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# CREATING A LEVEL PLAYING FIELD FOR BATTERY ENERGY STORAGE SYSTEMS THROUGH POLICIES, REGULATIONS, AND RENEWABLE ENERGY AUCTIONS

## CLIMATE ECONOMIC ANALYSIS FOR DEVELOPMENT, INVESTMENT, AND RESILIENCE (CEADIR)

Contract No.: AID-OAA-I-12-00038, Task Order AID-OAA-TO-14-00007

October 22, 2020

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*With:*

Abt Associates

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**Task Order: AID-OAA-TO-14-00007**

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U.S. Agency for International Development
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October 22, 2020

**DISCLAIMER**

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| **AEMO** | Australian Energy Market Operator |
| **BESS** | Battery energy storage systems |
| **BOO** | Build, own, operate |
| **BOT** | Build, operate, and transfer |
| **C&I** | Commercial and industrial |
| **CEADIR** | Climate Economic Analysis for Development, Investment and Resilience |
| **CPUC** | California Public Utilities Commission |
| **DER** | Distributed energy resources |
| **E3** | Economic Growth, Education, and Environment Bureau (USAID) |
| **EP** | Economic Policy Office (USAID/E3) |
| **EU** | European Union |
| **EV** | Electric vehicle |
| **FCAS** | Frequency control ancillary services |
| **FERC** | Federal Energy Regulatory Commission (United States) |
| **FiT** | Feed-in Tariff |
| **GCC** | Global Climate Change Office (USAID/E3) |
| **GHG** | Greenhouse gas |
| **GoB** | Government of Brazil |
| **GoC** | Government of Chile |
| **GoI** | Government of India |
| **GW** | Gigawatts |
| **GWh** | Gigawatt-hour |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **IESA** | India Energy Storage Alliance |
| **IOU** | Investor-owned utility |
| **IRENA** | International Renewable Energy Agency |
| **IRR** | Internal rate of return |
| **KIUC** | Kauai Island Utility Cooperative |
| **kWh** | Kilowatt-hour |
| **Li-ion** | Lithium-ion |
| **MW** | Megawatts |
| **MWh** | Megawatt-hour |
| **NREL** | National Renewable Energy Laboratory |
| **NYISO** | New York Independent System Operator |
| **OPIC** | Overseas Private Investment Corporation (currently, U.S. Development Finance Corporation) |
| **PPA** | Power purchase agreement |

| | |
|---|---|
| **PURPA** | Public Utility Regulatory Policies Act |
| **PV** | Photovoltaic |
| **P2X** | Power-to-X |
| **RAM** | Renewable auction mechanism |
| **RE** | Renewable energy |
| **REC** | Renewable energy certificate |
| **RFP** | Request for proposals |
| **RPS** | Renewable portfolio standards |
| **SCE** | Southern California Edison |
| **TN** | Technology-neutral (auction or other competitive procurement) |
| **TNRE** | Technology-neutral renewable energy (auction or other competitive procurements) |
| **TS** | Technology-specific (auction or other competitive procurement) |
| **U.S.** | United States |
| **USAID** | United States Agency for International Development |
| **U.K.** | United Kingdom |
| **USG** | United States Government |
| **VAR** | Volt-ampere-reactive |
| **VRE** | Variable renewable energy |

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This work was funded by the United States Agency for International Development (USAID) Economic Growth, Education, and Environment Bureau (E3) Global Climate Change (GCC) Office. It was managed by the GCC and the E3/Economic Policy (EP) Offices. CEADIR would like to thank Dr. Eric L. Hyman (EP Contracting Officer's Representative and Activity Manager for Economic Analysis) and Matthew Ogonowski (formerly, GCC Alternate Contracting Officer's Representative and Activity Manager for Clean Energy). CEADIR would also like to acknowledge guidance provided by Sarah Lawson (E3/Energy and Infrastructure Office).

The authors would like to thank interviewees from the following organizations for their valuable insights: the Australian Government Deregulation Task Force; Blue Solar (Thailand); Brasil Biofuels; Comisión Nacional de Energía (Chile); Hawaiian Electric Company; Inter-American Development Bank; International Finance Corporation; Navigant Consulting, Inc.; University of Queensland's School of Economics; World Bank energy team and storage initiative; and Xcel Energy. The authors would like to thank Alexa Smith-Rommel (Abt Associates) for editorial support.

# EXECUTIVE SUMMARY

Auctions have proven to be the most efficient and effective procurement mechanism for expanding renewable electric power capacity in developed and developing countries. Unlike negotiated procurements or feed-in tariffs, auctions can reduce the costs of developing new power generation capacity by promoting competition and efficient price discovery as the technology has improved and production costs have declined. Auctions can also reduce costs by increasing fairness and transparency in government and utility procurement processes. Auctions that lead to long-term, power purchase agreements (PPAs) have enabled renewable energy (RE) developers to obtain the financing needed to implement their proposals.

Some RE auctions have focused on one or more specific technologies, such as photovoltaics (PV), wind power, or hydropower. Although technology-specific auctions can be used to diversify the types of RE resources on the power grid, they limit competition and might not produce a least-cost mix of technologies. Technology-neutral renewable energy (TNRE) auctions are less prescriptive than technology-specific auctions because they focus on capacity or generation targets, rather than how to achieve them.

RE resources are intermittent and may not be available when and where they are needed on the grid to meet peak power demand. Various types of RE resources have different patterns of intermittency and can be combined to reduce the overall variability of grid power supplies. Battery energy storage systems (BESS) can also help *firm up* RE supplies by reducing the impacts of intermittency on the ability to meet market demand, especially peak loads. Although BESS costs have been relatively high, they have been declining rapidly and are anticipated to continue falling.

Utility-scale BESS is expected to play an increasing role in meeting future peak electricity loads. It may allow utilities to avoid or defer costly capital investments in generation capacity that would otherwise be needed to meet peak loads without outages or reductions in the quality of the power. In some places, RE combined with BESS, is already replacing natural gas peaking plans. BESS will bring new opportunities to reduce costs, increase service reliability, and reduce greenhouse gas (GHG) emissions and other environmental impacts. BESS has already proven to be technically and economically viable in developed countries and a few developing countries.

To date, most auctions for RE energy have not specifically solicited utility-scale BESS. Some auctions in Arizona, California, and India have procured *firm power* commitments (a guaranteed supply of electricity despite adverse conditions or peak loads), which can encourage use of BESS. Some RE capacity auctions have not excluded bids with BESS. For example, in 2017, a RE auction in Thailand awarded a contract to a bidder that combined PV and storage.

However, RE auction pricing rules often put BESS at a disadvantage by not allowing *value stacking* (payments for the multiple services that this technology can provide for the grid). Examples of these ancillary services include black start, spinning reserves, non-spinning reserves, and voltage and frequency regulation, maximizing the system's value to the grid by providing multiple system services. Some of these services are commonly used, while others such as spinning reserves are needed less frequently over the course of a day. Black start is only rarely required.

This report addresses ways to improve the enabling environment for BESS and create a level playing field for BESS in auctions. It is intended to help government policy makers, regulators, utilities, and RE developers. It examines the importance of new regulatory frameworks, time-differentiated tariffs, and value stacking to provide fair compensation for the grid services provided. It discusses the impact of the bidding rules, including auction prequalification requirements, evaluation criteria, structuring of contracts in TNRE auctions, winning bidder liabilities, local content requirements, and battery recycling and safety issues.

CEADIR identified a series of findings and recommendations to help create a level playing field for utility-scale, front-of-the-meter BESS procurement:

- Government agencies and utilities need to modify rules, procedures, and rate provisions in RE auctions to provide a level playing field for bids that include BESS.
- Auction rules and requirements should not limit the eligibility and competitiveness of bids that include BESS as a standalone resource or in combination with other resources. RE auctions should generally be technology neutral and allow bids for standalone BESS and co-located or hybrid systems of BESS plus RE capacity. Auctions that allow higher prices or scoring based on domestic content can deter investments in BESS.
- Policymakers should consider auctioning contracts with different levels of firmness to meet the specific needs of the power system. There is an international trend toward transferring part of the RE resource intermittency risk away from buyers to sellers. The regulatory framework and procurement and market rules should give sellers the necessary flexibility to manage RE intermittency risks.
- At current technology prices, the ability to charge for the multiple services that BESS can provide to the grid (*value stacking*) is important for investment returns. Storage can provide other services for the grid or large users in addition to firm power. Although the unit costs of BESS have fallen, the financial viability of the investments may still depend on value stacking from multiple services. There are currently no industry standards or markets for pricing all BESS services, particularly in developing countries. Auctions can promote value stacking for storage assets.
- Various business models can be used for front-of-the-meter BESS in RE auctions. Those models may require different product specifications, rules, and price and nonprice award criteria in auctions. CEADIR identified seven business models ranging from BESS as a standalone resource to provision of firm capacity and associated power generation by paired RE plus BESS technologies.
- As the market for BESS matures, more sophisticated auction designs can facilitate competition and innovation and expand the range of products and services provided. New markets for ancillary services can be introduced in countries with relatively sophisticated power markets. A *combinatorial auction* can also help bidders monetize the full range of their services (*sourcing optimization*).
- As in other auctions for RE resources, many risks exist in competitive procurement of paired RE plus BESS. Auction design risks include underbidding and undercontracting. Power purchase agreement (PPA) implementation risks include nonrealization risks, construction risks, and operational risks.

# 1. TECHNICAL BACKGROUND

## 1.1. STUDY PURPOSE, METHODS, AND SCOPE

USAID asked the Climate Economic Analysis for Development, Investment and Resilience (CEADIR) Activity to discuss the impact of the policy and regulatory environment and the design and implementation of renewable energy (RE) auctions on the creation of a level playing field for utility-scale, battery energy storage systems (BESS) investments. The purpose of this report is to help government policy makers, regulators, utilities, and RE developers in developing countries facilitate private investments in BESS that are financially and economically viable.

This report discusses ways to create neutral or favorable conditions for BESS. It examines the importance of new regulatory frameworks, time-differentiated tariffs, and value stacking to provide fair compensation for the range of grid services provided by BESS. It discusses the impact of auction bidding rules, including prequalification requirements, evaluation criteria, structuring of contracts in technology-neutral renewable energy (TNRE) auctions, winning bidder liabilities, domestic content requirements, and battery recycling and safety issues. This report draws on experiences in the United States (U.S.), other developed countries, and developing countries.

CEADIR conducted desk research and interviews for this study between July 2019 and February 2020. The team interviewed 16 representatives of RE auction participants, including some that resulted in awards for BESS. CEADIR also interviewed representatives of the following organizations:

1. Australian Government Deregulation Task Force (The Treasury)
2. Blue Solar Group (energy developer in Thailand)
3. Brasil Biofuels (a parastatal energy developer)
4. Comisión Nacional de Energía (Government of Chile)
5. Hawaiian Electric Company (U.S. utility)
6. Inter-American Development Bank
7. International Finance Corporation (multilateral development bank headquarters)
8. International Finance Corporation/India (multilateral development bank country office)
9. Navigant Consulting, Inc. (U.S. consulting firm acquired by Guidehouse LLP)
10. University of Queensland's School of Economics (Australia)
11. World Bank energy team and storage initiative (multilateral development bank)
12. Xcel Energy (U.S. utility)

Blue Solar received a contract to supply solar power plus battery energy storage in a RE auction in Thailand.[1] In 2017, the Comisión Nacional de Energía in Chile held a TNRE auction that resulted in an award for a solar photovoltaic (PV) and storage project to supply power at night. The Hawaiian Electric Company and Xcel Energy have conducted TNRE auctions that resulted in contracts that included BESS.

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[1] http://www.bluesolar.co.th/EN/product/spp_hybrid_firm.html

The other interviewed organizations included governmental entities, an energy developer in Brazil, development finance institutions, a U.S. consulting firm, and an Australian university.

The rest of Section 1 discusses the importance of energy storage, types of energy storage, the benefits of battery energy storage, markets and valuation of BESS services, trends in battery costs and deployment, and new and emerging technology alternatives. Section 2 addresses the policy and enabling environment for BESS in the U.S. and other countries, including policies and regulations, compensation methods and markets, and storage duration and dispatchability requirements. Section 3 discusses the importance of RE auctions and examples of their use for BESS. Section 4 addresses design and implementation issues for RE auctions. Section 5 presents key findings and recommendations. Annex A discusses some related CEADIR work. Annex B provides some additional examples of utility-scale BESS.

## 1.2. IMPORTANCE OF ENERGY STORAGE

Energy storage allows utilities, electricity suppliers, and grid operators to save surplus power for later use. The demand for electricity (*load*) varies seasonally and over the course of a day. Energy storage can offset the volatility of intermittent RE resources, help meet *peak load* at times of high demand, cover supply disruptions, and maintain the quality of electricity supplies. It can also reduce wasted power generation because electricity cannot be used if there is insufficient immediate demand or transmission and distribution capacity (*curtailment*). Energy storage allows electricity to be retained when it is not needed for immediate use or has a low value for the power grid and sold later when the value to the system is high. Consequently, energy storage can be viewed as both power generation and load.

Electricity generation from RE resources varies by season, time of day, and weather and hydrological conditions. Some of this variability can be forecast, but generation levels can also change suddenly. *Variable renewable energy* (VRE) is sometimes called *RE resource intermittency*. These risks can be reduced by using multiple types or locations of renewable resources with different availability patterns (*geographical diversification*).[2] Large-scale hydropower is not classified as an intermittent RE source because water is stored in massive reservoirs to reduce availability problems. Nevertheless, severe droughts or floods can substantially reduce hydropower generation from large reservoir systems.

There is often a mismatch between renewable electric power availability on the grid and the market demand. Since renewable electric power plants have relatively low short-term marginal costs, they are generally the first sources to be dispatched by the electricity grid. However, RE generation is not always dispatchable when needed (*curtailment*).

Energy storage helps integrate variable RE on the macrogrid (mains) by reducing *curtailment* of generated power that exceeds the quantity demanded at the time (*load*). The stored power is made available later when needed, especially for peak load periods. Energy storage can also contribute to capacity reserves, defer the need for some transmission and distribution investments, and provide ancillary services for large macrogrids. It can help ensure a reliable power supply for small or isolated microgrids or minigrids.

Contracts often remunerate renewable electric power producers on a deemed generation basis. *Deemed generation* (*pay-as-generated*) provides payments for electricity that a generation unit could have produced, but did not generate for reasons outside of its control (such as insufficient demand or

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[2] There is an ongoing debate on whether to describe nonconventional RE as an intermittent resource. Some prefer the term variable renewable energy (VRE) because RE resource intermittency can imply a binary, on-off production pattern. However, the term *intermittency* is widely used in the industry and by the Institute of Electrical and Electronics Engineers (IEEE), the National Renewable Energy Laboratory (NREL), and U.S. power pools.

transmission capacity). Under most RE power purchase agreements (PPAs), electricity generators are not responsible for smoothing RE resource volatility. Instead, the grid operator has to make backup resources available to meet the combined variability from supply and demand. Governments and utilities allowed independent producers to benefit from this contractual arrangement to increase their investment incentives s, especially in the early years when RE had higher costs and perceived risks. However, under this type of contract, the electricity from a particular RE generation unit is a lower quality product than fully dispatchable electricity.

Some grid operators have handled RE intermittency by relying on other electricity sources, pumped hydropower storage, or excess generation capacity from spinning reserves. *Spinning reserves* are backup power generation units that can be ramped up quickly to meet immediate load requirements. Tait (2017) reported that U.S. utilities generally maintained spinning reserves equal to 3.0-4.5 percent of their average loads to cover potential generation outages.

However, as the proportion of RE increases, a system operator may face more challenges in maintaining a continuous supply of electricity, particularly in areas with small grids, limited storage, old generation fleets with limited ramp-up capacity, or inflexible RE power plants that have little ability to provide spinning reserves. Under these conditions, a system operator has to plan for and dispatch other sources of electricity in addition to renewable electric power. Some system operators have already faced challenges in managing RE intermittency. BESS can reduce these challenges by firming up renewable electric power generation.

Electric utilities in the U.S. have legal requirements to meet peak power requirements even though peak capacity may only be needed for short periods of time during a year. Development of new power generation capacity is expensive and can take a long time, especially for thermal, hydro, or nuclear power plants. Natural gas peaking power plants that can be ramped up quickly and pumped storage have often been used in the U.S.to meet peak loads. BESS can provide substantial financial benefits for utilities and electricity customers by reducing the peak load and flattening the load curve.

In addition to improving intermittent RE integration and meeting peak power demand, energy storage can provide other *ancillary services* in addition to spinning reserves. These services (including black start, non-spinning reserves, and voltage and frequency regulation) can contribute to the value of energy storage to the grid. These services ramp electricity supplies up or down over the course of a day to reduce curtailment, decrease price fluctuations, and increase grid stability. Some ancillary services are needed more often than others. For example, black start services are rarely needed, while spinning reserves may be needed from time to time during a typical hour. The value of these ancillary services to a power supply system and the ability of providers to obtain compensation for providing the services vary.

## 1.3. TYPES OF ENERGY STORAGE

Electricity can be stored through mechanical, electrical, electromechanical, chemical, or thermal technologies. *Pumped storage* is a type of mechanical storage that uses surplus hydropower to move water to higher elevations when the electricity cannot be sold or can only bring a low price because the supply exceeds the load. Later, when the load increases, the price of the hydropower rises. Then, the pumped water is released to flow back down through the turbines to generate additional electricity (Manion *et al.* 2019). Pumped storage is the most common type of utility-scale energy storage at the global level, although its applicability varies by country. In the U.S., pumped storage provided 95 percent of all electricity storage in 2017 (Zablocki 2019).

Pumped storage is generally only feasible when the storage capacity is at least 100 MW and is relatively costly to develop. It is only feasible in limited locations with hills or mountains and requires large areas of land. Pumped storage can be financially profitable, but it is energy inefficient. Between 20 and 40 percent of the generated electricity is wasted due to hydraulic and electrical losses and evaporation in pumping water from lower reservoirs for storage in higher reservoirs (Yang 2016).

Batteries are electromechanical storage devices and can be used in large- or small-scale applications. Battery storage is suitable for utility-scale systems (*front-of-the meter*) and end-user locations (*behind-the-meter*). Utility-scale BESS is rated in megawatts and hours of duration. For example, a system with a rated capacity of 20 MW and a four-hour storage duration can store 80 MWh of *usable electricity* after accounting for energy losses in storage and discharging.[3]

In 2020, three types of batteries were in commercial use for utility-scale energy storage – lithium-ion (Li-ion), sodium sulfur, and redox-flow (flow) batteries. Worldwide, approximately 80 percent of of utility-scale battery storage has used Li-ion technology (U.S. EIA 2018). Flow batteries are still at an early stage of commercialization. Compressed-air energy storage (mechanical) and molten salt storage (thermal) are mature nonbattery alternatives. Molten salt storage may be appropriate at concentrating solar power facilities. Compressed air energy storage can be viable for spinning reserves and black start (IRENA 2017a).

Table 1 summarizes the characteristics and applications of various energy storage technologies. Blanc *et al.* (2020) discussed the status, advantages, disadvantages, and technological and operational innovations of each of these technologies in greater detail. They also described applications of some of these technologies and conditions for replicability, value and cost effectiveness, and lessons learned.

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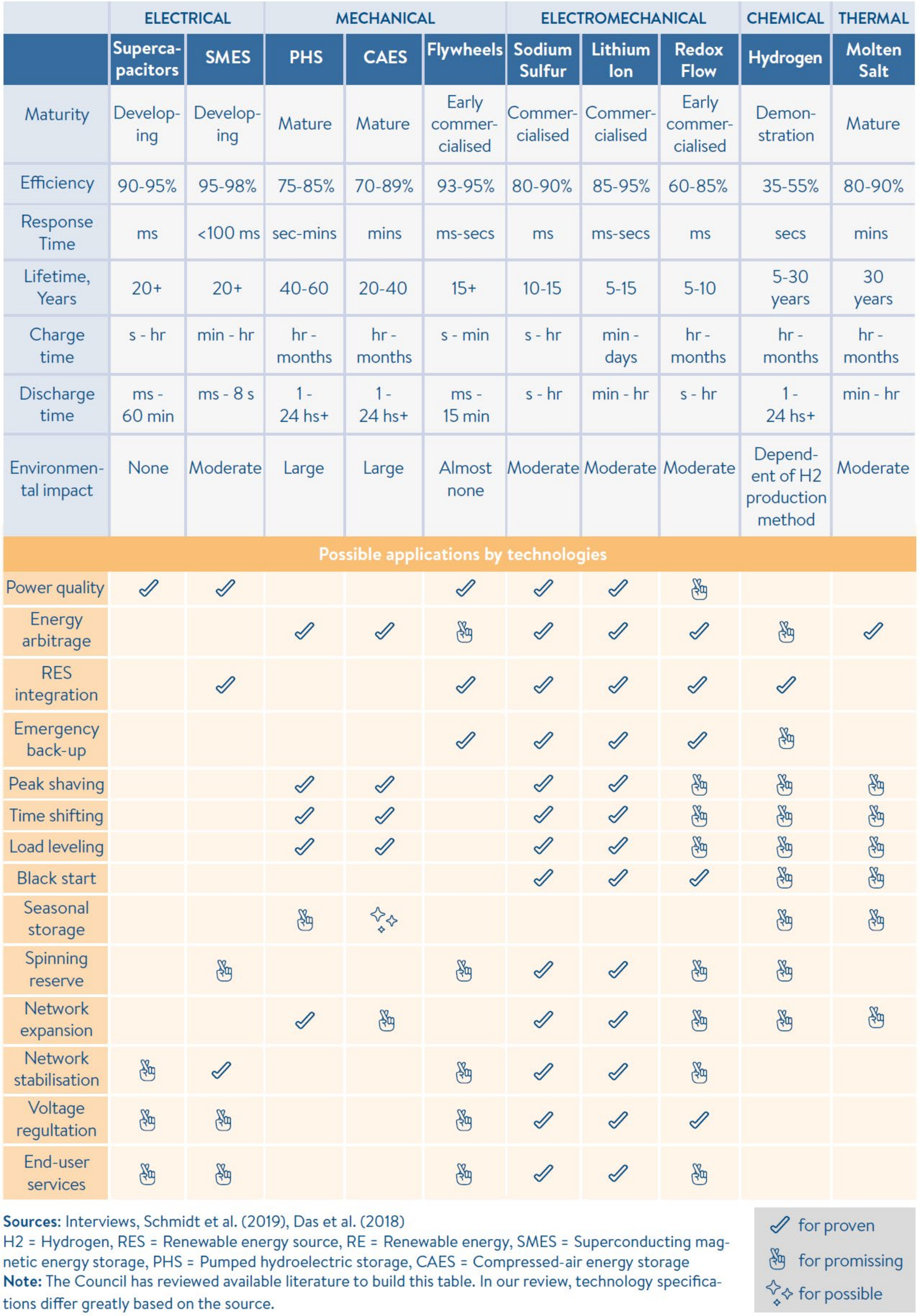
[3] Key characteristics of battery storage technologies include rated power capacity, energy capacity, storage duration, cycle life, self-discharge rate. *Rated power capacity* is the maximum energy discharge rate that can be obtained from a fully charged state. *Energy capacity* is the maximum amount of energy that the system can store. *Storage duration* is the amount of time that BESS can be discharged at its rated power capacity before the energy capacity is depleted. *Cycle life* is the amount of time or cycles a battery storage system can provide regular charging and discharging before failure or significant degradation. *The self-discharge* rate is the percentage of stored energy reduced through internal chemical reactions that is no longer available for use. *Round-trip efficiency* is the percentage of energy charged to the battery that can be discharged. For front-of-the-meter storage, the *AC-AC efficiency* is important (Bowen, Chernyakhovskiy, and Denholm 2019).

## TABLE 1: Characteristics and Applications of Energy Storage Technologies



| | ELECTRICAL | | MECHANICAL | | | ELECTROMECHANICAL | | | CHEMICAL | THERMAL |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Supercapacitors** | **SMES** | **PHS** | **CAES** | **Flywheels** | **Sodium Sulfur** | **Lithium Ion** | **Redox Flow** | **Hydrogen** | **Molten Salt** |
| Maturity | Developing | Developing | Mature | Mature | Early commercialised | Commercialised | Commercialised | Early commercialised | Demonstration | Mature |
| Efficiency | 90-95% | 95-98% | 75-85% | 70-89% | 93-95% | 80-90% | 85-95% | 60-85% | 35-55% | 80-90% |
| Response Time | ms | <100 ms | sec-mins | mins | ms-secs | ms | ms-secs | ms | secs | mins |
| Lifetime, Years | 20+ | 20+ | 40-60 | 20-40 | 15+ | 10-15 | 5-15 | 5-10 | 5-30 years | 30 years |
| Charge time | s - hr | min - hr | hr - months | hr - months | s - min | s - hr | min - days | hr - months | hr - months | hr - months |
| Discharge time | ms - 60 min | ms - 8 s | 1 - 24 hs+ | 1 - 24 hs+ | ms - 15 min | s - hr | min - hr | s - hr | 1 - 24 hs+ | min - hr |
| Environmental impact | None | Moderate | Large | Large | Almost none | Moderate | Moderate | Moderate | Dependent of H2 production method | Moderate |
| **Possible applications by technologies** | | | | | | | | | | |
| Power quality | ✓ | ✓ | | | ✓ | ✓ | ✓ | 🤞 | | |
| Energy arbitrage | | | ✓ | ✓ | 🤞 | ✓ | ✓ | ✓ | 🤞 | ✓ |
| RES integration | | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Emergency back-up | | | | | ✓ | ✓ | ✓ | ✓ | 🤞 | |
| Peak shaving | | | ✓ | ✓ | | ✓ | ✓ | 🤞 | 🤞 | 🤞 |
| Time shifting | | | ✓ | ✓ | | ✓ | ✓ | 🤞 | 🤞 | 🤞 |
| Load leveling | | | ✓ | ✓ | | ✓ | ✓ | 🤞 | 🤞 | 🤞 |
| Black start | | | | | | ✓ | ✓ | ✓ | 🤞 | 🤞 |
| Seasonal storage | | | 🤞 | ✨ | | | | | 🤞 | 🤞 |
| Spinning reserve | | 🤞 | | | 🤞 | ✓ | ✓ | 🤞 | 🤞 | |
| Network expansion | | | ✓ | 🤞 | | ✓ | ✓ | 🤞 | 🤞 | 🤞 |
| Network stabilisation | 🤞 | ✓ | | | 🤞 | ✓ | ✓ | 🤞 | | |
| Voltage regultation | 🤞 | 🤞 | | | 🤞 | ✓ | ✓ | ✓ | | |
| End-user services | 🤞 | 🤞 | | | 🤞 | ✓ | ✓ | 🤞 | | |

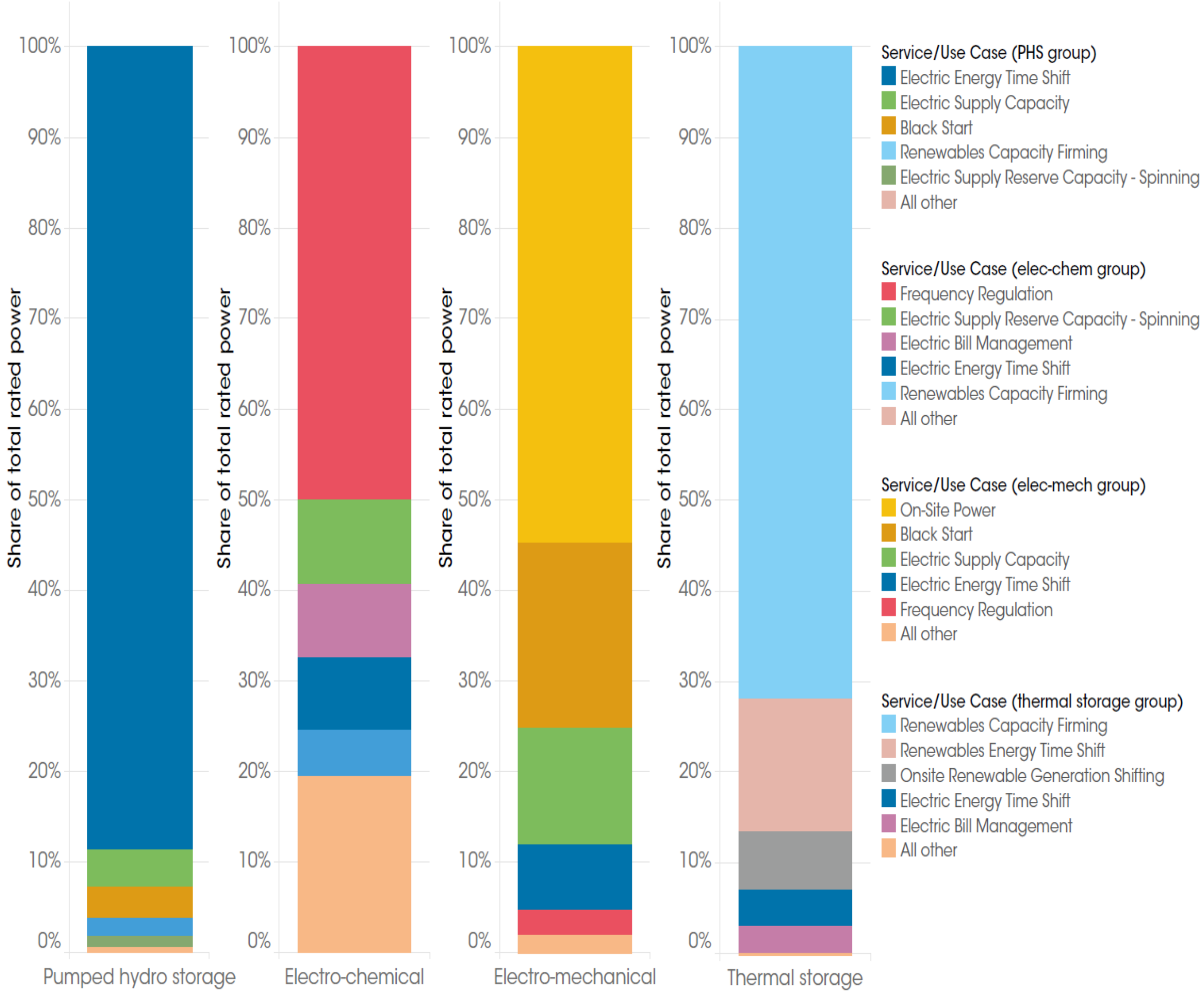
**Sources:** Interviews, Schmidt et al. (2019), Das et al. (2018)
H2 = Hydrogen, RES = Renewable energy source, RE = Renewable energy, SMES = Superconducting magnetic energy storage, PHS = Pumped hydroelectric storage, CAES = Compressed-air energy storage
**Note:** The Council has reviewed available literature to build this table. In our review, technology specifications differ greatly based on the source.

✓ for proven
🤞 for promising
✨ for possible

Source: Blanc *et al.* (2020)

The various types of energy storage have different use profiles. Figure 1 shows global energy storage power capacity by main use and technology type in mid-2017.

**FIGURE 1: Global Energy Storage Capacity by Main Use and Technology Type in Mid-2017**



Source: IRENA 2017a

Box 1 lists a series of guides, tools, and templates that the Electric Power Research Institute's Energy Storage Integration Council prepared to support energy storage.

**BOX 1. Tools to Support Energy Storage Deployment**

1. ESIC Energy Storage Implementation Guide
2. ESIC Energy Storage Technical Specification Template, v3.0
3. ESIC Energy Storage Test Manual
4. Electrical Energy Storage Data Submission Guidelines
5. ESIC Energy Storage Reference Fire Hazard Mitigation Analysis
6. ESIC Energy Storage Safety Incident Gathering and Reporting List
7. ESIC Energy Storage Commissioning Guide
8. ESIC Energy Storage Cost Template and Tool v2.0
9. Storage Value Estimation Tool and supporting documentation

(https://www.epri.com/pages/sa/epri-energy-storage-integration-council-esic?lang=en-US)

## 1.4. BENEFITS OF BATTERY ENERGY STORAGE

BESS can be combined with new or existing RE generation to increase dispatchability and meet peak load requirements. Co-location or hybridization of generation sources and BESS can reduce the costs through shared equipment and single interconnection and permitting. *Co-located resources* are multiple technologies at a common point of interconnection and participating as separate resources. Each resource is modeled independently.

*Hybrid facilities* or *hybrid resources* combine multiple technologies that are physically and electronically controlled by the plant owner or operator and participate on the grid as a single resource. A hybrid facility is optimized internally and bid as one supply curve (Ahlstrom 2020). Gorman *et al.* (2020) found that the benefits of adding a four-hour battery to a utility-scale PV system in the U.S. exceeded the costs. However, it is not always best to site batteries with generating units. Utility-scale RE generation is best located where solar or wind resources are abundant, land costs are low, and transmission capacity is available. There may be other locations where front-of-the-meter storage provides greater benefits for the transmission and distribution grid.

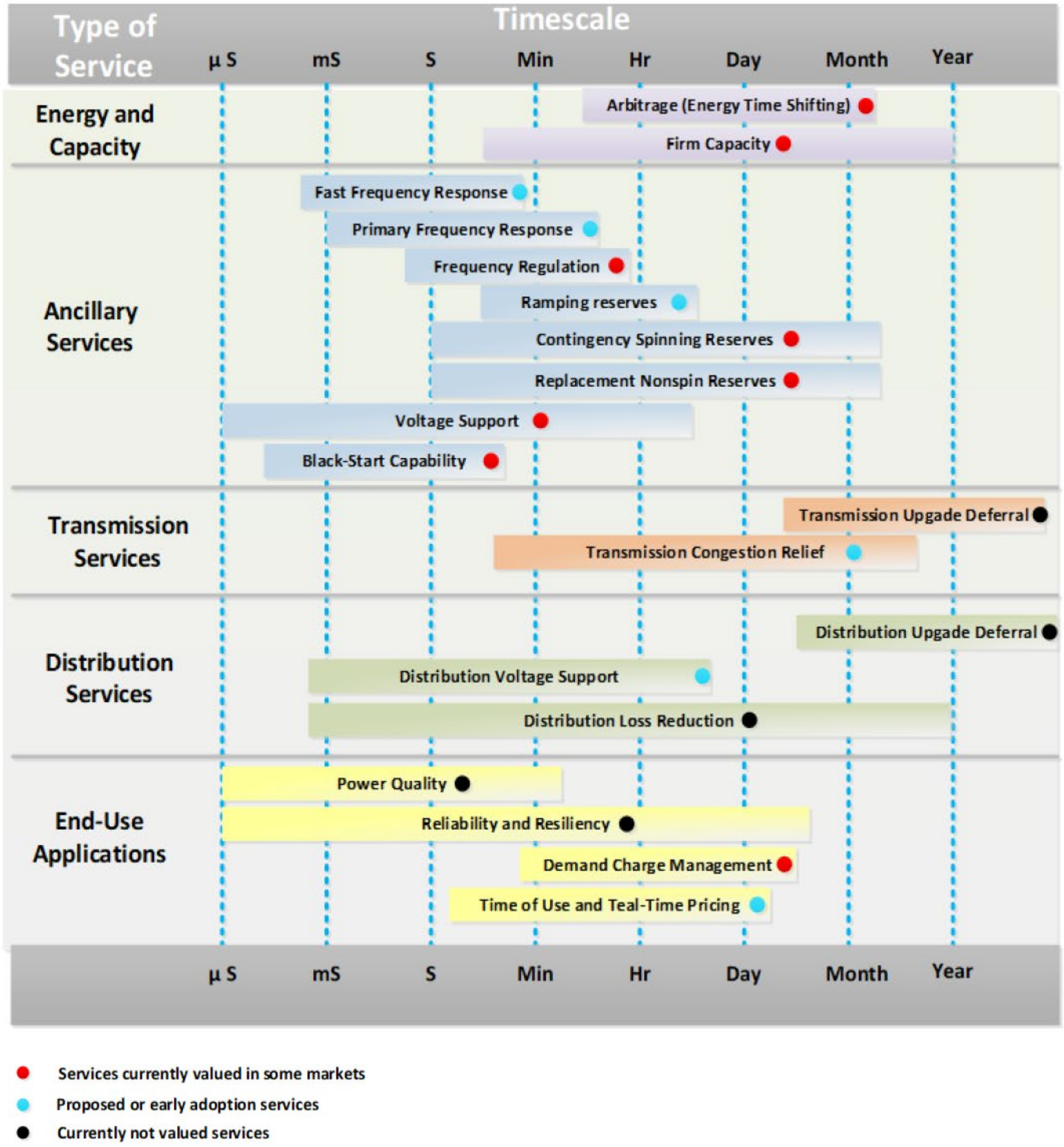
BESS can have dramatic effects on the ability to meet peak loads as the proportion of variable RE in the generation mix increases. The California Public Utilities Commission (CPUC) required state utilities to estimate the effective load carrying capability of PV and wind power in 2022, 2026, and 2030, with and without battery storage of various durations. The *effective load carrying capability* measures how much of the theoretical capacity of a generation technology can be realistically obtained to meet the peak load. The results varied considerably by utility and year, reflecting differences in the projected capacity, type of generation resource, proportion of VRE in the generation mix, weather, inverter loading ratio, capacity use rate, and peak load levels and timing.

The average effective load carrying capability for the included California utilities in 2022 was estimated at 4.8 percent for fixed PV, 5.8 percent for tracking PV, 99.4 percent for tracking PV with four hours of battery storage, 30.0 percent for wind, and 62.0 percent for wind with four hours of battery storage. The average effective load carrying capability for 2030 was substantially lower due to the larger share of

VRE—0.3 percent for fixed PV, 0.9 percent for tracking PV, 91.9 percent for tracking PV with four hours of battery storage, 25.3 percent for wind, and 49.9 percent for wind with four hours of battery storage. Without storage, wind was a much more reliable way to meet peak loads in the studied locations than tracking PV. However, in systems combining RE generation with storage, tracking PV was far superior to wind as a power source for charging batteries (Carden, Dombrowsky, and Winkler 2020).

BESS can provide fast, responsive, and high-quality ancillary services, including almost instantaneous power for voltage support. Figure 2 shows the range of services that BESS can provide and their timescale and marketability. However, the costs of current battery technologies increase as discharge times exceed four hours and there may be energy losses in storage.

**FIGURE 2: Range of Battery Energy Storage Services and Their Timescale and Marketability**



Source: Ericson and Statwick 2018

There are three categories of BESS service marketability:

1. Services that are commonly marketable through a PPA or similar contractual arrangement, such as electricity capacity or generation;
2. Services that are only marketable in locations with sophisticated power markets. BESS suppliers can participate in real-time or day-ahead markets for some ancillary services in Australia, Belgium, Germany, Netherlands, the United Kingdom, and the U.S. (IRENA 2019a). The Hornsdale facility in Australia sells frequency regulation under a long-term PPA and other ancillary services on the spot market (*merchant basis*); and
3. Services that have potential value to the power system, but cannot be sold because the markets are undeveloped (e.g., fast response ramping) or they serve a localized need (voltage regulation). Remuneration for these services is not available in long-term contracts or spot markets.

In some U.S. markets with independent system operators, power generators were previously expected to provide many ancillary services (such as inertial and governor response or frequency response during frequency excursions) without any additional compensation.[4] BESS can also provide these services, but the incentives for making these investments will be lower if payments are not available for these services. In some other markets, prices for ancillary services have been based on conventional generation. Fair compensation for the full range of ancillary services provided by BESS is important in developing a level playing field for this technology (Thomas, Chernyakhovskiy, and Denholm 2019).

Some utilities in California and Australia have replaced existing or planned fossil fuel generation with renewable electric power and BESS to reduce air pollution and greenhouse gas (GHG) emissions from baseload or peak load generation. Some aging natural gas-fired peaker units in Southern California have been retired early to help meet air pollution regulations. Some California utilities have installed BESS o instead of new natural gas peaker units to avoid community opposition.

Southern California Edison (SCE) cancelled plans to build a new 262 MW natural gas peaking plant in Oxnard. It then contracted for two 100 MW (400 MWh) Li-ion battery storage facilities: the Edison Puente Project in Oxnard with Strata Solar and the Alamitos Project in Long Beach with Fluence. Operations are expected to begin at Edison Puente in December 2020 and at Long Beach in 2021. SCE also contracted with other companies for 95 MW of dispersed storage in smaller, 10-40 MW units near Edison Puente (Spector 2019a, 2020a).

## 1.5. MARKETS AND VALUATION OF BESS SERVICES

Utility-scale BESS is still relatively new in many developed countries and most developing countries. Private developers will only supply the economically optimal amount of BESS capacity if they can obtain sufficient financial returns on their investments. Table 2 shows the duration and valuation of various utility-scale energy storage applications. In U.S. electricity markets, BESS services for arbitrage, firm capacity, and operating reserve can generally be sold at full value. However, energy storage services for transmission and distribution replacement and deferral have only been partially valued. Remuneration has often been unavailable for black-start services from energy storage.

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[4] The ability to maintain the load-generation balance is an important indicator of the reliability of grid operations. *Frequency excursions* occur when high or low frequency interconnection trigger limits are exceeded for five minutes or more. Long frequency excursions (*prolonged system recovery*) indicate an at-risk power system that may be subject to decreases in frequency response or degradation of regulation and reserve sharing capability (https://www.nerc.com/pa/RAPA/PA/Pages/FrequencyExcursions.aspx).

### TABLE 2: Duration and Valuation of Utility-Scale, Energy Storage Applications in U.S. Markets

| Application | Description | Duration of Service Provision | Typically Valued in U.S. Electricity Markets? |
|---|---|---|---|
| Arbitrage | Purchasing low-cost off-peak energy and selling it during periods of high prices. | Hours | Yes |
| Firm Capacity | Provide reliable capacity to meet peak system demand. | 4+ hours | Yes, via scarcity pricing and capacity markets, or through resource adequacy payments. |
| Operating Reserves | | | |
| • Primary Frequency Response | Very fast response to unpredictable variations in demand and generation. | Seconds | Yes, but only in a limited number of markets. |
| • Regulation | Fast response to random, unpredictable variations in demand and generation. | 15 minutes to 1 hour | Yes |
| • Contingency Spinning | Fast response to a contingency such as a generator failure. | 30 minutes to 2 hours | Yes |
| • Replacement/ Supplemental | Units brought online to replace spinning units. | Hours | Yes, but values are very low. |
| • Ramping/Load Following | Follow longer-term (hourly) changes in electricity demand. | 30 minutes to hours | Yes, but only in a limited number of markets. |
| Transmission and Distribution Replacement and Deferral | Reduce loading on T&D system during peak times. | Hours | Only partially, via congestion prices. |
| Black-Start | Units brought online to start system after a system-wide failure (blackout). | Hours | No, typically compensated through cost-of-service mechanisms. |

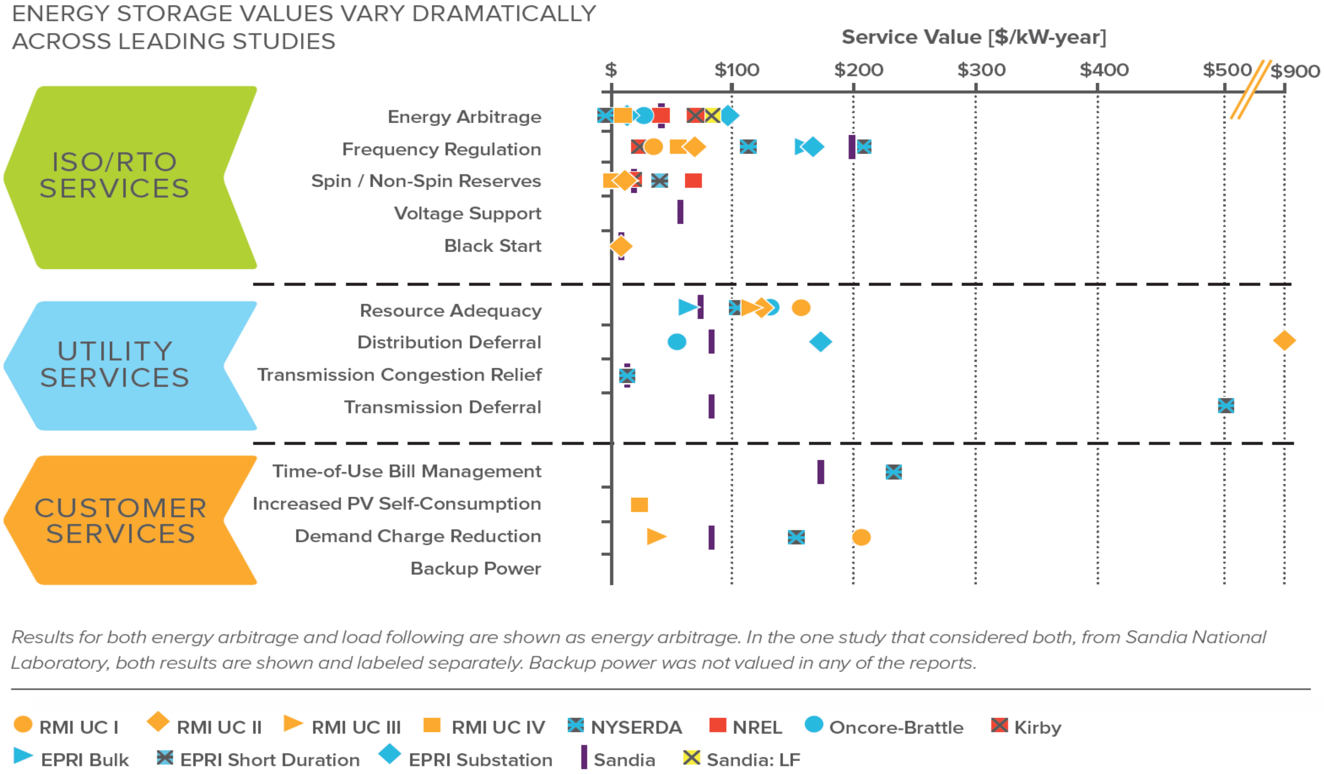
Source: Adapted from Bowen, Chernyakhovskiy, and Denholm 2019

It can be challenging to create adequate incentives for BESS in countries without regulated wholesale markets for electricity. Ancillary service markets for BESS are available in Australia, the United Kingdom (U.K.), the U.S., and some countries in Western Europe (IRENA 2019a).

Sufficient incentives for BESS investments in developed and developing countries may depend on the potential for value stacking (Cone 2018). *Value stacking* is the ability to obtain payments for the multiple power system services provided by energy storage. Value stacking may become an even more important revenue source for BESS suppliers as the value of peak load power, deferred transmission grid investments, or ancillary services increase. However, value stacking may become less critical for financial viability in the future as BESS costs decline.

Figure 3 shows the relative value of various energy storage services in diverse locations with different power market conditions and regulatory environments. Although the prices in this analysis are now over five years old, they still provide useful information on relative values.

**FIGURE 3: Relative Value of Energy Storage Services**



*Results for both energy arbitrage and load following are shown as energy arbitrage. In the one study that considered both, from Sandia National Laboratory, both results are shown and labeled separately. Backup power was not valued in any of the reports.*

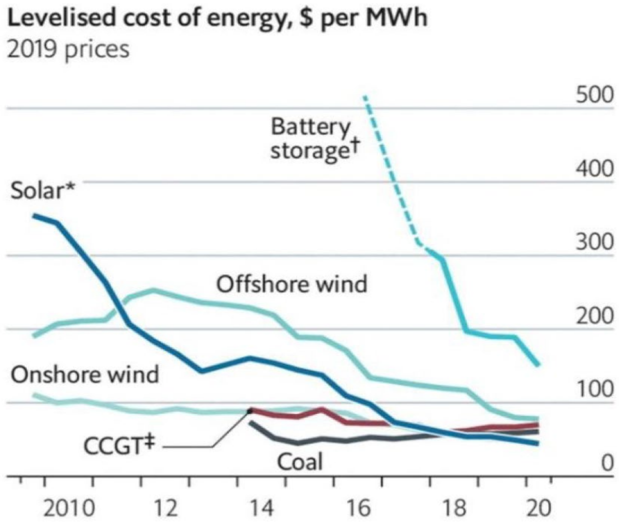
Source: Fitzgerald *et al.* 2015

# 1.6. TRENDS IN BATTERY ENERGY STORAGE SYSTEM COSTS AND DEPLOYMENT

## 1.6.1 COSTS

Between 2010 and 2019, Li-ion battery prices decreased an average of 13 percent per year, falling from $500/MWh to $150/MWh. A broader measure, the levelized cost of energy (LCOE) from Li-ion batteries decreased 84 percent. Figure 4 compares the LCOE for utility-scale solar power, onshore and offshore wind power, and BESS over this period.

**FIGURE 4: Levelized Cost of Energy from Utility-Scale Photovoltaics, Onshore and Offshore Wind Power, and Battery Storage, 2009-2019**



* Average of fixed and tracking systems

† Estimated using battery pack prices before 2018

‡ Combined Cycle Gas Turbines

Data: Vaclev Smil; BP Statistical Review of World Energy; BloombergNEF

Source: BloombergNEF 2019a

Lazard Ltd. (2019) modeled the unsubsidized, levelized cost of BESS for three front-of-the-meter applications: 1) storage for the wholesale power market (100 MW with 1-, 2-, and 4-hour durations); 2) storage for the transmission and distribution system located at substations or distribution feeders (10 MW with 6-hour duration); and 3) PV plus storage for the wholesale power market (100 MW of PV with 50 MW of 4-hour storage). The wholesale market applications of BESS costs ranged from $189-325/MWh (100 MWh) to $173-315/MWh (200 MWh) and $165-$305/MWh (400 MWh).

Transmission and distribution applications had much higher costs, $2,351-$3,989/MWh (60 MWh). The modeled PV plus storage systems for the wholesale market cost $102-139/MWh (100 MW of PV and 200 MWh of storage). Lazard Ltd. (2019) also estimated costs per unit of capacity ($/kW-year) and nameplate energy ($/kWh). These costs pertained to two types of Li-ion batteries (lithium-nickel-manganese-cobalt oxide and lithium-iron-phosphate) and two types of flow batteries (vanadium and zinc bromide).[5] Most of the cost reductions between 2018 and 2019 were for Li-ion batteries and not the balance-of-system or operating and maintenance costs. There were limited cost decreases for flow batteries and advanced lead-carbon batteries. The differences between the lowest and highest priced systems increased over that year.

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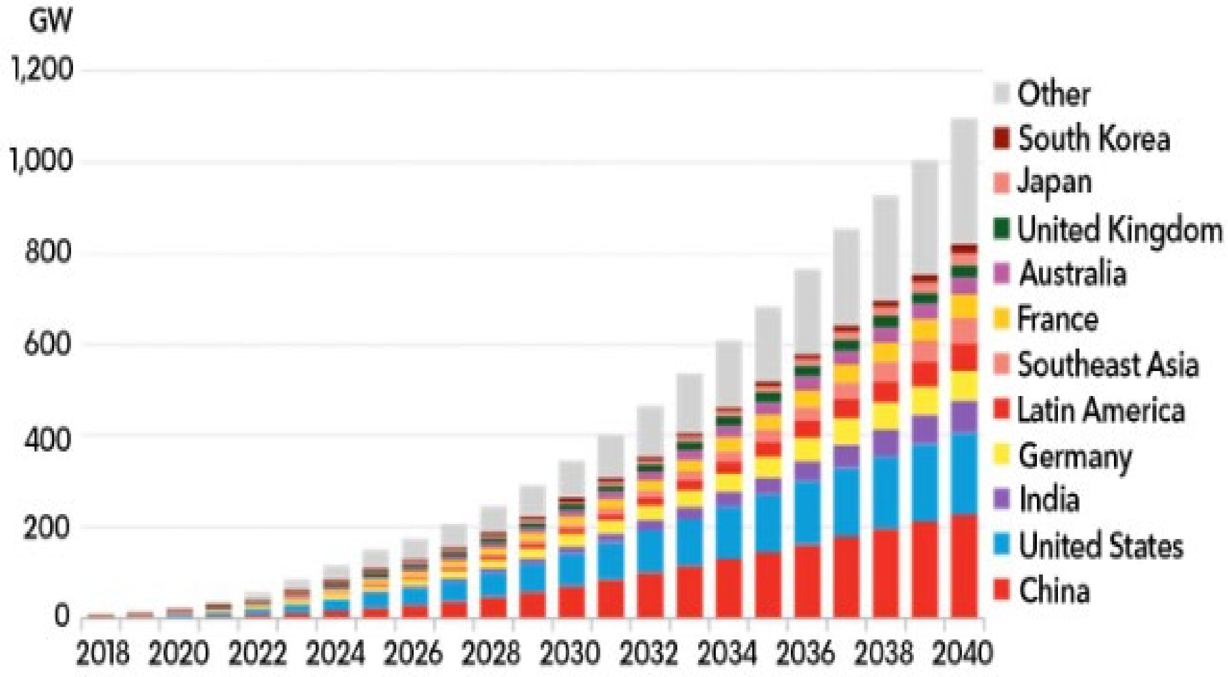
[5] Lazard Ltd. (2019) also estimated the costs of three behind-the-meter applications: 1) 2 MWh commercial and industrial (C&I) standalone storage ($485-1,042/MWh), 2) 2 MWh C&I PV plus storage ($223-384/MWh), and 3) 0.25 MWh residential PV plus storage installations ($457-663/MWh). These costs pertained to the two types of Li-ion batteries and advanced lead-carbon batteries.

## 1.6.2 MARKET POTENTIAL

In 2017, the U.S. was the largest market for utility-scale BESS with 431 MWh of supplied power, followed by Australia at 236 MWh. The total world supply was 2,300 MWh (Manghani and McCarthy 2018). In 2018, the installed capacity of BESS in the U.S. was 0.5 Gigawatts (GW). Heal (2017) estimated that the U.S. would need 10,000 Gigawatt-hours (GWh) of BESS to generate two-thirds of its electric power from renewable resources. BESS is expected to become increasingly important as an alternative to pumped storage and thermal peaking power plants. Trabish (2019) observed that the amount of storage needed to stabilize the U.S. grid as the intermittent RE share grows exceeded current build-out plans.

Figure 5 shows BloombergNEF projections of BESS capacity in major country and regional markets. They estimated that the global total would rise from 9 GW (17 GWh) in 2018 to 1,095 GW (2,850 GWh) in 2040. Policy goals, cost reductions, and increased use of BESS for ancillary services are expected to be important drivers of these investments. These projections assumed that Li-ion battery prices fall to $62/kWh by 2030, a 64 percent decrease below the 2018 price in electric vehicle (EV) battery manufacturing also drives down the cost of batteries for stationary energy storage (BloombergNEF 2019b). *Stationary energy storage* excludes batteries used in motor vehicles. Further development of other battery technologies could reduce BESS costs further or expand the range of viable applications.

**FIGURE 5: BloombergNEF Projections of Battery Energy Storage Capacity by Location (2018-2040)**

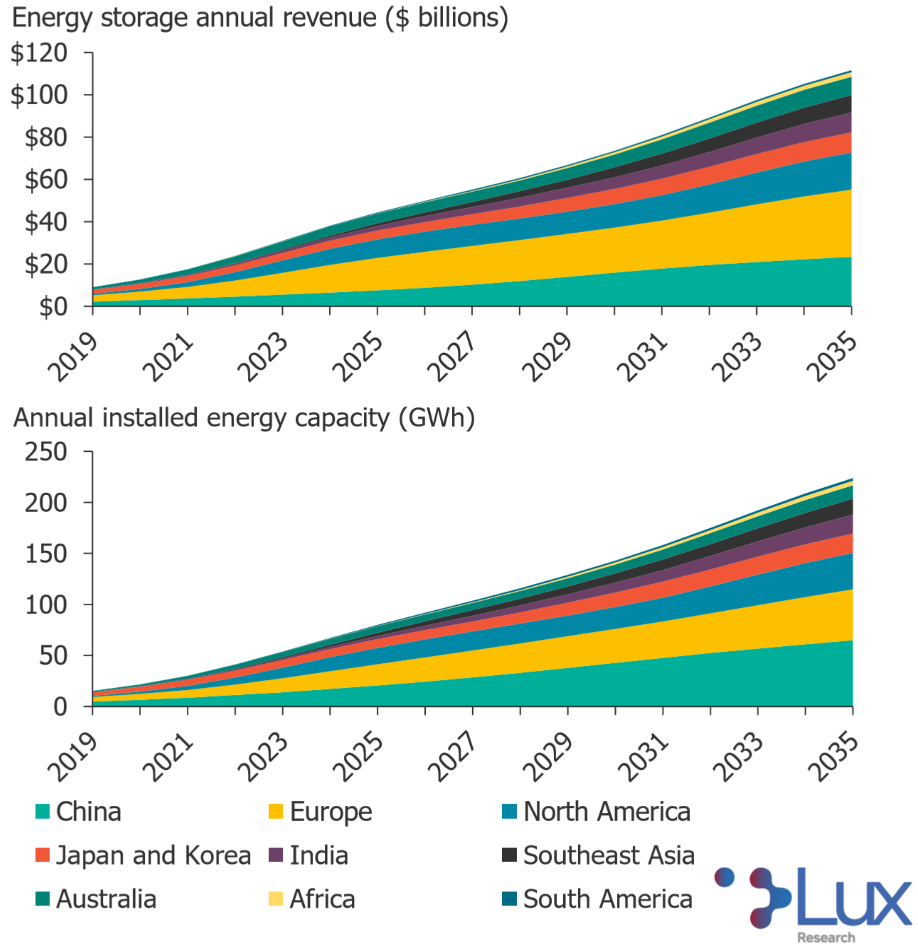


Source: BloombergNEF 2019b

Figure 6 shows Lux Research projections of stationary energy storage revenues and capacity from 2019 to 2035 in country or regional markets. Worldwide, stationary energy storage revenues were $9.1 billion in 2019 and are projected to reach $111.8 billion in 2035, a compound annual growth rate of 17.0 percent. The total installed capacity of stationary energy storage was 15.2 GWh in 2019 and is projected to be 222.7 GWh in 2035, a compound annual growth rate of 18.3 percent.

Over 40 percent of the projected growth in stationary storage between 2019 and 2035 is expected to be in China, India, Southeast Asia, and Africa. Lux Research predicted that lower battery costs, expansion of wind and solar power to one-third of global electricity capacity, and liberalization of electricity markets will drive this growth. However, they assumed that future annual cost reductions for Li-ion batteries would decline from the recent average of 10 percent to 2-4 percent as manufacturing capacity shifts to more energy-dense, EV batteries (Holzinger *et al*. 2019).

**FIGURE 6: Lux Research Projections of Annual Global Stationary Energy Storage Revenues and Installed Capacity**



Source: Holzinger *et al*. 2019

However, worldwide utility-scale BESS capacity only increased 2.9 GW in 2019, almost 30 percent less than in 2018. In South Korea, new BESS installations were 80 percent lower than in 2018 when the country installed one-third of the world's new capacity. The slower growth in South Korea followed concerns over Li-ion battery fires at multiple large facilities in 2018 and 2019. New BESS installations in Europe also slowed in 2019, but the U.S. and Australia markets expanded (IEA 2020).

Energy storage systems can be owned by power generation or vertically integrated utilities, transmission or distribution utilities, merchant power plants, bulk power consumers, or unrelated third parties. Sharma and Shah (2020) identified the following drivers for the increased investment in BESS:

1. Cost and performance improvements;
2. Grid modernization;
3. Increased use of RE;
4. Establishment of wholesale markets for electricity:
5. Financial incentives;
6. Phase-out of feed-in tariffs (FiTs) and net metering;
7. Self-sufficiency goals; and
8. National policies.

Sharma and Shah (2020) also noted the following barriers to increasing battery energy storage:

1. Perceptions of high prices;
2. Lack of standardization in technical requirements and processes (including balance of charge issues such maximum discharge amount, charge monitoring, and recharge cycle times for different types of batteries);
3. Outdated regulatory policies and market design; and
4. Incomplete valuation of the full range of BESS services.

Annex B lists some additional examples of large-scale BESS in various countries. Sandia National Laboratories maintains a database of grid-connected energy storage worldwide (https://www.sandia.gov/ess-ssl/global-energy-storage-database-home/). The International Energy Agency has a resource webpage on BESS (https://www.iea.org/fuels-and-technologies/energy-storage?utm_campaign=IEA%20newsletters&utm_source=SendGrid&utm_medium=Email).

## 1.7. NEW AND EMERGING TECHNOLOGY ALTERNATIVES

Changes in battery technologies may also drive energy storage growth due to potential performance and cost advantages. The duration of the energy storage requirement affects the type and size of battery installations. Many utilities have a peak load that lasts for two to three hours per day or less. Li-ion batteries are cost effective for these short durations. Most Li-ion batteries store energy for up to four hours, but some can accommodate five or six hours. Flow batteries can typically store energy for 8-10 hours. A zinc-air battery can store energy for up to 15 hours (Colthorpe 2020c).

*Flow batteries* store electrical charges in tanks of liquid electrolyte pumped through electrodes to extract the electrons. The spent electrolyte is returned to the tank and recharged by electrons from PV or wind power. Flow batteries have a wide range of discharge power, recharge power, and duty cycles. They are easily scalable because the energy storage capacity is determined by the size of the storage tank. By contrast, Li-ion batteries have a fixed power/energy ratio (Doetsch and Burfeind 2016).

Vanadium is useful in flow battery electrolytes because it can be charged and discharged reliably for thousands of cycles. Zinc-bromine is also a promising flow battery electrolyte. Various organic compounds, but some have to be replaced after a few months or require strongly acid or alkaline electrolytes that can corrode pumps and result in dangerous tank leaks. Flow batteries can also be based on a nontoxic, nonhazardous, and recyclable iron electrolyte in an acidic solution.

Service (2018) estimated that the market for vanadium and zinc-bromine flow batteries could grow to nearly $1 billion annually within five years. However, there are concerns about whether this rapid growth might increase vanadium prices substantially. Pivot Power hired redT to manufacture and install 2 MW (5 MWh) vanadium redox flow batteries in a hybrid with 50 MW of Li-ion battery capacity for the Energy Superhub Oxford project. This will be the largest flow battery in the U.K. and the world's largest hybrid flow and Li-ion battery. The Energy Superhub Oxford project received partial financial support from the government's Industrial Strategy Challenge Fund (Grundy 2020a). Rongke Power in Dalian China began construction of the world's largest vanadium flow battery (800 MWh).[6] ESS Inc. has sold 33-100 kW iron flow batteries that can provide 12 hours of electricity storage over 20,000 cycles for 25 years with little maintenance.[7,8]

Form Energy developed an aqueous air battery system that uses safe, abundant, and inexpensive materials to provide long-duration storage (150 hours). Its first commercial pilot project is a 1 MW (150 MWh) storage facility that will help Great River Energy replace coal-fired generation with a strong, but highly variable wind power resource.[9] Although several long-duration storage startups have not been able to compete with less costly, short-duration Li-ion batteries, Form Energy expects to be competitive on a dollar-per-kilowatt basis (Spector 2020c). In 2020, the U.K. Government invested $12.8 million in the world's largest liquid air battery facility. This 50 MW Trafford Project in Manchester will help power 200,000 homes with long-duration storage (Guest Contributor 2020).[10]

Other technologies can also improve integration of RE on the grid, with or without energy storage. Utilities benefit when owners of distributed solar power generation add autonomous advanced inverters to manage voltage.[11] Utilities can then use grid-edge devices, such as secondary volt-ampere-reactive (VAR) controllers, to complement the advanced inverters. NREL field tests in Hawaii found that advanced inverters and grid-edge devices can increase the solar hosting capacity of medium-voltage feeders by 40 percent, reducing the need to curtail VRE. NREL estimated that annual solar power

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[6] https://www.vanadiumcorp.com/news/industry/flow-battery-developer-to-build-world-s-largest-battery-storage-system/#:~:text=Rongke%20Power%20is%20a%20vertically,Tech%20Zone%20in%20Dalian%2C%20China.

[7] https://www.essinc.com/wp-content/uploads/2020/01/ESS_OnePager_1-22-20_lores.pdf.

[8] Primus, Invinity, Sumitomo, UET, ESS, and ViZn also produced flow batteries.

[9] Great River Energy is a wholesale electric power cooperative serving cooperatives with 700,000 customers in Minnesota.

[10] Based on the July 27, 2020 exchange rate of $1.28 per British pound.

[11] IEEE 1547-2018 standards for the interconnection and interoperability between utility electric power systems and distributed energy resources (DER), including design, production, installation evaluation, commissioning, operation, performance, safety, and maintenance of the interconnection, response to abnormal conditions, power quality, islanding, and periodic testing (https://ieeexplore.ieee.org/document/8332112)

curtailment rates with volt–VAR and volt–watt control capabilities could be less than 1 percent for 87 percent of the customers and 5-10 percent for 11 percent of the customers (Giraldez *et al.* 2018).

Surplus renewable electric power can be stored by running it through water to separate hydrogen and oxygen through electrolysis. This *green hydrogen* can then be used in stationary fuel cells for power generation. Unlike most batteries, hydrogen can store RE for dispatchable electric power for days or weeks. The International Energy Agency predicted that green hydrogen produced with wind power could be less expensive than natural gas by 2030.

In 2018, the 2.5 MW Markham Energy Storage Facility began operating North America's first multi-megawatt power-to-gas facility using RE for hydrogen production. This joint venture between Enbridge Gas Distribution and Hydrogenics Corporation provided grid regulation services to the Independent Electricity System Operator of Ontario, Canada. Linde, Siemens the Rhein Main University of Applied Sciences, and Mainzer Stadtwerke Energiepark in Germany used surplus wind power to produce green hydrogen. In Denmark, Orsted planned to use surplus power from a proposed 700 MW off-shore wind farm to produce hydrogen for large industrial customers.

The U.S. had several, large hydrogen energy storage pilots underway or planned. SoCalGas partnered with the National Fuel Cell Research Center on an electrolyzer to produce hydrogen from surplus solar power at the University of California at Irvine. Mitsubishi Hitachi Power Systems and Magnum Developer planned a 1,000 MW RE facility in Millard County, Utah that will produce green hydrogen and also store energy in flow batteries and solid oxide fuel cells (Weaver 2019). Xcel Energy and NREL developed a 110 kW wind power facility to produce peak power for the grid and hydrogen for a fueling station (O'Neill 2019).

Other nonbattery technologies that are still being developed may allow long-duration energy storage for days or weeks from stacked blocks, liquid air, or underground compressed air (Spector 2020b). Bravity Power, Ares Power, and Energy Vault were working on gravity-based energy storage. Hydrostor and Highview Power were developing compressed air or gas systems for energy storage (Wesoff 2020).

# 2. POLICY AND REGULATORY ENVIRONMENT FOR BATTERY ENERGY STORAGE

Many developed and developing countries have had policies and regulations that favored development of new power generation capacity over utility-scale energy storage. A neutral or supportive policy and regulatory framework is important to increase private investment in utility-scale BESS. Table 3 lists examples of neutral or favorable policies for BESS in developed countries. In 2020, many developing countries had unfavorable regulations for energy storage. For example, Nigeria classified energy storage as generation and made it illegal for power distribution companies to own storage systems. South Africa classified energy storage as distribution, but required owners to obtain a generation license for its installation.

## 2.1. UNITED STATES

In the U.S., the federal government regulates the wholesale power market and shares responsibility for regulating grid operations and interconnected generation and transmission resources with the states. State governments are responsible for establishing and implementing policies for electricity generation and distribution and regulating utilities and retail power markets within their borders.

### 2.1.1 FEDERAL GOVERNMENT

The Federal Energy Regulatory Commission (FERC) has the lead role in setting the national regulatory environment for electricity generation, transmission, and distribution. The Federal Power Act of 1935 expanded FERC's authority from coordination of hydropower generation to cover all interstate electricity transmission and wholesale power sales (*sales for resale*). The Federal Power Act directed FERC to ensure that wholesale market rules and rates are "just and reasonable" and not unduly discriminatory or preferential. FERC determines whether tariffs and incentives hinder wholesale market efficiency by providing insufficient compensation for an energy resource.

The Public Utility Regulatory Policies Act (PURPA) of 1978 aimed to conserve electricity and promote greater use of domestic nonrenewable and renewable resources in power generation. It began the process of restructuring the power industry from protected, vertically integrated "natural monopolies" that controlled all aspects of electricity generation, transmission, and distribution. It created a market for electricity from nonutility companies, encouraged cogeneration, ended promotional rate structures that increased electricity consumption, and encouraged energy efficiency.

PURPA established a mandatory purchase obligation that required utilities to buy power from small RE generators with a capacity up to 80 MW and cogeneration facilities if the price was less than the avoided costs of their own generation. It included an antidiscrimination provision for residential utility customers that generate solar power. PURPA also exempted RE developers from many federal and state regulations. The federal government delegated oversight of PURPA implementation to the states.

## TABLE 3: Examples of Neutral or Favorable Policies for Battery Energy Storage in Developed Countries

| Jurisdiction | Policy Initiative |
|---|---|
| California (U.S.) | **Facilitate RE integration and the energy transition**<br>• Procurement target of 1.325 GW for the state's three investor-owned utilities by 2020<br>• A procurement target of an additional 500 MW of RE capacity by 2016<br>• Increased funding for the Self Generation Incentive Program and R&D on energy storage and scaling up new technologies<br>• Energy storage roadmap issued in 2014<br>• Regulations on markets for behind-the-meter and utility-scale energy storage, reducing interconnection barriers, and the role of bulk energy storage |
| European Union | **Clean energy transition, system flexibility, and energy security**<br>• Funding for research, design, and development<br>• Role of energy storage in the European Clean Energy for All package<br>• Reducing barriers through nondiscrimination, competitive procurements, and fair rules on network access and pricing<br>• Broad definition of energy storage included reconversion to electricity and conversion into another energy carrier<br>• Energy storage recognized as a distinct asset class, separate from generation<br>• Battery Europe research and innovation platform |
| Germany | **Facilitate large-scale RE integration and system flexibility**<br>• Funding for research, design, and development<br>• Power-to-X (P2X): Conversion, storage, and reconversion of surplus power<br>• Hydrogen energy research<br>• Roadmap strategy issued in 2011<br>• Residential solar plus storage loan program |
| Japan | **Facilitate large-scale RE integration and resilience to extreme weather**<br>• Subsidies for behind-the-meter storage for net zero energy houses and resilience to blackouts caused by extreme weather |
| New York State (U.S.) | **Economic development, demand response, ancillary services, and upgrade deferrals**<br>• Energy storage roadmap issued in 2016 (with goals of 2 GW in 2025 and 4 GW in 2035)<br>• New regulatory and market mechanisms to accelerate use of energy storage<br>• Standardized codes and regulations accepted by all jurisdictions within the state |
| Republic of Korea | **RE integration, climate change, and support for manufacturers**<br>• Renewable portfolio standards: Projects that include energy storage benefit from a higher renewable energy certificate multiplier<br>• Tripled discount on electricity retail rates for commercial and industrial customers with behind-the-meter storage |
| United Kingdom | **Grid flexibility, system balancing, renewables integration, ancillary services**<br>• Funding for research, design, and development and an Energy Entrepreneurs Fund<br>• Storage eligible for renewables obligation and feed-in tariff<br>• License exemptions for small capacity storage<br>• Modified generation license for large-scale storage<br>• Removal or regulatory barriers to energy storage |

**TABLE 3 (Continued)**

| | |
|---|---|
| United States Federal Government | **FERC 841 on energy storage for RE integration, demand response, and ancillary services**<br>• Directed regional grid operators to remove barriers to participation of energy storage in wholesale electricity markets<br>• Mandated that markets recognize the characteristics of storage as neither generation nor load |

Source: Adapted from Blanc *et al.* 2020

The Energy Policy Act of 2005 amended PURPA following the development of wholesale electricity markets. It allowed FERC to terminate the mandatory purchase requirement if a qualifying facility can access at least one of the following types of markets:

1. Independently administered, auction-based, day-ahead, and real-time wholesale markets for sale of electricity or wholesale markets for long-term sales of electricity capacity or generation;
2. Transmission and interconnection services provided by a FERC-approved regional transmission organization with an open access tariff that provides nondiscriminatory treatment to all customers and competitive wholesale markets for long-term, short-term, and real-time sales to buyers other than the utility that has an interconnection with the qualifying facility; or
3. Wholesale markets for sale of capacity or electricity of comparable competitive quality as the above two types of markets (Kavulla and Murphy 2018).

This law also extended the FERC's jurisdiction to include some power plant sales and maintenance of the reliability of electricity services.

Previously, utilities or system operators were allowed, but not required, to pay for energy storage on a level playing field with generation or transmission and distribution investments. Wholesale power markets in the U.S. typically allowed payments for frequency regulation services. However, some regulators restricted cross-market compensation and limited where payments could be made for energy storage services.

In 2018, FERC Order 841 removed barriers to the participation of energy storage in wholesale electricity markets. It required independent system operators and regional transmission organizations to recognize the physical and operational characteristics of energy storage in developing these participation models. It required wholesale power markets to compensate energy storage suppliers for capacity, power generation, and ancillary services. It mandated regional grid operators to develop rules to open their markets to energy storage and submit compliance plans by December of 2018.

FERC Order 841 clarified that electricity sales to storage facilities for later resale to the grid or ancillary services were wholesale power market operations subject to FERC regulation. It classified electricity sales to storage facilities for later use by end users as retail sales under state jurisdiction (FERC 2019). FERC is responsible for ensuring that independent system operators and regional transmission organizations have removed barriers to entry for energy storage and offer fair and reasonable rates for storage services.

FERC Order 841 had a transformational effect on the growth of utility-scale BESS in the U.S. despite some implementation issues. For example, PJM Interconnection LLC required a 10-hour storage duration for battery participation in its capacity market in the mid-Atlantic states, which was not feasible for Li-ion batteries. Some industry groups argued that this specification violated FERC Order 841 by making storage less competitive than fossil fuel generation. However, FERC Order 841 did not specifically address the duration of storage.

Subsequent FERC rulings in 2020 on complaints against the New York Independent System Operator (NYISO) put BESS and RE at a disadvantage compared to fossil fuel generation (Walton 2020). The National Association of Utility Regulatory Commissioners and the Edison Electric Institute opposed some aspects of FERC Order 841 in a legal challenge while the Solar Energy Industries Association and Advanced Energy Economy trade association supported the regulation (Konidena 2020). In 2020, the U.S. Court of Appeals upheld FERC Order 841 (Milford and Olinsky-Paul 2020). This court decision reduced the regulatory uncertainty and is expected to increase BESS deployments in the country.

## 2.1.2 STATE GOVERNMENTS

In the U.S., state governments regulate retail markets for electricity and set and implement policies that affect RE and BESS deployment. These policies include supply and demand-response requirements for electricity, renewable portfolio standards, environmental and GHG emission reduction targets, and net-metering. State governments are responsible for ensuring efficient price signals in retail markets for electricity, which includes the framework for compensating utility-scale energy storage suppliers. State regulators coordinate with independent system operators and regional transmission organizations to ensure that BESS suppliers do not receive duplicative compensation from both the retail and wholesale markets. However, it can be challenging to unbundle the payments for various BESS services in different locations and times.

*Renewable portfolio standards (RPS)* are mandatory targets for the minimum percentage of electricity sales generated from RE resources. RPS requirements have been successful in diversifying electricity generation sources. They have also accelerated technology development and cost reductions from economies of scale in production and procurement. Roughly half of the growth in RE generation since 2000 in the U.S. can be attributed to RPS policies.

At the end of 2019, 29 U.S. states plus Washington, DC and three territories had a mandatory RPS. An additional eight U.S. states and one territory had voluntary RE targets. Most state RPS targets ranged from 10-45 percent of total electricity sales, but 13 states had targets of 50 percent or more. In many states, the RPS only applied to investor-owned utilities (IOUs). Other states also required municipalities and electric cooperatives to comply with the RPS, although sometimes with a lower target.

Some states had RPS carve-outs or RE credit multipliers for specific technologies, such as offshore wind or rooftop photovoltaics. *Carve-outs* require use of a specific technology for a certain share part of the RPS. *Credit multipliers* award additional RE credits for electricity produced by certain technologies. RPS carve-outs and exemptions need to be reviewed periodically to ensure that they do not have negative effects on newer technologies, such as BESS. Some states had RPS policies with cost caps that limited costs increases to a maximum percentage of ratepayers' bills. One state capped RPS gross procurement costs Some state RPS targets exempted certain sectors of the economy. (https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx).

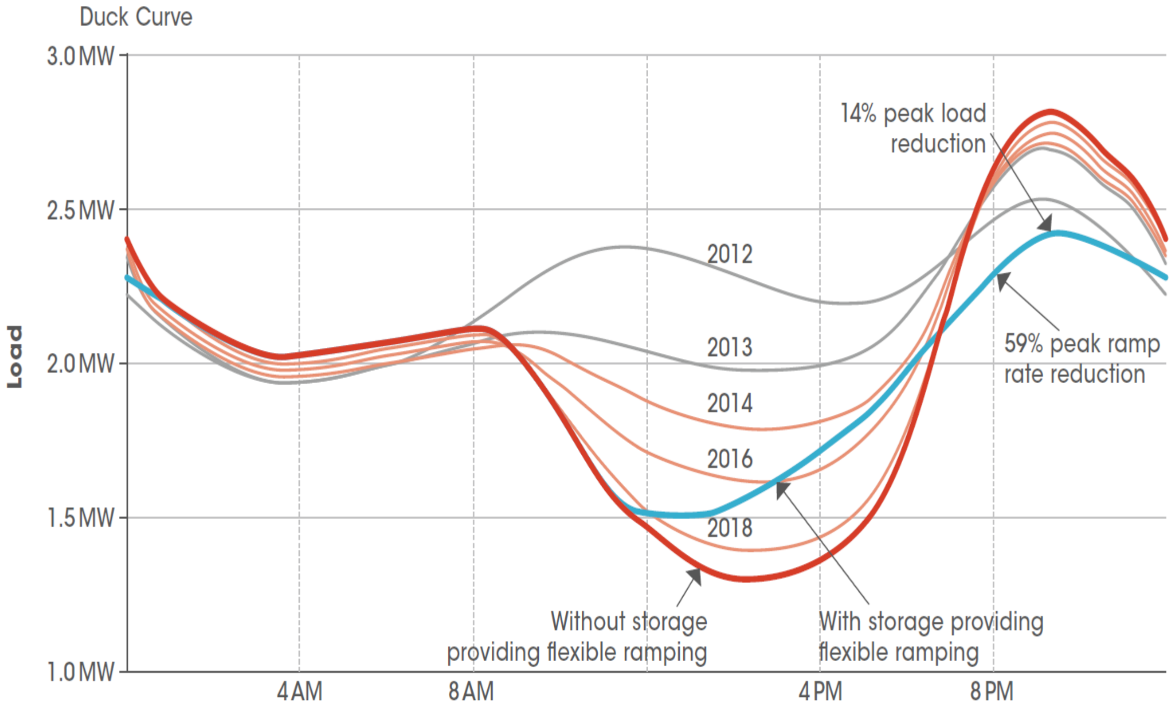
Some states required utilities with RPS requirements to demonstrate compliance through RE Certificates (RECs) issued when RE was sent to the grid. Eligible RE resources usually included wind, solar, biomass, geothermal and some hydroelectric facilities. However, several states allowed for landfill gas, tidal energy, combined heat and power, and energy efficiency improvements to qualify for RECs.

In 2019, 12 U.S. states and the District of Columbia had legislative or executive branch targets for CE or RE that exceeded their RPS requirements. However, many of these targets were aspirational, rather than mandatory. Over 200 U.S. cities and counties had mandates for100 percent CE or RE. More than 70 cities and counties in seven U.S. states were 100 percent CE powered (Trumbull *et al.* 2019).

In the first quarter of 2020, more electricity was generated in the U.S from utility-scale RE than coal. These three months are usually an important period for coal-fired generation, but increasing RE generation, low natural gas prices, and unusually warm weather reduced coal use. A similar outcome was expected in the second quarter of 2020 because RE generation usually increases in the spring and the load normally drops as less space heating is used (Feaster and Wamsted 2020).

BESS can reduce gaps between the amount of RE supplied and the demand for electric power over a 24-hour period. When graphed, these gaps often have a shape similar to a duck. The *duck curve* typically involves a low net load during the day and a large load in the evening hours when low-cost solar power is no longer available (Figure 7). California has often experienced this problem and Arizona and Nevada have as well, although to a lesser extent (St. John 2019a).

**FIGURE 7: Impact of Energy Storage Flexible Ramping on the Duck Curve (3 MW Feeder)**



**Source:** Sunverge (2015)

*Net metering* allows distributed generation owners (corporate self-suppliers and households with rooftop PV systems) to offset the grid power that they use with any surplus delivered to the grid. Industry practices often do not allow net metering unless required by law. Net metering can increase the incentives for distributed generation, but state and utility policies vary in how long the banked credits can be retained and whether they are valued at a retail or wholesale price. A database of state incentives for RE and energy efficiency shows 40 U.S. states that require net metering.[12]

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[12] https://www.dsireusa.org/

Many U.S. states with net metering limit how much of the surplus capacity of a generator qualifies for this incentive. For example, New Jersey limited net metering for residential customers to 100 percent of baseline consumption up to 10 MW, while Maryland allowed any amount of net metering up to 200 percent of baseline consumption. New Jersey only allowed community or aggregated net metering for public sector entities. Community or aggregated net metering capacity could be up to 2,000 MW in Maryland and 5,000 MW in the District of Columbia (PEPCO Holdings 2016).

Nevada slashed the net metering payment rate in 2015 and reinstated it in 2017 after rooftop solar growth declined and major solar installers announced they were going to end operations in the state (Gearino 2018). Maine also restored a net metering program after it had been cut. In 2017, Indiana replaced net metering with a lower compensation rate and the state's rooftop solar industry growth rate declined 93 percent in 2018. Arizona also reduced the net metering payment rate. In 2019, Michigan retained its net metering requirement, but began allowing utilities to deduct hypothetical transmission costs from payment rates (Malewitz 2019).

Legislatures and regulatory agencies in some states have also reduced incentives for distributed generation and energy storage by allowing utilities to impose additional standby demand charges, backup fees, or other fixed charges on customers who produce some of their own electricity. These states have included Alabama, Florida, Georgia, Indiana, Kansas, Michigan, Oklahoma, Tennessee, Texas, Virginia, and Wisconsin (Ryan 2016). Kansas, Michigan, and Wisconsin subsequently eliminated utility backup fees through legislation action or court decisions (Driscoll 2020).

Sandia National Laboratories maintained a database on energy storage policies of the federal government and state governments (https://www.sandia.gov/ess-ssl/global-energy-storage-database-home/). The Pacific Northwest National Laboratories also had a database of energy storage policies and regulatory requirements, demonstration projects, procurement targets, and consumer protections for U.S. states (https://energystorage.pnnl.gov/regulatoryactivities.asp).

## 2.2. OTHER COUNTRIES[13]

### 2.2.1 AUSTRALIA

The Australian Energy Market Operator projected that two-thirds of the new power generation capacity over the next 20 years would come from RE. To accommodate the increase in RE, it estimated monthly requirements of 120 GWh of BESS, 300 GWh of shallow pumped storage, and 550 GWh of deep pumped storage by 2030 (AEMO 2019).

### 2.2.2 BRAZIL

The Government of Brazil (GoB) was a pioneer in adopting auctions for electricity and designing reverse auction processes. In 2004, it required each major load center to ensure its own supply through contracts for generation capacity procured through competitive auctions. The GoB has used a variety of auction products and models tailored to specific contexts. However, Brazil has only adopted utility-scale BESS on a small scale because of ample pumped storage capacity. Most of the existing BESS was procured through an auction in Roraima State. However, co-located, utility-scale BESS is expected to

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[13] In 2020, the U.S. Department of Commerce Commercial Law Development Program began developing a handbook on international good practices for integrating BESS in African power systems, with support from Power Africa. This handbook will describe the policies, regulations, and management guidelines for utility-scale and microgrid-scale energy storage systems.

increase due to transmission and distribution constraints and the government's adoption of new PPA structures that transfer RE intermittency risks to the sellers (Beltran 2020).

### 2.2.3 CHILE

In 2015, the Government of Chile (GoC) issued a long-term energy policy with ambitious targets for the RE share of electric power that increase from 20 percent by 2025, 60 percent by 2035, and 70 percent by 2050 (Ministry of Energy of Chile 2015). Subsequently, the GoC issued a short-term energy roadmap for 2018-2022 consistent with the long-term policy (Ministry of Energy of Chile 2018).

Chile still lacked a comprehensive regulatory framework for energy storage in 2019. To accelerate BESS investments, the GoC will need to revise its wholesale power market rules and operation manuals to establish energy storage as a standalone technology and reconsider how storage is valued relative to generation and transmission and distribution alternatives. The GoC did not offer any incentives for utility-scale BESS (BloombergNEF and Acciona 2019).

Despite the lack of a regulatory framework, BloombergNEF and Acciona (2019) projected that Chile's cumulative installed BESS capacity will increase from less than 2 GW in 2035 to nearly 6 GW in 2040 and approximately 13 GW in 2050. Utility-scale BESS would allow retirement of more than 10 GW of backup, oil-fired generation and could comprise about 80 percent of the total energy storage capacity in 2040 and 2050. A total of $35 billion of new investment would be needed for new generating capacity (93 percent for wind and solar power) and $8 billion for energy storage through 2050. If Chile completely eliminated coal-fired generation, more wind power and BESS capacity would be needed and earlier.

In 2017, Engie commissioned NEC Energy Solutions to develop a 2 MW (2 MWh) BESS for spinning reserves and other ancillary services for a semi-isolated system at the northern end of the grid in Arica. This containerized Li-ion system began operations in 2019 (Colthorpe 2019c). In 2020, Chile had three other BESS installations—the 20 MW Cochrane system, 20 MW Angamos system, and 12.8 MW Andes system (Bnamericas 2020). AES was also developing a "virtual dam" with a total of 10 MW (50 MWh) of BESS at run-of-the-river hydropower installations in the Cajón del Maipo Valley.

In 2019, the GoC allowed remuneration of ancillary services through energy auctions.[14] This change in the rules for capacity payments and an earlier change on grid coordination are favorable for BESS. With its abundant solar resources, Chile also has potential for low-cost, large-scale production of hydrogen. However, the GoC has not adopted any policy incentives for green hydrogen and industry has not demonstrated any interest as a result (Bnamericas 2020).

### 2.2.4 EUROPEAN UNION (EU)

In 2018, 31 European countries were subject to the European Energy Certificate System, and some also had national guarantee of origin requirements for renewable energy. The EU recognized the importance of BESS for variable RE integration in its Electricity Market Design Directive of May 2019. This directive reduced barriers to energy storage by requiring nondiscriminatory and competitive procurement of balancing services and fair rules for grid access and vehicle battery charging (IRENA 2020a).

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[14] Reglamento de Servicios Complementarios, March 27, 2019 (https://www.globallegalinsights.com/practice-areas/energy-laws-and-regulations/chile)

In 2019, the European Commission's European Clean Energy Package (CEP) defined storage as an entity separate from generation, transmission or load, preventing it from being double-taxed when charging and discharging (IEA 2020).

## 2.2.5 INDIA

India's national government set ambitious targets for increasing the renewable electric power capacity to 175 GW by 2022 and 450 GW by 2030. The 2030 RE target is 40 percent of total projected electricity capacity. India has used REC requirements to accelerate wind and solar power development. Despite substantial RE resources, seasonal monsoons create major resource intermittency problems that differ for wind and solar power and vary across the country (Mukerjee, Venkat, and Dhamija. 2020). India allowed electricity banking to improve variable RE integration, but it had a negative impact on the financial viability of distribution utilities and caused some regulatory issues. As a result, distribution utilities have curtailed electricity banking facilities (Mukherjee, Venkat, and Dhamija 2020).

The IEA concluded that India has a large need for energy storage over the coming decades because of its ambitious RE targets and rapidly growing demand for electricity (Pavarini 2020). The India Energy Storage Alliance (IESA) estimated that over 70 GW (200 GWh) of energy storage capacity would be needed by 2022 (Mukherjee, Venkat, and Dhamija 2020). India has taken initial steps in deploying energy storage, but further cost decreases will be needed to scale up use (Frangoul 2020).

The lack of a regulatory framework for storage has impeded investments (Central Electricity Regulatory Commission 2017). Regulatory issues that need to be addressed include market entry fees, cost recovery structures that vary with the purpose and ownership of energy storage assets by generation, transmission, or distribution companies; use of licensee assets; and revenue sharing. BESS could reduce the reliance of large commercial, industrial, and institutional electricity users on distribution companies for backup power. Lower distribution company profits could increase electricity rates for small-scale customers. Clarity is needed on whether energy storage will be regulated at the national or state levels. National-level regulation would be best for inter-state transmission assets. State-level regulation may be more appropriate for storage owned by generators operating in a single state.

In 2020, the Ministry of Power drafted an amendment of the Electricity Act of 2003 to address contract enforcement for RE and hydropower purchase obligations, tariff setting and payment security, private sector participation, and the financial health of power distribution companies. The IESA commented on the absence of a policy and regulatory framework for BESS in the draft amendment. It recommended defining energy storage to include ancillary services, electric vehicle charging infrastructure, vehicle-to-grid integration, and microgrids. It also recommended that conventional power generators be allowed to include the costs of mandated BESS in annual fixed or supplemental charges. Owners of nondedicated energy storage should be able to enter into multiple contracts with users of the services.

The IESA also recommended giving distribution companies the flexibility to implement RE and storage separately or together and take on storage purchase obligations instead of hydropower purchase obligations. It proposed requiring all electricity supply licensees to meet power quality norms and recommended establishment of ancillary service markets within two years (Mukherjee, Venkat, and Dhamija 2020).

## 2.2.6 PHILIPPINES

The Philippines had wholesale electricity spot markets for Luzon and the Visayas. However, in 2017, the wholesale markets did not have specific provisions for grid-connected BESS, unlike pumped hydropower storage. BESS had not been classified and, if classified as a generation source, it would have been subject to tests that were not appropriate for the technology (Philippine Electricity Market Corporation 2017).

In April 2019, the Philippine Department of Energy issued a circular with rules for BESS.[15] The new rules allowed generation companies to own standalone or integrated BESS and register to participate in the wholesale electricity spot market. However, the system operator will not be allowed to own and operate BESS. The market operator must incorporate BESS into the wholesale electricity spot market and assess its impact on the market. The draft also highlighted licensing and permitting and connection and operational requirements and responsibility for proper environmental disposal and recycling of batteries and components (Colthorpe 2019d). The Philippine Department of Energy issued the final circular in September of the same year. It allowed front-of-the-meter energy storage facilities to register to participate in bilateral electricity supply contracts, wholesale electricity spot market trading, managing intermittent RE, provision of ancillary services, auxiliary load management for generation companies, deferral of transmission or distribution upgrades, and distribution utility demand and power quality management (Saulon 2019).

## 2.2.6 THAILAND

IRENA (2017b) identified the following challenges to scaling up RE deployment in Thailand: 1) limited experience in operating the power grid with a large proportion of variable RE, 2) weak interconnection with other countries, and 3) a peak load that often occurs after sunset. In 2019, the Government of Thailand estimated that RE would provide 29,358 MW—33 percent of total power generation capacity by 2037. This projection included 15,574 MW of solar power, 5,786 MW of biomass generation, 3,000 MW of hydropower from domestic or imported sources, 2,989 MW of wind power, and 900 MW of waste to energy (Thailand Department of Alternative Energy and Efficiency 2019).

The Electricity Generating Authority of Thailand is the sole power buyer for generators larger than 10 MW. The Metropolitan Electricity Authority and Provincial Electricity Authority oversee purchases of electricity from generation units with a capacity below 10 MW. Thailand also planned to open its energy market to private electricity trading. The Energy Regulatory Commission will establish a blockchain system for decentralized management of power distribution by the state utilities. Private power generators would pay the utilities a transmission fee for retail trading based on the amount of power transferred and congestion in the transmission lines. Small electricity producers would be allowed to link with a financial network provider to access new markets through peer-to-peer trading (Pugadmin 2020b).

## 2.2.7 UNITED KINGDOM

In 2019, the U.K. passed legislation requiring net zero carbon emissions at the economy-wide level by 2050.[16] Utility-scale BESS has been developed for electricity capacity markets, intermittent RE integration, and ancillary services in the U.K. One of the reasons for the projected increase in BESS is to improve integration of world's largest installed capacity of offshore wind power. Energy storage also played an important role in balancing the country's power system when the demand decreased 20 percent during the covid-19 pandemic in 2020.

Orsted installed the first standalone BESS in the country, the 20 MW Carnegie Road Project in Liverpool in 2019. NEC Energy Solutions supplied the Li-ion battery and power conversion system

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[15] https://www.doe.gov.ph/sites/default/files/pdf/announcements/proposed-dc-providing-framework-for-ess-in-electric-power-industry.pdf

[16] https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law

(Colthorpe 2019b). In 2020, the U.K. had 1 GW of installed BESS capacity and an additional 4 GW was in the planning stage.

In 2020, Limejump and its parent company, Shell, signed a seven-year offtake agreement for energy storage from the 100 MW Minety Project in an area of southwest England with extensive solar power capacity. Under this agreement, Shell will take on the liquidity risk and downside price risk in exchange for supply certainty and upside price protection (Parnell 2020).

In mid-2020, the U.K. government announced that it would relax planning laws to remove barriers to large BESS projects with capacities over 50 MW in England and 350 MW in Wales. The government anticipated that these policy changes could triple the national BESS capacity and drive production of battery cells five times larger than those that were available. Batteries and other flexible technologies could save the U.K. power system $51.2 billion by 2050 (Guest Contributor 2020).[17]

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[17] Based on the July 21, 2020 exchange rate of $1.28 per British pound.

# 3. AUCTIONS AND OTHER PROCUREMENTS FOR RENEWABLE ENERGY AND BESS

This section discusses compensation methods and markets for BESS. It then discusses some developed and developing country experiences with auctions for RE in general and BESS in particular. It also addresses design and implementation issues for RE and BESS auctions, including qualification and bidding requirements, award criteria and payment methods, post-award discussions and risk liability, and implementation of awarded contracts.

## 3.1. IMPORTANCE OF RENEWABLE ENERGY AUCTIONS

It is often more efficient for utilities or government agencies to procure electric power capacity and generation from private sector providers, rather than providing these services directly themselves. Use of auctions or other competitive procurements to obtain these services can still be beneficial for a vertically integrated utility or government agency even in the absence of a wholesale power market or deregulated system of electricity generation, transmission, and distribution. However, many of the ancillary services that energy storage can provide have not been marketed, even in places with sophisticated wholesale power markets.

Around 2005, several countries stopped issuing new feed–in tariffs (FiTs) to subsidize RE investment and began using auctions instead as a more economically efficient approach.[18] FiTs became unnecessary when the unit costs of renewable electric power decreased due to more efficient RE technologies and manufacturing methods and economies of scale in production.

Auctions can reduce costs by stimulating competition and more efficient price discovery. They can also reduce the transaction costs of energy developers by increasing fairness and transparency in the procurement process. By 2020, most countries had moved away from FiTs, and a large number have used RE auctions. Many of these countries have obtained new electricity capacity or generation at lower prices in each successive auction.

RE auctions are *reverse auctions,* where the buyer issues a request for proposals (RFP) for the desired amount of a service meeting stated specifications. The buyer often sets qualification requirements for eligibility. Eligible offerors then submit bids for the lowest price they are willing to accept for a specific quantity and quality of the service. When the auction period ends, the buyer selects a set of offerors with the lowest bids until the desired procurement amount is contracted. The buyer generally reserves the right to reject bids that it considers too high or inconsistent with the specifications.

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[18] *Feed-in tariffs* are long-term contracts that provide premium prices as an incentive for increasing investment in renewable electric power production. Some governments offered FiTs when renewable electric power was substantially more expensive than electricity from fossil fuel. Even then, FiTs were not an efficient way to promote RE because it was difficult for governments or utilities to determine the minimum amount of subsidy needed and this amount varied by technology and location and changed over time.

Auctions have proven to be the most efficient and effective procurement mechanism for expanding renewable electric power capacity in developed and developing countries. Auctions that led to long-term, PPAs have enabled RE developers to obtain viable financing for implementation of their proposals. Auctions can also help governments or utilities guide the location and timing of new electric power capacity more precisely (Wigand, Amazo, and Lawson 2019). RE auctions can help spur private investment by giving investors the confidence that projects will be awarded using fair contracting practices. They can also decrease the administrative costs of procurements and promote policy objectives such as RE targets, electricity rate reductions, service reliability improvements, pollution and GHG emissions reductions, and economic development.

Some RE auctions have focused on one or more specific technologies, such as PV, wind power, or hydropower. *Technology-specific RE auctions* can diversify the types of electric power generation technologies and resources used in a country or subnational jurisdiction. However, they prescribe solutions that may not be optimal and may limit competition and the ability of the private sector to respond with new technologies. As a result, technology-specific auctions are less likely to result in a least-cost system.

*Technology-neutral renewable energy (TNRE) auctions* focus on capacity or generation targets, rather than the ways to achieve the targets. They typically allow bids for any type of renewable electric power generation technology without any quotas or preferences. Ideally, a TNRE auction should also allow bids for non-generation alternatives, such as BESS or demand-side management approaches. However, many auctions that have provided equal opportunities for any type of RE generation technology have neglected storage and demand-side approaches.

Manufacturers and energy developers make plans to pursue particular markets and investments based on the policy and regulatory environment and government and utility announcements about RE targets and future auctions. In many developing countries, national governments make the decisions on when to hold RE auctions and amounts and types of goods and services to be procured. Changes in government administrations in Mexico and Thailand have resulted in cancellations or indefinite suspensions of RE auctions. Stop-and-go changes in government policies increase risks and uncertainty that adversely affects private sector engagement and may increase long-term system costs.

## 3.2. COMPENSATION METHODS FOR BESS IN AUCTIONS

Many RE auctions to date have only procured investments in generation facilities. Auctions or contracts that only provide payments for generation resources may not provide sufficient incentives for an optimal amount of BESS. Only a small proportion of RE auctions have included storage as an option and usually combined with RE capacity.

Very few RE auctions have solicited *firm power*: the ability to provide electricity when and where it is needed on the grid with a high degree of certainty. Firm power contracts require companies to make guaranteed commitments to deliver an agreed amount of power at all times over a specific period, even under adverse conditions. Auctions or contracts that provide payments for firm power generation are more favorable for energy storage technologies. If storage is not part of the mix, suppliers may be required to make up shortfalls in firm power supply by buying electricity on the spot market or paying a financial penalty. Lon Huber, formerly Navigant's Energy Director, stated, "Solicitations that put all bids on a level playing field, define attributes the utility needs, and are open to all sources are proving to be the storage industry's best friend" (Trabish 2019).

*Load balancing*, *load matching*, and *daily peak demand reserves* refer to various methods of storing excess electricity during low demand periods for release when the demand rises. The ability to maintain load-generation balance at all times is a key indicator of system performance. Prolonged system recovery could indicate at-risk operations, decline in frequency response or degradation of regulation and reserve sharing capability.

One of the main advantages of utility-scale BESS is the ability to charge batteries when electricity costs are relatively low and release the electricity for sale on the grid when the price is relatively high at times of peak load or supply disruptions. This advantage, called energy *price arbitrage,* only exists if regulators allow electricity suppliers to charge time-differentiated tariffs at the wholesale level.

*Time-differentiated producer tariffs* can increase incentives for investments in front-of-the-meter BESS. Whether retail customers pay time-differentiated rates is a separate issue, but that is also desirable to encourage energy conservation and demand shifting at peak periods and purchases of behind-the-meter battery storage.

Additional payments may be available for the ancillary services provided by utility-scale BESS. In some jurisdictions, regulatory or wholesale market regimes have not allowed payments for these ancillary services. This is no longer the case in the U.S. following FERC Order 841. The value of ancillary services is becoming increasingly important for stimulating investments in BESS, especially in developed countries. In the U.S, the regional transmission organization such as PJM Interconnection LLC allows payments for frequency regulation services.

IRENA (2020a) developed an Electricity Storage Valuation Framework to estimate the costs and value of electricity storage for various stakeholders and the resulting challenges for developers and investors. The framework can support development of policies that allow stakeholders to monetize the benefits of electricity storage based on their system value. This report also included eight case studies showing different revenue streams from energy storage: 1) operating reserves, 2) flexible ramping, 3) energy arbitrage, 4) variable RE smoothing, 5) transmission and distribution investment deferral, 6) peaking plant capital savings, 7) off-grid variable RE, and 8) behind-the-meter storage.

Lazard Ltd. (2019) prepared illustrative value snapshots showing the internal rate of return (IRR) for some specific examples of front-of-the-meter BESS. It shows that the benefits of BESS are very system-specific. In Southern California, the California Independent System Operator (CAISO) obtained an IRR of 35.0 percent for one-hour storage for the wholesale power market, 18.4 percent for two-hour storage, and 9.7 percent for four-hour storage. However, in the U.K. wholesale power market, the IRR for storage was only 2.5 percent. The IRR for storage for transmission and distribution was 18.5 percent for the New England Independent System Operator (NYISO) in New Hampshire. The IRR for PV plus storage was 7.7 percent in South Texas for the Electric Reliability Council of Texas and 13.8 percent in Australia. These value snapshots showed a modest improvement over the previous year, mainly due to battery cost reductions.[19]

Financial investors may find BESS attractive for short-duration storage for the wholesale power market; the transmission and distribution system; and, in some cases, utility-scale PV plus storage (which benefits from shared infrastructure costs). However, financial investors would consider the returns unfavorable for four-hour storage for the wholesale power market in the absence of subsidies, tax incentives, or other policy inducements. Lazard Ltd. (2019) also disaggregated the IRRs by type of storage service. In

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[19] The financial returns for behind-the-meter storage also varied substantially and would require subsidies or tax incentives. Standalone storage for commercial and industrial applications had an IRR of 8.6 percent in San Francisco for CAISO and 28.2 percent in Ontario. PV plus storage yielded an IRR of 13.8 percent in San Francisco for CAISO and 22.8 percent in Australia. The IRR for residential PV with storage was 14.0 percent in the Hawaiian Electric Company service area, but only 2.7 percent in Germany (Lazard Ltd. 2019).

the illustrative examples, the most attractive financial returns were from ancillary services (where valued), demand response, and demand charge mitigation.

## 3.3. EXAMPLES FROM THE UNITED STATES

Even before implementation of FERC Order 841, some utilities, regional transmission organizations, and independent system operators in the U.S. procured battery storage capacity. This section presents examples of RE auctions and other procurements that have included BESS in Arizona, California, Colorado, Hawaii, Nevada, and other states.

### 3.3.1 ARIZONA

In 2016, Tucson Electric Power issued a technology-specific solicitation to procure 10 MW of battery storage capacity to improve service reliability and study how BESS can support RE expansion. The utility was able to buy two systems of this size for what it had expected to pay for one. It awarded a contract to NextEra for a 10 MW lithium nickel-manganese-cobalt battery system. It also contracted with E.on for a 10 MW lithium titanate oxide battery system combined with 2 MW of solar power capacity (Wichner 2016).

Tucson Electric Power was one of the first utilities in the U.S. to allow combined bids for solar power and BESS in a RE auction. The designer of the utility's auction, Carmine Tilghman, noted that "There are opportunities utilities don't know about. Our solicitation allowed market participants to show us these opportunities" (Trabish 2019).

In May 2017, Tucson Electric Power signed a 20-year PPA with NextEra Energy for 100 MW of solar power at less than $0.03/kWh and 30 MW (120 MWh) of BESS at a cost of $0.015/kWh ($15/MWh) for delivery in 2019. Without investment tax credits and other subsidies, this storage would have cost $90/MWh. If the solar capacity operates for 10 hours a day, it can produce 1,000 MWh of electricity. The BESS component will allow storage of 12 percent of the solar power generated. Dividing the storage cost by 12 percent and assuming a 20 percent efficiency loss in battery charging and discharging, the cost per unit of electricity stored was $0.13/kWh. This storage cost less than gas-fired peak power generation in Arizona, but more than off-peak power generation. As BESS costs decline, utilities will be able to increase the proportion of renewable electric power stored, reducing the costs per unit of storage used (Maloney 2017a and 2017b).

Arizona Public Services, the state's largest investor-owned utility, plans to add 850 MW of BESS and at least 100 MW of solar generation by 2025. It expected to add 200 MW of BESS to existing utility-scale PV installations, install 500 MW of BESS in other facilities it owns, and contract for 150 MW of BESS from third-party sources (Pyper 2019).

### 3.3.2 CALIFORNIA

#### California Public Utilities Commission (CPUC)

In 2010, the CPUC established a Renewable Auction Mechanism (RAM) for IOUs to procure power from 3-20 MW projects that meet RPS requirements. This streamlined mechanism 1) allowed bidders to set their own prices for the competitive auction process; 2) required a simple, nonnegotiable contract and standardized valuation process; and 3) allowed expedited CPUC regulatory reviews. Bids were selected in order of lowest prices until the specified auction capacity was reached. Bid prices were not subject to negotiations after the auction. The projects had to go through a Phase II Interconnection Study. Each IOU developed its own standard contract, but projects had to be online within 36 months (a six-month extension was available for regulatory delays).

Between 2011 and 2015, the CPUC held six auctions under the RAM with mandated procurement targets for each of the three IOUs—Pacific Gas & Electric, San Diego Gas and Electric, and Southern California Edison (SCE). Bidders were required to pay a development deposit of $20,000/MW for 3-5 MW projects. For 5-20 MW projects, the deposit was $60,000/MW for intermittent RE and $90,000/MW for baseload capacity. No performance deposit was required for successful bidders with projects up to 5 MW. Successful bidders with projects larger than 5 MW had to pay a performance deposit of 5 percent of the forecast project revenues.

In 2015, the CPUC eliminated the 20 MW cap on projects eligible for the RAM. It also allowed the IOUs to use the streamlined auction process for additional purposes (system resource adequacy, local resource adequacy needs, reliability, local capacity, the Green Tariff Shared Renewables Program, and any CPUC or legislative mandate). It broadened the geographic location beyond the service area of the three IOUs to include the entire CAISO control area. The CPUC stopped mandating procurement targets for the RAM, but required the IOUs to discuss use of the RAM in their annual RPS procurement plans. Each utility can hold as many RAM auctions as specified in their procurement plans.

The projects must be based on commercialized technology. Bidders can either own or lease the sites or document options to purchase or lease the site after a RAM contract is awarded. Each development team must have a member that has completed or begun construction of a project of similar technology or capacity. Developers must file interconnection applications before bidding. Bids are compared against similar product types—baseload, peaking, and intermittent capacity (https://www.cpuc.ca.gov/Renewable_Auction_Mechanism/).

### Southern California Edison

SCE has held several auctions that have included BESS. In 2014, it solicited 2,200 MW in new generation and storage resources, including 250 MW of BESS, to offset the 2013 closure and pending decommissioning of the San Onofre Nuclear Generating Station and anticipated retirement of old, natural gas peaking power units. In 2016, SCE issued a solicitation for energy storage facilities with grid connections to one of four designated substations. It also issued a broader solicitation for RE capacity, energy storage, load reduction, resource adequacy, or ancillary services to allow deferral of investments in power distribution (https://www.sce.com/procurement/solicitations/esdd).

In 2018, SCE awarded auction contracts to seven RE generation projects that included a total of 195 MW of BESS. These projects are expected to begin operations between December 2020 and March 2021. Payments under these contracts will be based on delivered capacity in $/MW/month (Spector 2019a). In 2018, SCE also issued a solicitation for distributed energy resources (DERs) to defer the need for capital investments for distribution infrastructure upgrades at two distribution projects without reducing system reliability. These DERs included energy efficiency, demand response, RE capacity, and energy storage. This solicitation tested an expedited procurement process that would conclude within four months (https://www.sce.com/procurement/solicitations/iderrfo). In early 2019, SCE complied with a mandate from the state legislature by issuing a solicitation for 20 MW of BESS to compensate for the partial shutdown of the Aliso Canyon natural gas storage facility (www.sce.com/procurement/solicitations/aliso-canyon-energy-storage).

SCE held an auction that resulted in seven PPAs for a total of 770 MW of grid-connected BESS to replace gas peaker plants. Most of the winning projects will be located at existing solar power facilities that will charge the batteries during sunny days and discharge them to smooth out intermittency and meet the peak demand in the late afternoons and evenings. This huge procurement exceeded the rest of the U.S. storage market in 2019. The utility expected half of this capacity to be operational by August 2021, a record turnaround time for projects of this size (St. John 2020).

### 3.3.3 COLORADO

In 2017, Xcel Energy held an auction for PPAs in Colorado with separate RFPs for 1) dispatchable resources (gas turbines and standalone storage); 2) intermittent RE resources (wind, solar, hydro with reservoirs, geothermal, biomass or recycled energy power without storage); 3) semi-dispatchable resources (any intermittent RE resource with storage or fuel back up); and 4) non-dispatchable resources (coal-fired thermal and run-of-river hydropower). Bid prices were denominated in $/MW/month for dispatchable resources and $/MWh for non-dispatchable resources or bids that included storage with a non-dispatchable resource.

The utility received 430 bids, including 350 for intermittent RE or semi-dispatchable RE with BESS. The median bids were $21/MWh for wind plus storage and $36/MWh for PV plus storage. The lowest previous bid for PV plus storage in the U.S. was $45/MWh in Arizona. The median bids were $6,700/MW/month for gas-fired combined cycle units and $11,300/MW/month for standalone BESS (Walton 2018).

Xcel Energy's auction design process enabled the utility to obtain a large number of bids at record low prices. Reasons for this success may include

1. The long lead time between proposal submission and the required construction date. Proposals were due in 2017 and projects were not expected to begin operations until 2023. Over this period, BESS prices are expected to continue declining and developers assumed some cost savings in setting their bids.
2. There were separate sub-auctions for energy products with different characteristics to ensure comparability of bids within each auction.
3. Xcel Energy publicized the auctions widely to national and state industry associations, and energy developers. It posted the RFP on its website and held a pre-bidding conference.

One potential problem is that the auction for semi-dispatchable RE did not specify a minimum duration for the storage. Although this allowed lower-cost bids, it also reduced the amount of storage that was offered. The likely result will be a smaller amount of usable renewable electric power from these projects.

Xcel Energy's experience showed that TNRE auctions 1) reduced the cost of projects with RE generation and storage, 2) increased the number of participants in the energy storage market, and 3) allowed battery storage to emerge as a competitive technology (Lackner, Koller, and Camuzeaux 2019). However, since the winning bidders were not required to begin construction until 2023, it is still premature to assess the success of bid implementation.

### 3.3.4 HAWAII

The State of Hawaii previously depended heavily on high cost, imported diesel fuel for power generation, resulting in some of the highest retail prices for electricity in the United States. In recent years, the state experienced rapid growth in solar power capacity (utility-scale and behind-the-meter) that exceeded the ability of the transmission grid. Solar power provided over 11 percent of the state's total electricity consumption and 57 percent on the Big Island (Hawai'i). Since 2015, the Hawaiian Electric Company has required residential rooftop PV installations that export surplus power to the grid to have a utility-operated shut-off. A 2015 utility report estimated that solar power curtailment rates were as high as 10 percent on Oahu and 20-50 percent on Maui and Hawai'i. As PV system owners install autonomous advanced inverters and utilities add VAR controllers, solar power curtailment rates are expected to fall to single-digit levels (Thurston 2019). The State of Hawaii has a 100 percent RPS mandate by 2045, which is only likely to be feasible with a major expansion of energy storage.

Contracts for utility-scale solar power in Hawaii have already routinely included BESS. In 2017, the Kauai Island Utility Cooperative (KIUC) opened its first utility-scale solar power facility with battery storage. Under a PPA, KIUC paid Tesla $0.14/kWh for a 13 MW PV system with a 13 MW (52 MWh) battery. The cost of storage was $0.17/kWh under this contract. KIUC also signed a PPA with the AES Lawai Corp. at $0.11/kWh for a 28 MW PV system with a 20 MW (100 MWh) battery. The cost of the storage component was $0.13/kWh (Maloney 2017). When the AES Lawai facility began commercial operations in April 2019, it was the largest PV plus BESS peaker power plant in the world (https://energy.ehawaii.gov/epd/public/energy-project-details.html?rid=13d--119af92658e80c6).

KIUC increased its proportion of RE (solar, hydropower, and biomass) from 8 percent in 2010 to 55 percent in 2019 and has a goal of 70 percent by 2030. On most days, at least 90 percent of Kauai's daytime electricity consumption is from RE sources. On sunny days, KIUC reaches 100 percent renewable electricity for five hours or more. Battery storage has helped KIUC increase system reliability by 50 percent. In 2019, KIUC saved $3.8 million by replacing diesel generation with utility-scale solar power plus storage (https://website.kiuc.coop/renewables).

In February 2019, the Hawaiian Electric Company held an auction for solar power with and without BESS. This resulted in contracts for six projects for PV plus BESS with a total capacity of 255 MW of solar power and 1,055 MWh of four-hour battery energy storage. The accepted bids for PV with BESS were between $80 and $90 per MWh. Since a Hawaiian Electric auction for solar power alone had average accepted bids of $40/MWh, the incremental cost for BESS was $40-$50/MWh (Hawaiian Electric Company 2019).

Hawaiian Electric was also planning two large BESS projects to increase the reliability of the O'ahu electric grid and expand renewable electric power generation—a 20 MWh battery storage system at the 20 MW West Loch Solar facility and a 100 MWh battery system at the Campbell Industrial Park Generating Station (http://www.hei.com/CustomPage/Index?keyGenPage=1073751872).

## 3.3.5 NEVADA

Nevada Energy was seeking to double its RE capacity between 2018 and 2023 to meet the state's 50 percent RPS by 2030. In 2018, Nevada Energy awarded PPAs for six RE projects with a total capacity of 1,000 MW, including 100 MW of BESS (400 MWh). The prices ranged from $26-30/MWh for solar power and $6,110-$7,760/MW per month for BESS. In 2019, Nevada Energy received regulatory approval for its integrated resource plan, which included three large PV plus storage projects: 1) Quinbrook Infrastructure Partners and Arevia Power's Gemini Project, 2) 8Minute's Southern Bighorn Project, and 3) EDF's Arrow Canyon Project. These three projects were expected to more than double the state's electric power capacity by 2023. Storage will shift the availability of the solar power from the mid-day generation peak to meet load requirements in the late afternoon and evening.

Together, the three projects would add 1,200 MW of solar power capacity and 590 MW of BESS. The Gemini Project will be the largest solar power plus storage project in the U.S., with 690 MW of PV and 380 MW of BESS. With the planned storage capacity, the Southern Bighorn Project will be able to operate 65 percent of the time during peak summer hours, compared to approximately 30 percent for the average utility-scale solar power facility in Nevada. The Gemini and Southern Bighorn Projects will use batteries with a four-hour storage duration while the Arrow Canyon Project would have a five-hour storage duration. These projects reflected the trend toward longer duration storage as battery prices fell (St. John 2019a).

### 3.3.6 NEW YORK

New York State's Green New Deal set ambitious goals of 70 percent of electric power from RE by 2030) and 100 percent carbon-neutral electricity by 2040. The state's Climate Leadership and Community Protection Act also set specific targets of 6,000 MW of distributed solar power by 2025 and 9,000 MW for offshore wind by 2035. To improve the integration of variable RE, New York State plans to deploy a large amount of energy storage—1,500 MW by 2025 and 3,000 MW by 2030 (Konidena 2020). NYISO held auctions for RE capacity with storage.

### 3.3.7 OTHER STATES

In 2019, Florida Power and Light had the largest PV and BESS facility under construction in the U.S.—the 409 MW PV and 900 MWh Manatee Energy Storage Center of NextEra Energy (St. John 2019a).

NextEra Energy was the world's largest owner of solar power capacity outside of China and the largest owner of U.S. wind farms. Over half of NextEra's new solar power projects will include battery storage. The company's CFO, Rebecca Kujawa noted that, "customers are increasingly interested in a near-firm, low-cost renewable product" (Merchant 2019).

PacifiCorp provides electricity to 1.9-million customers in six western states from Oregon to Wyoming. This utility's integrated resource plan for 2025 set targets of an additional 3,500 MW of wind power, 3,000 MW of utility-scale solar power, and 600 MW of BESS. PacifiCorp is owned by Berkshire Hathaway. Other utilities owned by this company (including Nevada Energy) have also made relatively strong commitments to increasing RE and BESS (St. John 2019b).

PJM Interconnection LLC procured 300 MW of BESS for dynamic frequency regulation in the mid-Atlantic states.

## 3.4. EXAMPLES FROM OTHER COUNTRIES

This section discusses examples of auctions and other procurements for RE and BESS in Australia, Brazil, Chile, European Union, India, and Thailand. Some of these RE auctions in developed countries solicited bids that included a specific amount or duration of battery storage. Most of the RE auctions in developing countries discussed below allowed BESS as an option, rather than a requirement for an award.

### 3.4.1 AUSTRALIA

The State Government of South Australia conducted a TNRE auction that awarded a contract to Neoen for 315 MW of wind power capacity and 100 MW (129 MWh) of battery storage at the Hornsdale Power Reserve (Table 4). This was the world's largest Li-ion battery when it began operating in December of 2017. Tesla manufactured the batteries, which covered one hectare of land.

Seventy MW (10 MWh) are reserved for power system reliability. This was the first demonstration of a wind or solar farm providing frequency control ancillary services (FCAS) to Australia's National Electricity Market. The balance of storage capacity operates on a market basis, selling energy and ancillary services in the wholesale market.

**TABLE 4: Hornsdale Power Reserve (HPR)**

| HPR<br>100MW, 129MWh | Battery Capacity | Project Objectives | Services Provided |
|---|---|---|---|
| SA Government Reserved Capacity | 70MW,<br>10MWh | • Improved System Security for SA network<br>• Downward pressure on ancillary services prices<br>• Improved reliability of supply | • Participation in System Integrity Protection Scheme (SIPS)<br>• Fast Frequency Response<br>• Contingency FCAS<br>• Regulation FCAS<br>• Back-up reliability measure |
| Neoen Market Capacity | 30MW,<br>Balance of energy | • Commercial market participation<br>• Optimised bidding across energy and all eight FCAS markets | • Energy Arbitrage<br>• Regulation FCAS<br>• Contingency FCAS |

The Hornsdale Power Reserve helped maintain grid stability, previously provided by fossil fuel generation. It took fossil fuel power plants take several minutes to respond to sudden changes in demand or supply. BESS has a faster demand response ability than fossil fuel generation and can be less expensive. Hornsdale's battery storage has also had an important role in frequency control and other ancillary services (Suba 2020). In the last quarter of 2019, frequency control services contributed to record revenues from utility-scale batteries in the Wholesale Electricity Market for the South West Interconnected System of Western Australia (Keating 2020).

Windlab and Eurus Energy developed the Kennedy Energy Park in northern Queensland—the world's first utility-scale power plant combining wind turbines and single-axis tracking PV panels with BESS. This site was notable for a high, daytime solar flux and strong night winds. Construction of the Kennedy hub was completed in December 2018. The project was energized in August 2019, but its commercial operation has been delayed due to complications in the connection process (https://www.windlab.com/our-projects/kennedy-energy-park/; https://kennedyenergypark.com.au/).

In Australia, BESS has generally been designed for *intra-day market arbitrage*—allowing power suppliers to charge batteries during off-peak times and discharge them for peak load sales at higher prices. Power suppliers could also reserve part of their storage capacity for ancillary service sales. BESS was typically designed for a four-hour storage duration. Market decisions determined the sizing of BESS.

## 3.4.2 BRAZIL

The GoB conducted a series of auctions that increased the national installed capacity for electricity from 91 GW in 2005 to 158 GW in 2017. However, the country contracted too much RE too quickly. Many of the contract recipients could not obtain grid connections or financing in a timely manner and faced substantial financial penalties for failure to deliver power. Furthermore, the 2016 economic crisis reduced the growth in electricity demand. To mitigate those problems, the GoB held de-contracting, market-based auctions that allowed existing PPA holders to get out of their contracts by bidding to accept lower financial penalties (Molina, Scharen-Guivel, and Hyman 2018).

In 2019, the thirtieth national energy auction awarded contracts for 2.979 GW of generation capacity—35 percent from wind, 25 percent from natural gas, 18 percent from solar energy, 15 percent from hydropower, and 8 percent from biomass. It did not seek to procure any BESS. The auction prices were based on power generation, rather than capacity. The prices per MWh ranged from $20.54 for solar power to $24.07 for wind power, $45.80 for biomass power, $45.97 for natural gas, and $52.08 for hydropower (Beltrán 2020).

Roraima State in northern Brazil lacked connections to the national power grid. In 2019, the Chamber of Commercialization of Electric Energy (CCEE) held two auctions for renewable and non-renewable electric power capacity and firm power in Roraima State. The CCEE prequalified bids for 156 projects with a total capacity of 6 GW. The ceiling price in the auction was $277.48/MWh. The CCEE selected nine winning bids with a total of 294 MW of capacity (6,420.5 MWh of power). The lowest winning bid was $170/MWh and the highest was at the ceiling price. The average price was $213.60/MWh. Seven of the winning bids were for RE, but the largest was for a natural gas unit and the most expensive was for a small diesel unit. The successful bidders received 15-year PPAs for RE installations and seven-year PPAs for non-renewable power generation.

Only one of the winning bids in the Roraima State auction considered short-term duration BESS. Brasil Biofuels proposed a hybrid with 31 MW of palm oil biofuel capacity, and 25 MW of solar power capacity and possibly 30 minutes of storage capacity The contract did not require Brasil Biofuels to provide storage if it can meet the contracted electricity capacity and firm power requirements without it, but the company expects that storage will reduce the fuel costs and smooth integration of the biofuel and solar power generation (Agência Nacional de Energia Elétrica 2019; Bellini 2019b).

### 3.4.3 CHILE

In 2014, Chile held its first auction for renewable and conventional power. ACCIONA Energia Chile received an auction award to develop PV plus storage. Storage allowed the company to obtain higher prices for the electricity. Between 2015 and 2017, Chile held TNRE auctions for non-firm power using a combinatorial process to reduce total system supply costs.

One of the winning bids in the 2017 auction combined PV generation with storage to supply power at night. Cox Energía won a contract to supply 140 GWh of power at a price of $34.40/MWh. Even though this bid included a requirement to supply electricity at night, it was close to the record low, average auction bid of $32.50/MWh. Cox Energía may be counting on further decreases in Li-ion battery costs to make this contract profitable because the facility is not required to begin operating until 2024 (Deign 2017a).

In 2018, Chile changed the desired product in electricity auctions to firm power in time-differentiated blocks. Bidders were required to offer a fixed amount of firm power during each of the three time blocks (peak, off-peak, and mid-load) in specified seasons of the year. They could choose how to allocate their delivered power across the time blocks. Bidders could use any combination of power generation technologies. They were allowed, but not required, to include energy storage mainly to improve integration of solar and biofuel generation, rather than meet peak loads requirements.

### 3.4.4 EUROPEAN UNION (EU)

In 2017, EU State Aid Guidelines required member countries to use auctions to procure renewable electric power capacity from the private sector. This could be done through single unit, multi-unit, or multiple sequential auctions. Many EU countries have now switched from single technology-specific auctions for RE to TNREs (e.g., Germany, Netherlands, Slovenia, Spain, and the U.K.). Most EU auctions have had prequalification requirements and some had nonrealization penalties.

Initially, Germany allowed developers to get permits after winning onshore wind power auction bids. It later required onshore wind power developers to obtain permits before submitting bids. This deterred participation by smaller and newer companies and the auctions were *undersubscribed*—they did not meet their procurement targets. Germany subsequently reversed this change in wind power auction rules.

There has also been a trend toward cross-border RE auctions open to bids from other EU countries. Cross-border auctions involving Denmark and Germany have created challenges due to differences in the legal frameworks in the two countries (Kreiss 2018). Mutual cross-border participation between France and Germany in RE markets has decreased prices in EU energy storage and ancillary service markets. Although this trend benefited electricity users, it reduced incentives for new BESS installations, particularly for long-duration storage. It is also expected to increase use of long-term offtake agreements to shift long-term risks from BESS developers to buyers of storage services (Grundy 2020b).

France and Luxembourg have held national auctions to facilitate trading of national RE guarantee of origin requirements (RECS International and VaasaETT 2019). In 2020, France held an energy capacity market auction with low carbon emission requirements (less than 200 g of $CO_2$ per kWh). This was the first example of an energy auction with a binding carbon emissions factor. This auction awarded seven-year PPAs for 253 MW of energy storage capacity and 124 MW of demand response capacity with a contract-for-differences requirement (Colthorpe 2020a).

In August 2020, the Government of Portugal held an auction for 700 MW of grid-connected electric capacity in 10-100 MW units. It was the second renewable auction in the country. Six hundred and seventy megawatts of solar capacity was awarded. Unlike the previous year's auction, which was limited to PV and concentrating solar power, this auction allowed competition between solar power and solar plus storage facilities using BESS or thermal storage. Three products were auctioned and awarded, as shown in Table 5.

**TABLE 5: Government of Portugal's Award for Renewable Electrical Power**

| Product | Number of Lots | MW awarded | Pay-out | Product Description in the TOR |
|---|---|---|---|---|
| Contract for differences | 4 | 177 | Price received = bid price = spot price +- premium | Prêmio Variavel por Diferenças |
| Fixed compensation to national electricy system | 1 | 10 | Pay-out = spot price net of bid price | Compensação Fixa ao SEN |
| PV plus storage | 8 | 483 | Pay-out = fixed payment (bid-price) minus difference between spot and strike price – to insure the system against high spot prices | Premio Fixo por Confiabilidade |

Source: Republica Portuguesa 2020.

## 3.4.5 INDIA

India has held national and state government auctions for utility-scale solar and wind power. Under-contracting and underbidding have been common problems in some of these auctions (IRENA 2019b). Some auctions had unfavorable contract terms with future prices denominated in domestic currency without inflation adjustments. As a result, some auction winners found it difficult to obtain bank financing (Molina, Scharen-Guivel, and Hyman 2018).

India has experienced transmission congestion problems that have hindered efficient use of existing RE resources. The Government of India (GoI) has expressed concern about nonrealization of PPAs for delivered power due to underbidding and curtailment of generated power due to grid congestion. In future auctions, the GoI plans to solicit firm power for peak hours. This change will encourage bidders to offer projects combining RE generation and storage. The awards will be based on bid prices for firm power during critical hours. The FiT price will only apply to off-peak power. The desired duration of battery storage to meet peak load requirements will be four hours, but the terms and conditions for the participation of BESS in utility-scale auctions were still being defined.

In August 2019, the Solar Energy Corporation of India (SECI) announced the world's largest RE auction. The procurement target was 1.2 GW of solar and wind power with pumped storage or BESS to firm up power generation. Even though the developers were responsible for mitigating the RE intermittency risks and supplying power in two time-differentiated price blocks, the auction was oversubscribed.

SECI announced the winners of this auction in February 2020. Greenko Energy Holdings obtained a contract to supply 600 MW of firm power for six hours per day during peak demand hours at $0.089/kWh and 300 MW off-peak at$0.042/kWh. ReNew Power received a contract to develop 300 MW of firm power at $0.096/kWh during an 11-hour daily peak period and $0.042/kWh off peak. To meet the firm power requirements, both firms will have to develop BESS capacity—2,250 MWh for Greenko Energy Holdings and 750 MWh for ReNew Power (Saurabh 2020). Solar plus storage bids were less costly than coal-fired generation (Kenning 2020).

In May 2020, the GoI applied a new type of RE auction target for round-the-clock capacity. It defined *round-the-clock* as providing 400 MW or more of renewable power available at least 80 percent of the time over the year and at least 70 percent in each month. This target pertained to the overall auction, rather than each bid or awarded project (Bullard 2020). In another recent development, the National Mission on Transformative Mobility and Battery Storage was seeking to facilitate establishment of a 50 GW advanced energy storage manufacturing facility in India (Parikh 2020).

### 3.4.6 THAILAND

In August 2017, Thailand held an auction to procure 300 MW of generation capacity for delivery in 2021 from facilities with a capacity of 10-50 MW. Two-thirds of the total capacity was expected to come from biomass, biogas, or waste-derived fuel. The remaining one-third of the capacity was expected from solar, wind, or small-scale hydro power combined with battery storage. The total capacity was allocated across nine geographic zones and there were simultaneous auctions for the quotas for each zone. Unfilled generation capacity from a zone could be transferred to another zone if the bid prices were lower and it could be accommodated on the transmission grid.

The solicitation required bidders to offer to operate at 98 percent or more of their proposed capacity between 9:00 AM and 10:00 PM on weekdays (peak period) and only 66.3 percent during the off-peak periods. Successful bidders would receive PPAs with financial penalties for failure to supply the agreed amounts of power. There was a ceiling price of $110.9/MWh with no price premium for any specific generation technology (IRENA 2019b).

Only 42 of the 85 bids received met the prequalification requirements. Contracts were awarded to the 17 qualified bids with the lowest prices for generated power. This auction procured the targeted 300 MW of capacity at prices ranging from $60-$110/MWh and averaging $75/MWh. Fourteen of the winning bids were for biomass power from bagasse at sugar mills. The remaining three projects were hybrid solar power—one with biogas, one with biomass, and one with battery storage.

Blue Solar received a contract to install 42 MW of solar power capacity with 12 MW of BESS capacity (54 MWh with a discharge duration of at least four hours). Its bid price was $78/MWh, slightly above the average winning bid. Some bidders in the 2017 auction recommended that future auctions allow greater flexibility and focus on firm power for peak periods (O'Mealy, Sangarasri *et al.* 2020).

### 3.4.7 UNITED KINGDOM

The U.K. will need substantial capital investment to replace aging fossil fuel generation with RE resources, meet projected increases in the demand for electricity, and accommodate peak load requirements (typically in the early evening in winter). The Energy Act of 2013 established a capacity market to ensure security of electricity supplies at the least cost to consumers using a contract-for-differences approach. In 2014, the U.K. issued Electricity Capacity Regulations as well as Capacity Market Rules. In 2018, it established financial rewards and penalties for Electricity System Operators.[20]

The Capacity Reserve Market remunerates power generators and energy storage suppliers based on the amount of electric power capacity they guarantee to make available at the needed rate at any moment in time, regardless of whether this electricity is actually used. Capacity payments are in addition to the revenue from electricity sales.

The U.K. held its first capacity auction in 2014. Since then, it has often held one or more capacity markets auctions each year. Most of the auctions have been for one-year contracts to supply capacity either in the next year (T1), second year (T2), third year (T3), or fourth year (T4). The U.K. has not held capacity market auctions for each time period every year. Some of the T4 auctions have included a small proportion of longer-term contracts for up to 15 years.

The U.K first awarded capacity market contracts for BESS in 2016, when 500 MW was contracted for operation in the winter of 2020/2021. However, only 150 MW of storage was contracted in a subsequent auction for 2021/2022 due to the lower auction clearing price and changes in market rules to discourage use of short-duration batteries (Grey Cell Energy 2018). Fluence Energy received a contract for 60 MW of storage for the Capacity Reserve Market with a majority of the revenue coming from frequency regulation services (Spector 2018).

In 2020, the U.K. held four capacity market auctions for RE—T1, T2 for 2021/2022, T3 for 2022/2023, and T4 for 2023/2024. Regulatory and market design issues prevented batteries from competing directly as a storage technology in the 2020 auctions. Nevertheless, two developers submitted bids that included BESS classified as demand-side response and received contracts (Colthorpe 2020a).

## 3.5. EXAMPLES OF RENEWABLE ENERGY AUCTIONS FOR BATTERY ENERGY STORAGE AND THEIR CHARACTERISTICS

Table 6 summarizes the characteristics of example RE auctions that have included BESS in developed and developing countries.

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[20] https://www.legislation.gov.uk/ukdsi/2014/9780111116852/contents; https://www.gov.uk/government/publications/capacity-market-rules; and https://www.ofgem.gov.uk/electricity/wholesale-market/market-efficiency-review-and-reform/system-operator-incentives

## TABLE 6: Examples of RE Auctions That Have Included BESS in Developed and Developing Countries

| Location | Technology Neutral? | Product Auctioned | Type of Contract | Award Criteria |
|---|---|---|---|---|
| **Australia** | Largely yes (wind, solar and any storage) | Wind and/or PV with storage | Contract-for-differences | Lowest power price |
| **Brazil** | Yes | Capacity and power generation | Firm power available 24x7 (less during off-peak) | Lowest firm power prices |
| **Chile (Time-Variant)** | Yes | Previously: nonfirm power; Currently: firm power in time-differentiated blocks | Currently: time-differentiated power blocks (daily and seasonal) | Lowest firm power price per time block |
| **France** | No (emissions requirements enabled only demand-side response and energy storage to participate) | Capacity | Contract-for-difference | Included low carbon emission requirements (less than 200 g of $CO_2$ per kWh) |
| **India** | Largely, yes (wind, solar and any storage) | Previously: nonfirm power; currently: semidispatchable firm power | Firm power (peak and off-peak) | Lowest prices for peak power with standard FiTs for off-peak power |
| **Portugal** | No (allowed competition between solar power and solar plus BESS or thermal storage) | Firm energy during critical periods (spot price higher than strike price) | Fixed payment for delivering energy during critical periods at strike price | Lowest capacity payment (Euros/MW/year) |
| **Thailand** | Yes | Firm power in nine geographic zones | Firm power (peak and off-peak) | Lowest firm power price (peak and off-peak) for each geographic zone |
| **U.S. – Arizona (Tucson Electric Power)** | No (only solar and BESS) | PV and BESS | Blended PPA. Contract sets charge and discharge parameters for BESS | Lowest price premium for BESS over PV only price |
| **U.S. – California (Southern California Edison)** | Yes | Peak capacity | Capacity ($/MW/month) | Lowest peak capacity price |
| **U.S. – Colorado (Xcel Energy)** | Yes | Various, including semi dispatchable firm power | $/MWh for semi dispatchable resources | Lowest power price |

## TABLE 6 (Continued)

| | | | | |
|---|---|---|---|---|
| **U.S. – Hawaii (Hawaiian Electric Company)** | No (only solar and BESS) | PV and BESS | MWh x deemed delivery, with adjustments for actual performance through fee-based agreements or tolling.[21] | Ranking of price and nonprice factors, followed by best and final offer |
| **U.S. – Nevada (Nevada Energy)** | No (only solar and BESS) | PV and BESS | PPA price for solar power ($/MWh); capacity payments for storage ($/MW or $/MWh) | Lowest prices for solar power and BESS capacity |
| **U.S. – Mid-Atlantic States (PJM Interconnection LLC)** | Yes (often, BESS-only bids competing with other resources) | Capacity and ancillary services | Frequency regulation, capacity payment, others | Lowest prices for capacity and ancillary services |

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[21] A tolling arrangement is a structure that allows the PPA customer to control the contracted resource through dispatch instructions.  The customer tells the power producer when to ramp generation up and down to meet requirements associated with current grid conditions.  To compensate the generator, the customer will make an energy payment and a capacity payment (Sinaiko 2017).

# 4. AUCTION DESIGN AND IMPLEMENTATION ISSUES FOR BATTERY ENERGY STORAGE

This section provides detailed information on design and implementation issues for RE auctions that include BESS. It covers ways of defining the products and services, designing PPAs, qualification and bidding requirements, evaluation criteria for nonprice and price factors; domestic content requirements or preferences, post-award discussions and contracting risks, and PPA implementation risks.[22]

Lackner, Koller, and Camuzeaux (2019) identified five general lessons to help create a level playing field for BESS in RE auctions:

1. Use technology-neutral auctions and promote competition by announcing the auction schedule in advance, following transparent administrative processes, and holding pre-auction conferences to explain the rules;
2. Encourage a large number of bidders to increase competition, reduce market power dominance, and make collusion more difficult by limiting the amount of RE capacity or generation that can be offered by a single bidder;
3. Leverage existing policy and regulatory frameworks, market rules and structures, and incentives;
4. Earmark some auctioned capacity for less mature technologies (such as other types of batteries besides Li-ion). Mandating some use of newer technologies will increase the cost of the procurement, but it can help new technologies become competitive in the future and might reduce supply chain risks (for example, lithium shortages); and
5. Balance penalties for delivery failures with fostering competition.

## 4.1. DEFINING PRODUCTS AND SERVICES AND PAYMENT ARRANGEMENTS

One of the first steps in designing an RE auction is to define the products and services that will be procured. The products and services can include 1) development of new power generation or storage capacity through build, own, transfer (BOT) or build, own, operate (BOO) arrangements; 2) securing long-term supplies of electricity from generation and/or storage; and 3) long-term provision of ancillary services.

BESS capacity can be added together with new RE generation capacity or at a later time. BESS is often classified as semi-dispatchable power because the system operator can choose when to discharge energy from the charged batteries.

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[22] For broader or more introductory auction design material, readers may wish to visit USAID's competitive procurement webpage at https://www.usaid.gov/energy/procurement/auctions, including a Policymakers Guide for Designing Renewable Auctions (https://www.usaid.gov/energy/scaling-renewables/policymakers-guide-auctions), and an auctions library that includes resources for considering an auction, bidding rules, pre-qualification, and case studies.

Solicitations should define when the energy storage product or service needs to become available and the duration. A RE generator might not be able to produce the expected amount of power at certain times due to the intermittency of RE resources. Also, a mismatch between the timing of the electricity generated and the quantity that the buyer can resell on the grid may lead to *curtailment* of the delivery or transmission of electricity.

Power system products and services can be defined to assign the risks of RE resource intermittency and/or transmission and market constraints to either the suppliers or the buyer (*offtaker*). The assignment of responsibility for these risks will affect the prices that suppliers are willing to bid in an auction and the incentives for including BESS with RE capacity or generation. Risk liabilities can also affect the availability or cost of financing for the suppliers and their ability to implement their contracts on time or at all.

Some possible risk allocation profiles include:

***Deemed generation.*** This refers to the amount of electricity that a generator is capable of producing, but that cannot necessarily be delivered due to transmission system constraints or that the grid operator cannot resell due to insufficient demand when the electricity is available. A deemed generation contract assigns the supply risks to the power producers and transmission and demand risks to the buyer. The supplier is required to generate a certain amount of electricity over the settlement period—or pay a financial penalty (shortfalls or surpluses can also be carried out to the next settlement period). Tax credits may also be provided based on deemed generation. The supplier can generate less power over a shorter time period with no penalty as long as the shortfalls are made up over the subsequent settlement period. The settlement period is typically one month, with some form of reconciliation on a yearly basis. With deemed generation, the buyer is responsible for paying the supplier for curtailment due to transmission or market constraints (*compensation for constrained-off generation*). Under the deemed generation approach, there are no incentives for BESS. A *take-and-pay* arrangement is a type of deemed generation contract typically used for wind and solar (Overseas Private Investment Corporation (OPIC) 2019). The offtaker must take, and pay a fixed tariff for, all energy delivered (no dispatch required). If the offtaker cannot physically take the energy and output is "curtailed," energy will be calculated and paid for on a "deemed" delivered basis. Take-and-pay arrangements shield generators from curtailment risks. They are especially relevant to developing markets where risk perception is high, or where information on power dispatch and grid quality is not complete enough for bidders to incorporate curtailment risk into the bid price. The curtailment costs of the take-and-pay model may be passed on to the consumers in their electricity bills, or they could be borne by the system operator (IRENA 2019b). Take-and-pay arrangements do not provide incentives for energy storage.

***Pay-as-generated.*** In this kind of contract, the seller is paid for the energy produced, regardless of when it is actually produced. There may be some obligations to deliver a certain quantity of MWh per month/year. However, those are not necessarily binding constraints, as some tolerance is built into the arrangement. Production or shortfalls are carried out to the next settlement period. The RE energy seller bears the risk of dispatch. This risk is minimized because in most cases RE sources have priority on dispatch (due to their low short-run marginal cost). RE generators receive no payment for curtailed electricity, except if there are wholesale market rules that establish compensation for constrained-on/constrained-off generators.

Deemed-generation and "pay-as-generated" are relatively "generous" because they allocate many important risk elements to buyers (offtakers), who bear the costs of resource intermittency risks. These types of contracts were common in the early stages of RE development. They have been used in Argentina, Brazil, Chile, and India. Those types of contracts provide no incentives for the RE generation owners to install BESS.

***Pay-as-contracted*.** In this arrangement, the supplier is obligated to deliver the agreed amount of power. This amount of power may be constant or profiled over time (for example, according to the load curve or in daily time intervals). The supplier has to manage the intermittency risk, using financial or physical hedges, and deal with any shortfalls (and surpluses) by buying (or selling) power on the spot market. Spot market prices are more volatile than long-term contract prices, introducing a price-risk element. Australia has used this approach in some PPAs. Some Australian energy developers with these contracts have purchased put or call options to hedge against the volatility of spot market prices. The other possibility is to allow the developer to hedge this risk using a combination of physical assets backing the auction bid. Depending on the auction rules, the developer may establish a portfolio of different RE sources with or without BESS, or even using non-RE assets to meet the delivery profile set forth in the contractual requirements (e.g., Chile). *Pay-as-contracted* provides a better alignment between production and market requirements. As RE markets mature, policy makers will consider transferring the intermittency risk from buyers to sellers, who are likely to be in a better position to create their portfolio of assets and/or contracts and manage this risk more efficiently. BESS should have a stronger role to play under this scenario, if it is allowed to participate.

Haufe and Ehrhart (2018) identified the advantages and pitfalls of various RE auction formats for both bidders and offtakers under various market and policy conditions based on theory and experiences in different countries.

Table 7 compares seven potential business models for BESS in RE auctions or other competitive procurements. The alternatives may require different product specifications, rules, and price and nonprice award criteria.

**TABLE 7: Seven Business Models for BESS in Auctions or Other Competitive Procurements**

| Product | BESS as a Standalone Resource | BESS for Peak Loads or "Capacity Markets" | BESS for Time-Differentiated Supply Blocks | BESS for Semi-Dispatchable Electricity | BESS for Firm Power and Dispatchable 24/7 Capacity | BESS for Ancillary Services | BESS for Stacked Services |
|---|---|---|---|---|---|---|---|
| **Competing sources** | All sources | All sources | RE and/or non-renewable energy | RE | All sources | Natural gas peaking plants | BESS specific |
| **Examples** | Orsted (Liverpool, U.K.) | India (TNRE), Australia, California, U.S. Power Pools (TN), and France (BESS and DR) | Chile (all sources), Colombia (RE only) | Thailand | Roraima State in Brazil | Hornsdale Power Reserve (Australia); U.S. power pools | ESKOM (South Africa) |
| **Type of Auction or Procurement** | TN or TS | TN or TNRE | TN or TNRE | TNRE | TN | TN | TS |

[a] All sources may include natural gas peaking plants, RE capacity, and RE generation.

[b] TN = technology-neutral; TNRE = technology-neutral renewable energy; TS = technology-specific

## 4.1.1 BESS AS A STANDALONE RESOURCE

Front-of-the-meter BESS can be a standalone resource to support the requirements of generation, transmission, and distribution. Standalone BESS can perform like virtual power lines, reducing or deferring the need for capital investments to expand peak load capacity or upgrade the transmission or distribution system. They can also provide local ancillary services such as voltage control. Distribution-level BESS can also improve the quality of electricity and increase resilience to extreme weather. These types of utility-scale BESS are usually owned and managed by system operators or distribution utility (IRENA 2019a, 2019c).

Since there are few siting challenges with BESS, it can be located close to urban load centers. BESS does not require a large area, so the availability or cost of land near urban areas is not a major concern, in contrast with ground-based wind or solar power. BESS, when located next to RE power plants, make a better use of the connection assets, particularly if solar PV and wind production are combined. On the other hand, placing storage near the load can reduce transmission and distribution losses and congestion (Bowen, Chernyakhovskiy, and Denholm 2019).

The impacts of standalone BESS on RE generation and GHG emissions depend on the sources of electricity to charge the batteries and the types of generation displaced when the battery energy is discharged. Batteries can be charged with electricity from renewable or non-renewable resources and can displace renewable or non-renewable generation.

Orsted's 20 MW Carnegie Road Project in Liverpool in the United Kingdom is a standalone BESS facility. NEC Energy Solutions supplied the Li-ion battery and power conversion system (Colthorpe 2019b).

### 4.1.2 BESS FOR PEAK LOADS OR CAPACITY MARKETS

One of the most common business models is combining BESS with variable RE generation to meet peak load requirements (which occur routinely) and to a lesser extent to address system contingencies (such as breakdowns, planned maintenance, and extreme weather evens). BESS owners may receive a much higher price for peak load power than baseload power if utilities are required to avoid shortfalls and if other supply alternatives (such as natural gas turbines) are more expensive. The power from a hybrid of RE generation and BESS is classified as semi-dispatchable because typical Li-ion batteries can only store electricity for four hours.

The Hornsdale Power Reserve in Australia allocated 30 percent of its BESS capacity trade on a commercial basis. By firming up the generated wind power, the plant was able to sell peak load electricity when spot prices were higher (*stacking energy arbitrage*). In the first years of operation, this use of BESS has had a much higher market value per unit of capacity than the ancillary frequency control services. The company owner, Neoen, has received a large part of its BESS revenues from a smaller share of its storage capacity, since 70 MW (10 MWh) were reserved for power system reliability (IRENA 2020a).

Southern California Edison (SCE) contracted for the world's two largest Li-ion battery storage facilities as an alternative to controversial, natural gas peaking power plants. Strata Solar has begun construction of the Edison Puente Project in Oxnard, which is expected to be online in December 2020. Fluence (a joint venture of Siemens and AES Storage) was constructing the Alamitos Project in Long Beach, planned to begin operations in 2021. Both facilities will have 100 MW (400 MWh) BESS systems to help solar power meet peak loads. SCE also contracted with other companies for an additional 95 MW of dispersed storage in smaller, 10-40 MW units around Edison Puente (Spector 2019a).

### 4.1.3 BESS FOR TIME-DIFFERENTIATED SUPPLY BLOCKS

Time-differentiated supply blocks combine RE with BESS for peak and off-peak power, with price adjustments by time of day and/or seasons of the year, and in some cases, supply location. This variable pricing structure can increase incentives for investments in BESS and reduce total system costs for power generation and transmission.

RE auctions in Chile used a contract-for-differences arrangement with time-differentiated prices that varied by season and across three daily time blocks.[23] The bidders were allowed to combine RE generation with BESS and decide how to allocate their power deliveries across the daily and seasonal time blocks. For example, a solar power producer could offer electricity in the late morning-early afternoon time block and receive an off-peak price or store it for delivery during a peak period and receive a higher price. The GoC used an optimization model to meet the time-differentiated load requirements while minimizing the total system cost. Chile's auctions included a pay-as-contracted approach with differences settled at spot market prices. Some bids proposed BESS to shift electricity to more valuable blocks.

The Solar Energy Corporation of India used a similar, but simpler approach, in an auction for RE combined with BESS in 2020. There were two time-differentiated price blocks based on peak periods (5:30-9:30 AM and 5:30 PM-12:30 AM) and off-peak periods (all other hours).

### 4.1.4 BESS FOR SEMI-DISPATCHABLE POWER TO FIRM UP RENEWABLE ELECTRIC POWER

BESS can provide semi-dispatchable (or near-firm) power to enable suppliers to deliver grid electricity during daily peak and off-peak periods despite RE intermittency. This business model is also appropriate for minigrids or microgrids. Thailand conducted an auction for BESS to firm up RE generation that was subdivided by nine geographic areas to reduce regional disparities in electricity access.

### 4.1.5 BESS FOR FIRM POWER AND DISPATCHABLE 24/7 CAPACITY

This business model combines BESS with either renewable or non-renewable generation and imposes financial penalties for failure to deliver the contracted amounts of power at all times every day. In this business model, it is assumed that there is not an organized wholesale market, and bidders do not have the option to buy power from other sources. As a result, the suppliers are responsible for ensuring that they can provide a reliable supply from their own generation and storage resources. This business model is appropriate for isolated areas where the physical supply of power is critical and reliable backup power sources are limited or absent.

### 4.1.6 BESS FOR ANCILLARY SERVICES

BESS can provide ancillary services to an electricity grid—either to a distribution company or to a power pool. BESS services have been procured for frequency regulation in Australia, Chile, and the U.S.

The Hornsdale Power Reserve in Australia allocated three-quarters of its BESS capacity for frequency control ancillary services. It will receive a fixed payment for 10 years for making the frequency control capacity available, whether or not it is actually needed. These payments can be viewed as a government subsidy, but they were based on a relatively low price per unit of this reserved capacity (IRENA 2020a).

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[23] The three time blocks were 11:00 PM to 8:00 AM, 8:00 AM to 6:00 PM, and 6:00 PM to 11:00 PM.

### 4.1.7 BESS FOR THE PROVISION OF STACKED SERVICES

As described earlier in this report, BESS can potentially provide a gamut of services to the system—the so-called "stacked value."

One way to capture the full value of BESS services is for an integrated utility, system operator, or distribution utility to own the storage assets or have full control over them through a build, own, operate (BOO) or build, own, operate, and transfer (BOT) arrangement. These types of public-private partnerships allow the buyer to take full advantage of all the benefits of BESS for the power system

BESS are sized to meet the requirement of the specific use for which they are designed. This imposes a technical limit on the spectrum of stacked value that BESS can provide. For example, a storage duration of 30 minutes is sufficient for the provision of frequency regulation or to smooth integration between solar and backup thermal generation. Four to six hours of storage duration are recommended for participation in capacity markets. Longer duration storage is recommended for energy-arbitrage or off-grid applications. In spite of those technical limitations, there is always the possibility of using BESS to capture several stacked benefits, therefore optimizing the use of the assets and making them more valuable to developing countries.

Unfortunately, only a few of those services are currently monetized, and even fewer can be traded in the market. Therefore, typical auctions that tender one product (e.g., frequency regulation, capacity, or peak power), do not seem to be well suited to contract the full range of services that BESS can provide to the power system.

Three competitive procurement variations may be put in place to ensure that most of the BESS benefits are captured:

1. Have an integrated utility own, maintain and operate the assets, such as proposed by ESKOM in South Africa.
2. Have the system operator (or an integrated utility) tender a BOT-type contract for control over the BESS assets. In this case, the contracting party would not own the assets, but would have full operational control of them—that is, the ability to use the BESS in a way that makes sense for the system as a whole. In such an arrangement the owner will receive a fixed compensation for capacity made available to the system operator.[24] This is a sensible business model for system operators and integrated utilities to tender BESS in the future.
3. Implement combinatorial auctions for more than one BESS product.

## 4.2. DESIGNING POWER PURCHASE AGREEMENTS

PPAs are contracts that specify the products or services to be purchased, the price, and the time period (often 10-25 years for solar or wind power or BESS), among other terms. Before announcing an auction, a utility or government agency will need to decide on the general terms of the PPAs that will be

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[24] This BOT kind of arrangement has been extensively used, and with great success, to tender transmission assets in Peru, Colombia, and Brazil, among other countries. The developer is responsible for building and maintaining the transmission assets, making those available to the system operator. The system operator decides the use of each line to minimize the generation cost and to maintain system stability. The payment to the asset owner, resulting from the auction, is a fixed amount to remunerate the investment and recover O&M costs, and does not depend on the line capacity utilization. The system operator abides by technical standards and loading characteristics of each line and substation.

available to successful bidders. These terms need to be specified in the solicitation because they will affect the interest of energy developers in participating in the auction and their bid prices.

A PPA gives energy developers a reasonable expectation that they can recoup their capital; operating, maintenance, and replacement costs, and earn an acceptable rate of return on their investments. A PPA is critical for financing because it increases confidence in the ability of developers to repay loans or remunerate equity investors. It also gives a utility or government agency long-term access to a projected volume of products or services at a known cost.

PPAs are complex documents with detailed terms and conditions that can be designed in many different ways. These contracts must clearly communicate rights, responsibilities, rewards, and the allocation of risks among the buyers, sellers, regulators, and third parties (such as financial service providers and insurers). The World Bank has developed a series of sample PPA documents for different sizes and types of power system procurements (https://ppp.worldbank.org/public-private-partnership/sector/energy/energy-power-agreements/power-purchase-agreements).

PPAs for renewable electric power and/or BESS often extend for 10 to 20 years and include a specified price or pricing formula. Power sector investments in developing countries require substantial amounts of foreign exchange for imported components and their financing is often denominated in a major foreign currency. Currency and inflation risks can seriously erode the value of long-term, fixed price contracts. Developing country currencies are often subject to sharp policy-related devaluations or market volatility. The impact of these risks on investment incentives can be reduced by denominating PPA prices in the major foreign currency used for purchasing or financing the imported components. An inflation adjustment is also important even when PPA prices are set in foreign currency or the local currency equivalent.

Some PPAs include financing or guarantees to reduce risks of offtaker creditworthiness. These may include liquidity instruments or facilities; a domestic government (*sovereign*) guarantee; or external loan guarantee from a donor, development bank, or trade facilitation agency. The agreements should allow suppliers to convert domestic currency revenues into foreign exchange and transfer the funds outside the country. PPAs should contain provisions to eliminate or mitigate legal and policy risks. Most banks will only provide financing for PPAs that make the offtaker responsible for the costs of changes in laws or tax rates that substantially affect the investment returns.

Transmission and interconnection risks can be reduced by securing approvals in the qualification requirements or pre-award stages. However, a PPA will still need to specify who bears any remaining transmission and interconnection risks. If there are substantial transmission and interconnection risks, banks may only be willing to provide loans to the energy developer if the offtaker bears all or most of the costs (OPIC 2019).

Most commercial contracts have a *force majeure* provision that excuses either party from meeting their obligations if a major, unusual event outside their reasonable control precludes compliance with the contract. Natural disasters, wars, civil unrest, terrorism, and pandemics are examples of events that may enable a contract party to successfully invoke the force majeure exception and have it upheld in court. Force majeure does not apply to everyday risks such as insufficient wind or solar resources, transmission or distribution system constraints, or demand-related curtailment.

If insurance is available for force majeure risks, a PPA contract can require it be purchased to reduce some of the financial losses for either party. Private insurance companies usually avoid covering force majeure risks other than natural disasters. The World Bank Group's Multilateral Investment Guarantee Agency, U.S. Development Finance Corporation and other bilateral trade promotion agencies, and some national governments may offer insurance for some of these risks.

PPAs should specify the process for dispute resolution. OPIC (2019) recommended that the contracts provide for offshore arbitration in a neutral location under rules generally acceptable to the international community; for example, the United Nations Commission on International Trade Law (UNCITRAL), London Court of International Arbitration (LCIA), or International Chamber of Commerce (ICC).

PPAs should clearly state the basis for termination by either party and responsibility for termination payments. If the PPA is terminated for any reason and a facility is transferred to the offtaker, the contract should provide for a termination payment no less than the outstanding bank debt. If the offtaker defaults on the agreement, it should be responsible for a return on the energy developer's equity investments. The PPA should allow collateral assignment of the agreement to the energy developer's lenders, with the right to receive notice and cure the default. Additional step-in rights are usually specified in separate agreements between the lenders and the offtaker (OPIC 2019).

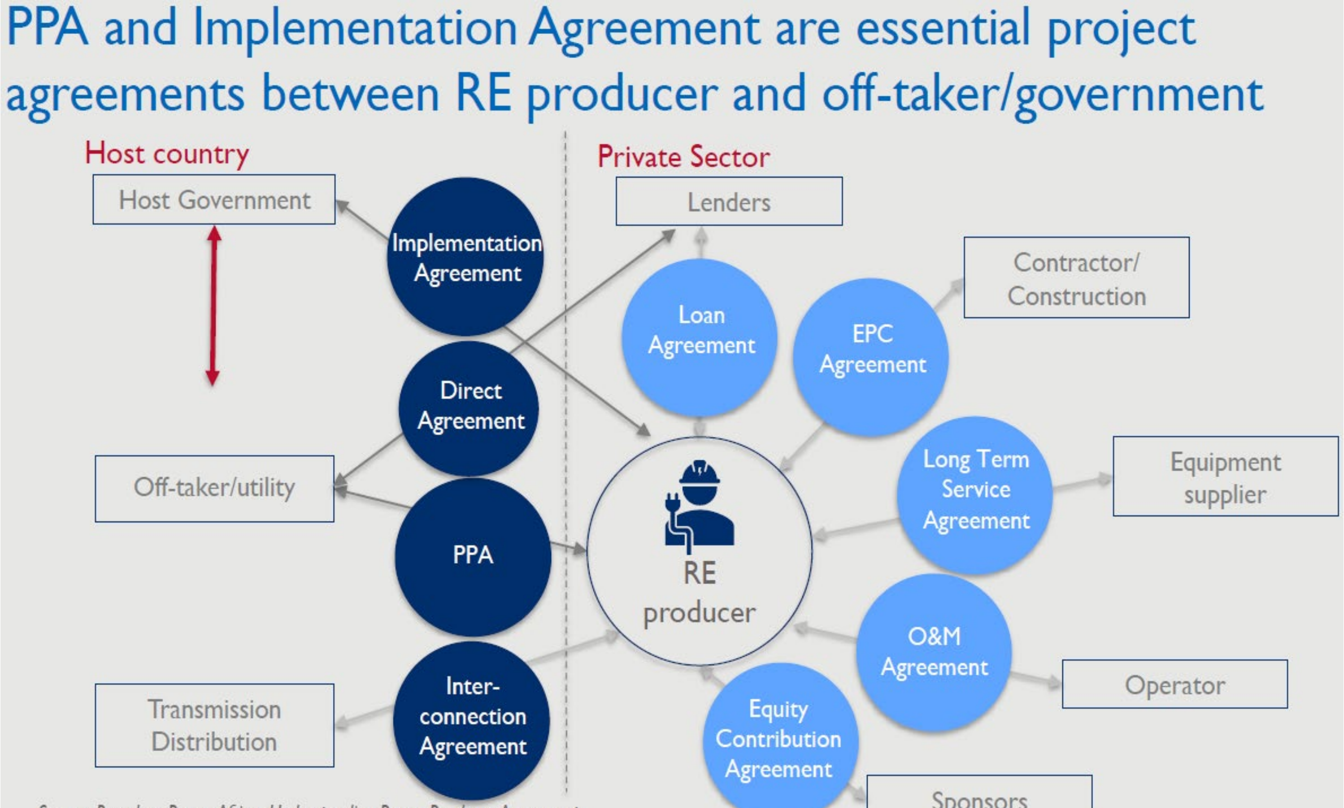
## 4.3. IMPLEMENTATION AGREEMENTS

Figure 8 shows the key agreements for auction parties. *Implementation agreements* build on the PPAs and further specify arrangements between the RE producer, offtaker, and other stakeholders during construction and operation.

1. Government: Primary support obligations on issues such as land, access, permitting, and relief from import restrictions. It ensures that the government is "on notice" and aware of the investment.
2. RE producer: Reciprocal obligations such as limitations on change of control, decommissioning of the project (if there is no land lease requirement), and compliance with law.

In some countries, elements from the implementation agreement can be part of the PPA. The implementation agreement covers risks not fully covered in the PPA, such as political events, force majeure, legal and tax changes, and convertibility and repatriation and expropriation.

**FIGURE 8: Key Agreements for Auction Parties**



Source: Based on Power Africa, Understanding Power Purchase Agreements

Source: Amazo *et al.* 2020

## 4.4. QUALIFICATION AND BIDDING REQUIREMENTS

*Qualification* requirements are used to determine whether potential bidders are eligible to participate in an auction. Qualification and bidding requirements can be useful in limiting competition to energy developers that have the ability to finance, develop, construct, and operate a project successfully. If these requirements are too loose, a utility or government agency will incur costs in reviewing bids and negotiating contracts with applicants that are likely to fail. Awards for dubious projects may also displace awards for good projects, especially if the weak applicants submit unrealistically low bids (*underpricing*).

If qualification and bidding requirements are too stringent, reduced competition may lead a utility or government agency to accept higher cost bids to meet its procurement targets. These requirements may also place domestic or small companies at a disadvantage relative to foreign or large companies. Consequently, it is important to balance the prospects for successful completion of projects with competition, business development, and industry growth objectives. Auctions can also establish other types of safeguards that may be more effective, such as requiring completion bonds (Azuela *et al.* 2014).

Early wind power auctions in Germany required bidders to demonstrate similar past experience and financial capability and submit building permits in advance. This reduced overall participation rates and posed particular obstacles for new or small firms. Germany reduced these requirements for wind power auctions in 2017-2018 and competition greatly increased. IRENA (2019b) recommended that documentation of the technical capacity to implement a proposal should be sufficient to allow a company to compete in an auction. Successful bidders can obtain site-specific permits and financing after receiving contracts.

There are two basic approaches for the qualification process with different purposes:

1. Auctions that base awards solely on price often use a pass-fail qualification process. Only applicants that pass this screening are allowed to submit financial proposals. Price-based awards are most useful in procuring products or services that are well understood by both the buyer and sellers and have fairly standard contracting terms that require little negotiation.

   Dynamic reverse auctions are particularly appropriate for efficient price discovery to help reduce unit costs when awards are based on price. Dynamic reverse auctions are likely to become the industry standard as business models for standalone and co-located or hybrid BESS facilities mature. Procurement of RE capacity and generation have already largely shifted from individual requests for proposals for customized (*bespoke*) PPAs to price-based auctions leading to standardized PPAs. Non-utility companies have increasingly used price-based bid selection to acquire renewable electric power from independent generators.

2. Auctions that base awards on price and nonprice factors often evaluate the technical qualifications of applicants before the financial proposals. Sealed-bid auctions are most appropriate when awards are based on price as well as nonprice factors. A *sealed-bid auction* requires bidders to submit closed bids by the auction deadline to keep information confidential from other bidders or potential bidders. The sealed bids are opened on the same specified date.[25] An evaluation committee produces a technical score or ranking for each applicant. The same committee or another with greater financial expertise only reviews cost proposals from bids that have met the cutoff technical score or ranking.

   Auctions based on price and nonprice factors are appropriate when the buyer is open to bids that present different project design, location, or technology options that may reduce costs, improve effectiveness, or foster innovation. A flexible auction design can yield a diverse set of proposals and bidders. However, it may require more due diligence in reviewing the bidders' qualifications, evaluating the technical and financial proposals, and negotiating contracts. The additional review costs, time, and complexity may not be justified if the product and contract terms are relatively standard and the buyer knows what it wants.

## 4.5. EVALUATION CRITERIA FOR NONPRICE FACTORS

CEADIR examined the bid evaluation criteria in grid services auction solicitations from Hawaiian Electric and Xcel Energy and identified the following nonprice evaluation criteria:

1. **Experience and qualifications.** Proposals were evaluated on the experience of the developer in obtaining, aggregating, and managing customer assets to deliver grid services. Developers were expected to have experience financing, delivering, and interconnecting at least one project of a similar size and technology. Preference was given to developers with successful experience delivering services to multiple utilities or in the service territory for the proposed project.
2. **Proposals needed to include a site-specific description and plans**, including rights of way, property acquisition plan, equipment configuration, transmission and interconnection construction and procurement, opportunities for future expansion of the project, required permits, evidence of

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[25] https://www.investopedia.com/terms/s/sealed-bid-auction.asp

community support, and a Gantt chart of project development activities with guaranteed dates for substantial completion.

3. **Financial strength and financing plan.** Financial plans were required to address project ownership, capital cost and capital structure, sources of debt and equity, and evidence of interest in financing the project. The financial strength of the developer or their credit support providers were considered. Preference was given to developers and sources of financing with investment-grade credit ratings from a reputable rating agency (S&P, Moody's, or Fitch).
4. **Developers were asked to provide two years of audited financial statements** for their businesses as well as any parties that would backstop their financial obligations. The financial plans had to state whether the project would have recourse or nonrecourse financing, the proportions of debt and equity financing, the expected cost of debt, how construction and operations would be financed, and what financing commitments that had already been obtained, and collateral or bond requirements.
5. **Model PPA and modifications.** Xcel Energy's RFP contained a model PPA and encouraged bidders to accept the standard contract terms where possible. However, it allowed bidders to propose changes to some specific sections. The evaluation process considered the additional risks associated with proposed contract modifications. The utility negotiated final PPA terms with successful bidders.
6. **Contract capability bid.** RFPs generally include maximum procurement targets and may also set limits on the amount that can be obtained from a single bid. Some utilities have contracting goals for small businesses. Some utilities are more concerned that small projects may increase bidder capability risks and total contract management and system integration costs. A utility may also be concerned about technology diversification, but typically assesses this on a portfolio basis, rather than an individual developer basis.
7. **Customer or participant acquisition strategy.** Utilities often assess the credibility of the customer or participant recruitment strategy; market risks; and experience with the proposed market for grid services. Some utilities give additional consideration to proposals that use local installers, technicians, and subcontractors.
8. **Conformance with the utility's code of conduct.** To reduce reputational risks, some utilities have a code of conduct or customer service standards for contractors. They may evaluate the prior experience of bidders with the code of conduct or customer service standards. Some utilities may want to review the relevant policies and procedures of bidders.
9. **Conformance with information assurance policies.** Utilities may want to review the ability of bidders to meet information assurance standards for secure data transfer, data protection, and encryption.
10. **Property acquisition plan.** Bidders may be asked to demonstrate that they already own, lease, or have legal access to the land for the proposed project or have the ability to purchase or lease the land.
11. **Permitting plan.** Bidders may be asked to demonstrate that they have the necessary permits to construct and operate the proposed project (such as environmental or land use permits and zoning).
12. **Community and state support.** Xcel Energy required bidders to submit a plan for monitoring local community and state government support during development and operation of the project and working to resolve issues.

## 4.6. EVALUATION CRITERIA FOR PRICE BIDS

Auction award decisions can be made in several ways. Some auctions have used a pass-fail qualification process for the technical scores and then selected proposals based on the financial bids. Other auctions have used a weighted average of the technical and financial scores. Some auctions have selected finalists based on nonprice and price factors and asked them to consider reducing their prices in a *best and final financial* (BAFO) *bid*. Hawaiian Electric used this BAFO approach in its 2019 auction for PV with BESS. Table 8 lists sample criteria to evaluate price bids in RE auctions.

**TABLE 8: Sample Criteria for Evaluating Price Bids in RE Auctions**

| Award Criteria | Calculation | Examples |
|---|---|---|
| Lowest bids for installed capacity | \$/MW x MW | Roraima State in Brazil |
| Lowest bids for delivered power | \$/MWh x MWh of delivered power | Australia |
| Lowest bids for generated power, with location-based adjustments | (\$/MWh x MWh of generated power) + (positive or negative nodal adjustment factor) | Mexico |
| Lowest bids for peak power (fixed FiT for off-peak power) | (\$/peak MWh x peak MWh) + (FiT in \$/MWh x off-peak MWh) | India |
| Lowest bids for firm power in specific time blocks | (Firm power delivered in each time block) x (bid price for the time block) weighted by an optimization algorithm<br>Surpluses and shortfalls traded on the spot market at other prices | Chile |
| Lowest bids for RE generation and BESS capacity | (\$/MWh x MWh of generated power) + (\$/MW x MW of storage capacity) | Nevada (U.S.) and Thailand |

RE auctions generally lead to PPAs with fixed prices or price formulas over the long-term contract period. However, future spot market prices will also affect the net revenues of the suppliers if their PPAs have a contract-for-differences provision.

## 4.7. DOMESTIC CONTENT REQUIREMENTS OR PREFERENCES

Some countries have included domestic content requirements or preferences in RE auctions for technologies and/or labor. Various approaches have been used, including 1) strict requirements for use of domestic content, 2) minimum percentages for the domestic share of total capital or equipment costs, 3) bid price adjustments or evaluation preferences, and 4) award quotas.

The rationale for these requirements or preferences may include reducing national balance of payments problems, supporting the development of infant industries, increasing the profitability of domestic companies (for economic development, domestic revenue mobilization, and rent-seeking behavior by political elites), employment generation, and/or accelerating the transfer or development of new technologies. Relatively few developing countries still limit access to foreign exchange or control exchange rates to reduce imports. Domestic content requirements or preferences can have negative effects, such as may reducing competition; increasing costs; and reducing the quantity, quality, reliability, or durability of goods and services.

Some countries have tied the availability of government or parastatal development bank loans for RE to domestic content requirements. Table 9 lists examples of developed and developing countries that have had domestic content requirements or preferences in auctions or public sector financing of RE generation.

Since the purpose of an auction is to obtain goods and services that offer the best value as a result of open competition, it is generally best to avoid imposing domestic content requirements or preferences. If used, they should be designed to have limited effects on competition and award prices and clearly specified in the solicitation documents. The ability of a bidder to meet the requirements or preferences can be addressed in the prequalification or proposal evaluation process. All qualified bidders should be allowed to compete.

Domestic content requirements or preferences have been included in some auctions or other procurements for RE capacity or generation. They have not yet applied to utility-scale battery storage, a relatively new industry with a small number of manufacturers, primarily in developed countries. Developing countries are not yet in a position to apply protectionist trade policies to BESS, but this may change in the future.

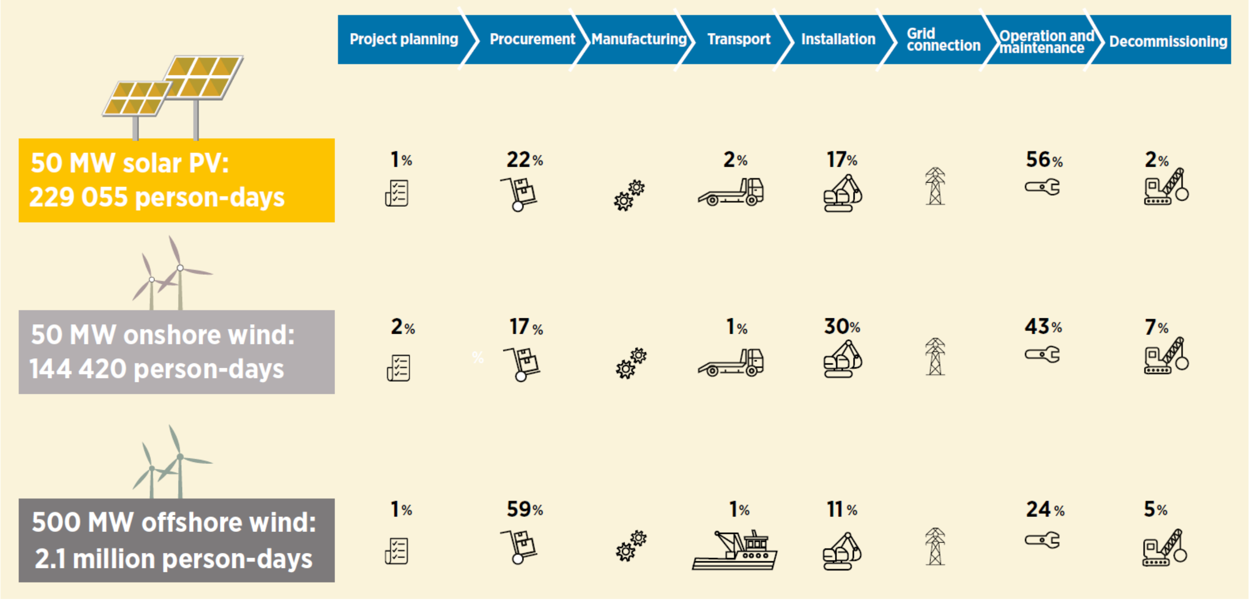
**TABLE 9: Examples of Domestic Content Requirements or Preferences in RE Auctions and Public Financing**

| Country | Years | Domestic Content Requirements or Preferences |
|---|---|---|
| Argentina | 2017 | Foreign technology imports were only permitted when domestic alternatives did not exist. Tax benefits were available if at least 60 percent of project materials were sourced domestically (IRENA 2019b). |
| Brazil | 2009 to 2012; 2013 to date | In 2009, wind power auction winners were required to source 40 percent of their components domestically to qualify for subsidized loans from the Brazilian Development Bank. In 2012, the domestic content share for subsidized financing increased to 60 percent. Since 2013, all wind power developers had to produce or assemble at least three of the four main components (towers, blades, nacelles, and hubs) in Brazil (Ferroukhi et al. 2015). |
| China | 2003 – 2011 | Onshore wind power auction participants had a 50 percent domestic content requirement in 2003, which increased to 70 percent in 2005 and ended in 2009. Few foreign companies were able to compete in wind power auctions between 2003 and 2009 and product quality suffered. Grants under the Special Fund for Wind Power Manufacturing were subject to domestic content requirements until 2011 (IRENA 2019b). |
| India | 2010-2014 | In 2010-11, the Solar Mission Initiative required participating developers to source crystalline silicon PV modules domestically. In 2011-2012, the requirement was extended to crystalline silicon PV cells. In 2014, the National Solar Mission Auction had a special window for projects that used domestically manufactured equipment. The levelized cost of energy was about 15 percent higher in the special auction window (IRENA 2019b). |
| Malaysia | 2017 | The Large-Scale Solar Auction 2 limited foreign ownership to 49 percent. The bidder had to be a domestic company or consortium with at least 51 percent Malaysian equity (O'Mealy, Sangarasri *et al.* 2020). |

| Country | Years | Domestic Content Requirements or Preferences |
|---|---|---|
| Saudi Arabia | 2017 2019 | Saudi Arabia's 2017 PV auction had a domestic content requirement of 30 percent. The winning bidder, the Sakaka PV independent power producer, also agreed to employ mainly local labor in the first year of operations (IRENA 2019b). |
| South Africa | 2011 | The Renewable Energy Independent Power Producer Procurement Programme initially had domestic content requirements of 45 percent for PV and 40 percent for other RE technologies. These requirements were subsequently increased to 65 percent. Job creation and domestic content requirements received 50 percent of the nonprice evaluation scores (IRENA 2019b). |
| Tunisia | 2017 and 2019 | In 2017, a government tender for 70 MW of solar capacity reserved 10 MW for domestic developers with projects smaller than 1 MW. In 2019, all the prequalified bidders in a government tender for 500 MW of utility-scale solar capacity were large foreign-owned companies. A separate tender for six 10 MW and ten 1 MW solar power units was only open to domestic companies (Bellini 2019b). |
| Turkey | 2017 and 2019 | Renewable Energy Resource Areas auctions in 2017 had a 65 percent domestic content requirement. The winning solar bidder was required to build a solar panel manufacturing facility in country with a capacity of at least 500 MW, establish a research and development (R&D) center, and employ at least 100 permanent technical staff. The winning bidder for onshore wind power also had to establish an R&D facility. At least 80 percent of the engineers in onshore and offshore wind projects had to be Turkish (IRENA 2019b). |
| U.S. (Hawaii) | 2019 | Hawaiian Electric provided extra evaluation points for bids that committed to use of local installers and technicians (Hawai'i Electric Light 2019). |

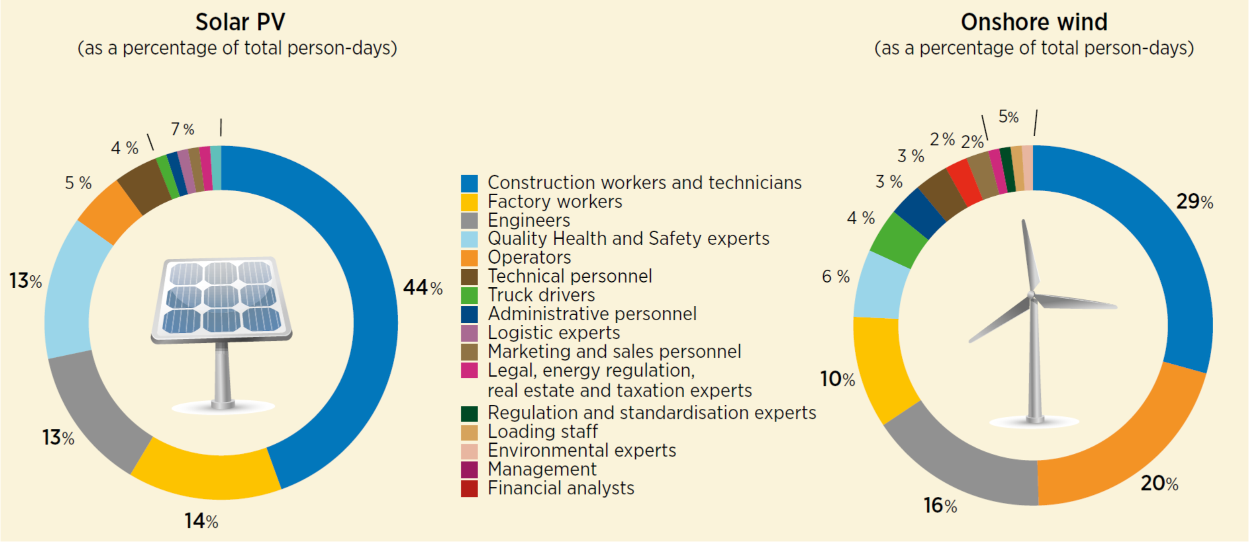
Manufacturing of utility-scale Li-ion batteries is still a high-tech, capital-intensive industry for developed countries and advanced developing countries and this may also be the case for emerging technologies. Figure 9 presents illustrative lifecycle labor requirements for RE investments. Some public procurements have included requirements for training or mentoring of local workers for installation, operation, and maintenance of BESS applications and developing the capacity of local engineering, procurement, and construction companies. Construction and installation and operation and maintenance are the most labor-intensive stages in the project lifecycle. Figure 10 shows the distribution of labor skills needed for 50 MW PV units and onshore wind power.

**FIGURE 9: Illustrative Lifecycle Labor Requirements for RE Investments**



Source: IRENA 2019d

**FIGURE 10: Distribution of Labor Skills for 50 MW PV and Onshore Wind Power Units**



Source: IRENA 2019d

There may more efficient alternatives to imposing domestic content requirements on BESS procurements or financing: 1) increasing the capacity of industry associations to help develop the market for BESS; 2) bringing together diverse expertise on engineering, contracting, legal services, and financing; 3) promoting safe use, disposal, and recycling of batteries; and 4) improving the policy and regulatory environment for BESS.

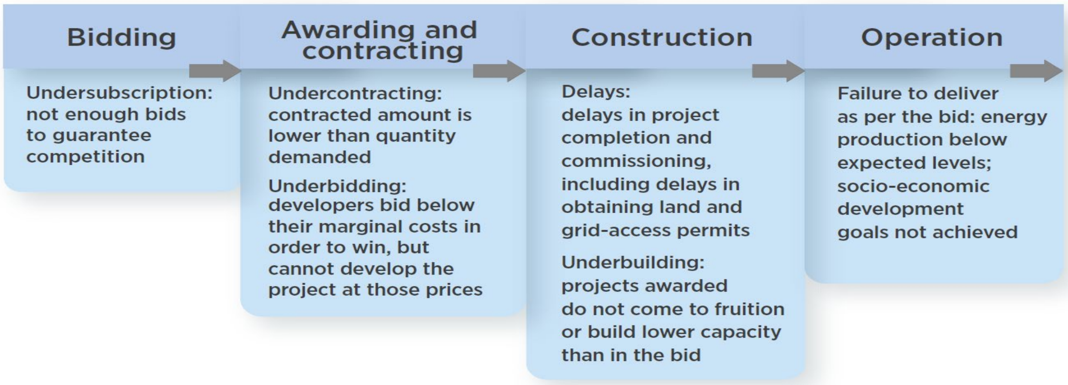
## 4.8. POST-AWARD DISCUSSIONS FOR PPAS AND REDUCING UNDERCONTRACTING RISKS

Many auctions use standard PPA forms based on products or services specified in the solicitation and do not allow post-award negotiations on the basic terms and conditions. Some auctions, particularly those based on both price and nonprice factors, allow s for further negotiations after then winners have been announced. Post-award discussions may address implementation issues, such as:

1. Due diligence for financial closure and financing;
2. Pending permits, environmental licenses, connection approvals, and transmission or distribution agreements;
3. Required or recommended consultations with local governments and communities and other stakeholders;
4. Compliance with market rules and grid codes;
5. Regulations for safe battery use and recycling or disposal;
6. Construction plans, monitoring, and inspections;
7. Final approvals and commissioning; and
8. Procedures for monitoring goods and services, including deviations between the contracted and supplied volumes and quality.

Auction awards do not always lead to signed PPAs and this is usually due to problems with the winning bidders. Other reasons for failure to sign PPAs include offtaker financial difficulties or major staff or leadership changes or changes in market conditions or government policies. Figure 11 shows underperformance risks at each stage of the auction process.

**FIGURE 11: Underperformance Risks at Each Stage of the Auction Process**



Source: IRENA 2019d, Figure 2.1.

**Underbidding and undercontracting risks.** Reverse auctions do not reward cautious bidding. *Underbidding* occurs when developers underestimate their costs and offer prices that are too low for successful implementation (Milgrom 1989). *Sealed-bid auctions* do not allow developers to benefit from *price discovery*—learning about the bid prices of other offerors. Developers with low bid prices may be more likely to be selected as auction winners. Underbidding problems can be worse when the costs of an emerging technology are expected to decrease over time, as was the case with solar and wind power and is now happening with BESS.  Underbidding can be reduced by setting time limits on completion of the projects.

*Undercontracting* occurs when the amount of capacity or generation contracted through an auction is less than the desired amount.  Undercontracting risks may be high when there is a low auction participation rate due to unfavorable policy and regulatory environment, weak market conditions, or unfavorable market rules.  It can also happen when there is a low yield rate of PPAs from the selected bids.  A similar, but less extreme, result may occur when an offtaker uses post-auction negotiations to induce selected bidders to reduce their prices in post-auction negotiations.

After submitting their bids, auction participants may realize that their assumptions about decreasing costs were too optimistic or they may obtain more realistic information about costs.  Actual or perceived bidding errors can lead to seller's remorse, or "winner's curse" (Amazo *et al.* 2020).  The timing of the auction and its technical requirements (such as proof of access to the site, RE resource measurements, and grid connection agreement) also affect the certainty of the project risks and costs, as shown in Figure 12 (Amazo *et al.* 2020). Auction winners may walk away from their bids by not signing supply contracts.  This problem is more likely to occur in sealed-bid auctions.  It is unlikely when dynamic reverse auctions allow price discovery by bidders.

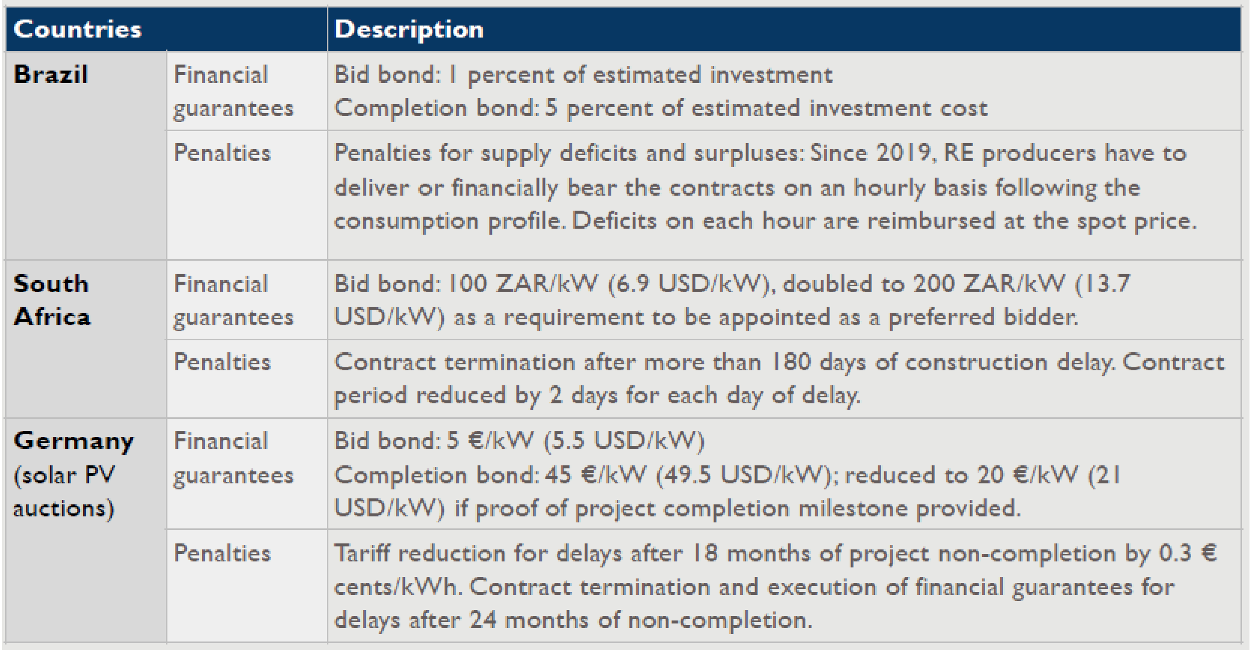
**FIGURE 12: Effects of  AuctionTiming and Technical Requirements on Project Risks and Costs**

Source: Amazo et al. 2020

Undercontracting risks may be higher if the auction does not impose any penalties on winning bidders that do not sign PPAs.  Some auctions require bid bonds or impose other penalties such as disqualification from future auctions to make it costly for selected bidders to walk away without signing contracts, as illustrated in Table 10.  A selected bidder may still choose not to sign a PPA because the financial penalties are usually larger for breaching a contract than turning down a contract.

Furthermore, auctions that require bid bonds or other noncontracting penalties can be less competitive and produce less efficient results by reducing the number of interested bidders and causing them to offer higher prices.  As a result, Kress, Ehrhart, and Haufe (2017) recommended that RE auctions avoid bid bond requirements and noncontracting penalties and apply stricter prequalification criteria instead. They also suggested better planning to estimate the undercontracting rate in advance and compensate for it by soliciting a larger volume of goods and services than originally planned.

**TABLE 10: Country Examples of Auction Financial Guarantees and Penalties**



| Countries | | Description |
|---|---|---|
| **Brazil** | Financial guarantees | Bid bond: 1 percent of estimated investment<br>Completion bond: 5 percent of estimated investment cost |
| | Penalties | Penalties for supply deficits and surpluses: Since 2019, RE producers have to deliver or financially bear the contracts on an hourly basis following the consumption profile. Deficits on each hour are reimbursed at the spot price. |
| **South Africa** | Financial guarantees | Bid bond: 100 ZAR/kW (6.9 USD/kW), doubled to 200 ZAR/kW (13.7 USD/kW) as a requirement to be appointed as a preferred bidder. |
| | Penalties | Contract termination after more than 180 days of construction delay. Contract period reduced by 2 days for each day of delay. |
| **Germany** (solar PV auctions) | Financial guarantees | Bid bond: 5 €/kW (5.5 USD/kW)<br>Completion bond: 45 €/kW (49.5 USD/kW); reduced to 20 €/kW (21 USD/kW) if proof of project completion milestone provided. |
| | Penalties | Tariff reduction for delays after 18 months of project non-completion by 0.3 € cents/kWh. Contract termination and execution of financial guarantees for delays after 24 months of non-completion. |

Source: Amazo *et al.* 2020

## 4.9. PPA IMPLEMENTATION RISKS

A signed PPA is just the start of the process. Many additional risks can emerge in construction and implementation.

**Nonrealization risks.** *Nonrealization risk* refers to the failure of auction winners to implement their contracted projects. Bidders selected after the auction is conducted may choose to opt out before signing a contract. This can occur when PPA holders or their potential sources of financing are concerned about the profitability of the investment based on expected costs and the bid prices. Underbidding increases nonrealization risks. However, a PPA might not require a developer to complete construction or supply power for several years and the developer might be counting on future cost reductions to make the investment feasible.

In general, the availability of financing has not been a problem for RE auction winners when PPAs set prices in a strong currency with inflation adjustments. Global energy companies generally have access to corporate equity and on-balance sheet corporate debt. Independent Power Producers (IPPs) and domestic RE developers often relied on project financing capitalized by development finance institutions (DFIs) and national development banks or investment funds. There was relatively limited involvement by commercial banks due to the 15-20-year loan tenors needed to meet investment return targets.

Some commercial banks have structured innovative RE financing, often with development banks or institutional investors. Examples have included 1) mini-perm loans with requirements or incentives for refinancing within 5-10 years when net revenues are favorable; 2) warehousing of loans for securitization through long-term bonds for projects with environmental benefits (*green bonds*) issued on domestic or global capital markets; and 3) energy investment trusts that can be sold on equity markets, such as Mexico's Fibra-E (Molina, Scharen-Guivel, and Hyman 2018).

Failure to complete investments can also occur if the offtaker signed a PPA for too much renewable power over a too short time period. Some PPAs bring contractual obligations to purchase power from other sources if the developer cannot generate or store the agreed amount. Energy developers typically structure partnerships and financing on an individual project basis that provides no recourse to the assets of their parent companies if they fail.

Some PPAs require contract recipients to post performance bonds (project completion bonds) obtained from third-party guarantors. Typically, auction winners are required to post a project completion bond before they can sign a contract. It serves as a guarantee against issues that may be encountered in project implementation. Most auctions impose partial confiscation of the completion bond if the project is delayed. It is forfeited if the winning bidder does not build the project or live up to contractual commitments. The amount of the bond is generally calibrated to constitute sufficient disincentive for delay or failure to complete, without being so high that it imposes barriers to entry on too many potential players (IRENA 2019b). Energy developers may be able to abandon a contract without penalty under force majeure provisions. Governments may also be susceptible to political pressures to allow companies to exit from contracts without incurring the stipulated penalties.

**Construction risks.** Underperformance during construction, referred to as underbuilding, can be associated with delays in project completion, installation of less capacity than committed, or project cancellation.

> **Lead time.** The *lead time* is the period between the contract award date and the required start of operations. The auction buyer sets the lead time and announces it in the solicitation documents. If the lead time is too short, there may be a higher risk of delays. If the lead time is too long, auction participants may have a greater tendency to underbid because they may expect that costs will fall or technology performance will improve more. However, a long lead time may expose developers to greater inflation and currency risks, although this will vary with how the contract prices are denominated and indexed. Most PPAs permit the buyer to terminate the contract after the maximum allowable construction time has been reached (IRENA 2019b).
>
> **Risks in obtaining permits and grid connection approvals**. Some auctions require offerors to document that they have received environment and land use permits and grid approvals as a prequalification or bidding requirement. Some auctions only require successful bidders to obtain permits and grid connection approvals, either before or after PPAs are signed. In general, energy developers bear the risks of delays or failure to obtain permits and approvals after a PPA has been signed. They are still responsible for meeting their contractual obligations and any associated financial losses or penalties. The inability to obtain required permits and approvals is rarely allowed as a justification for force majeure.
>
> **Risks of environmental or social disputes.** Environmental or social disputes that preclude RE development are rare, but have occurred (e.g., some wind power development in Oaxaca, Mexico been blocked by opposition from indigenous communities). These disputes can often be avoided through serious stakeholder consultations, payment of fair prices for renting or buying land, or benefit-sharing arrangements with communities. BESS only requires a small amount of land and is unlikely to generate disputes unless combined with large-scale RE generation.

**Other operational risks.**

> **RE resource intermittency risks**. Deemed generation and pay-as-generated contracts assign RE resource risks to offtakers. Contract-for-differences arrangements make the power suppliers responsible for RE resource risks. The incentives for investments in RE development with BESS or standalone BESS are better when power suppliers bear RE intermittency risks since storage can serve as a physical hedge to help ensure reliable power delivery. The development of parametric insurance markets (a financial hedge) for RE resource risks could reduce incentives for BESS. Conversely, battery storage (a physical hedge) could make

parametric insurance less necessary. It will depend on which option is cheaper at different points in time.

**Technology risks**. BESS technologies are relatively new and there may be risks in integrating them with balance-of-system components, RE generation, and new and complex smart grid technologies. Computerized smart grid systems may be used to decide how often and how deeply batteries are discharged. Technology integration risks may increase when equipment and software are sourced from multiple manufacturers and installers.

**Safety problems.** BESS can present fire and other safety risks in manufacturing facilities, warehouses, and installations. Most of the safety problems have been with Li-ion batteries and have been due to design or manufacturing flaws, poor installation or control and protection systems (Colthorpe 2019a). There have been some Li-ion battery explosions from undetermined causes (Spector 2019b). PPAs that include BESS should clearly specify responsibilities for inspections, maintenance, and mitigation measures to reduce risks to people and infrastructure.

**Cost overruns.** Battery storage technologies are still new and evolving, which makes it more difficult to estimate future costs of construction, operation, maintenance, and replacement. Developers may be able to buy insurance to reduce their potential financial risks from cost overruns at an added cost. Munich Re was the first company to announce that it would offer insurance for long-term maintenance, and replacement cost overruns on large BESS installations. If the maintenance, repair, or replacement costs exceed the threshold stated in the policy, the owner or operator will receive a cash payout. Munich Re's policy also covers BESS buyers affected by insolvency of the BESS developer or battery supplier (Eriksen 2020).

**Battery disposal and recycling.** Many countries have not yet developed standards for replacement, disposal, and recycling of utility-scale BESS. Nevertheless, PPAs should address safe disposal and recycling of batteries and other system components. Lithium and some of the materials needed for new types of batteries can be costly and in limited supply and there may be negative environmental effects from additional mining. Most existing, utility-scale BESS installations are still 10-15 years away from needing to replace the batteries. If safe disposal or recycling facilities are not available in the country, spent utility-scale batteries may need to be sent to another country.

# 5. FINDINGS AND RECOMMENDATIONS

Affordable energy storage is a critical link between wider adoption of intermittent RE, power system reliability, and carbon emission reductions. However, the focus of most investment to date has been on short-duration, battery storage for efficiency gains. There has still been limited progress in adoption of cost-effective daily, weekly, and seasonal solutions on a global scale. Table 11 identifies the World Energy Council and CAISO's five key takeaways on energy storage. Table 12 contains their five recommended steps to increase energy storage investment.

**TABLE 11: World Energy Council and CAISO Five Key Takeaways on Energy Storage**

| | |
|---|---|
| **1** | **SHARED ROADMAPS**<br>Energy storage is a well-researched flexibility solution. However, while the benefits of energy storage are clear to the energy community, there has been limited bridge-building with policy-makers and regulators to explore the behavioral and policy changes necessary to encourage implementation. |
| **2** | **MARKET DESIGN - ACCESS & STACKING**<br>Market access and the ability to stack different services simultaneously will enable cost-effective deployment of energy storage, regardless of the technology. |
| **3** | **MORE THAN BATTERIES**<br>Energy storage is too often reduced to battery technologies. Future-proofing our energy systems means considering alternative solutions and ensuring technologies have equal market opportunities. Demonstration projects of such technologies are necessary to disprove bias towards specific technologies. |
| **4** | **SECTOR COUPLING**<br>Energy storage presents a sector coupling opportunity between hard-to-abate sectors, such as mobility and industry and clean electricity. Different vectors of energy can be used, including heat, electricity and hydrogen. |
| **5** | **INVESTMENT**<br>Relying on investments by adjacent sectors such as the automotive sector is not enough. The energy sector must adopt more aggressively technologies aligned with the end-goal: affordable clean energy for all. |

Source: Blanc *et al.* 2020.

**TABLE 12: Five Steps to Increase Energy Storage Investment**

**STEP 1: Enable a level playing field**

- Clearly define how energy storage can be a resource for the energy system and remove any technology bias towards particular energy storage solutions
- Focus on how energy storage can contribute to a better energy transition

**STEP 2: Engage stakeholders in a conversation**

- Engage all relevant stakeholders to explore all potential energy storage needs
- Consider whether alternatives may be more suitable than energy storage

**STEP 3: Capture the full potential value provided by energy storage**

- Provide equitable access to ESS to all energy market services and products
- Stack revenues through the ability of storage technologies to offer multiple simultaneous market services
- Explore sector coupling opportunities with industry

**STEP 4: Assess and adopt enabling mechanisms that best fit to your context**

- Learn from & with others to identify those policies that best suit to your circumstances
- Ensure that there is no bias against or for behind-the-meter energy storage

**STEP 5: Share information and promote research and development**

- Maintain a long-term horizon in mind and promote R&D, especially for long duration storage
- Promote information sharing across the industry and beyond

Source: Blanc *et al*. 2020.

CEADIR proposes the following specific recommendations to help create a level playing field for utility-scale, front-of-the meter BESS procurement:

**BESS will bring new opportunities to reduce costs, increase service reliability, and reduce GHG emissions and other environmental impacts**. BESS has already proven to be technically and economically viable in developed countries and a few developing countries. Governments or utilities should compare the costs and benefits of BESS to other alternatives (such as diversifying the mix of RE resource types or using pumped storage). Many U.S. states and some cities have set mandatory RPS or voluntary targets that may make the combined installation of RE generation capacity and BESS necessary or desirable.

**The regulatory framework and procurement and market rules should give sellers the necessary flexibility to manage RE intermittency risks.** Sellers should be able to hedge the intermittency risk from a physical and financial perspective. No economic value is added in simply shifting the risks from buyers to sellers without improvements that increase economic efficiency. However, economic value can be added when sellers combine multiple types or locations of RE resources (via assets or contracts); add storage with generation facilities to meet grid requirements; and deploy new technologies such as production forecasts, inverters that provide ancillary services, and smart integration between generation, storage, and distributed energy resources.[26]

**Changes in government policies and wholesale and retail market pricing regulations will be needed to enable BESS to compete with other technologies.** In the U.S., FERC Order 841 of 2018 was transformational in reducing barriers to the participation of BESS in wholesale markets for electricity capacity, peak load supply, ancillary services, and grid reliability. System operators in the U.S. have redesigned their market rules to ensure compliance. Many developing countries have not yet provided regulatory clarity for BESS as both a load and generation source.

**Government agencies and utilities need to modify rules, procedures, and rate provisions in RE auctions to provide a level playing field for bids that include BESS.** Many developing countries have policies, regulations, and tax rules or subsidies that favor certain types of electric power technologies over BESS. Few developing countries have clarified the regulatory framework and market rules for utility-scale BESS as a load and generation source. Many lessons from RE auctions can inform the design of auctions for front-of-the-meter BESS. For example, dynamic reverse auctions may be preferable to sealed bid auctions because they allow bidders to benefit from price discovery to reduce problems from undercontracting and failure to finance and implement PPAs.

**Auction rules and requirements should not limit the eligibility and competitiveness of bids that include BESS as a standalone or hybrid solution**. Some rules and regulations impose direct restrictions or disincentives for BESS, while others are a result of unintended consequences. Auction rules and requirements should be reviewed periodically as new technologies become more available or less costly over time. There is a lot of variation in RE auction designs, including eligibility provisions, award criteria, business models, and contract award terms.

**RE auctions should generally be technology neutral and allow bids for standalone BESS, and co-located or hybrid systems of BESS plus new RE capacity**. The PPA form should be included in the solicitation documents so that bidders can understand the general terms. However, there is no single business model or set of contract provisions for BESS.**Auctions that allow higher prices or scoring based on domestic content can deter investments in BESS**. Utility-scale batteries are currently imported in most developing countries, and there are substantial economies of scale in manufacturing them. Domestic content requirements or preferences can increase end-user electricity prices because they reduce competition. There are generally other more economically efficient alternatives for governments to develop a national industry or generate jobs. If domestic content requirements or preferences are included, they should be clearly specified in the bid qualification process.

**Policymakers should consider auctioning contracts with different levels of "firmness**" to meet the specific needs of the power system. There is an international trend towards transferring part of the RE resource intermittency risk away from buyers (large users or distribution companies) and onto sellers (power generators), as part of the product and contract design. Since firmer power is more valuable, utilities and large users will have to pay a higher price for it, but may be very willing to do so. Under some circumstances, sellers may be better positioned to manage intermittency risk and provide firm or near-firm energy as required by the system, leveraging the potential of new technologies such as BESS.

**At current technology prices, the ability to charge for the multiple services that BESS can provide to the grid (*value stacking*) is important for investment returns.** Storage can provide

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[26] A thorough cost-benefit methodology for distributed energy resources is presented in National Energy Screening Project (2020).

other services for the grid or large users in addition to firm power supply. Other potential services include the ability to supply peak loads with less new generation and transmission and distribution capacity and facilitate intraday price arbitrage. Bidirectional electric vehicle chargers also provide opportunities for peak load shifting. BESS can provide *ancillary services*, such as better frequency and voltage regulation, black start capability, and spinning and operating reserves. Some ancillary services are transient (fast response ramping power up and down) or localized (voltage regulation), making it difficult to obtain remuneration for them in the value stack. Although ancillary services add value to the power system, they are often viewed as side benefits, since there are currently no markets for monetizing all BESS services.

**Although the unit costs of BESS have fallen, the financial viability of the investments may still depend on value stacking from two or more services**. If the unit costs continue to decline, investments in BESS to reduce RE intermittency risks alone may become more viable. There are currently no industry standards/markets for pricing the various services of BESS. In some developed countries and many developing countries, markets have not yet emerged for the ancillary services. In these locations, suppliers of BESS or RE with storage might not receive any additional compensation for ancillary services at this time.

**BESS auctions could help in value stacking to make assets more profitable, particularly in developing countries**. However, there are some problems with fully capturing the benefits of BESS. Many of those benefits are not marketable. Auctions combining energy, capacity, frequency regulations, and other services represent an optimal way to maximize the benefits of BESS. BESS auctions so far have tendered only one product, sub-optimizing the benefits that BESS could provide to the system. Alternatively, ISOs and integrated utilities could auction BESS capacity and be in charge of operating the assets to capture most of the benefits that BESS can provide to the system, in a BOT kind of contractual arrangement.

**Various business models can be used for front-of-the-meter BESS in RE auctions**. These may require different product specifications, rules, and price and nonprice award criteria in auctions. CEADIR identified seven business models. BESS can be a standalone resource for the transmission or distribution grid, without being associated with an electricity generation facility. One of the most common business models is BESS plus variable RE generation to meet peak load requirements and system contingencies. BESS can be combined with RE for time-differentiated supply blocks for peak and off-peak power, with price adjustments by time of day and/or seasons of the year, and in some cases, supply location. BESS can provide semi-dispatchable power to enable suppliers to deliver grid electricity during daily peak and off-peak periods despite RE intermittency. This business model is also appropriate for minigrids or microgrids. BESS can provide firm power and dispatchable capacity throughout the day and week with either renewable or non-renewable generation. This model is suitable for isolated, off-grid systems. BESS can also be combined with RE generation facilities to provide ancillary services to an electricity distribution company or power pool. Finally, the full value of BESS services can be captured when an integrated utility, system operator, or distribution has control over them through a build, own, operate (BOO) or build, own, operate, and transfer (BOT) arrangement.

**As the market for BESS matures, more sophisticated auction designs could facilitate competition and innovation and expand the range of products and services provided.** Most auctions for BESS or RE plus storage to date have been for easily marketable products, such as RE capacity or firm power. These products were the focus of the auction and formed the basis of the PPAs. Some ancillary services of BESS are sold in countries with relatively sophisticated power markets. The Hornsdale plant in Australia sells ancillary services, price arbitrage, and other services in different markets. In theory, an auction for battery storage systems could combine energy, capacity, and some ancillary services in a combinatorial auction if all these products are marketable. In practice, it is difficult to procure the entire range of stacked benefits through an auction and PPA. A *combinatorial auction* allows bids for bundles of items that provide multiple services or technologies. A combinatorial auction can help governments or utilities meet their requirements more effectively and efficiently. It can also help bidders reduce their costs and monetize the full range of their services (*sourcing optimization*). A combinatorial auction could solicit bids that package renewable electric power capacity, firm power, and ancillary services. Game theory approaches and computational algorithms can improve decision making in combinatorial auctions (Cramton, Shoham, and Steinberg 2006; Hsieh 2010).

**As in other auctions for RE resources, many risks exist for paired RE plus BESS competitive procurements.** Following RE auction contract awards, successful bidders may be unable to implement their proposed investments immediately or for several years. Potential risks include limited ability of the grid or market to integrate the additional capacity for some time, bid prices that are too low for profitability at expected technology prices, breakdowns in partnership arrangements, and difficulties in obtaining financing.

# ANNEX A: RELATED CEADIR WORK

CEADIR analyzed experiences with RE reverse auctions in six countries, focusing on the policy and regulatory environment, characteristics and results of the auctions, and financing of winning bids. That report was based on interviews with investors and representatives of financial institutions and governmental entities in El Salvador, Mexico, and Peru and secondary information on Brazil, India, and South Africa (Molina, Scharen-Guivel, and Hyman 2018).

In a separate report, CEADIR interviewed developers and investors who participated in the 2017 RE auctions in Thailand and Malaysia. That report assessed the cost-effectiveness of these auctions in mobilizing private investment and finance and participant perceptions and recommendations for improving future auctions. The recommendations focused on 1) achieving government objectives for energy reliability and security; 2) addressing grid access and interconnection challenges; 3) improving transparency in the bidding process; 4) promoting improved technologies, innovation, and sustainability; 5) increasing financial incentives; 6) expanding foreign investment to expand the market for larger-scale RE projects; and 7) addressing post-award requirements (O'Mealy, Sangarasri et al. 2020).

CEADIR hosted a Renewable Energy and Smart Grid Suppliers Forum to engage U.S. firms interested in beginning or expanding business in developing country markets on May 1, 2018. The forum focused on sales of equipment and services for utility-scale wind and solar power, smart transmission and distribution, related information and communication technologies (ICTs), demand-response tools, and energy storage. It also focused on provision of technical services for utility and grid planning, reverse auctions, grid integration of variable RE, and RE zones. The forum engaged 71 participants from U.S. companies, trade associations, nongovernmental organizations, and U.S government (USG) agencies.[1]

The forum report highlighted recommendations and insights from private sector leaders that have successfully expanded sales of RE, smart grids, and energy storage products and services in developing countries. It also identified the types of assistance and support offered by USG agencies to help U.S. firms assess market opportunities and enter or increase sales in developing countries (Enriquez *et al.* 2018).

On March 7, 2019, a CEADIR webinar addressed opportunities for U.S. suppliers of smart grid and minigrid technologies in Africa. This webinar included speakers from the West Africa Power Pool; GRIDCo (a utility in Ghana); PowerGen Renewable Energy (a company in Kenya); the USG's Power Africa Initiative, U.S. Department of Commerce's International Trade Administration (ITA), and U.S. Trade and Development Agency (USTDA).[2]

On March 12, 2019, CEADIR convened a forum on opportunities for U.S. smart grid, minigrid, and energy storage suppliers and sources of financing. This forum focused on

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[1] The presentations are available at https://www.climatelinks.org/content/renewable-energy-and-smart-grid-suppliers-forum-emerging-market-opportunities-us-firms

[2] These presentations are available at https://dec.usaid.gov/dec/GetDoc.axd?ctID=ODVhZjk4NWQtM2YyMi00YjRmLTkxNjktZTcxMjM2NDBmY2Uy&pID=NTYw&attchmnt=VHJ1ZQ==&rID=NTIyNDA5

1. Emerging markets in Africa, Asia, and Latin America for smart grid, minigrid, and energy storage products and services;
2. Business models to overcome barriers in emerging markets for expanding sales and investment;
3. Strategies and opportunities for U.S. suppliers of technologies, services, and financing; and
4. Available USG assistance for American and developing country companies.

This forum engaged 117 participants from U.S. companies and USG agencies. The forum report highlighted recommendations and insights from private sector leaders that have successfully deployed smart grid, minigrid, and energy storage technology products and services in developing countries. It also identified the types of assistance and support offered by USG agencies to help U.S. firms assess market opportunities and enter or increase sales in developing countries (O'Mealy, Bauer, *et al.* 2020).[3]

Parametric insurance can help RE generators reduce the financial risks from insufficient resource availability. However, parametric insurance is a relatively new product that may only be feasible for hydropower and large-scale PV or wind power generators (Enríquez *et al.* 2020).

CEADIR has also prepared a related report on guidance to prepare a plan or roadmap for integration of grid-connected distributed energy resources (Doyle *et al.* 2020). *Distributed energy resources (DER)* include distributed generation, distributed power, and demand-response programs. *Distributed generation* refers to decentralized production of electricity near the point of use, whether connected to a centralized distribution grid (mains), minigrid, or microgrid or only serving off-grid users. When distributed generation is connected to the grid, owners may be able to sell their surplus power to other grid customers. *Distributed power technologies* include gas turbines; reciprocating engines; backup generators; and electricity storage through pumped hydropower, batteries, or flywheels. *Demand response programs* include technologies and financial incentives for electricity consumers to reduce their total electricity consumption or peak period use or shift consumption to off-peak periods.

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[3] The forum presentations are available at: https://dec.usaid.gov/dec/GetDoc.axd?ctID=ODVhZjk4NWQtM2YyMi00YjRmLTkxNjktZTcxMjM2NDBmY2Uy&pID=NTYw&attchmnt=VHJ1ZQ==&rID=NTIyNDEz. Other CEADIR webinars on renewable energy and energy efficiency technologies, policies, and financing can be found at https://www.climatelinks.org/project/ceadir-series-navigating-climate-economy

# ANNEX B: EXAMPLES OF UTILITY-SCALE BATTERY ENERGY STORAGE SYSTEMS

| Utility-Scale Battery | Location | Service Provided | Description |
|---|---|---|---|
| Tesla 100 MW/ 129 MWh Li-ion battery storage project at Hornsdale Wind Farm | South Australia, Australia | Frequency regulation<br>Capacity firming | The battery is intended to provide contingency reserves and ancillary services to the Southern Australia grid (Brakels, 2018). |
| STEAG's 90 MW/120 MWh battery storage project | Germany | Frequency regulation | German energy company STEAG has installed an aggregated capacity of 90 MW/ 120 MWh battery storage at six different sites in Germany, each having a battery storage capacity of 15 MW/ 20 MWh.<br>Batteries are connected to the grid at 10 kV and are intended to provide primary frequency control reserve for 30 minutes according to the requirements of the transmission system operator (STEAG GmbH, 2017). |
| 38.4 MW/250 MWh sodium-sulphur battery by Terna | Italy | Grid investment deferral<br>Reduced RE curtailment | Italy had an excess of wind generation, and the transmission capacity was not enough to transport all this energy to the north of the country, resulting in wind curtailments. In 2015, Terna installed the battery system to absorb the wind energy and use it during later periods with low wind demand, avoiding the need to invest in new transmission capacity. Additionally, this battery can provide services such as primary and secondary reserves, load balancing and voltage control (NGK, 2019). |
| NGK Insulators 34 MW/204 MWh sodium- sulphur battery storage system | Rokkasho, Aomori, Japan | Capacity firming<br>Reduced RE curtailment<br>Ancillary services | A 34 MW/ 204 MWh battery storage system was connected to a 51 MW wind farm in northern Japan. The batteries will store the excess renewable energy produced and sell it during peak hours. Further, the batteries will provide frequency regulation and serve as spinning reserves (IRENA, 2015). |
| 1.5 MWh battery + 270 kW solar PV project implemented by Secretariat of the Pacific Community | Yap State, Federated States of Micronesia | Reduced reliance on diesel generators in mini-grids | A 1.5 MWh battery system, combined with a cumulative solar PV capacity of 270 kW was deployed over five islands of Yap State, encompassing ten mini-grids. The intended application provides energy access in some areas and displaces costly diesel generation in others (IRENA, 2015). |

| Utility-Scale Battery | Location | Service Provided | Description |
|---|---|---|---|
| Low-carbon Li-ion battery in Glassenbury (40 MW) and Cleator (10 MW) | United Kingdom | Frequency regulation | These two projects were awarded during the UK auction in 2016 to provide enhanced frequency regulation. Glassenbury has an annual production of 20 MWh, while Cleator produces 7 MWh. Together they provide a quarter of the total enhanced frequency regulation capacity in the United Kingdom and help stabilise the frequency in the grid (Low Carbon, 2019). |
| AES-SDG&E<br>30 MW/120 MWh Li-ion battery storage project | California, United States | Capacity firming<br>Reduced RE curtailment<br>Capacity investment deferral | The US utility San Diego Gas & Electric developed a 30 MW/120 MWh Li-ion battery storage project near one of its substations in Escondido to store excess renewable energy production in the state and also serve as a capacity reserve (SDG&E, 2017). |
| 2 MW/6 MWh battery storage in San Juan Capistrano | California, United States | Grid investment deferral | The battery system offsets the peak demand overload and avoids distribution upgrades. Additionally, this battery can participate in other ancillary services thanks to its control system (Greensmith, 2016). |
| Renewable Energy Systems and Utility of Ohio's 4 MW/2.6 MWh battery storage project | Columbus, Ohio, United States | Frequency regulation | Driven by FERC Order 755, which mandates that independent system operators pay storage providers for the performance of their systems, Renewable Energy Systems, a United Kingdom-based firm, built a 4 MW/2.6 MWh battery storage system to provide frequency regulation services to PJM, a regional transmission operator in the United States (RES, 2017). |

Source: IRENA 2019c, pp. 17-18

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