



Energy Storage Trends and Opportunities in Emerging Markets

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Alex Eller
Research Analyst

Dexter Gauntlett
Principal Research Analyst

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Executive Summary



1.1 EXECUTIVE SUMMARY

Energy storage is a crucial tool for enabling the effective integration of renewable energy and unlocking the benefits of local generation and a clean, resilient energy supply. The technology continues to prove its value to grid operators around the world who must manage the variable generation of solar and wind energy. However, the development of advanced energy storage systems (ESS) has been highly concentrated in select markets, primarily in regions with highly developed economies. Despite rapidly falling costs, ESSs remain expensive and the significant upfront investment required is difficult to overcome without government support and/or low-cost financing. This type of advanced technology requires significant knowledge and expertise to be developed and operated cost-effectively. Furthermore, the services provided by ESS systems are often not properly valued or recognized within existing energy market regulations. Even with these barriers, installations of stationary ESSs are increasing dramatically around the world as system costs are rapidly decreasing and as energy markets are being reformed to allow for the use of more distributed resources.

The International Energy Agency (IEA) estimates that by 2020, developing countries will need to double their electrical power output to meet rising demand. It is estimated that by 2035, these nations will represent 80 percent of the total growth in both energy production and consumption. In order to meet

worldwide goals for reduction of greenhouse-gas emissions, a substantial portion of this new generation capacity will likely come from renewable sources. While the costs for renewable generation continue to fall, integrating and effectively using these new resources, especially in regions with weak grid infrastructure, will require energy storage. Furthermore emerging economies must bring reliable electricity service to about 1.2 billion people who currently lack access. Experience over the past several decades has shown that the traditional, centralized grid cannot or will not cost-effectively provide even basic electrical service to underserved populations in a reasonable amount of time. Distributed and remote power systems have enormous potential to provide service around the world, but are subject to a number of barriers.

Energy storage deployments in emerging markets worldwide are expected to grow over 40 percent annually in the coming decade, adding approximately 80 GW of new storage capacity to the estimated 2 GW existing today. This report will provide an overview of energy storage developments in emerging markets along with details on the services ESSs can provide at the utility-scale, in buildings, and in remote power systems. Key trends and barriers for the technology in emerging markets will also be explored in depth. Finally, case studies are included to highlight successful projects around the world that demonstrate both the challenges and potential for energy storage in emerging markets.



Market Overview



2.1 INTRODUCTION

There are several fundamental contributing factors that set the stage for energy storage in different regions. Each country's energy storage potential is based on the combination of energy resources, historical physical infrastructure and electricity market structure, regulatory framework, population demographics, energy-demand patterns and trends, and general grid architecture and condition. The efficiency and/or level of quality of performance of these fundamental factors creates demand for new products and services, and energy storage is increasingly being sought to meet these emerging requirements.

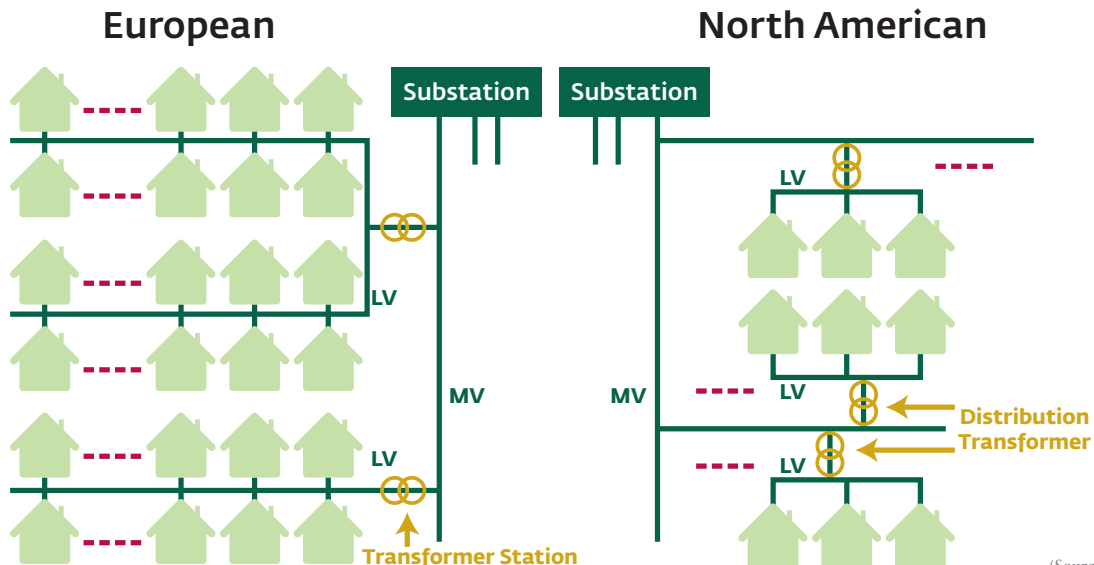
2.1.1 PHYSICAL GRID INFRASTRUCTURE

The physical structure of any electricity system will have an impact on the market for energy storage. There are significant differences among power systems around the world in both physical architecture and operations due to historical patterns of customer living conditions and power usage as well as to

specific grid configurations designed to accommodate these circumstances. These differences play a particularly important role in the structure of distribution circuits, and are important to understand in the context of energy storage market development because of their importance in determining the specifications of customer-sited ESSs. There are two main models of power distribution networks which have been replicated around the world: the North American model and the European model. (See Figure 2.1).

In North America, the suburbs are overwhelmingly ubiquitous, which has led to low-density, single-family residences spread out radially from urban cores. This, in turn, dictates a power distribution grid of radial design, with relatively long feeder circuits, numerous step-down transformers (typically the pole-top variety) per feeder, and relatively few customers served by each transformer compared to more densely populated regions. This model is seen in other regions of the world as well, most notably in parts of Latin America, Australia, and New Zealand.

Figure 2.1 Simplified European vs. North American Distribution Network Architecture



(Source: Navigant Research)

In contrast, in Europe, parts of Asia Pacific, and other more densely populated regions, the extended suburb is not a common phenomenon since the region is more densely populated than North America. As a result, distribution circuits are more concentrated and shorter in length, with fewer step-down transformers (typically housed in better-protected transformer substations rather than on pole-tops) per feeder and many more customers per transformer.

Designs in other world regions, which in many cases are still being built out, tend to be hybridized between these two basic models. This tends to be the case in many emerging markets where power systems generally are less developed.

2.1.2 REGULATORY FRAMEWORK AND MARKET STRUCTURE

The regulatory framework and economic structure of an electricity market determines the level of competition that exists at different levels of the electric power industry and is an important consideration when examining the potential for energy storage deployments. There are two main models for national power grids that are based on the amount of regulation and competition. In fully regulated markets, a single entity controls the generation, distribution, and retail sales of electricity. In contrast, in deregulated or more liberalized markets, such as those in Australia, Germany, and certain states in the United States, there is competition between suppliers at the generation level as well as at the retail level, where customers can choose their supplier. However, most countries employ some hybrid version of these two models at the national level, resulting in a difficult-to-navigate patchwork of regulations within a given region. These structures will determine the final customer for an energy storage system in a market, as well as the services a system is allowed to perform, and the ownership model, that is whether the system is owned by a public entity, by the transmission owner or operator, or by a third party or independent power producer (IPP).

2.1.3 POPULATION AND ENERGY USAGE TRENDS

Population demographics in countries around the world also play a role in determining the structure of the power grid, and will be an important factor in the development of energy storage markets. Countries with more densely populated urban areas will require more concentrated distribution circuits delivering higher voltage power, representative of the

European model. However an important factor is the rate of growth of the urban population. For example, the Middle East/Africa region currently has the lowest percentage of population living outside of urban areas, as well as a large percentage of people living without access to electricity. This region, which has the highest global annual growth in urban population at about 1.9 percent, is experiencing rapid urbanization which is driving the need for significant investments in electrical infrastructure for cities.

While growing urban populations increase the need for new electrical infrastructure, potentially driving the creation of an energy storage market, rural and isolated communities are driving the market for a different set of energy storage technologies. Isolated communities that rely on remote power systems primarily fueled by diesel generators have been some of the first communities to adopt energy storage. This is because the potential for savings from a reduction in fuel consumption creates a strong business case for storage systems. The mix of urban and rural populations, as well as the growth rates for those groups, is an important factor in determining the size and structure of a regional energy storage market.

2.1.4 GRID ARCHITECTURE AND PERFORMANCE CONDITIONS

The overall stability of the electrical grid in a particular country or region is an important consideration in determining the potential market for stationary ESSs. Similar to other factors explored in this report, the stability of the grid will influence the type of ESSs that will be deployed, and how they are used. In areas with relatively unstable grids that experience frequent outages, distributed energy storage systems (DESS) and microgrids will become increasingly popular to protect customers from outages. These systems will be the most popular for commercial and industrial facilities where even short outages can result in significant economic losses.

Additionally, operators of unstable grids are likely to deploy utility-scale ESSs to minimize the likelihood of outages affecting large numbers of customers. Many countries around the world are pursuing grid modernization and expansion initiatives to improve service quality and availability. The stability of the existing grid infrastructure plays an important role in these efforts, particularly for developing countries looking to attract foreign investment for manufacturing and industrial processes. For multinational companies looking to expand manufacturing

into emerging markets, the reliability of local power supplies is a key consideration when evaluating potential locations.

In addition to the factor of stability, the age and overloading of grid infrastructure in a given area can also have a major impact on the demand for energy storage. In many cases, energy storage is becoming a cost-effective alternative to replacing conventional infrastructure, particularly in helping substations, and transmission and distribution (T&D) lines be able to meet growing peak demand in select areas. As ESS prices continue to decline, storage will increasingly be an attractive alternative to replacing conventional infrastructure or deferring investments. This trend is discussed in greater detail in section 2.2 of this report.

2.2 MARKET DRIVERS AND TRENDS

While the specific drivers to develop energy storage markets vary by region and market segment, the overarching goal of ESS deployments is to make the electricity grid more efficient, resilient, secure, cost-effective, and sustainable, as well as to expand the menu of available electricity market services. This report covers three of the primary stationary energy storage market segments. Utility-scale refers to systems installed on transmission or distribution networks providing services to grid operators. Behind-the-meter (BTM) systems are installed on the customer side of a utility meter and primarily help reduce costs and improve resiliency for commercial and industrial (C&I) or residential customers. Remote power systems refer to storage systems operating as part of isolated electricity networks. The specifics of each market segment are covered in the following sections.

The varying drivers and barriers for energy storage around the world stem from numerous factors, including differences in the physical structure of the grid, needs and desires of end users, and the regulatory and market structure in a given country or region. Since the impacts of particular distributed energy resources (DER) on the grid vary considerably by technology and region, it is necessary to understand the factors shaping the ESS market in each area, as well as the differing views in utilities around the world on the proliferation of new storage capabilities. The following sections explore some of the key issues in energy storage markets for developing countries around the world. Greater detail is also provided for the services that ESSs can offer as well as for the emerging business models and dynamics that are fueling the industry's growth.



Distributed Energy Resources encompass a broad set of solutions that include systems and technologies designed to operate closer to customers on the electricity grid.

2.2.1 UTILITY-SCALE

Perhaps the most important driver of utility-scale ESSs is the substantial growth in the amount of renewable energy being deployed around the world. We anticipate that more than 78.0 GW of new solar and wind generating capacity will be installed globally in 2016, and that 378.1 GW is projected to be installed over the next five years.¹ These variable forms of power generation present challenges to local electrical grids, which typically are not designed to handle variable generation output and are often already stretched-out in delivering the existing electricity already online. Issues arise from the need both to safely integrate variable resources and to align supply and demand in order to avoid curtailing energy. ESSs are particularly well suited to smoothing the variable output of renewables and controlling the rapid ramping up and down of solar and wind generation. The waste or curtailment of renewable energy production presents a key opportunity for long-duration, utility-scale ESSs to enable greater utilization of these resources by shifting energy supply in ways to be better aligned with demand.

The next major driver is the effort by governments around the world to reduce carbon emissions. In late 2015, the Paris Agreement was negotiated by 197 countries that agreed to set emissions reduction targets with the aim of limiting global warming to less than 2°C compared to pre-industrial levels. The agreement was accompanied by a set of targets for emissions mitigation in individual countries. In the aggregate, the IEA estimates that \$13.5 trillion in additional investment will be required just to achieve these goals. These national mandates and the reduced costs of renewable generation are resulting in falling competitiveness and retirement of many coal-fired power plants. As new coal plant deployments are replaced by renewables and distributed resources, the grid will need new sources of inertia to maintain stability. Inertia on the grid has traditionally been provided by the rotating mass of thermal power generators, which allows the system to maintain stability if a portion of generation or transmission assets go offline. Energy storage is emerging as an ideal solution for providing real and synthetic inertia as ever-expanding clean power sources come online and cannot replicate the inertia provided by large-scale fossil-fueled generators.

Software and control systems are becoming increasingly important to utilities to capture multiple revenue streams, improving project profitability.

Another key driver is the need for new infrastructure to modernize and expand the grid. The grid in developing economies needs to have aging infrastructure modernized and to be expanded to be able to serve rapidly growing populations and to bring power to an estimated 30 percent of the global population without access to electricity. According to the United Nations Sustainable Energy for All initiative (SE4All), \$45 billion in investment through 2030 will be required to provide universal access to modern electric power.² Energy storage is set to play a key role in these investments, enabling better utilization of both new and existing resources as well as strengthening the grid against diverse threats, including natural disasters and physical attacks.

The fourth major driver is the need to improve the resilience of the electrical grid. Recent natural disasters have highlighted the fragility of a centralized grid architecture. This has resulted in many communities opting for more local generation and use of microgrids to ensure that they still have power during a disaster. This dynamic will play a major role in emerging economies where grid infrastructure may already be unreliable, and can benefit from the resiliency provided by energy storage.

As a result of these trends, grid operators and regulators are beginning to recognize the value of ESSs for multiple services. Utilities have begun including ESSs in their resource planning processes as falling systems costs have made storage an attractive alternative to certain infrastructure investments. As deployed systems continue to meet expectations, standardized contracts are likely to become the norm, which can result in more predictable revenue streams. Due to this maturation of the industry, the financial community is growing more comfortable with investments in energy storage, which are further lowering the cost to deploy systems and accelerating growth of the industry.

¹ Other analysts project levels as high as 104 GW of new solar and wind power in 2016, and 644 GW over the next five years (Bloomberg New Energy Outlook 2016).

² SE4All Global Tracking Framework Report, "Progress Toward Sustainable Energy 2015"

2.2.2 BEHIND-THE-METER

To date, backup power has been one of the major selling points for energy storage. Both distributed customers and utilities are interested in utilizing battery systems in homes to improve the resilience of their power supplies and to help mitigate the effects of power outages caused by natural disasters or grid equipment failures. To enable an adequate supply of backup power, the sizing of an ESS is crucial. If there is too little power or energy capacity (measured in kW and kWh, respectively), the system will not be able to support critical loads during an outage. However, an oversized system will be prohibitively expensive compared to alternatives.

The ability to provide backup power is particularly key to the value proposition of battery storage systems. While controllable water heaters and other forms of thermal energy management can reduce electricity costs and can provide some services to grid operators, they will not be able to provide power for critical loads during an outage.

In large BTM energy storage markets, such as the United States, the main driver for these systems has been the ability to reduce electricity expenses. This is primarily done by reducing peak demand and time-of-use (TOU) rates. Demand charges are charges levied by electric utilities based on the maximum electricity demand of a customer over a period ranging from 15–60 minutes, typically over an interval of 30, 60, or 90 days. These charges may then stay in place for 30, 60, or 90 months, and such charges can account for a significant portion of a C&I customer's bill. Since energy cost management is the primary function of energy storage for C&I customers, utility rate structures are expected to determine the economics in a given market. The higher and more volatile electricity prices and demand charges are for C&I customers, the better is the business case for energy storage.

A key component of the energy storage value proposition in developed and emerging markets is consuming the majority of energy generated by onsite solar photovoltaic (PV) and other distributed generation (DG) systems. In most developed countries, the compensation structure for solar PV discourages the use of ESSs because PV system owners are guaranteed payment for any excess energy that their system generates at a rate that is equal to or higher than the retail cost of electricity. However, due to the successful growth of the solar PV industry in Organisation for Economic Co-operation and Development

Virtual aggregation of distributed systems allowing systems to provide grid services and compete in energy markets, greatly increases the value proposition of ESSs.

(OECD) countries, compensation programs (including net metering and feed-in tariffs [FIT]) are being phased out or replaced with alternative rate structures in many areas. When these types of programs are eliminated, or when compensation for exported energy falls below the retail price of electricity, ESSs can allow end users to save money. By storing excess solar PV energy produced throughout the day, customers can avoid purchasing energy from the grid during evening peak demand periods when electricity rates may be highest in markets with dynamic pricing. In places such as Hawaii, Germany, and Australia, the distributed storage industry is being fueled by the decrease in solar PV compensation and high retail rates of electricity, encouraging a model of storage operation known as self-consumption.

BTM energy storage can also allow for much greater levels of renewable energy penetration. Distributed renewables, particularly solar PV, can cause significant issues for distribution networks when too much power is fed back onto the grid. Most distribution equipment was not designed to handle significant back-feeding of electricity, and either requires adding upgrades to the equipment or setting limitations on the amount of variable generation produced. BTM storage allows customers to keep onsite the excess energy generated, preventing many of these issues. These systems can also automatically respond to grid signals to correct frequency, voltage, and reactive power, thereby greatly improving grid stability and reducing barriers and objections to increasing deployments of distributed renewables.

The impact of increasing DER deployments will vary in different countries and regions around the world. Much of this variation will be due to both existing and planned additions of centralized generation in a given area. Given the vast landscape of technologies that DER includes, most countries in the

Table 2.1 Estimated Fuel Savings and System Costs of Energy Storage Technologies in Remote Microgrids by Battery Type, World Markets: 3Q 2016

Battery Type	Installed Cost (\$/kW)	Est. Annual O&M Cost (\$/kW)	Avg. Round-Trip Efficiency	Est. Annual Fuel Savings (L/kW)	Est. Annual Fuel Savings (\$/kW)
Flow Battery: Utility-Scale	2,300.2	31.1	70%	1,680	1,831.2
Flow Battery: Distributed	2,874.4	34.5	70%	1,680	1,831.2
Advanced Lead-Acid: Utility-Scale	2,903.5	66.2	80%	1,920	2,092.8
Advanced Lead-Acid: Distributed	3,284.5	66.8	80%	1,920	2,092.8
Lithium Ion: Utility-Scale	2,062.0	47.3	90%	2,040	2,223.6
Lithium Ion: Distributed	2,150.3	50.8	90%	2,040	2,223.6

(Source: Navigant Research)

coming decade are expected to utilize more new DER capacity additions than centralized generation additions, especially solar PV, generator sets (gensets), and energy storage. In regions where DER capacity deployments will significantly outpace centralized generation, pressure to restructure electricity networks both physically and economically to handle the changing technology landscape will be felt more acutely.

2.2.3 REMOTE POWER SYSTEMS

It is important to identify how remote power systems can differ. One major distinction is the size of the system. Where larger remote systems have been generally known as microgrids, the smaller denominations are known as nanogrids. The business case for nanogrids echoes many of the same arguments used on behalf of microgrids. These smaller, modular, and flexible distribution networks are the antithesis of the bigger-is-better economies of scale thinking that has guided energy resource planning over much of the past century. Nanogrids embrace a bottom-up energy paradigm. In some cases, the networks articulate a business case even more radical than that for a microgrid; in other cases, nanogrids peacefully coexist with the status quo.

One distinction between types of remote power systems is the physical proximity of a system to a centralized grid system. Systems that are co-located with a large, centralized grid system are known as grid-tied; others that are independent from a centralized grid are known as remote. A second distinction is

who is the owner of the remote system: an electricity customer, a utility, or another entity. In each ownership category, systems may be grid-tied or remote. This report section focuses solely on remote systems, since the benefits of grid-connected storage systems were covered in the previous sections.

Remote power systems typically rely on small diesel generators to support electricity needs. The cost of electricity provided by these systems can be very high in comparison to grid-connected systems. As a result, many new remote power systems are being designed to reduce costly diesel fuel consumption by integrating

A nanogrid, a smaller subset of a microgrid, is an electrical domain no greater than 100 kW and limited to a single building structure or primary load representing distributed generation devices, energy storage, eVs, and smart loads capable of islanding and/or energy self-sufficiency through some level of intelligent DER management or controls

solar PV, distributed wind, or other renewable resources into the network. Perhaps the most attractive remote system markets in the world today are communities that burn diesel fuel as a primary source of electricity. The key driver for this market is displacing high-cost diesel fuel with variable renewable resources. Once these substitutions take place, there is often a need for both energy storage and more sophisticated controls to make operations more robust. Microgrids were first developed for this segment, and remote, grid-independent power systems represent the largest, long-term market opportunity in terms of the number of systems deployed in the global remote system market, including many emerging market countries.

Table 2.1 provides a breakdown of the cost of ESSs within remote power systems and the expected reduction in diesel fuel usage on a per-kilowatt basis. This analysis is built using diesel offset assumptions, including diesel pricing of \$1.09 per liter. The table refers to utility-scale as an ESS centrally located in a remote power system with a capacity of more than 250kWh, and distributed as smaller systems physically dispersed in a power system with less than 250 kWh of capacity.

An example of this type of remote system is the Kodiak Island Microgrid in Alaska. The project, active since 2014, generates a vast majority of its 42 MW of power exclusively from wind and pumped hydro resources. The island also includes two flywheels and a lead-acid battery bank to provide power stability. This system supplies electricity to 15,000 residents across seven independent communities. An additional example is the Brookfield Energy Suburban Solar Microgrid Project in Australia. This project, rated at a total capacity of 80 MW, includes solar PV, diesel, and energy storage to power a new housing development without conventional grid support. Brookfield and developers built the business case of this project around cost savings from network development, connection fees, and the falling costs of solar PV and energy storage. This project is scheduled to come online in 2017.

Overall, the business case for energy storage in a remote power system is built primarily around the ability of storage to maximize renewable generation use and minimize peak load, with secondary benefits including ensuring the overall stability of the system. Ultimately, the operational objective of the power system and the technology composition will determine which

type of ESS is used in a remote system, and to what degree. The technology composition of each system is unique, because it is a response to a set of preferences and requirements set by each individual end user.

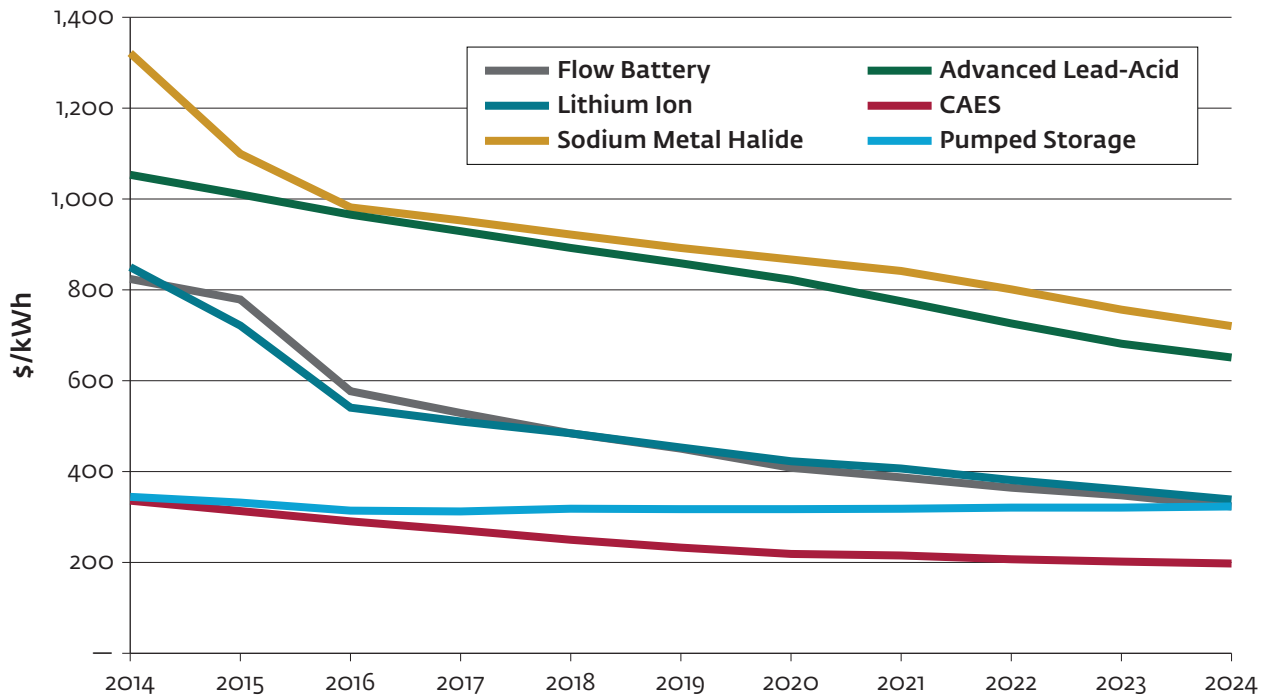
The services that energy storage systems deliver to remote systems are not dissimilar to the services that they deliver to the traditional grid: resource optimization (fuel, solar PV, wind), resource integration (solar PV, wind), stability (frequency, voltage), and load management (leveling and shifting). Understanding the relative importance of each service to a remote system customer is critical to building a compelling business case for energy storage for remote power systems, particularly in the face of alternatives that have lower upfront costs in developing countries, such as natural gas or diesel generators. Traditional centralized transmission and distribution (T&D) grid infrastructure is costly to build out, and often costs much more than building new remote systems. Grid-independent distributed systems may be less risky financially, are incremental by nature, and synchronize with evolving trends and business models related to power systems in many emerging economies.

2.3 MARKET BARRIERS

Countries around the world will experience growth in the energy storage market at different rates, driven by differing factors. Numerous factors are limiting the growth of the stationary energy storage market worldwide. Several of these barriers include:

- *Lack of familiarity with storage technology among utilities, regulators and financiers*
- *High upfront costs*
- *The need for highly skilled and experienced technicians to maintain and operate systems correctly*
- *Regulations preventing third-party or customer ownership of certain DERs*
- *Regulations preventing storage from competing in energy, ancillary service, or capacity markets*

These and other barriers limiting the growth of energy storage in new markets are explored in the following sections.

Chart 2.1 Utility-Scale Energy Storage System Cost Trends by Technology, Global Averages: 2014–2024

(Source: Navigant Research)

2.3.1 UTILITY-SCALE

A number of challenges remain for the growing utility-scale ESS industry, especially in developing markets. As is the case with the entire energy storage industry, the high upfront cost for systems remain the most significant barrier to growth. However there are additional issues that are specific to the utility-scale segment. Many ESS developers still see a significant need for more education because many industry stakeholders, including utilities, regulators, developers, and financiers, are often not familiar with energy storage, the technology's benefits, and how it should be properly managed. In addition, in most regions, ESSs are not sufficiently recognized in competitive markets for being able to offer both energy capacity and ancillary services. Many ESS developers and vendors believe that ESSs should have their own set of rules and be treated as a unique technology in regulatory frameworks because of the diverse benefits they can provide.

Additionally, in many areas there has been a growth of deployments of distributed ESSs paired with increasingly sophisticated aggregation software. This approach allows these systems to provide value for both the host customer and the

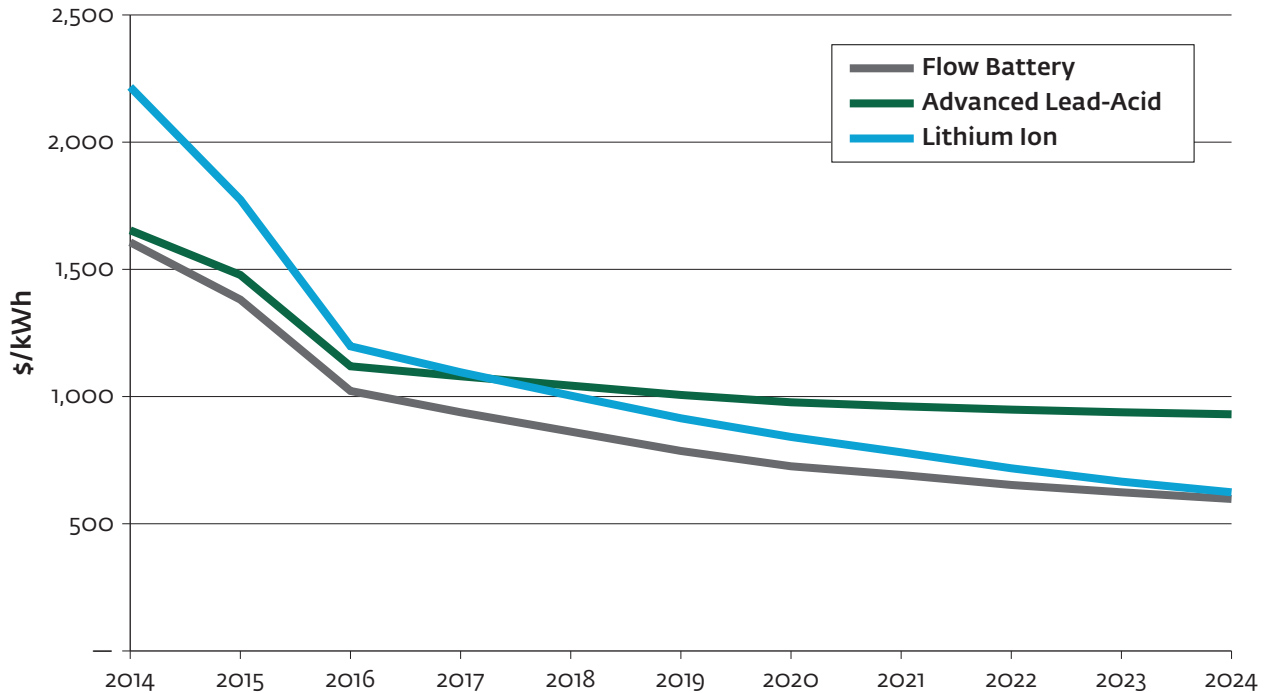
grid operator. While this is an important development for the overall ESS industry, it has the potential to reduce the demand for larger utility-scale systems because the same services can be provided by a distributed ESS network.

Despite the major reductions in system costs that have been achieved over the past several years, utility-scale energy storage remains an expensive technology. The upfront cost for systems is one of the major barriers to the market's growth. Chart 2.1 provides a comparison of the cost trends and forecasts for various ESS technologies. This assumes a duration of 4 hours for battery technologies (ex. 1 MW / 4 MWh), and a 10-hour duration for compressed air and pumped storage systems.

2.3.2 BEHIND-THE-METER

Despite its potential, the behind-the-meter energy storage industry is still very much a developing market. The BTM energy storage market is made up of both C&I and residential customers. With the exception of a small number of early adopters' markets, such as Japan and Germany, commercial activity is largely limited to C&I customers and only a relatively small capacity of residential systems have been deployed. However despite the industry's growth, the

Chart 2.2 Behind-the-Meter Energy Storage System Cost Trends by Technology, Global Averages: 2014–2024



(Source: Navigant Research)

economics simply do not justify the high upfront cost of installing these systems for most customers around the world. High upfront costs are the main barrier to BTM storage growth. While system costs have fallen rapidly and are expected to continue their downward trajectory, growth in this market is highly dependent on the rate structures utilized for BTM customers and on the involvement of local utilities.

Critical factors enabling this market are the programs supporting solar PV that compensate system owners for excess generation. However, many utilities are opposed to these programs, including net metering and FITs, which can be disruptive to the power industry as a whole and may not appropriately value the cost of maintaining enabling grid infrastructure owned by the utility. The elimination of these programs would greatly constrain the energy storage market, given how closely tied it is to the development of the solar PV market. The distributed storage industry knows it cannot expect to follow the same path as solar PV by relying on subsidies to prop up the industry. There must be a sustainable value proposition regardless of subsidies, and this may require changes in rate structures and regulations that effectively quantify the value created by distributed energy and ESSs while

accurately accounting for the underlying grid system cost to support these new distributed systems.

Chart 2.2 provides an illustration of the pricing trends and forecasts for BTM energy storage. This represents an average of costs across both residential and C&I markets, and assumes systems with a 2-hour duration (for example 50 kW / 100 kWh). As shown in the chart, system costs have come down dramatically in the past two years, these markets were nearly non-existent in most regions in early 2014.

Other major barriers to BTM energy storage around the world have been the issuance of restrictive regulations and resistance from existing utilities. Utilities in some areas have actively worked to prevent customers from using BTM storage to consume more of the electricity they generate on-site. These efforts have included enactment of regulations prohibiting third-party system ownerships (which have driven market growth in leading markets) as well as ones imposing special fixed charges or tariffs for self-consumption of power generated onsite. Despite the fact that these systems, when properly coordinated and incentivized, can improve the stability of the grid and allow for more renewables to be added effectively, they

are viewed by some utilities as a direct threat to their business since it could allow some clients to defect from the grid or greatly reduce the amount of energy they purchase from the grid. However, this is not always the case, and forward-looking utilities in some leading BTM storage markets are supporting and using BTM ESSs as a resource that can provide unique benefits to the grid.

2.3.3 REMOTE POWER SYSTEMS

Diesel gensets and the high cost of diesel generation in isolated areas figure prominently in remote power systems. Diesel costs are influenced by a number of factors, including domestic availability of fuel, transportation networks for fuels, weather conditions, safety conditions, fuel theft, subsidies, and taxes. These factors may have different impacts in each region. For instance, theft and weather conditions are not an issue in Denmark, but the Danish government taxes fuels and energy heavily, whereas in India theft and weather conditions are a major concern.

Although an ESS paired with solar PV or another renewable resource has the potential to continue supplying power throughout a lengthy outage, there is little financial justification to do so given the relatively low cost of alternatives like diesel and natural gas generator sets. Conventional diesel generators can be purchased for about \$650/kW, with the energy capacity only limited by the amount of fuel available. While diesel fuel is typically readily available in most countries, the cost of running diesel generators for significant periods of time is cost-prohibitive, particularly in rural regions in emerging

markets where the cost of diesel can be two to three times as expensive when compared to urban areas. By comparison, the average distributed ESS costs nearly \$3,000/kW installed, with a finite amount of energy capacity. As a result, it is critical that ESS vendors design their systems to be able to provide multiple services and capture several revenue streams in order to produce a more favorable return on investment (ROI).

Development challenges in deploying these systems in remote areas also exist. Attractive remote markets like commodity extraction industries are in an economic down-cycle and therefore companies may hesitate to invest in new infrastructure not directly related to production or with longer payback times. Furthermore, because many commodity extraction operations are highly cost-driven and conservative, companies may view the integration of energy storage as risky. The cost-driven nature of this market is also true for other applications like village electrification. While this is the remote market segment that is attracting the most support from governments and international development finance institutions, it also faces some of the most difficult challenges due to the financial viability of clients, historic patterns of energy theft and/or adulteration, and deeply embedded energy subsidies that challenge private sector business models. Furthermore, in many areas, the ability to safely and cost-effectively access many remote communities, along with the lack of local technical expertise to operate and maintain the installed systems, is hindering remote power system development.

Applications for Stationary Energy Storage



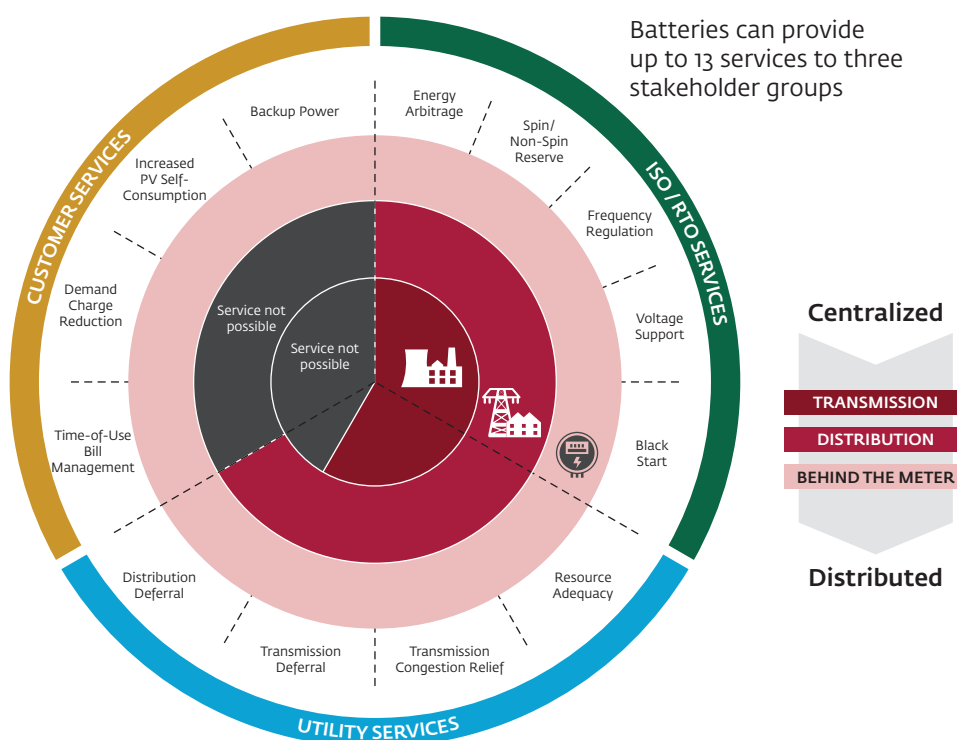
3.1 INTRODUCTION

This section includes an overview of the stationary energy storage value chain, lists components in energy storage systems, and describes applications of energy storage in the context of emerging markets. Energy storage projects exist and thrive in several geographies, but a number of emerging market countries have the resource potential to be among the most active participants in energy storage today. We expect that select emerging markets will be hotspots of storage activity over the next five to fifteen years. Activity in the energy storage market may be catalyzed by specific, progressive utilities that actively seek to modernize their assets. This will be followed by an

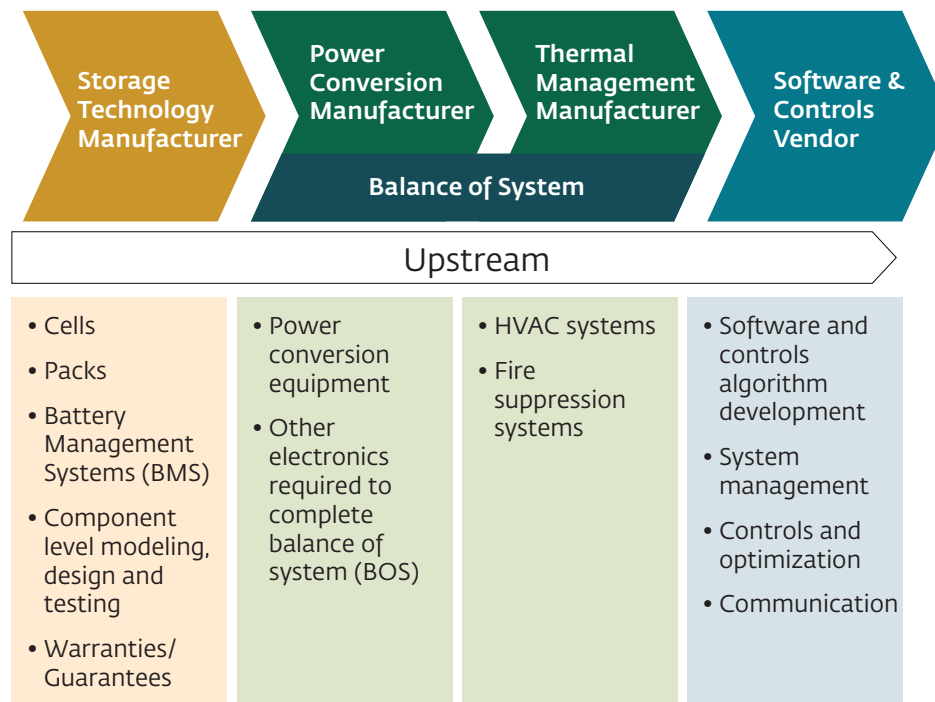
increase in region-wide mandates or International Organization for Standardization (ISO)-wide changes in market structures. This means that the opportunities will be limited to specific utilities, as opposed to all utilities, or to distributed customers in a geographic territory.

Energy storage systems are being implemented to meet a variety of different applications across the grid. Locations range from generation, transmission, or distribution sites with utility-scale systems to electricity end-users' properties using BTM systems, Figure 3.1 shows how utility services, customer services, and market services are related across sectors.

Figure 3.1 Battery Energy Storage Value Chain, Upstream Portion: Utility-Scale and BTM



(Source: Rocky Mountain Institute's The Economics of Battery Energy Storage)

Figure 3.2 Battery Energy Storage Value Chain, Upstream Portion: Utility-Scale and BTM

(Source: Navigant Research)

Utility-scale projects include large storage systems designed for power applications, which require high power over relatively short periods of time, as well as for energy-intensive applications, such as shifting renewable generation to align with times of high demand, that require large amounts of energy over a long period of time. In contrast, BTM projects tend to include residential- or commercial-scale systems designed for energy applications, which must hold enough energy to discharge for multiple hours. In unique cases, high power systems make sense in BTM applications for industrial customers where large pieces of equipment used in industrial processes cause spikes in demand. Generally, however, two to four hours of duration is typical for BTM applications.

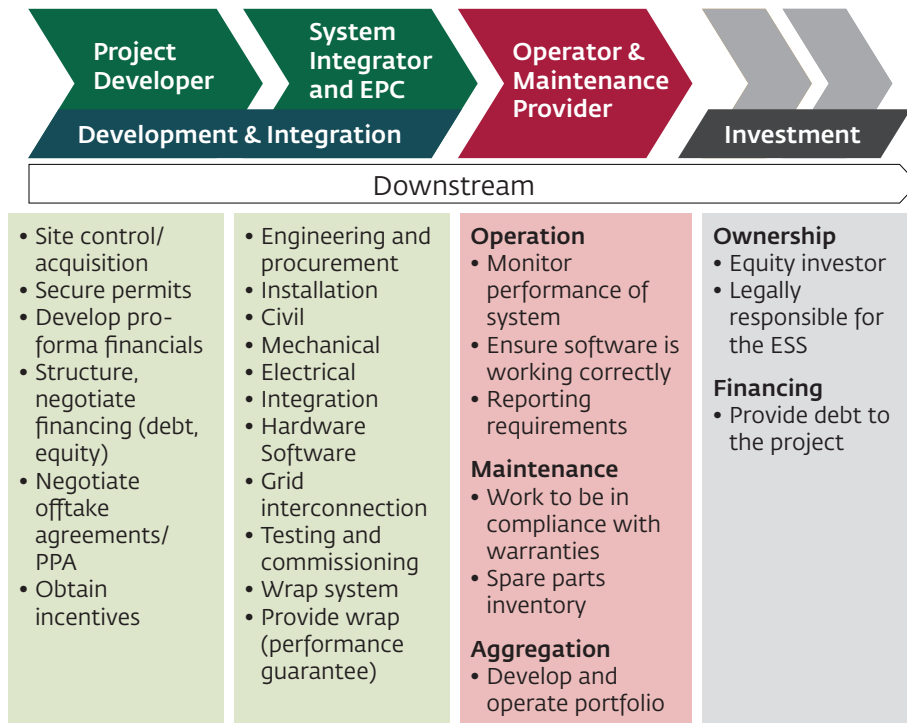
3.1.1 THE ENERGY STORAGE VALUE CHAIN

ESSs are not all created equal; services, functionalities, and pricing structures can vary from project to project. However, certain components remain consistent for utility-scale and distributed deployments. As an example, Figure 3.2 details the upstream portion of the value chain for batteries.

The upstream components of the ESS include the following:

- **Storage Technology**—Storage technologies include mechanical (for example, flywheel, compressed air, pumped hydro), electrochemical (for example, lithium ion, flow battery), and thermal (for example, ice, phase change materials). Individual technologies are tailored for different applications. Li-ion batteries currently dominate the market, but a diverse blend of battery technologies is beginning to be deployed. Thermal energy storage using molten salt is also being widely used in connection with concentrated solar power (CSP) projects.
- **Power Conversion**—Power conversion technologies primarily include bidirectional inverters (hardware) and some software within the inverter. Inverters are relatively technology-agnostic, meaning the inverter market will grow with the overall energy storage (ES) market.
- **Thermal Management**—Thermal management technologies maintain the desired temperature range within a system and are critical for optimizing storage capacity, lifespan, performance, and safety. High-temperature storage

Figure 3.3 Battery Energy Storage Value Chain, Downstream Portion: Utility-Scale



(Source: Navigant Research)

technologies such as sodium-sulfur batteries use vendor-specific custom systems, while other technologies such as flow batteries tolerate a wider range of temperatures without heating, ventilation, and air conditioning (HVAC).

- **Software & Controls**—Software and controls technology is required for all aspects of system operation and performance. Three sub-components make up the software and controls component of an energy storage system.
 - Advanced sensors and system management devices monitor performance, manage health, and set dispatch/cycle frequency limitations of systems.
 - Controls manage charge and discharge rate, optimize economic dispatch, balance competing applications and obligations, and control aggregated distributed systems.
 - Communications technologies send and receive data and control signals, and support software and firmware upgrades.

The following sections will differentiate between application focuses of grid-tied utility-scale energy storage, BTM energy

storage, and energy storage for remote power systems. Each one of these segments has their own respective value propositions, drivers, and barriers.

3.2 GRID-TIED UTILITY-SCALE

Further down the ESS value stream, systems become increasingly nuanced to fit certain applications. Utility-scale systems require special functionalities and controls to ensure reliability, safety, and profitability. As an example, Figure 3.3 illustrates the downstream portion of the of the battery energy storage value chain for these types of projects.

The downstream components of utility-scale ESSs include the following:

- **Project Developer**—The developer role is typically the consolidator, connecting system development, integration, engineering, procurement, and construction (EPC), and financing to reduce multiple levels of mark-up
- **System Integrator and EPC**—The competencies and services included in this portion of the energy storage value chain

include a number of technical functions, system design, and follow-on services that transform hardware and software into an intelligent storage-based solution that delivers maximum return on investment. As a part of system integration services, vendors execute some or all of the following tasks:

- Select, procure, and integrate the core battery technology
- Provide communications with different systems such as the utility or a market
- Execute and/or facilitate installation through an EPC firm
- Ensure performance of the system to the stipulated technical requirements
- **Operator & Maintenance (O&M) Provider**—The O&M provider is responsible for hardware/software technical issues that may arise for a given project, often provided by the hardware manufacturer or system integrator. Broad expertise is required to address a significant fraction of the market because maintenance requirements are highly dependent upon specific technologies. Because of the newness of energy storage technology, specialized expertise is not widely prevalent.
- **Investment Entities**—Financiers are responsible for providing the upfront costs for funding new projects. Risk for these entities is currently high due to a lack of proven,

long-term deployments and to significant regulatory and market uncertainty.

Although many ESSs being deployed today are often designed to provide only one service to the grid (for example, frequency regulation), it is important to note that a single ESS is often capable of serving multiple applications. This will add complexity to the industry, since over time it is expected that it will become common for an individual ESS to serve various applications. Additionally, specific terminology for applications varies around the world. For example, the application known as “frequency regulation” in North America is called “frequency response” in the United Kingdom and “primary control reserve” in Germany and most of mainland Europe. Therefore, it is important to understand the purpose of each application and its technical requirements to be able to know the regional differences in terminology. Table 3.1 provides an overview of utility-scale energy storage applications that support the grid and ancillary services.

Several factors contribute to the bankability of a project. Choosing the correct business model is perhaps one of the most important considerations to ensure project value. Within new ESSs that are being deployed, there is a great deal of variability in the specific arrangements between system owners, grid operators, and customers. The three business model categories shown below, merchant, utility-owned, and capacity contracts, represent the main models for ESS deployment. It is important

Table 3.1 Utility-Scale Energy Storage Applications

Application	Capacity Requirement	Classification	Discharge Cycles per Year	Applicable Technologies
Peak Pricing Arbitrage	4–6 hours	Bulk Storage	200–400	Advanced Batteries, Compressed Air Energy Storage (CAES), Pumped Storage
Generation Capacity	2–6 hours	Bulk Storage	200–600	Advanced Batteries, CAES, Pumped Storage
Transmission and distribution (T&D) Asset Capacity	2–4 hours	Bulk Storage	201–600	Advanced Batteries, CAES
Frequency Regulation	1–15 mins	Ancillary/Power Services	1,000–20,000	Advanced Batteries, Flywheels, Ultracapacitors
Volt/VAR Support	1–15 mins	Ancillary/Power Services	1,000–20,000	Li-ion, Advanced Lead-Acid, Flywheels, Ultracapacitors
Renewables Ramping/Smoothing	1–15 mins	Ancillary/Power Services	500–10,000	Advanced Batteries, Flywheels, Ultracapacitors

(Source: Navigant Research)

to note that within each category, different entities have employed a variety of specific ownership models.

- **Merchant Model**—The merchant model enables energy storage owners and operators to unlock revenue streams through participation in competitive electricity markets, including ancillary services markets. The merchant storage plant owner—often an IPP that owns multiple generation assets—can also establish a power purchase agreement with a utility, or directly with other electricity end users, to provide services at specific times. By participating in competitive electricity markets, energy storage can provide plant operators with a wide range of revenue-generating options.
- **Utility Owned**—Utilities are investing in energy storage to defer the cost of electrical T&D upgrades needed to meet growing electricity demand. ESSs can help improve grid reliability by managing T&D congestion and improving T&D performance, allowing utilities to increase the lifespan of infrastructure assets and to avoid purchasing additional equipment.

- **Capacity Contract**—As utilities begin to consider energy storage within their portfolio of solicited capacity products, local capacity requirements for energy storage deployments become important. Capacity contracts involve utilities procuring energy storage-as-a-service from providers that offer reliable load reduction, typically in a set geographic location where there are capacity constraints.

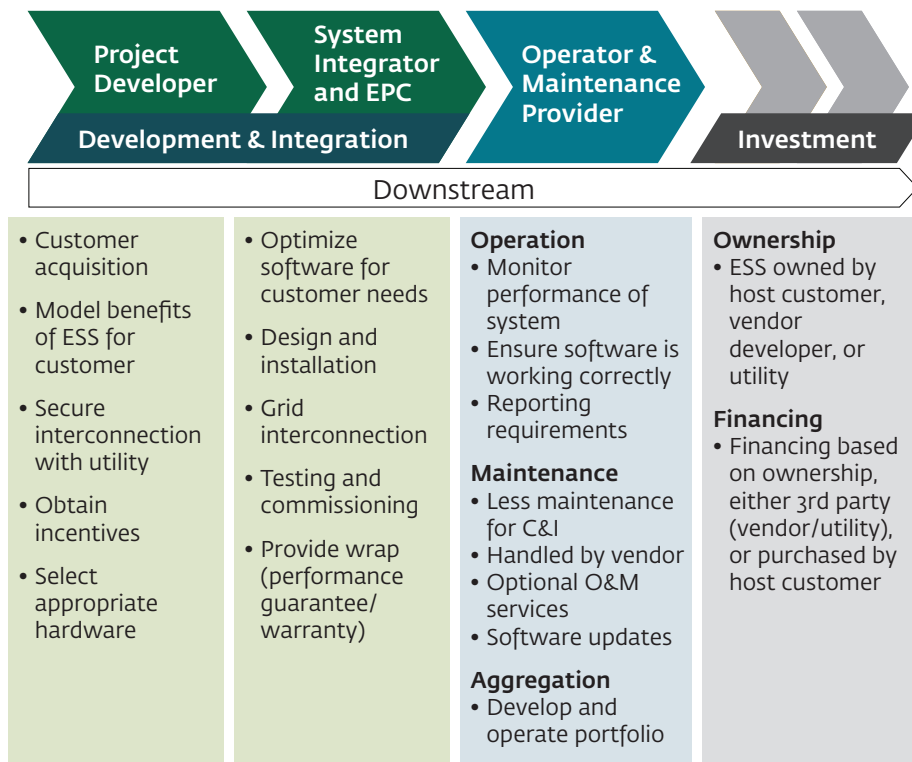
3.3 GRID-TIED BEHIND-THE-METER

There are similar downstream components of the value chain with BTM systems as there are with utility-scale systems, but the scope of the players varies slightly. Figure 3.4 details the BTM downstream value chain.

The downstream components of BTM ESSs include the following:

- **Project Developer**—The project developer in smaller distributed systems models the incentives and paybacks for the customer, ensuring that the proper hardware and software adequately suit the customer’s needs. In the BTM market many project developers also provide

Figure 3.4 Battery Energy Storage Value Chain, Downstream Portion: BTM



(Source: Navigant Research)

system integration, O&M, and financing, and often own the systems as well. While some projects have separate companies for several downstream components, leading BTM ESS providers usually handle all downstream functions themselves.

- **System Integrator and EPC**—The primary technical differentiation between BTM players is in software and controls. It is important to note that broad and deep expertise is required to compete in this area, and many players have first secured their reputations in another value stream component. Several BTM providers only offer software platforms, system design, and integration, as opposed to other companies that provide all downstream aspects of a project.
- **O&M Provider**—Operators in this segment also can play the aggregator role; this will become more valuable as policy changes enable greater DER market participation. The need for human operator intervention will decrease over time as the automation capabilities of software and controls increase.

- **Investment Entities**—Innovative financing mechanisms are fueling the growth of the energy storage market, as they did for solar PV and CSP.

The technology of choice for BTM systems is the li-ion battery, although various electrochemical and thermal energy storage systems have been deployed in this sector. Li-ion batteries, along with other advanced batteries, have the ability to improve power quality and provide backup power for an extended period of time. ESSs for BTM customers often need to be designed specifically for the host customer. Given the significant variations in energy usage profiles, it can be difficult for vendors to offer a single, standardized system that will meet a customer's needs without being oversized. In addition, while utility-scale storage systems often provide one specific service to the grid, many BTM systems will need to be more flexible. For example, a BTM ESS may be required to discharge at high power for 15–30 minutes to shave peak demand, but also to provide several hours of backup power or to participate in a 4-hour demand response (DR) event. Because of this need for flexibility, some vendors offer hybrid systems, including multiple technologies, to meet both power- and energy-centric building needs efficiently.

Table 3.2 BTM Energy Storage Applications

Market Drivers	Customer Applications	Description/Benefit
Rising electricity rates, increasing electric vehicle (EV) use, increasing energy management system use	Demand charge reduction	Respond automatically to building load spikes—reduced electricity expenses
	Time-of-use (TOU) energy bill management	Manage charging and discharging based on retail electricity rates—reduced electricity expenses
Increasing solar PV installations	Onsite generation self-consumption	Maximize consumption of onsite generation, primarily solar PV—reduced electricity expenses
Need for resiliency/power quality	Backup power/improved power quality	Protect sensitive equipment from power quality fluctuations/outages—ensure operability during grid outage
	Ancillary services	Provide frequency regulation, voltage support, electric supply reserve capacity, etc.—improved efficiency of centralized generation, smoother integration of variable generation
Grid stability concerns and capacity needs	Demand response (DR)/	Manage charging and discharging based on retail electricity rates—reduced electricity expenses
	Transmission and distribution investment deferral	Limit investments in new infrastructure through reduced peak demand

(Source: Navigant Research)

As with other forms of energy storage, BTM storage can be a highly flexible and valuable resource on the grid, improving efficiencies for multiple stakeholders. Much of the focus in the distributed storage industry has been on identifying the optimal ways to extract both consumer and utility value for BTM customers. To date, the key to the market's development has been the active participation and support of utilities.

Behind-the-meter energy storage at customer facilities offers the ability to provide services for both the end-use customer and the local utility/grid operator. Table 3.2 provides an overview of services that BTM ESSs can provide. While some of these services—such as demand charge reduction—have a clear economic value that is relatively easy to predict and measure, other services are either currently unavailable to BTM systems or difficult to quantify. For example, there is much debate within the industry over the value of backup power and improved power quality. Although there is a direct economic impact if power is lost at a facility or residence, the industry has yet to settle on a standard value for this service. Additionally, while BTM ESSs can efficiently provide ancillary services to the grid, they are currently unable to do so in nearly all cases due to existing regulatory frameworks.

Business models may vary across different BTM systems. The business model chosen typically depends on the company's other offerings and experience with commercial and industrial (C&I) customers. Many leading vendors offer a variety of ownership and financing options tailored to customer needs.

- **Vendor/Third-Party Owned**—The vendor/third-party owned model includes a wide range of agreements between vendors and their customers. The two leading third-party owned business models are power purchase and power efficiency agreement plans. These models have allowed a growing number of C&I customers to benefit from energy storage without incurring significant upfront expenses.
- **Transactional Sale**—The transactional sale business model is a more traditional sale of an ESS to end-use customers. This model is typically popular among customers with more complex building systems that have a dedicated energy and facility management staff.
- **Holistic Energy Management**—Several leading C&I ESS providers are entering the market by offering more holistic energy management services, as opposed to offering ESSs

exclusively. Many of these firms include energy service companies (ESCO) that offer long-term energy management contracts to their customers. Some of these ESCOs are in turn being acquired by utilities.

Residential ESS business models are still in the early development stages in most markets, but there are three primary ownership models that utilities are tending to use to deploy the technology.

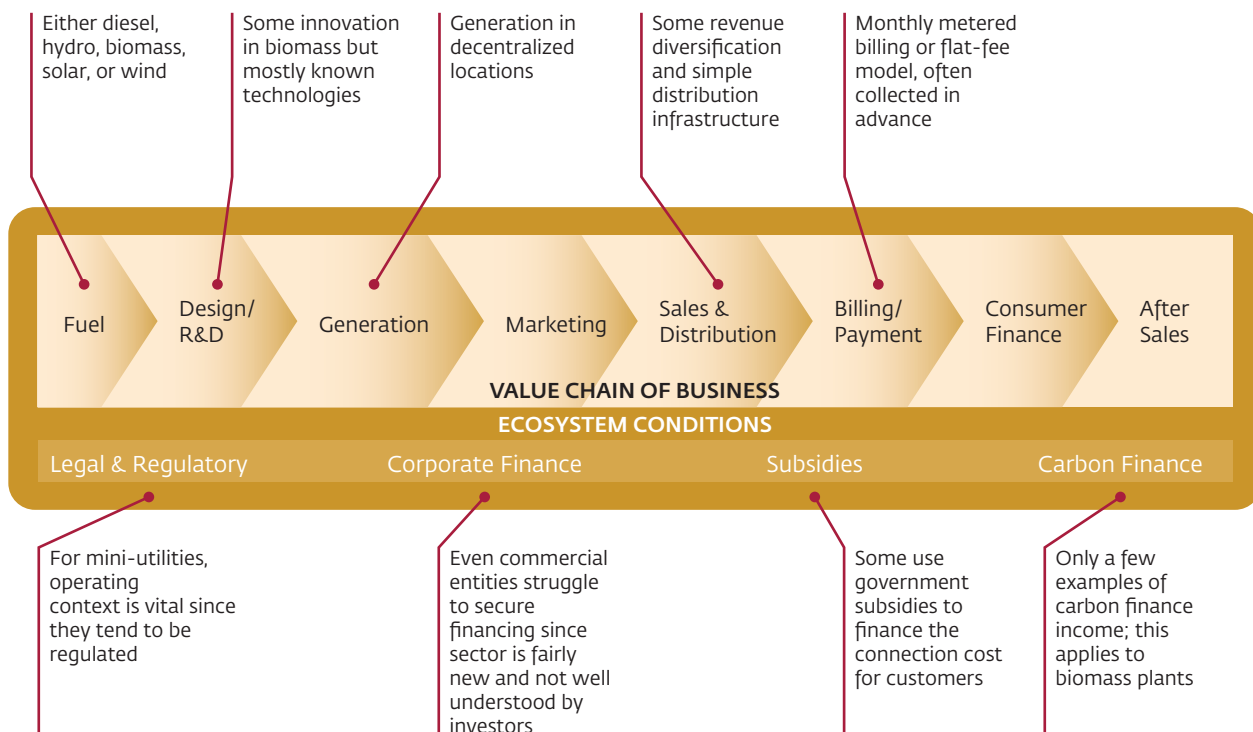
- **Full Utility Ownership and Control**—The full utility ownership and control model has no upfront cost, and customers pay monthly fees for backup power. The utility manages the ESS remotely, and the need of the grid is prioritized over customer needs.
- **Full Customer Ownership and Control**—In the full customer ownership and control model, the customer pays the full cost of the system with no utility control. The system is managed onsite by the customer or a third party, and the software prioritizes customer needs over grid needs.
- **Hybrid**—In the hybrid business model, the utility may control the system at certain times, and priorities can vary by program. Upfront costs may be shared between the customer and the utility.

3.4 REMOTE POWER SYSTEMS

The value chain of remote microgrids and nanogrids differs slightly in makeup from utility-scale and BTM systems. Figure 3.5 illustrates the major components of a remote power system project.

The business case for ESSs for remote power systems varies significantly between grid-tied and off-grid systems. Systems connected to the utility grid focus on synchronization issues and are pioneering software that can generate new revenue streams for asset owners by using ancillary services. On the other hand, off-grid systems integrate high penetrations of variable renewables and are addressing frequency and voltage challenges within a tightly confined space. In actuality, both sets of systems are critical to advancing greater reliance on various forms of DG and advanced energy storage. One might think that remote systems would lag behind their grid-tied counterparts, but this is not necessarily so. Remote systems have excelled in providing prototypes of robust smart inverters and containerized systems that can sustain operations in

Figure 3.5 Energy Storage Value Chain: Remote Power Systems



extreme heat and cold, and their performance is often a matter of life and death for users.

Defining the business case for energy storage within remote power systems requires several considerations. Some issues to consider are listed below

- *The need for 24/7 islanding capability requires a more robust (and sometimes redundant) infrastructure design.*
- *The costs attached to construction are higher due to logistical challenges faced in both cold and hot climates. Furthermore, transportation and installation costs are at a premium due to the distance to and from supplier locales and microgrid/nanogrid deployment sites. Many of these sites are also subject to extreme weather conditions, ranging from hurricanes, monsoons, typhoons, and severe storms, all of which increase costs.*
- *On the lower end of the scale (that is, nanogrids), economies of scale are hard to achieve. Small systems lack the ability to obtain bulk purchasing discounts, thereby increasing overall costs (and related implementation revenue). Small systems*

also incur greater costs for development/integration per unit of capacity.

- *While there may be legacy assets that can be integrated into microgrids, more often than not these assets will not be maintained well and will require upgrades and modifications to be incorporated into modern networks designed to optimize and maximize renewable generation harvest.*
- *Control costs are high due to the lack of available smart grid infrastructure at many sites and the need to rely on variable renewables to reduce operating costs. These factors, along with the complexity of managing a remote power system, result in control costs that are much higher than the costs in grid-tied systems.*

There are several remote power system market segments where ESSs have the potential to thrive. The list below details defining characteristics of each.

- **Commodity Extraction**—Remote commodity extraction industries are among the least developed markets for remote systems, but they could become among the most attractive over the long run. Mining, oil, and natural gas companies

typically have deep pockets, and due to the energy-intensive nature of industrial processes, are willing to pay for higher reliability and security of supply. On the down side, many commodity markets have been depressed recently and these companies are often hesitant to invest in new infrastructure not directly related to production or that require longer simple payback times.

- **Physical Islands**—Perhaps the most attractive remote power system markets in the world today are any physical islands that have yet to be connected to a larger grid and that burn diesel or some other fossil fuel as a primary source of electricity. A number of pilot projects have been launched in various developing market countries across the Caribbean, the Mediterranean, off of Africa, and throughout the Asia Pacific region. The key initiative driving this market is an effort to displace diesel or other fossil fuels with variable wind or solar PV resources. Once this fuel substitution take place, the need often arises for both energy storage and more sophisticated controls—in short, a remote power system.
- **Village Electrification**—In terms of sheer numbers, the village electrification segment of the remote power system market is expected over time to become the market leader for the overall market as a whole. Given that many of these systems will be extremely small in scale (ranging from 10 kW to 300 kW), the segment still remains relatively unattractive to utilities, financial investors, technology companies, and developers. However, recently a growing volume of entrepreneurial seed capital, utility corporate social responsibility funding, and capital from corporate and social investors is beginning to flow into new business models seeking to tap this market potential.

Nanogrids are easier to implement than microgrids in many ways. Therefore, many nongovernmental organizations (NGOs) and institutional sources of funding are interested in funding rural electrification via solar PV nanogrids. Introducing energy access in a modular way via nanogrids helps build economic activity through increased usage of lights, cell phones, and laptops, all of which lead to more transactions and greater information exchange, which, in turn, creates demand for and capacity to incorporate a more diverse suite of energy products and services.

Certain parameters exist to illustrate the market opportunities for energy storage for remote systems. Table 3.3 outlines key aspects and associated assumptions.

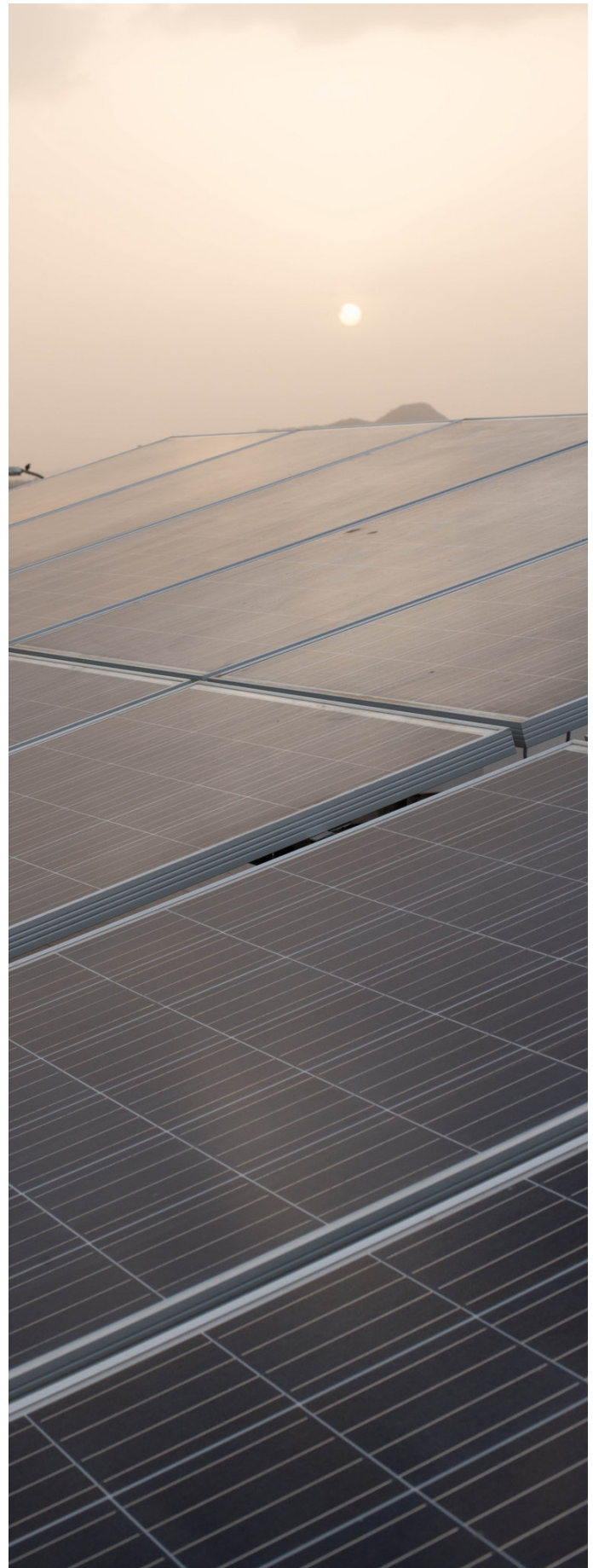


Table 3.3 Market Parameters for Remote Power Systems

Market Drivers	Customer Applications
Engineering Challenges	The plethora of companies offering hardware, software, and hybrid control solutions for remote microgrids and nanogrids continue to proliferate, with larger players (ABB, SMA, and General Electric) co-sharing market opportunities with smaller, more localized concerns.
Extreme Weather Patterns	The extreme weather events that have accelerated in frequency worldwide will continue, resulting in increased power shortages and a corresponding need for more resilient infrastructure globally, including regions not interconnected with a utility grid.
Economy Considerations	The global economy continues to suffer from uncertainty, which may limit the ability of governments to move forward with robust infrastructure development programs unless private sector funding can be leveraged.
Energy Access Goals	Developing countries will also benefit from efforts by the UN and others to end energy poverty through remote power systems. Several of these initiatives have crystalized in the past two years.
Diesel Prices	The key value proposition for microgrids, as well as nanogrids to a lesser extent, is the high cost of diesel generation in remote markets. The steep decline in oil prices has somewhat moderated this value proposition, although this motivation is still a fundamental driver of this remote market.
Declining Energy Storage Costs	Forecasts of continued decline in solar PV prices also anticipate a similar drop in energy storage costs, especially for Li-ion batteries, as well as the potential for major energy storage technology breakthroughs with substantial cost advantages.
Government Regulations	Current and planned regulations in place in the United States, the EU, and Asia Pacific will continue and will be enacted within current established timeframes. Trends toward tighter carbon limits are adopted at the current pace of approvals.
High DER Proliferation	Renewable energy targets as high as 100 percent are now being enacted in jurisdictions as diverse as Alaska, Hawaii, and Denmark. Many of these targets include remote microgrid and nanogrid applications and opportunities.

(Source: Navigant Research)

Regional Market Analysis and Forecasts



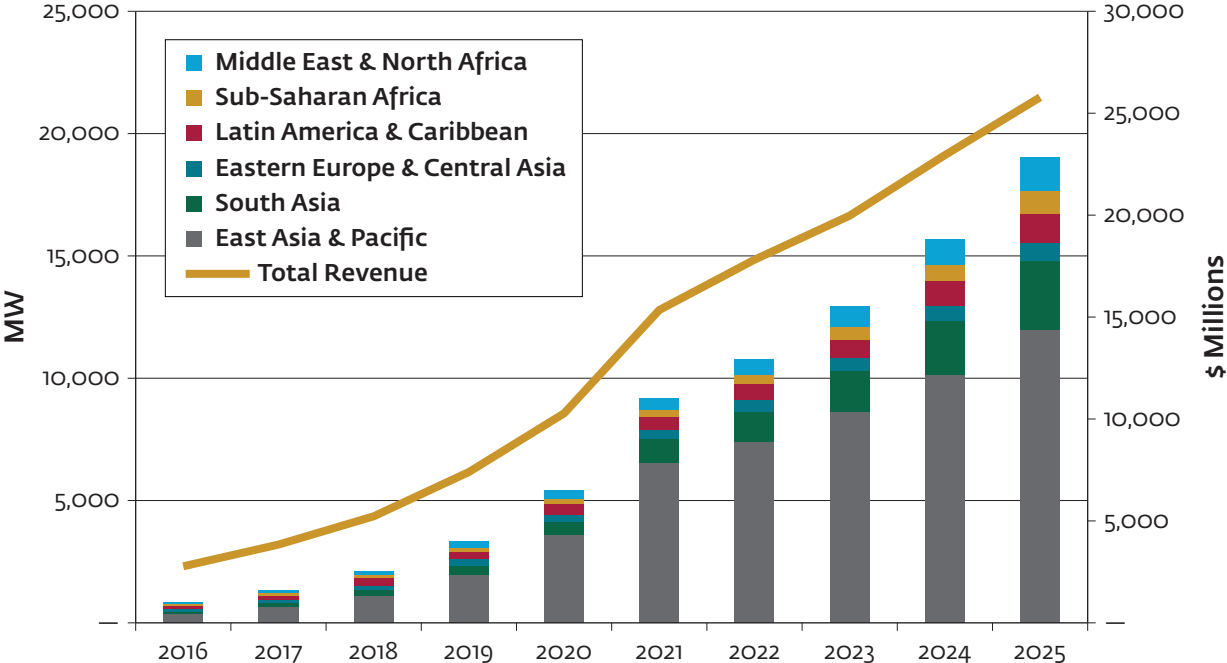
3.5 INTRODUCTION

In emerging markets around the world, there is only limited experience with energy storage, yet vast potentials exist to benefit from the technology. Many of these markets share similar energy market dynamics and needs for new resources. Driven by growing urban populations, many emerging markets have a significant need for new electricity reserve capacity, particularly to meet peak demand. Many emerging market countries have a weak grid infrastructure that is susceptible to frequent outages and that has only limited capacity to effectively integrate local renewable energy resources. Furthermore many of these countries have not yet provided

electricity service to portions of their population, providing an opportunity for microgrids equipped with energy storage to negate the need to expand centralized grid infrastructure to new areas. Energy storage is a valuable tool to support the needs of many emerging markets and using it can provide a reliable peak capacity resource, improve grid reliability, and facilitate the integration of renewable energy.

Chart 3.1 provides forecasts for new energy storage capacity and revenue for each of the six major developing regions identified in this report.

Chart 3.1 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Region, Emerging Markets: 2016–2025



(Source: Navigant Research)

The development of distributed and local energy resources, including renewables and energy storage, can provide significant economic growth, jobs, and a sustainable energy future in emerging markets. Energy storage deployments in emerging markets worldwide are expected to grow by over 40 percent annually in the coming decade, resulting in approximately 80 GW of new storage capacity. The following sections explore energy storage market activity, challenges, and potential in emerging markets worldwide.

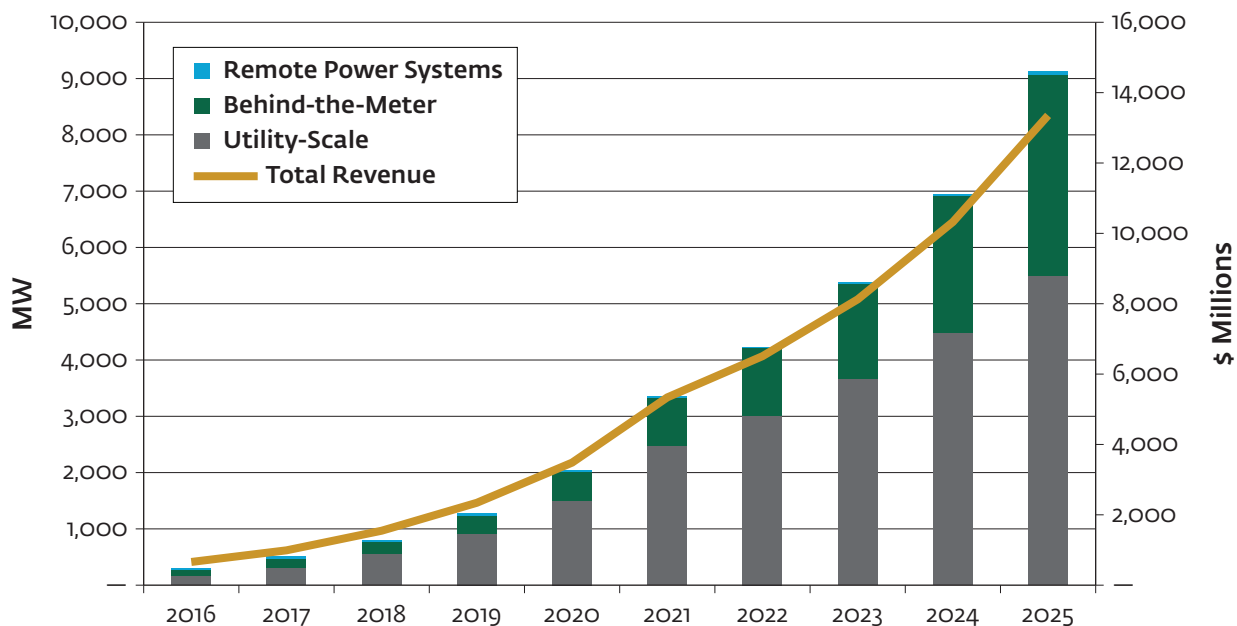
3.6 EAST ASIA & PACIFIC

There are two main types of power grids found in the Asia Pacific region, each with different characteristics and opportunities for energy storage. On one side are the highly developed nations—such as Japan, South Korea, New Zealand, and Australia—and certain major cities with advanced grids that operate reliably and utilize advanced technologies. In contrast, many nations in the region are still developing fundamental infrastructure systems and have limited or unreliable power grids. These developing regions areas are also experiencing rapid population growth and urbanization, resulting in an increasing demand for electricity. The expanding

grid in developing countries is likely to include large amounts of renewable energy, which is becoming increasingly cost-effective throughout the world. The majority of ESSs in these areas will be owned by utilities or grid operators, because the industry has not developed to the point of having a competitive market of energy system providers. Additionally, in many of these areas the industry is likely to adopt a more distributed approach to grid development, using more local power generation and microgrid systems.

We expect that the largest energy storage market in the East Asia & Pacific region will be China. The Chinese economy has gradually been opening to foreign investment and free market forces over the past several decades, and this trend has been accelerating in recent years. The state-owned State Grid Corporation of China—the world’s largest utility—has already been deploying ESSs to provide various services throughout its grid. Furthermore China is in the process of reforming its energy markets to allow non-state owned power providers to enter the market, opening opportunities for IPPs to provide ancillary and capacity services with ESSs. (See Chart 3.2).

Chart 3.2 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Market Segment, China: 2016–2025



(Source: Navigant Research)

The region is expected to be a major market for remote microgrids, although the requirements for these projects vary greatly on a country-by-country basis. Developing nations in the region face more urgent issues related to power supply. Key challenges that developing Asia Pacific nations face include low electrification, an underdeveloped power grid infrastructure, and a lack of capital to underwrite new technologies to advance power grid services. In a region where simply providing sufficient electricity is challenging, governments and utilities are struggling to establish efficient ways to supply power to rural villages and remote islands. The thousands of islands throughout this region with limited or new electrical infrastructure present some of the most attractive near-term opportunities for energy storage. In order to capitalize on this opportunity, developers and governments must work together to overcome the high cost of deploying systems driven by logistical challenges and a lack of local technical expertise. The Sumba Island case study in section 4.4 of this report provides an example of successful collaboration.

The individual governments and market stakeholders in Asia Pacific seek to solve their current shortage of reliable energy

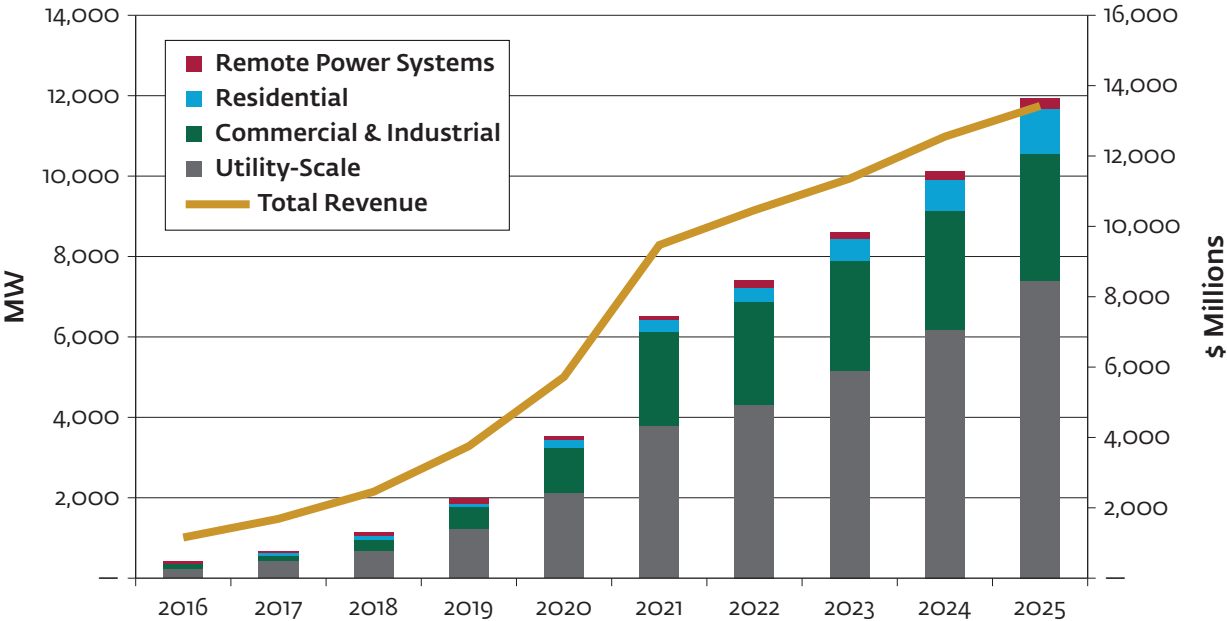
East Asia & Pacific Market Barriers

- Vertically integrated, highly regulated energy markets
- Access to affordable financing
- Limited renewables outside of select markets
- Underdeveloped grid infrastructure

by launching various initiatives, policies, support programs, and test trials. The focus areas of these microgrid initiatives are geared toward increasing power capacity at the test sites and then allowing industry (including utilities) to take the next steps forward.

Outside of the developed markets of Japan, South Korea, Australia, there are currently 28,610 MW of energy storage

Chart 3.3 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Market Segment, East Asia & Pacific: 2016–2025



(Source: Navigant Research)

systems deployed in East Asia & Pacific. (See Chart 3.3). However over 88 percent of this capacity comes from pumped hydro storage (PHS), which are primarily state-owned plants in China (25,399 MW). Pumped storage plants are also operational in the Philippines and Taiwan. In 2016, AES completed a 10 MW installation in the Philippines, the first grid-scale battery energy storage facility in Southeast Asia.

Across the developing markets in the region, there are currently 1,784.5 MW of ESS capacity in the pipeline. The majority of this capacity (1,640 MW) is pumped hydro storage. However battery technologies are beginning to make an impact. There are 141.5 MW of li-ion storage projects in the pipeline with 100 MW in the Philippines, and 41.5 MW in China. The market may be further catalyzed by new policy initiatives, such as China’s target for 10 GW capacity of concentrated solar power by 2020, and plans for technological innovation, for example, in thermal energy storage. There is also the opportunity for knowledge and technology transfer from hybrid solar/storage projects that have been announced in some Pacific Islands, for example Reunion, Guadeloupe, and American Samoa. A leading battery project developers in the

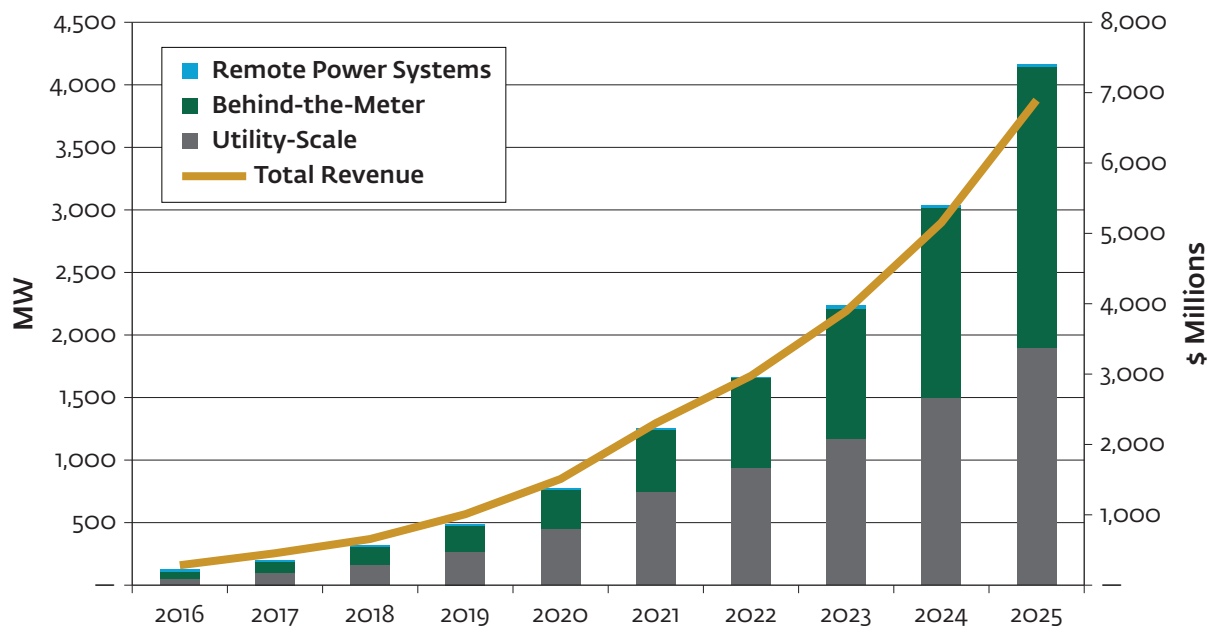
region’s emerging markets is AES Energy Storage Japanese conglomerate Marubeni Corp.

3.7 SOUTH ASIA

The market for energy storage in the South Asia region is dominated by India. (See Chart 3.4). In India, several key factors are driving the market for energy storage, perhaps most notably the ambitious National Solar Mission. In 2014, Prime Minister Narendra Modi announced a national target to install 100 GW of solar PV capacity by 2022, which would make the country one of the largest solar power markets in the world. As of the end of September 2016, the cumulative installed solar capacity was over 8.6 MW. India’s rapid population growth, particularly in urban areas, is driving the need for increased investment in both electricity generation capacity and T&D infrastructure across the country. Furthermore, the country experiences frequent power outages due to severe weather, insufficient generation capacity, and fragile infrastructure, which contribute heavily to the need for new investments to improve the grid’s resilience and reliability.

Despite a major effort by government and regulators, deployments of both renewables and energy storage have

Chart 3.4 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Market Segment, India: 2016–2025



(Source: Navigant Research)

South Asia Market Barriers

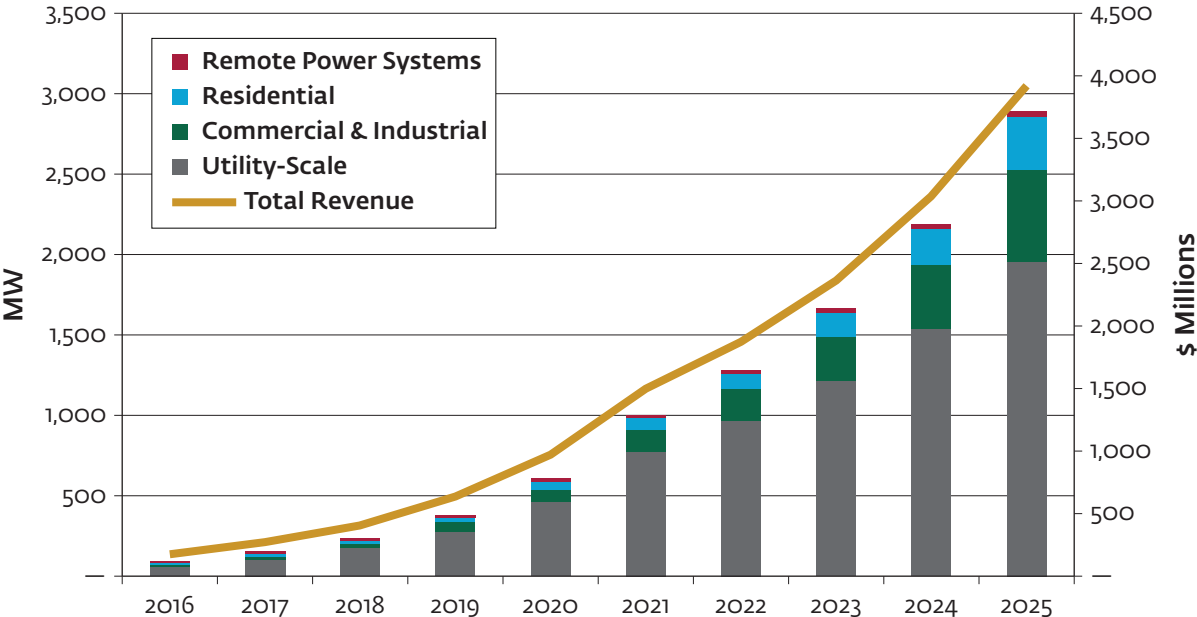
- Underdeveloped grid infrastructure
- Limited local experience and knowledge of energy storage
- Access to affordable financing
- Lack of competition in markets

lagged behind expectations in India. A number of planned projects have been delayed or canceled due to a lack of affordable financing and to cost overruns resulting from poorly planned development and limited local technical expertise. Furthermore the weak condition of the grid and poorly organized energy markets are proving to be significant barriers to deploying storage. However there have been positive developments in recent months. A July 2016 tender for several hundred megawatts of new solar PV capacity includes the requirement that every 50 MW of PV capacity must have

5 MW / 2.5 MWh of associated energy storage. This type of requirement, typically only used for island grids, is necessary to ensure grid stability because the ESSs will be used to smooth solar PV output and control ramp rates. To overcome barriers to storage development in India and throughout the region, this type of requirement for combined solar PV plus storage may be crucial for establishing local technical expertise and developing investor trust in the technology and project development process.

Other than India, there have been very few energy storage market developments in South Asia to date, and deployments are expected to be limited over the coming decade. (See Chart 3.5). One exception would be increasing interest in pumped hydro storage throughout the region. In October 2016, governments from Nepal and Bangladesh signed an agreement to develop a total of 1,600 MW of PHS capacity in Nepal through two different projects. While this ambitious plan could greatly improve the region’s ability to integrate new renewable generation capacity, the fact that there have been barriers to PHS development around the world could mean that there could be significant delays to these projects in South Asia, which have barely begun their preliminary planning. It is very

Chart 3.5 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Market Segment, South Asia: 2016–2025



(Source: Navigant Research)

possible that full commissioning of these PHS projects could not happen until past the 10 year horizon for these forecasts. In the near-term, much of the new energy storage capacity in the region is expected to come from the remote power system market segment. This new capacity will primarily be deployed for village electrification and physical island systems to expand energy services to new customers and improve reliability.

3.8 EASTERN EUROPE & CENTRAL ASIA

The market for energy storage in Eastern Europe & Central Asia is dominated by a single technology, pumped hydro storage. This region has a significant installed base of energy storage resources with 9.3 GW of pumped hydro capacity installed, and an additional 3.5 GW that is either under construction or in planning stages. Storage systems are spread among 10 countries in the region. The countries with the largest capacity are Ukraine with 2,568 MW, Poland with 1,158 MW, and the Czech Republic with 1,102 MW. This existing capacity of storage resources will limit the need for additional large-scale storage providing peak capacity and resource adequacy in the region in the near-term. New demand for energy storage will be driven by the need for grid support/resiliency and the integration of variable renewable generation. It is expected that 2.3 GW of new variable generation (wind & solar) capacity will be installed in the region in 2016, with a cumulative 31.1 GW of new capacity by 2025.

There are a number of challenges facing energy storage development in Eastern Europe. Electricity markets in the region have traditionally been very highly regulated and dominated by state-owned enterprises dating back to the Soviet era. Although there is a push for greater competition through deregulation, that transition is happening at different rates throughout the region, with little progress being made in most markets. Given the lack of competitive markets, there are limited opportunities for independent companies to own storage assets. It is likely that mandates or other government influences will be required to stimulate the regional market. A further challenge is the high level of generation overcapacity throughout the region. For example, at most times, Bulgaria has available an estimated 80 percent of excess generation capacity as a result of Soviet-era policies to build large centralized generation facilities despite the limited demand for energy. This excess capacity can limit the need for new renewable generation and energy storage because the grid has sufficient flexibility to accommodate fluctuations in demand.

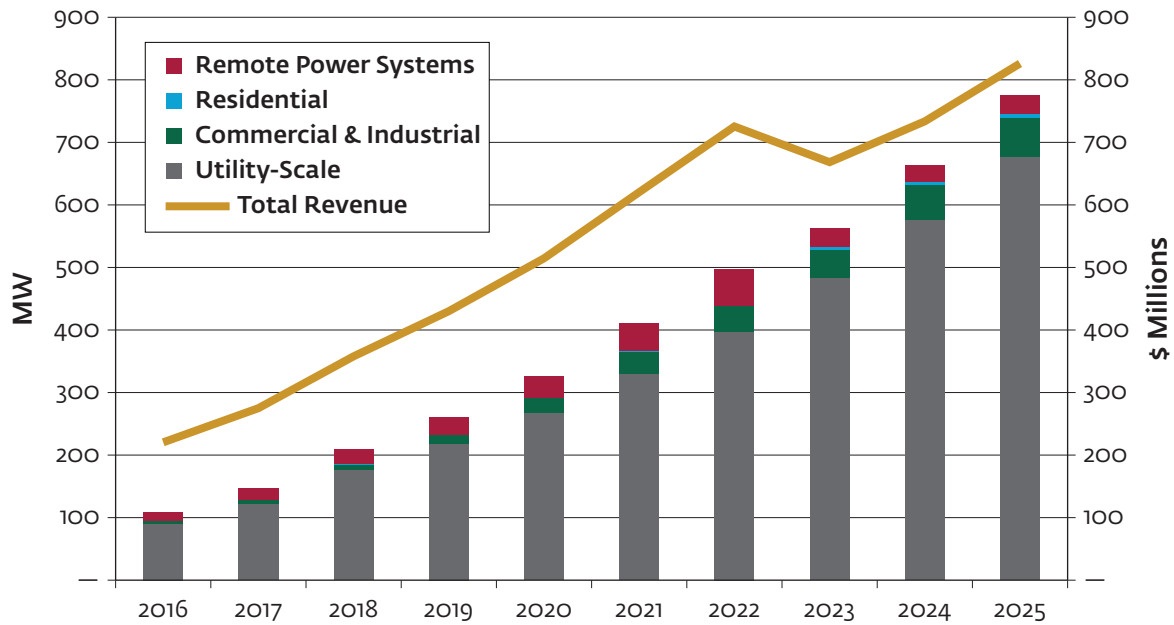
Eastern Europe & Central Asia Market Barriers

- Already existing PHS resources, limited need for new ESS.
- Current generation over-capacity
- Highly regulated, state-run energy markets
- Lack of financing and vendors for distributed renewables and storage

Despite these challenges, there is a potential for a strong energy storage market in Eastern Europe in the coming decade. The most attractive markets are likely to be the European Union (EU) countries in the region (Hungary, Latvia, Slovenia, Estonia, Lithuania, Romania, Bulgaria, Czech Republic, and Slovakia) since these countries are bound to EU laws regarding electricity market deregulation and reduction of greenhouse-gas emissions. In addition, there are potentially attractive opportunities in Southern European countries, such as Croatia, Serbia, and Georgia. In Central Asia, it is noteworthy that Kazakhstan has committed to increasing variable renewable energy from wind and solar, which introduces the possibility of energy storage deployments. It is likely that most energy storage activity in the region will involve distribution-level systems designed to improve grid reliability and integrate distributed generation. These systems can also allow for the deferral of infrastructure investments, a benefit which large-scale pumped hydro plants cannot provide. Furthermore there will likely be numerous opportunities to expand or upgrade existing pumped hydro storage plants in the region. An estimated 44 percent of the region's pumped hydro capacity (4.1 GW) was built before 1990 and will require upgrades and turbine replacements in the coming years.

As shown in Chart 3.6, deployments of distributed (behind-the-meter) energy storage are expected to be slow growing, and limited overall in the coming decade. While the region does have a less reliable grid compared to developed regions, there have been to date limited deployments of distributed

Chart 3.6 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Market Segment, Eastern Europe & Central Asia: 2016–2025



(Source: Navigant Research)

solar PV and other renewables, which are a key precursor to development of distributed storage. Much of the slow growth is due to regulations and rate structures which make it uneconomical to deploy behind-the-meter resources, as well as to the lack of available vendors and project financing.

3.9 LATIN AMERICA & THE CARIBBEAN

Latin America is seen as one of the most attractive emerging markets for energy storage development. The anticipated growth in renewable generation, rapidly growing populations, and relatively unstable grid conditions are among the major factors driving interest in energy storage throughout the region. From 2016 to 2020, Navigant Research expects that an additional 21 GW of wind³ and 15 GW of solar⁴ generation will be added to the grid in Latin America. In order to effectively integrate and utilize these new resources, grid operators must invest in new infrastructure, including energy storage, to help match supply with demand and to ensure system stability. To date there is approximately 1 GW of ESS

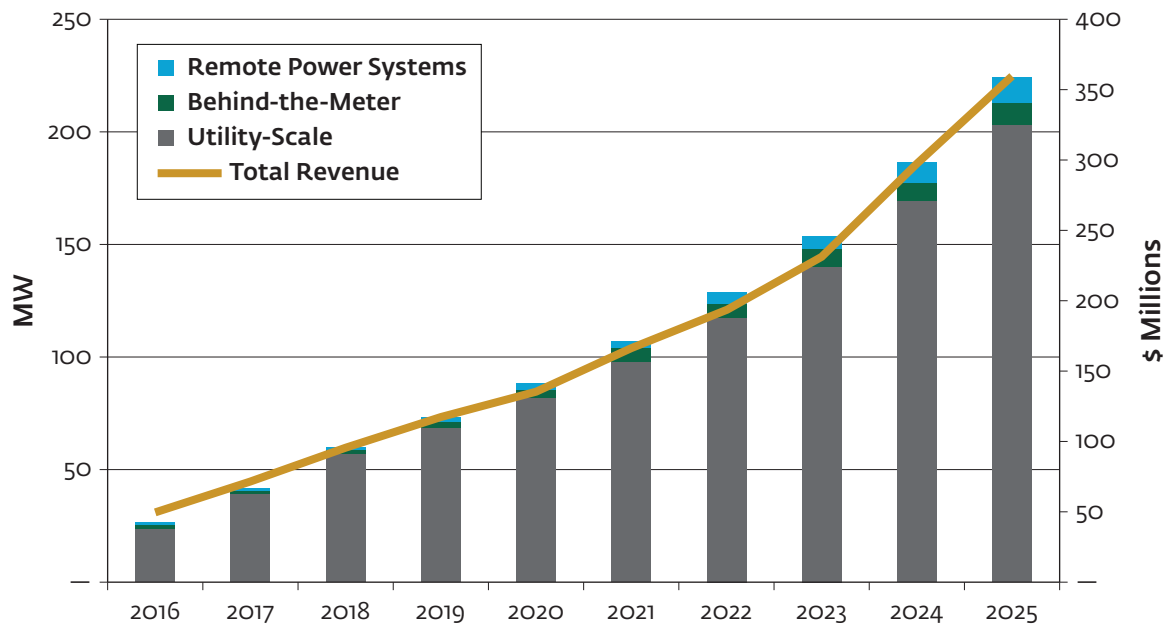
capacity installed in the region. However nearly 95 percent of that capacity comes from two pumped hydro storage facilities in Argentina. The battery energy storage market has been gaining traction, with three large-scale systems commissioned in Chile and El Salvador over the past three years, developed by AES Energy Storage and Altairnano, accounting for 42 MW of capacity. The regional pipeline of storage projects continues to grow with a diverse set of technologies, including battery, compressed air, flywheel, pumped storage, and thermal energy storage projects.

Three countries in Latin America—Chile, Mexico, and Brazil—have emerged as the most attractive markets for both renewable energy and energy storage development. These countries, along with Argentina, represent the largest and most advanced economies in the region and have a history of significant foreign investment. This has led to well-established finance sectors supporting the development of renewable and energy storage projects by offering relatively low-cost capital. Additionally these countries have, or are in the process of establishing, relatively deregulated electricity markets. By separating companies that provide either generation, transmission/distribution, or retail services, these markets have allowed

³ For comparison, The Global Wind Energy Council's forecast for Latin America from 2016–2020 totals 31 GW.

⁴ GTM Research has published a cumulative forecast for 2016–2020 at 27 GW of solar for the region.

Chart 3.7 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Market Segment, Brazil: 2016–2025



(Source: Navigant Research)

third parties, including multinational IPPs, to own and operate energy projects. This framework has resulted in the successful development of battery ESSs, including the Angamos project discussed in section 5.3, that were independently developed and financed by foreign firms and joint ventures. This structure in turn led to projects then being free to contract to provide services to the grid operator.

Mexico, Chile, and Brazil also have significant renewable resources and their governments are supportive of clean energy development. Chile and Mexico have both recently held successful auctions for new renewable capacity that have had very high participation and some of the lowest prices per megawatt-hour globally. Government support has also led to a relatively stable and transparent regulatory framework for renewables in these countries, which along with longer-term power purchase agreements (PPA) and contracts have provided the stability required for major foreign investors and developers to enter the market. Similar contract structures for energy storage will have a major impact on investor confidence and the overall return on investment (ROI) of new projects. While only a few major ESS projects have been commissioned outside of Chile to date, the level of government support, new renewable

generation, and transparent regulatory structures are expected to result in a rapidly growing market throughout the region.

The Chilean electricity market was deregulated in the 1980s resulting in the unbundling of generation and transmission/distribution, along with large-scale privatization that led to major new investments. Recently, the country's market has been undergoing changes driven by increasing demand for electricity and new infrastructure development, notably the interconnection of three separate regional grids. Northern Chile's Atacama Desert has the strongest solar resource in the world, and as a result, solar PV has been substantially developed there. Much of the energy storage activity to date has focused on integrating solar PV in the country's north.

Though activity has been limited to date, the Mexican market is ramping up, driven in part by regulatory reforms to break up the state-owned electricity monopoly the Comisión Federal de Electricidad (CFE). Under these reforms, independent operators could sell both capacity and ancillary services in a competitive market, presenting opportunities for renewable and energy storage developers.

Latin America & Caribbean Market Barriers

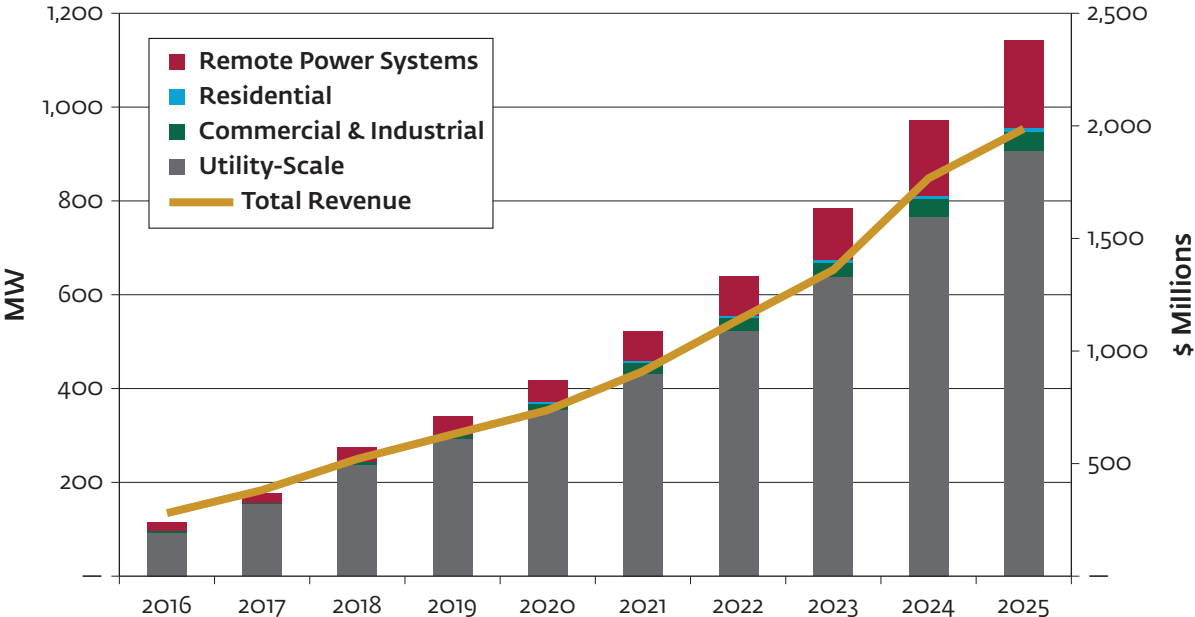
- Economic instability in some countries
- Existing market regulations that limit innovation
- Access to affordable financing
- Underdeveloped grid infrastructure

Today, Mexico produces about 23 percent of its electricity from renewable energy, and its new target is 35 percent by 2024. In addition, large energy consumers are now legally required to source 5 percent of their electricity needs from renewable energy starting in 2018. Following these reforms, Mexico’s first renewable energy auction in March 2016 resulted in 10 projects with 15-year and 20-year contracts for clean energy certificates.

This new ambitious target presents challenges with regards to the integration of variable renewable energy, and for this reason, both the Ministry of Energy (Secretaria de Energia, SENER) and the State-owned company Federal Commission of Electricity (CFE) are exploring storage solutions, such as pumped storage hydropower or batteries. The Energy Sector Management Assistance Program (ESMAP) is supporting an analysis of the regulatory framework to evaluate the feasibility of storage.

As the region’s largest economy and electricity market, Brazil has vast potential for renewables and energy storage development. (See Chart 3.7). However recent political and economic instability has negatively impacted development in the country. In the past several months, six developers who were awarded PPAs in Brazil’s first energy auction in 2014 have undertaken efforts to terminate their agreements due to a lack of affordable financing and the absence of a local supply chain, which is required under Brazilian law. The country will need to undertake major changes to its auction program and energy policies in order to attract the same level of interest that Mexico, Chile, and Argentina have garnered from investors

Chart 3.8 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Market Segment, Latin America & the Caribbean: 2016–2025



(Source: Navigant Research)

and developers. While the successful efforts in Mexico, Chile, and Argentina have focused on renewable energy development, similar programs can be enacted for energy storage. In other regions, new renewable energy projects are required to include energy storage. Thus an established and well-functioning renewable energy procurement model can also allow for eventual development of a strong storage market.

As shown in Chart 3.8, a significant portion of the new energy storage capacity expected to be deployed in Latin America and the Caribbean will likely come from remote power systems. Most of this new capacity is anticipated to be in physical island microgrid systems. There are a number of ESS projects already in operation or planned on islands throughout the Caribbean that are utilizing multiple technologies. These include an 8 MW li-ion system developed by AES Energy Storage in the Dominican Republic, where that company is also already planning a second project. There are also numerous smaller ESS projects being planned to facilitate renewables integration in Puerto Rico, the Cayman Islands, Jamaica, and the U.S. Virgin Islands. Perhaps the most active market in the Caribbean is Aruba, where the local government has established an ambitious goal of energy independence to use mainly renewable generation by 2020. There are two flywheel energy storage projects totaling 10 MW under development by Temporal Power, along with an underwater compressed air energy storage system from Hydrostor, and numerous smaller battery projects.

3.10 SUB-SAHARAN AFRICA

A number of challenges have resulted in limited energy storage market activity in Sub-Saharan Africa to date. The market has been restricted by a lack of affordable financing, limited local technical experience, and a lack of familiarity with newer technologies that are used in utility scale energy storage systems, in addition to the logistical challenges faced by pilot pioneering infrastructure projects in much of the region. Although an estimated 1.6 GW of grid-tied energy storage has to date been installed in Africa, 1.4 GW of it comes from large pumped hydro storage.

During the forecast period, South Africa is expected to be the largest market in the region for energy storage. The country has been capitalizing on significant renewable energy resources in recent years with large deployments of renewables, mainly solar PV and wind, but also in some cases including CSP with thermal energy storage. South Africa does have existing storage

Sub-Saharan Africa Market Barriers

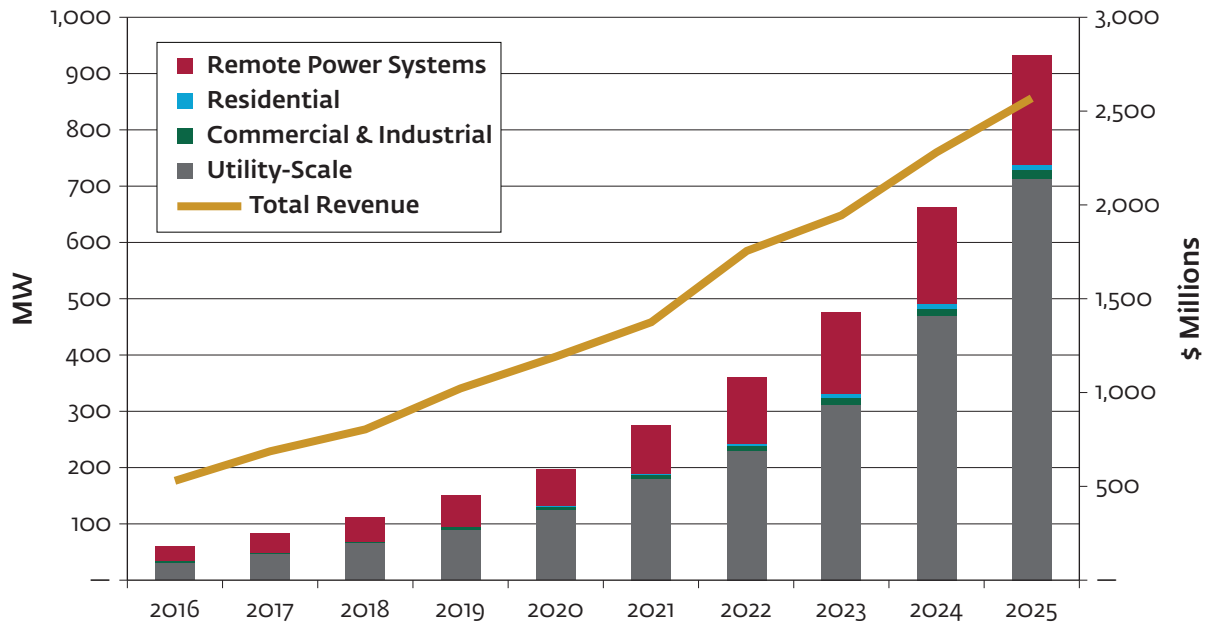
- Access to affordable financing
- Political and economic instability
- Lack of local technical expertise
- Underdeveloped grid infrastructure
- Limited renewable energy development to date

resources in the form of 1,580 MW of pumped hydro storage, and this figure may double by the end of 2016 if the delayed Ingula plant comes online with an estimated 1,332 MW of new capacity. Eskom is South Africa's monopoly supplier. The group generates the majority of electricity in the country and is the sole buyer of electricity from IPPs as well as the dominant player in the distribution system. Eskom South Africa is part of the Southern African Power Pool, which as of 2013 was looking into developing an ancillary services market for the Southern Africa region. However, no concrete results of these efforts have yet been disclosed. The substantial amount of newly-commissioned renewable generation, along with a more advanced grid and project development/finance environment, makes South Africa the top market in the region.

As has been seen in South Africa, the integration of renewable generation is likely to be the key driver for energy storage in Africa. There are strong renewable resources in the region, with a growing level of government support in many countries. We expect an estimated 25.9 GW of new wind and solar capacity to be installed by 2025. A portion of this capacity will come from distributed solar PV systems which may include energy storage to enable islanding microgrids for facilities to maintain power supply during the region's frequent outages.

A number of European entities, both public and private, are focused on remote power systems in the Sub-Saharan Africa region, historically one of the poorest parts of the world. However, it is now economically one of the fastest growing regions, largely due to its impoverished past setting the stage for the emergence of new economic activity. According to

Chart 3.9 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Market Segment, Sub-Saharan Africa: 2016–2025



(Source: Navigant Research)

Deloitte, annual economic growth has averaged 6 percent over the last 15 years, and similar growth trends are expected to persist over the next five years. Industrial activity is largely focused on extraction of oil and gas and mineral resources—often located far from any conventional grid—as well as on agricultural and forestry ventures (also often located in remote areas). Both of these economic opportunities are ideal applications for nanogrids and microgrids.

In the Sub-Saharan Africa region, remote power systems are expected to provide roughly 70 percent of energy services over the next few decades given the lack of grid connectivity in the region. (See Chart 3.9). It is expected that the majority of these remote power systems will include energy storage as the technology continues to decrease in price, and many power systems will begin to rely more heavily on variable renewables. However it is also estimated that the necessary funding gap to meet the needs for Sub-Saharan Africa’s continued economic growth exceeds 50 percent or even 60 percent of the required levels of investment. This gap is being addressed by nations of the European Union (EU), China, Japan, and the United States through loans, equity investments, and grant-based

development financing, as well as through private sector investments.

3.11 MIDDLE EAST & NORTH AFRICA

In the Middle East and North Africa region, there has been limited energy storage project activity to date. Of the 1,026 MW of capacity currently installed, 1,020 MW comes from a single pumped hydro plant in Iran. While most battery projects have been very small research and development (R&D) systems, there is currently a pipeline of 128 MW of a battery energy storage system (BESS). This includes two NaS battery projects from NGK Insulators in the United Arab Emirates, representing a combined 648 MWh of capacity, as well as a project in Jordan. There are also a number of CSP projects that include thermal energy storage installed in Morocco and the United Arab Emirates.

While to date there have been limited energy storage deployments in the Middle East, nations in the region are working to exploit their significant renewable energy resources. Utility-scale solar deployments are expected to increase at a compound annual growth rate (CAGR) of 16.2 percent over



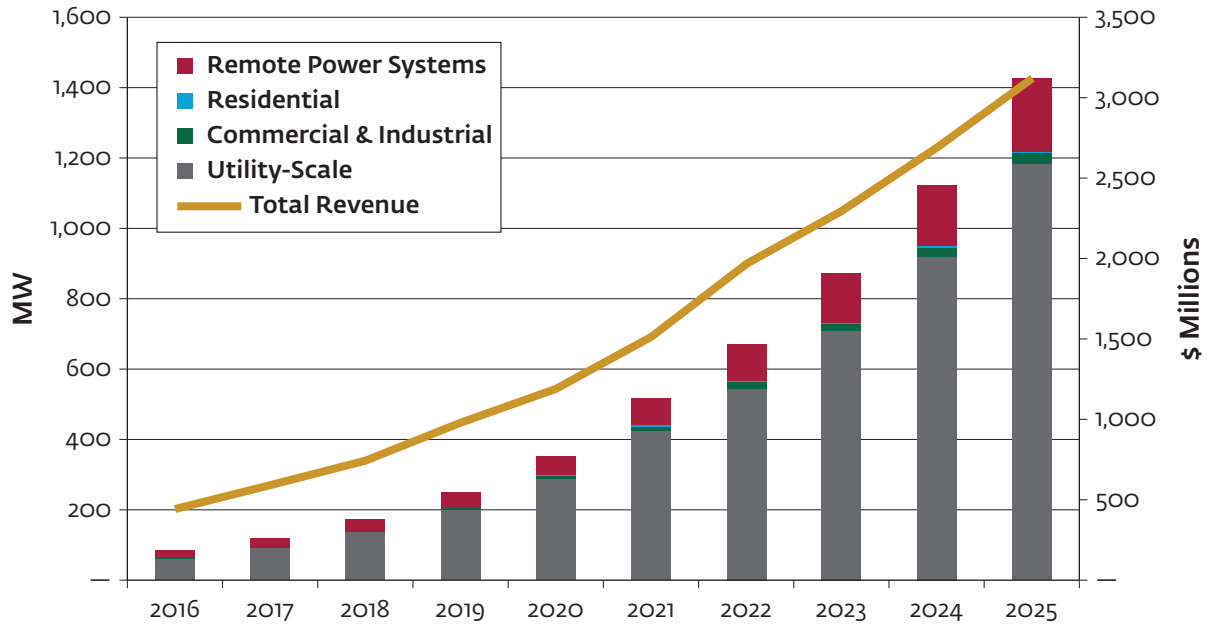
Middle East & North Africa Market Barriers

- Political instability
- Highly regulated, state-run energy markets
- Low-cost fossil fuels in most of region
- Access to affordable financing

the coming decade with 33 GW of new capacity expected. (See Chart 3.10). These developments, combined with a rapidly growing and increasingly urbanized population, are expected to lead to increasing demand for energy storage to help manage intermittency and to improve grid resilience in the region. Many countries in the Gulf region are looking to deploy large amounts of renewable energy to reduce the amount of domestic fossil fuels used for local power generation. This will free up that fuel to be sold abroad, bringing in much needed revenue for government programs. These countries are exploring energy storage to help integrate these new generation resources and to help improve the grid's stability and reliability. However the historical low cost for fossil fuels and subsidized retail electricity, combined with highly regulated electricity markets, remain significant barriers to storage development since there is little urgency or ability for customers to deploy BTM technologies.

The most significant barrier to developing energy storage development, or to obtaining foreign investment, is the political and economic instability throughout the region. Other challenges facing energy storage in the Middle East and North Africa are similar to those in other developing regions, including a lack of affordable financing, local knowledge, and technical expertise. Despite the vast potential for renewable energy, particularly solar, only a limited amount of new generation capacity has been built to date, and national targets previously set have often not been met (notably by Saudi Arabia). Most markets in the region are highly regulated and dominated by state-owned entities which face only limited competition. However this dynamic does not necessarily limit opportunities for energy storage. For example, there is some momentum from independent power producers (IPPs) in markets like Egypt, Morocco, Jordan, and Tunisia. If a country's dominant utility or government is considering deployment of large amounts of storage, they may seek to do so directly rather than working through private companies in a competitive market. Thus it is critical for vendors and IPP companies to educate energy ministries, national electric utilities, power system regulators, and other large C&I customers in the region on the potential benefits of energy storage. There is also a need to pilot commercial-scale storage projects that provide solid reference cases to demonstrate the value of technology.

Chart 3.10 Projected Annual Stationary Energy Storage Deployments, Power Capacity and Revenue by Market Segment, Middle East & North Africa: 2016–2025



(Source: Navigant Research)

The potential for energy storage development in the Middle East and North Africa is driven mainly by a rapidly growing urban population throughout the region, as well as by expected additions to renewable energy capacity. Both factors will result in the need for new flexible generation resources and peaking capacity in addition to new infrastructure to accommodate increasing demand and variable generation. A notable market with high potential for energy storage in the region is Jordan, where a leading project developer, AES Energy Storage, is currently developing a 20 MW lithium ion ESS. Jordan has two main challenges; increasing energy demand (particularly peak demand) due to population growth and urbanization; and very limited domestic fossil fuel resources to meet demand. Over 95 percent of the country’s energy needs come from imports, which have occasionally suffered from disruptions, resulting in high retail electricity prices. The Jordanian government through its new renewable energy law has encouraged development of wind and solar PV to help provide additional domestic

electricity supplies, and energy storage may soon be required to help effectively integrate and manage the growing amount of variable generation within the country’s power system.

Opportunities for concentrated solar power (CSP) and thermal energy storage projects are of particular interest in this region. In February 2016, Morocco inaugurated the 160 MW Noor 1 CSP plant, which it plans to augment by 2018 with two additional phases totaling 350 MW. A 43 MW CSP installation is under construction in Duba, Saudi Arabia, that is expected to start producing power in 2017. Saudi Arabia has announced plans to implement as much as 34 GW of CSP in the coming decades and the Sultanate of Oman is also considering large utility-scale use of CSP. In Oman, in 2013, GlassPoint commissioned a 7 MW pilot project for enhanced oil recovery using CSP technology, followed by an announcement in 2015 of a \$600 million 1 GW project to be fully financed by Petroleum Development Oman.

Case Studies



4.1 INTRODUCTION

The energy storage industry is taking shape in different ways around the world. As a result, successful projects have been undertaken in numerous shapes and sizes, and no one-size-fits-all approach has been found to be ideal across all markets. This is especially true in emerging economies where projects have often been designed to solve a very specific problem, with limited opportunities for replication in other areas. To fully realize the potential of energy storage, it is crucial that project developers and regulators in emerging economies understand the factors that have led to successful projects in other regions and how the right conditions can be established in their own areas. The following sections provide overviews of three projects as case studies for successful energy storage development. These projects were undertaken in highly developed, middle income, and emerging economies. The sections provide details on the specific factors in each project that have resulted in success and replicability.

4.2 VILLAGE OF MINSTER, OHIO, UNITED STATES

The energy storage system commissioned in early 2016 in Minster, Ohio, in the United States, has been cited as a leading case study for effectively deploying this technology. The project offers an example of providing value to multiple stakeholders, including the local municipal government, while also improving the stability of the grid and facilitating the integration of renewable energy. Minster is a small town with only about 2,800 residents. However there are several large C&I facilities which require reliable and high quality power for their operations. As a part of the PJM Interconnection regional market, the town must purchase electricity in a competitive market with costs impacted by the total peak capacity required. Minster's local government has been exploring possibilities to reduce electricity expenses.

The town worked with developer Half Moon Ventures to construct a 4.2 MW solar PV plant that will reduce the total amount of energy purchased from the market while also reducing the town's carbon footprint. However solar PV alone cannot guarantee a reduction in the town's peak demand, which drives much of the overall cost for electricity. With this and other factors in mind, Minster and Half Moon Ventures developed a large-scale energy storage system with systems integrator S&C Electric and battery provider LG Chem. The 7 MW / 3 MWh li-ion system will provide numerous benefits for the town's residents and businesses. This project was financed and is owned by the developer Half Moon Ventures, but details on the financing structure have not been made public.

The stacking of revenue streams will be important for energy storage to be a solid investment, particularly in emerging markets where project development may be more expensive and where there are fewer opportunities to generate revenue in competitive markets. The town's primary stated goal for this project is to reduce its cost for imported electricity by reducing the total peak demand which determines its peak load contribution to the regional grid. However peak demand is rarely reached in the town and the ESS may only be required to actually reduce peak demand for about 10 days per year, enabling the system to be available for other services most of the year. In practice, the primary application for this system is providing frequency regulation services in PJM's competitive ancillary services market. When peak demand is unlikely to be met, the system bids its capacity into the market to respond to signals to absorb or discharge power, earning revenue based on the amount of energy dispatched. Additionally, this system is used to improve power quality in the village, a key consideration for its C&I customers. The addition of a large solar PV system on the town's grid presents the possibility of rapid fluctuations in output which can cause damage to grid infrastructure. By smoothing solar PV output, the ESS

allowed the town to avoid purchasing power factor correction capacitors that would cost an estimated \$350,000. According to a July 2016 article on UtilityDive, the power purchase agreement tariff is 7 US cents / kWh generated plus a premium of 2.5 US cents / kWh to reflect the “smoothing” of the PV power and deferred investment in reactive power compensation. The resulting all-in power cost of 9.5 US cents / kWh is at parity with Minster’s average retail tariff. The economics are further improved by a payment from the PJM frequency regulation market, determined through a bidding process.

A key aspect of any energy storage project is trust that the system will deliver expected value and savings, thus unlocking affordable financing. In the Minster project, the performance of the battery was guaranteed through a warranty from LG Chem, a well-established and reputable vendor. Furthermore, performance in the PJM frequency regulation market was guaranteed by Viridity, an S&C Electric and market analysis software provider. The involvement of these trusted vendors limited the risk to the customers and kept project costs low because they enabled affordable financing. Another key to the success of this project was the use of advanced software platforms provided by S&C and Viridity to manage the operation of the system and to analyze opportunities to earn revenue in the PJM market. These platforms can greatly improve a project’s economics by identifying the most lucrative operation of the storage system at all times.

Software is key to improving the value proposition of energy storage, particularly in emerging markets, by determining the ideal system size and analyzing the optimal services a system should provide. This project provided a model that should be, and already is, being replicated around the world. A challenge for this replication, however, is whether a project can be financed with complex revenue streams that financiers are unfamiliar with. Working with reputable and established vendors can greatly reduce the risk to customers and lenders for such projects.

4.3 AES ANGAMOS ENERGY STORAGE ARRAY, CHILE

Commissioned in 2012, AES Energy Storage’s Angamos li-ion storage facility was the second large-scale advanced energy storage project undertaken in Chile. (See Picture 4.1). The project is integrated with a 544 MW coal power plant near the town of Mejillones. The plant is owned by AES Gener, an

Picture 4.1 Lithium Ion Battery Containers at the AES Angamos Plant in Chile



(Source: AES Corp.)

AES Corporation subsidiary which also owns the Angamos storage system. Building on the success of AES’s first energy storage project in the region, which was commissioned in 2009, the company developed the 2012 Angamos project to allow the thermal plant to operate at optimal efficiency levels while still meeting its required obligations to provide spinning reserve capacity. This legally required capacity is required to be available to maintain grid stability in the event of an unexpected transmission loss or the failure of a large generator. Furthermore the plant is required to adjust its output periodically in response to changes in the grid’s frequency because coal-fired plants are inherently inefficient and slow to respond to rapid changes in system frequency. The ESS with a 20 MW peak capacity can provide the plant’s required spinning reserves while also injecting and absorbing power, allowing the coal generators to run at optimal efficiency.

This project was privately financed by its owner Empresa Eléctrica Angamos S.A., which is a subsidiary of AES Gener and also owns the associated Angamos power plant. The ability of the corporation to privately finance this project greatly simplified the development process, and the owner’s close relationship with regulators and knowledge of the Chilean energy market resulted in streamlined interconnection and integration. It is estimated that the total investment required to develop and commission the Angamos ESS plant was roughly \$30 million. By covering the thermal plant’s reserve capacity and frequency regulation requirements, the plant will be able to increase its generation output by an estimated 4 percent, about 130 GWh annually. Wholesale electricity prices vary considerably throughout Chile, and many generators are contracted directly through power purchase agreements.

Nevertheless, in 2014, the average spot market prices in the country were \$104.4/MWh. By increasing the annual output of the plant by 130 GWh, the ESS could result in maximum additional annual revenue of \$13.5 million for the plant. This would result in a payback period of only 2.2 years for the 20 MW storage facility.

The main beneficiary of the additional revenue generated by the Angamos ESS will be AES which both developed and owns the system as well as the associated power plant. However there are numerous benefits to the entire region from the development of this project. In addition to the investment in the region and the creation of construction and engineering jobs, this system will improve the overall reliability of the power grid and can decrease both wholesale prices and retail electricity rates. By allowing the coal power plant to run at greater levels of efficiency, less fuel is required to generate a given amount of electricity, reducing the marginal costs of generation. These savings can allow the plant to bid lower prices into wholesale markets, driving down average prices in the region. Additionally the fast responding and more accurate frequency regulation provided by the ESS can allow for a greater amount of renewable energy to be added in the region without compromising grid stability.

This project takes advantage of Chile's energy market deregulation, which separates entities for the generation, transmission, and retail sales of electricity in wholesale markets. This market structure allows AES to deploy private capital to improve the efficiency of its plants and its competitiveness in the wholesale markets while at the same time providing new infrastructure to support the regional grid's growth and to integrate renewables. With some of the highest levels of solar irradiance in the world, the Chilean government is looking to deploy large amounts of solar PV in the country's north. This project will help facilitate the integration of these new resources and help the country meet a goal of generating 20 percent of its energy from renewables by 2025. The Angamos project is considered a major success and is leading to additional projects. AES Energy Storage is building another 20 MW project in Northern Chile, and developer NEC Energy Solutions announced a 12 MW ESS in 2015. Chile's experience provides a good framework for how emerging markets can capitalize on local renewable resources and the capital of foreign investors. Allowing for more open competition among energy generation and ancillary service providers has been key for these

developments in Chile, and should be considered by market regulators in other countries.

4.4 SUMBA ISLAND MICROGRID, INDONESIA

Indonesia's Sumba Island has become a leading case study for the integration of energy storage into remote microgrids to enable the electrification of isolated communities. In 2013 the Indonesian Ministry of Energy assumed responsibility for a national goal of achieving 100 percent renewable energy for Sumba. As a result the island of 650,000 inhabitants, with only about 25 percent of the people having access to any electricity, has received financial and technical support from a number of outside agencies. Because of the island's mountainous terrain and isolated villages, the Indonesian national utility estimates the cost of installing conventional power lines to deliver electricity to all residents would be roughly \$22,000 per half mile, a cost far too expensive to justify in view of the limited demand for electricity to provide revenue.

Sumba Island has two separate electricity grids that are supplied almost entirely by imported diesel fuel. The two systems can support a total peak capacity of 13.0 MW and regularly experience a nighttime peak demand (driven by lighting) of 9.3 MW with an average daytime base load demand of 5.9 MW. However recent studies indicate total peak demand could reach 28.5 MW by 2020, with over 15.1 MW of average base load. This growing demand will necessitate the need for significant new electrical infrastructure to achieve the country's ambitious goals for renewable-based electrification. The past three years have seen significant progress on Sumba in reaching the 100 percent renewables goal. With support from outside groups, such as the Asian Development Bank, new generation facilities, including a 660 kW wind farm, several solar PV plants, and various micro-hydro power plants (less than 50 kW) have been built. (See Picture 4.2). Studies of renewable potential on the island have shown that enormous resources are available, including up to 150 MW of wind power at three accessible sites. Furthermore 6.5 MW of solar PV and 800 kW of hydro power are currently under development. These new generation assets clearly have the potential to meet the island's rising electricity demand. However the limited existing infrastructure will make the integration and optimization of this new variable generation very challenging.

In an effort to effectively integrate new renewables and improve the grid's stability and power quality, a 400 kW flow battery

energy storage system (ESS) was commissioned on the island in late 2013. (See Figure 4.2). The battery was supplied by the Chinese firm Prudent Energy, and power electronics, controls, and system integration services were obtained from ABB. The primary services provided by the ESS will be improved power quality and stability through the provision of frequency regulation and voltage support, which is particularly important when integrating a high percentage of variable generation. This system can also provide additional generation capacity when renewables are not available.

Government support was key to the financing and development of this project. The flow battery system was financed primarily the Indonesian Agency for the Assessment and Application of Technology (BPPT for its initials in Indonesian). The group is a non-ministerial government agency, under the coordination of the Ministry for Research and Technology of Republic of Indonesia, and has the tasks of carrying out government duties in the fields of assessment and application of technology. BPPT worked with Indonesia's state utility and Sumba's local electrical cooperative to provide this ESS.

The financial justification for this ESS project is primarily based on the reduction of diesel fuel used to power the islands. Analysis conducted on the island in 2009 found that the average cost of generating low-voltage power is approximately \$0.26/kWh, of which diesel fuel accounts for about 75 percent of the costs. However in an effort to make electricity more affordable, the average selling price on the island is \$0.08/kWh, suppressed by subsidies resulting in a government loss of \$0.18/kWh. Although exact savings estimates are not available, a 50 percent reduction in diesel use through storage and optimized wind, solar, and hydro generation could result in an end-user cost savings of 35 percent, or roughly \$0.09/kWh. This savings was achieved while also limiting the need for new transmission and distribution infrastructure as well as helping meet renewable deployment and electrification goals.

Other keys for a successful remote microgrid integrating energy storage are viable business plans, ownership structures, payment mechanisms, and a "project champion". In the case of Sumba, the collaboration between national utility Perusahaan Listrik Negara (PLN) and the island's local cooperative

Picture 4.2 Commissioning Solar PV alongside Wind Farms on Sumba Island



(Source: Sumba Iconic Island)

Corporasi Peduli Kasih is crucial. The involvement of a national utility is advantageous because the utility company can more easily absorb the costs for a system's deployment in an effort to meet its mandate to expand renewable generation. Furthermore the utility has both the technical expertise and local knowledge required to support commissioning and ongoing operation.

Sumba's local cooperative is also critical because the group currently handles electricity sales and payment collection in remote communities. The cooperative is also responsible for educating and training local residents on the operation and maintenance of the microgrid systems. As the financial results of this project emerge over the coming years, perhaps more important in evaluating the success of the project will be the involvement by and benefits to local residents. Sumba's model of utilizing both the national utility and the local cooperative may prove particularly effective in engaging and educating the island's residents, hopefully leading to both sustainable employment and continued opportunities for local clean energy development.

While the island is still working to achieve its goal of generating 100 percent renewable electricity, more work remains to be done. However progress to date has been very promising, and the Indonesian government is considering expediting Sumba's renewable energy target to 2020, and views the island as a nationwide blueprint for remote electrification.

Conclusion



5.1 CONCLUSION

Energy storage technologies hold significant potential to help drive development in emerging economies by improving the quality of the electricity supply and facilitating the effective integration of renewable energy. The rapidly falling costs and improving capabilities of stationary ESSs, along with growing industry expertise, will quickly open new markets and cost effective applications for energy storage. Developments in the industry to date have shown that the specific trends and dynamics in energy storage markets around the world vary widely; this is particularly true for many emerging economies. The specifics of each market, such as the applications that storage systems will provide, and the types of technologies best suited to them, will depend on a number of factors, including:

- *The mix of existing generation resources, including penetration of renewables*
- *The existence of existing energy storage resources, in particular, operating pumped hydro plants which can greatly limit the need for new ESSs*
- *The extent of the electricity market that is deregulated versus that of vertically integrated utilities, which will determine who can own ESS and what services can be provided*
- *The electricity rate structures for customers, which will determine the value and operational parameters of BTM storage*
- *Stability and reliability of the electricity grid, including factors such as frequency of outages for customers due to lack of generation capacity, lack of transmission capacity, aging infrastructure, and extreme weather*

Most activity in the energy storage market to date has centered on select countries and regions, mostly with well-developed economies and in energy markets with favorable regulatory

frameworks for extracting value for storage projects. There are a number of lessons and best practices that can be learned from the industry in these areas, and the limited development that has already taken place in emerging economies can be analyzed.

Perhaps the most important factor in a successful energy storage market is the availability of low-cost financing for ESS project development. In order to unlock low-cost financing, it is important to utilize technology from reputable and established vendors that can offer warranties and performance guaranties on their products. This reliable technology must be paired with experienced and capable system integrators who ideally have a record of previous successful project development. It is also critical that energy storage industry participants educate relevant stakeholders, such as investors, grid operators, and energy regulators, on the benefits of energy storage. These factors can reduce the perceived investment risk, and greatly increase interest and trust in energy storage as a beneficial technology for emerging markets, thus reducing the cost to finance and develop such projects. This in turn will result in more replicable projects, rather than highly customized and specific systems, which will be crucial for the market to truly reach scale.

Finally there are a number of barriers to energy storage market growth that must be overcome. Some of these barriers, such as the level of competition, and some aspects of regulation in energy markets, are complex and unlikely to be changed in the near-term. Officials in some advanced power markets have begun exploring ways to revise market rules and regulations to boost the participation of ESSs and other DERs in their grids. Although these efforts remain in early stages, there are a number of operational practices and regulatory changes and practices that can enable better energy storage systems and foster the transformation of power systems into more resilient, clean, and technologically diverse grids. These include:

- *Consider ESS as a unique and agnostic asset on the grid, recognize the highly flexible nature of the technology, and allow multiple players on the grid system to install, own, and operate the system*
- *Open-up competitive markets for ancillary services to multiple technologies rather than only sourcing from large generators, thereby allowing storage operators to obtain additional sources of revenue for different services provided, enabling financial feasibility*
- *Encourage longer-term contracts for services from energy storage, thereby reducing risk for finance institutions.*
- *Allow aggregated DERs to participate in capacity and ancillary service markets*
- *Introduce time-varying rates to better align supply with demand, allowing customers to use BTM energy storage to reduce their electricity costs*
- *Reform utility business models to encourage conservation and efficiency rather than large capital investment: Although energy storage is often a cheaper alternative to substation or transmission investments, utilities are often incentivized to make large capital investments*

Other barriers, such as the requirement to use locally produced products in storage systems as part of procurement processes, are easier to change. These types of local content requirements, while well-intentioned, have proven to be a significant barrier to energy storage development given the lack of vendors with quality technology in many emerging markets and the scale economies in existing manufacturing hubs. It is also recommended that utilities and governments in emerging markets always consider ESSs alongside traditional grid investments. Given the falling costs of the technology, storage will continue to be an economical alternative or addition to large-scale grid infrastructure in many areas. Requests for information from storage vendors and developers have proven to be an effective way to help stakeholders in emerging markets better understand the potential opportunities and impact for energy storage in their service territories and areas of operation.

Despite these barriers it is expected that energy storage will play an increasingly important role in the development of many emerging market countries over the coming decade. The impact of energy storage technology can be magnified if stakeholders take into account the lessons and recommendations discussed in this report.



List of Abbreviations

BPTT	Indonesian Agency for the Assessment and Application of Technology
BTM	Behind-the-Meter
CAES	Compressed Air Energy Storage
CAGR	Compound Annual Growth Rate
C&I	Commercial and Industrial
CFE	Federal Commission of Electricity
CSP	Concentrated Solar Power
DER	Distributed Energy Resources
DR	Demand Response
EPC	Engineering, Procurement, and Construction
ES	Energy Storage
ESCO	Energy Service Company
ESMAP	Energy Sector Management Assistance Program
ESS	Energy Storage Systems
EU	European Union
IEA	International Energy Agency
IFC	International Finance Corporation
IPP	Independent Power Producer
O&M	Operator and Maintenance
PHS	Pumped Hydro Storage
PPA	Power Purchase Agreement
PV	Photovoltaic
ROI	Return on Investment
T&D	Transmission and Distribution
TOU	Time-of-Use

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NOTES

CAGR refers to compound average annual growth rate, using the formula:

$$\text{CAGR} = (\text{End Year Value} \div \text{Start Year Value})^{(1/\text{steps})} - 1.$$

CAGRs presented in the tables are for the entire timeframe in the title. Where data for fewer years are given, the CAGR is for the range presented. Where relevant, CAGRs for shorter timeframes may be given as well.

Figures are based on the best estimates available at the time of calculation. Annual revenues, shipments, and sales are based on end-of-year figures unless otherwise noted. All values are expressed in year 2016 United States dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

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1320 Pearl Street, Suite 300
Boulder, CO 80302 USA
Tel: +1.303.997.7609
<http://www.navigantresearch.com>

