Resource Adequacy Benefits of Offshore Wind

Executive Findings

November 6, 2025

CRA Charles River Associates

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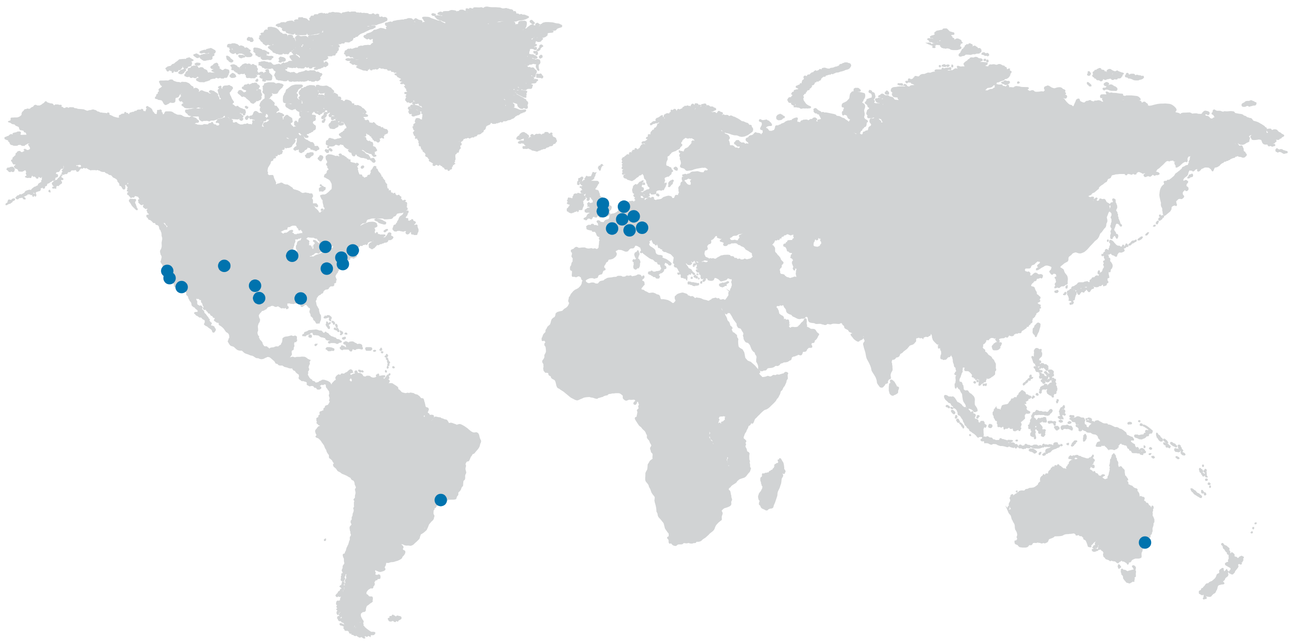

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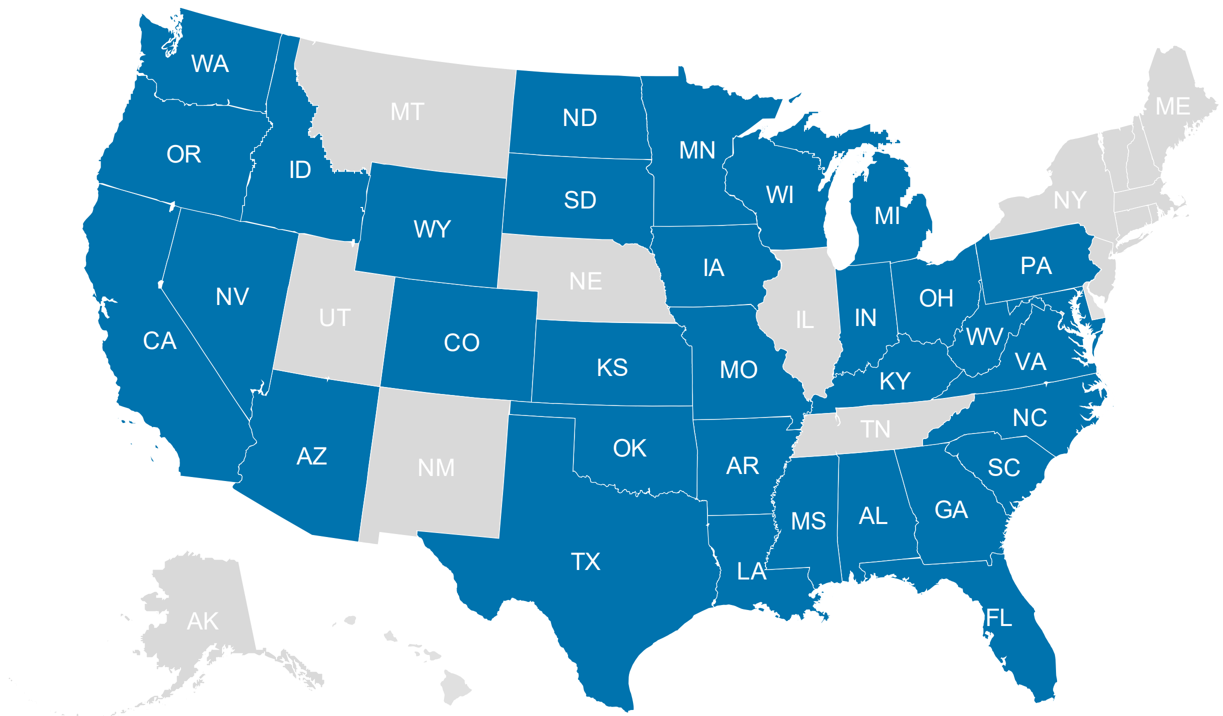
CRA offers resource planning support to utilities across the country

In recent years, CRA has supported electric, gas and combined IOUs and POUs in more than 30 states to address market forecasting, strategy, and investment planning questions.

States Where CRA Has Recently Supported Utilities in Strategy, Resource and Investment Planning



Client Examples

NiSource
Dominion Energy
Alliant Energy
PG&E
Southern Company
Great River Energy
FirstEnergy
Liberty
CPS Energy
Minnkota Power Cooperative
A Touchstone Energy® Cooperative
entergy
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OSW can help solve imminent risks

No single technology can fully support projected load growth. While OSW faces development challenges, it offers meaningful potential to strengthen reliability and complement other system investments

1

Reliability risks imminent without urgent action

Load growth has outstripped net addition of accredited capacity. Risks are shifting to winter.

2

OSW shows synergies with emerging risk profile

OSW's strongest output aligns with times of greatest system stress. It can be developed offshore in constrained regions and help harden gas systems.

3

OSW less competitive on LCOE, but LCOE misses full story

LCOE does not capture OSW's reliability and locational benefits.

4

OSW's ELCC is competitive but will decline

OSW's ELCC is strong but expected to decline with higher penetration.

Resource adequacy concerns are emerging on the market, raising concerns among policy makers and driving up capacity prices

> **“This country … is heading for a reliability crisis caused by early retirements of dispatchable resources coupled with the failure to construct sufficient equivalent capacity, all while demand rises at an unprecedented pace largely driven by data-center growth.”** – Mark Christie, Former FERC Chairman[1]

Growing demand, particularly in Winter

Load is growing rapidly

- Load growth is driven by domestic growth in strategic industries – including data centers and semiconductors – and electrification
- Forecasts for data center growth range from 33 GW to 109 GW[2]

Load is growing faster in winter than in summer

- Multiple markets are projected to become winter peaking and/or winter-constrained

Infrastructure & Supply Chain Constraints

Natural gas supply chains are stressed

- Increased wait times and costs for turbines

Strain on existing infrastructure

- Existing infrastructure is at or near limits in some regions, particularly downstate NY and New England. Other regions have plentiful pipeline capacity

Bringing new resources is challenging

- Interconnection and permitting for all resources are complex, with delays of 3-5+ years common

Real world consequences

Capacity prices are rising nationally

- Multiple markets saw increases in 2025, with MISO and PJM seeing 210% and 22% increases

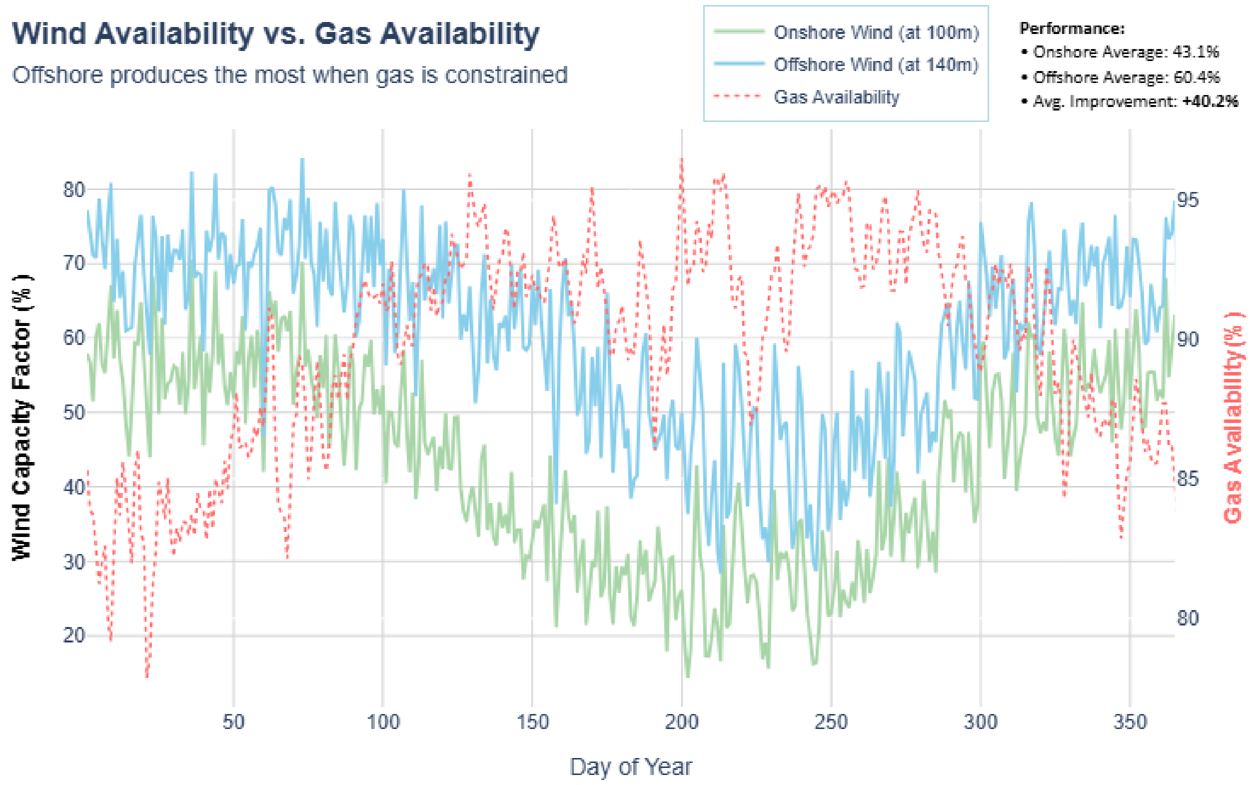
Weather-driven stress events are more frequent

- Over 11 years, five cold weather events jeopardized the electric grid or caused outages, particularly Winter Storm Uri and Elliott.[3] Performance has improved recently, but common-cause failures remain a concern.[4]

Sources:
1. Dissent from ER25-1674-000
2. DOE Report on Reliability
3. NERC Winter Reliability 2023-2024
4. NERC Winter Reliability 2024-2025

OSW can play a meaningful role in maintaining resource adequacy and augmenting investments made in transmission and other generating technologies

OSW brings strong generation to fill emerging high stress hours when NG and solar are at their lowest generation



Strong year-round generation, but greatest output during **highest stress hours**

Strategic siting near transmission- and natural-gas growing coastal load pockets

Fuel diversity increases resilience to common-cause outages

80 GW in queues to meet short-term growth while wider investments materialize

Sources:
1. NREL Wind Tool Kit
2. CRA Analysis

Resource adequacy ensures there is enough – and the right kind of – generation

Resource adequacy is one element of maintaining grid reliability.

Resource adequacy ensures the generator portfolio mix can maintain reliability across a wide range of conditions.

If there is insufficient generating capacity in a given hour, operators will perform **load shedding**, intentionally disconnecting load, to maintain the stability of the grid.

Historically, load shedding risks were limited to a small number of peak hours, but it is increasingly spread across a range of hours.

Utility planners are incorporating increasingly complex planning methods to evaluate the resource adequacy of potential generation mixes. These models include the factors listed below.

Generator outages

Planned and unplanned

Load Uncertainty

Weather variability

Renewable variability

Weather variability

Extreme weather

Multi-hour and multi-day events

Common cause outages

Disruptions in fuel supplies

Load is growing and load shapes are changing due to data center development; manufacturing onshoring; and electrification of industry, heating, and transit

Data centers powered by AI boom

Hyperscale data centers are driving up electric demand. A single data center can now bring GWs of new demand versus 10s-100s of MWs from a typical factory.

Onshoring of critical infrastructure

Policy makers have prioritized onshoring of key manufacturing sectors, including semiconductors manufacturing. These sectors require abundant, reliable electricity.

Electrification of transit and heating

Electrification is occurring due to state policy objectives and consumer choice. Higher load growth is occurring in winter months.

Electrification of manufacturing

Legacy industries are choosing to electrify to reduce costs, attract investors and customers, and achieve internal decarbonization targets.

Electricity demand is growing across the country. The future grid will also have more consistent demand across all hours and in higher growth in winter versus summer months.

Nationally, the grid is facing new challenges due to changing load and resource dynamics

Load Growth

Data centers, manufacturing growth (semiconductors and others), and electrification are driving load growth

Higher winter load and stress

Many systems are becoming summer peaking, but winter constrained

Changes in resource mix

Shift toward natural gas, solar, storage, and wind

Greater spread in risk hours

Historically risk concentrated in peak hours; now risk spread across wider range of hours

Common cause outages

Winter Storms Uri and Elliott highlighted risk of correlated outages in cold weather

Strains on bringing new resources

Disruptions to supply chains and interconnection delays have slowed additions of new resources

Meeting the moment

Energy leaders are investing in infrastructure and developing new approaches for maintaining reliability

ELCCs represent the contribution of a resource toward meeting a desired RA standard (LOLE or EUE)

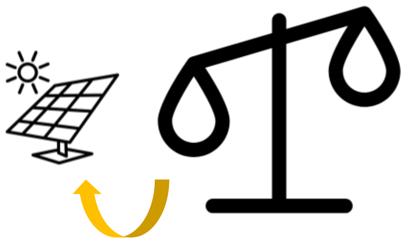
ELCCs represent the contribution of resources during the **riskiest hours, which are not always peak gross load hours**

Step 1:

Base Case:
LOLE = 0.1 days/year
EUE = 0.002%

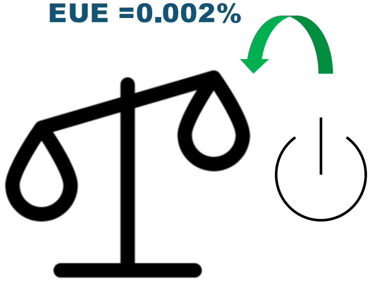
Step 2:

Generation Removed:
LOLE > 0.1 days/year
EUE > 0.002%



Step 3:

Perfect Gen Iteratively Added:
LOLE = 0.1 days/year
EUE =0.002%



Step 4:

Compute ELCC:
LOLE = 0.1 days/year
EUE = 0.002%

$$\frac{\text{Added Perfect Gen}}{\text{Nameplate Generation}} \rightarrow \textit{Average ELCC}$$

Loss of Load Expectation (LOLE): measures how often load shedding occurs

- Systems are typically planned to 0.1 LOLE days per year, which represents an expected one day in ten years with at least one loss of load event of any magnitude and for any duration
- Most common metric used to compute ELCCs and PRMs

Expected Unserved Energy (EUE): measures the size of load shedding over the entire year

- Emerging as an alternative to LOLE
- Systems are typically planned to an EUE metric; **0.002%** normalized EUE is emerging as a popular target
- As with LOLE, ELCC values can be computed using EUE as the target metric

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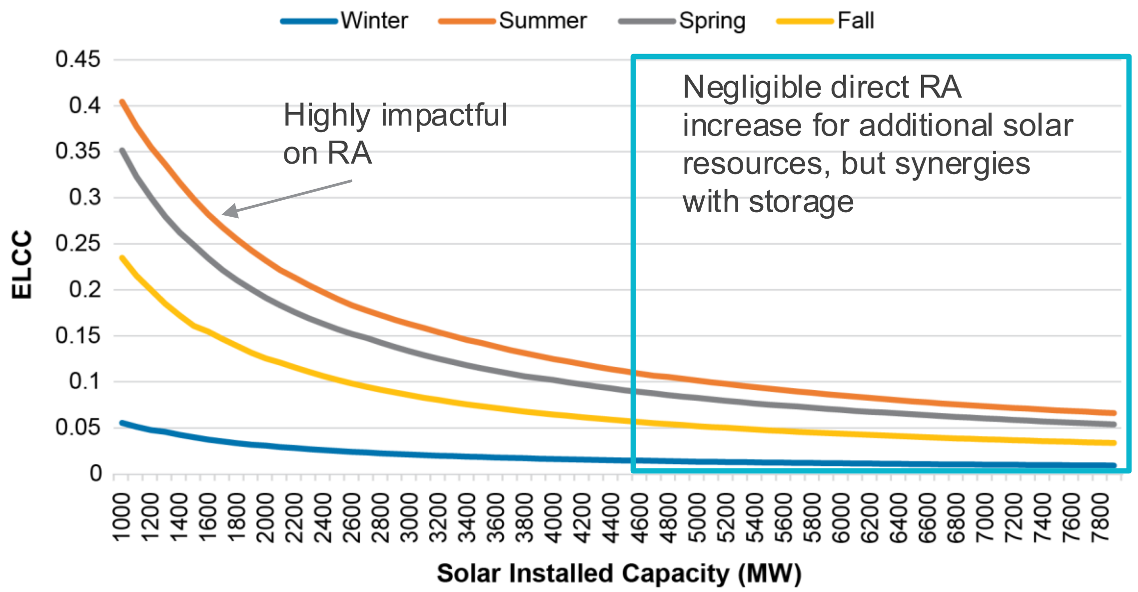
ELCCs capture a technology's contribution toward maintaining grid reliability

Average vs Marginal ELCC

- **Average ELCC** computes the average contribution across all the resources of a technology type toward meeting a reliability target
  - Varies across seasons
- **Marginal ELCC** measures the contribution of the next additional MW of a technology type
  - Useful for providing a forward signal for the technologies needed to mitigate risky hours
  - Typically, sharply higher declines than average ELCC
- Note, we cannot compare ELCC values between methods, but can compare relative performance between technologies

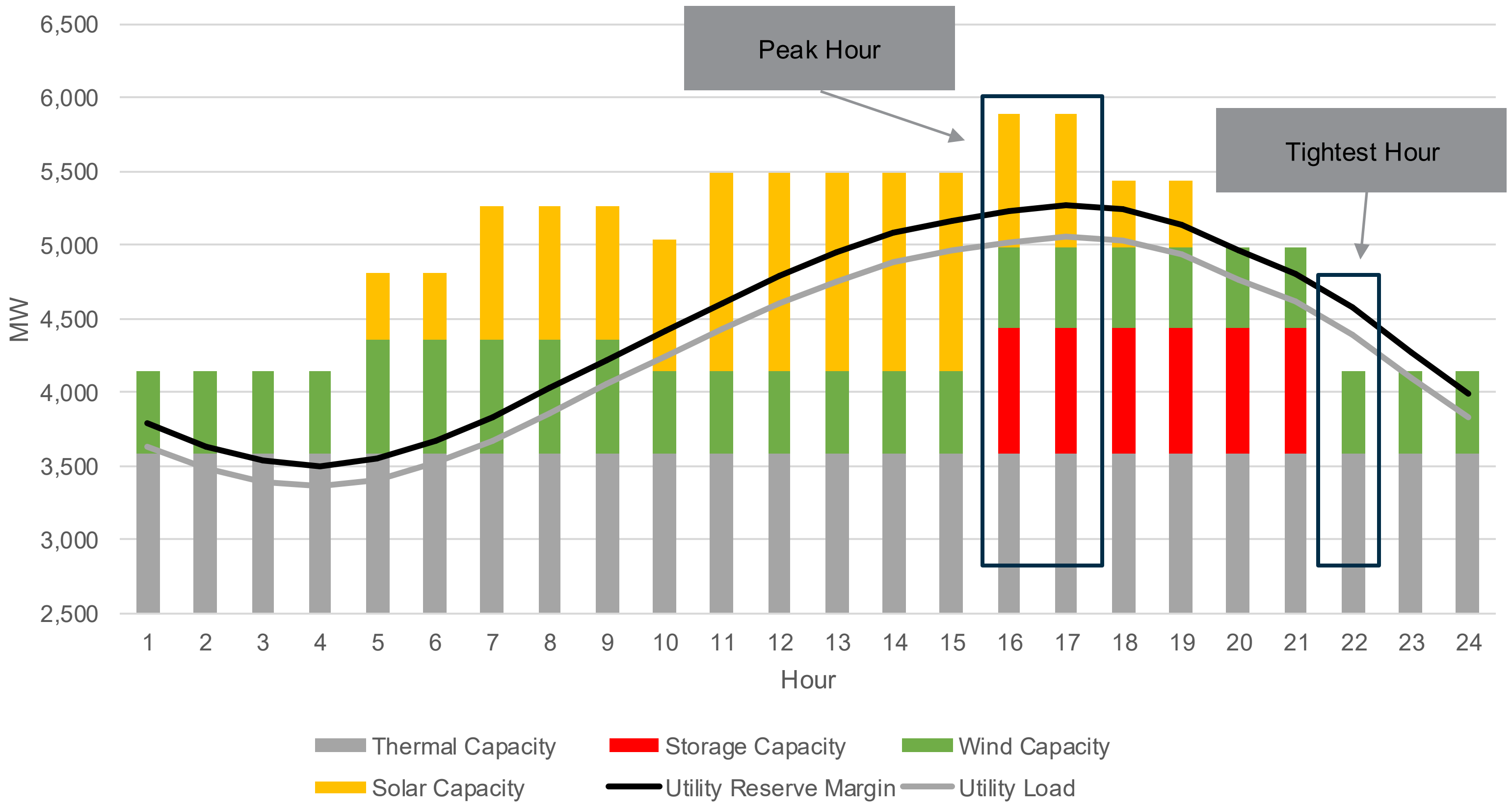
Illustrative Example: Average Seasonal ELCC



Why do ELCCs decline?
ELCCs decline with penetration – particularly for marginal ELCC - because each added MW overlaps less with remaining risk periods. Declining ELCCs do not capture the benefit of earlier MW additions.

Source
Introducing CRA AdequacyX

ELCC values of a resource declines as the riskiest hours shift



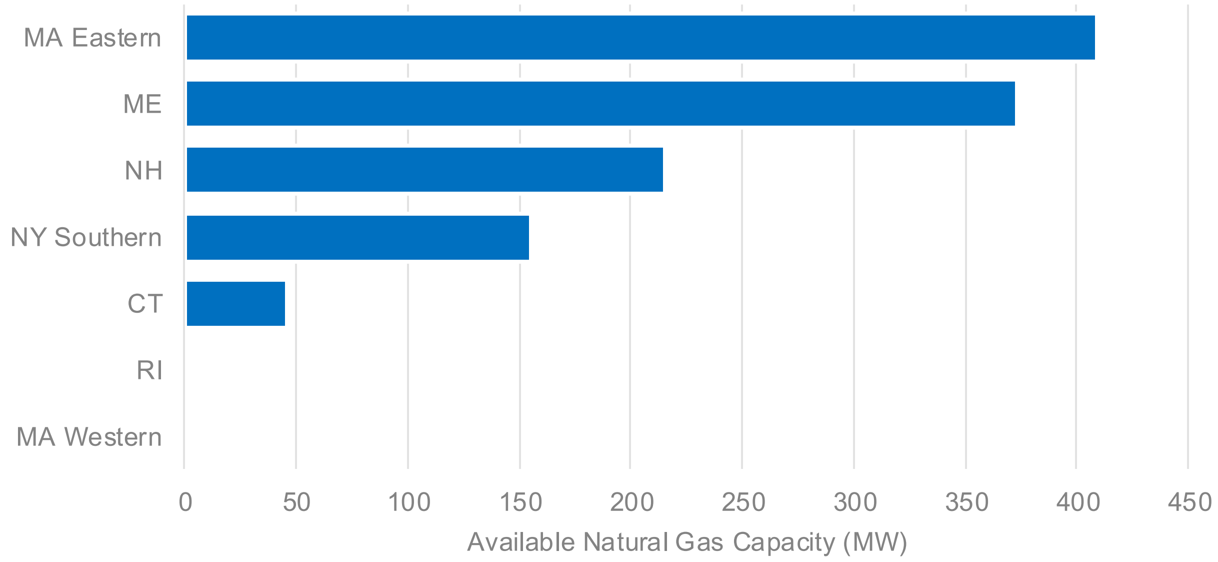
ELCC values are highest for resources which generate during high risk hours. **Increasingly, high risk hours are not restricted to high load hours.**

Renewable generation can be a victim of its own success; as it shifts risk to hours where its generation is less, its ELCC value decline.

Legacy technologies are critical to supporting load growth, but each tech faces challenges

Status & Challenges	
Onshore Wind	Strong winter performance reflected in modest ELCCs, but best sites are located **far from coastal load pockets**
Solar	Increasingly cost competitive and leading resource in interconnection queues, but **lowest ELCC values**
Storage	Moderately high ELCCs, but net energy consumers and may be **limited during long-duration**, winter events
Natural Gas	Backbone of grid, but long lead time, **cold weather generator outages, and fuel constraints in NE are concern**
Other	New coal unlikely (except for uprates), next-gen nuclear or geothermal likely cannot be developed in time to meet near-term growth

There is limited headroom on existing gas infrastructure to add new gas generators with firm contracts in the Northeast



From stakeholder feedback, Gas EPCs state that adding new natural gas resources is more challenging and expensive

Stakeholders pointed at strained supply chains, lengthy permitting process, and limited labor pools as key pain points. Manufacturing capacity is operating close to 90%, and prices have tripled between 2022 and 2025.

Sources:
1. https://gasoutlook.com/analysis/costs-to-build-gas-plants-triple-says-ceo-of-nextera-energy/
.2. CRA Analysis

Reliability risks facing the country are real, as load growth has outpaced additions of net new resources

Multiple markets across the country face **imminent resource adequacy risks.** ELCC can measure a technology's ability to help solve risks.

Emerging grid risks look different than historical risk. Risk is spread over a wider range of hours and not necessarily during periods of peak demand.

Legacy technologies – particularly natural gas – are critical to maintaining reliability. However, supply chains and **existing infrastructure are stressed.**

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Various analytical approaches and metrics can be used to evaluate costs

Levelized cost of energy (LCOE)

Purpose: Simplest and most common cost comparison metric (e.g., $/MWh)

Covers: Capital + fixed + variable O&M + fuel costs per unit of energy generated

Limitations:
Excludes **transmission costs** (sometimes) and **system interactions**

- Ignores **capacity value** (a resource's ability to contribute to planning reserve margins and periods of grid stress)
- Treats each technology in isolation

Normalized LCOE

Purpose: Adjusts LCOE to reflect both **energy and capacity** value to show an effective LCOE per accredited MW

Covers: LCOE divided by ELCC

Limitations:
Excludes **transmission costs** (sometimes) and **system interactions**

- Still treats technologies in isolation and neglects interactions between resources

Integrated resource planning & bill analysis

Purpose: Consider the full cost of a resource mix on a portfolio-wide basis

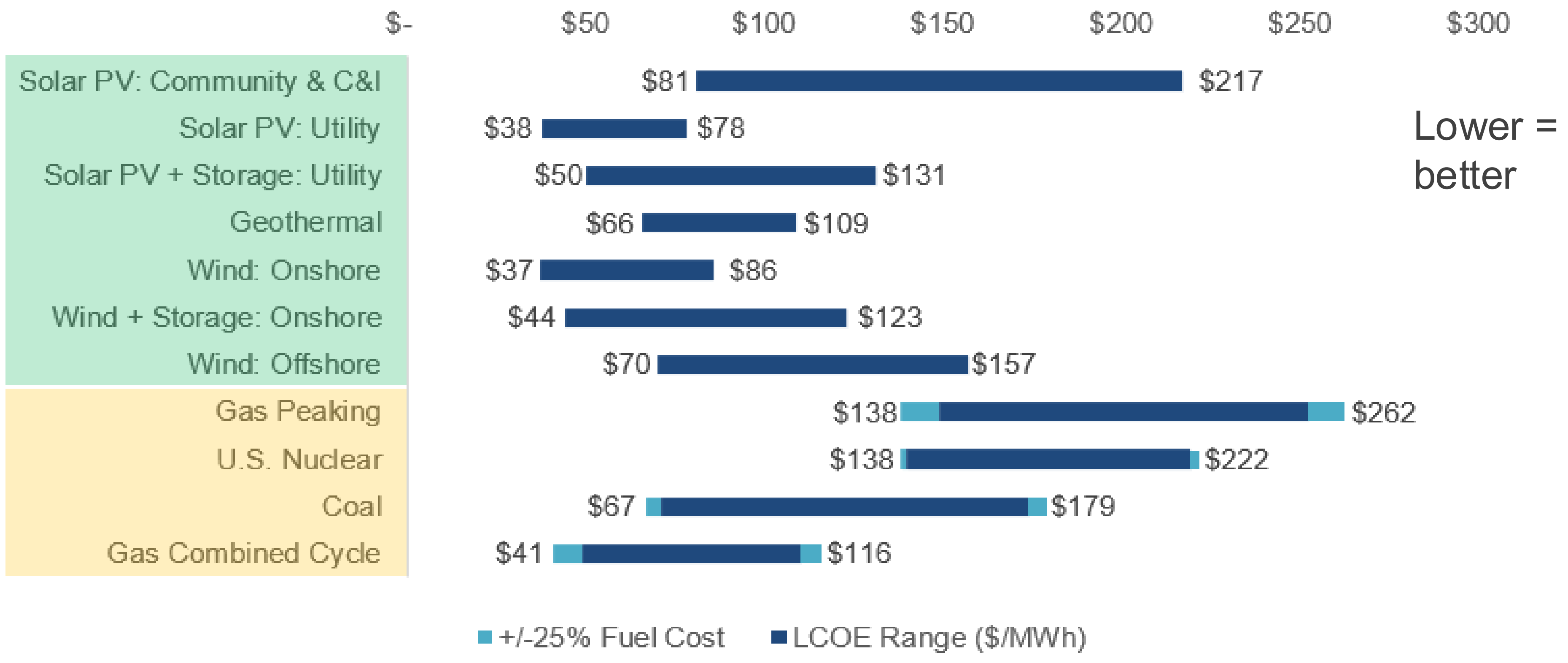
Covers: Energy, capacity, transmission costs, policy requirements, and interactions between technologies

- **Bill analysis** can convert portfolio-wide decisions into impact on customer bills

Limitations:
Challenging to compute and difficulty translating the impact of a single technology on cost

This white paper used LCOE and N-LCOE to evaluate the costs of OSW, but further analysis is needed to fully compare the cost impact of OSW

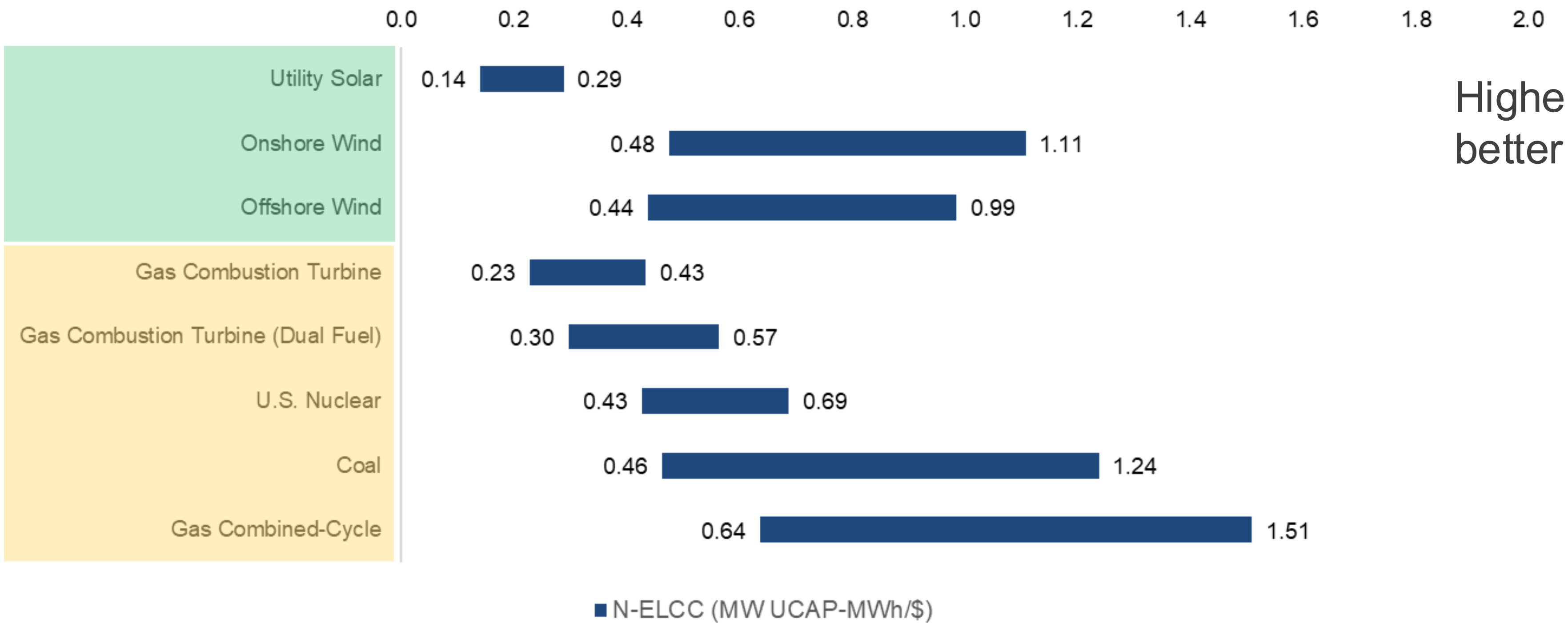
OSW's cost competitiveness using Lazard's LCOE varies project-by-project



On an LCOE basis, OSW is generally more expensive than other renewables, but cost competitive with thermal resources

Sources:
1. Lazard's LCOE+

Using ELCC values from PJM, OSW has competitive performance on an N-ELCC basis, where a higher value indicates better performance



Higher = better

Discrepancies between LCOE and N-LCOE results highlight the limitations of using LCOE alone

Sources:
1. Lazard's LCOE+
2. PJM 2026/2027 BRA
3. CRA Analysis

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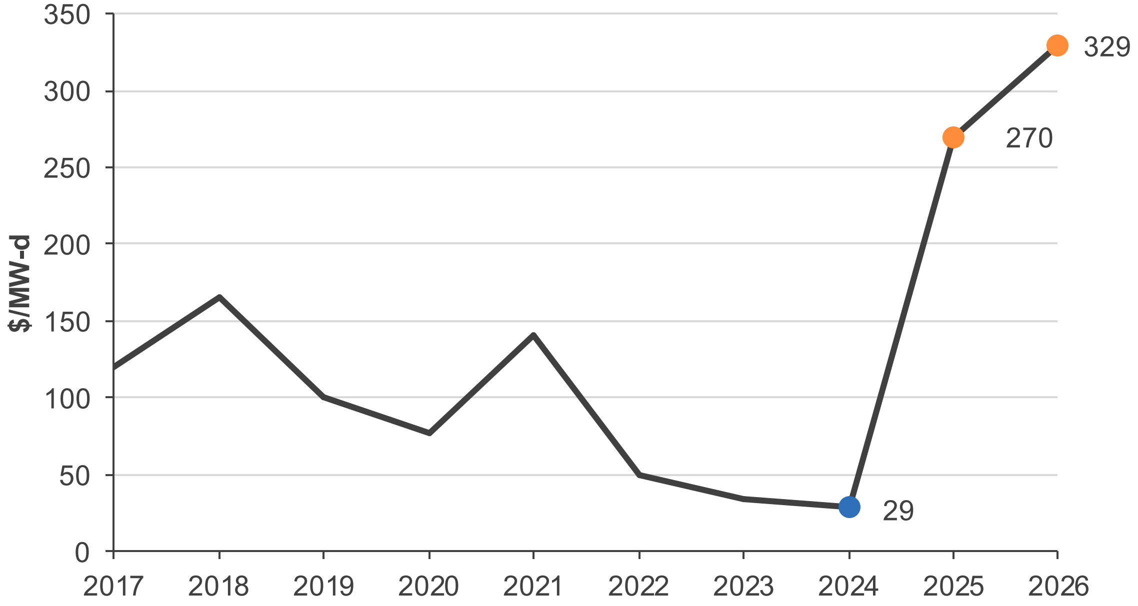
Nationally, markets are tightening; OSW is a potential resource to solve emerging gaps

PJM	NYISO	ISO-NE
Challenges: Among the steepest load growth in the United States, driven by data centers. Risk now concentrated in winter months. Slow interconnection queues dominated by solar and storage. **Role of OSW:** Scalable near-term option in coastal zones. ELCC = 69% in latest auction—higher than many storage and thermal resources.	**Challenges:** Transitioning to winter-peaking by late 2030s. Constrained natural gas infrastructure. Downstate congestion and retirement of peakers driving localized risk. **Role of OSW:** Highest accreditation of renewables (CAF ~32%). Delivers directly into downstate load pockets (NYC, Long Island). South Fork currently online. Several projects have been cancelled or face uncertain futures due to cost pressures and permitting uncertainty.	**Challenges:** Winter peak growth 3x summer. Gas pipelines fully utilized in heating season. Storage vulnerable during prolonged cold snaps. **Role of OSW:** Accreditation projected at >90% in some studies, rivaling thermal resources. Block Island currently online. However, delays and uncertainty around key OSW projects, including Revolution Wind, due to stop-work order.
CAISO	**ERCOT**	**International**
Challenges: Summer peaks remain binding. Aggressive decarbonization targets accelerate solar/storage buildout. Managing the “duck curve” as solar drops off in evenings. **Role of OSW:** Coastal winds strongest in late afternoons/evenings. Complements solar, reduces need for storage, scalable in-state resource.	**Challenges:** Peak demand projected to nearly double by 2044. Ongoing exposure to extreme weather and natural gas disruptions. **Role of OSW:** Offshore faces cost barriers, but diurnal trends and strong winter performance gives indicator of OSW’s potential role.	**Challenges:** Rising reliability and affordability crises due to age, economics, and policy driven retirements of coal and nuclear resources and geopolitical instability from the Russia-Ukraine war. **Role of OSW:** Commercially mature technology. Viewed as cornerstone of adequacy strategy by leaders in the U.K., Germany, and Denmark. Built at multi-GW scale with streamlined permitting and experienced developers.

PJM has seen a sharp uptick in capacity prices and growing reliability risks due to tightening markets

PJM capacity auction for delivery year 2025/26 cleared at ~9x the previous price. 2026/2027 auction further grew by 1.2x



Reduced Supply:

- Between **2012 – 2022**, PJM retired **47 GW of mostly dispatchable resources** (coal, diesel, gas)
- 94% of the queue is composed of solar and storage resources

Growing Demand:

- PJM's **2025 Load Forecast** projects **+55 GW in summer** and **+62 GW in winter** peak demand over the next decade — among the highest growth rates in the U.S.

Market Rule Changes:

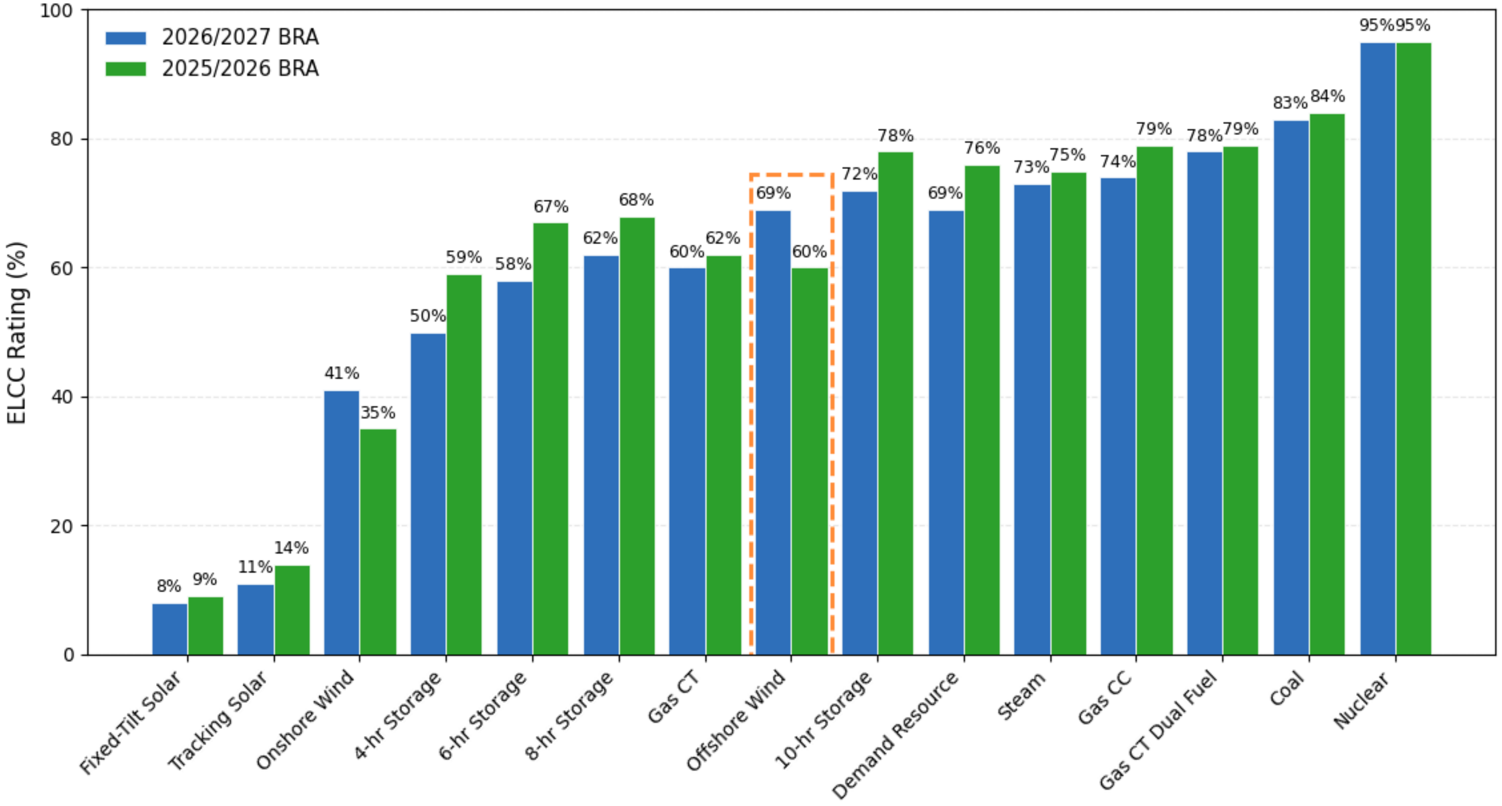
- Changes in the PJM approach to capacity accreditation which place a greater emphasis on winter performance to mitigate emerging periods of high stress

Growing reliability risks, particularly in Maryland and Virginia

- DOE and PJM have warned of risks if new, high ELCC resources are not interconnected to the system

Sources:
1. PJM 4R report
2. CRA Analysis
3. PJM 2025/2026 BRA Report
4. PJM 2026/2027 BRA Report

OSW represents an additional, high ELCC resource that can be directly connected to strained coastal regions



OSW's ELCC of **69%** outstrips 8-hr storage and CTs (without dual fuel).

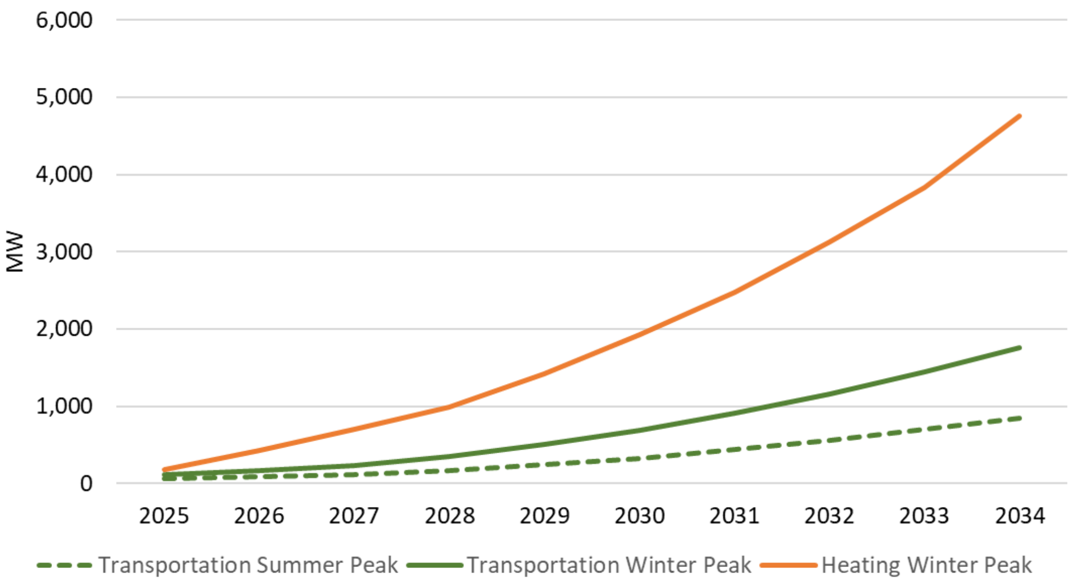
Wind ELCCs increased approximately 15% between auction years due to increasing shift to winter risk.

The Coastal Virginia Offshore Wind Project shows OSW's potential to deliver clean energy at scale to key stressed regions, **Dominion and BGE.**

Sources:
1. PJM 2025/2026 BRA Report
2. PJM 2026/2027 BRA Report

ISO-NE faces significant stress on natural gas fuel supply in winter

ISO- NE has substantially higher winter load growth than summer load growth due to electrification of heating



Growing winter constraints

- ISO-NE's winter load growth is projected to meaningfully outstrip summer growth
- Growth will occur during the strained, coldest days
- ISO has raised concerns on the ability to recharge storage resources on multi-day cold weather events

Fuel risks:

- Warnings from utilities, NERC, and Northeast Power Coordinating Council about stress on NG system
- Limited capacity to import natural gas
- The region is reliant on LNG port and trucking for fuel

Coastal load pockets

- Load is concentrated near coastal regions and near Boston, far from the areas with highest onshore wind potential

Policy uncertainty

- ISO-NE is counting on advanced OSW projects, like Revolution Wind. Limited time to pivot to alternatives if these are delayed or canceled.

Sources:
1. ISO-NE CELT
2. *2021 Economic Study: Future Grid Reliability Study, Phase*
3. https://www.eia.gov/todayinenergy/detail.php?id=62404
4. Northeast Gas/Electric System Study, 2025
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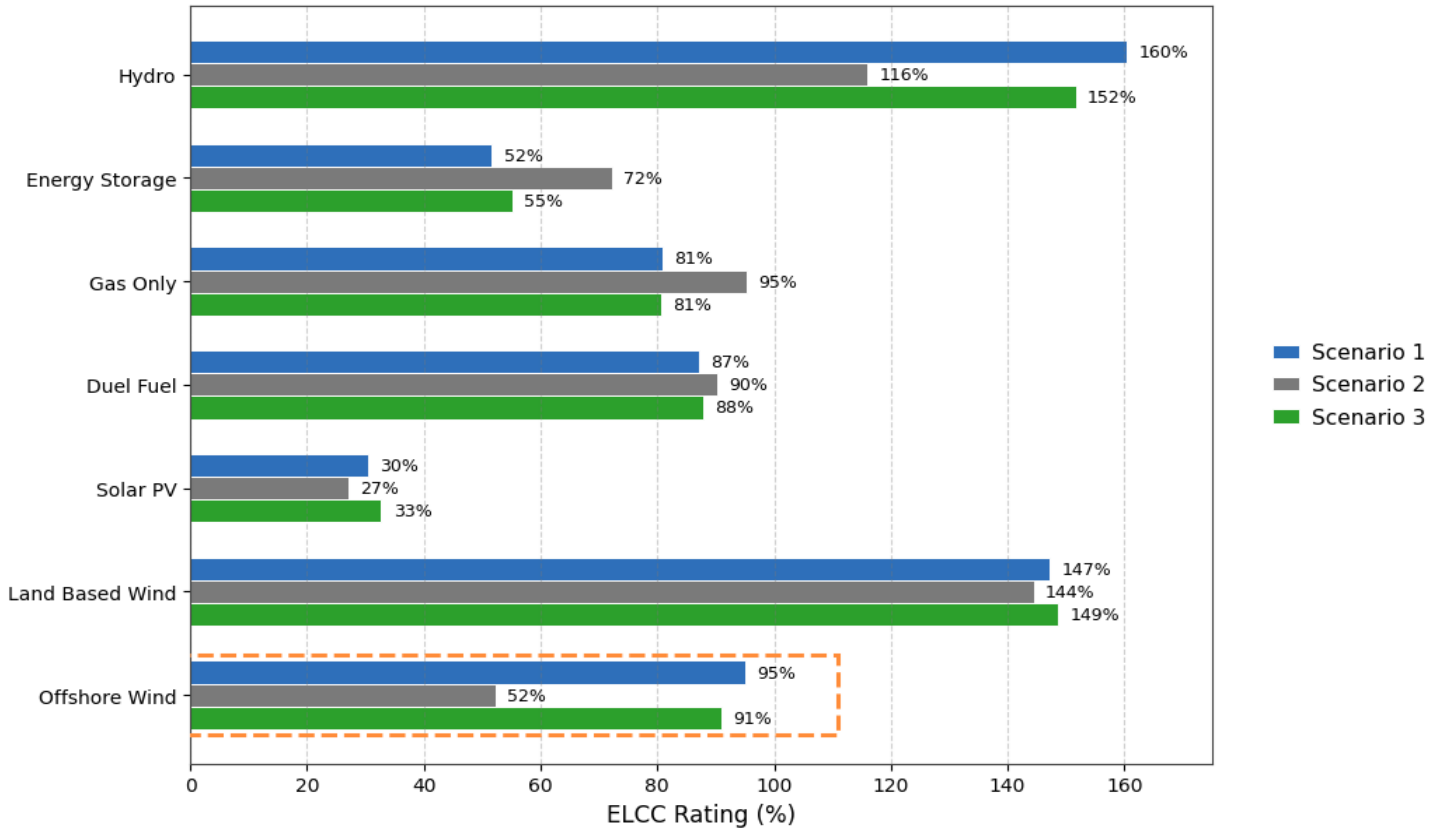
ISO-NE ELCC values are high for initial investment, but decline as the technology becomes mature



OSW is competitive with thermals at lower penetration (1 GW), but declines as OSW becomes mature (3.3 GW) and **shifts risk from high wind hours**

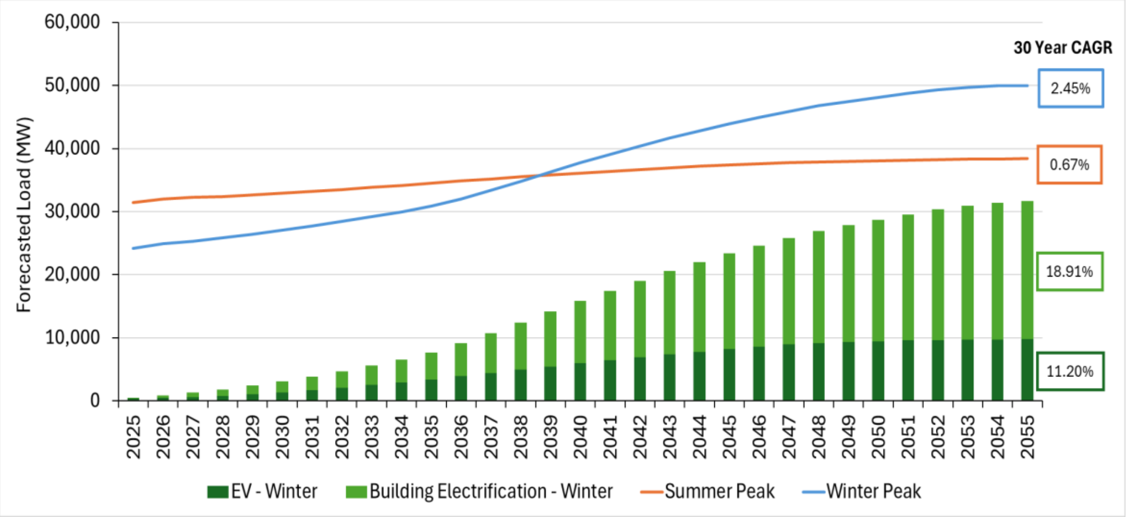
OSW can still play a role in charging storage and easing NG constraints as ELCC declines

S1	1 GW offshore/0.3 GW onshore
S2	3.3 GW offshore/1GW onshore
S3	1 GW offshore/0.3 GW onshore

Sources:
1. ISO New England, Impact Analysis Sensitivity Results – May 2024

NYISO is seeing tightening winter margins and stress in downstate regions

NYISO has substantially higher winter load growth than summer load growth due to electrification of heating



Transition to winter peaking:

- NYISO is projected to transition from summer to winter peaking in the 2030s
- Growth will be correlated with already strained, coldest days

Downstate stress:

- NYISO has retired 1,600 MW of peaking generation in the downstate region since 2019
- These regions are experiencing the highest load growth and are already transmission constrained
- The use of distillate back-up fuels demonstrates the stress on natural gas fuel systems on the coldest days
- NYISO found risks in downstate regions starting in 2026

Evolving approach to capacity accreditation:

- ELCCs not applied to thermal resources. OSW leads renewables by a factor of 3x in winter
- Market Monitor has raised concerns that cold weather outages are not accurately captured

Sources:
1. NYISO 2025 Gold Book Forecast and RNY Report
2. NERC 2024 Long-Term Reliability Assessment
3. NYISO 2025 Q3 STAR

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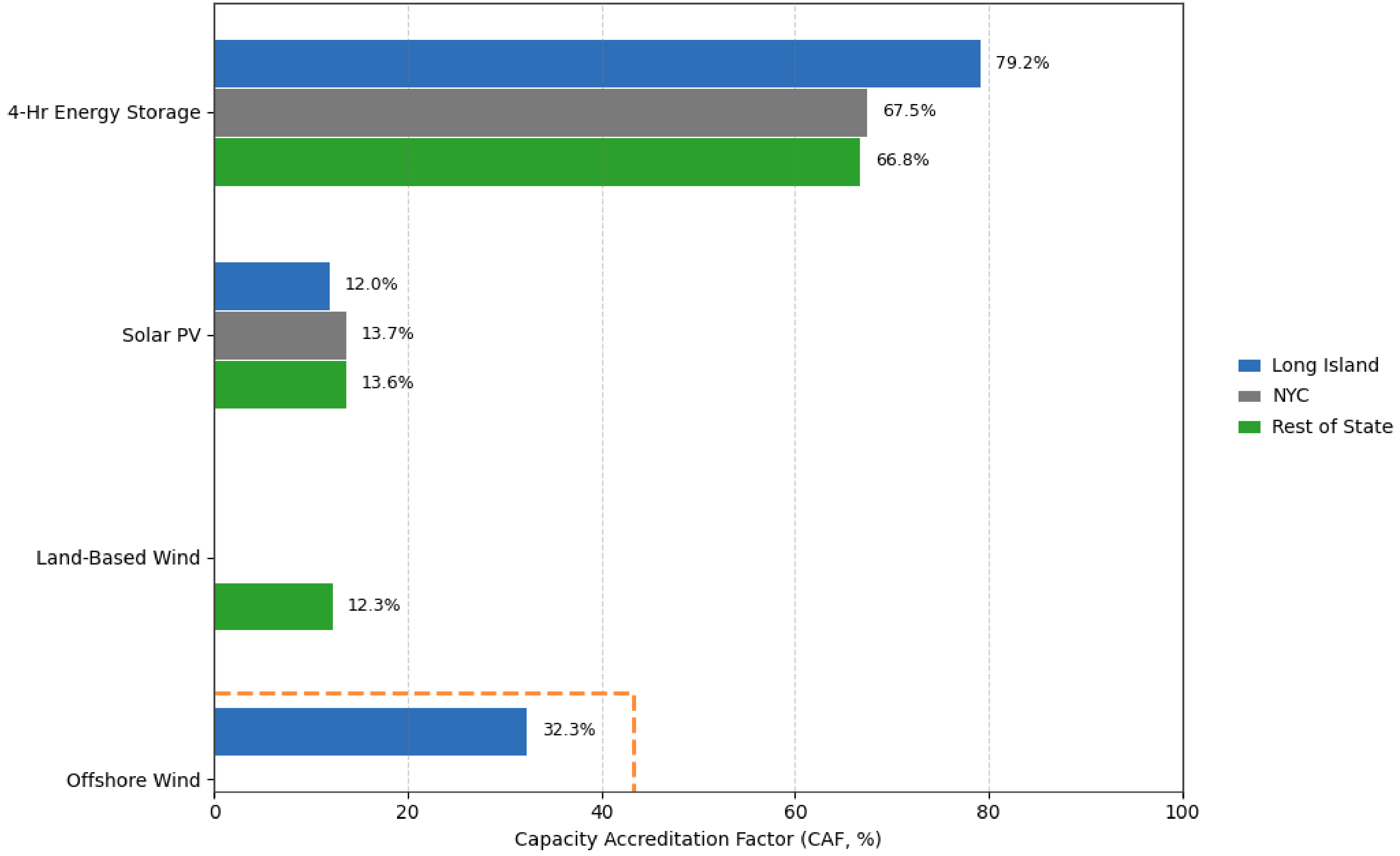
NYISO’s ELCC values evolving and do not fully capture the reliability potential of OSW



OSW leads among renewables but is only provided for existing OSW project – South Fork. South Fork demonstrates the role OSW can play in solving transmission and NG constraints.

OSW’s accreditation likely to increase substantially as methodology **evolves to capture winter risk.**

Sources:
1. NYISO, Final Capacity Accreditation Factors for the 2024–2025 Capability Year

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OSW’s ELCC leads among renewables and competitive with thermals in some markets

OSW’s ELCC is competitive due to stress-aligned generation.
It also provides **siting benefits** by connecting directly to key coastal load centers.

OSW’s ELCC will decline with higher penetration, as reliability risk shifts to lower-wind periods.

OSW complements other technologies,
with particular potential to **ease natural gas constraints** during peak winter conditions.

The US faces twin resource adequacy and affordability challenges due to aging infrastructure and load growth

Context

Load is growing at a pace not seen in decades. Policy makers and regulators have raised concerns on how the American grid can reliably and affordably meet load growth, given constraints on existing infrastructure and supply chains.

Action

The authors provided a third-party, data-driven review on the role **offshore wind** (OSW) can play in solving emerging gaps. We provided a market-by-market analysis, through the lens of ELCC values.

Findings

OSW's ELCC value consistently leads among renewables. Its contribution will decline with penetration, but initial GWs are competitive with thermal resources in some markets due to its strongest periods of generation aligning with periods of greatest stress.

OSW's NE Role

A future white paper will delve into contributions of OSW in ISO-NE and NYISO using IRP-type analysis. We will examine the reliability and affordability of different technology pathways.

While there is no one path to a reliable grid, OSW can play a meaningful role. It brings strong winter generation, offers siting advantages near constrained coastal regions, and consistently achieves high ELCC values

ISO-NE's ELCC Scenarios evaluate a range of technology futures

Scenario	Retirements	Resource Additions
Scenario 1	438 MW coal	2 GW solar, 0.3 GW onshore wind,1 GW offshore wind, 0.2 GW 4-hour storage
Scenario 2	1.3 GW oil	6.5 GW solar, 1 GW onshore wind, 3.3 GW offshore wind, 0.8 4-hour storage
Scenario 3	None	2 GW solar, 0.3 GW onshore wind,1 GW offshore wind, 0.2 GW 4-hour storage

Sources:
1. ISO New England, Impact Analysis Sensitivity Results – May 2024

Resource Adequacy is a single but critical element of overall grid reliability

Resource Adequacy (RA) ensures there is **sufficient generating capacity** to meet load, with a certain probability (depending on the selected reliability standard)

- Historically, RA planned for a single or small number of peak load hours
- New tools have been developed to successfully account for the **increasing penetration of intermittent generation** and energy-limited resources
- These new tools focus on chronological operations and resource interactions and simulate a wide variety of weather conditions

✓ These methods capture uncertainty in load and generation
✓ Interactions between technologies are increasingly important to achieve a reliable resource mix

Reliability Metrics/Standards	PRM	ELCC
Loss-of-Load (LOL) probabilistic metrics are used to evaluate resource adequacy and related reliability criteria: • **Time duration**: *LOLH* (hours/year) • **Frequency**: *LOLEv* (events/year), *LOLE* (days/year) • **Size:** *EUE* (MWh/year)	**Planning Reserve Margin (PRM)** is the amount of capacity, in %, above the expected weather-normalized load that a system must carry to meet the reliability standard. It is used to ensure adequate power supply given a forecasted peak in the years ahead.	**Effective Load-Carrying Capability (ELCC)** measures the capacity contribution of a resource or resource portfolio to the system's reliability needs. ELCC can capture the complexity of resource interactions through hourly simulations of system conditions.

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