E3 Recost

Q4 2024 Release

October 2024

Energy+Environmental Economics

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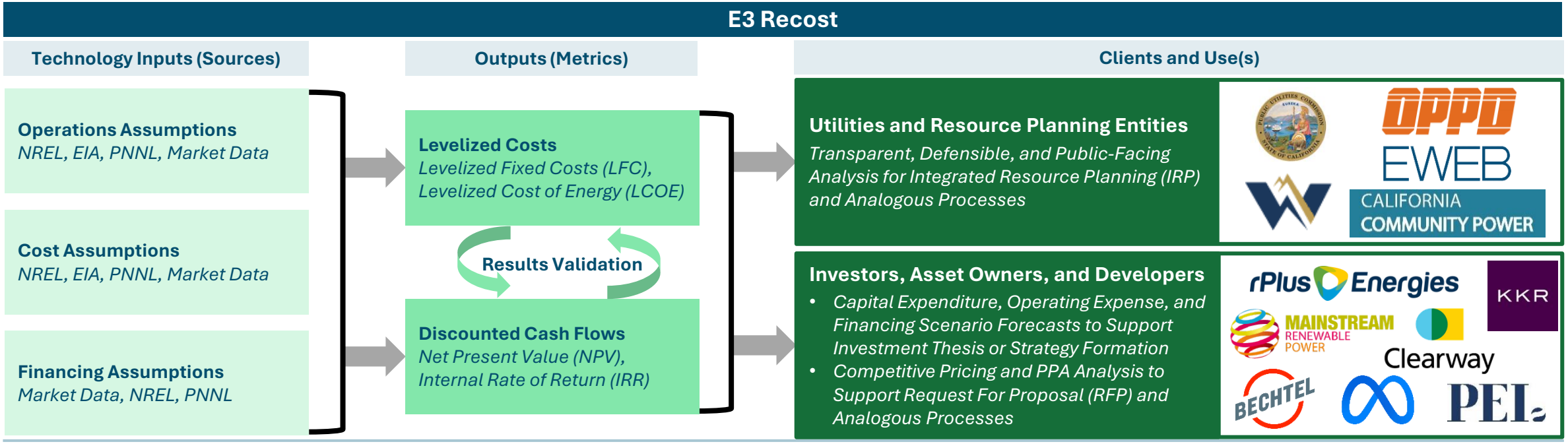
Energy+Environmental Economics

What is E3 Recost?

Overview of Model and Use(s)

- **Recost** is E3's in-house discounted cash flow model used to calculate levelized fixed costs and levelized cost of electricity for mature and emerging technology resources, inclusive of financing costs
- **Recost** is optimized for two goals:
  1) Evaluate the fundamental economic costs of building new resources to inform energy system modeling, validate investment theses, and shape resource strategy for public and private sector stakeholders
  2) Estimate the expected cost to contract these resources under Power Purchase Agreements (PPAs), and support the calculation of Levelized Cost of Capacity (LCOC) using each resource's Effective Load Carrying Capability (ELCC)

Recost is built to inform the ongoing debate around how to finance and build the resources necessary for the energy transition by leveraging E3's expertise on this topic



What is E3 Recost?

Technologies Evaluated in Recost

***Recost** currently evaluates the following technologies, with the ability to modify any cost or operating parameter as appropriate:*

Biomass	Dedicated Biopower
Energy Storage*	1) Utility-scale lithium-ion battery storage 2) BTM lithium-ion battery storage 3) Pumped storage hydro (PSH) 4) Vanadium flow battery storage 5) Long-duration energy storage (LDES) technologies*
Geothermal	1) Hydrothermal (Flash, Binary) 2) Enhanced (Flash, Binary)*
Hydropower	1) New Non-Powered Dams (NPD) 2) Existing Non-Powered Dams
Hydrogen*	1) Production (electrolysis) 2) Storage 3) Transport 4) Conversion and combustion, including CCGTs, CTs, and fuel cells*
Natural Gas*	1) Natural gas combustion turbines (CT) 2) Combined cycle gas turbines (CCGT) 3) Reciprocating internal combustion engines (RICE) 4) CCGT new build and retrofit units equipped with carbon capture and storage (CCS)*
Nuclear*	1) Small modular reactor (SMR) units 2) Pressurized water reactor (PWR) units
Solar	1) Utility-scale solar photovoltaic (PV) systems 2) Commercial behind-the-meter (BTM) solar PV 3) Residential behind-the-meter (BTM) solar PV 4) Solar thermal systems
Wind*	1) Onshore wind 2) Offshore wind (fixed-bottom) 3) Offshore wind (floating)

** Includes emerging technologies evaluated by E3.*

Executive Summary

Q4 2024

Long Covid, meet the energy transition: Post-Covid shocks embedded in long-run costs

Declines in the costs of resources key to the energy transition (onshore wind, utility-scale solar, and battery energy storage systems) were impeded, halted, or reversed between 2020–2023. With the cost spikes from recent years now fully embedded in our forecasts, the message is clear: cost levels have not returned to the pre-Covid expectations for 2025, and there are multiple strong headwinds facing any return to pre-Covid cost reduction paths.

What's in a name? The Inflation Reduction Act begins to shape post-inflation economics

In E3's view, the primary energy-sector impact of Inflation Reduction Act (IRA) is the pressure applied to reduce resource costs closer to pre-Covid trajectories. Looking ahead, IRA incentives are the most meaningful path to sustained national power sector decarbonization, and the certainty provided through 2032 is a boon to clean energy sector growth. Beyond 2032, development trajectories are more uncertain than before, as the sector enters the period during which the sunset provisions of the Act may be triggered.

The new, complicated normal: complexity is now a feature, not a bug of the energy transition

Reduced learning curve impacts for mature clean technologies and more rapid potential cost declines for emerging technologies will continue, but U.S. industrial policy now means that location matters more than ever before; it will be difficult, if not impossible, to discuss a "generic" project over the coming decade.

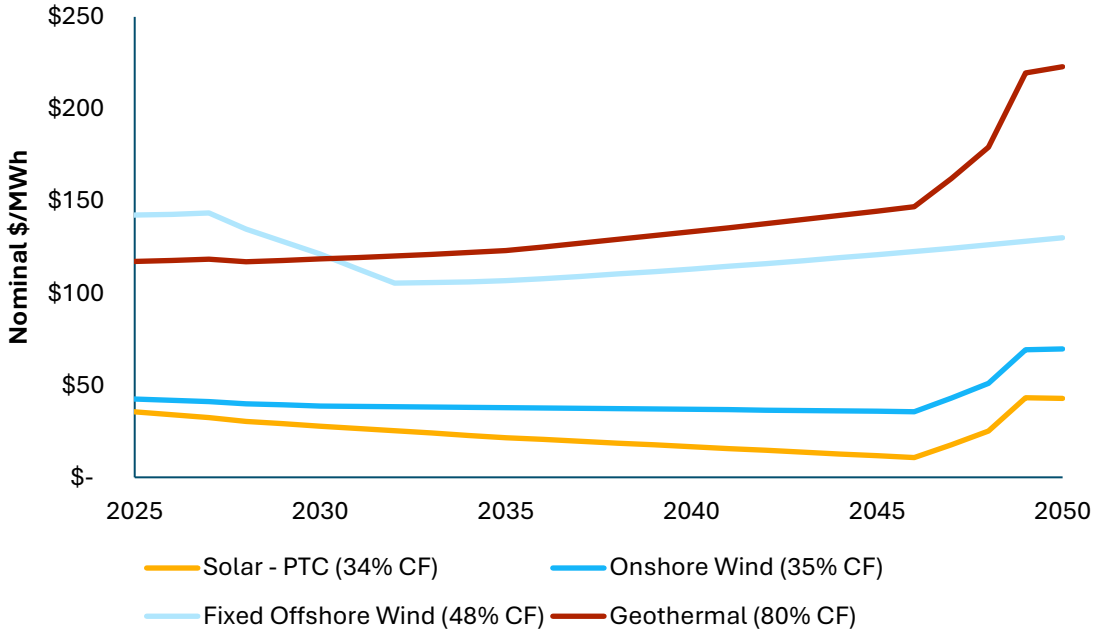
In a world where costs and benefits are more complicated, E3's Recost forecasts aim to provide transparency and rigor

E3 Resource Cost Forecast: Q4 2024

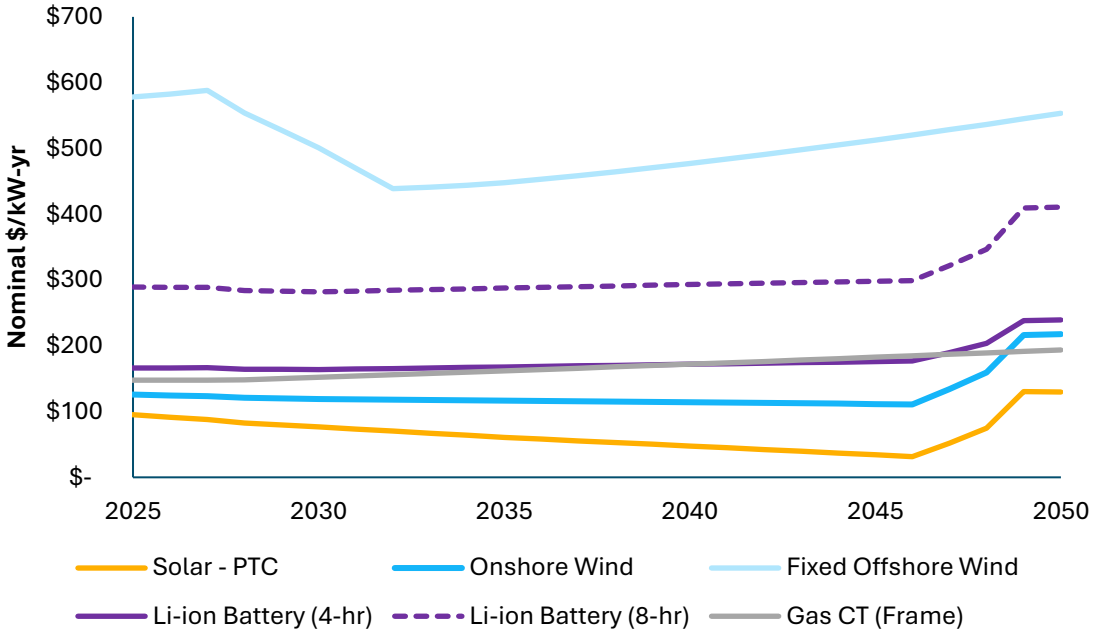
Executive Summary

- **Production Tax Credits drive LCOE outcomes:** Solar eligibility for the PTC makes this the rational election for new generators in areas with good resource potential, despite the greater recapture risk.
- **Clean, firm, dispatchable generation capacity carries a consistent cost premium:** while geothermal cost declines are expected over time in real terms, nominal costs increase and emerging competitor technologies are more competitive in many cases (e.g., gas CCGT with CCS).
- **Energy storage costs favor lithium-ion batteries, for now:** while certain configurations of Pumped Storage Hydro (PSH) enjoy a current cost advantage to Li-ion batteries, emerging longer-duration storage technologies may further erode lithium's advantage in the future.

Recost LCOE Estimates for Selected Resources



Recost LFC Estimates for Selected Resources



Technology costs in this deck represent non-specific, indicative nationwide averages for CAPEX, LFC, and LCOE. Capacity factors are indicative. LCOE is not used as an input in IRP modeling and is reported as reference only. Final resource costs for use in IRP modeling will be localized to account for regional changes in CAPEX, O&M, IX, and taxes.

About E3

Energy+Environmental Economics

Who is E3?

Thought Leadership, Fact Based, Trusted.

130+ full-time consultants

30+ years of deep expertise

Engineering, Economics, Mathematics, and Public Policy Degrees


San Francisco


New York

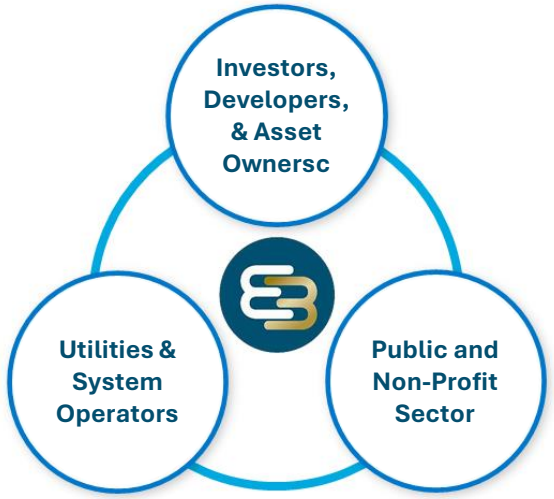

Boston


Calgary


Denver

E3 Clients

300+ projects per year across our diverse client base



Asset Classes Supported by E3

- Utilities
- Thermal Resources
- Transmission
- Emerging Technologies
- Electric Vehicles and Infrastructure
- Software and IoT
- Decarbonized Fuels
- Energy Storage
- On/Off-Shore Renewables
- Distributed Generation and Flexible Loads

Who is E3?

Our Practice Areas

- E3 is the largest consulting firm focused on the clean energy transition in North America
- E3 is a recognized thought leader on decarbonization and clean energy transition topics
- E3 has three major practice areas covering energy systems from bulk grid to behind the meter

Climate Pathways & Electrification

- Long-term energy & climate scenarios
- Electrification and low-carbon fuels analysis
- Future of gas

Asset Valuation & Markets

- Energy market price forecasting
- Strategic advisory
- Due diligence
- Market design
- Transmission planning

Integrated System Planning

- Electric system planning: reliability and resource analysis
- Planning for utility and state RPS + GHG targets
- Utility planning and procurement decisions

Economy-Wide Energy Systems ← Bulk Grid Power Systems → Grid Edge / Behind-The-Meter

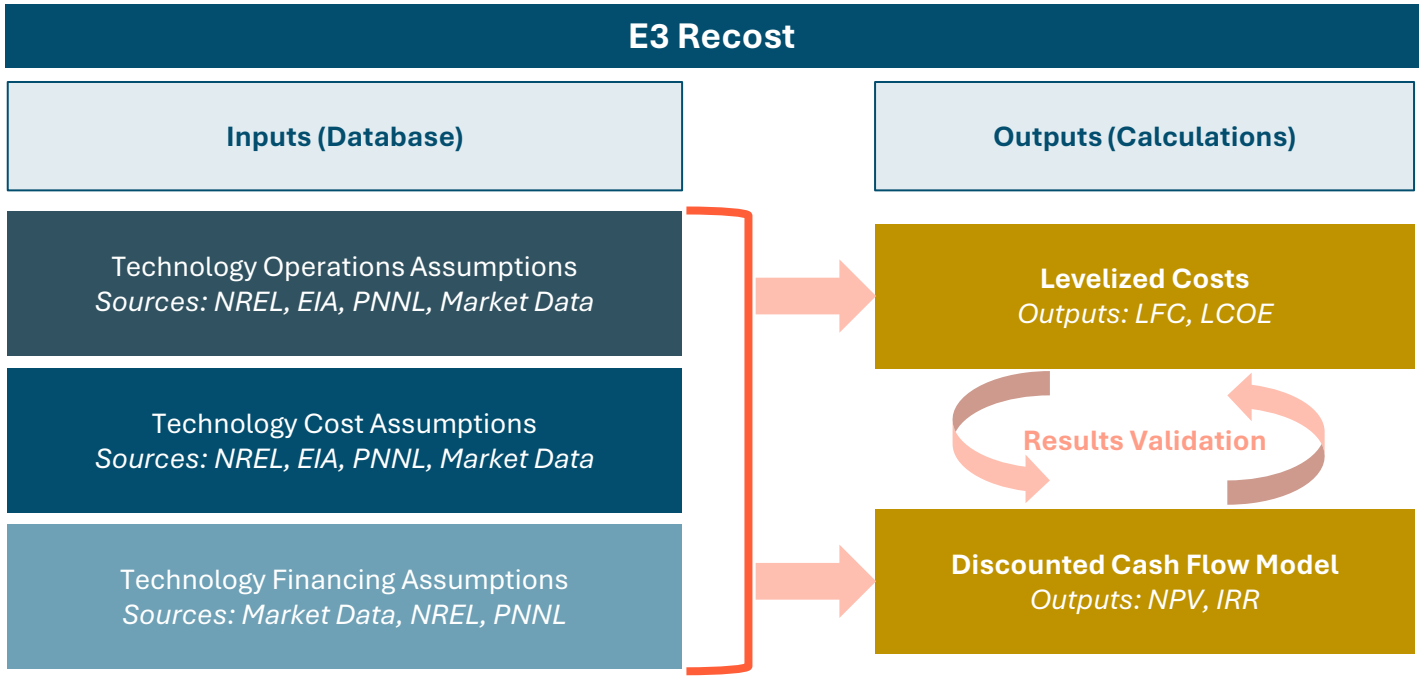
Recost Overview

Energy+Environmental Economics

E3 Resource Cost Estimates

Recost Model Overview

- **E3's Recost model calculates levelized fixed costs (LFC) and the levelized cost of electricity (LCOE) for a range of conventional and emerging technologies**
  - LFC is reported in $/kW-yr, and LCOE is reported in $/MWh
- **LFC and LCOE are calculated by initial commercial operations date (COD), from 2025 through 2050**
- **Recost estimates are calculated using inputs from various sources:**



Calculation of Levelized Costs

Recost Model Overview

+ **Levelized Fixed Cost (LFC) ($/kW-yr):** the levelized ***capacity*** payment that a system would need every operating year over its useful life to cover fixed costs, including amortized capital costs (capex), fixed operations and maintenance (O&M) costs, property taxes, and investment tax credits (if applicable)
  - This output is used to calculate Levelized Cost of Capacity (LCOC) by adjusting for Effective Load Carrying Capability
+ **Levelized Cost of Electricity (LCOE) ($/MWh):** the levelized ***energy*** payments that a system would need for every operating hour over its useful life to cover all costs, including fixed cost components as well as fuel costs, variable O&M, and the federal production tax credit (if applicable)
  - An electricity generator that collects revenue over its useful life at the LCOE will have an NPV of $0

$$\mathbf{LFC} = \frac{\mathrm{NPV}(\text{Fixed Costs}, \$)}{\mathrm{NPV}(\text{Capacity}, \mathrm{kW})}$$

Fixed Costs =
+ Capital Expenditures and Interconnection Costs
+ Investment Tax Credit
+ Fixed O&M
+ Property Taxes
+ Warranty
+ Repowering & Augmentation

$$\mathbf{LCOE} = \frac{\mathrm{NPV}(\text{Total Costs}, \$)}{\mathrm{NPV}(\text{Energy}, \mathrm{MWh})}$$

Total Costs =
+ LFC
+ Variable O&M
+ Fuel
+ Production Tax Credit

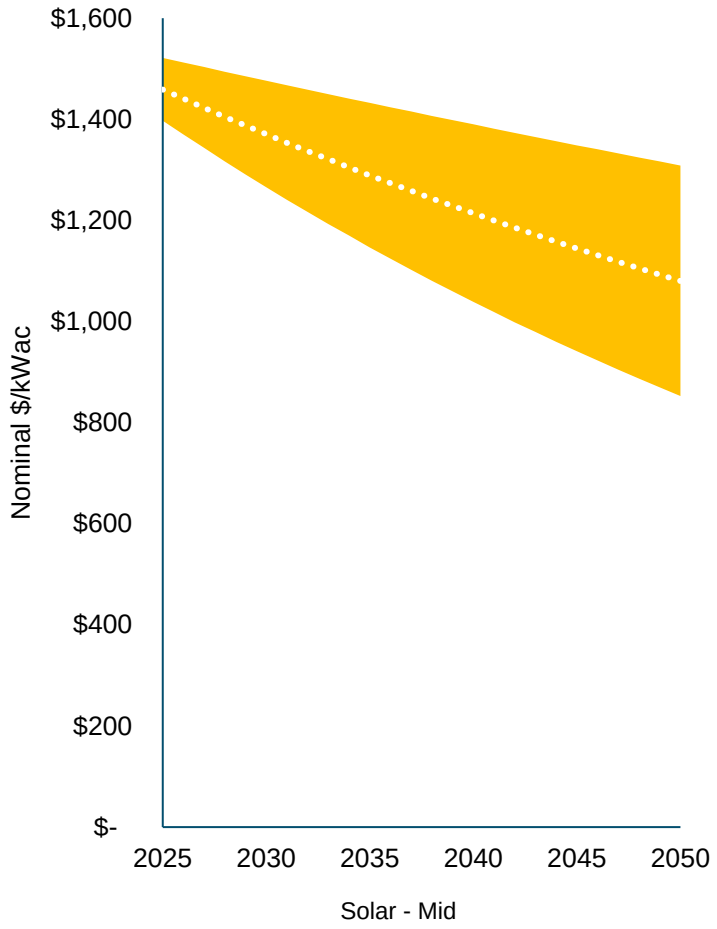
Recost Assumptions: Q4 2024

Energy+Environmental Economics

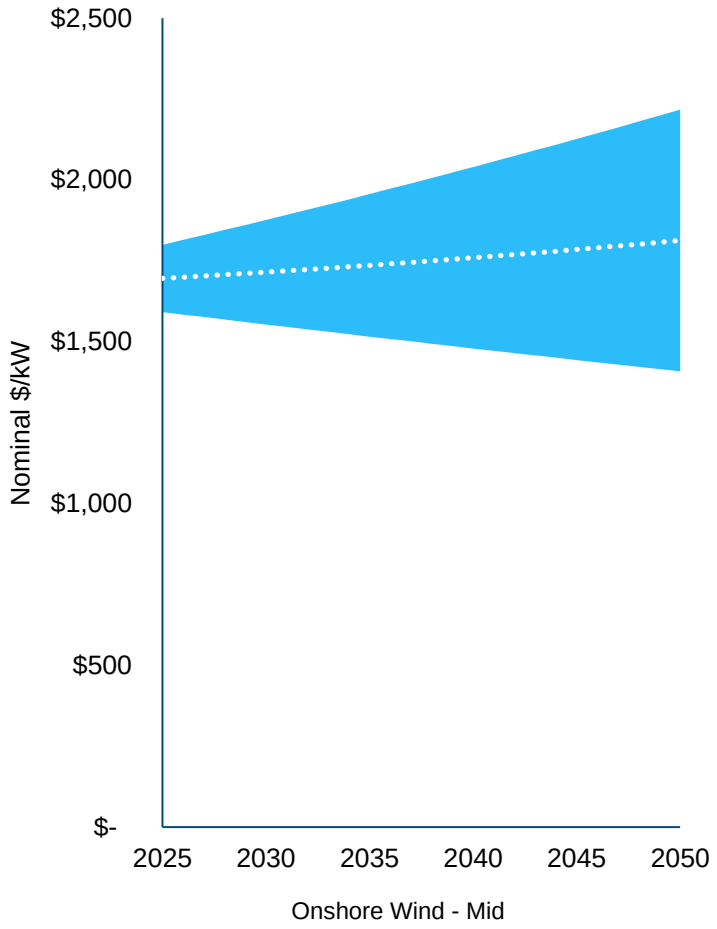
Upfront Capex Forecasts for Selected Resources

Recost Assumptions: Q4 2024

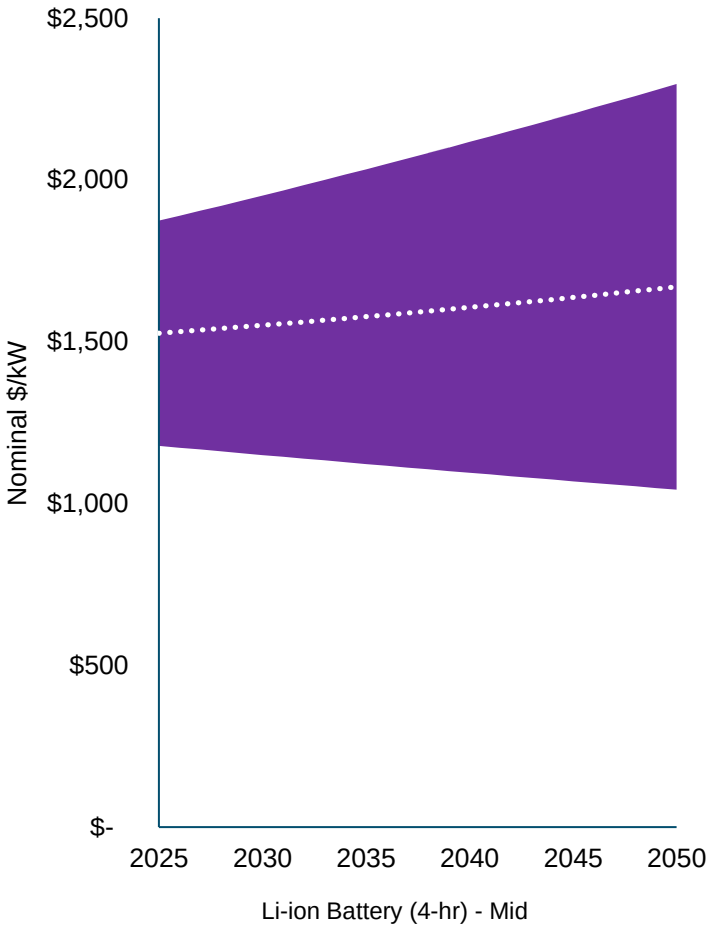
Utility-Scale Solar PV



Onshore Wind



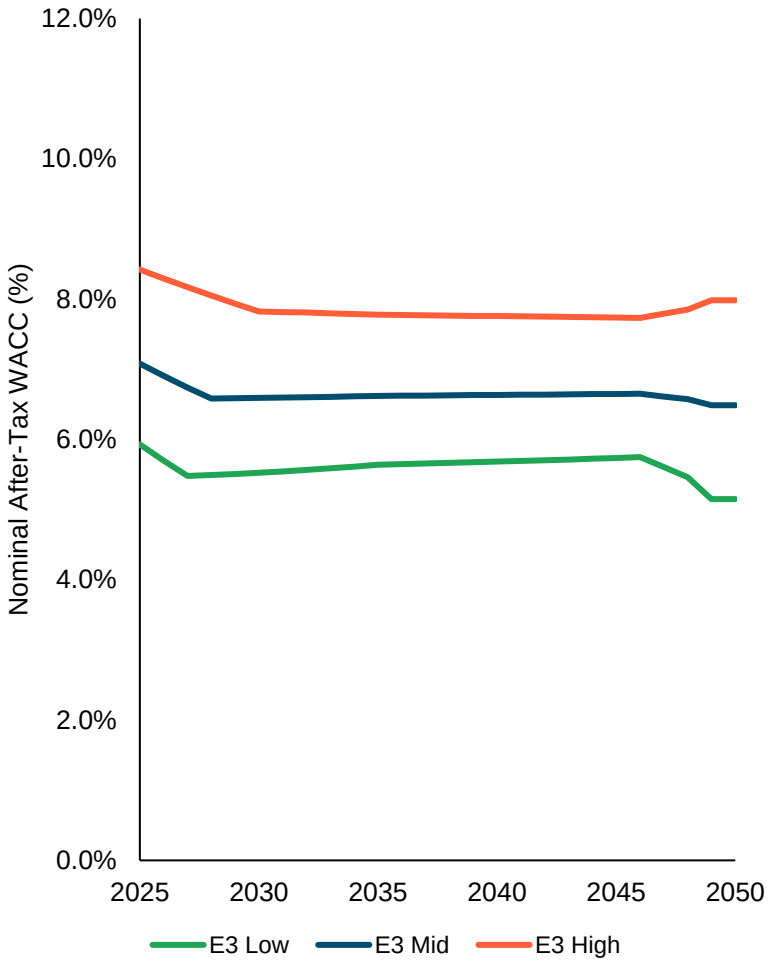
Li-ion Battery Storage (4-hour)



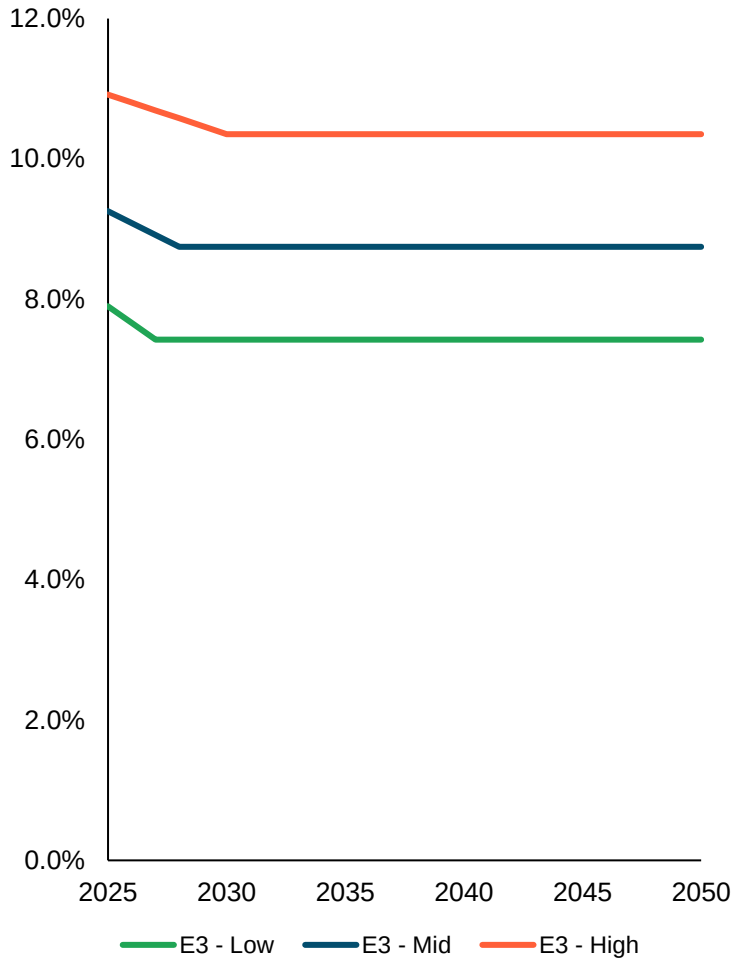
Financing Costs (WACC) for Selected Resources

Recost Assumptions: Q4 2024

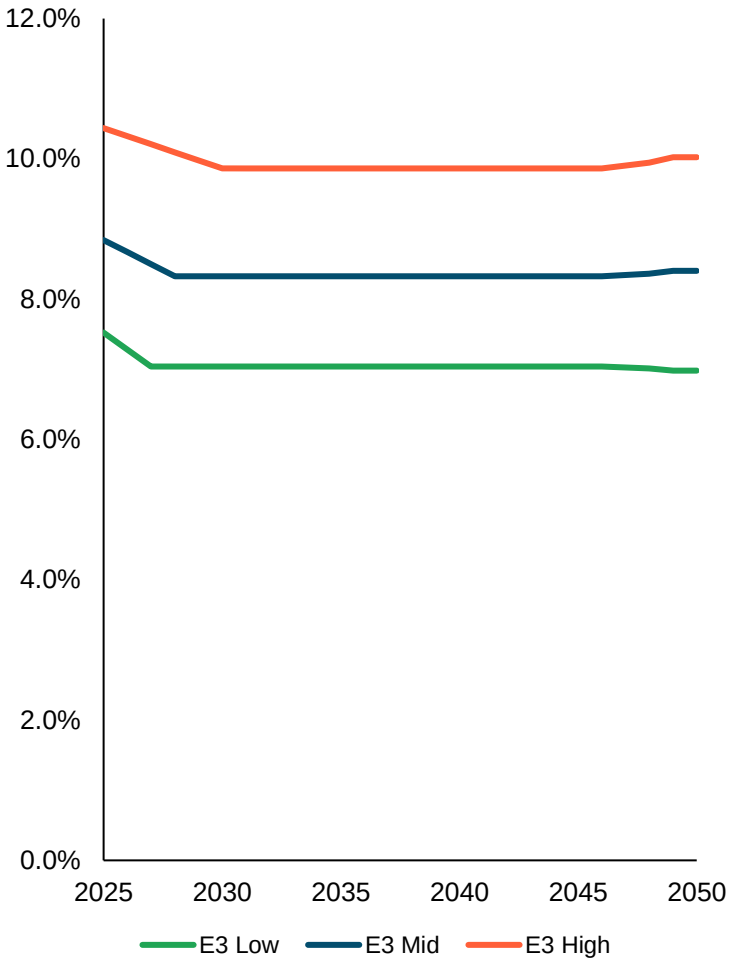
Utility-Scale Solar PV & Onshore Wind



Fixed-Bottom Offshore Wind



Utility-Scale Li-ion Battery Storage

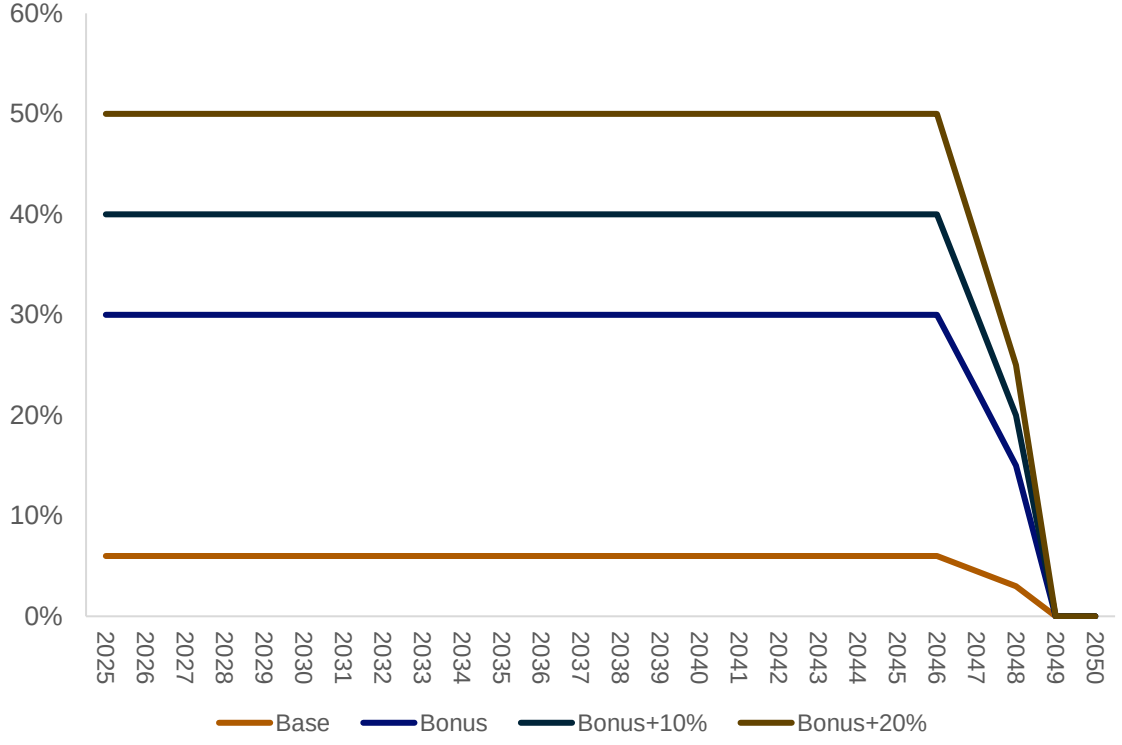


Tax Credit Schedules Under the Inflation Reduction Act

Recost Assumptions: Q4 2024

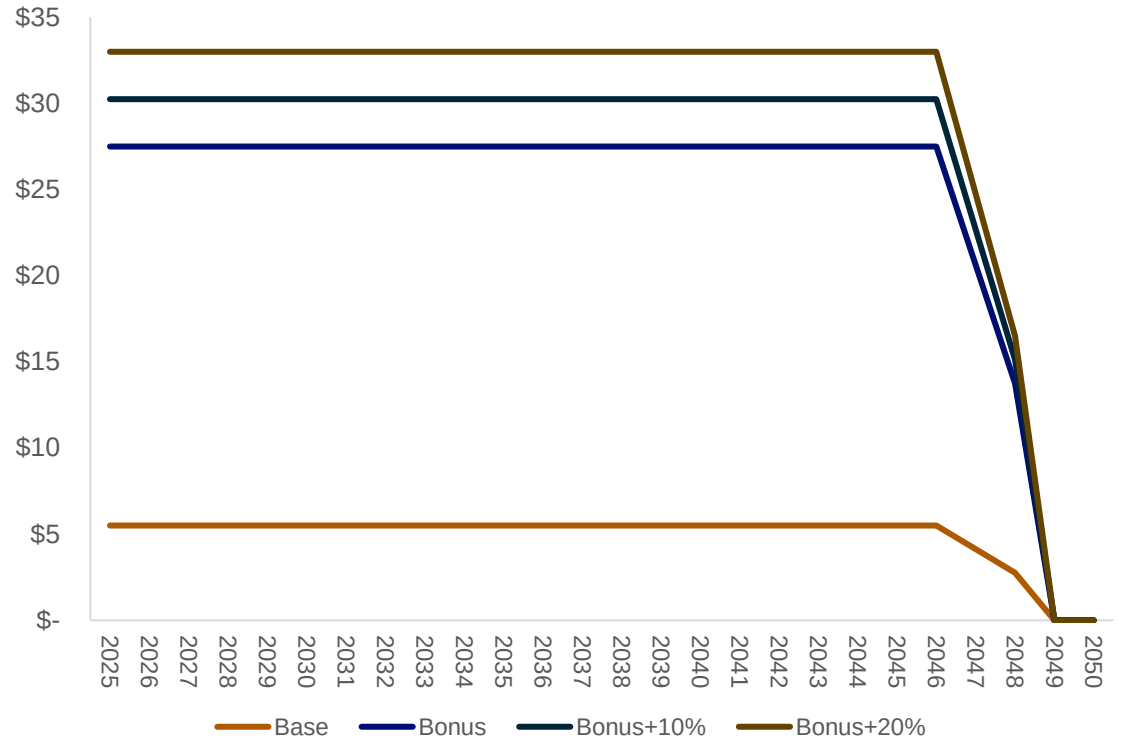
Technology-Neutral Investment Tax Credit (ITC)[1, 2]

Utility-Scale Resources



Technology-Neutral Production Tax Credit (PTC)[2]

Utility-Scale Resources



Timing of decline reflects E3 expectation that the U.S. achieves the carbon emissions reduction target mandated by the Inflation Reduction Act for the electricity sector (75% of 2022 levels) by 2045, after which the three-year phase-out of credits would extend through 2048.

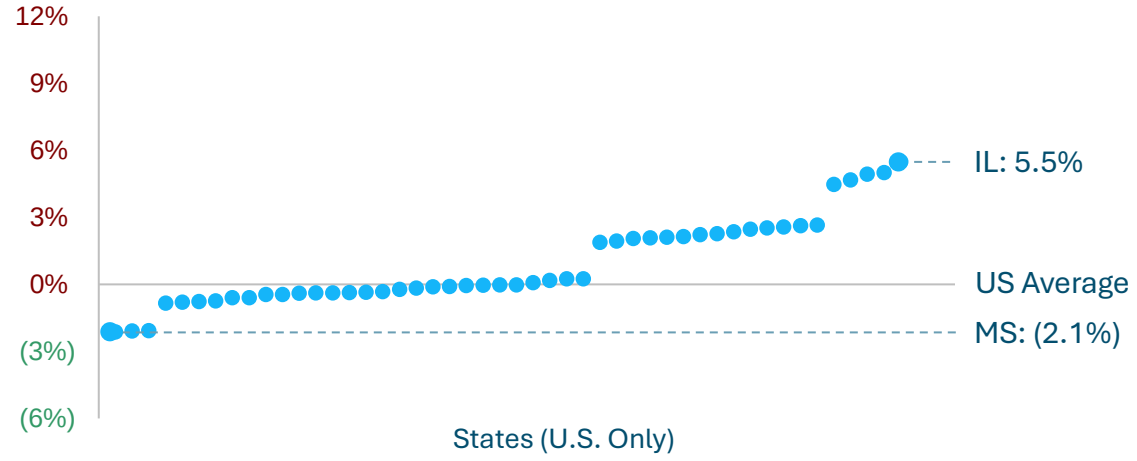
[1] Eligibility for the "Bonus" IRA incentives (assumed for all technologies) is subject to meeting certain prevailing wage requirements; additional 10% adders available for meeting additional domestic content and energy community criteria; tax credits are assumed to be monetized at 90% of their effective value.

[2] For projects electing the ITC, the cost basis eligible for the tax credit is assumed to be equal to 95% of project capital costs.

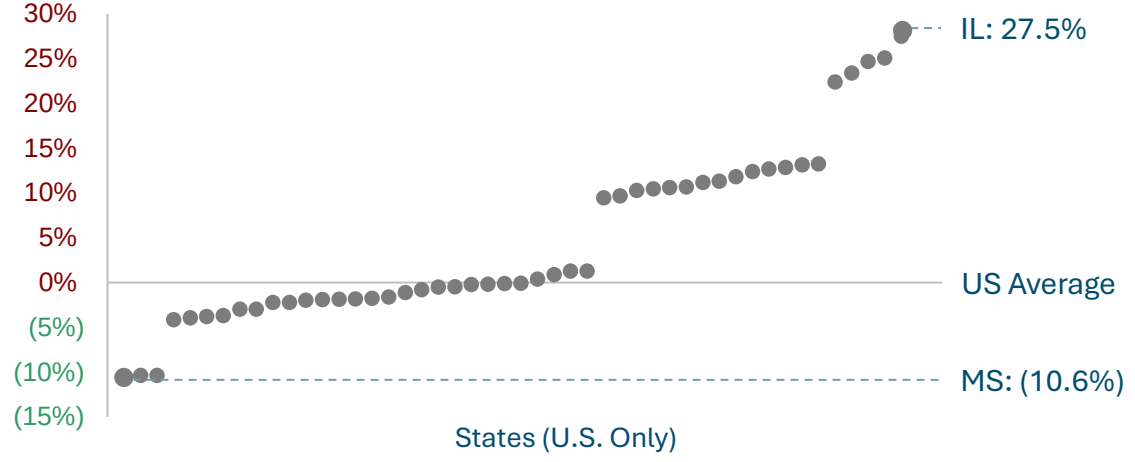
State-Specific Cost Adjustments – Selected Technologies

Recost Assumptions: Q4 2024

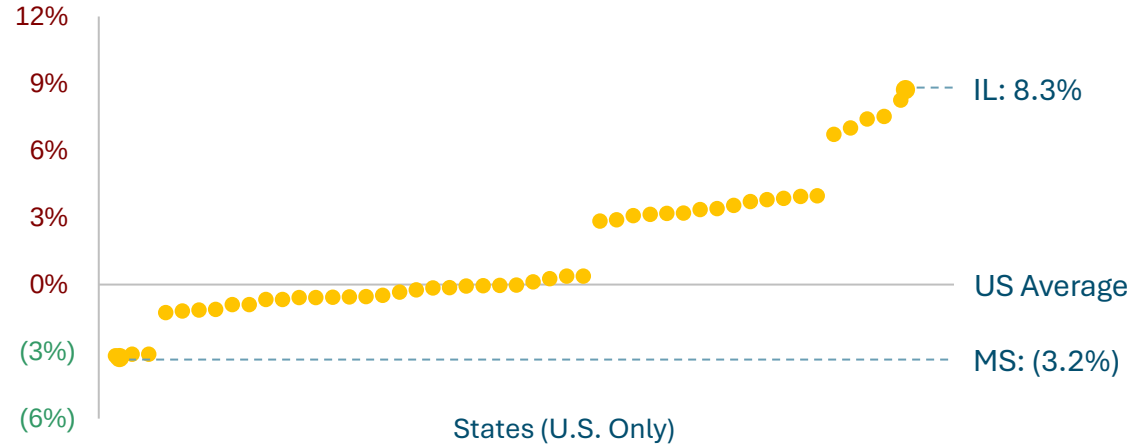
Onshore Wind



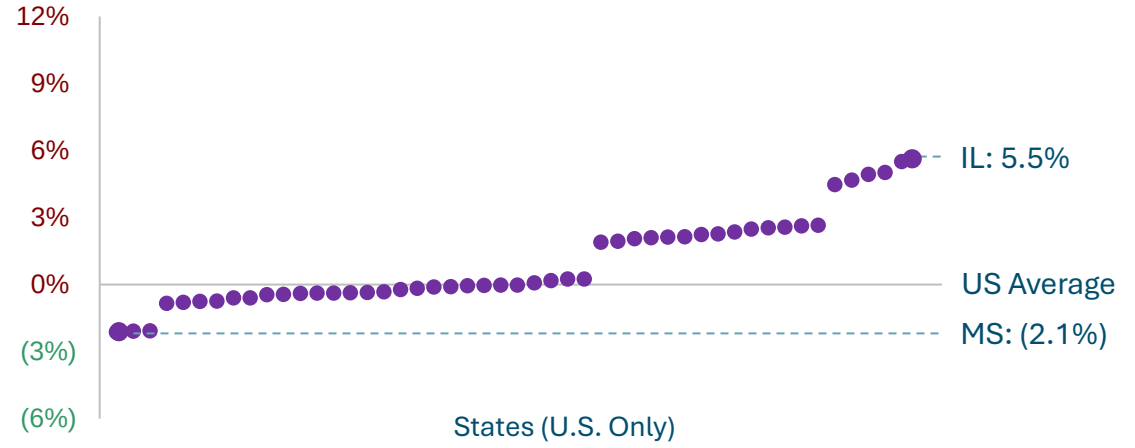
Gas CT (Frame)



Solar



Li-ion Battery (4-hr and 8-hr Duration)



Regional cost multipliers are represented as the difference from the US Average, which is assumed to be 100%.

Cost of Capital

Recost Assumptions: Q4 2024

The cost of capital matters:

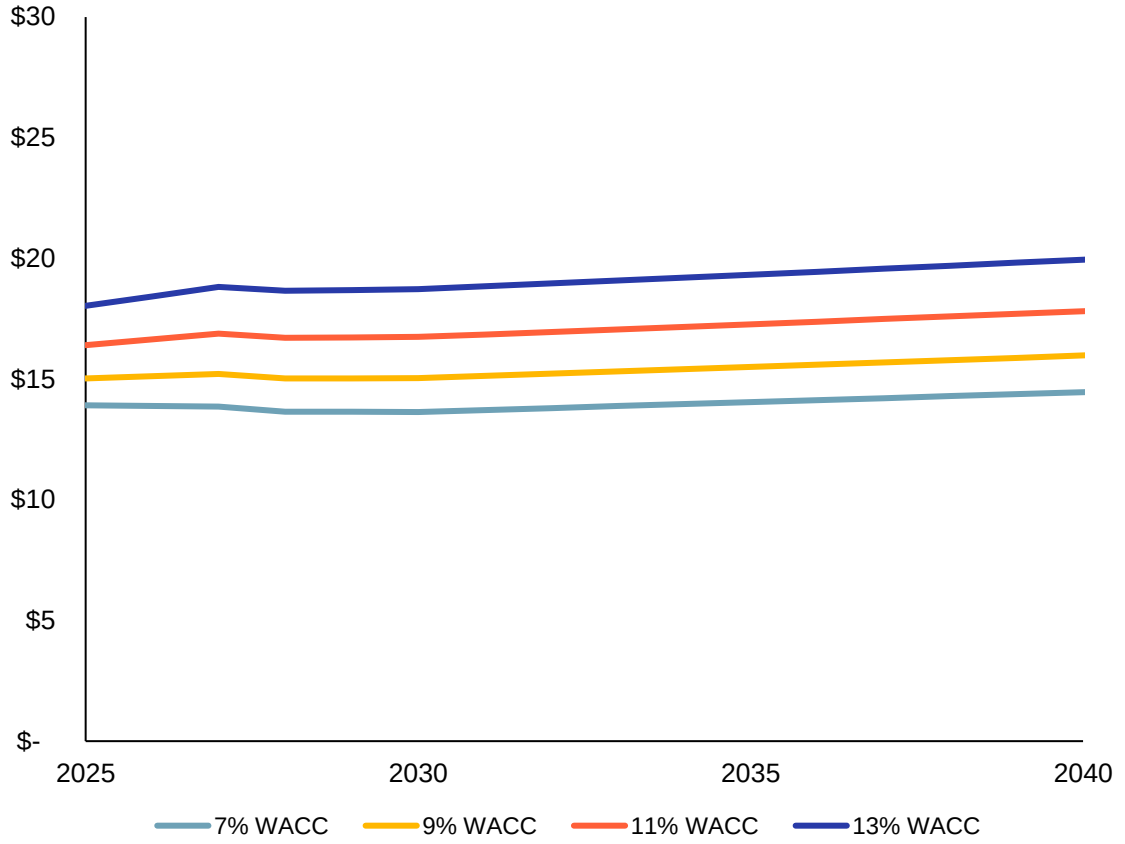
+ E3 finds that a **1% increase in WACC can raise the LCOE for a clean energy technology by more than 10%, and can raise the LFC of Battery Energy Storage Systems by more than 5%**
  - Impacts vary between LCOE and LFC metrics in part due to the different nature of these calculations, most notably the importance of energy generated to the LCOE calculation
+ This input is especially meaningful for capitally intensive technologies, such as offshore wind, that have LCOE estimates on the order of $100/MWh in the near-term

E3 expects the cost of capital to remain elevated in the near-term, with significant uncertainty longer-term:

+ E3 calculates and forecasts the cost of capital for all resources using current market data
+ Interest rates are expected to decline over time in the wake of the most recent Fed rate cut, but depth of current rate cut path is unclear
+ Corporate tax rate outcomes may be affected by the outcome of the November election
+ Fundamental equity return drivers will be the key determinants of future trends; besides interest rate knock-on impacts, this raises the importance of technology-specific factors for reducing equity hurdle rates (elevated commodity prices, supply chain challenges)

4-hr. California BESS Project Levelized Fixed Costs (LFC) Under Different After-Tax WACC Assumptions (Including ITC)

(nominal $/kW-month)



Note: WACC sensitivities were calculated by adjusting Cost of Equity while holding Cost of Debt constant.

Recost Forecasts:
Q4 2024

Energy+Environmental Economics

Levelized Fixed Costs (LFC)

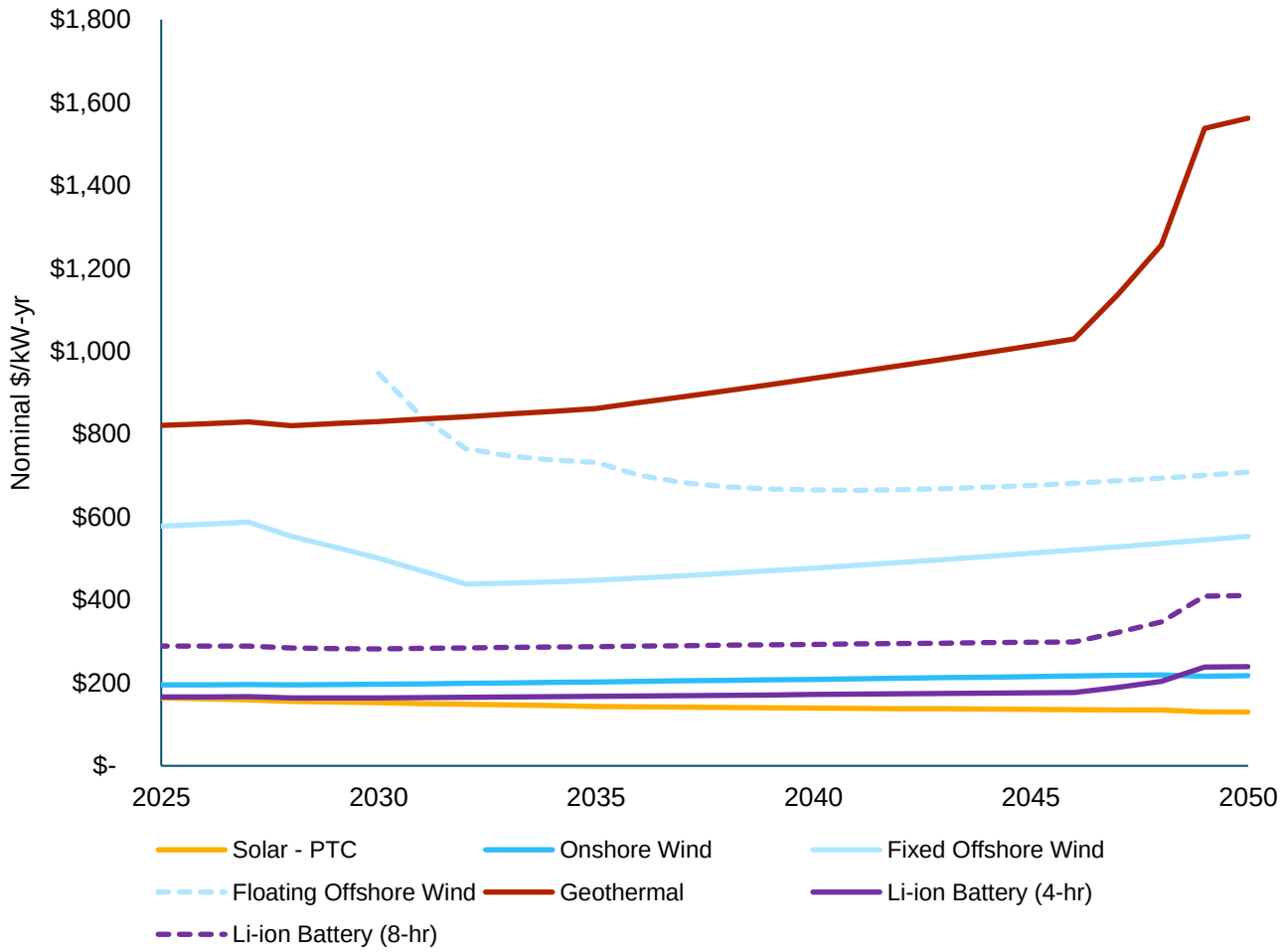
Recost Forecasts: Q4 2024

- LFC remains the **default metric for many utility resource planning processes**, making it one of the core outputs analyzed in Recost
- Capacity costs for mature, non-firm technologies (i.e., onshore wind and solar) are persistently competitive, but **this advantage may be degraded by capacity accreditation mechanisms in various markets**
- Longer-duration storage technologies (e.g., flow, iron-air, A-CAES) are becoming increasingly competitive as alternatives to 8-hour lithium-ion battery storage assets, auguring **potential shifts in development trends** over the coming years

Note: All projections shown in this analysis are an estimate of future resource costs. Results for LFC or LCOE do not constitute market price forecasts for a given technology or region.

E3 LFC Forecast

Nominal $/kW-yr



Levelized Cost of Electricity (LCOE)

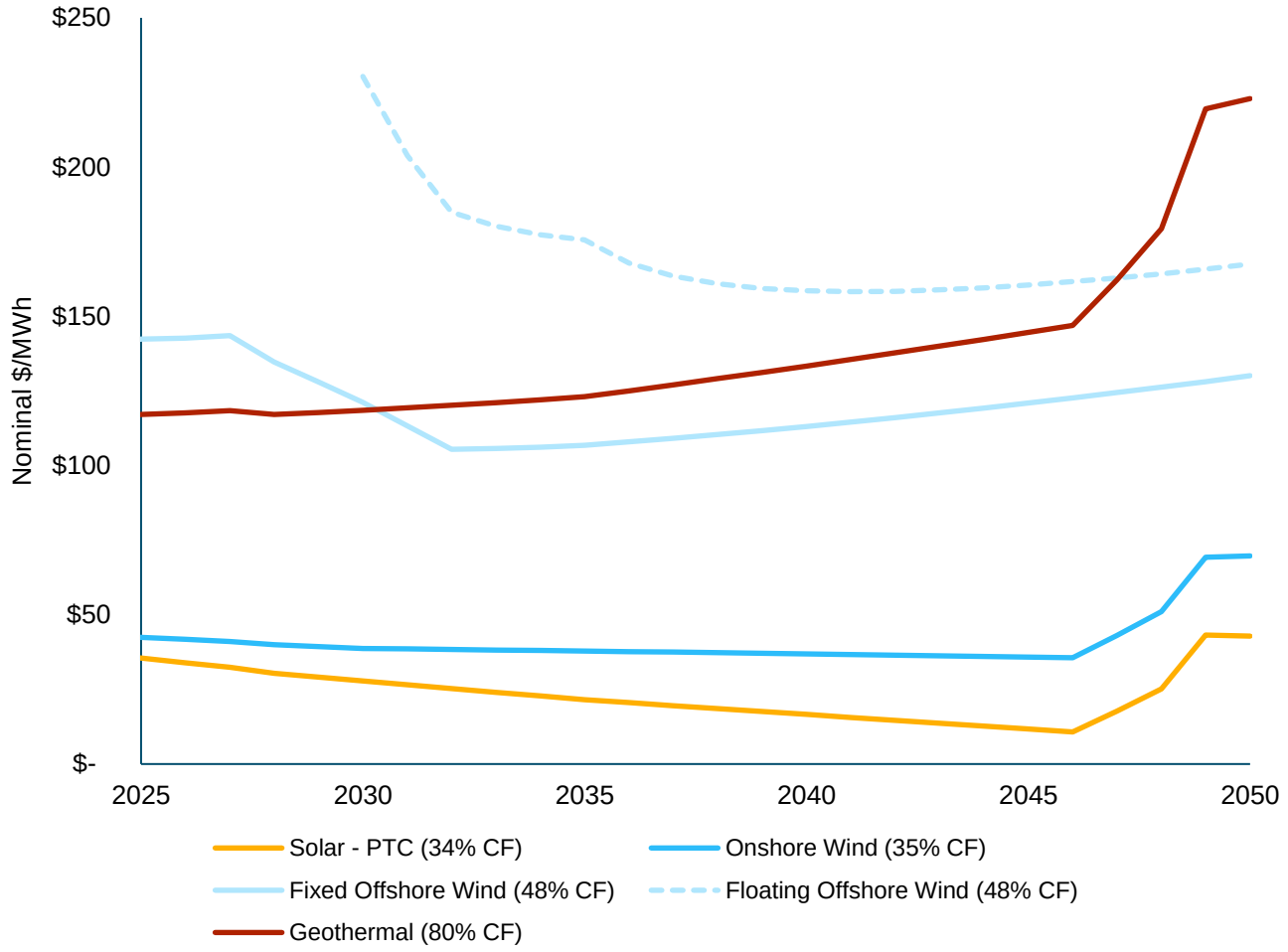
Recost Forecasts: Q4 2024

- **Capacity factor and tax credit election** drive a wide range of LCOE results across wind and solar resources
  - The **PTC is the dominant economic election for higher-capacity factor** solar resources, making solar the least-cost clean energy resource across forecast years; this conclusion is highly sensitive to capacity factor and curtailment expectations
- Offshore wind, especially fixed-bottom installations, can out-compete geothermal by 2035, but **long-run development decisions will be contingent on project location**
  - In California, for example, all offshore wind must be floating, so geothermal is expected to remain competitive in CAISO

Note: All projections shown in this analysis are an estimate of future resource costs. Results for LFC or LCOE do not constitute market price forecasts for a given technology or region.

E3 LCOE Forecast

Nominal $/MWh



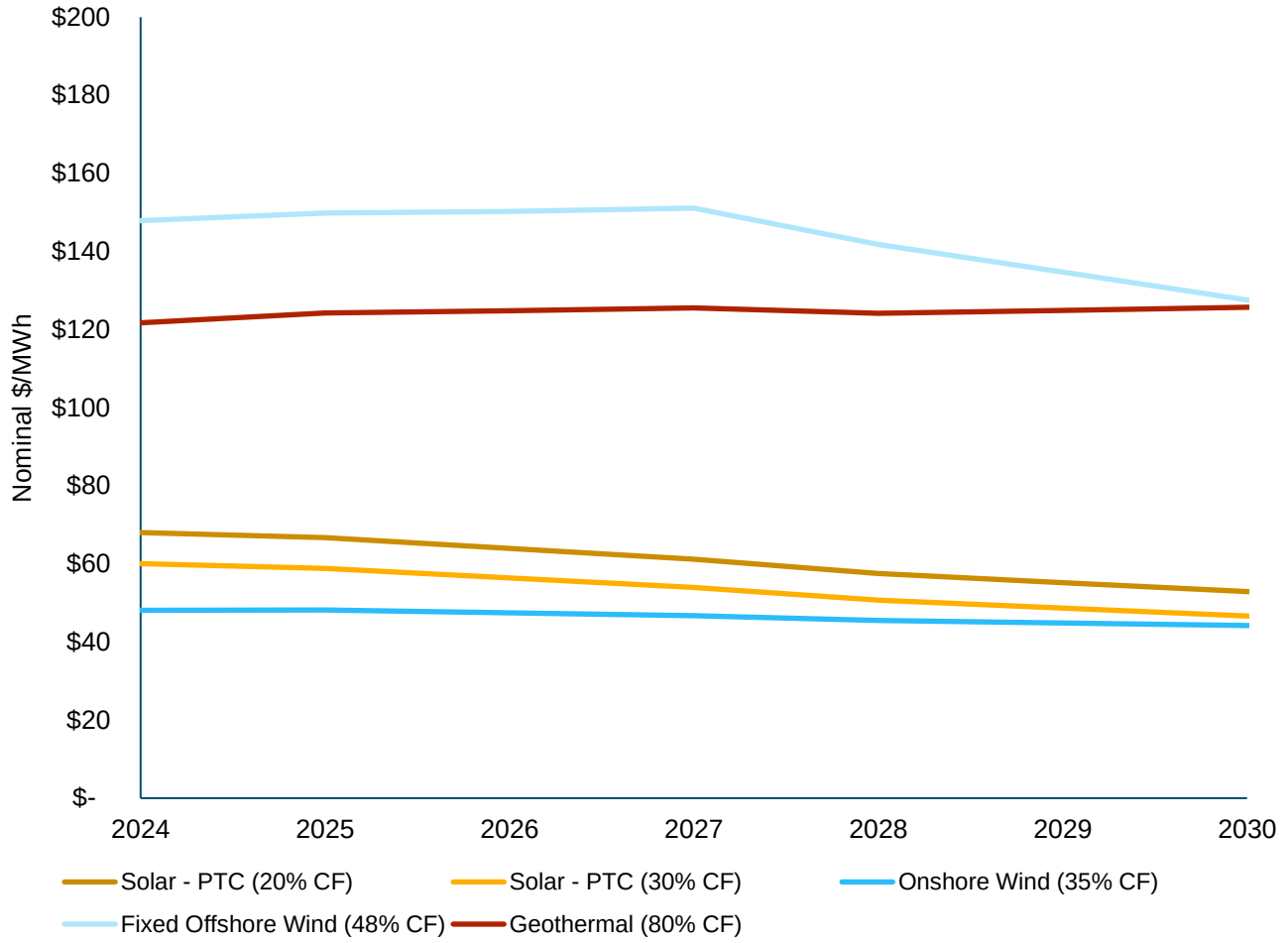
Implied Flat Nominal PPA Prices Through 2030

Recost Forecasts: Q4 2024

- **Each point shown on the chart corresponds to the implied PPA price that E3 would expect an asset to sign in that year, for a term of 20 years**
  - For example, E3 would expect a generic solar project with an expected capacity factor of 30% to contract at $59/MWh in nominal terms in 2025, all else being equal
- **Estimates shown here correspond to E3 expectations based on market fundamentals, and E3 expects individual project contracts may differ materially from these forecasts**
- **Solar and wind generation remain the most cost-competitive source of clean energy in PPA terms through 2030, with longer-term trends to be driven by offshore wind and, potentially, clean combustion with fuels such as green hydrogen**

E3 Flat Nominal PPA Forecast

Nominal $/MWh



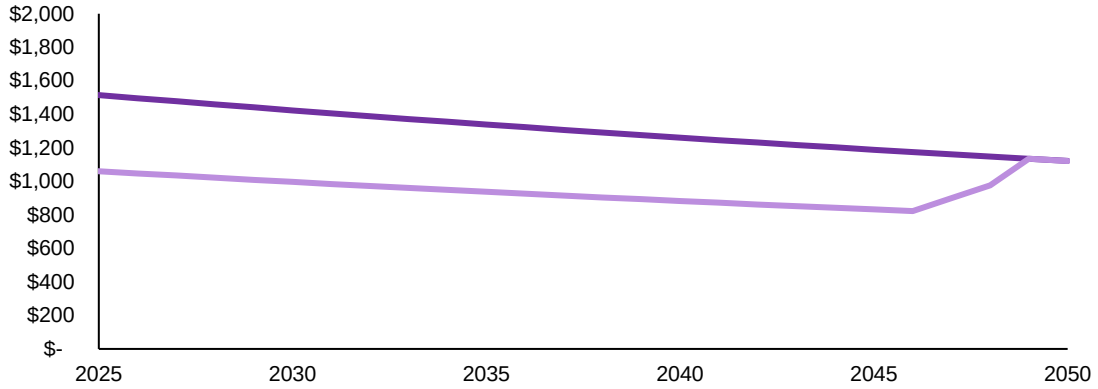
Solar Capex and LCOE Trends

Recost Forecasts: Q4 2024

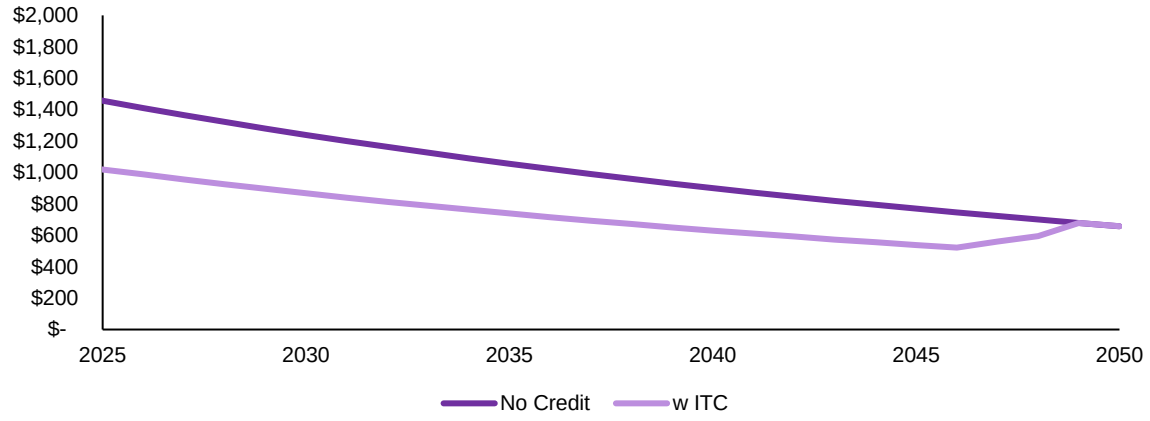
E3 expects long-term declines in nominal and real solar capex and LCOE

Solar Capex in CAISO (with and without ITC)

(nom $/kW)

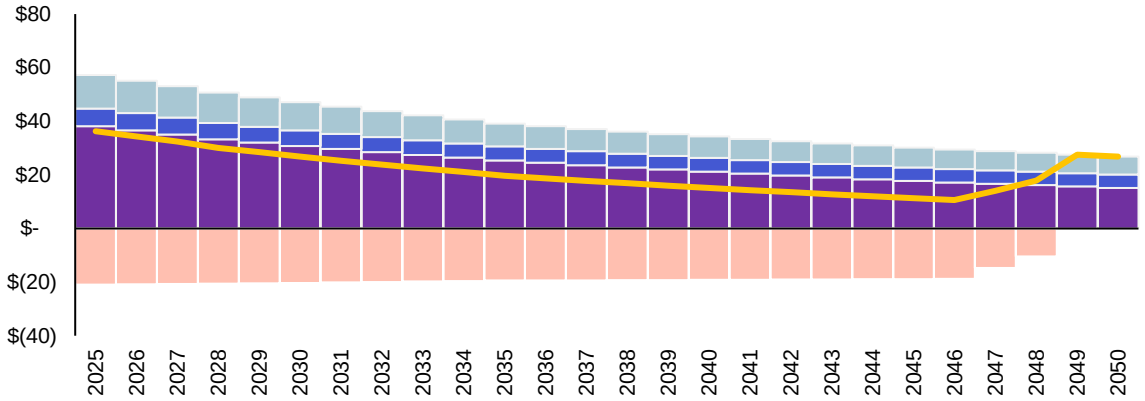


($2023/kW)

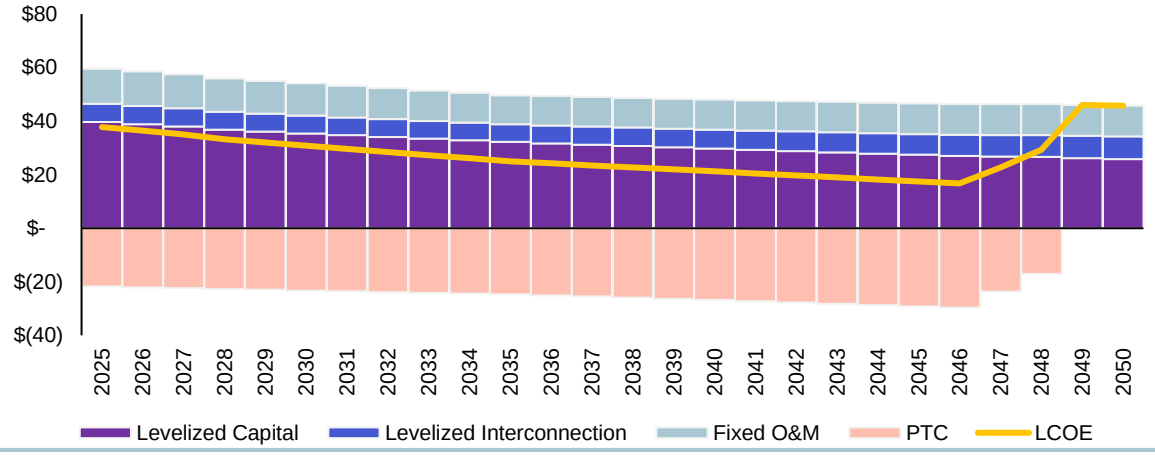


Solar LCOE in CAISO (with PTC) – *34% CF*

($nom/MWh)[1]



($2023/MWh)[1]



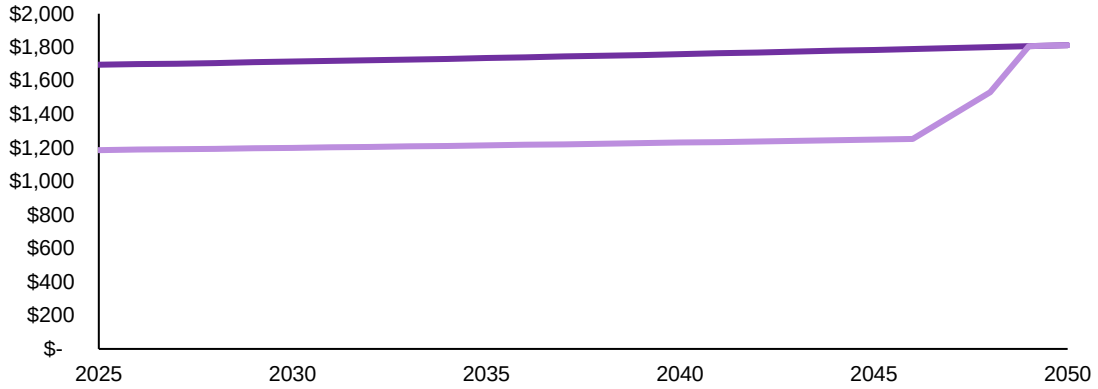
Onshore Wind Capex and LCOE Trends

Recost Forecasts: Q4 2024

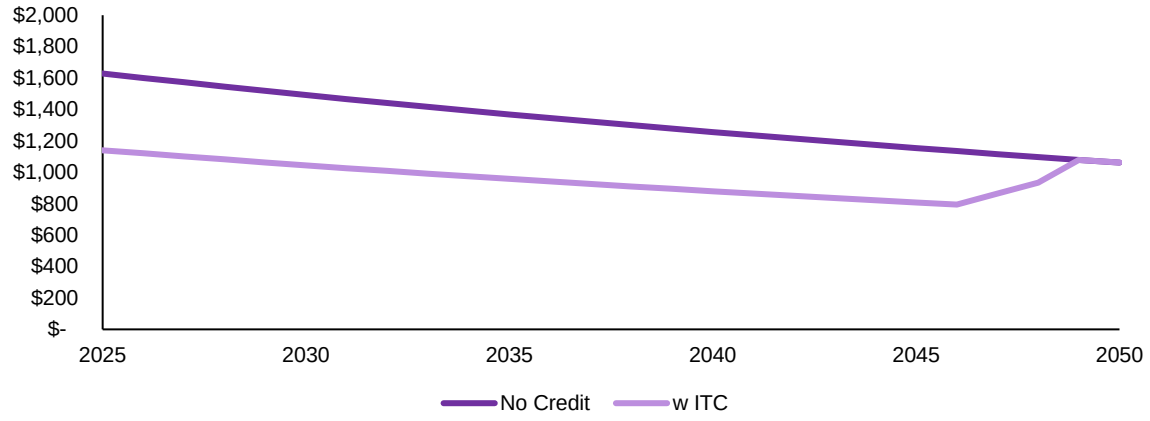
E3 expects long-term declines in real wind capex and LCOE, but nominal costs remain flat until tax credits expire

Wind Capex in Nebraska (with and without ITC)

(nom $/kW)

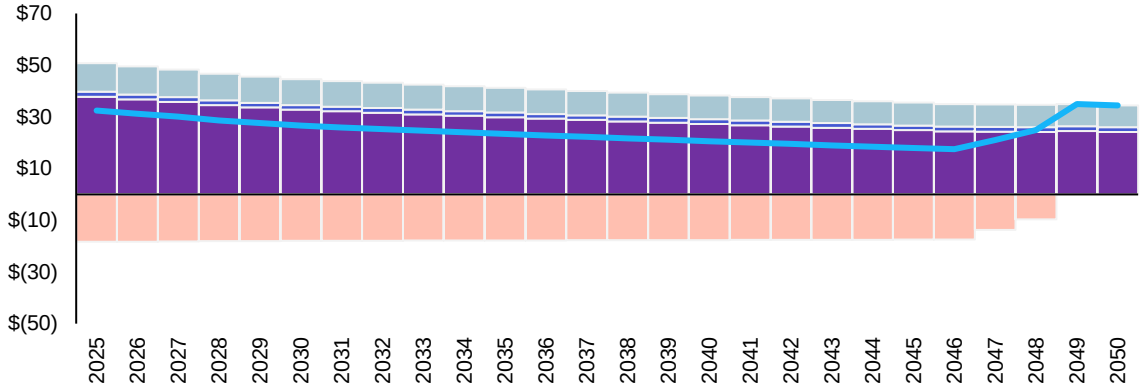


($2023/kW)

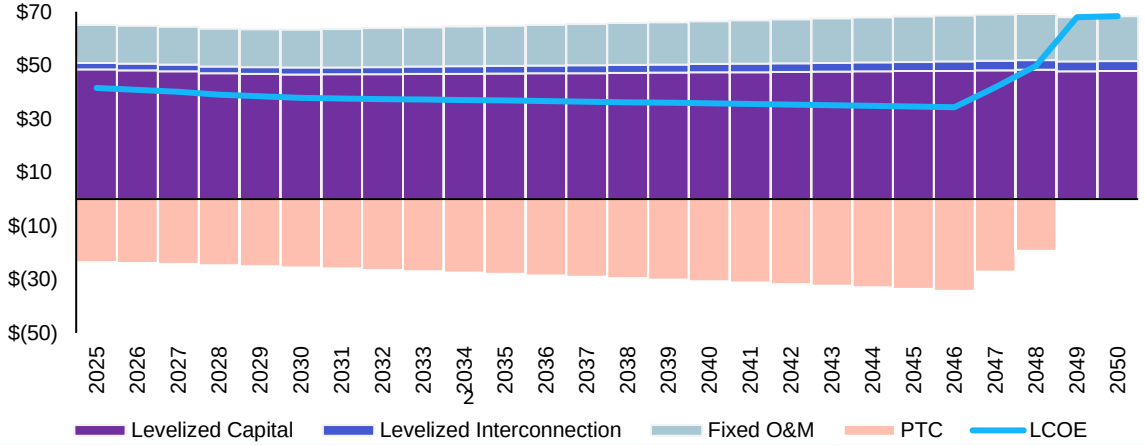


Wind LCOE in Nebraska (with PTC) – *35% CF*

(nom $/MWh)[1]



($2023/MWh)[1]



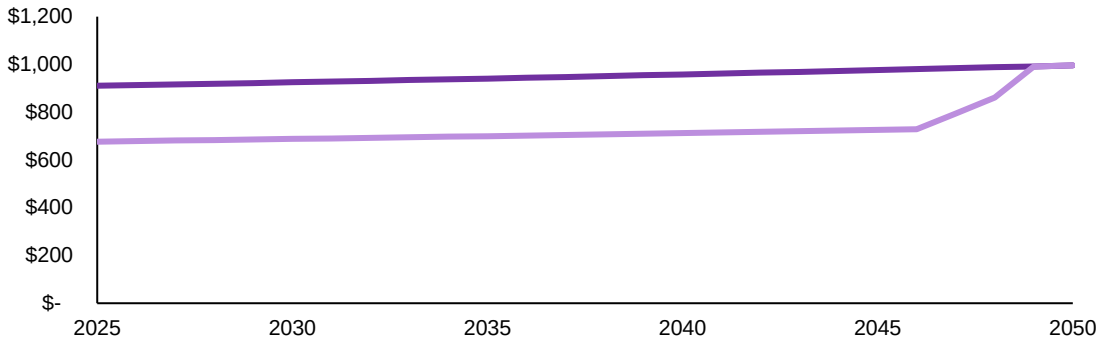
2-Hour BESS Capex and LFC Trends

Recost Forecasts: Q4 2024

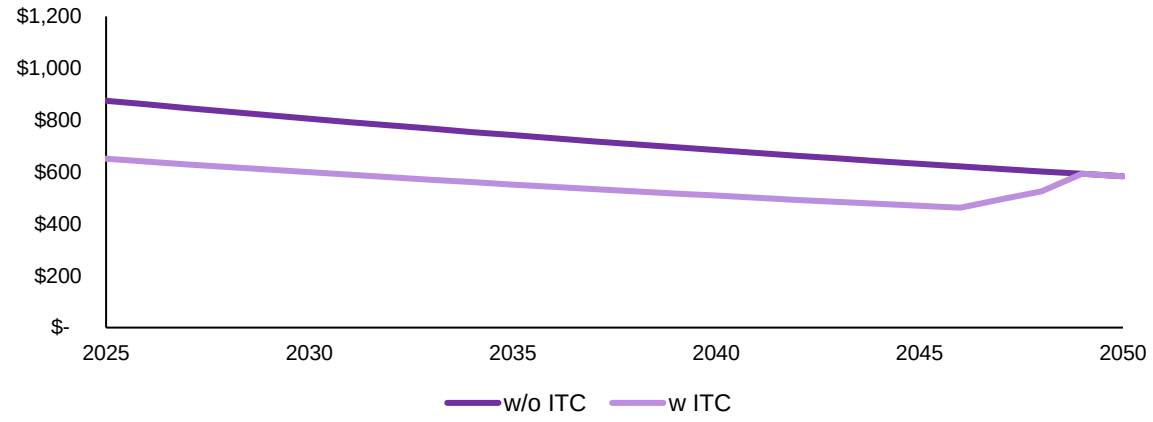
E3 expects long-term stabilization in BESS costs, with critical ITC support

2-hr. BESS CAPEX in ERCOT (with and without ITC)

(nom $/kW)

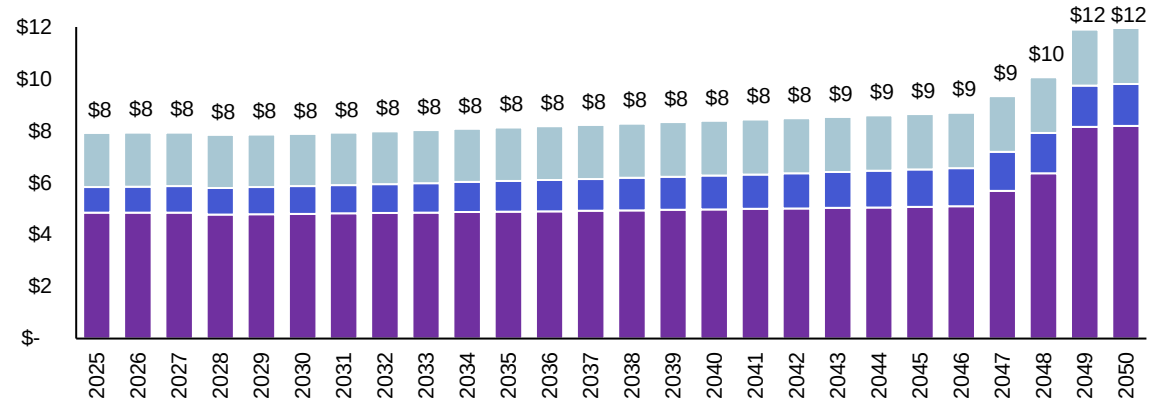


($2023/kW)

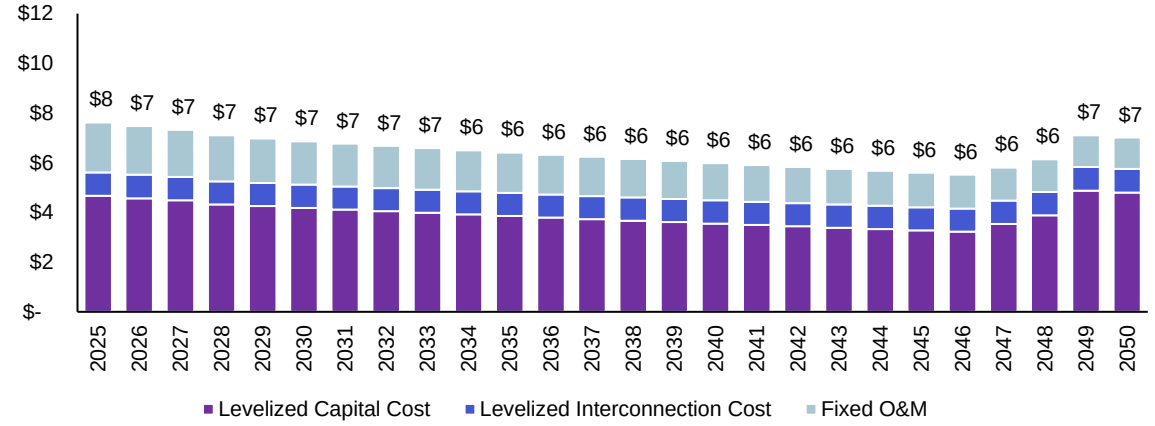


2-hr. BESS Levelized Fixed Costs (LFC)[1] in ERCOT (with ITC)

(nom $/kW-mo)



($2023/kW-mo)



[1] Projections of LFC (expressed in $/kW-mo) are an estimate of future resource costs; Recost results for LFC do not constitute market price forecasts for a given technology or region.

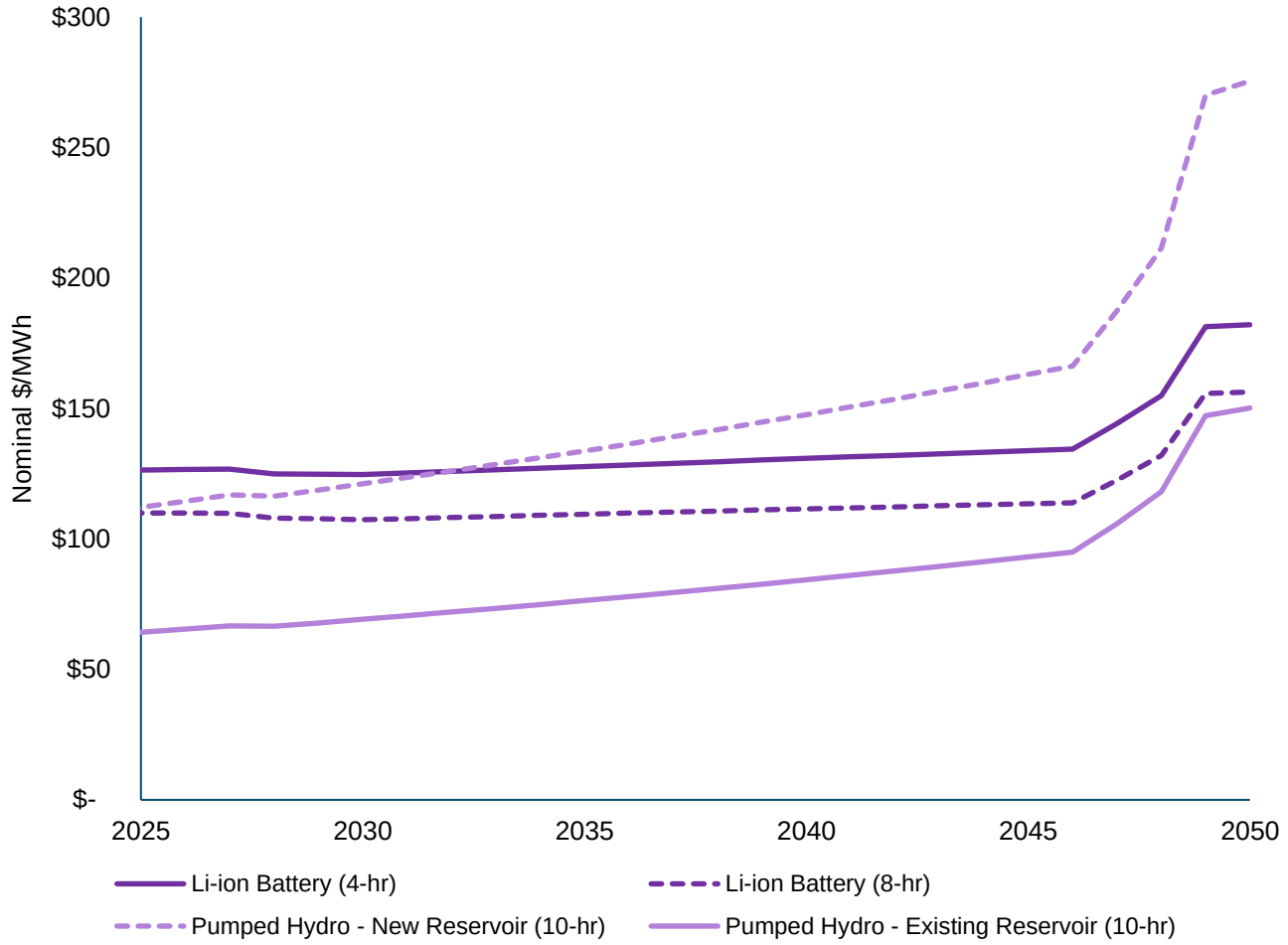
Levelized Cost of Storage (LCOS)

Recost Forecasts: Q4 2024

- **Existing-reservoir Pumped Storage Hydro (PSH) retains a cost advantage relative to 4-hour lithium-ion battery storage into the 2030s**
- **Battery storage costs moving forward will be shaped by multiple factors, most notably:**
  1) Commodity input costs and
  2) Supply chain dynamics
- **ITC value for energy storage in percentage terms will likely be higher in the near term for PSH, given domestic content requirement (DCR) bonus requirements, but long-term manufacturing on-shoring may erode this advantage**
- **Initial evidence reviewed by E3 suggests that battery development activity has begun to migrate towards Energy Community jurisdictions as defined by the IRA, taking advantage of siting flexibility[2]**

E3 LCOS Forecast

Nominal $/MWh[1]



[1] Levelized Cost of Storage is LFC normalized by the annual storage discharge (hours): assumes 300 cycles per year for pump hydro and 365 cycles per year for Li-ion battery, and 90% depth of discharge for both storage types

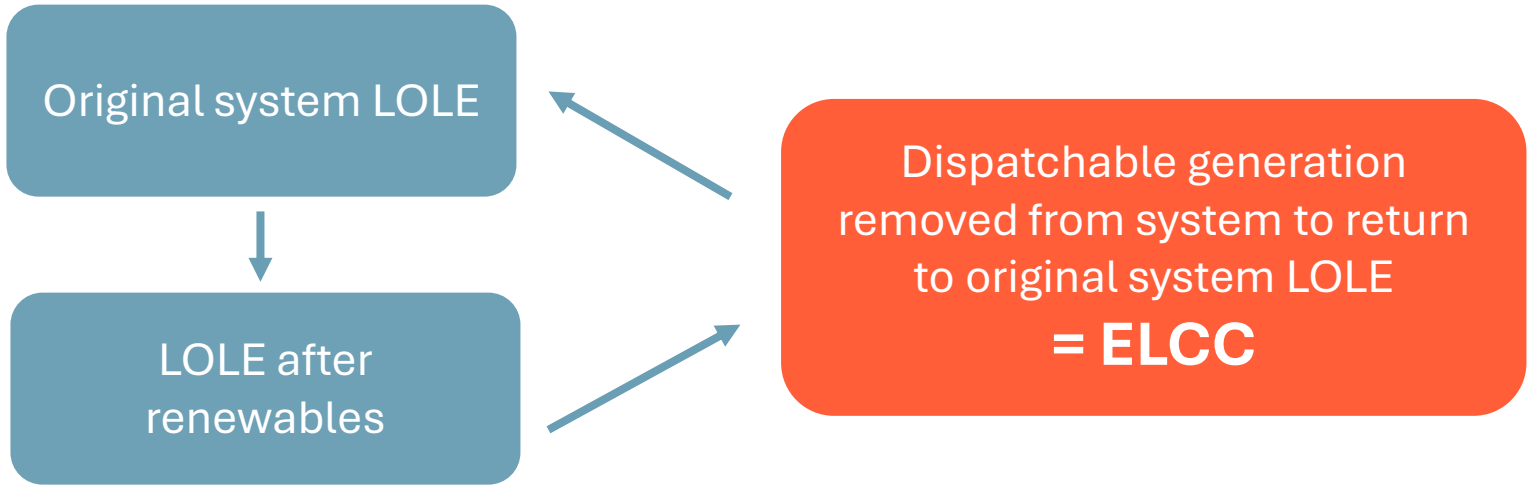
[2] https://www.ethree.com/energy-community-adder/

Resource Planning Context: Effective Load Carrying Capability (ELCC)

Energy+Environmental Economics

What is ELCC?

- **ELCC is the additional load met by an incremental generator while maintaining the same level of system reliability. This is also the equivalent 'perfect capacity' of a variable resource**
- **ELCC is a more technically rigorous method to calculate 'effective capacity' compared to other measures**
- **ELCC is calculated as follows:**
  1) Adding renewables to the system decreases Loss of Load Expectation (LOLE) (total # of hours with lost load)
  2) Removing dispatchable generation increases LOLE
  3) The amount of generation that can be removed from the system to return system to original LOLE is the ELCC



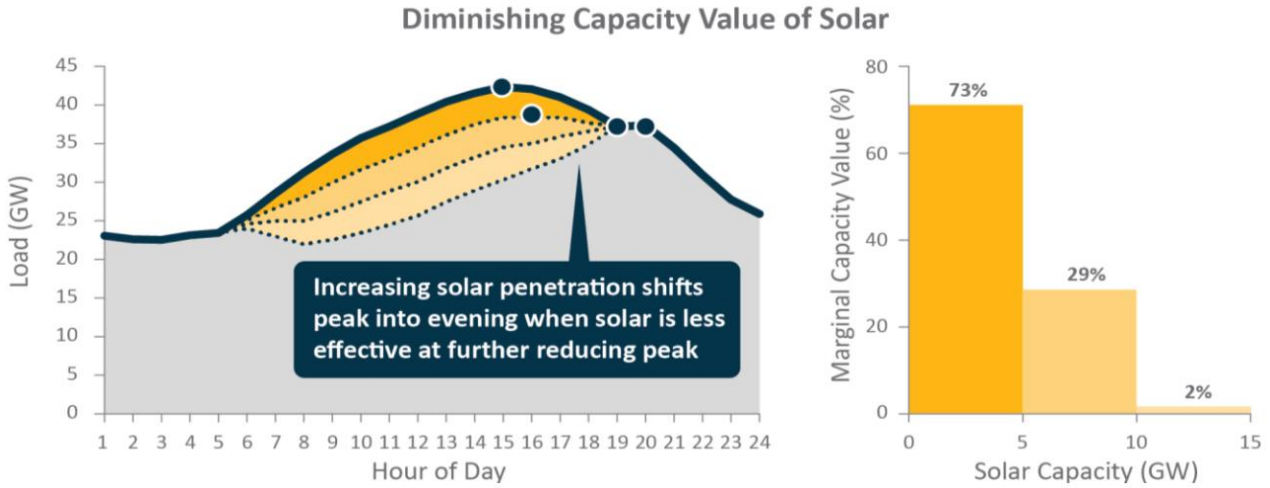
Why Does ELCC Matter?

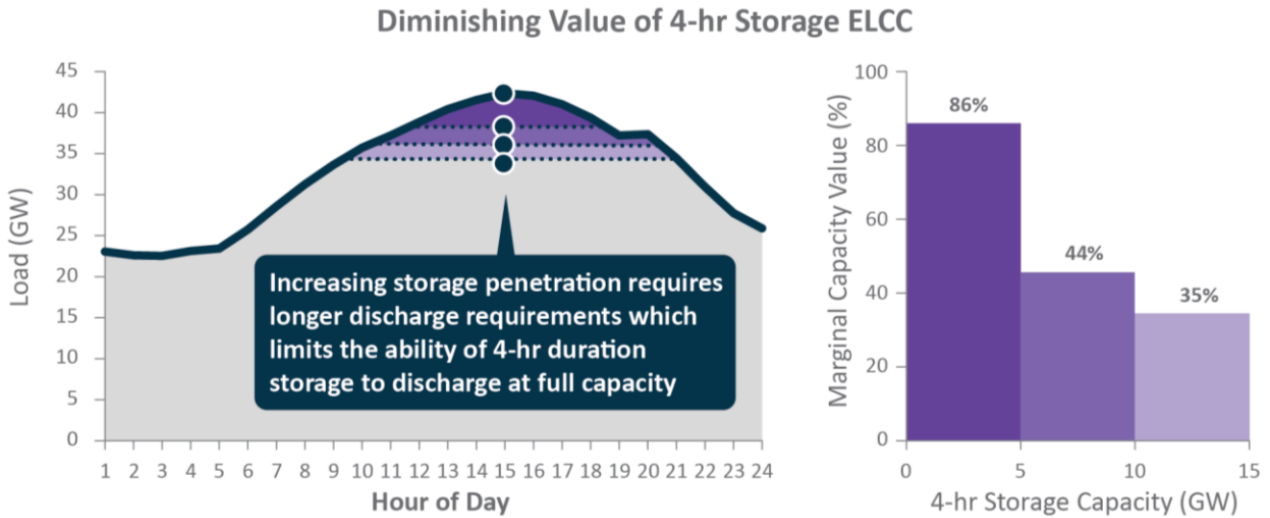
+ **ELCC captures the diminishing marginal returns of a specific resource with increasing scale**
  - Continuing to add more and more to an electricity system will produce lower and lower marginal resource adequacy benefits: for example, increasing solar penetration results in decreasing incremental impact on net peak demand, an effect that jurisdictions such as California have already encountered at today's penetration levels of solar

+ **ELCC allows us to distinguish between nameplate capacity and effective capacity:**
  1) Nameplate capacity refers to the maximum rated output of a resource; for example, a solar generation resource that can discharge up to 100MW has a nameplate capacity of 100MW
  2) Effective capacity refers to the 'perfect capacity' equivalent contribution that the system can rely upon from a given resource; for example, a solar resource that can discharge up to 100MW may only be relied upon for 10MW of output in system peak hour, so the effective capacity of the resource would be stated as 10MW

Ultimately, ELCC matters for two reasons:

1) **Maintaining system reliability as new clean resources are added to the grid requires, and**
2) **Compensating resources for capacity value based on their actual contributions to maintaining system reliability**





Source: https://www.ethree.com/wp-content/uploads/2020/08/E3-Practical-Application-of-ELCC.pdf

How Does ELCC Impact Recost Forecasts?

- **Recost forecasts the fundamental economic costs of a given resource, anywhere in North America**
  - These forecasts are agnostic to ELCC, and may be thought of as the price of 'perfect capacity' described earlier
- **The capacity value of a resource as reflected under a capacity contract (e.g., Resource Adequacy in California) will be different for every system in North America**
  - ELCC reflects the capacity mix of the system to which the new resource is added as well as the load characteristics of the system, both of which will vary from market to market
- **Therefore, E3 recommends calculating expected capacity payments for a given resource by applying an ELCC adjustment to the Levelized Fixed Costs shown in these materials**
  - Conversely, calculating the capacity cost in effective capacity term requires dividing the nameplate capacity by the ELCC input for comparability to other resources with higher and lower ELCC

For an energy storage resource where:
Nameplate Capacity = 100MW
State-Specific Levelized Fixed Cost (Recost Output) = 150 $/kW-yr
Resource- and Market-Specific ELCC = 80%

Expected Annual Capacity Payment = 100MW * 150$/kW-yr * 80% * 1000MW-per-kW = **$11.25mm, or 112.50 $/kW-yr**

and Levelized Cost of Capacity = 150$/kW-yr ÷ 80% = **187.50$/kW-yr**

Note: Calculation above is simplified and excludes adjustments for additional contract terms (e.g., round-trip efficiency, operating deviation factors).

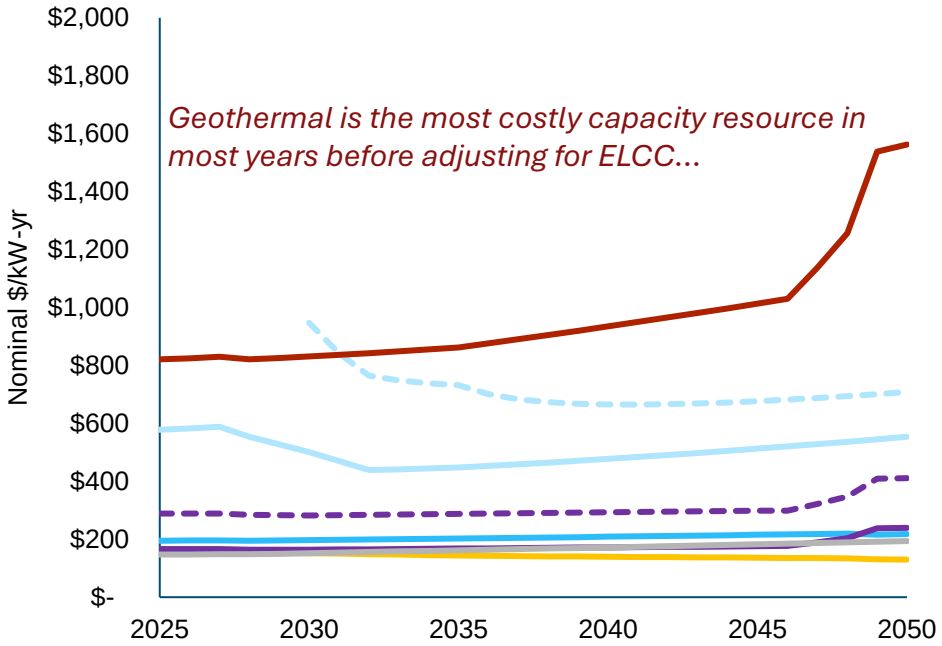
The Impact of ELCC: Levelized Cost of Capacity (LCOC)

+ Under simplified and static ELCC assumptions (see table), the impact of ELCC on resource cost expectations is clear: **firm, dispatchable resources retain a significant cost advantage for reliability purposes**

Resource Class	ELCC
Solar PV – PTC	10%
Onshore Wind	15%
Fixed Offshore Wind	40%
Floating Offshore Wind	40%
Geothermal	70%
Li-ion Battery (4hr)	75%
Li-ion Battery (8hr)	85%
Gas CT - Frame	90%

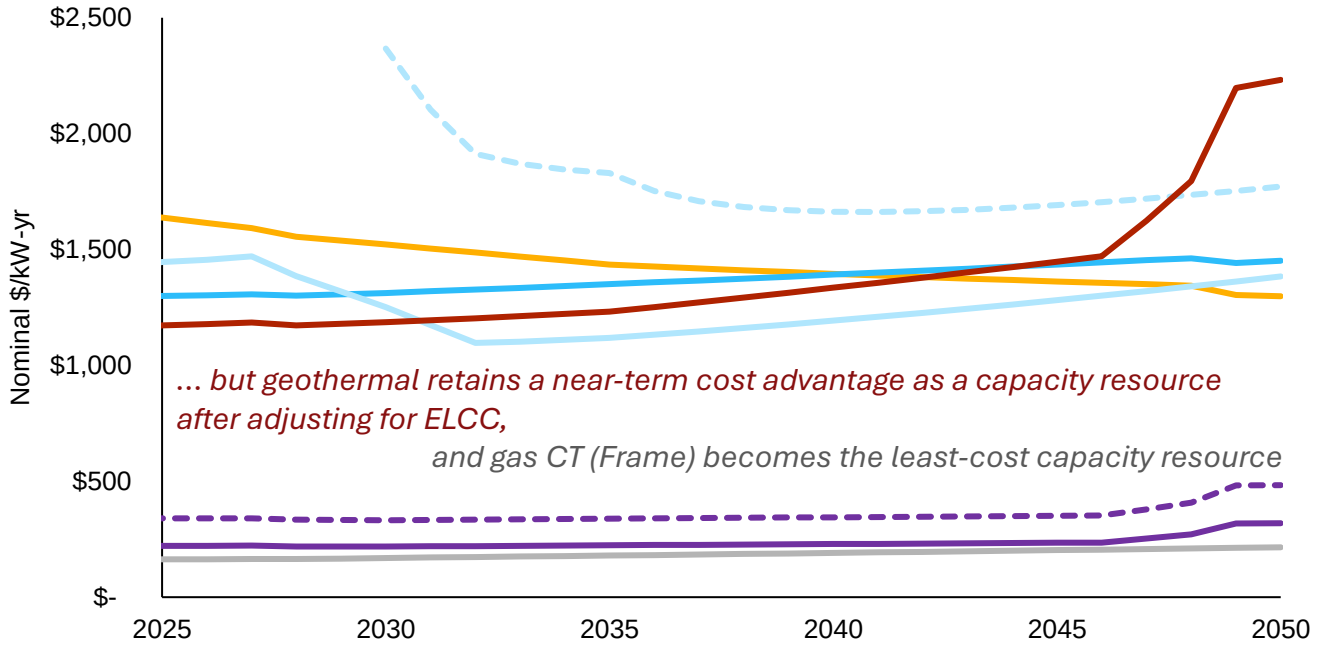
E3 LFC Forecast

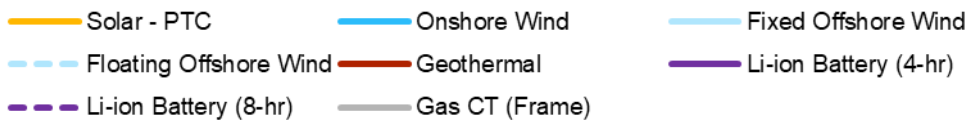
Nominal $/kW-yr of Nameplate Capacity



E3 LCOC Forecast

Nominal $/kW-yr of Effective Capacity



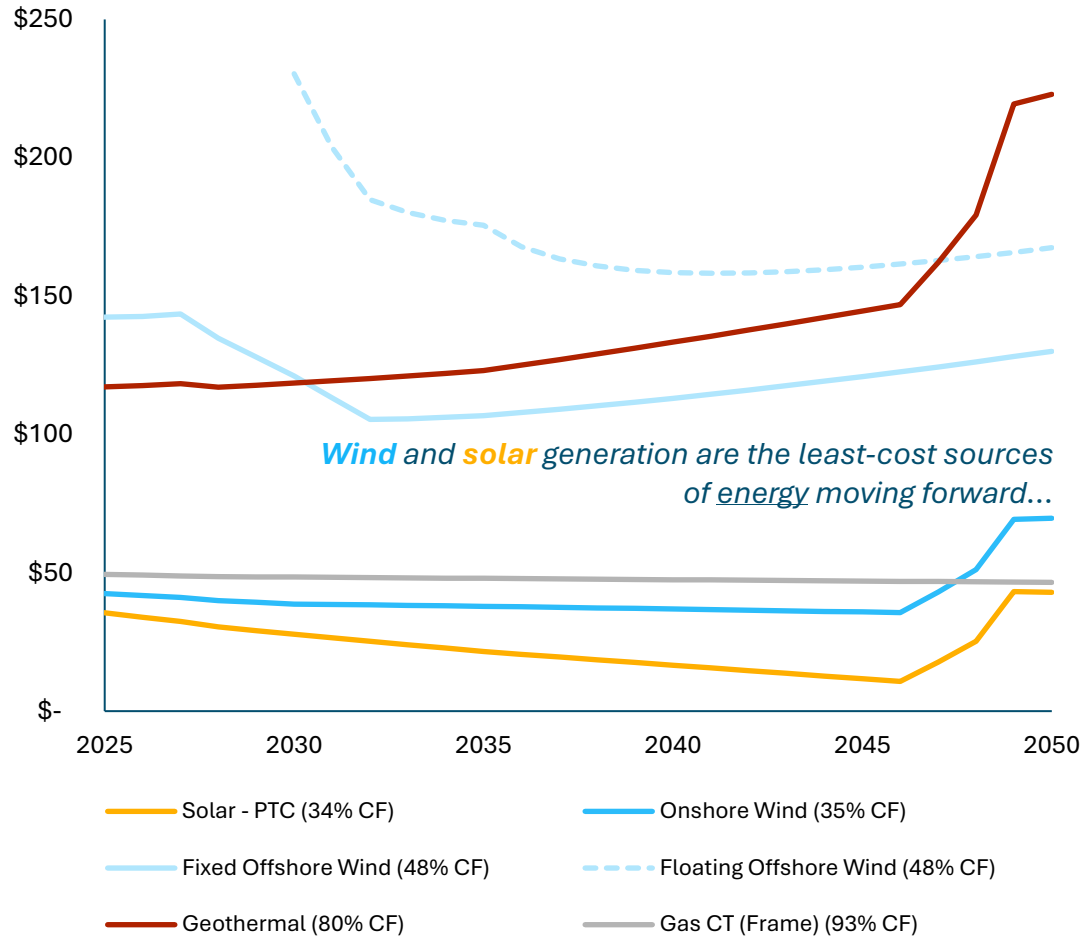


Resource Comparison: LCOE and LCOC

Recost Forecasts: Q4 2024

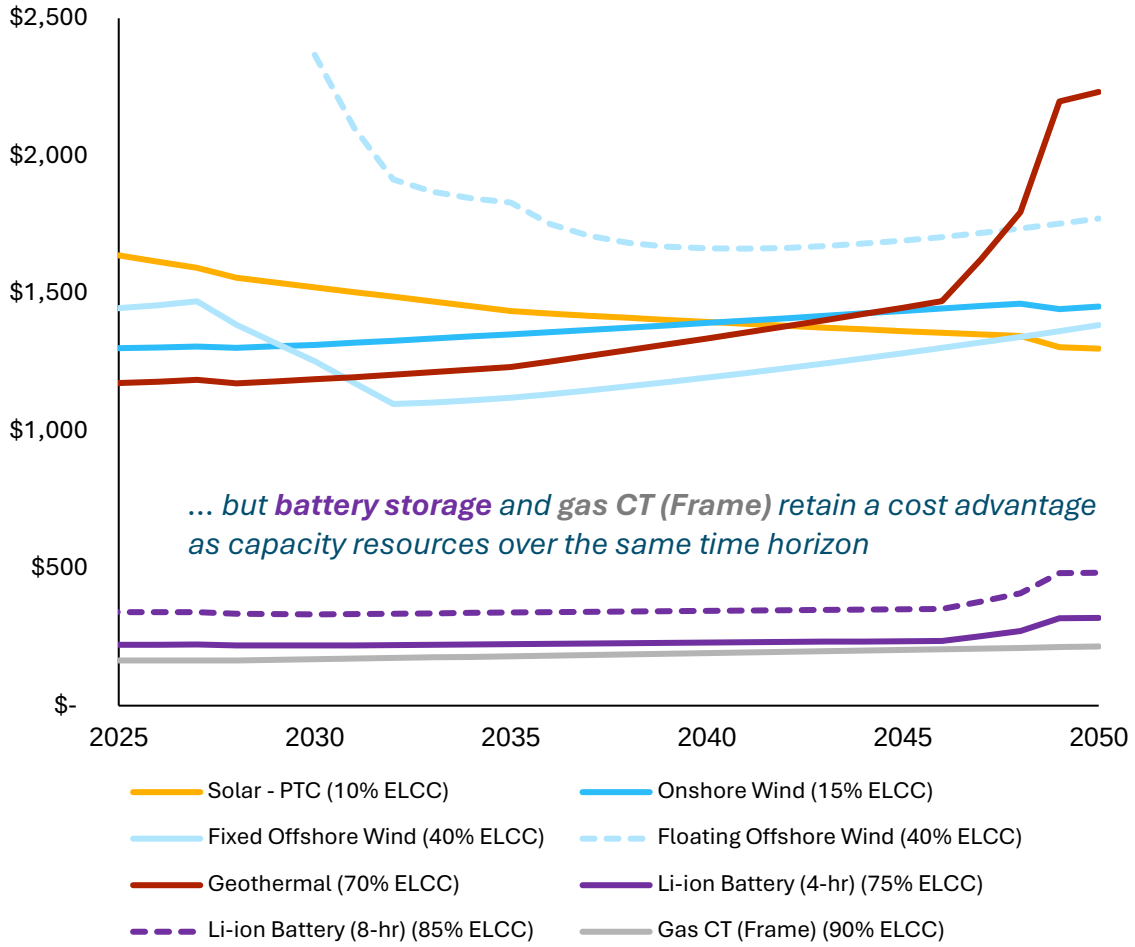
E3 LCOE Forecast

Nominal $/MWh of Available* Energy



E3 LCOC Forecast

Nominal $/kW-yr of Effective Capacity



* Available energy denotes the technical potential output of a project, without adjusting for congestion or curtailment (physical or economic).

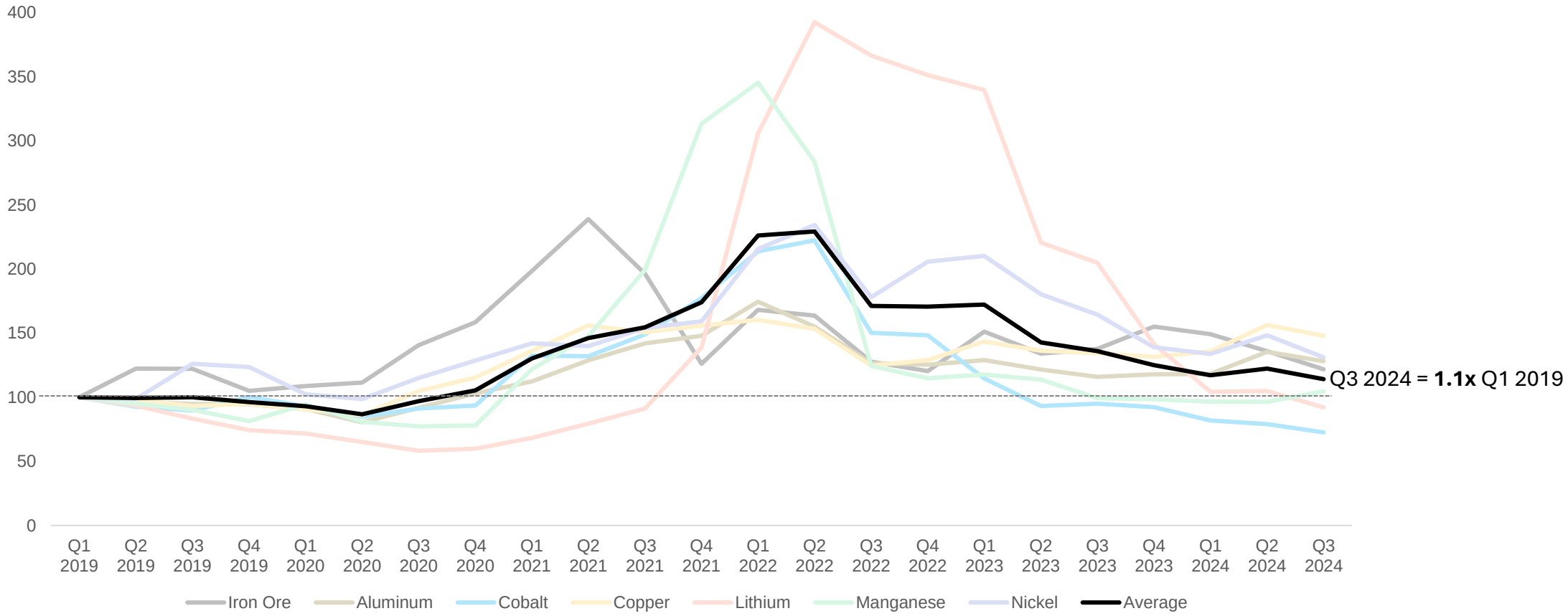
Appendix

Energy+Environmental Economics

BESS project costs have been driven by raw material costs, which have moderated since post-Covid spikes

Battery Storage Commodity Input Price Index

Q1 2019 = 100



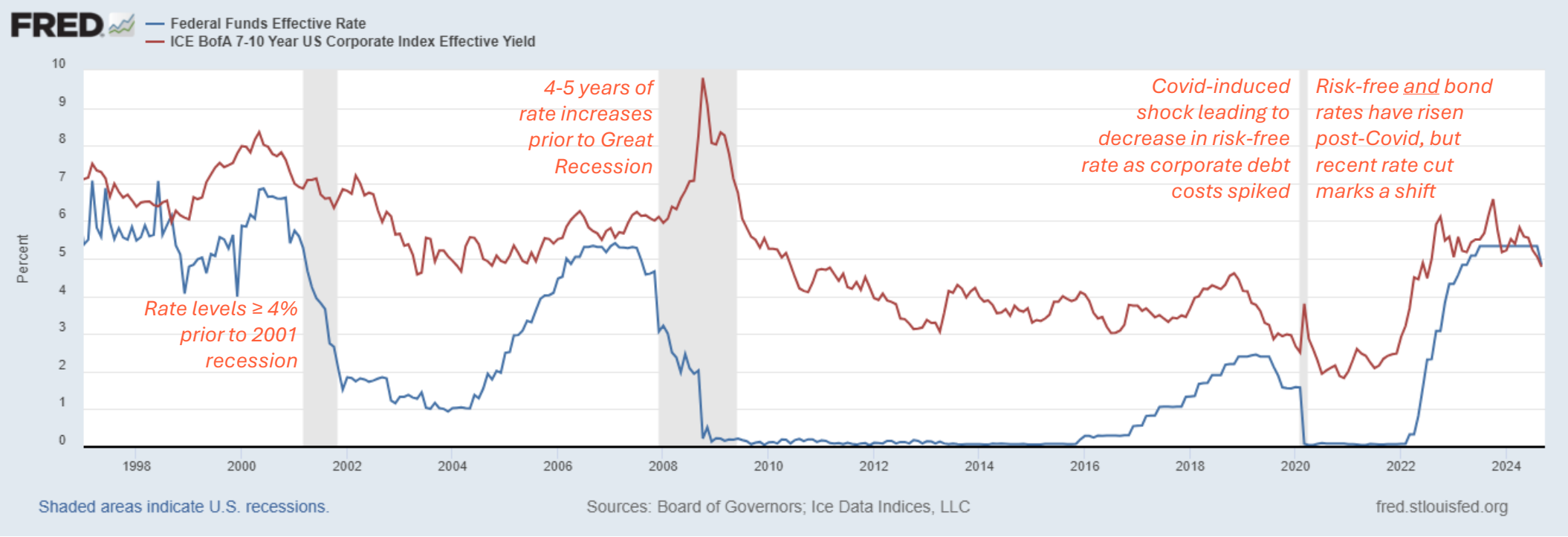
Other BESS capex increase drivers include increases in soft (labor), EPC, and interconnection costs

Source: IMF Quarterly Data as of 10/17/2024 (https://data.imf.org/?sk=471DDDF8-D8A7-499A-81BA-5B332C01F8B9&sId=1390030341854).

Debt costs increased post inflation-spike in 2021, driven by higher interest rates, but the Fed rate cut marks a new era

- In reaction to spiking inflation post-Covid, the Federal Reserve raised interest rates significantly
- The Fed rate cut in October 2024 marks the first since 2020 and appears to be mitigating yield curve inversion
- There is uncertainty in how long high interest rates will persist, but historic trends from the 1990s and 2000s suggest interest rates could remain elevated for 3-7 years following a recession

U.S. Historic Interest and Corporate Debt Rates



Thank You

marketprices@ethree.com

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