were utilized to identify the snapshots
  - The 2040 and 2050 hourly profiles were directly available
  - The 2035 hourly profile was created by averaging 2030 and 2040
  - Load profiles include the impact of energy efficiency and exclude the impact of behind-the-meter Photovoltaics (PV)

* See slide 11 of FGRS assumptions part 1 presentation for reasons for selecting 2019 weather year
https://www.iso-ne.com/static-assets/documents/2021/04/a8_2021_economic_study_request_assumptions_part_1_rev2_clean.pdf

Snapshots of Interest

- The hourly load data for 2035, 2040, and 2050 was reviewed, and peak load hours were found to occur in the following timeframes

Snapshot	Months	Hours
Summer Daytime Peak	May – September	9 AM to 5 PM
Summer Evening Peak	May – September	7 PM to 10 PM
Winter Evening Peak*	January – April	4 PM to 10 PM

- A minimum load level is not included at this time
  - DC contingency analysis only finds thermal violations and the primary concerns at minimum load level are high voltages
  - Curtailments could be used at minimum load levels to avoid any thermal issues

*Winter daytime peak load will not be tested because the daytime loads in winter are lower than the evening loads

Snapshots of Interest, Cont.

- The review of All Options Pathway hourly load data resulted in three snapshots for each study year based on the highest coincident loads in New England:
  - New England Winter Peak
  - New England Summer Daytime Peak
  - New England Summer Evening Peak
- A single winter peak snapshot for all states will be studied as the New England coincident load was found to be highly correlated with each states' peak load for the winter evening peak
- Since the summer peak load in the northern New England states was non-coincident with the New England summer peak load, an additional snapshot will be added to each study year to cover net peak loads for ME, NH, and VT under summer peak conditions
  - While the non-coincidence of summer peak load was observed for the daytime and evening peak conditions, a single additional scenario was added to cover the northern New England summer evening peak since the net load for the evening peak was higher
- This gives a total of 12 cases to be studied (four cases each for 2035, 2040, and 2050)

ASSUMPTIONS

TRANSMISSION TOPOLOGY

Transmission Topology

- The transmission topology from the Year 10 Summer Peak Load Needs Assessment case (2031 NA case) in the 2021 Transmission Planning Base Case Library will be used. The 2031 NA case features:
  - All in-service, under construction, planned and proposed reliability projects on the ISO Project List and ISO Asset Condition List from March 2021 and known Local System Plan projects from October 2020
  - The Upper Maine and New Hampshire preferred solutions
  - A1 & B2 Reconductoring project

- Two additional sets of transmission upgrades were added to the 2031 NA case based on previous resource integration studies
  - First Cape Cod Resource Integration Study
  - Second Maine Resource Integration Study

- The summer transmission facility ratings in the 2031 NA case will be:
  - Retained for the summer snapshots
  - Replaced by the winter ratings in the winter snapshots

LOAD MODELING

Load Representation Overview

- The projected peak All Options Pathway load is significantly higher than the 2021 CELT forecasted load for 2030
  - The 2050 peak power consumption* level is over 56,000 MW and the power consumption level for 2030 per the 2021 CELT is about 27,500 MW
  - The load growth is largely due to electric vehicle (EV) charging and heating
- The All Options Pathway load is broken down into multiple categories. The 2050 Transmission Study will use two categories of load: EV load and non-EV load
  - This separation was retained to allow for evaluating the impact of modifying EV load profiles and/or curtailment of EV loads
- To restrict the scope of the 2050 Transmission Study to the development of transmission infrastructure, all loads will be modeled at substations operated at 69 kV and above
  - A significant expansion in the distribution and sub-transmission infrastructure, which is beyond the scope of this study, is also expected to facilitate the All Options Pathway loads through 2050
- The following slides discuss how the loads will be modeled

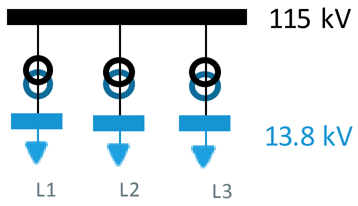
*Power consumption is load consumed by customers (load minus EE). The power consumption is assumed to include distribution losses. Behind-the-meter (BTM) PV is excluded.

Load Modeling

- All modeled loads will be initially deleted from the 2031 NA case with the following exceptions
  - Station service loads will be retained for non-retired generators
  - Maine mill loads will be modeled based on their contractual values (consistent with current practices for peak load conditions)
- New loads will be placed at each load-serving transmission substation for each snapshot using the percentage of each state's load by bus from 2019 historical data, and total state loads from the All Options Pathway data
  - The following slide describes an example

Example of Load Allocation – Substation A in RI

- Given
  - Substation A is a hypothetical substation in RI consisting of three transformers with a load at the low side of each transformer
  - The snapshot of interest from the All Options Pathway data is the winter peak which occurs on January 20, 2050 at 6 PM

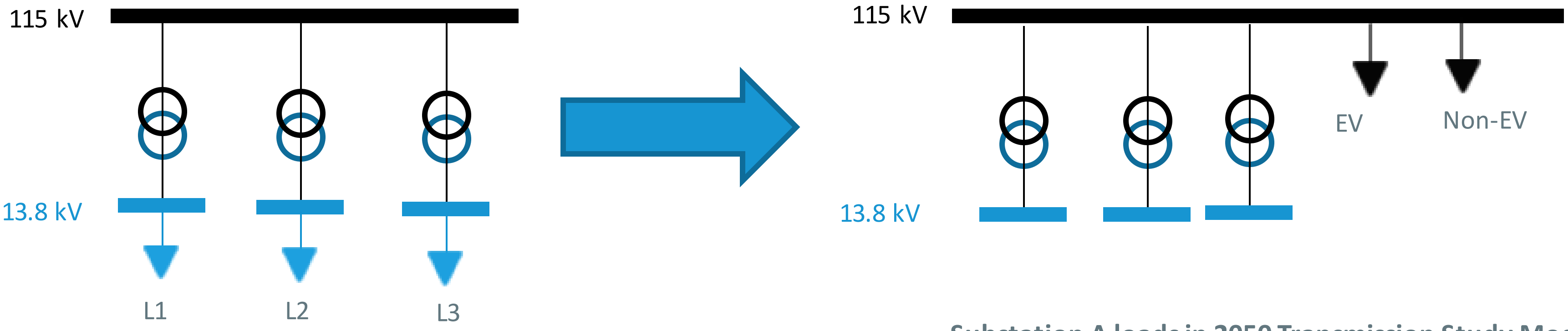


Example of Load Allocation – Substation A in RI

- Step 1: Calculate the percentage of RI load at Substation A from historical data for a similar timeframe
  - For the purposes of this example, let us assume L1+L2+L3 is 1.5% of RI load on Jan 20, 2019 at 6 PM
- Step 2: Allocate the All Options Pathway projected RI load for Jan 20, 2050 at 6 PM at Substation A using the percentage from Step 1

Example of Load Allocation – Substation A in RI

- Result
  - Two loads will be added at Substation A
    - EV load and
    - Non-EV load
  - 1.5% of total RI EV load for the hour is allocated to Substation A
  - 1.5% of total RI other non-EV loads for the hour is allocated to Substation A



Substation A loads in Current Planning Models

Substation A loads in 2050 Transmission Study Models

Total Loads in Each Snapshot

	Peak Power Consumption* by Snapshot (MW)			
	Summer Daytime Peak	Summer Evening Peak A (New England Coincident Peak)	Summer Evening Peak B (Northern New England Peak)	Winter Peak
2035	29,375	26,749	25,741	35,116
2040	32,447	32,968	31,968	43,046
2050	40,004	38,601	38,492	56,997

- The summer peak power consumption in the 2031 NA Case is:
  - 90/10 CELT Summer Peak Load – EE = 27,520 MW
- Based on CELT 2021** data, the winter peak power consumption for 2030*** is:
  - 90/10 CELT Winter Peak Load – EE = 21,938 MW

* Power Consumption is assumed to include distribution losses, and reductions due to EE, but not include transmission losses
**Comparison made with CELT data because a winter peak case was not created for the 2021 TP Base Case Library
*** 2030 was used because the CELT 2021 data only includes winter peak load and EE data through 2030

RESOURCE MODELING

Resource Data

- The All Options Pathway resource data provides nameplate MW values by state for the years 2035, 2040 and 2050 by resource type
  - Biomass
  - Combined cycle gas turbine (CCGT)
  - Combustion turbine (CT)
  - Ground-mounted photovoltaic (GM PV)
  - Hydro
  - Nuclear
  - Offshore wind fixed
  - Offshore wind floating
  - Onshore wind
  - Rooftop photovoltaic (PV)
  - Storage
- All oil, coal, diesel, and municipal solid waste (MSW) resources will be assumed retired by 2035
- The following slides discuss how the resources will be modeled by type

Generator Unit Capabilities

- Transmission planning studies utilize several maximum power ratings depending on the study type and season.* A few of the maximum power ratings are:
  - Summer Network Resource Capability (NRC)
  - Winter NRC
  - Summer Qualified Capacity (QC)

- The All Options Pathway resource data provides nameplate MW values by state for the given study year

- The 2050 Transmission Study will assume the following generator maximum power ratings assumptions
  - For summer snapshots
    - Summer QC for natural gas units since the power output for natural gas generators is more sensitive to ambient temperature than other generators
    - Summer NRC for all other resource types
  - For winter snapshots
    - Winter NRC for all natural gas units since the power output for natural gas generators can be higher at lower temperatures and is more sensitive to ambient temperature than other generators
    - Summer NRC for all other resource types

*See Section 2.3 of the Transmission Planning Technical Guide for an explanation of the maximum power ratings used by study type

Nuclear, Hydro, and Biomass

- Per the All Options Pathway data, nuclear, hydro, and biomass (non-MSW*) generators in 2035, 2040, and 2050 remain unchanged from the existing fleet
- Nuclear, hydro, and biomass (non-MSW) units in the 2031 NA case will be retained for all three study years (2035, 2040, and 2050) in the 2050 Transmission Study

State	Resource Type	2031 NA Case & 2050 Study (MW)
Connecticut	nuclear	2,217
Maine	nuclear	0
Massachusetts	nuclear	0
New Hampshire	nuclear	1,309
Rhode Island	nuclear	0
Vermont	nuclear	0
New England Total	nuclear	3,526

State	Resource Type	2031 NA Case & 2050 Study (MW)
Connecticut	hydro	136
Maine	hydro	667
Massachusetts	hydro	307
New Hampshire	hydro	573
Rhode Island	hydro	0
Vermont	hydro	131
New England Total	hydro	1,814

State	Resource Type	2031 NA Case & 2050 Study (MW)
Connecticut	biomass	44
Maine	biomass	342
Massachusetts	biomass	18
New Hampshire	biomass	246
Rhode Island	biomass	40
Vermont	biomass	82
New England Total	biomass	772

*Non-MSW includes resources with the fuel types: landfill gas, wood, and wood waste solids

Nuclear, Hydro, and Biomass Availability by Snapshot

- Nuclear and biomass will be assumed at 100% availability for all of the snapshots for the three study years
- The hydro generators dispatch in the summer peak snapshots will be consistent with ongoing practice in Needs Assessments
- Hydro generators in the winter peak snapshots will be dispatched based on historical outputs in 2019 for the winter peak load conditions

Natural Gas

- The tables below show the natural gas units
  - From the All Options Pathway data
  - Natural gas units in the 2031 NA case
- The following slide addresses necessary modifications of natural gas units in the All Options Pathway data

State	Resource Type	2031 NA Case* (MW)	All Options Pathway		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	CCGT	4,813	3,280	3,292	2,661
Maine	CCGT	1,483	1,288	1,290	1,290
Massachusetts	CCGT	5,264	5,640	5,640	5,582
New Hampshire	CCGT	1,383	1,261	1,998	1,998
Rhode Island	CCGT	2,045	1,833	2,154	2,154
Vermont	CCGT	0	530	658	658
New England Total	CCGT	14,988	13,832	15,032	14,343

State	Resource Type	2031 NA Case (MW)	All Options Pathway		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	CT	1,382	268	284	109
Maine	CT	389	3	61	61
Massachusetts	CT	1,147	657	657	532
New Hampshire	CT	424	7	94	94
Rhode Island	CT	0	3	13	13
Vermont	CT	0	240	333	294
New England Total	CT	3,342	1,178	1,442	1,103

* The CCGT totals in the 2031 NA case include the gas turbines and the steam turbines that are a part of a combined cycle plant

Natural Gas Modification from the All Options Pathway

- Vermont – the natural gas generation assumed in the All Options Pathway is brought to zero due to limited pipeline infrastructure and lack of queue activity in Vermont
- New Hampshire – projected NG growth will be modeled as additional units close to NG pipelines with retiring generators
- Rhode Island – no change from the 2031 NA case is needed as the All Options Pathway data showed only slight deviations from the 2031 NA case
- Connecticut – to maintain the total NG generation in New England from the All Options Pathway data, a slower rate of NG retirement is assumed in Connecticut
- Maine and Massachusetts – only modeling the retirements of CTs is needed
- Adjusted numbers in all states to ensure that the MW totals reflected the Summer NRCs of existing units

Natural Gas

- The following tables
  - Reflect the modifications made to the All Options Pathway Data for the natural gas units
  - Show the final Summer NRC capabilities used in the 2050 Transmission Study

State	Resource Type	2031 NA Case (MW)	2050 Transmission Study		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	CCGT	4,813	4,080	4,080	3,514
Maine	CCGT	1,483	1,483	1,483	1,483
Massachusetts	CCGT	5,264	5,264	5,264	5,264
New Hampshire	CCGT	1,383	1,383	1,989	1,989
Rhode Island	CCGT	2,045	2,045	2,045	2,045
Vermont	CCGT	0	0	0	0
New England Total	CCGT	14,988	14,255	14,861	14,295

State	Resource Type	2031 NA Case (MW)	2050 Transmission Study		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	CT	1,382	781	781	444
Maine	CT	389	67	67	67
Massachusetts	CT	1,147	745	745	745
New Hampshire	CT	424	0	94	94
Rhode Island	CT	0	0	0	0
Vermont	CT	0	0	0	0
New England Total	CT	3,342	1,593	1,687	1,350

Natural Gas Availability by Snapshot

- Natural Gas resources will assume 100% availability for all snapshots for the three study years

Rooftop PV and Ground-Mounted PV

- The tables below show the Rooftop PV and Ground-Mounted (GM) PV from the All Options Pathway data that will be used without modification in the 2050 Transmission Study
- All Rooftop PV will be modeled as negative loads (similar methodology as 0-5 MW PV units in current studies)
- All GM PV will be modeled as generators (similar methodology as >20 MW in current studies)

State	Resource Type	2050 Transmission Study		
		2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	PV	2,882	3,166	3,735
Maine	PV	951	1,091	1,371
Massachusetts	PV	5,494	5,994	6,994
New Hampshire	PV	820	938	1,174
Rhode Island	PV	704	788	957
Vermont	PV	627	694	827
New England Total	PV	11,478	12,671	15,058

State	Resource Type	2050 Transmission Study		
		2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	GM PV	3,326	4,319	9,291
Maine	GM PV	3,432	3,432	3,432
Massachusetts	GM PV	1,219	4,406	16,200
New Hampshire	GM PV	3,348	5,088	8,714
Rhode Island	GM PV	48	51	1,330
Vermont	GM PV	863	1,508	2,640
New England Total	GM PV	12,236	18,804	41,607

Rooftop PV Locations

- A geographical mapping developed by ISO-NE for the TPCET Pilot Study maps rooftop PV to cities and towns in each state in New England by substation*
- Based on the town level PV at the end of 2019, the percentage of each city and town's PV at each substation 69 kV and above was calculated and scaled-up to meet the desired state totals
- The percentages calculated above will be used to apply the state totals for Rooftop PV in 2035, 2040, and 2050 on a bus-by-bus basis
  - This provides the rooftop PV nameplate at a bus

* See slides 25-26 of the presentation at https://www.iso-ne.com/static-assets/documents/2020/09/a3_transmission_planning_for_future_grid.pdf

Ground-Mounted PV Locations

- A small amount of the projected GM PV in the 2050 Transmission Study is modeled based on existing and planned PV resources modeled as generators in the 2031 NA case (1,340 MW)
- The remaining GM PV will be distributed evenly by state across transmission substations in New England in cities and towns with a population density less than 3,000 people per square mile
  - This assumption was made in recognition of the challenges to find locations for GM PV in areas with high population density

List of Towns and Cities without New GM PV

Massachusetts			Connecticut	Rhode Island	ME, NH and VT
Arlington, MA	Marblehead, MA	Springfield, MA	Ansonia, CT	Central Falls, RI	Portland, ME
Belmont, MA	Medford, MA	Stoneham, MA	Bridgeport, CT	East Providence, RI	Manchester, NH
Boston, MA	Melrose, MA	Swampscott, MA	Hartford, CT	Newport, RI	Burlington, VT
Brockton, MA	Nahant, MA	Wakefield, MA	New Britain, CT	North Providence, RI	St. Albans, VT
Brookline, MA	New Bedford, MA	Waltham, MA	New Haven, CT	Pawtucket, RI	Winooski, VT
Cambridge, MA	Newton, MA	Watertown, MA	New London, CT	Providence, RI	
Chelsea, MA	Norwood, MA	Weymouth, MA	Norwalk, CT	West Warwick, RI	
Everett, MA	Peabody, MA	Winchester, MA	Stamford, CT	Woonsocket, RI	
Hull, MA	Quincy, MA	Winthrop, MA	Waterbury, CT		
Lawrence, MA	Randolph, MA	Woburn, MA	West Haven, CT		
Lowell, MA	Revere, MA	Worcester, MA			
Lynn, MA	Salem, MA				
Malden, MA	Somerville, MA				

PV Availability by Snapshot

- The following table shows the PV availability, developed in the TPCET Pilot Study, by snapshot in the 2050 Transmission Study

Snapshot	Hours	PV Availability Assumption
Summer Daytime Peak	9 AM to 5 PM	40% of nameplate*
Summer Evening Peak	7 PM to 10 PM	10% of nameplate for Hour Ending (HE) 7PM and 0% of nameplate for HE 8PM or later**
Winter Evening Peak	4 PM to 10 PM	0% of nameplate (peak expected after sunset)

* Consistent with daytime peak low renewable scenario from TPCET – See slide 33 of https://www.iso-ne.com/static-assets/documents/2021/08/a3_transmission_planning_for_the_clean_energy_transition_pilot_study_results_and_assumption_changes.pdf

** 10% and 0% based off the TPCET assumptions for evening peak loads. It is assumed that sunset occurs sometime between 7PM and 8PM and 10% PV availability is assumed before sunset and 0% beyond sunset

Example of PV Modeling – Substation A in RI

- This example will review how rooftop PV and new GM PV will be modeled at Substation A for a daytime peak snapshot in 2050
- Consider that Substation A in RI feeds 100% of the load in Town B which has a population density that is less than 3,000 people per square mile
- Rooftop PV:
  - Total rooftop PV in 2050 in RI = 1,000 MW
  - Percentage of total RI PV in Town B at the end of 2019 = 2%
  - Amount of rooftop PV allocated to Town B = 20 MW
  - PV availability for daytime peak = 40%
  - Magnitude of negative load associated with rooftop PV = 40% of 20 MW = 8 MW

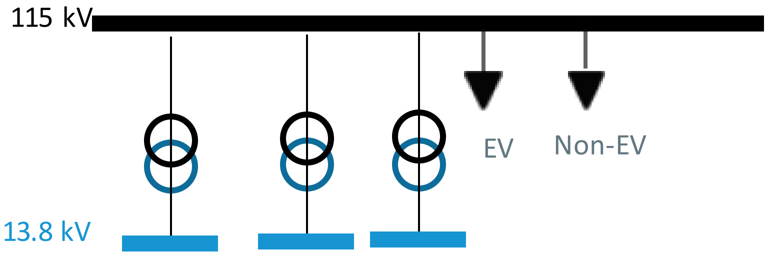
Example of PV Modeling – Substation A in RI

- GM PV:
  - Total GM PV in 2050 in RI = 700 MW
  - Existing GM PV in 2031 NA case in RI* = 100 MW
  - New GM PV in RI = 600 MW
  - Number of substations in RI that are located in towns with population density < 3,000 people per square mile = 20
  - Nameplate GM PV at each substation (including substation A) = 600/20 = 30 MW
  - PV availability for daytime peak = 40%
  - Generator Output of GM PV at Substation A = 40% of 30 MW = 12 MW

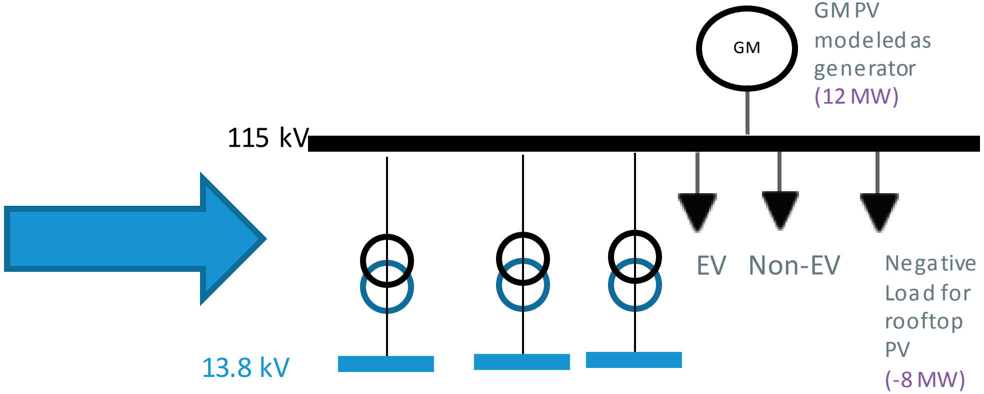
* For this example the 100 MW of existing Ground Mount PV is located at other substations in RI and not at Substation A

Example of PV Modeling – Substation A in RI

- Result of PV Modeling
  - One negative load will be added at Substation A to reflect rooftop PV
  - One generator will be added at Substation A to reflect GM PV



Substation A prior to PV Modeling



Substation A with PV Modeling – Daytime Peak

Onshore Wind

- The table below shows the onshore wind generation
  - From the All Options Pathway data
  - Onshore wind generation in the 2031 NA case
- The following slide addresses necessary modifications of onshore wind units in the All Options Pathway data

State	Resource Type	2031 NA Case (MW)	All Options Pathway		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	Onshore wind	0	16	15	16
Maine	Onshore wind	969	845	359	304
Massachusetts	Onshore wind	44	456	447	447
New Hampshire	Onshore wind	207	181	182	175
Rhode Island	Onshore wind	33	56	45	55
Vermont	Onshore wind	149	251	290	285
New England Total	Onshore wind	1,402	1,805	1,338	1,282

Onshore Wind Modification from the All Options Pathway

- Given minimal growth of onshore wind in Connecticut, Rhode Island and Massachusetts, the levels of onshore wind in the 2031 NA case will be maintained for the three study years

- The All Options Pathway data projected that NH onshore wind would decrease after 2030
  - The 2050 Transmission Study will hold the wind resources in NH constant at the 2031 NA case levels for all three study years

Onshore Wind Modification from the All Options Pathway, Cont.

- The All Options Pathway data projected that ME onshore wind would increase to 1,233 MW by 2030 then decrease through 2050
  - The 2050 Transmission Study will model 1,233 MW of onshore wind capacity for the three study years
  - An additional 1,200 MW of onshore wind will be assumed in ME based on recent legislation in Maine that seeks proposals for additional onshore wind in Aroostook County and Northern ME, bringing the onshore wind total in ME to 2,433 MW
  - The new onshore wind in Aroostook County and other parts of northern Maine will be modeled as a 1,200 MW injection at the new Pittsfield 345 kV substation, which is part of the Second Maine Resource Integration Study

Onshore Wind, Cont.

- The following table
  - Reflects the modifications made to the All Options Pathway Data for the onshore wind units
  - Shows the final nameplate capabilities that will be used in the 2050 Transmission Study

State	Resource Type	2031 NA Case (MW)	2050 Transmission Study		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	Onshore wind	0	0	0	0
Maine	Onshore wind	969	2,433	2,433	2,433
Massachusetts	Onshore wind	44	44	44	44
New Hampshire	Onshore wind	207	207	207	207
Rhode Island	Onshore wind	33	33	33	33
Vermont	Onshore wind	149	289	289	289
New England Total	Onshore wind	1,402	3,006	3,006	3,006

Onshore Wind Availability by Snapshot

- The following table shows the Onshore availability, developed in the TPCET Pilot Study, by snapshot in the 2050 Transmission Study

Snapshot	Hours	Onshore Wind Availability Assumption
Summer Daytime Peak	9 AM to 5 PM	5% of nameplate*
Summer Evening Peak	7 PM to 10 PM	5% of nameplate*
Winter Evening Peak	4 PM to 10 PM	65% of nameplate (discussed in the next slide)

* Consistent with daytime peak low renewable and summer evening peak scenario from TPCET – See slide 33 of https://www.iso-ne.com/static-assets/documents/2021/08/a3_transmission_planning_for_the_clean_energy_transition_pilot_study_results_and_assumption_changes.pdf

Onshore Wind Availability for Winter Peak Conditions

- The following table is from the DNV Report – Analysis of Stochastic Data Set, dated February 24, 2021
- The data* shows that for 95% of the hours with very low temperatures (<10° F), the onshore wind availability exceeds 63.2%
- On this basis a 65% availability was assumed for onshore wind

Table 2-14 Selected quantiles of onshore wind generation coincident to the daily load peak for New England cold snaps and heat waves

Temperature (°F)	Onshore wind (% capacity)							
	Min	P1	P5	P50	P95	P99	Max	Average daily peak load (MW)
<10[1]	61.2%	61.5%	63.2%	80.8%	87.6%	88.1%	88.3%	21,748
<15	5.9%	7.1%	9.2%	68.8%	87.4%	88.9%	90.9%	21,017
<20	4.8%	7.0%	9.4%	63.0%	85.7%	88.1%	91.0%	20,365
<32	2.3%	7.0%	13.0%	45.2%	83.9%	87.6%	92.6%	19,212
>85	1.7%	3.5%	5.2%	19.4%	44.8%	58.1%	78.7%	23,096
>90	1.9%	3.8%	6.3%	18.0%	51.2%	64.4%	76.6%	24,157
>95	6.7%	6.9%	8.1%	11.5%	25.8%	30.6%	36.6%	24,442

1 Only 14 events so use results with caution.

* The sample set for daily peaks at temperatures below 10°F is small, and using an expanded data set of hours (<15°F) would justify the use of a lower availability for winter peak. However, the higher outputs are consistent with the general trend observed by DNV that for cooler temperatures, higher wind outputs are observed. Moreover, even with the higher wind availability for the small set of hours, there are insufficient resources to meet the winter peak load in the three study years. Assuming a lower wind availability exacerbates the resource insufficiency and requires the addition of more resources to the case to meet the winter peak demand.

Offshore Wind

- The table below shows the offshore wind units (fixed and floating)
  - Modeled in the 2050 Transmission Study without modification from the All Options Pathway data
  - Comparison to the offshore wind units found in the 2031 NA case

State	Resource Type	2031 NA Case (MW)	2050 Transmission Study		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	Fixed	0	472	636	1,872
Maine	Fixed	0	59	60	67
Massachusetts	Fixed	2,474	5,845	6,656	6,681
New Hampshire	Fixed	0	190	190	410
Rhode Island	Fixed	753	485	490	468
Vermont	Fixed	0	0	0	0
New England Total	Fixed	3,227	7,051	8,032	9,498

State	Resource Type	2031 NA Case (MW)	2050 Transmission Study		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	Floating	0	0	0	0
Maine	Floating	0	902	3,015	6,933
Massachusetts	Floating	0	302	2,667	9,791
New Hampshire	Floating	0	41	714	1,177
Rhode Island	Floating	0	1,153	2,205	4,555
Vermont	Floating	0	0	0	0
New England Total	Floating	0	2,398	8,601	22,456

Interconnection Points for Offshore Wind Beyond those Included in 2031 NA Case

- New additional offshore wind units will be interconnected to 345 kV stations or major 115 kV stations that are located relatively close to the shore

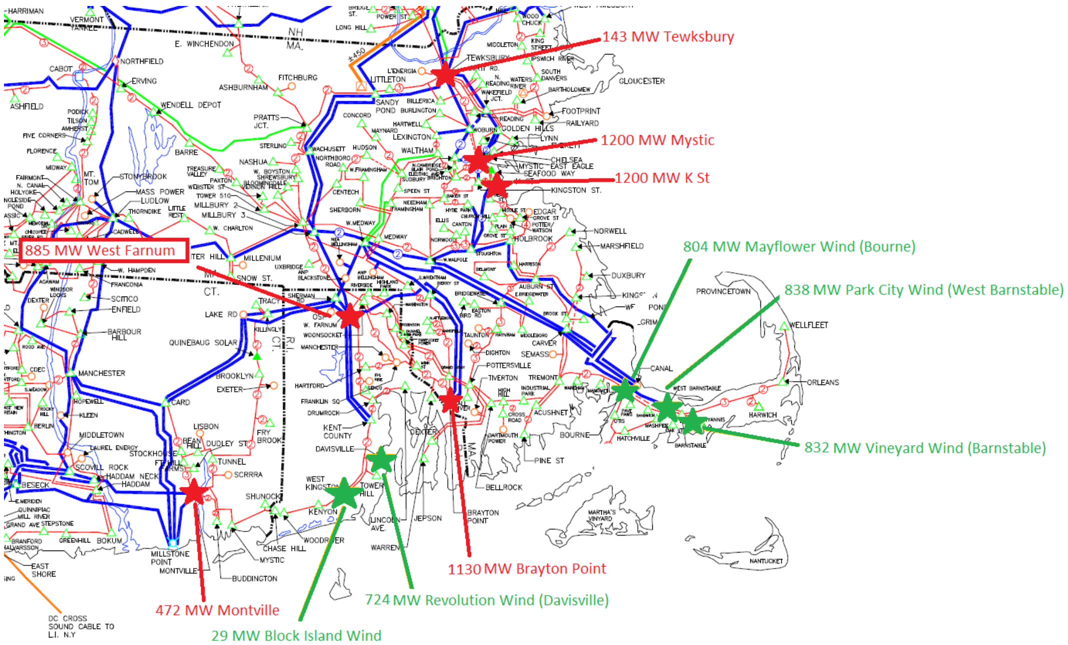
- The maximum size for a single offshore wind farm will be assumed to be 1,200 MW, with no more than 2,400 MW of offshore wind farms being interconnected to the same bus

- The locations discussed on the next slides are intended to be a starting point and may be adjusted as the study progresses
  - As an example, the transmission leads that bring the offshore wind generation onshore could be built such that the offshore wind interconnects to a more central location on the system

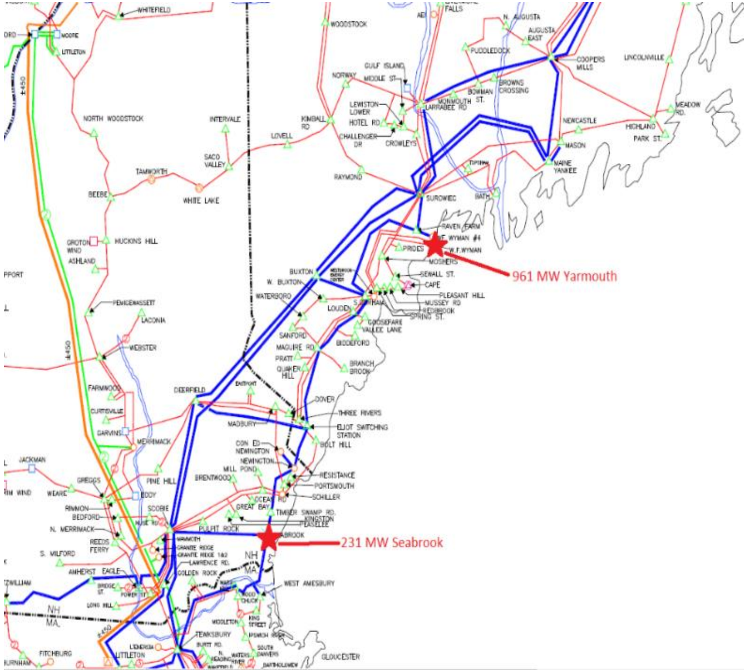
New Offshore Wind in 2035

Green = Existing/Planned

Red = New Wind Additions



NEMA/SEMA/RI/CT

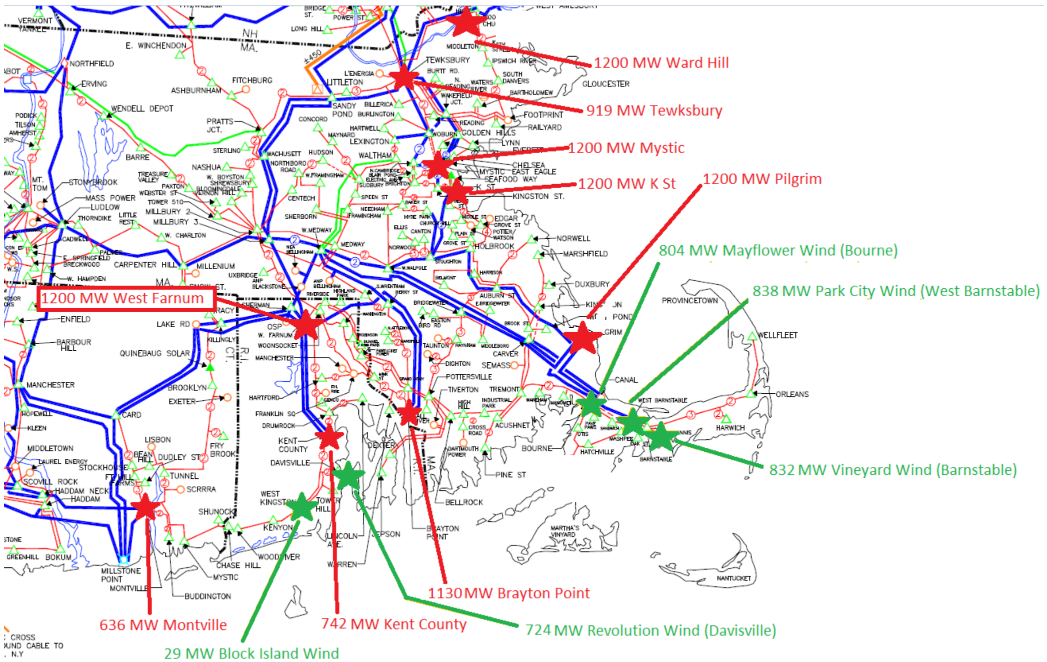


ME/NH

New Offshore Wind in 2040

Green = Existing/Planned

Red = New Wind Additions



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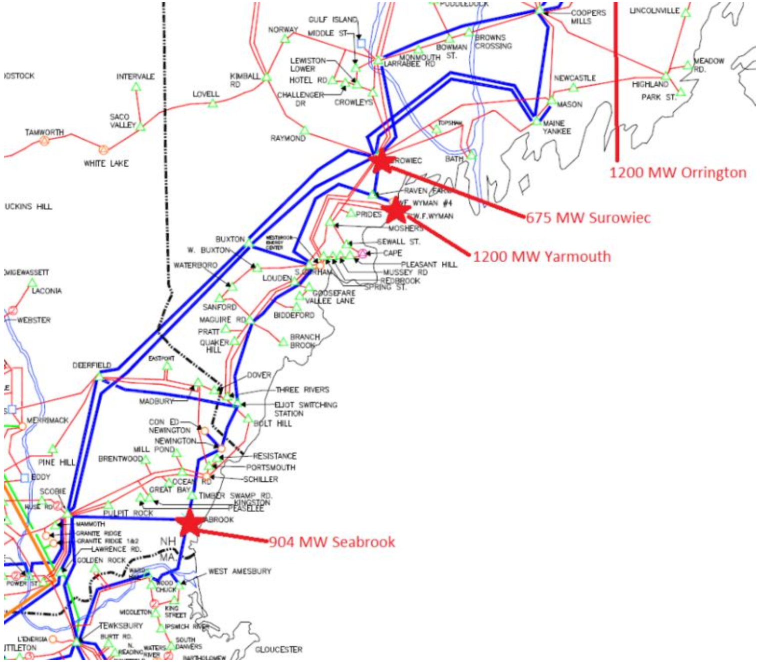
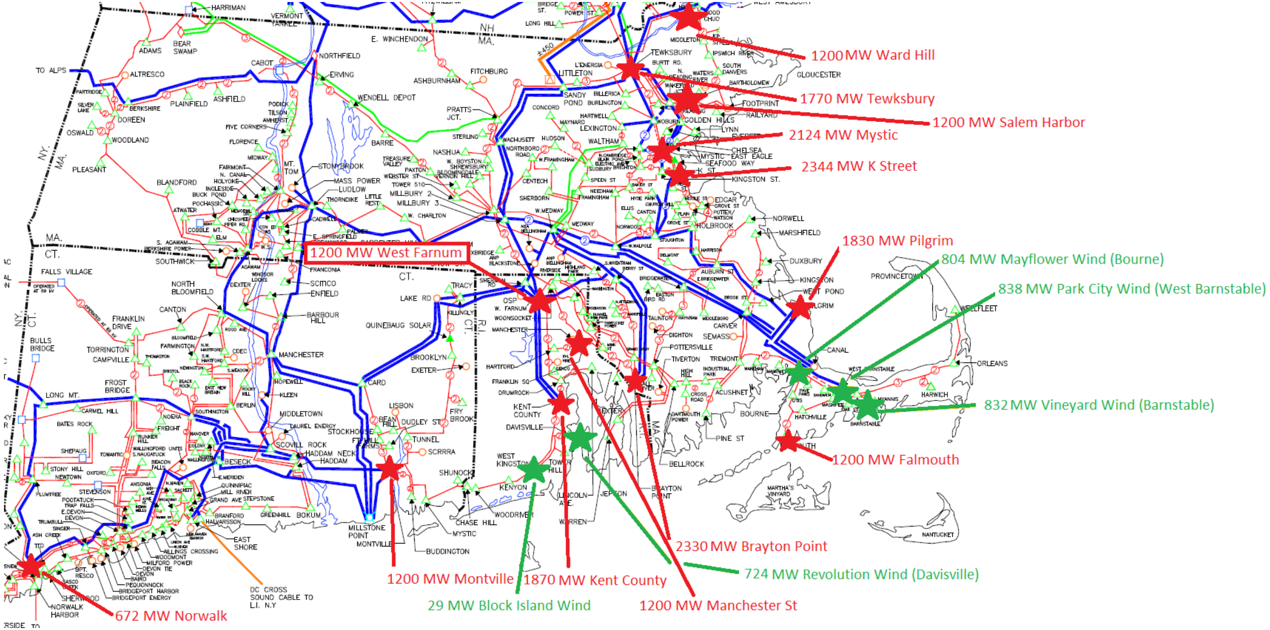


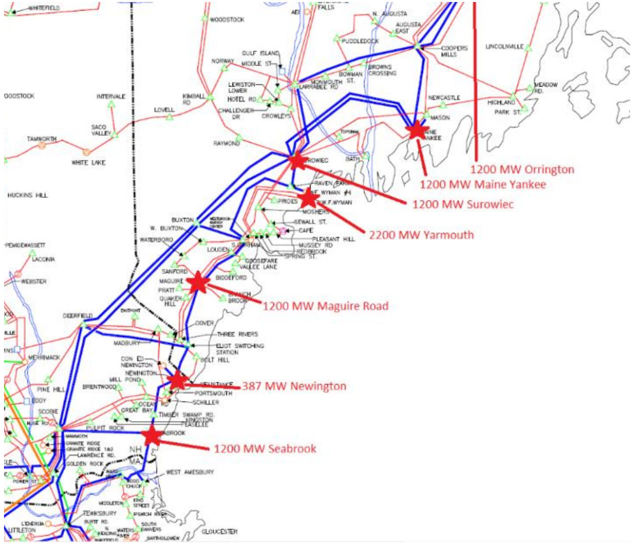
ME/NH

New Offshore Wind in 2050

Green = Existing/Planned
Red = New Wind Additions



NEMA/SEMA/RI/CT



ME/NH

Inclusion of Wind Integration Upgrades

- The study includes the upgrades from the First Cape Cod Resource Integration Study (CCIS)
  - These upgrades interconnect approximately 1,200 MW of additional offshore wind on Cape Cod
  - The upgrades include a new 345 kV substation at Falmouth and two 345 kV lines that connect the Falmouth substation to Bourne 345 kV and West Barnstable 345 kV
- The study also includes the upgrades from the Second Maine Resource Integration Study
  - These upgrades interconnect 520 MW of additional onshore wind in northern ME
  - The upgrades include a new 345 kV substation at Pittsfield, a new 345 kV line from Pittsfield to Coopers Mills and the looping-in of the Orrington to Albion Road 345 kV line into the new Pittsfield substation
- These upgrades are included primarily because they provide new interconnection points for wind resources
  - These upgrades may be modified as the study progresses

Offshore Wind Availability by Snapshot

- The following table shows the Offshore availability, developed in the TPCET Pilot Study, by snapshot in the 2050 Transmission Study. The availability assumption applies to both fixed and floating* units

Snapshot	Hours	Offshore Wind Availability Assumption
Summer Daytime Peak	9 AM to 5 PM	5% of nameplate**
Summer Evening Peak	7 PM to 10 PM	5% of nameplate**
Winter Evening Peak	4 PM to 10 PM	40% of nameplate (discussed in the next slide)

* Given that the ISO only had availability data for fixed offshore wind units, the availability data for fixed offshore wind units was used for floating offshore wind units as well
** Consistent with daytime peak low renewable and summer evening peak scenario from TPCET – See slide 33 of https://www.iso-ne.com/static-assets/documents/2021/08/a3_transmission_planning_for_the_clean_energy_transition_pilot_study_results_and_assumption_changes.pdf

Offshore Wind Availability for Winter Peak Conditions

- The following table is from the DNV Report –Analysis of Stochastic Data Set, dated February 24, 2021
- The data* shows that for 95% of the hours with very low temperatures (<10° F), the fixed offshore wind availability exceeds 39.4%
- On this basis a 40% availability was assumed for offshore wind

Table 2-15 Selected quantiles of offshore wind generation coincident to the daily load peak for New England cold snaps and heat waves

Temperature (°F)	Offshore Wind (% capacity)							
	Min	P1	P5	P50	P95	P99	Max	Average Daily Peak Load (MW)
<10[1]	37.2%	38.0%	39.4%	89.6%	93.4%	93.7%	93.8%	21,748
<15	2.3%	12.7%	18.5%	74.3%	93.1%	94.3%	96.4%	21,017
<20	0.2%	1.7%	12.1%	67.0%	92.5%	93.9%	96.5%	20,365
<32	0.2%	1.4%	4.9%	69.4%	92.5%	93.9%	97.1%	19,212
>85	0.0%	1.1%	2.2%	25.8%	87.2%	91.6%	96.4%	23,096
>90	0.2%	1.3%	2.4%	20.6%	87.5%	91.8%	96.0%	24,157
>95	1.4%	1.8%	2.1%	6.8%	65.9%	87.4%	92.6%	24,442

1 Only 14 events so use results with caution.

* The sample set for daily peaks at temperatures below 10°F is small, and using an expanded data set of hours (<15°F) would justify the use of a lower availability for winter peak. However, the higher outputs are consistent with the general trend observed by DNV that for cooler temperatures, higher wind outputs are observed. Moreover, even with the higher wind availability for the small set of hours, there are insufficient resources to meet the winter peak load in the three study years. Assuming a lower wind availability exacerbates the resource insufficiency and requires the addition of more resources to the case to meet the winter peak demand.

ENERGY STORAGE

Energy Storage

- The table below shows the storage facilities
  - From the All Options Pathway data
  - Storage units found in the 2031 NA case
- The following slide addresses necessary modifications of storage resources in the All Options Pathway data

State	Resource Type	2031 NA Case (MW)	All Options Pathway		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	Storage	0	18	401	2,282
Maine	Storage	213	12	18	46
Massachusetts	Storage	2,270	1,782	1,827	2,916
New Hampshire	Storage	0	14	55	496
Rhode Island	Storage	0	14	67	730
Vermont	Storage	0	13	44	216
New England Total	Storage	2,483	1,853	2,412	6,686

Storage Modification from the All Options Pathway Data

- The projected storage values for 2035-2050 in Maine are less than the value in the 2031 NA case
  - The 2031 NA case storage will be increased to 400 MW for the 2035, 2040, and 2050 study years
- The projected storage values for 2035 and 2040 in Massachusetts are less than the value in the 2031 NA case
  - The 2031 NA case storage will be retained in the 2035 and 2040 study years
- All planned Battery Energy Storage Systems (BESS) in the 2031 NA case were assumed to have 2 hours of energy storage
  - The planned BESS in the 2031 NA case have the ability to operate at nameplate output for 2 hours based on the data received as part of the new capacity qualification process

Summary of Storage

- The following table summarizes the assumed nameplate MW values for storage

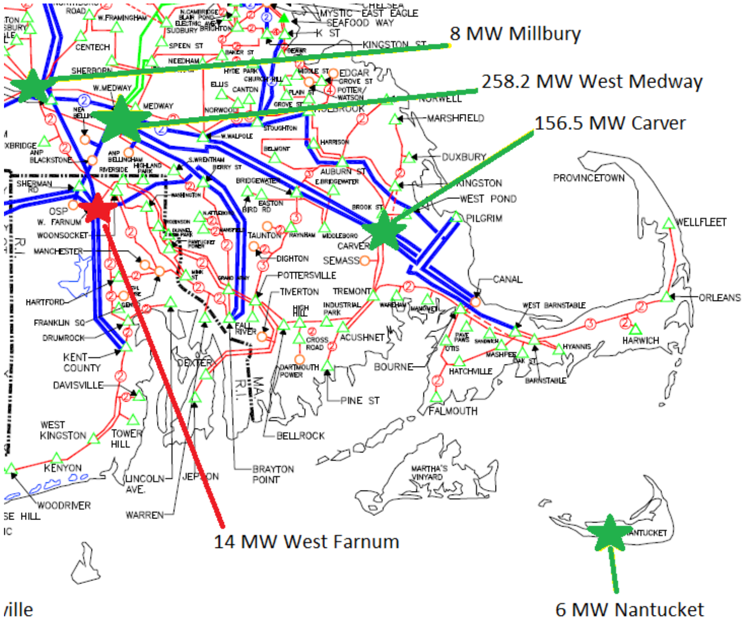
State	Resource Type	2031 NA Case (MW)	2050 Transmission Study		
			2035 (MW)	2040 (MW)	2050 (MW)
Connecticut	Storage	0	18	401	2,282
Maine	Storage	213	400	400	400
Massachusetts	Storage	2,270	2,270	2,270	2,916
New Hampshire	Storage	0	14	55	496
Rhode Island	Storage	0	14	67	730
Vermont	Storage	0	13	44	216
New England Total	Storage	2,483	2,729	3,237	7,040

Additional Details of Future Storage

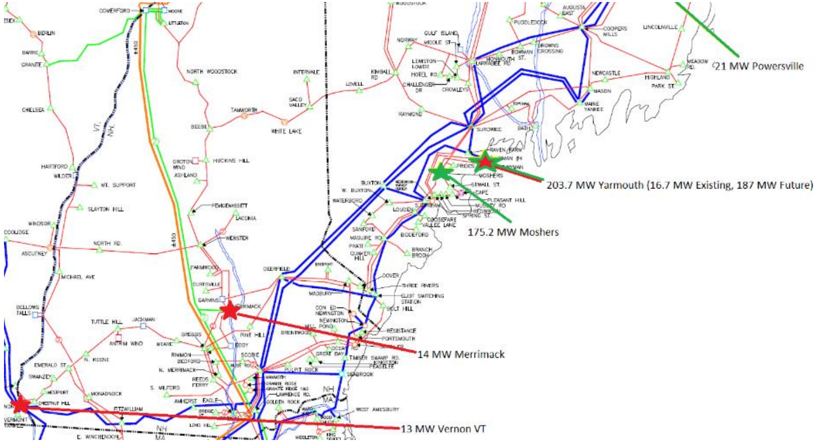
- The future storage not in the 2031 case will be modeled as 4-hour BESS
  - Consistent with the assumption for new BESS in FGRS Scenario 3
- The BESS will be located at major 345 kV stations or at generation stations with expected retirements
  - Locations closer to load centers will be prioritized

BESS in 2035

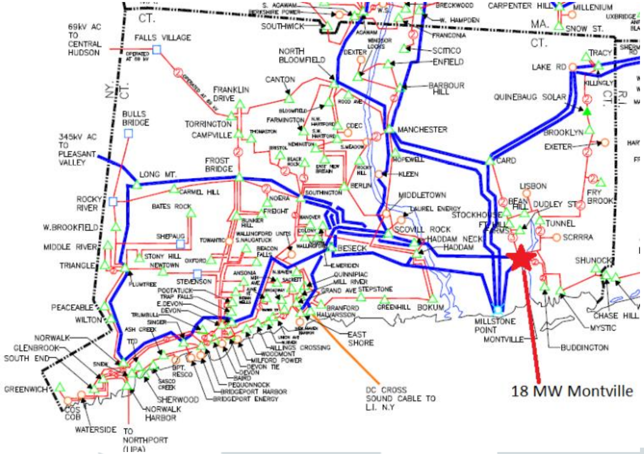
Green = Existing/Planned
Red = New Battery Additions



NEMA/SEMA/RI



ME/NH/VT

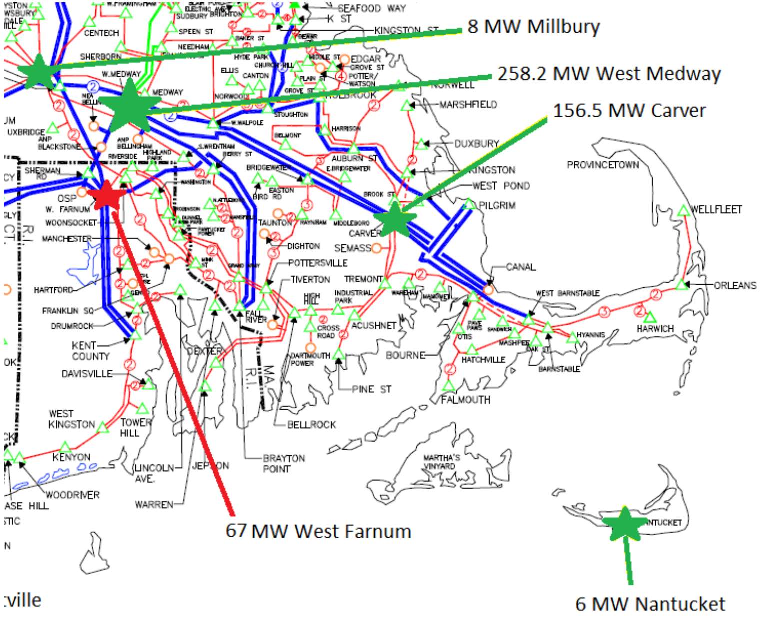


CT

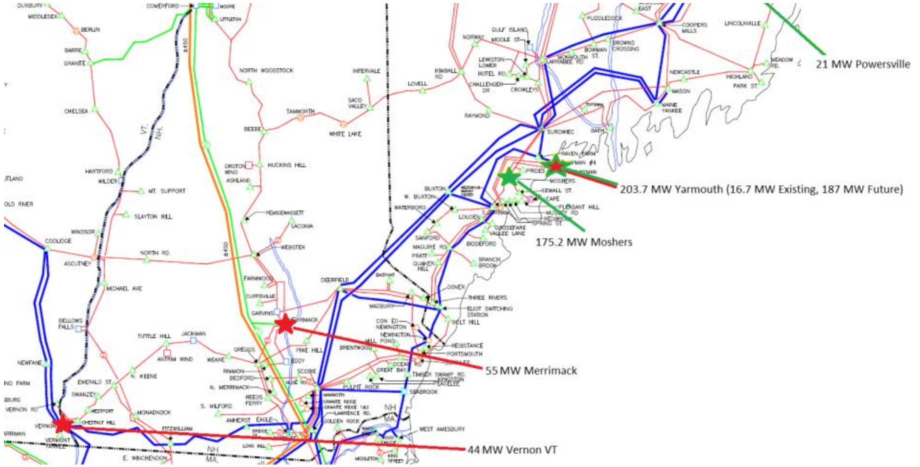
BESS in 2040

Green = Existing/Planned

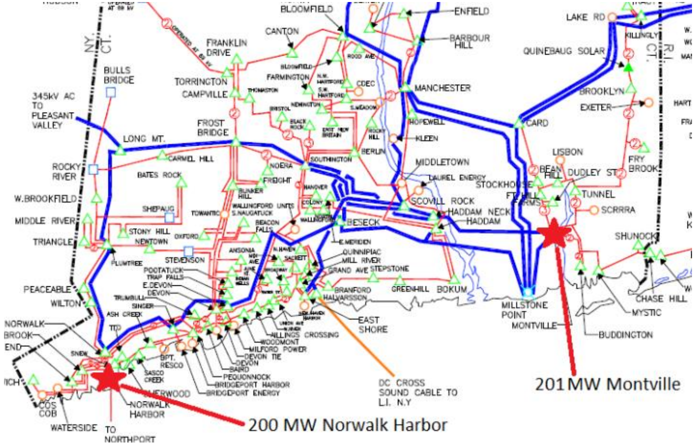
Red = New Battery Additions



NEMA/SEMA/RI



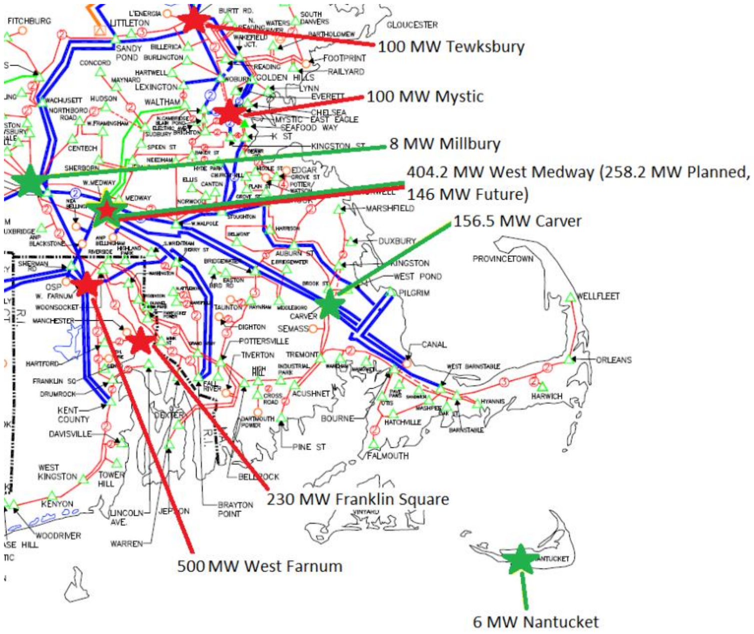
ME/NH/VT



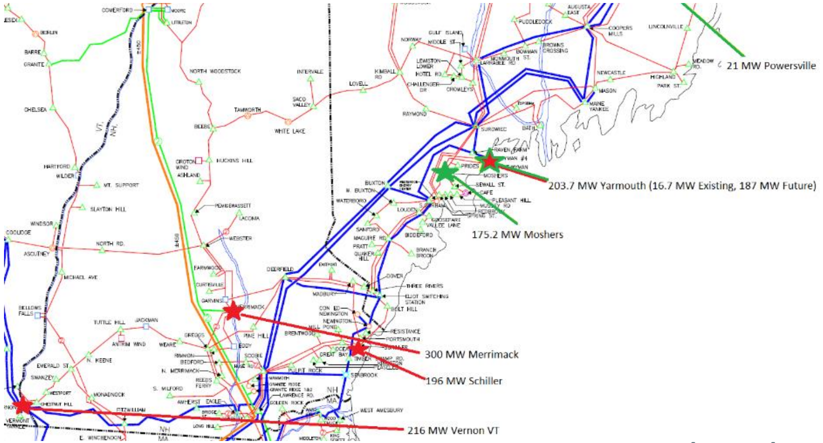
CT

BESS in 2050

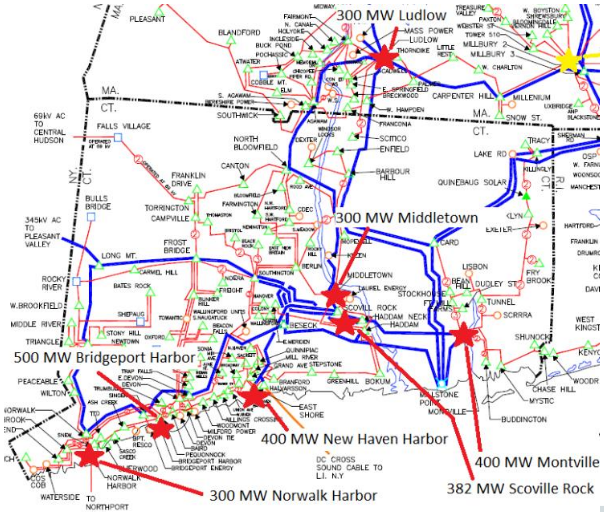
Green = Existing/Planned
Red = New Battery Additions



NEMA/SEMA/RI



ME/NH/VT



CT/WMA

BESS Availability by Snapshot

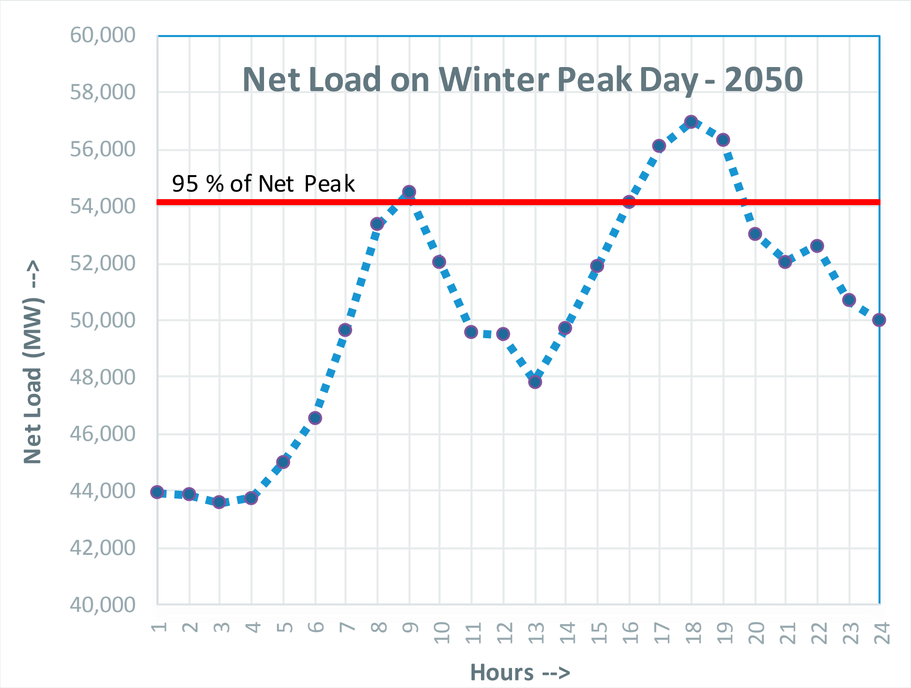
- The following table shows the BESS availability, developed in the TPCET Pilot Study, by snapshot in the 2050 Transmission Study.

Snapshot	Hours	BESS Availability Assumption
Summer Daytime Peak	9 AM to 5 PM	Offline*
Summer Evening Peak	7 PM to 10 PM	Discharging at minimum of (Nameplate MW, (MWh)/6)*
Winter Evening Peak	4 PM to 10 PM	Discharging at minimum of (Nameplate MW, (MWh)/6) (Discussion on next slide)

* Consistent with daytime peak low renewable and summer evening peak scenario in slide 19 of https://www.iso-ne.com/static-assets/documents/2021/03/a6_energy_storage_in_transmission_planning_studies.pdf

BESS at Winter Peak

- Justification for the discharge rate assumption:
  - Net load* on the winter peak day in 2050 is within 95% of its daily peak for 4-5 hours
  - One-sixth of MWh capacity reflects the observed duration of loads above 95% of daily peak and includes an additional hour to provide margin for uncertainty in battery behavior and load shapes
  - Reduction in capacity reflects the possibility of individual batteries slowly discharging throughout the peak, or the aggregate effects of many batteries quickly discharging at different times during the peak hours



*Net load = Hourly power consumption – hourly Solar PV (2019 hourly PV availability * 2050 nameplate PV)

Availability of Pumped-Storage Hydro

- The availability of Pumped-Storage Hydro Units will be similar to the availability of batteries:
  - Summer Daytime Peak – Offline
  - Summer Evening Peak – Discharging at minimum of (Pmax, MWh/6)
  - Winter Peak – Discharging at minimum of (Pmax, MWh/6)
- Known Pumped-Storage Hydro Storage Capability
  - Northfield Mountain can store up to 8,725 MWh
  - Bear Swamp can store up to 3,028 MWh

INTER-AREA TIES

Imports from Adjacent Areas

- NY-NE AC ties – 1,850 MW import from NY (450 MW increase in transfer capability per FGRS assumptions)
- NECEC – 1,200 MW
- Phase II – 1,400 MW
- NB-NE – 1,000 MW
- Highgate – 225 MW
- New DC line from Quebec into Vermont – 1,000 MW (modeled as injection at Coolidge 345 kV)

RESOURCE ADEQUACY

Resource Overview

- Sufficient resources are required to perform a transmission planning study. However, the 2050 Transmission Study does not meet this constraint for some snapshots

	Resource Insufficiency by Snapshot (MW)*,**			
	Summer Daytime Peak	Summer Evening Peak A (New England Coincident Peak)	Summer Evening Peak B (Northern New England Peak)	Winter Peak
2035	N/A	N/A	959 MW	2,705 MW
2040	N/A	2,813 MW	1,788 MW	6,844 MW
2050	N/A	3,598 MW	3,487 MW	13,407 MW

* N/A indicates that there are sufficient resources in the snapshot model. A positive value indicates insufficient capacity resources
** Transmission loss of 2.5% assumed to calculate resource insufficiency. Actual losses in cases may vary, which would impact the resource insufficiency.

Resource Insufficiency – 2050 Winter Peak Example

Resource Insufficiency = Resource Requirement – Imports - Generation

Resource Requirement (MW)	
Peak Load	56,997
Station Service + Mill Load	829
Transmission Losses (2.5%)****	1,425
Reserves*	1,400
EFORd**	0
Resource Requirement	**60,651**

Inter-area Flows	Winter Peak (MW)
NB-NE	1,000
NECEC	1,090
Phase II	1,400
NY-NE	1,850
Highgate	225
Coolidge HVDC	1,000
Total Imports	**6,565**

Generation Type	Nameplate *** (MW)	% Avail.	MW Avail. (MW)
Nuclear	3,527	100%	3,527
Biomass	773	100%	773
Natural Gas CCGT	15,062	100% of	15,062
Natural Gas CT	1,376	Winter NRC	1,376
Hydro - RR	528	historical	358
Hydro - Pondage	1,275	historical	621
Hydro – Pumped Storage	1,841	Energy	979
BESS	5,198	storage assumption	3,248
Rooftop PV	15,058	0%	0
Ground Mounted PV	39,153	0%	0
Onshore Wind	3,006	65%	1,954
Offshore Wind - Fixed	9,498	40%	3,799
Offshore Wind - Floating	22,456	40%	8,982
Total Generation			**40,679**

2050 Winter Peak Resource Insufficiency = 60,651 MW – 6,565 MW – 40,679 MW = 13,407 MW

*The reserves in the model will be turned online if the loss of a large resource is the first contingency in the N-1-1 analysis

** All natural gas, nuclear and biomass units will be online in all the base cases. Impacts of the loss of a single resource will be captured through the N-1-1 analysis

*** For all existing and planned resources in the 2031 NA case, the nameplate value is the Summer NRC rating

**** Transmission loss of 2.5% assumed to calculate resource insufficiency. Actual losses in cases may vary., which would impact the resource insufficiency.

Addressing Resource Insufficiency

- Proxy generators will be added at offshore wind locations in proportion to the size of the wind farm
  - As an example, if 5% of the total New England offshore wind is at Mystic 345 kV, then 5% of the shortfall MW will be allocated to Mystic 345 kV
- The proxy generators represent various sources of additional energy, such as:
  - Increased availability of floating offshore wind farms
  - Co-located storage at the offshore wind locations

Snapshots with Excess Supply

- In the snapshots with excess supply (resources > power consumption), the excess resources will be curtailed in the following order
  - Imports on the NY-NE AC ties will be reduced to as low as 0 MW
  - Natural gas CTs
  - Natural gas CCGTs

STUDY METHODOLOGY AND DELIVERABLES

Study Methodology

- One dispatch for each load level will be studied in the initial analysis
  - Will not assume any forced outages
- N-1 and N-1-1 DC contingency analysis monitoring all PTF facilities
  - Contingency analysis will be consistent with NERC, NPCC, and ISO-NE criteria

Study Outcomes and Deliverables

- After the initial analysis is performed and thermal violations are identified, transmission upgrades will be evaluated
  - As a part of the transmission upgrade evaluation, adjusting the injection points of offshore wind will also be considered
- Cost estimates for transmission options evaluated will be developed by third-party consultant(s)
  - Cost estimates for the interconnection of new resources to the POIs considered will not be a part of the transmission upgrade cost development

Schedule and Next Steps

- A 15 day comment period will be provided for stakeholders to provide written comments on this presentation
  - Please submit comments to pacmatters@iso-ne.com by December 2nd, 2021
- The ISO, through discussions with NESCOE given the study purpose and focus on state laws and policies, will consider PAC feedback and finalize scope of work – Q4 2021
- The ISO expects to discuss initial results of the analysis at PAC – Q1 2022

Questions