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Achieving 80% GHG Reduction in New England by 2050

Why the region needs to keep its foot on the clean energy accelerator

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Reaching 2050 climate goals is feasible — but New England must keep its foot on the accelerator

There is nearly complete consensus that minimizing the risk of catastrophic effects related to climate change requires advanced economies around the world to greatly decarbonize by mid-century. Many countries and U.S. states, including all of the New England states, have committed to doing so through a mix of mandates, targets, and goals that typically require economy-wide reductions in greenhouse gas emissions of at least 80% relative to a 1990 baseline. This requires largely replacing the oil and natural gas currently used in transportation and buildings with carbon-free alternatives.

There is much uncertainty about how such deep decarbonization will be achieved, and the mix of steps that need to be taken will certainly differ region by region. Nonetheless, it is clear that the electric sector is poised to play a central role.

A supply of low- or zero-carbon electricity enables decarbonization of large portions of the transportation system. This electrification can be direct — by using battery electric vehicles for personal transportation and almost certainly most other short haul transport, or indirect — by using electricity to produce hydrogen and potentially further advanced substitutes for liquid fuels.

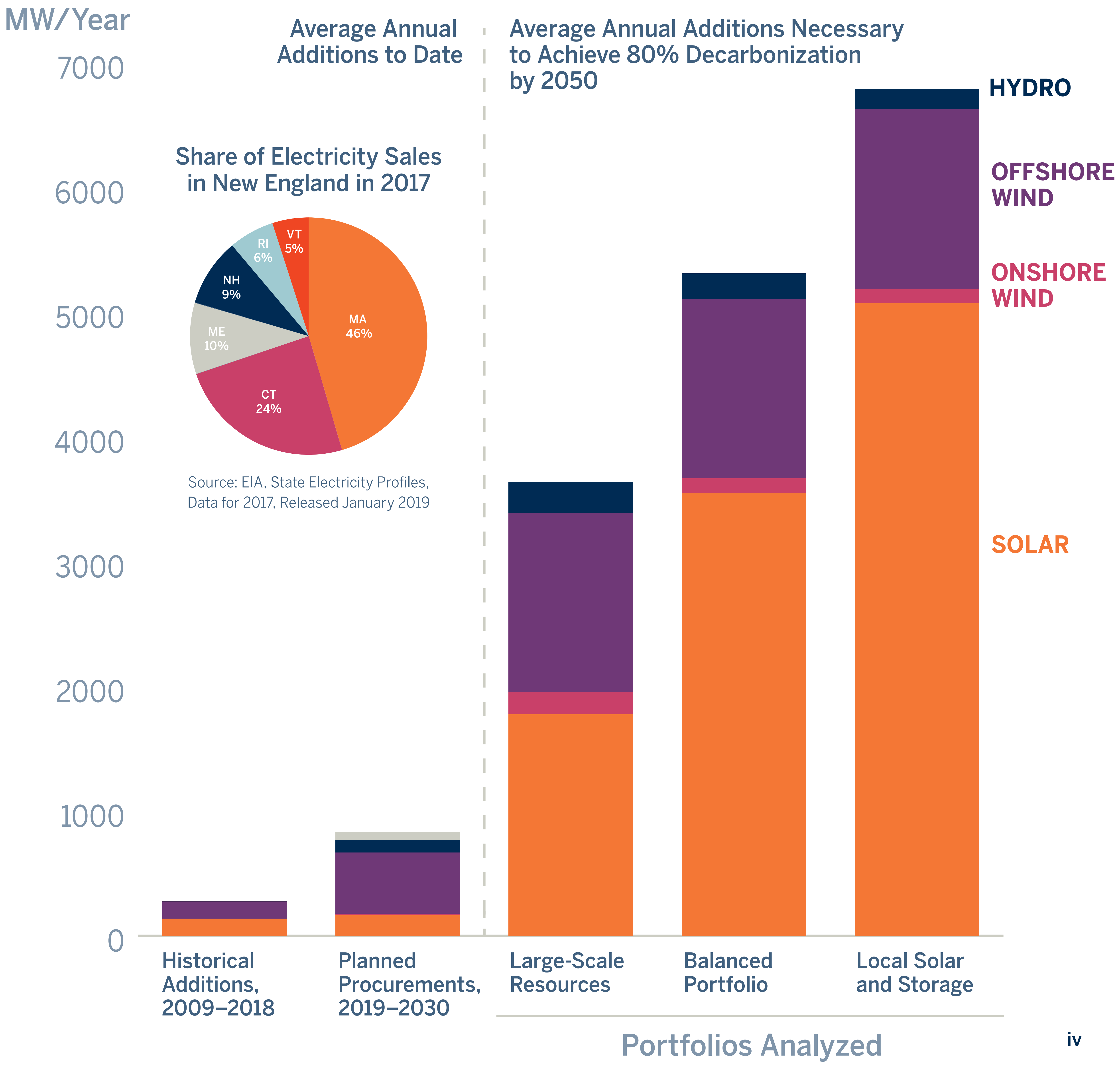
The same two electrification pathways will likely also dominate decarbonization of the building sector, primarily related to space and water heating. In many regions, heat pumps can supply both heating and cooling needs and can therefore substitute directly for fossil-based heating. Where heat pumps remain insufficient or impractical, renewable gas produced from excess renewable energy will likely play a role.

In either case, global and local economies will need to rely much more heavily on emissions-free electricity. By our estimates, **the U.S. electric sector would need to produce twice as much electricity in 2050** to meet all demand than it does today.

This means that over the next three decades, the electric sector faces dual challenges and opportunities: supplying twice as much electricity while replacing almost all of the coal- and gas-fired power plants with a new set of emissions-free resources. In fact, given that the typical renewable resource — a solar panel or wind turbine — generates electricity during fewer hours a year than a typical coal or gas plant, the capacity of all resources, including short- and long-duration storage needed by 2050, will grow even more. For New England as a whole, this could mean a total of 160 GW of capacity by mid-century, 5x the current capacity.

The good news is that the pace of deploying renewable energy resources has been picking up. New England, for instance, installed on average 300 MW of new renewable capacity per year over the last decade. Annual deployments are poised to more than double between 2020 and 2030 by adding 800 MW per year in additional renewable capacity.

Figure ES1: Average Annual Clean Energy Additions 2019–2050 for Various Portfolios

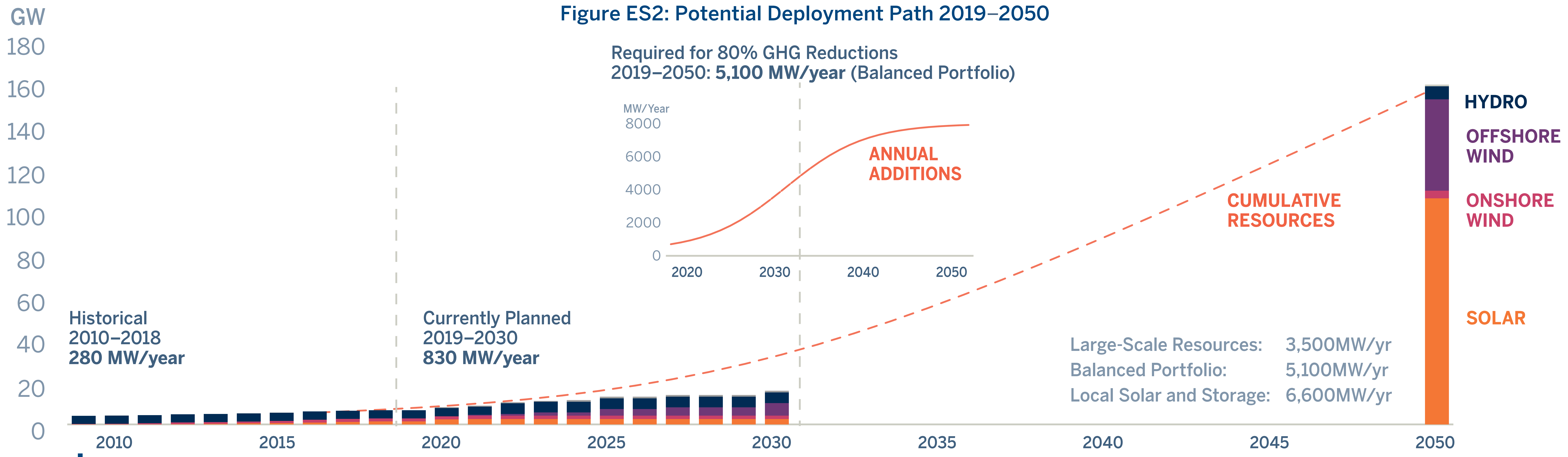


However, adding 800 MW per year through 2050 is not nearly enough. In fact, as shown in Figure ES1, between 2019 and 2050, between 3.5 GW and 6.6 GW of renewable capacity, including 2–5 GW of solar and 2–3 GW of wind, will need to be added each year on average.

Put differently, **New England will need to accelerate annual deployments 4- to 8-fold compared to what is planned for the coming decade.** While that sounds daunting, such ramp-ups are not unprecedented.

As a matter of fact, the acceleration New England needs is in line — if not slower — than the ramp up that wind and solar technologies have seen over the past 20 years. Over that time, annual wind installations globally have grown by over 11% per year on average, and solar PV by close to 41%. By contrast, to reach the 2050 targets in New England, annual installations of renewable projects would need to grow by about 9% per year. The ramp up does not have to happen on day one. Rather, the focus will need to be on mechanisms to keep the collective foot

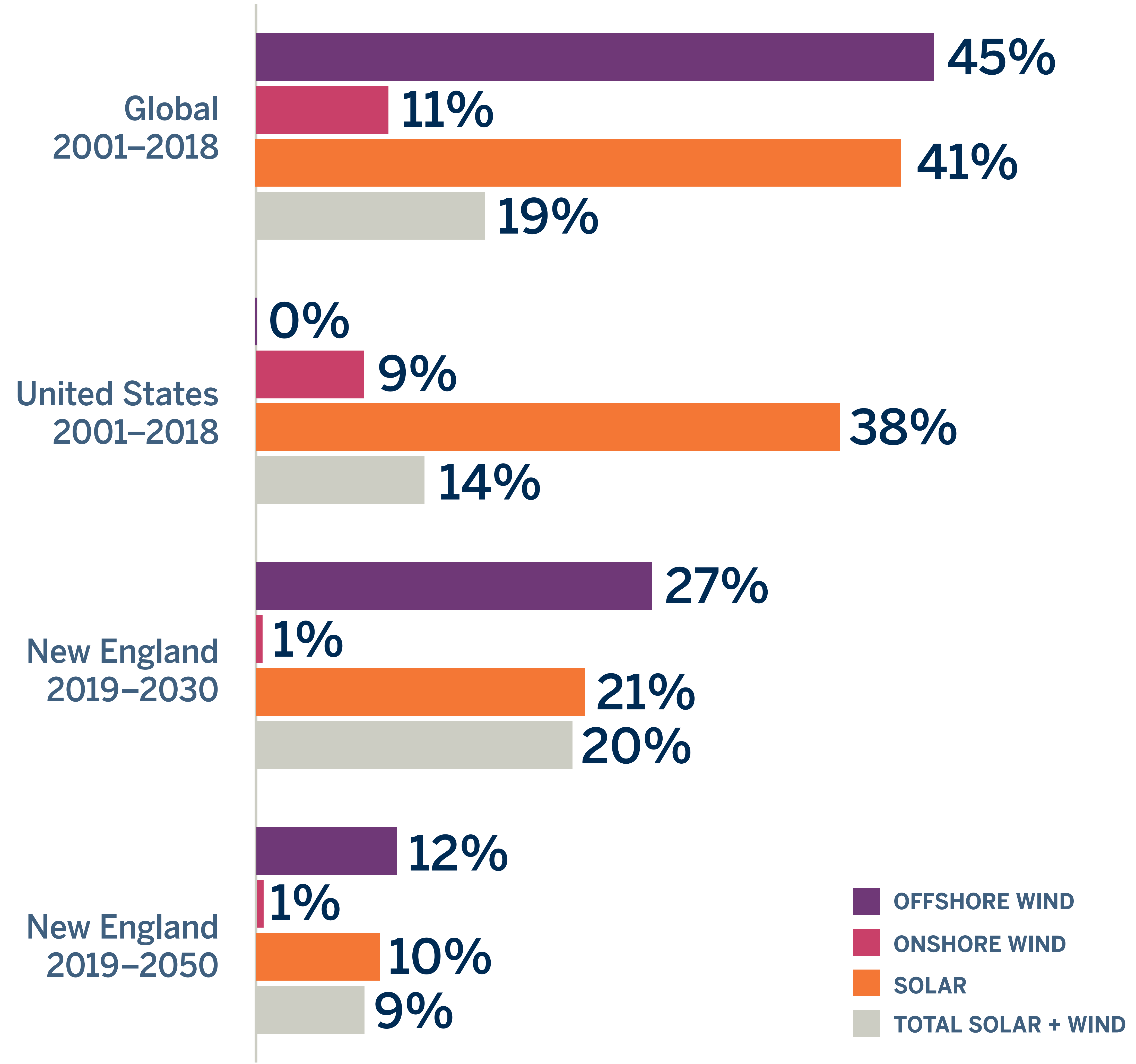
Figure ES2: Potential Deployment Path 2019–2050



on the clean energy accelerator until annual installations approach a level that sustains an entirely new and significant industry based on renewable energy in the future. Assuming that future growth of energy demand beyond 2050 will be modest and a typical renewable energy project will last 25–30 years, New England would need to replace about 4–5% of our facilities every year, or 7–8 GW of capacity each year, after 2050.

The bottom line is that if New England wants to make good on their greenhouse gas emissions reduction goals, they will need to keep their foot on the clean electricity development accelerator over the next critical decades to 2050. The current pace of adding more solar PV, onshore and offshore wind, battery storage, etc., is simply insufficient. However, if New England keeps growing these new industries at roughly the current rate, the region may have a chance to achieve the commitments made to decarbonize our economies by 2050 and do its part to reduce the risks of catastrophic climate change. And, in the process, it will create a substantial and sustainable new green economy.

Figure ES3: Rate of Growth of Annual Additions



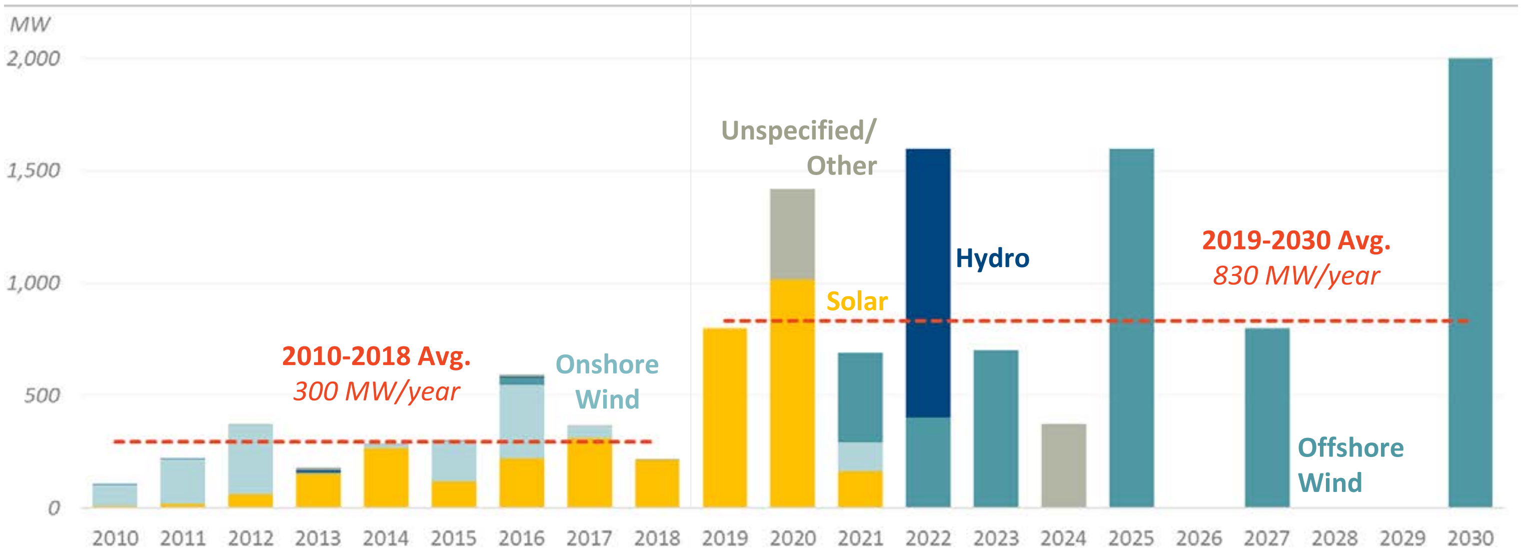
Report contents

Study Purpose

Is New England adding enough clean energy to achieve 80% GHG reductions by 2050?

- All of the New England states aim to reduce GHG emissions by 80% in 2050
- State-by-state commitments to adding clean energy resources in New England have accelerated substantially over the past decade and are expected to increase

Historical and Planned Annual Renewable Procurements in New England

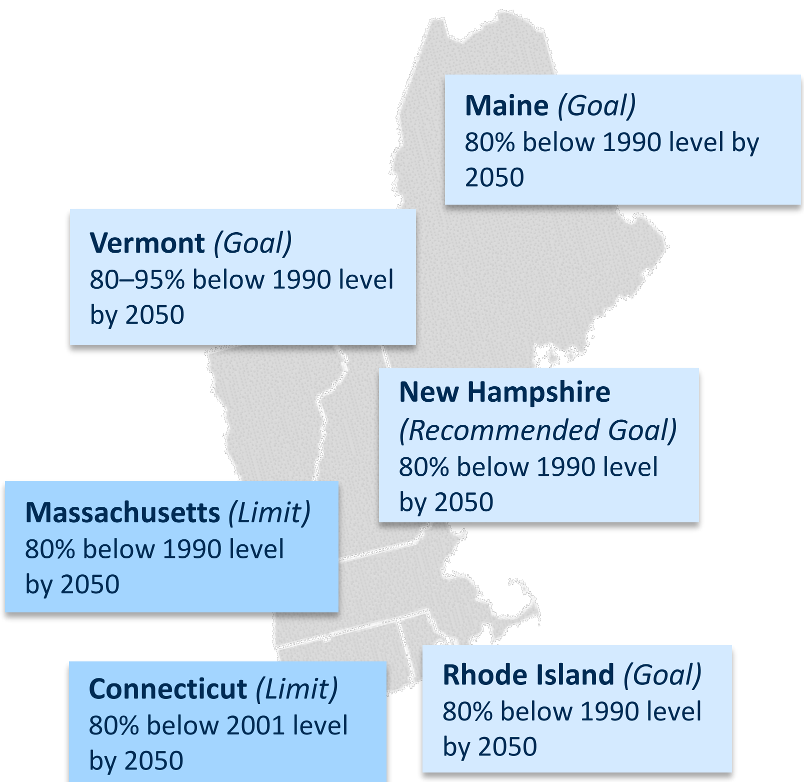


Sources and notes: ABB, Velocity Suite and Brattle analysis of state renewable procurement programs. Historical solar capacity includes only installations over 1 MW. Planned solar procurements include MA 83A resources, SMART program resources, and CT Public Act 17-3 resources.

Study Purpose: Estimate whether and how much clean energy resource additions in New England need to accelerate to achieve the 2050 decarbonization goals

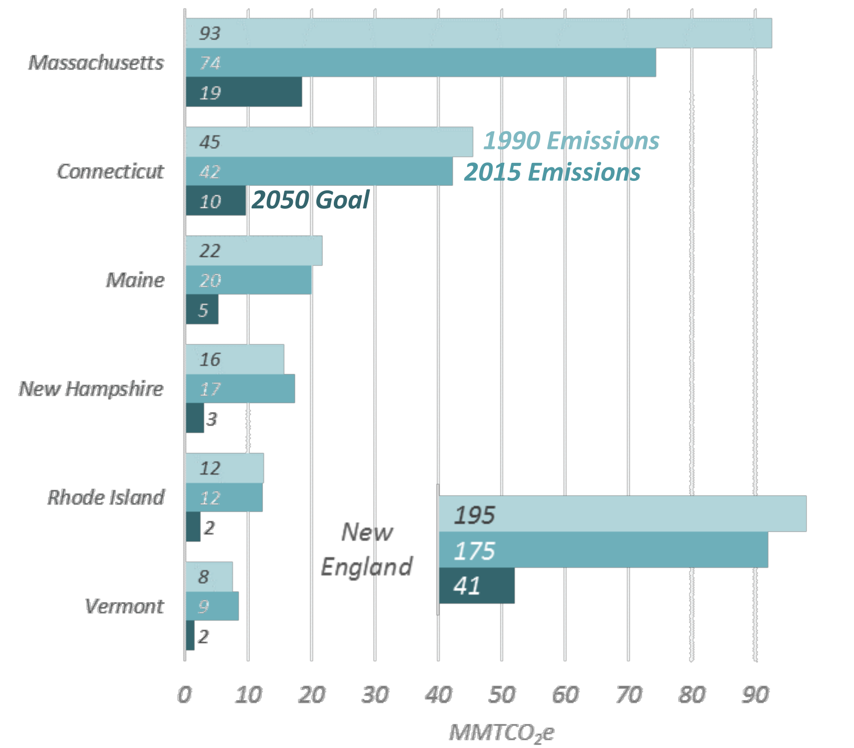
All New England states have set limits or goals to reduce 2050 GHG emissions by 80% or more

New England GHG Reduction Goals



Source and notes: Brattle review of New England proposed or implemented GHG emissions reductions. The stringency of the reductions vary state by state, with MA and CT both passing firm limits on future emissions, while others have set reduction goals. Map: Copyright © 2019 S&P Global Market Intelligence.

Historical GHG Emissions and 2050 Goals



Source and notes: State GHG Inventories. Inventories include all fuel consumed within the state and non-energy emissions. Fuel consumed includes air- and shipping-related fuel demand, and emissions related to electric imports. Non-energy emissions, such as agricultural, industrial processes, and natural gas system, differ state by state, and are generally a small contributor to overall emissions. See slides 30–35 for more details. 2050 Goal shown for each state assumes 80% reduction in 2050 relative to the relevant year.

At minimum, New England economy-wide emissions must decrease from 175 MMT in 2015 to 41 MMT or below in 2050 to meet these targets

There are currently three primary approaches for reducing GHG emissions by 80%

1 Reduce Electric Sector Emissions

Replace fossil generation with low-carbon, clean energy, including onshore wind, offshore wind, solar, and hydro

Build the necessary infrastructure (e.g., storage, transmission) to maintain a reliable power

2 Expand Energy Efficiency

Increase efficiency of end-use energy demand including existing and new buildings and transportation vehicles

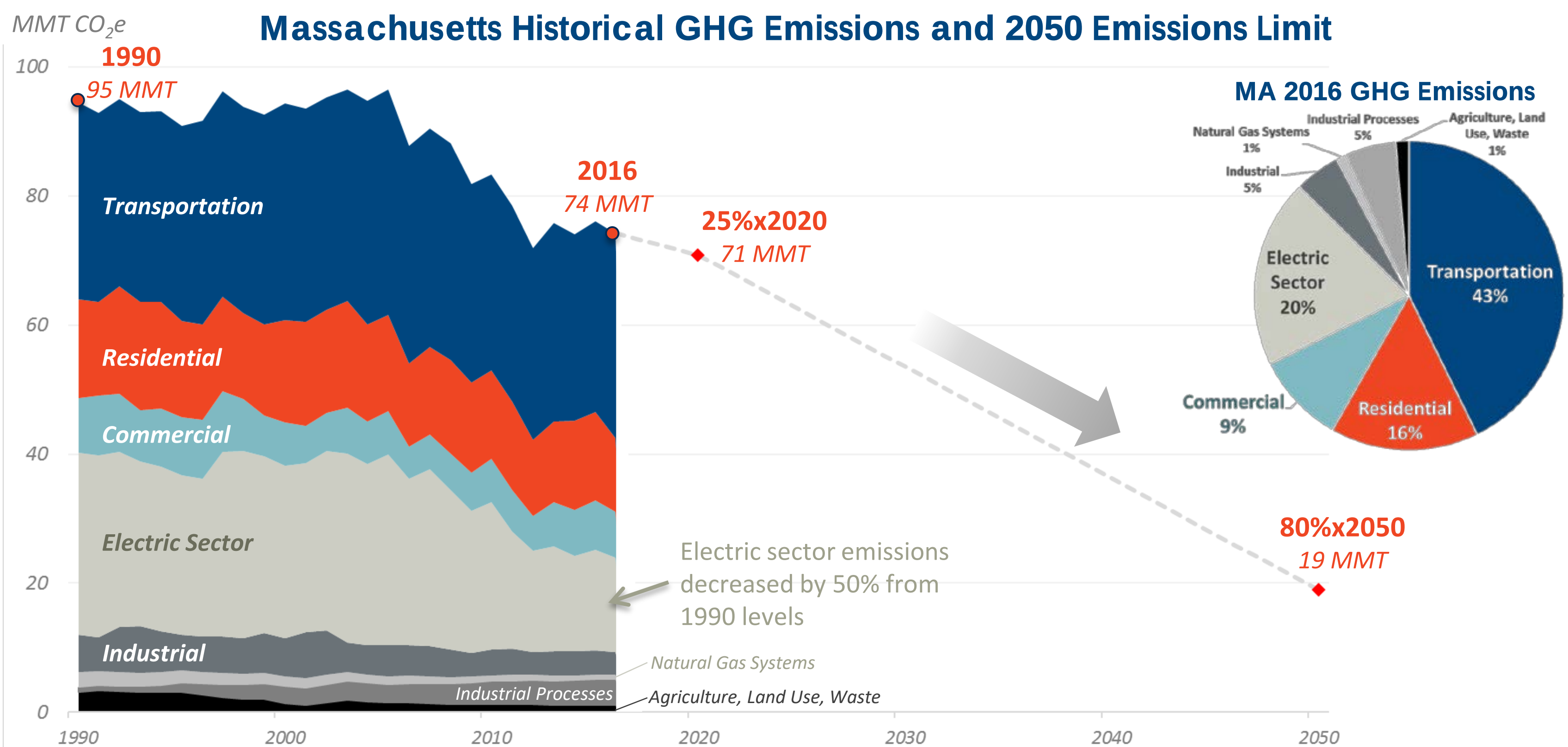
3 Electrify Transportation and Buildings

Increase adoption of electric-powered technologies such as heat pumps for space and water heating and electric vehicles for transportation

Note: There are many additional approaches to reducing GHG emissions in New England as well as approaches to offsetting the impacts of GHG emissions. For example, the potential for "smart growth" development strategies in Massachusetts could offset about 2 million metric tons of GHG emissions (see: Foster, et al., Wildlands and Woodlands: 2017 Report Summary, 2017). For details on the approaches being pursued in Massachusetts, see the Massachusetts Clean Energy and Climate Plan for 2020: 2015 Update.

Decarbonizing New England

MA GHG emissions decreased by 21% since 1990 primarily due to electric sector reductions



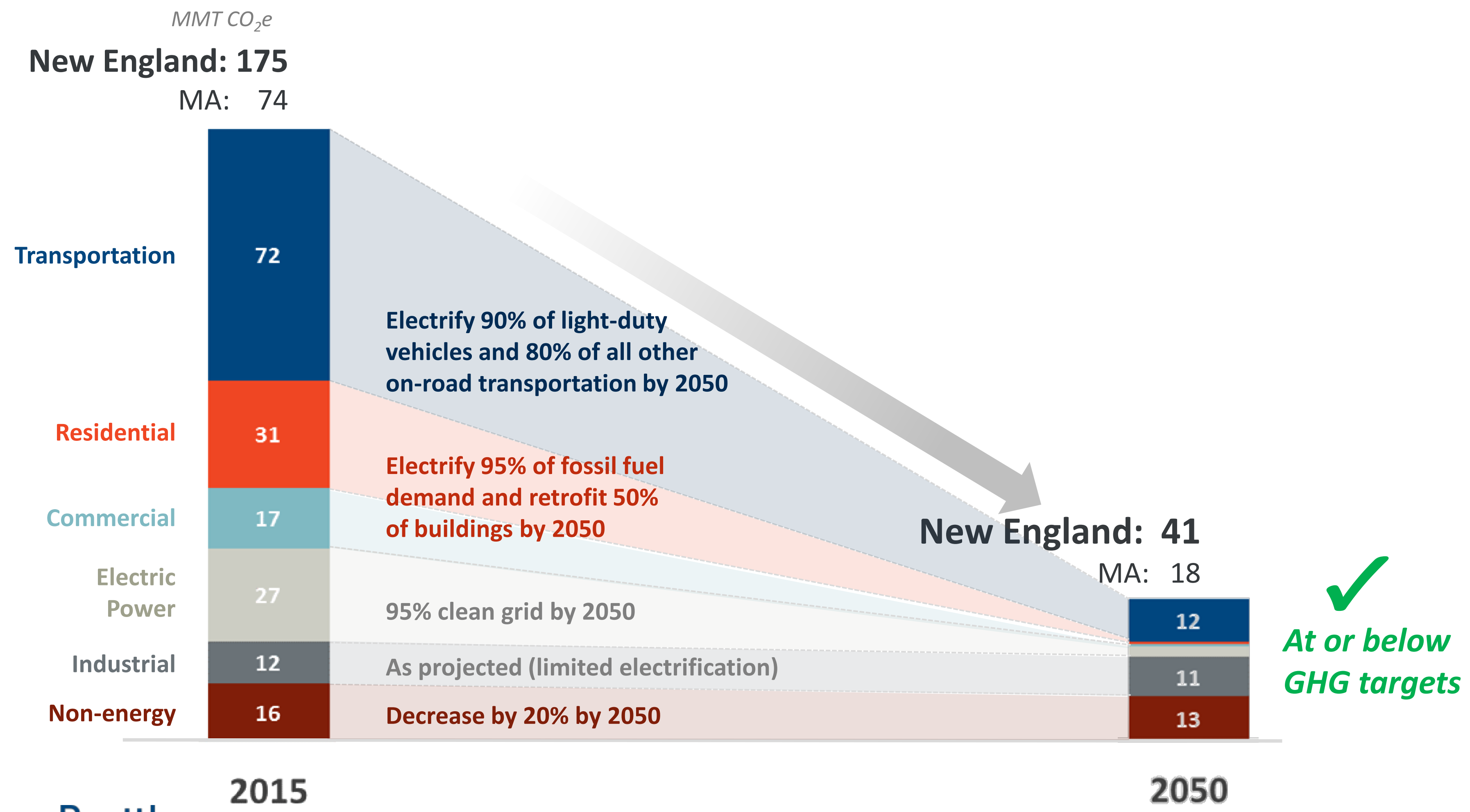
Source: MA GHG Emissions Inventory, December 2018. Note: Energy-related emissions (e.g., transportation, electricity, buildings, industrial) in this figure are based on state inventory.

To achieve the 2050 goals, New England must *electrify* the largest remaining sources of GHG emissions – transportation, residential heating, and commercial heating – and so a sustained focus on adding clean energy resources and decarbonizing the electric sector is essential to meeting these goals.

Decarbonizing New England

Vast electrification and a nearly decarbonized electric sector likely needed to meet 2050 goals

One Potential New England Decarbonization Path



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Electrification will require adoption of several emerging technologies

- **Transportation**: The availability and attractiveness of **EVs for passenger cars** is **increasing rapidly**, and options for other types of vehicles are beginning to emerge:
  - Delivery trucks
  - Heavy duty trucks
  - School and transit buses
- **Heating**: **Air source heat pumps** (ASHP) **and ground source heat pumps** (GSHP) are the primary technology for electrifying space heating and water heating in buildings, but current **deployment levels** in **cold climates** remain **low**
- **Building Efficiency**: Much more **efficient new buildings** and significant **retrofits of existing buildings** will be necessary to reduce future demand, especially for heating

Projected Technology Adoption and Efficiency

Transportation	Vehicles in NE (thousands)	Vehicles in MA (thousands)	EV Market Share (%)		Efficiency (miles/kWh)	
			2020	2050	2020	2050
Light-Duty Vehicles	12,490	5,270	<1%	90%	2.7	3.5
Medium-Duty Vehicles	160	70	<1%	80%	0.5	0.6
Heavy-Duty Vehicles	140	60	<1%	80%	0.3	0.4

Heating	Units in NE* (millions)	Units in MA* (millions)	Electric Heating Market Share (%)		Avg. Efficiency (COP)	
			2020	2050	2020	2050
Space Heating Units	5.6 (Res) 0.3 (Com)	2.5 (Res) 0.1 (Com)	9%	95%	ASHP = 1.7 GSHP = 3.6	ASHP = 2.0 GSHP = 3.6
Water Heating Units	5.6 (Res) 0.3 (Com)	2.5 (Res) 0.1 (Com)	36%	95%	2.8	3.4 - 3.8

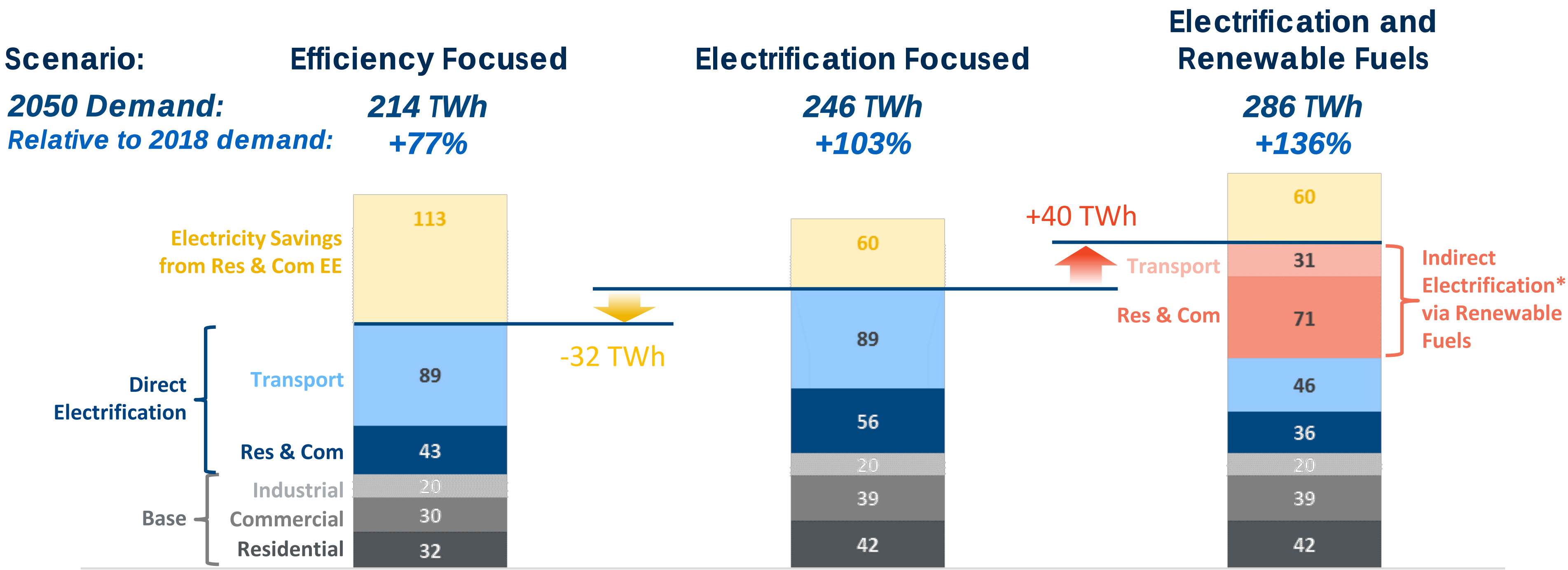
**Note: A "unit" represents housing units for the residential sector and buildings for the commercial sector. We assume ASHPs provide 75% of electrified space heating demand and GSHPs provide the remaining 25% in 2050. Space heating COP reflect seasonal average (November to March).*

Building Efficiency	Units in NE (millions)	Units in MA (millions)	EE Retrofits per Year		Energy Savings of Retrofits (%)	
			2018	2020-2050	2018	2050
Residential Units	5.7	2.6	1-2%	2%	10-40%	40-70%
Commercial Buildings	0.3	0.1	1-2%	2%	10-40%	40-70%

2050 Electricity Demand

Electricity demand will likely double by 2050 across plausible scenarios

2050 New England Annual Electricity Demand (TWh)



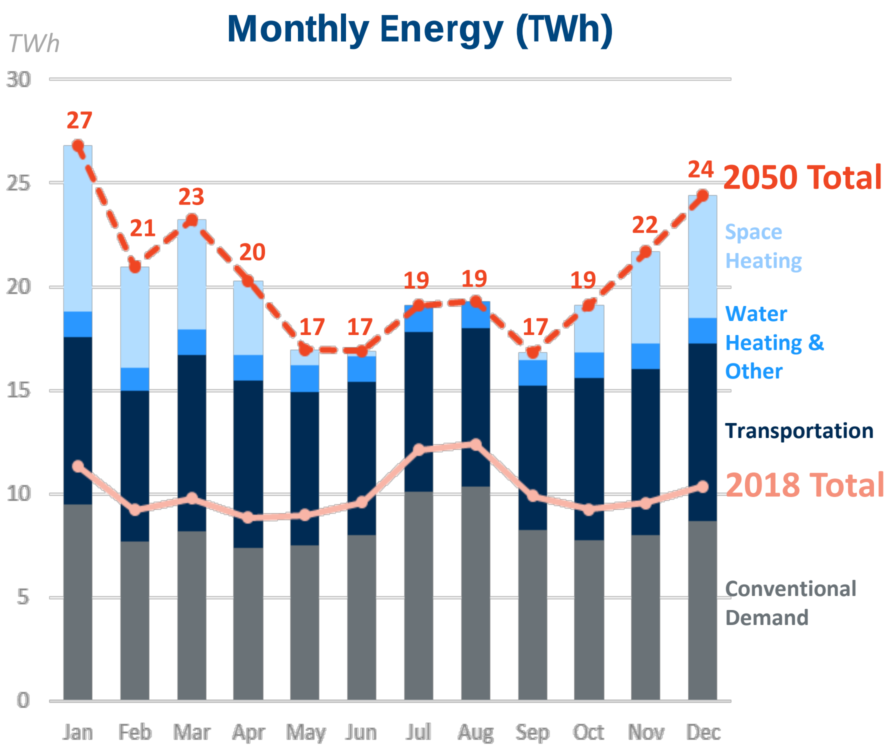
	Efficiency Focused	Electrification Focused	Electrification and Renewable Fuels
Building Energy Efficiency	1.5%/year	0.7%/year	0.7%/year
Building Electrification	All fuels: 80% Direct	All fuels: 95% Direct	Natural Gas: 50% Direct, 50% Indirect Other Fuels: 95% Direct
LDV/MDV Electrification	90%/80%	90%/80%	90%/80%
HDV Electrification	80%	80%	100% Indirect
Clean Electricity Generation	95%	95%	100%

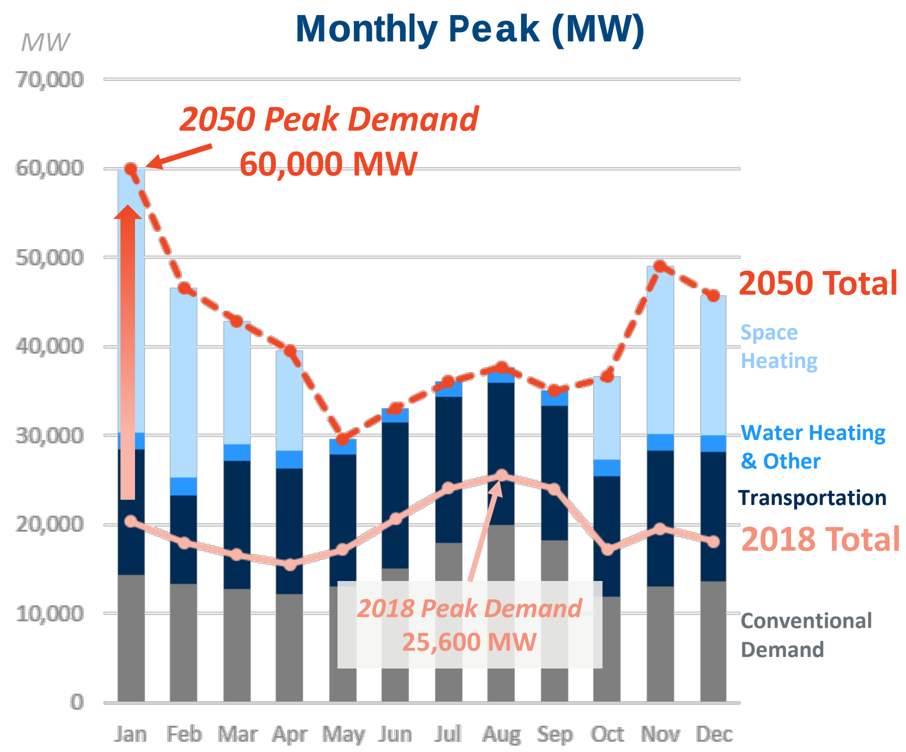
*Source and notes: 2050 demand based on projections in EIA 2019 AEO for New England and Brattle analysis of electrification and energy efficiency adoption rates and assumed efficiencies summarized on prior slide. *Indirect electrification refers to the production of renewable gas (hydrogen, methane) from electricity that is then burned as the end-use fuel.*

Demand grows the most in the winter due to heating electrification, doubling peak demand

Projected 2050 New England Demand

Scenario: Electrification Focused





Source: Monthly conventional demand based on ISO-NE 2018 monthly demand pattern. See appendix slides for more detail. Hourly temperatures based on 2018 weather conditions, which was an average year for heating demand, but had a relatively warm February. Incremental electrified demand based on Brattle analysis.

The 2050 portfolio of generation resources will need to meet this new pattern of demand.

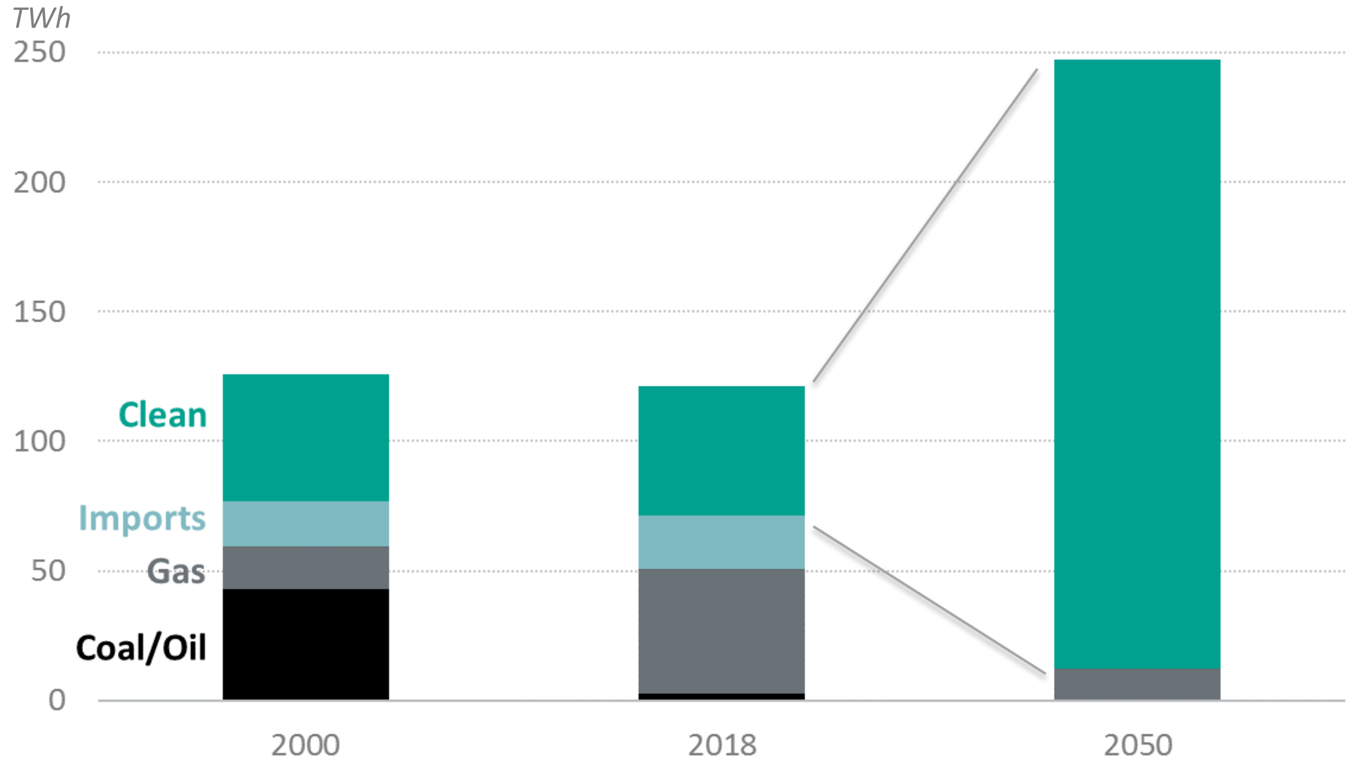
2050 Clean Energy Resource Options

Supplying the increasing demand will require a massive buildout of clean energy resources

- Replace about **50% of supply** currently from fossil fuel-fired resources
- Supply the **100% increase in demand** from electrification

Historical and Projected 2050 New England Generation Mix

Scenario: Electrification Focused



Source: ISO-NE, Key Grid and Market Stats, https://www.iso-ne.com/about/key-stats/, accessed June 28, 2019.

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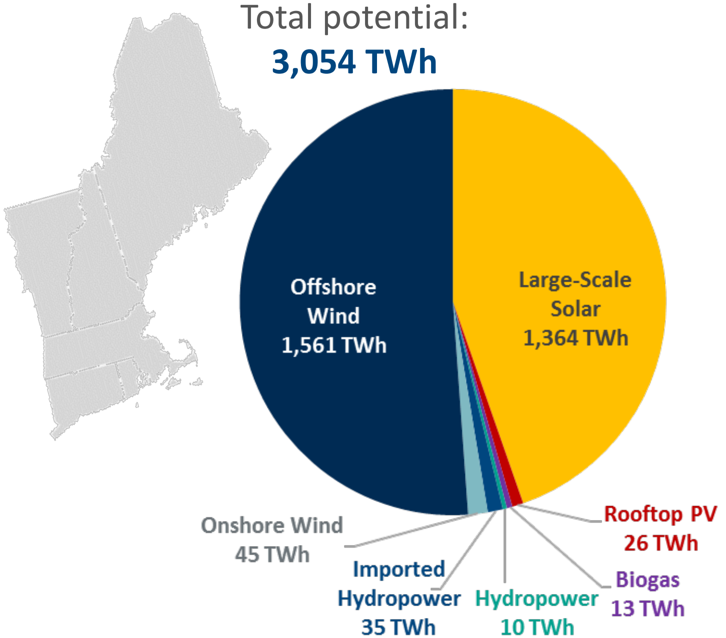
2050 Clean Energy Resource Options

Offshore wind and solar provide the vast majority of potential clean energy resources

Clean Energy Resource Technical Potential

New England

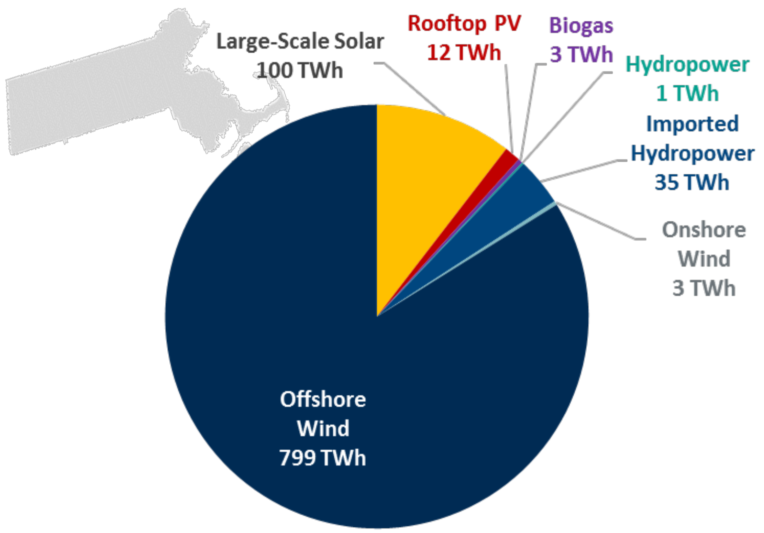
Total potential:
3,054 TWh



Electricity demand forecast in 2050:
214–286 TWh

Massachusetts

Total potential:
953 TWh



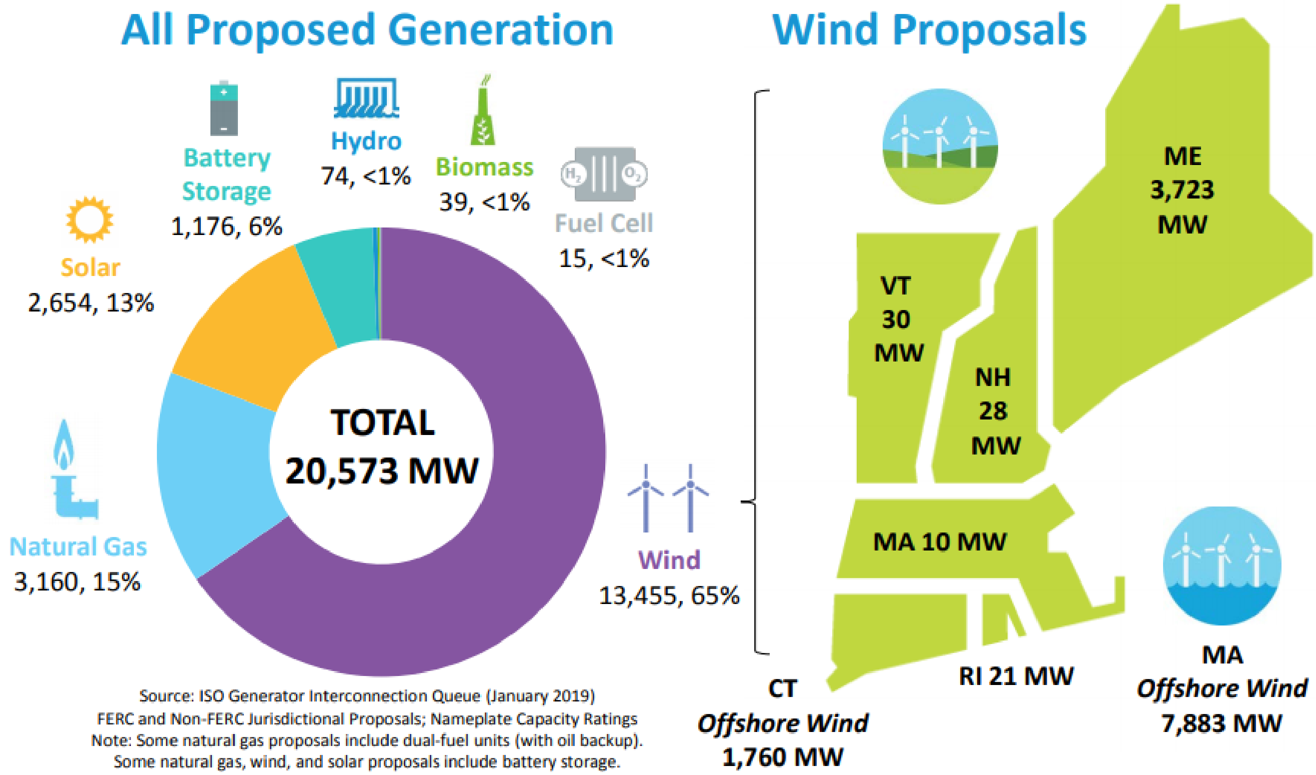
Electricity demand forecast in 2050:
95–140 TWh

Sources: For New England renewables, see: NREL, Renewable Energy Technical Potential, https://www.nrel.gov/gis/re-potential.html. For Imported hydropower, see: EER, et al., Deep Decarbonization in the Northeastern United State and Expanded Coordination with Hydro-Quebec, April 2018. Maps: Copyright © 2019 S&P Global Market Intelligence.

Technical potential for clean energy resources is 10x higher than projected 2050 demand.

2050 Clean Energy Resource Options

Development of these clean energy resources is currently underway across New England



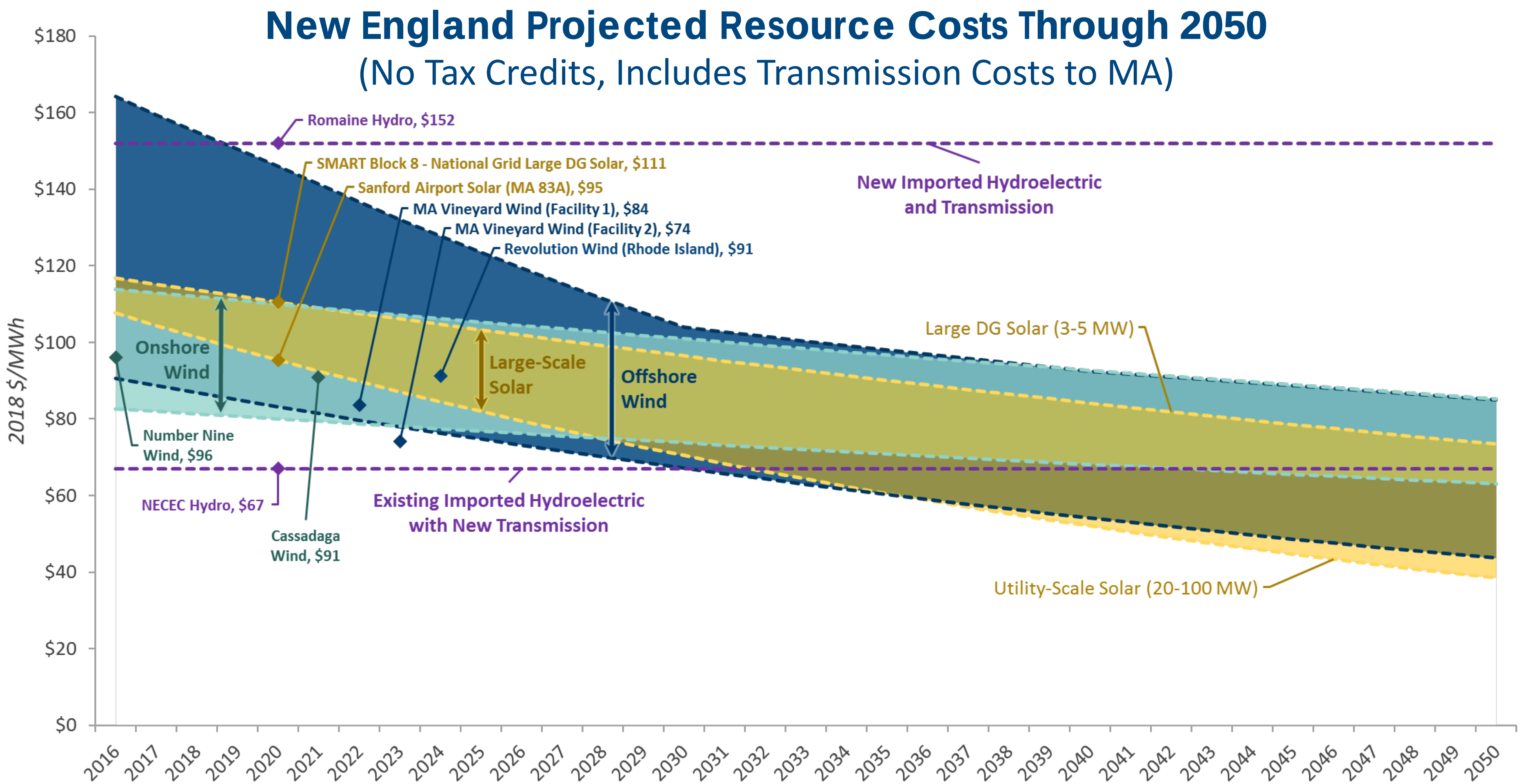
Source: ISO-NE, Resource Mix, https://www.iso-ne.com/about/key-stats/resource-mix, accessed June 28, 2019. Graphic used with ISO New England Inc.'s permission. ISO-NE did not endorse, approve, or author The Brattle Group publications.

Note: Solar PV development tends to be underrepresented because rooftop and small distribution-connected facilities are not required to submit a request to ISO-NE's interconnection process.

While offshore wind is currently the largest source of new capacity being developed in New England, a mix of clean energy resources will be necessary to meet 2050 demand.

2050 Clean Energy Resource Options

Renewable costs decline and remain comparable through 2050; lower cost than new hydro resources



Sources and Notes: Cost ranges for offshore wind from the NREL ATB, for solar from Brattle analysis of recent procurements and SMART, for onshore wind from SEA projections developed for UCS 2016 study and Brattle analysis of recent procurements, and for hydro from Brattle analysis of recent procurements and CLF estimated costs of Romaine and necessary transmission. Onshore wind and imported hydro costs include the costs to build transmission to remote resources: onshore wind = +$10 - $25/MWh; imported hydro = +$25 - 35/MWh. Estimated cost of recent procurements based on Brattle analysis of publicly available PPA prices with adjustments for tax credits and additional revenues from capacity market, assuming cost recovery escalates at inflation (2.5%/year) over 20 year period. See technical appendix for more details.

2050 Clean Energy Resource Options

However, each clean energy resource faces additional constraints that may limit its role

Onshore Wind

- **Transmission needs:** ISO-NE analysis found that an additional 700 MW can be added in northern Maine before transmission upgrades are likely necessary, and states have not agreed on how to plan or pay for the upgrades to the highest quality resources.
- **Local opposition:** ME placed a moratorium on new wind farms in 2018 that was recently lifted.

Offshore Wind

- **Nascent industry:** Large-scale capacity has yet to be built and regulatory hurdles still exist to their development, but New England states procured 1,500 MW by 2025 and are targeting 5,900 MW by 2035. Current BOEM wind energy areas in New England support about 11 GW and DOE is targeting 86 GW nationwide by 2050.
- **Transmission needs:** Transmission is necessary to connect to the existing network and upgrade the network. Integrating 15–24 GW of offshore wind will require about 3,000 miles of lines.

Solar PV

- **Generation profile:** Generates solely during daytime hours and less in winter than summer.
- **System balancing needs:** Significant storage resources will be necessary to match solar output to demand and other clean energy resources needed to meet growing winter demand.

Hydro Imports from Québec

- **Transmission needs:** Additional transmission infrastructure required to import hydro resources from Quebec. Each HVDC line can provide 1,000–1,200 MW of import capacity.
- **Local opposition:** Denial of Northern Pass permit in NH demonstrates challenges to new lines.

Sources: See technical appendix for sources.

Several clean energy resource portfolios could supply the 2050 New England electric system

- Since costs for onshore wind, offshore wind, and solar PV are relatively uncertain and projected to be comparable, other constraints and "integration" considerations are primary determinants of portfolio composition
- To meet GHG goals, natural gas-fired generation was limited to 13 TWh (or 5% of demand) across all scenarios – and could be further decarbonized with use of renewable gas (RNG)

2050 New England Clean Energy Portfolios

Portfolio	Description	Total Supply Capacity	Energy Storage Capacity	Renewable Curtailments
Large-Scale Resources	• Maintain **existing nuclear** • Procure **4 GW** of **incremental hydro imports** • Rely on **large-scale renewables** procurements	145 GW	13 GW	23%
Balanced Portfolio	• **Keep Seabrook** but **retire Millstone** • Add **3 GW** of **incremental hydro imports** • Procure a **mix of wind and solar**	191 GW	28 GW	25%
Local Solar and Storage	• **Limit** large-scale procurements of **nuclear and hydro** • Rely more heavily on **local solar and storage** resources	237 GW	48 GW	27%

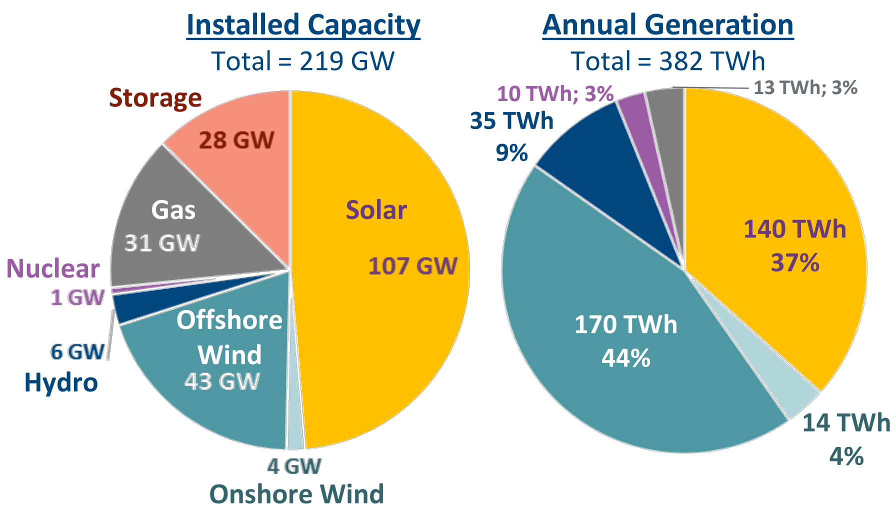
Note: Energy storage capacity estimated based on a 4-hour battery.

2050 Resource Portfolios

A mix of clean energy resources and storage will be necessary to decarbonize the power system

New England Resource Mix

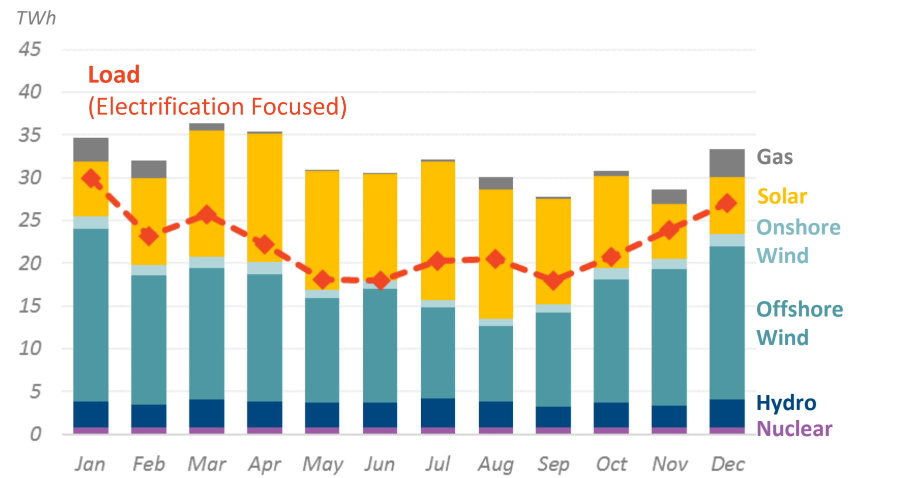
Scenario: Balanced Portfolio



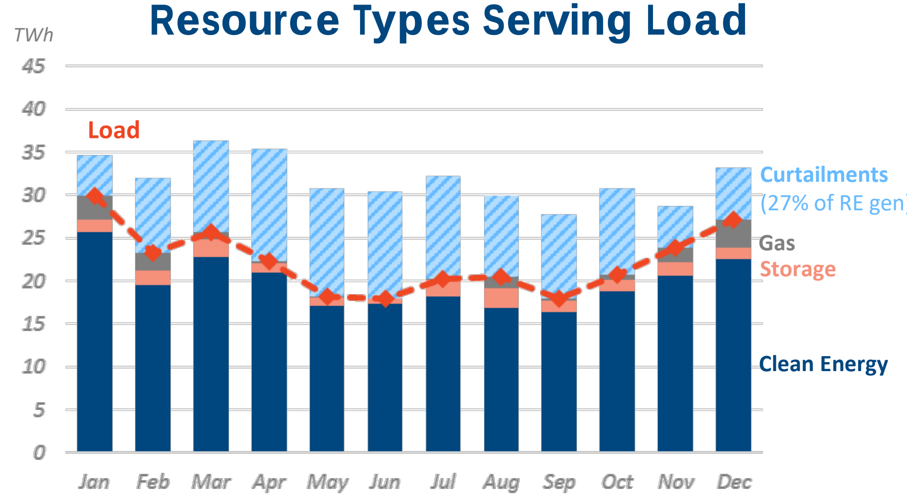
- 107 GW of solar accounts for about 50% of capacity and 37% of generation
- 47 GW of wind, primarily offshore, provides nearly 50% of generation
- 28 MW of storage primarily needed to shift excess solar generation to peak load hours
- 27% of renewable generation is curtailed due to periods of over-generation and limited storage capacity

See Technical Appendix for details on other portfolios.

Monthly Generation by Resource



Resource Types Serving Load



Note: Load includes T&D losses. Curtailments include battery losses.

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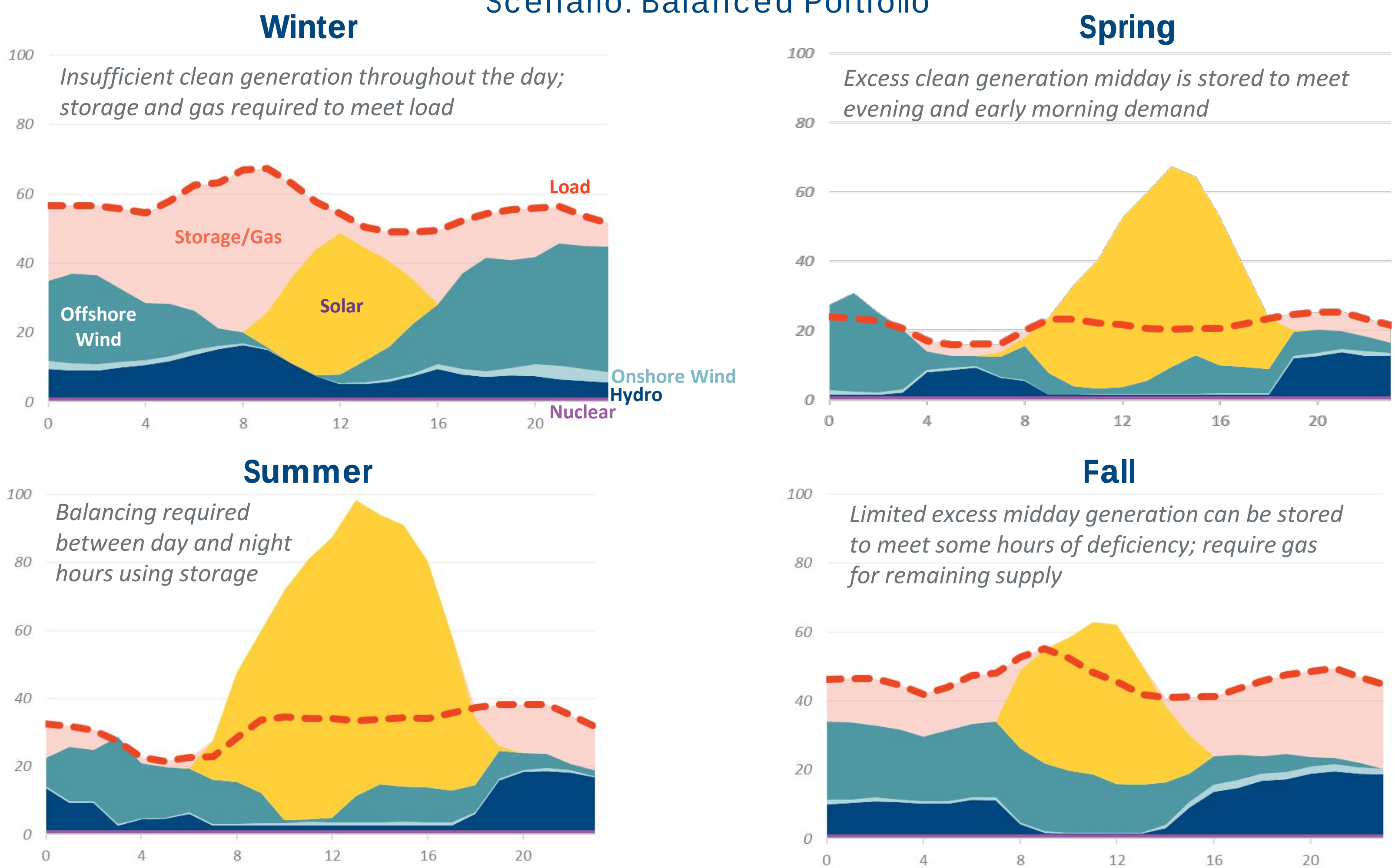
Storage, gas, and hydro will play key roles in balancing system supply and demand

Hourly Electric Sector Load and Supply

Scenario: Balanced Portfolio



Note: The figures show the generation and load profiles during a high demand day of the respective season.

Additional considerations may result in higher or lower capacity needs

Additional clean energy resources and storage may be needed to maintain power system reliability, which will become even more important in a highly electrified future

- Our analysis relies on normalized generation and electricity demand that do not account for tighter system conditions that may occur during periods with low output and high load
- Solar and wind are both susceptible to prolonged periods of reduced generation
- Heating demand could be significantly higher during colder-than-average winters, especially during extended periods of extreme cold temperatures

On the other hand, several factors could reduce clean resource needs:

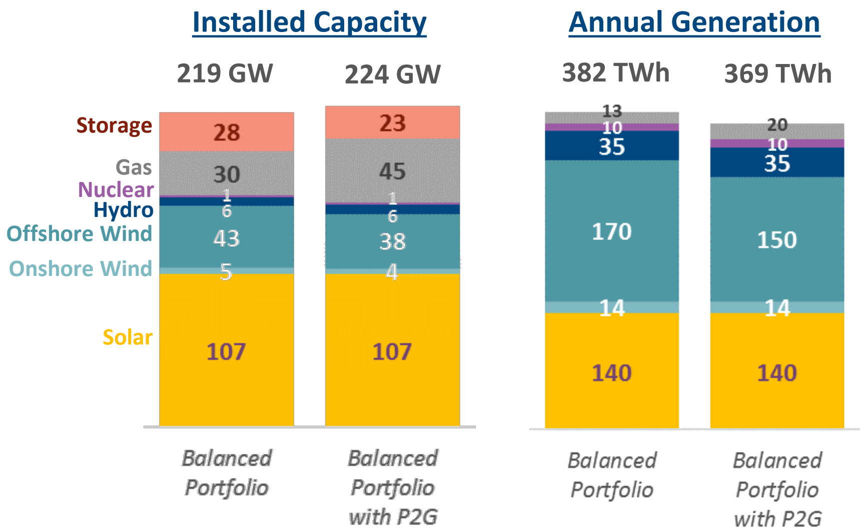
- *Flexible load*: Loads that can more closely follow renewable generation profiles will reduce curtailments, clean energy capacity, and storage capacity
- *Imports/exports*: Transactions that take advantage of variations in renewable generation and demand across markets will reduce the need for local renewable and storage capacity
- *Seasonal storage*: Producing renewable gas from electricity (P2G) during periods of excess generation will reduce curtailments and provide an alternative dispatchable clean energy resource (more on next slide)

2050 Resource Portfolios

Power-to-gas (P2G) could reduce renewable and storage capacity and decrease emissions

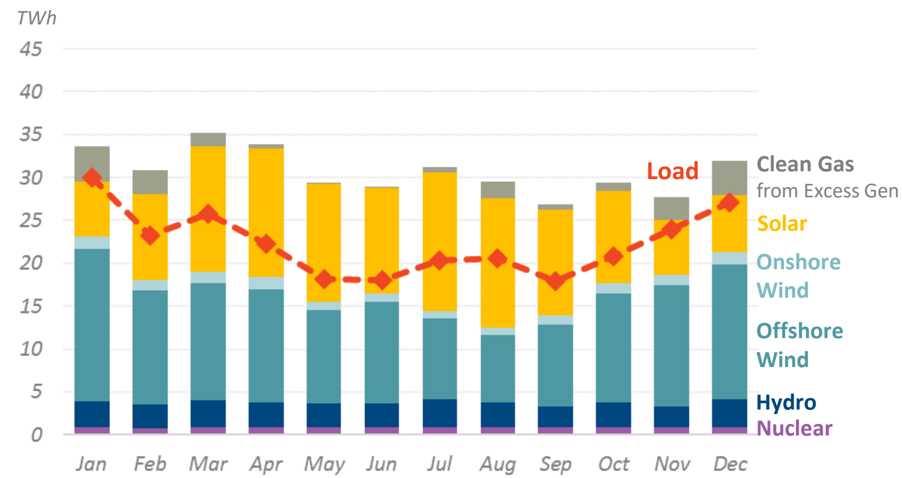
New England Resource Mix

Scenario: Balanced Portfolio with P2G

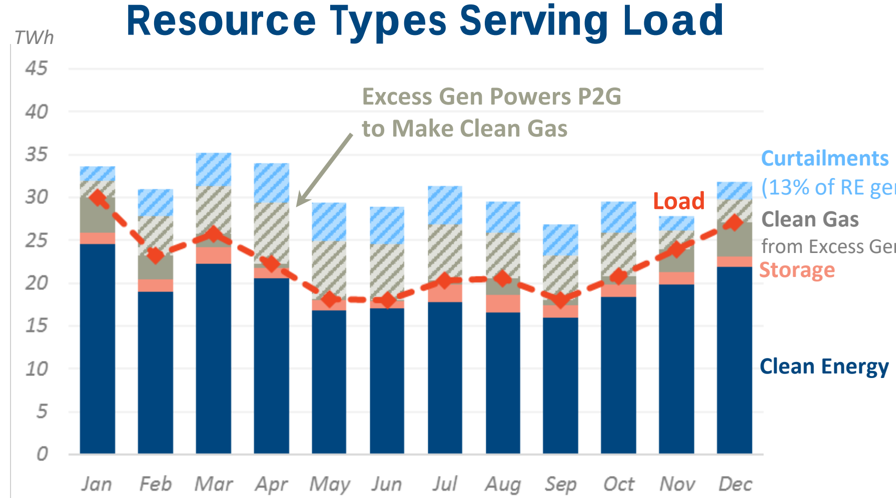


- Excess renewable energy could be used to produce renewable gas (RNG), which can then generate electricity using gas turbines or supply building heating systems
- While inefficient compared to the direct use of electricity (and not yet deployed at scale), significant excess generation may make P2G a cost-effective solution for seasonal storage
- Adding P2G reduces offshore wind by 5 GW and storage by 5 GW, but doesn't fundamentally alter portfolio
- Renewable curtailments are cut in half (27% to 13%)

Monthly Generation by Resource



Resource Types Serving Load



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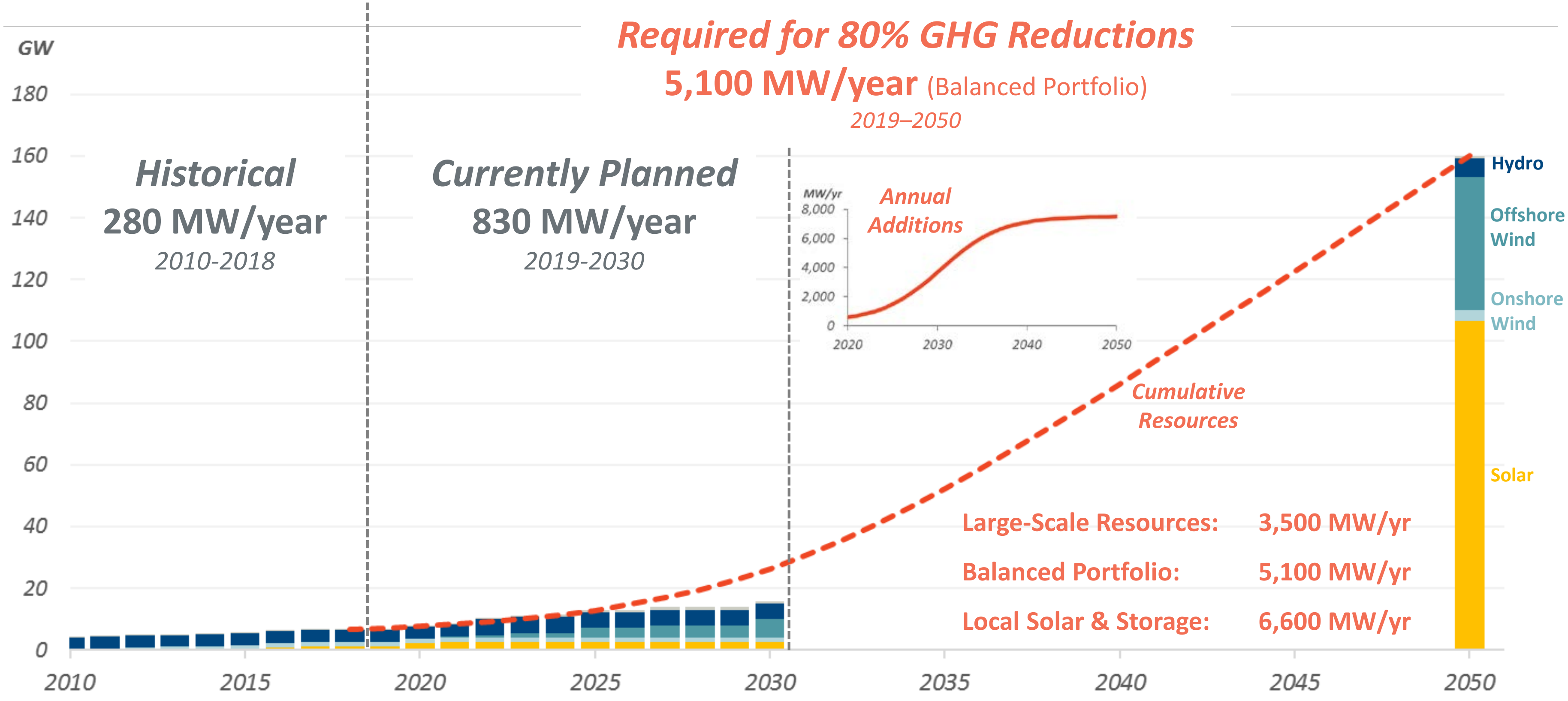
Note: Load includes T&D losses. Curtailments includes battery losses. Assuming 33% round trip efficiency for renewable gas production and electricity generation.

Conclusion

New England must significantly accelerate the addition of clean energy resources

Cumulative Clean Energy Resources in New England



Annual clean energy resource additions need to increase by 4–8x overall

Large-scale solar resource additions will need to increase by 10–25x to meet these goals

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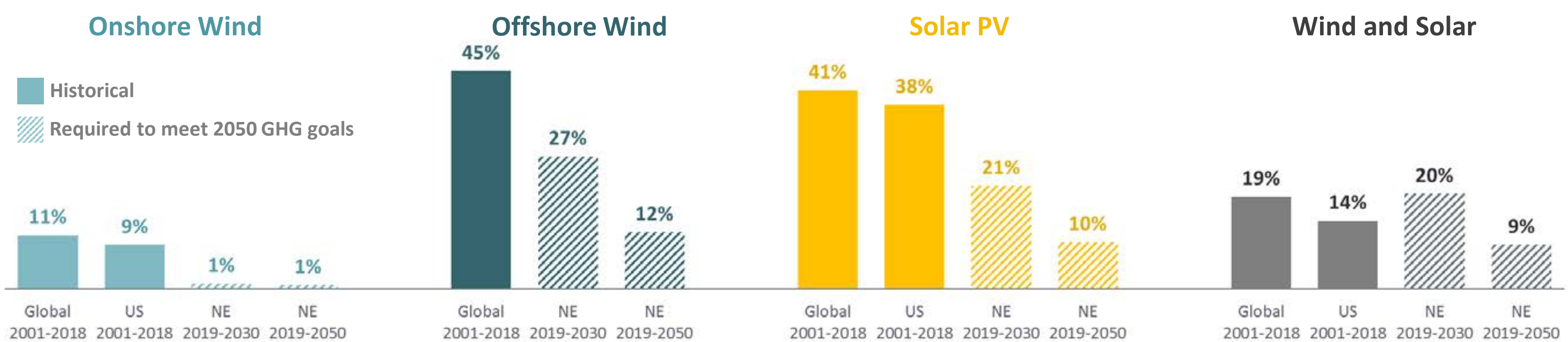
Conclusion

This scale of clean energy additions can be achieved if New England keeps its foot on the accelerator

- A portfolio of 160 GW of clean energy resources by 2050 with an average life of 25 - 30 years and 1% annual growth thereafter imply a "steady state" industry that would **replace and build** about **7.5 GW of capacity a year from 2050 onward**, or 9x the annual planned installations of **800 MW per year** in the near-term
- This implies a growth rate of annual installations of 20% per year through 2030 and 9% per year overall between 2019 and 2050
- While ambitious, this rate of growth is similar to or smaller than the growth of global annual renewables deployments over the past 20 years, which have averaged **11% per year** for wind, **45% per year** for offshore wind and **41% per year** for solar PV

Growth Rate of Annual Capacity Additions



Source: IRENA, Renewable Electricity Capacity and Generation Statistics, July 2019. Note: New England ("NE") bars represent the needed annual growth in the Balanced Portfolio to achieve 2050 goals.

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Dr. Jurgen Weiss is an energy economist with 25 years of consulting experiences. He specializes in issues broadly motivated by climate change concerns, such as renewable energy, energy efficiency, energy storage, the interaction between electricity, gas, and transportation. He spearheads Brattle's electrification efforts. He works for electric utilities, NGOs, and government entities in North America, Europe, and the Middle East. Dr. Weiss holds a Ph.D. in Business Economics from Harvard University, an M.B.A. from Columbia University and a B.A. from the European Partnership of Business Schools.

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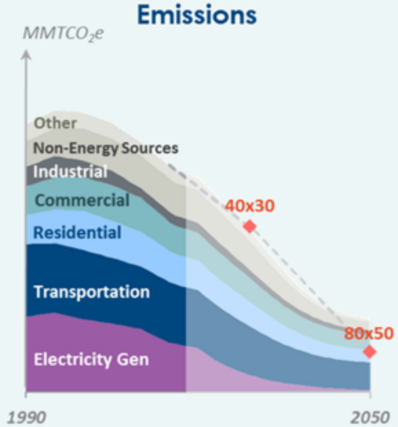
Mr. John Michael Hagerty is a Senior Associate with experience in analyzing electrification, state and federal renewable and climate policies, and the New England wholesale electricity markets. Michael's experience related to deep decarbonization and electrification includes analyzing the California carbon market, estimating the scale of transmission needs in an electrified future, and estimating the benefits and costs of electrification. Mr. Hagerty holds a M.S. in Technology and Policy from MIT and a B.S. in Chemical Engineering from the University of Notre Dame.

Brattle's Decarbonized Energy Economy (DEEP) Model

DEEP is an economy-wide energy and emissions model designed to investigate the implications of decarbonization policies. DEEP includes a bottom-up analysis of electrification and other approaches, such as energy efficiency, to achieve decarbonization mandates and simulates how these changes impact hourly electric load. DEEP then identifies investments in clean resources (e.g., renewables) and dispatchable resources (e.g., combustion turbines or battery storage) to reliably balance and operate the system. It is designed for rapid investigation of many scenarios and sensitivities.

Step 1
Identify required economy-wide de-carbonization

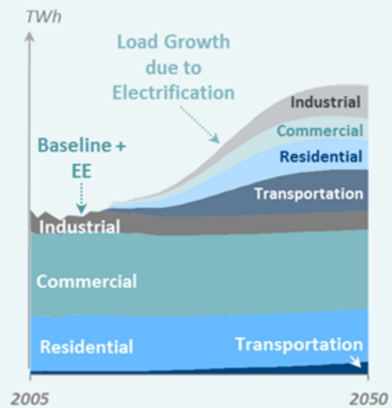
Economy-wide GHG Emissions



State sets **GHG emissions targets** to address climate change

Step 2
Evaluate implications for electric load

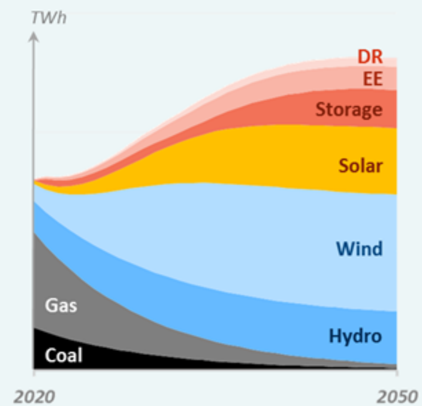
Load Forecast



Demand is driven by electrification needs triggered by the GHG goals

Step 3
Evaluate generation mix to de-carbonize electric sector

Supply Mix



Increase in **supply resources** needed to match higher electric demand

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