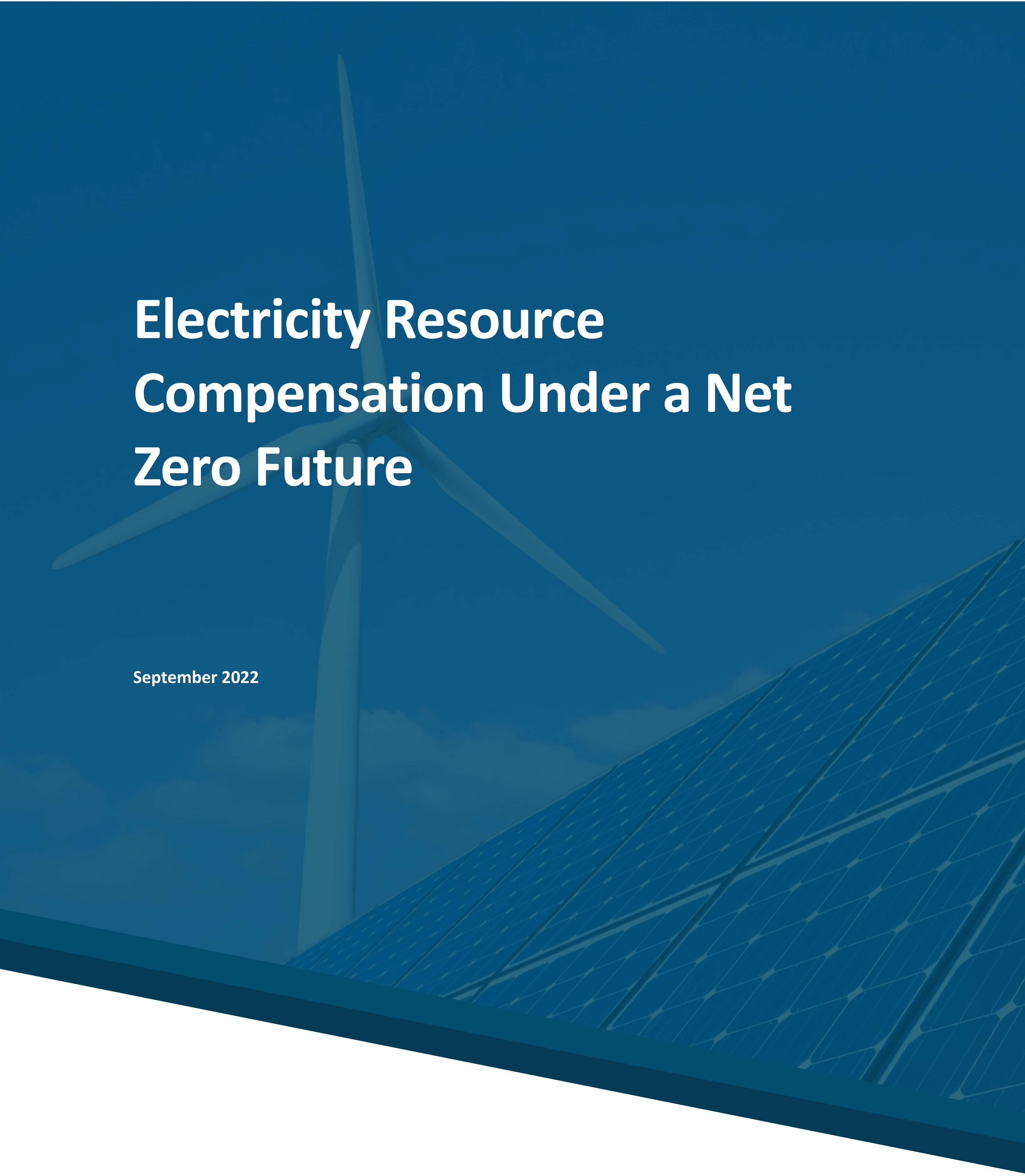

Electricity Resource Compensation Under a Net Zero Future

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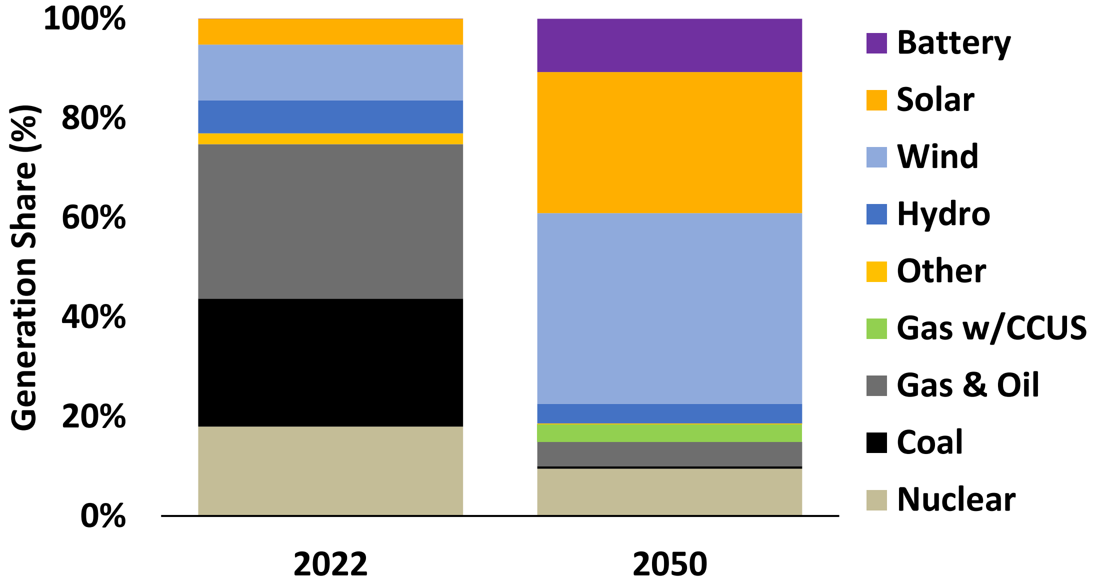
1. Introduction

Over the past decade, state governments, local municipalities, and large corporations have increased momentum for the adoption of net zero carbon policies, and with the signing of the Inflation Reduction Act in August 2022 that will provide hundreds of billions of dollars of investment in clean energy, that net zero carbon future now looks more achievable. E3 has been at the forefront of analyzing possible decarbonization pathways across North America. While there are multiple potential pathways on the road to net zero, it will ultimately result in a fundamental shift over time from an era of dominated by fossil fuel generation resources to one dominated by renewables, energy storage, and demand-side resources. This will result in a major transformation in how electricity markets function.

Figure 1. Generation Shift Example[1]



In May of 2021, E3 published a whitepaper titled "Scalable Markets for the Energy Transition: A Blueprint for Wholesale Electricity Market Reform[2]." This whitepaper discusses E3's views on decarbonized power systems and provides recommendations for the reform of wholesale electricity markets to ensure they can attract the necessary investment of new resources and continue to operate reliably. A key finding was that to achieve deep carbon reductions at the lowest possible cost, electricity markets must be accompanied by a scalable market mechanism to signal the value that society places on such reductions. For this, E3 proposed a tradable Bilateral Clean Energy Market (BCEM) mechanism that would provide a stable, predictable revenue source for the "missing money" needed to incentivize investment in clean

[1] Data pulled from High Electrification Scenario (with 95% CO_2 emission reductions below 2005 levels by 2050) in "2021 Standard Scenarios Report: A U.S. Electricity Sector Outlook," National Renewable Energy Laboratory, 2021, https://scenarioviewer.nrel.gov/

[2] "Scalable Markets for the Energy Transition: A Blueprint for Wholesale Electricity Market Reform," Energy & Environmental Economics, Inc., May 2021, https://www.ethree.com/wp-content/uploads/2021/05/E3-Scalable-Clean-Energy-Market-Design-2021.05.25.pdf

energy resources, i.e., the net cost of clean energy after energy, ancillary services, and capacity market value.

Among other observations, the whitepaper noted that electricity system operators will continue to need capacity, energy, and grid services, but at different quantities and at different times than historically. It also noted the predominance of state and local Renewables Portfolio Standards (RPS) or Clean Energy Standards (CES) as the primary policy mechanisms driving clean energy forward in the absence of a federal carbon price or CES. Despite its market inefficiency, E3 expects this trend to continue. And finally, the whitepaper provided a summary of key differences between a traditional grid that is primarily supplied by coal, nuclear and natural gas resources, and a future decarbonized grid that contains high levels of wind, solar and energy storage.

Table 1. Summary of Key Differences between the Characteristics of Traditional and Future Electric Power Systems

Category	Traditional Grid	Future Grid
Capital Costs	A range of capital costs from low (gas peakers) to high (nuclear)	Relatively high capital costs as a proportion of total lifetime costs
Operating Costs	High variable costs as a proportion of total lifetime costs	Low variable costs as a proportion of total lifetime costs
Bidding Behavior	Set by short-run marginal cost	Impacted by policy and shaped by opportunity cost
Capacity Characteristics	Firm and dispatchable; capacity contributions are independent and additive	Intermittent and dispatch-limited; capacity contributions are interrelated and dependent upon other resources on the grid
Nature of Reliability Constraints	Capacity limited: capacity sufficiency generally ensures energy sufficiency	Capacity and/or energy limited: capacity sufficiency may not ensure energy sufficiency
Flexibility Requirements	Low to moderate, subject to load uncertainty and generator contingencies	High, subject to load variability/uncertainty, generator contingencies, and generator variability/uncertainty due to weather
Load Interactivity	Low: grid operators largely serve passive loads	High: loads participate in retail and wholesale markets through self-generation, customer-sited battery storage, or load flexibility

Expanding on those observations in the Scalable Markets whitepaper, this whitepaper highlights the implications of decarbonization on the electricity markets and how new and existing resources are compensated for their various attributes and services, which should have a significant impact on how market participants view the long-term value of resources. This includes:

- Energy price formation
- Asset-specific attribute compensation
- Relative market size across energy market products
- Asset capture rates

2. Energy Price formation

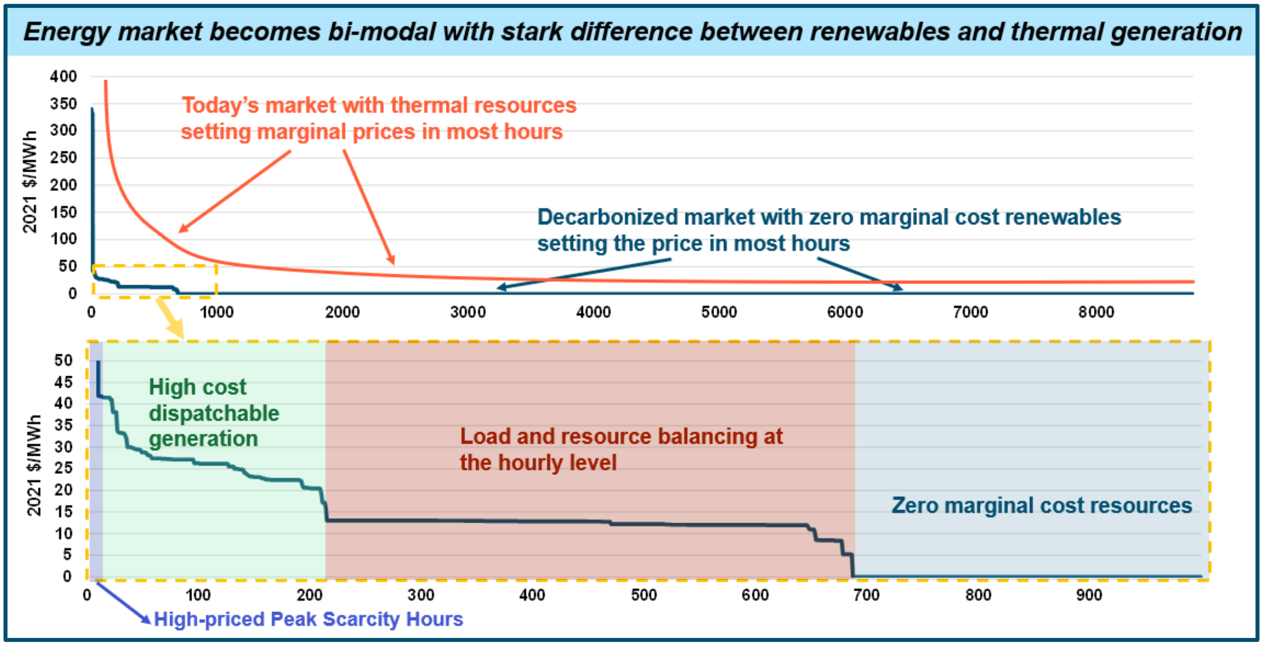
In electricity markets across the U.S. today, natural gas-fired resources set the marginal wholesale price of electricity during most hours, with the majority of hours set by combined cycle plants. Prices during high demand periods are set by higher-cost peaking resources, sometimes exceeding those levels either through scarcity-influenced market bidding or administrative mechanisms such as operating reserve demand curves (ORDCs). During periods of abundance, market prices are set by lower-cost coal or nuclear resources and increasingly by zero-marginal cost resources such as wind or solar.

A highly decarbonized grid will have a profound impact on the underlying resource type and hourly shape of wholesale energy prices. A highly decarbonized grid will increasingly trend toward a near bimodal market where zero-marginal cost resources set the wholesale power price in most hours except when forecast error and/or renewable "lulls" result in the need for the dispatch of high variable cost generation.

Figure 2 shows how a price duration curve could evolve under deep decarbonization, using ERCOT's North Zone as an example. Notably, the number of low-priced hours (under $10/MWh) is currently less than 2%. Under deep decarbonization with large amounts of wind or solar on the system, this could evolve to over 90% of time. These low wholesale energy prices will shrink the overall size of the energy market and revenue potential and lead to a shift in how resources are compensated.

The extent to which a market becomes bimodal under net zero will depend on its resource mix, both the makeup of renewables and the amount of energy storage. The realized market fundamentals will be dependent upon the specific loadshape and generation mix in each market. It is possible that given different combinations markets will be more or less bimodal.

Figure 2. Price Duration Curves – ERCOT-North Zone[3]

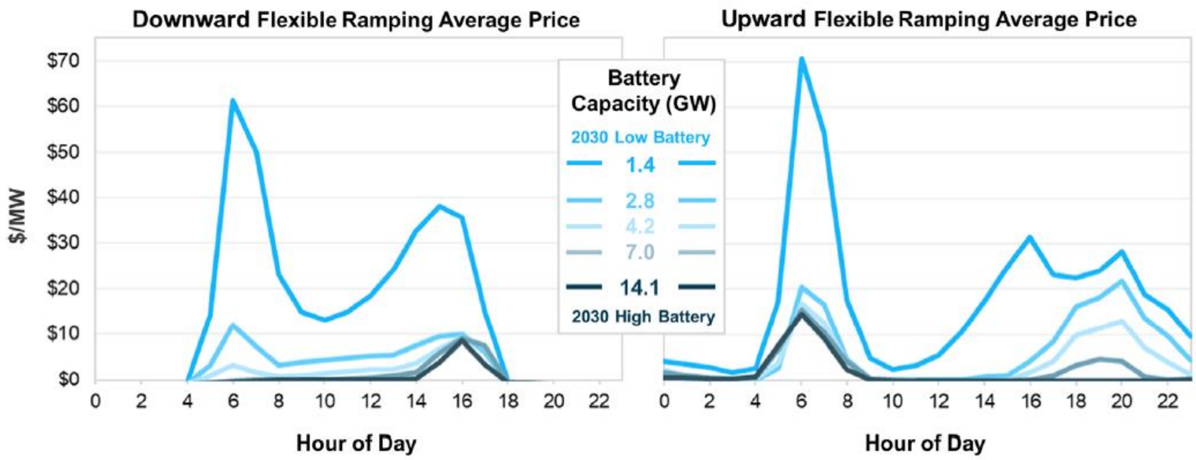


A highly decarbonized grid is expected to have much higher penetration of energy storage resources, which are effective at providing the operational flexibility needed for ancillary service markets. It is expected that these relatively thin markets will saturate quickly as more storage is brought online to fulfill state mandates, integrate increased renewables onto the grid, and facilitate broader decarbonization. This saturation will lead to declining prices in ancillary services markets, as well as the limited ability for any specific resource to clear those markets and obtain those revenues. For example, a report published by E3 in February 2022[4] finds that increased battery storage capacity in a system with high solar penetration, in this case CAISO, leads to much lower pricing for 15-minute flexible ramping. In fact, the marginal cost to provide within-hour ramping capacity is reduced to zero in most hours, which can be seen in Figure 3.

[3] Current data from Hitachi Energy Velocity Suite, accessed April 15, 2022; Forecast data derived by Energy & Environmental Economics, Inc.

[4] Yuchi Sun, James H. Nelson, John C. Stevens, Adrian H. Au, Vignesh Venugopal, Charles Gulian, Saamrat Kasina, Patrick O'Neill, Mengyao Yuan, *and* Arne Olson, "Machine learning derived dynamic operating reserve requirements in high-renewable power systems", Journal of Renewable and Sustainable Energy 14, 036303 (2022) https://doi.org/10.1063/5.0087144

Figure 3. Flexible Ramping Prices in CAISO in 2030 Under Varying Battery Capacity Penetrations



3. Resource compensation and market size shift

How we think about resource compensation and how generators are incentivized to be built and to continue operating will change as the wholesale electricity and ancillary service markets decline in importance. As a result of lower revenue in the energy and ancillary services markets, resources will need to rely more heavily on compensation from other markets, namely the clean or carbon-free attribute market for renewable and/or zero-carbon energy credits (RECs/ZECs), as well as capacity payments for providing reliability services.

These REC/ZEC and capacity markets will be needed to incentivize resources that either reduce the carbon intensity of the generation mix or are available for reliability in times of high demand and/or low renewable output.[5] These markets will be essential to ensuring resources are brought online and remain online, that would otherwise be uneconomic. Figure 4 below shows the evolution of the relative share of electricity markets under a pathway to net zero based on E3 analysis.

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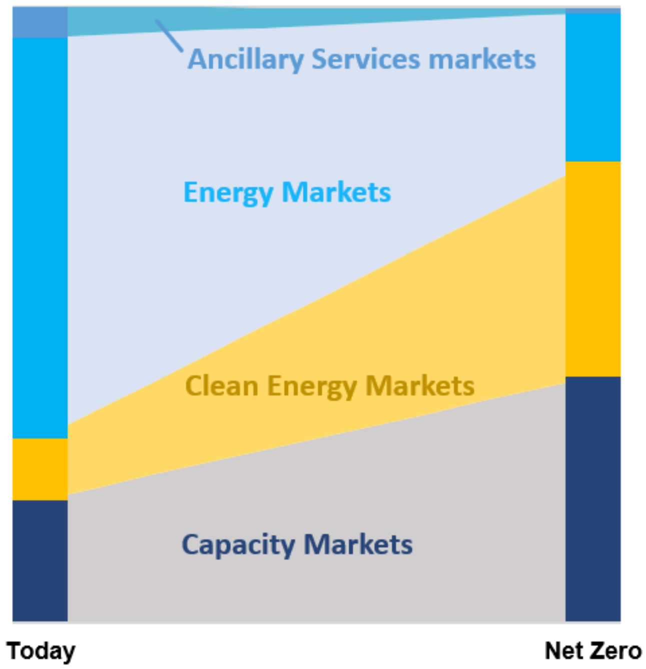
[5] Given the large amount of intermittent generation, the most challenging periods could evolve to also be based on low renewable output, not just peak demand.

Figure 4. Evolution of Electricity Markets under Net Zero



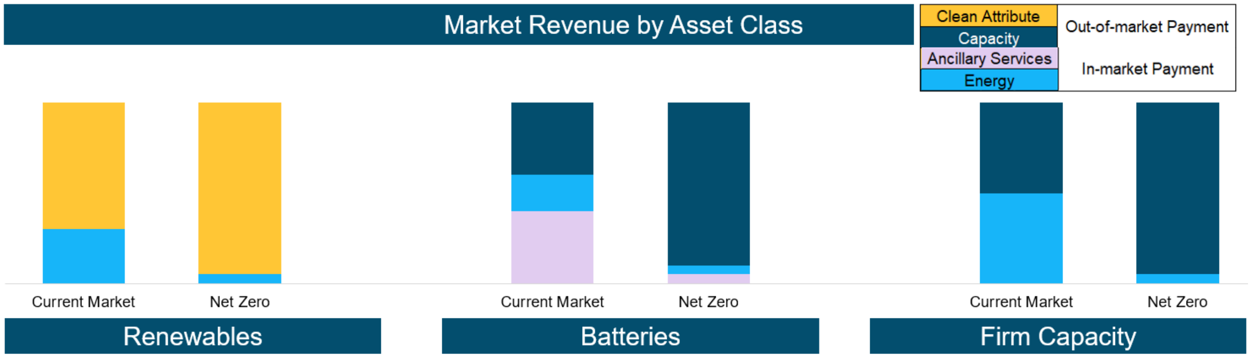
Further, as state requirements for clean and renewable energy increase over time, the size of the total market is also expected to increase. Lawrence Berkeley National Laboratory[6] expects that by 2050, state RPS and clean energy standards will require nearly 1,200 TWh of generation from their covered resources, more than double today's requirements, even under currently defined standards.

4. Asset-specific attribute compensation

The evolution of the relative size of these markets will be accompanied by a change in revenue sources that will evolve depending on asset class and will change how different types of resources are compensated. Renewables will evolve to rely on clean energy markets more heavily given their clean generation attributes and often lower capacity accreditation that is expected to decline in the future under higher penetration, while batteries and firm capacity will lean heavily on capacity markets. Both markets will fill the gap left by declining wholesale energy markets and saturated ancillary services markets.

[6] "U.S. Renewables Portfolio Standards 2021 Status Update: Early Release," Lawrence Berkeley National Laboratory, February 2021, https://eta-publications.lbl.gov/sites/default/files/rps_status_update-2021_early_release.pdf

Figure 5. Evolution of Market Revenue by Asset Class under Net Zero



Further, while the literature overwhelmingly demonstrates that increased scale and commoditization of the market for clean energy attributes leads to a more efficient and lower-cost clean energy transition[7], the widespread political and economic consensus required to make this work continues to be elusive in the United States. Instead, clean energy initiatives are more frequently driven by state and local policy preferences as well as voluntary initiatives on behalf of corporations and individuals that often desire to target specific resource types with carveouts or subsidies rather than seeking the least-cost clean energy sources in the near term. As a result, we expect a continued fragmentation and diversification leading to increased complexity in REC/ZEC markets. This is underlined by the proliferation of products and clean energy concepts available in the marketplace today including various definitions of "net zero" or "24x7" clean energy. REC/ZEC markets may further diversify to capture locational, temporal, and operational differences between resources, and to reflect policy preferences, leading to an even wider variety of more tailored market products. The Inflation Reduction Act recently passed by Congress and signed by President Biden will likely increase the complexity and diversity of clean energy markets through its array of resource-specific tax credits and funding sources.

Capacity markets are also undergoing structural change as a result of the shift away from "firm" or "dispatchable" resources toward variable resources such as wind and solar and duration-limited energy storage resources. Most organized capacity constructs are moving toward the use of Effective Load-Carrying Capability (ELCC)[8] for accrediting these resources. Key differences in the implementation of ELCC are emerging, however; for example, whether to use average or marginal ELCC values, how to define resource "classes" for ELCC calculation, how to accredit hybrid storage resources, and the extent to which ELCC values should vary by location are all issues that will need to be addressed in the coming years. Further, ELCC values will change over time as the resource mix changes in a market. Generation investors will need to have a deep understanding of these dynamics in order to develop reasonably accurate forecasts of this increasingly important revenue stream.

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[7] Including E3's research presented in *Scalable Markets*
[8] https://www.ethree.com/elcc-resource-adequacy/

5. Long-term contracts reflect high fixed cost system and enable highly levered financing

As the revenue from energy and ancillary services declines, this will also lead to a transition from a market structure that is largely tied to short-term bid-based markets to one that is more reliant on tailored long-term markets for specific resources with what are currently considered “out-of-market” payments. These markets will be less volatile than the hourly wholesale energy market, which will better facilitate economics that are more aligned with a future power market that is skewed much more towards fixed costs than variable costs. This more stable structure could be realized either as deep, liquid markets in large RTOs or long-term contracts in vertically integrated markets. Most importantly, this stability will provide increased revenue certainty that will enable cheaper levered financing. This lower cost financing will better enable the massive infrastructure investment needed for the clean energy transition that will take place over the coming decades.