MAY 20, 2020 | WEBEX

Anbaric 2019 Economic Study - Follow-up to the March 2020 PAC Meeting

Planning Advisory Committee Meeting

Haizhen Wang

LEAD ENGINEER, RESOURCE STUDIES AND ASSESSMENTS

Three 2019 Economic Study Requests

- Requests were submitted by the New England States Committee on Electricity (NESCOE), Anbaric Development Partners (Anbaric) and RENEW Northeast (Renew).
  - Presented to the PAC on April 25, 2019

Requester	Purpose of Request
NESCOE	Impacts on transmission system and wholesale market of increasing penetration of offshore wind resources https://www.iso-ne.com/static-assets/documents/2019/04/a2_nescoe_2019_economic_study_request_presentation.pptx
Anbaric	Impacts on energy market prices air emissions of large penetration of offshore wind resources https://www.iso-ne.com/static-assets/documents/2019/04/anbaric_2019_economic_study_request.pdf
Renew	Economic impact of conceptual increases in hourly operating limits on the Orrington-South interface from conceptual transmission upgrades https://www.iso-ne.com/static-assets/documents/2019/04/a2_renew_2019_economic_study_request_presentation.pdf

- This presentation focuses on the Anbaric Study

Previous PAC Presentations on Anbaric Study

- Draft scope of work and high-level assumptions were discussed on May 21, 2019
- More detailed assumptions were discussed on August 8, 2019
- Status update was given on November 20, 2019
- Study results were presented on March 18, 2020

Today's Presentation

- Information is being presented in response to questions raised at the March PAC meeting
- Additional tables and charts were developed to address:
  - How much offshore wind (OSW) energy was spilled behind the constrained SEMA/RI Export interface?
  - Why gas-fired resources were required to replace the retired nuclear generation?

Disclaimers

- All results use the 2015 solar and wind profiles. The results are specific to the 2015 weather year.
  - If a different weather year is used for profile shapes, the results will differ. The trends would be similar, but specific numeric results will change.
- Curtailment of specific resources is driven by the threshold prices.*
  - Different prices and/or order may result in different outcomes.
- Production cost simulations were performed under two conditions: Unconstrained and Constrained
  - Unconstrained transmission is modeled as a one-bus system.
  - Constrained transmission is modeled using the “Pipe and RSP Bubble” configuration.

* See Slide 23 for details on the threshold prices. Today’s presentation contains results of Base Assumption scenarios only, where NECEC threshold price is $2/MWh.

OSW SPILLED DUE TO CONSTRAINED SEMA/RI EXPORT INTERFACE

Anbaric 10000 and 10000_Sen (electrification) Scenarios

Both in TWh amount and as a percentage of the total OSW energy available in the SEMA /RI areas

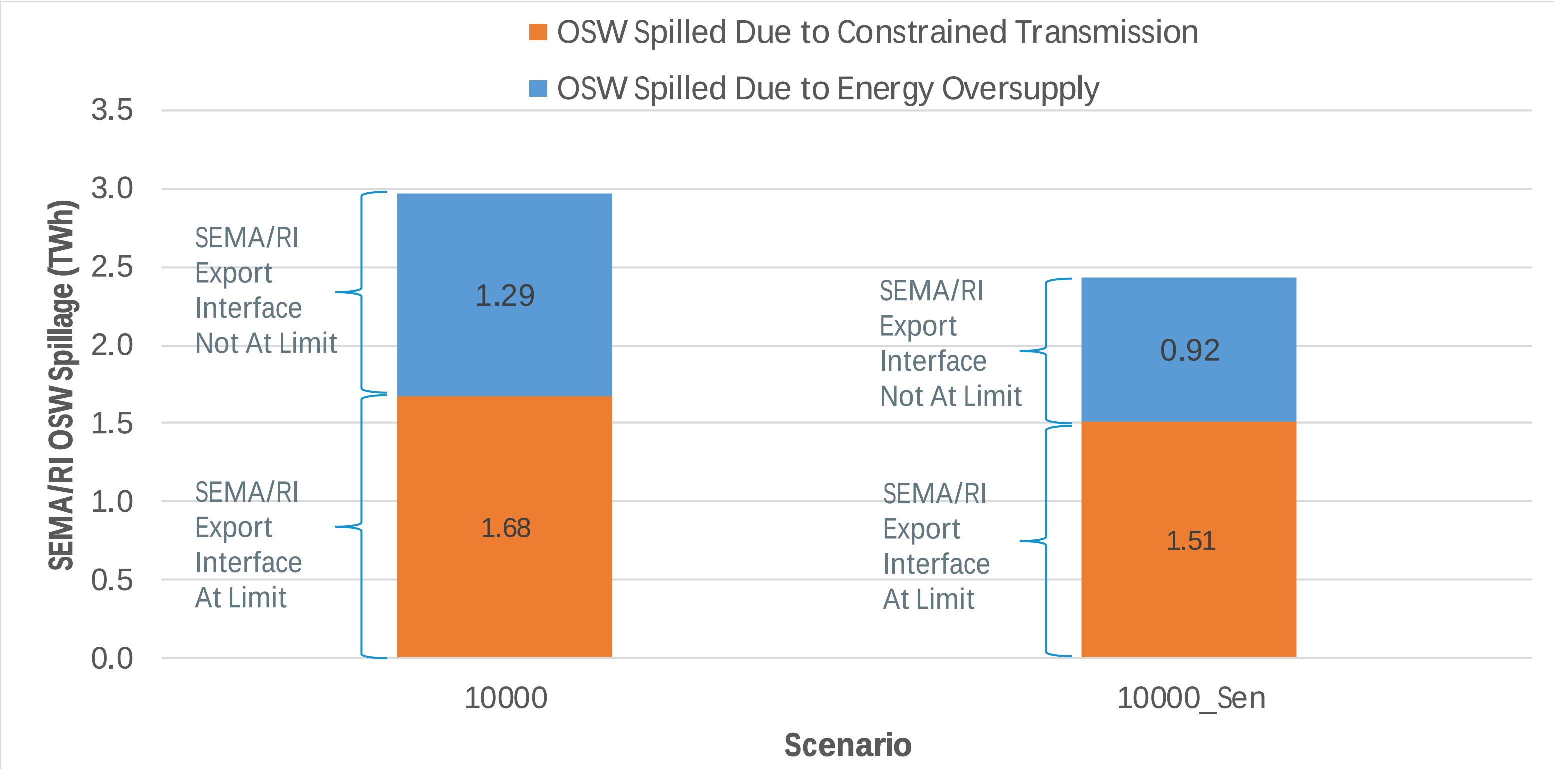
Key Observations

- Addition of 8,000 MW to 12,000 MW of OSW *plus* assumed resource retirements resulted in SEMA/RI export interface constraints
  - OSW spilled due to constrained SEMA/RI export interface was quantified for the Anbaric 10000 and 10000_Sen Scenarios
  - There was OSW spilled due to energy over supply as well
- Approximately 90% of the energy produced by OSW in SEMA and RI areas served loads in the Anbaric 10000 and 10000_Sen Scenarios*
  - Electrification lowered the OSW spillage by 0.53 TWh, which is 1.8% of the total OSW available and about 18% of the 2.97 TWh of spilled OSW observed in the Anbaric 10000 Scenario

* See Slide 22 for details on resource expansion assumptions modeled in the Anbaric scenarios.

OSW Spilled Behind the SEMA/RI Export Interface (TWh)

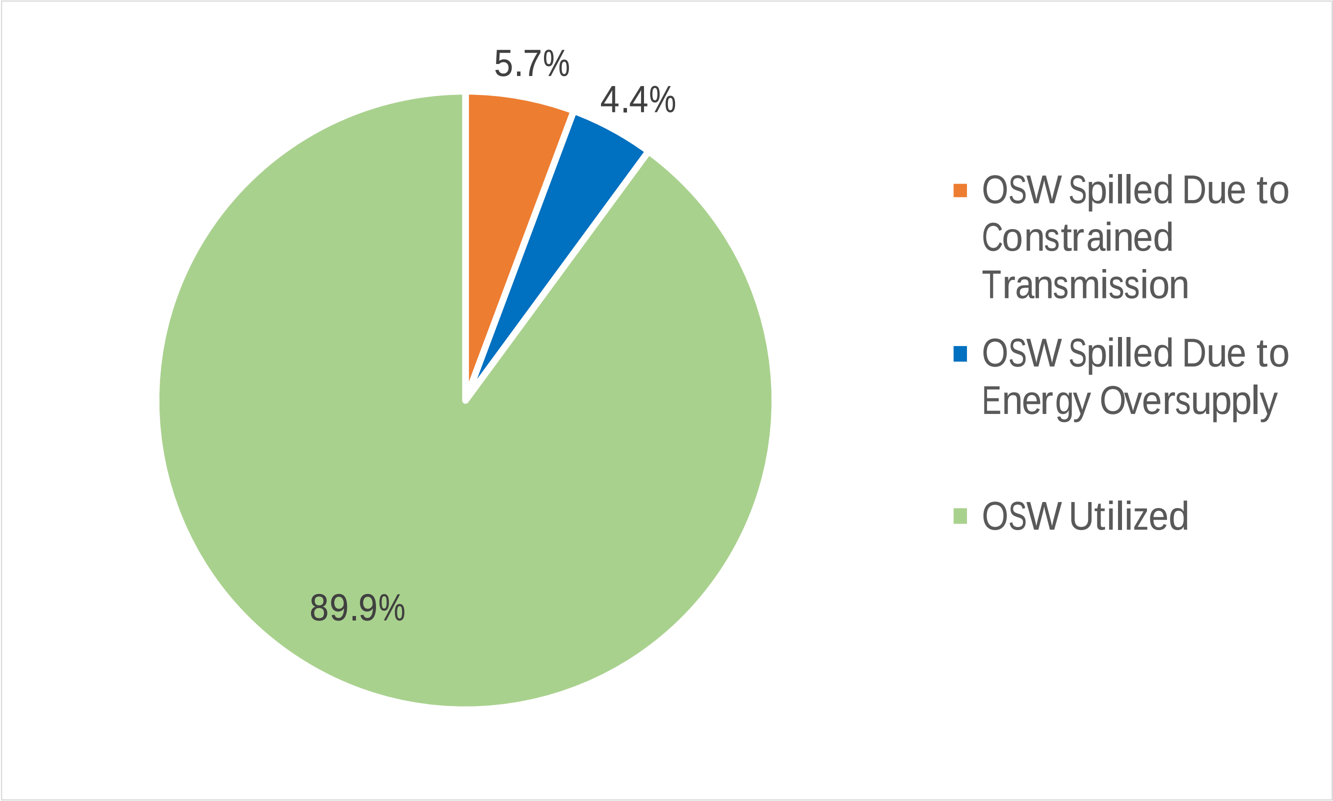
For Anbaric 10000 and 10000_Sen Scenarios, Constrained Transmission



- OSW interconnected into SEMA and RI areas was spilled due to either constrained SEMA/RI Export interface or energy oversupply
  - Electrification loads in the Anbaric 10000_Sen Scenario would reduce OSW spilled due to constrained transmission by 0.17 TWh, which was approximately 10.1% of the 1.68 TWh of total OSW spilled when the SEMA/RI Export interface was at its limit in the Anbaric 10000 Scenario

Energy Utilized vs. Spilled for OSW Located in SEMA/RI

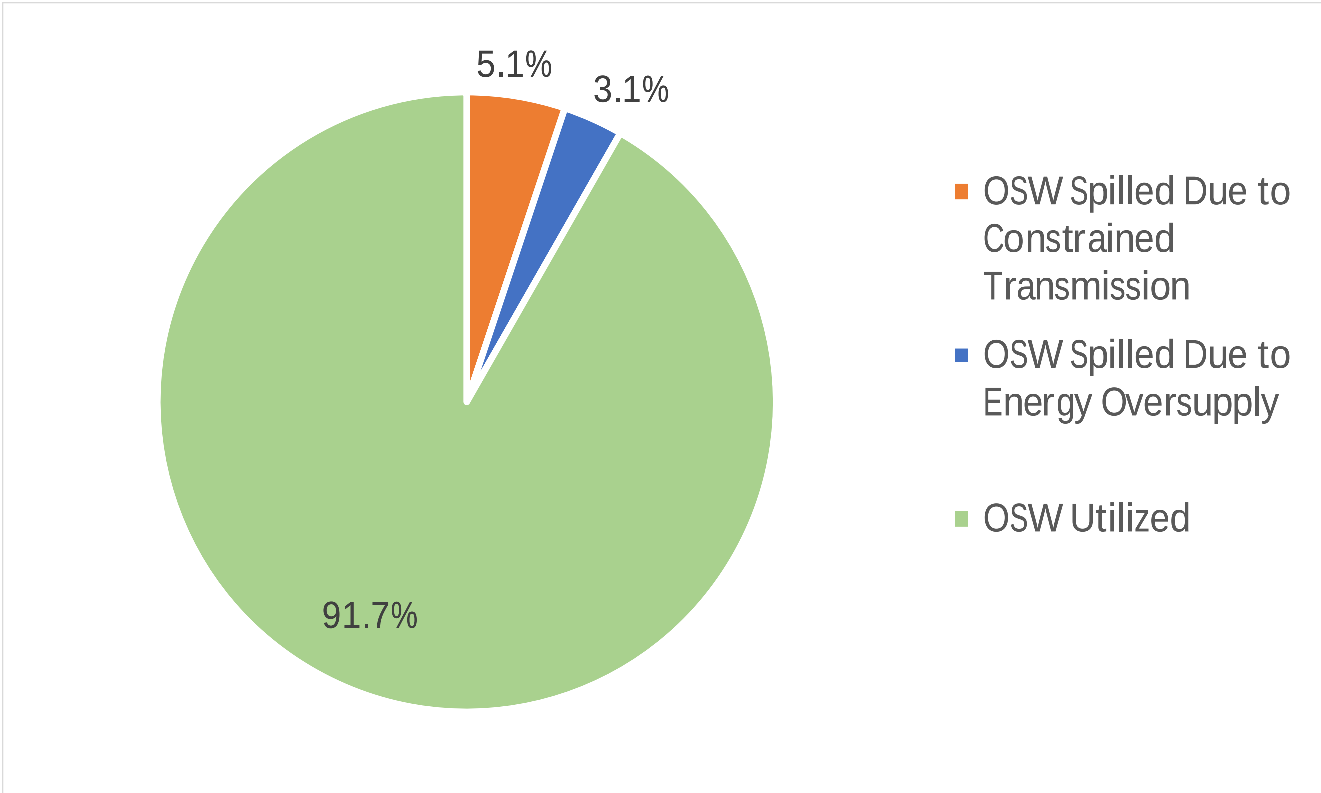
For Anbaric 10000 Scenario, Constrained Transmission



- Approximately 10.1% of the total OSW interconnected into the SEMA and RI areas was spilled in the Anbaric 10000 Scenario
  - Of that total, 5.7% was spilled when the SEMA/RI Export interface was constrained

Energy Utilized vs. Spilled for OSW Located in SEMA/RI

For Anbaric 10000_Sen Scenario, Constrained Transmission



- OSW was utilized to meet demand from electrification
  - Electrification demand increased approximately 1.8% of the OSW energy usage on the basis of the total energy available from OSW modeled within the SEMA/RI Export interface

GAS-FIRED RESOURCES WERE REQUIRED TO REPLACE RETIRED NUCLEAR

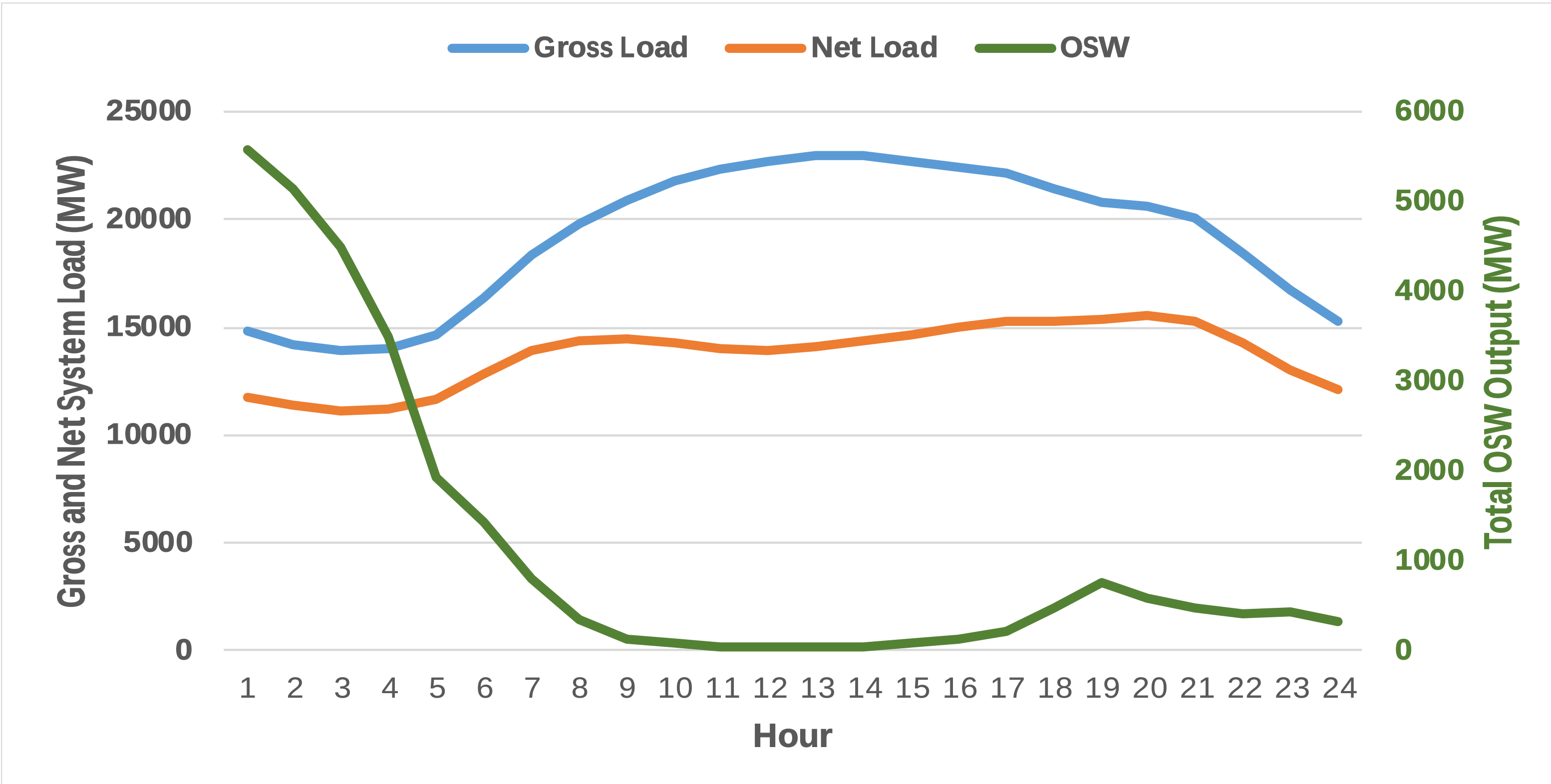
As demonstrated by a low wind summer day

Key Observations

- Gas-fired resources were required to partially replace retired nuclear generation in all Anbaric scenarios
  - Due to its intermittent nature, OSW does not follow loads
    - There were times when demands were high but OSW was low, especially during summer
  - A low-wind sunny summer day, July 2, 2030, was picked for demonstration

A Low-Wind Summer Day - July 2, 2030 (MW)

Loads and OSW Profiles, 8000 MW of OSW Addition Scenario

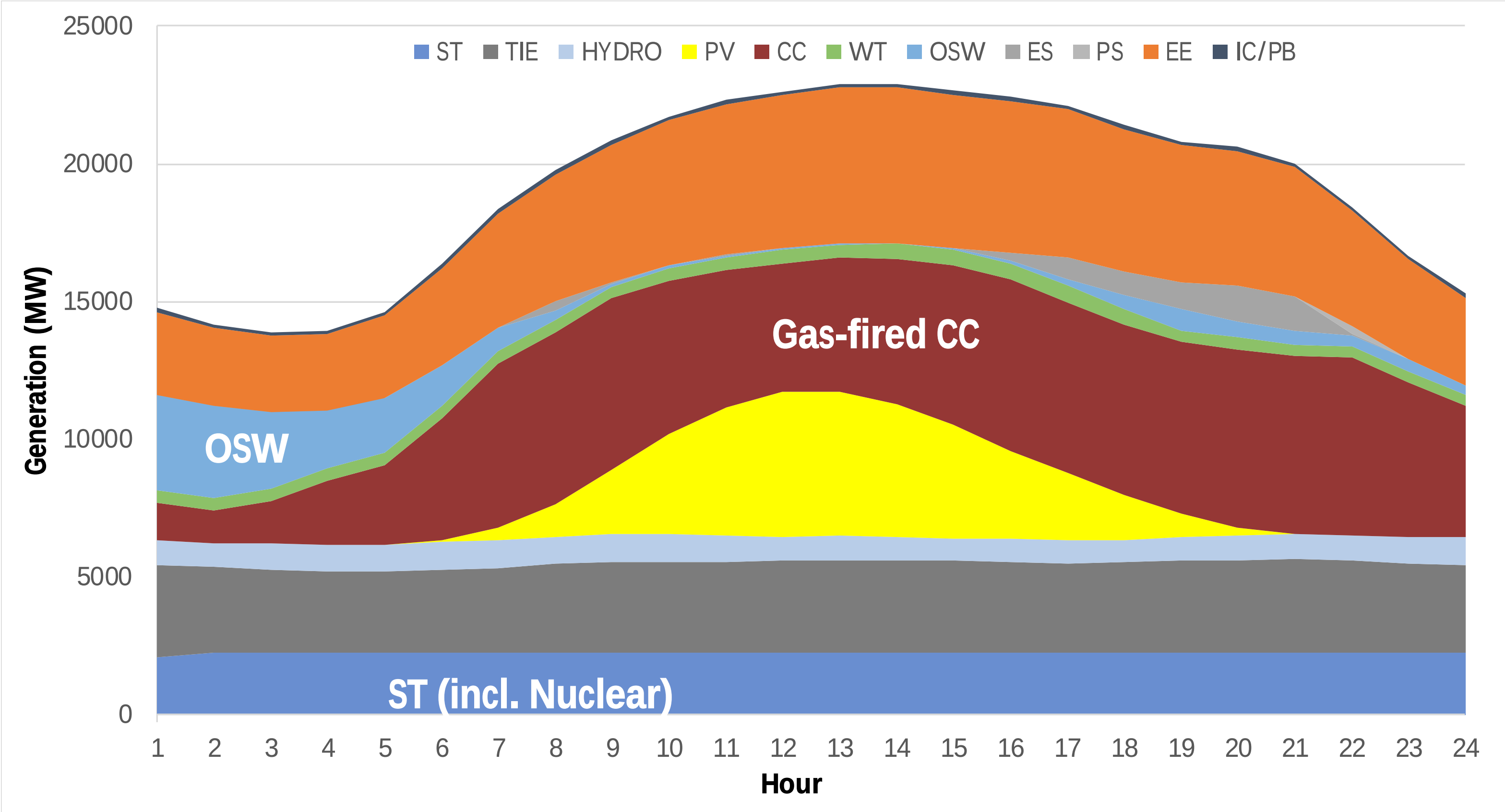


- July 2, 2030 was picked since it had relatively high summer load and, therefore, no spillage of renewables *plus* an OSW profile, which was almost opposite its load curve
  - High OSW output was observed at night when the loads were low
  - There was barely any OSW output during the day when the loads were high

Note: Net load here equals to gross load minus EE and BTM PV.

Production - July 2, 2030 (MWh)

For Anbaric 8000 Scenario, Constrained Transmission



- Gas-fired generation was required to serve loads when OSW output was low after the retirement of 2,000 MW nuclear generation

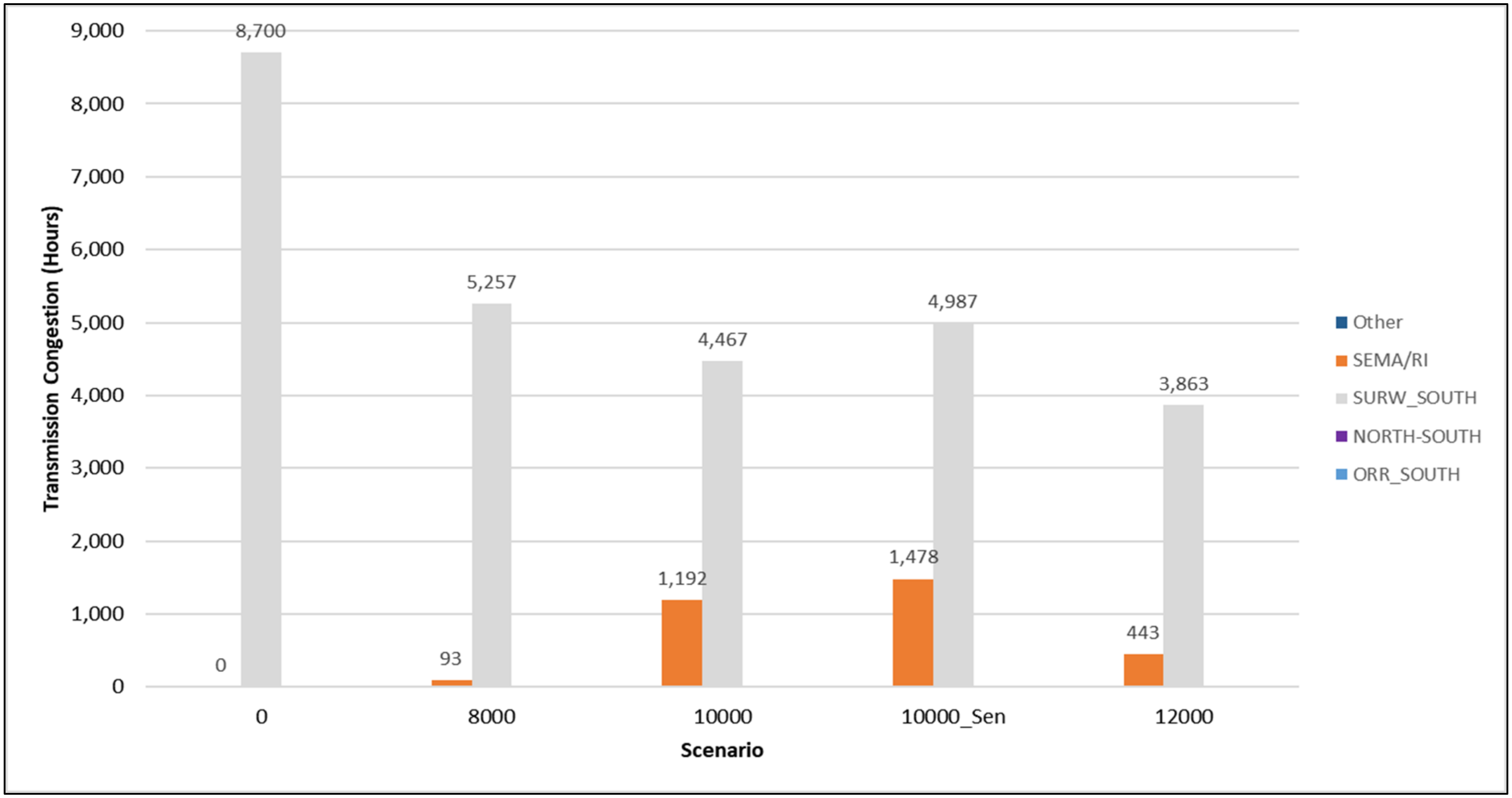
Next Step

- **Anbaric** – Publish final report in June/July

Questions

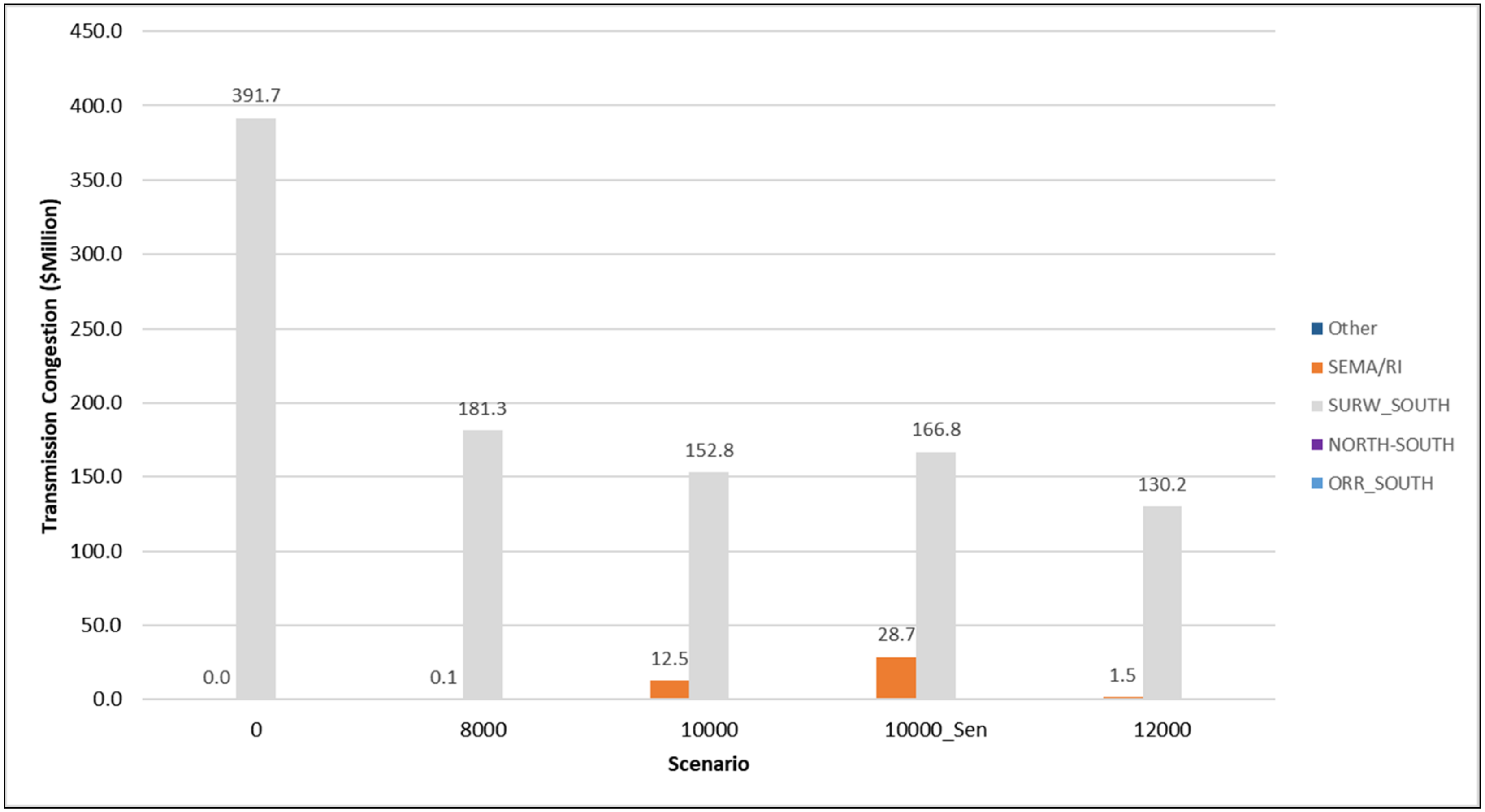
APPENDIX

Congestion by Interface (Hours)



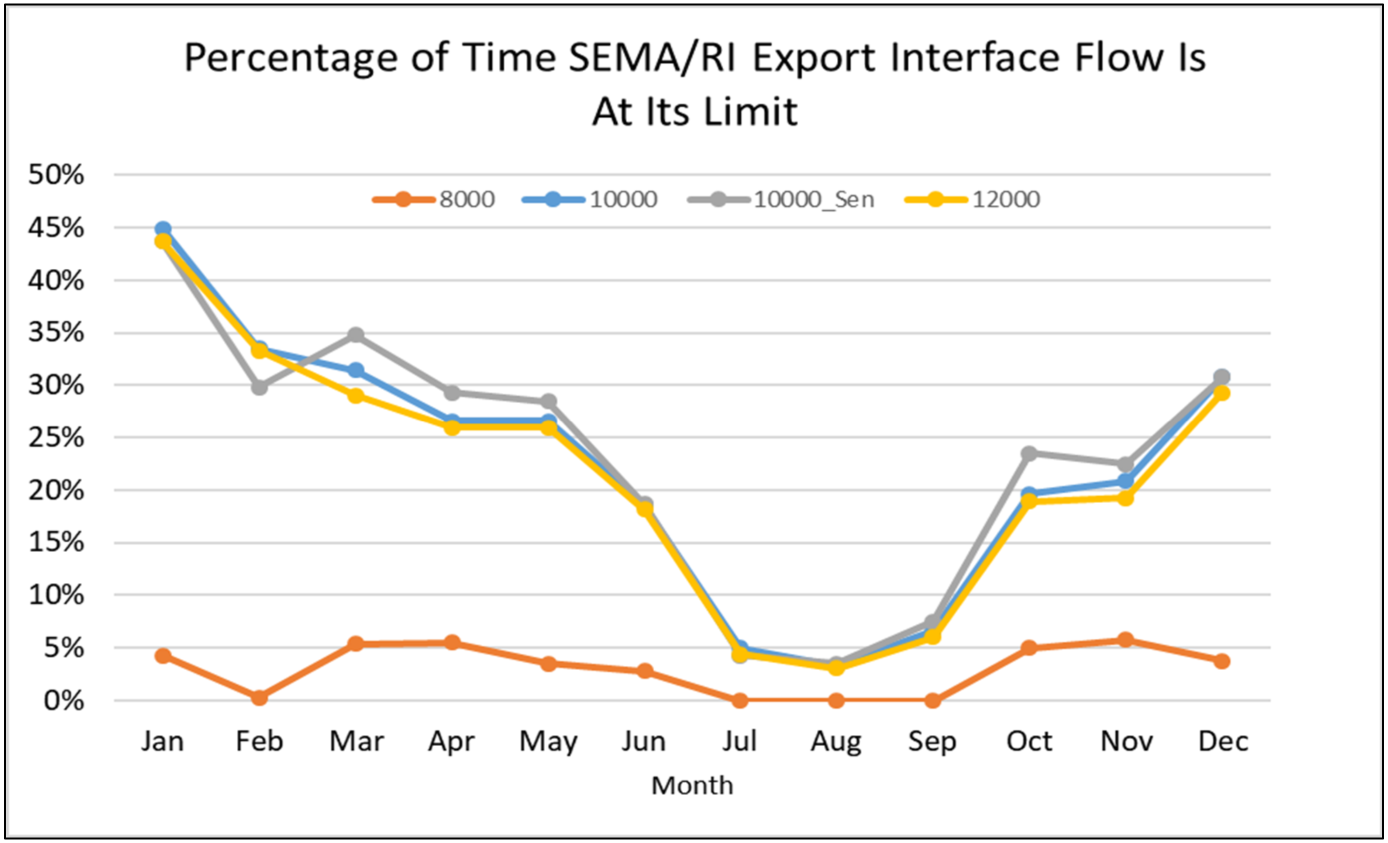
- SEMA/RI export interface is congested in the 8,000 to 12,000 MW scenarios because:
  - Majority of the OSW development concentrates in the SEMA and RI areas
  - More OSW generation is required to serve load outside of the SEMA and RI areas with the assumed nuclear retirements
- Surowiec South interface is heavily constrained assuming a transfer limit of 1,500 MW. Results barely show other transmission constraints.

Congestion by Interface ($ Million)



- SEMA/RI export interface congestion costs are highest in the 10,000 MW OSW scenarios
- Congestion costs in the 12,000 MW scenario are low because of lower shadow prices caused by the additional 2,000 MW of OSW (modeled in Boston and Connecticut) depressing LMPs outside of the SEMA and RI areas
- There is barely any other congestion except for the SEMA/RI export interface and the Surowiec South interface

SEMA/RI Export Interface Congestion by Month



- SEMA/RI export interface is congested more frequently with the addition of 10,000 MW or more OSW
- SEMA/RI export interface congestion occurs most often in the winter months, followed by the shoulder months
- The SEMA/RI interface is the least congested in the summer months

Comparison of Energy Production by Fuel Type (TWh)

For Constrained (Cstr.) and Unconstrained (Uncstr.) Transmission

Red represents production reduction, Green represents production increase

Scenario	Total Systemwide Energy Production by Fuel Type					
	NESCOE_8000_2		Anbaric_8000		Delta	
Fuel Type	Cstr.	Uncstr.	Cstr.	Uncstr.	Cstr.	Uncstr.
Offshore Wind	27.55	27.56	30.41	30.42	2.86	2.86
Onshore Wind	3.77	3.77	3.53	3.52	-0.24	-0.25
NG	16.67	16.67	23.30	22.43	6.63	5.76
Oil	0.00	0.00	0.00	0.00	0.00	0.00
Imports	19.41	19.41	20.86	21.87	1.45	2.46
Coal	0.05	0.04	0.16	0.09	0.11	0.05
LFG/MSW	2.69	2.69	3.16	3.09	0.47	0.4
PV	9.47	9.47	9.47	9.47	0.00	0.00
Wood	4.70	4.70	4.70	4.70	0.00	0.00
Nuc	29.85	29.85	12.33	12.33	-17.52	-17.52
EE/DR	36.09	36.09	36.09	36.09	0.00	0.00
Hydro	6.27	6.28	7.40	7.42	1.13	1.14
Total	156.52	156.53	151.41	151.43	-5.11	-5.10

Approximately 16 percent of the annual decrease in nuclear energy production due to assumed 2,000 MW of nuclear retirement was replaced by increase in OSW generation.

* Onshore wind was reduced in part because the Anbaric_8000 scenario assumes Surowiec South transfer limit of 1,500 MW while the NESCOE_8000_2 assumes a transfer limit of 2,500 MW.

Summary: Anbaric 2030 Scenarios Model Varying Degrees of Resource Expansions

<table>
<tr><th>Scenario</th><th>Gross Demand</th><th>EE</th><th>Behind-the-Meter PV (Nameplate)</th><th>Utility Scale PV (Nameplate)</th><th>Supply (incl. Demand Resources)</th><th>Retirements</th><th>RFP Committed Generation</th><th>Off-Shore Wind Additions (Nameplate)</th><th>Demand from Heat Pumps</th><th>Demand from Electric Vehicles</th><th>Battery Storage Additions</th></tr>
<tr><td>Anbaric_0
(Reference)</td><td colspan="4" rowspan="5">Based on 2019 CELT Forecast</td><td rowspan="5">2019 CELT generators and FCA 13 cleared resources</td><td rowspan="5">FCA 13, Mystic 8 & 9, 2,000 MW of nuclear[1] generation, 2,494 MW of oil units in CT and ME[2]</td><td>NECEC (1,090 MW of firm import) [3]</td><td>0 MW</td><td rowspan="4">None</td><td rowspan="4">None</td><td rowspan="4">2,000 MW</td></tr>
<tr><td>Anbaric_8000</td><td rowspan="4">NECEC (1,090 MW of firm import) [3] 2,300 MW of off-shore wind (nameplate) [4]</td><td>5,700 MW</td></tr>
<tr><td>Anbaric_10000</td><td>7,700 MW</td></tr>
<tr><td>Anbaric_12000</td><td>9,700 MW</td></tr>
<tr><td>Anbaric_10000_Sen
(Electrification)</td><td>7,700 MW</td><td>2,050 MW</td><td>550,000 vehicles[5]</td><td>4,000 MW</td></tr>
</table>

[1] Generation at Seabrook and Millstone reduced by a total of 2,000 MW, proportionally to their Seasonal Claimed Capacity.

[2] No more coal units in Connecticut and Maine. All remaining coal units are located in New Hampshire.

[3] The transfer limit of the Surowiec South interface is kept at 1,500 MW in the Anbaric study.

[4] Includes 1,600 MW from Massachusetts RFPs, 300 MW from Connecticut RFPs and 400 MW from Rhode Island RFPs.

[5] See Slide 27 for electric vehicle assumption.

Threshold Prices are Used to Decrease Production of $0/MWh Resources During Oversupply

*Use of different threshold prices than indicated will produce different outcomes, **particularly spillage of resources***

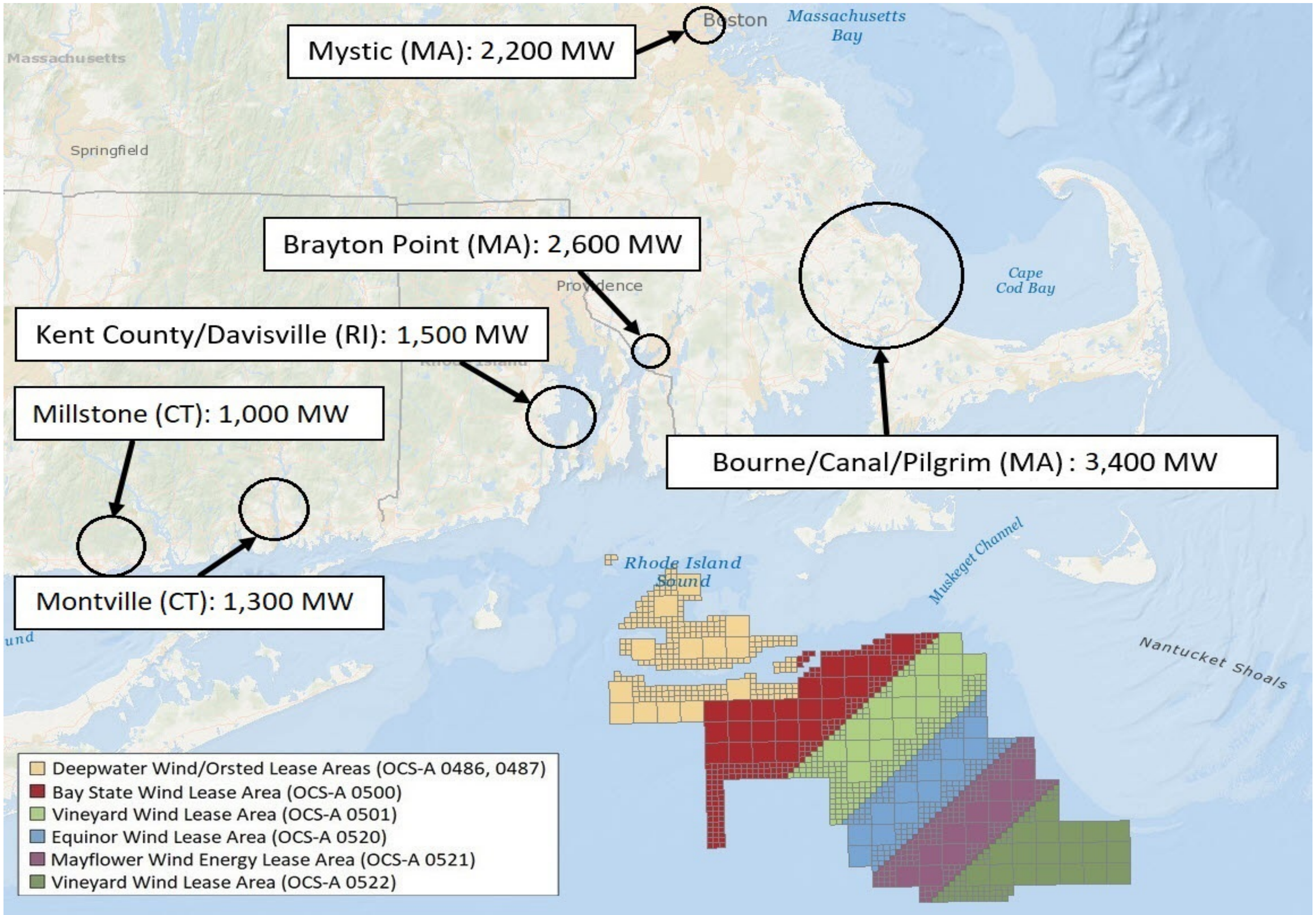
Price-Taking Resource	Threshold Price ($/MWh)
Behind-the-Meter PV	1
NECEC (1,090 MW)	2 11 (sensitivity)*
Utility Scale PV	3
Onshore/Offshore Wind	4
New England Hydro	4.5
Imports from Hydro Quebec (HQ) including Highgate & Phase II	5
Imports from New Brunswick (NB)	10

*Under base assumptions, NB imports, HQ imports, New England hydro, and Utility PV would be curtailed before curtailing NECEC. A set of NECEC sensitivity scenarios were performed assuming a higher threshold price of $11/MWh for NECEC that would result in curtailing NECEC energy first before curtailing other resources.

Anbaric 2019 Economic Study Offshore Wind Injection Locations (MW)

Anbaric Scenario	Interconnection Points (MW)						
	Montville (CT)	Millstone (CT)	Kent County (RI)	Brayton Point (SEMA)	Barnstable (SEMA)	Mystic (Boston)	Total
Anbaric_8000	800	–	1,000	1,600	3,400	1,200	8,000
Anbaric_10000	1,300	–	1,500	2,600	3,400	1,200	10,000
Anbaric_12000	1,300	1,000	1,500	2,600	3,400	2,200	12,000
Anbaric_10000_Sen (Electrification)	1,300	–	1,500	2,600	3,400	1,200	10,000

Locations of OSW Sites and Interconnection Points used for the 12,000 MW OSW Scenario



Approximate locations shown

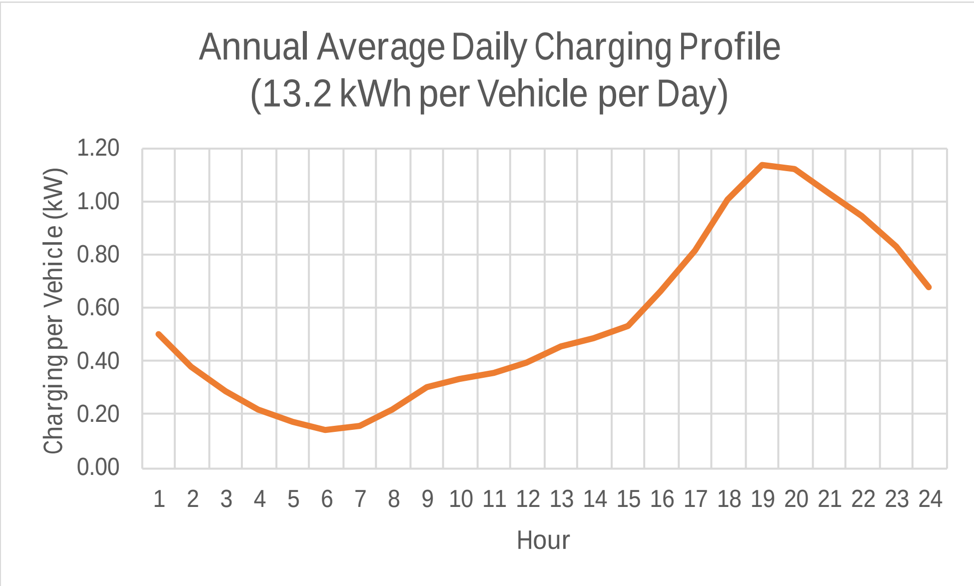
Resource Assumptions in Anbaric Scenarios

- Retirements modeled in the Anbaric scenarios
  - 2,000 MW of nuclear generation
    - Generation at Seabrook and Millstone reduced by a total of 2,000 MW, proportionally to their Seasonal Claimed Capability
  - Oil units in Connecticut and Maine with a total of 2,494 MW
    - All remaining coal units are located in New Hampshire

Name	RSP Subarea	Fuel Type	2019 CELT Seasonal Claimed Capacity (MW)	Fuel
Montville 5	CT	RFO	82	Oil
Yarmouth 1	SME	RFO	49	Oil
Middletown 2 & 3	CT	RFO	353	Oil
Yarmouth 2	SME	RFO	51	Oil
Yarmouth 3	SME	RFO	113	Oil
Montville 6	CT	RFO	400	Oil
Middletown 4	CT	RFO	403	Oil
New Haven Harbor 1	CT	RFO	440	Oil
Yarmouth 4	SME	RFO	603	Oil

Plug-in Hybrid Electric Vehicles (PHEVs) Characteristics

- Historical data from NREL suggests that PHEV charging tends to start in the later part of the day and continue into the night
  - The ISO modified the daily PHEV charging profile it used in the 2016 Economic Study to reflect this shift in the charging period
  - Charging ramps-up between 4 pm and midnight



Penetration (Thousand PHEVs)	**550**
Max charging (MW) (7PM)	627
Annual Charging Energy (GWh)	2,650

Internal Transmission Interface Limits (MW)

Single-Value, Summer Peak,[a] Non-Firm, Transmission Interface Limits for Use in Subarea Transportation Models										
Interface	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Orrington South Export	1325	1325	1325	1325	1325	1325	1325	1325	1325	1325
Surowiec South	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Maine-New Hampshire	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Northern New England-Scobie + 394	3450	3450	3450	3450	3450	3450	3450	3450	3450	3450
North-South	2725	2725	2725	2725	2725	2725	2725	2725	2725	2725
East-West	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
West-East	2200	2200	2200	2200	3000[f]	3000	3000	3000	3000	3000
Boston Import (N-1)	5400[b]	5400	5700[c]	5700	5700	5700	5700	5700	5700	5700
Boston Import (N-1-1)	4500[b]	4500	4600[c]	4600	4600	4600	4600	4600	4600	4600
SEMA/RI Export	3400	3400	3400	3400	3400	3400	3400	3400	3400	3400
SEMA/RI Import (N-1)	1280	1280	1280	1280	1800[f]	1800	1800	1800	1800	1800
SEMA/RI Import (N-1-1)	720	720	720	720	800[f]	800	800	800	800	800
Southeast New England Import (N-1)	5400[b]	5400	5700[c]	5700	5700	5700	5700	5700	5700	5700
Southeast New England Import (N-1-1)	4500[b]	4500	4600[c]	4600	4600	4600	4600	4600	4600	4600
Connecticut Import (N-1)	2950	3400[d]	3400	3400	3400	3400	3400	3400	3400	3400
Connecticut Import (N-1-1)	1750	2200[d]	2200	2200	2200	2200	2200	2200	2200	2200
SW Connecticut Import (N-1)	2500	2500	2800[e]	2800	2800	2800	2800	2800	2800	2800
SW Connecticut Import (N-1-1)	1750	1750	1900[e]	1900	1900	1900	1900	1900	1900	1900

- The internal transmission interface limits for 2025 will also be used for 2030
- N-1 limits will be used in the 2019 Economic Studies
- https://www.iso-ne.com/static-assets/documents/2019/03/a8_fca14_transmission_transfer_capabilities_and_capacity_zone_development.pdf

Internal Interface Transfer Capability (Notes)

a) Limits are for the summer period, except where noted to be winter
   - The limits may not include possible simultaneous impacts, and should not be considered as "firm"
   - For the years within the FCM horizon (CCP 2023-2024 and sooner), only accepted certified transmission projects are included when identifying transfer limits
   - For the years beyond the FCM horizon (CCP 2024-2025 and later), proposed plan approved transmission upgrades are included according to their expected in-service dates

b) Increase associated with the Greater Boston upgrades, with the Wakefield – Woburn 345 kV line in service (CCP 2021-2022 and later)

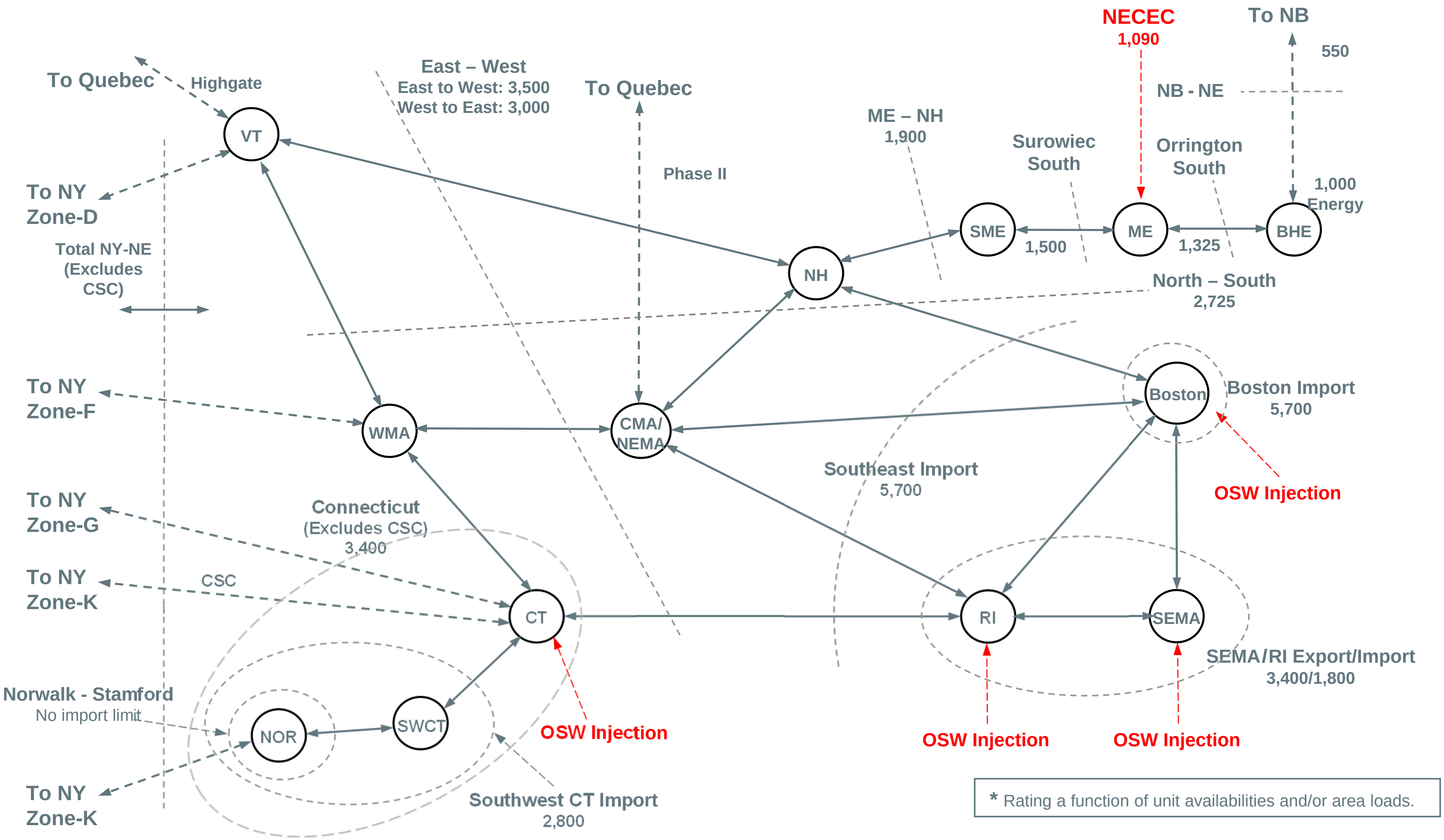
c) Increase associated with the Greater Hartford/Central Connecticut upgrades

d) Increase associated with the Southwest Connecticut (SWCT) upgrades

e) Increase associated with the Southeast Massachusetts/Rhode Island (SEMA/RI) Reliability project upgrades

f) Decrease associated with the updated load assumptions, updated Northern New England (NNE)-Scobie transfer capability and retirement of Mystic 7, 8 & 9

Assumed New England Transmission Constrained Representation for 2030 (MW)



Acronyms

- BOEM – Bureau of Ocean Energy Management
- CC – Combined Cycle
- CELT – Capacity, Energy, Load, and Transmission Report
- CSO – Capacity Supply Obligation
- Cstr. – Constrained
- DR – Demand-Response
- EE – Energy Efficiency
- EIA – U.S. Energy Information Administration
- FCA – Forward Capacity Auction
- FCM – Forward Capacity Market
- LMP – Locational Marginal Price
- LSE – Load-Serving Entity
- MSW – Municipal Solid Waste

Acronyms, cont.

- NECEC – New England Clean Energy Connect
- NESCOE – New England States Committee on Electricity
- NG – Natural Gas
- NICR – Net Installed Capacity Requirement
- NREL – National Renewable Energy Laboratory
- OSW – Offshore Wind
- PHEV – Plug-in Hybrid Electric Vehicle
- PV – Photovoltaic
- RFP – Request for Proposals
- RGGI – Regional Greenhouse Gas Initiative
- SCC – Seasonal Claimed Capability
- ST – Steam Turbine
- Uncstr. – Unconstrained