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RESEARCH REPORT

Energy Storage for Microgrids

Advanced Flow, Advanced Lead-Acid, Advanced Lithium Ion, and Sodium Metal Halide Batteries and Flywheels for Grid-Tied and Remote Microgrid Applications

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Section 1
EXECUTIVE SUMMARY

1.1 Overview

Navigant Research defines the fundamental concept of a microgrid as: "An integrated energy system network consisting of distributed energy resources (DER) and multiple electrical loads and/or meters operating as a single, autonomous grid either in parallel to or 'islanded' from the existing utility power grid."

Energy storage can be a useful enabling technology in any type of microgrid, delivering services to the microgrid itself and to the centralized grid (in the case of grid-tied systems). Energy storage deployed within a microgrid can deliver varied services including fuel optimization, load management, voltage support, frequency regulation, and renewable asset optimization.

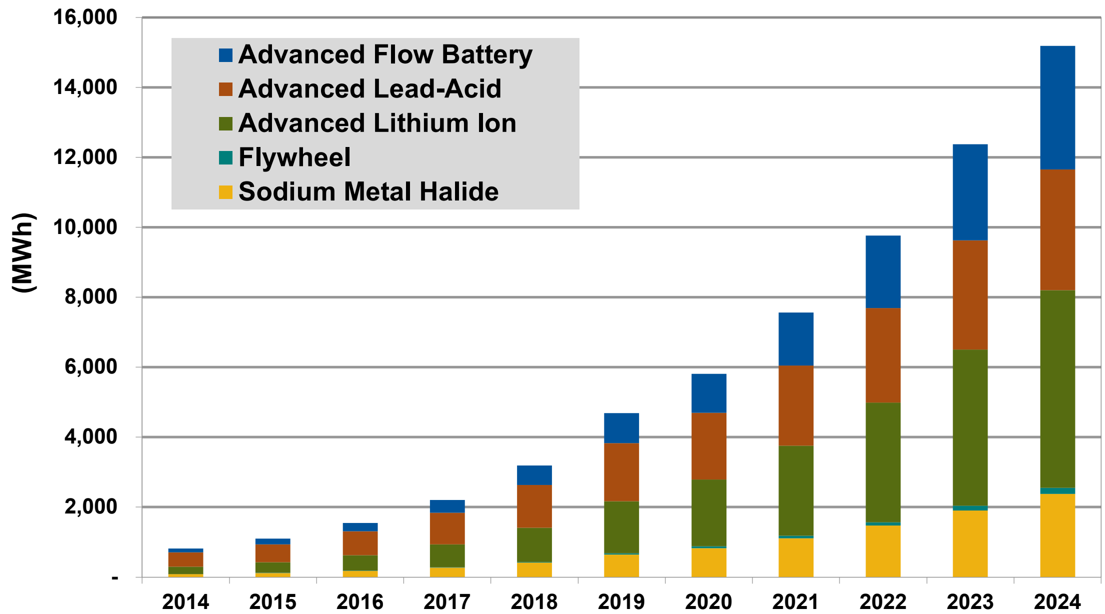
The strongest markets for energy storage for microgrids (ESMG) will be the grid-tied customer-owned microgrid segment in North America, supported by robust growth in microgrids during the next 10 years and favorable regulatory developments that are expected to help improve return on investment (ROI) through participation in ancillary service markets. Technology adoption in this region is balanced between all technologies with a definite bias toward lithium ion (Li-ion) batteries, which are anticipated to take up to 40% market share of this specific market segment.

ESMG activity in Europe and Asia Pacific will be more balanced between remote microgrids, grid-tied customer-owned systems, and grid-tied utility-owned systems. Although Asia Pacific will be a strong market for advanced batteries, particularly Li-ion chemistries, Europe is forecast to adopt a more even portfolio of technologies.

In contrast, the markets in Latin America, the Middle East, and Africa are almost all remote systems, and, as a result, chemistries that are more rugged, cycle well, and can truly maximize renewables on a microgrid system will do better in these markets. These are the smallest markets for microgrids, but they are also the markets that could change rapidly. Energy insecurity and economic growth play heavily in Latin America and Africa, in particular, and could push these regions to innovate and leapfrog ahead of the forecast.

This report forecasts the market for five energy storage technologies in the microgrid market: advanced flow, advanced lead-acid, advanced Li-ion, sodium metal halide (SMH) batteries, and flywheels. Segmentation is also provided for the grid and off-grid markets, as well as customer-owned, utility-owned, and military systems.

Chart 1.1 Installed Energy Storage Energy Capacity in Microgrids by Technology, World Markets: 2014-2024



(Source: Navigant Research)

Section 2
Market Issues

2.1 Defining Microgrids

The first distinction between types of microgrids is a microgrid's physical proximity to a centralized grid system. Microgrids that are co-located with a large, centralized grid system are known as grid-tied; microgrids that are independent from a centralized grid are known as remote microgrids. The second distinction is the owner of a microgrid system: an electricity customer, a utility, or the military. Systems may be grid-tied or remote in each ownership category.

Navigant Research defines the fundamental concept of a microgrid as: "An integrated energy system network consisting of distributed energy resources (DER) and multiple electrical loads and/or meters operating as a single, autonomous grid either in parallel to or 'islanded' from the existing utility power grid."

2.1.1 Grid-Tied

With a grid-tied microgrid, the most common configuration is for DER to be tied together on its own distribution feeder, which is then linked to the larger utility grid at a single point of common coupling.

2.1.1.1 Customer-Owned

The majority of grid-tied microgrids today are deployed by end-use customers who are not getting the quality of energy services they desire from their host distribution utilities. The typical focus of these microgrids is aggregating existing onsite generation with multiple loads that are co-located in a campus setting. These microgrids tend to be among the largest in use and may require master controller systems. Microgrids boost reliability, but they may also be viewed as a means of increasing revenue streams from onsite power generation (and storage), because these energy services can then be sold to the utility hosting the local distribution grid. Grid-tied customer-owned microgrids typically appear on college campuses, in commercial and industrial settings, such as data centers, and, less frequently, in residential communities.

2.1.1.2 Utility-Owned

A small but growing group of utilities is plowing new ground when it comes to microgrid alternatives to conventional distribution system upgrades. Still in their infancy, grid-tied utility-owned microgrids could become vehicles for maximizing the value of investments in smart grid infrastructure and leverage utility-owned assets with customer-owned assets. Rather than ceding the microgrid market completely to deregulated, independent power producers (IPPs) or energy service companies, utility distribution microgrids (UDMs) could provide an avenue for utilities to stay relevant as new technology marches forward. Smart grid technology trends are challenging these institutional players to reinvent themselves, or, in their worst-case scenario, disaggregate completely. A future peppered with customer-owned microgrids could literally be a do or die issue for utilities. On the other hand, UDMs could figure prominently in this transition/transformation of the power grid as bidirectional resources, variable resources, and DER grow in stature and relevance.

2.1.1.3 *Military*

The focus of grid-tied military microgrids is security, both cyber and physical. The U.S. Department of Defense (DOD) has a mandate to shift to renewable energy supplies as a matter of national security. Thus, distributed renewables play a vital role in this strategic shift, especially since utility and state regulations limit opportunities for importing above-market priced offsite renewable energy supplies. To date, only the U.S. military is moving forward with military microgrids, though interest in this networking platform is growing within military agencies in the United Kingdom, Canada, France, and China.

2.1.2 Remote

These microgrids rarely, if ever, connect with any larger utility distribution grid network. Many of these microgrids are designed to reduce diesel fuel consumption by integrating solar photovoltaic (PV), distributed wind, or other renewable resources into the network. It is this segment in which microgrid technology was first developed and which represents the largest long-term market opportunity in terms of number of systems deployed.

2.1.2.1 *Customer-Owned*

Customer-owned remote microgrids are divided into three main market segments. The first is village electrification microgrids. In terms of sheer numbers, this segment of the remote microgrid market will be the market leader for the overall market as a whole. Given that many of these systems will be extremely small in scale, however, the segment remains unattractive from the perspective of large technology companies or developers. While this is the market segment that is attracting the most support from governments and institutions, it also faces some of the most difficult challenges due to the financial viability of clients, historical energy theft, and deeply embedded energy subsidies that challenge private sector business models. Still, many small-scale entrepreneurs are flocking to this business opportunity in India and Africa.

The second segment is perhaps the most attractive microgrid market in the world today. This is any physical island that has yet to be connected to a larger grid and burns diesel fuel as its primary source of electricity. In essence, this is the low-hanging fruit. A number of pilot projects have been launched in critical markets, such as the Caribbean, the Mediterranean, the North Sea, and throughout Asia Pacific. The key driver for this market is displacing diesel fuel with variable wind or solar resources. Once these substitutions take place, there is often the need for both energy storage and more sophisticated controls – in short, a remote microgrid.

The third segment, remote commodity extraction, is the least-developed market for remote microgrids, but it could be one of the most attractive in the long run. Mining and oil/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 downside, commodity markets, such as mines, are in an economic slump, and are therefore hesitant to invest in new infrastructure not directly related to production. Furthermore, many commodity extraction operations are highly cost-driven and conservative. As a result, these microgrids customers require much more information, data, and validation than is currently available for microgrids in general and renewables and energy storage in microgrids specifically. Energy and mining companies require more demonstration projects and long-run data of at least 2 years or more; without this, these customers view the integration of renewables via microgrids as risky.

2.1.2.2 Utility-Owned

While investor-owned utilities face substantial regulatory obstacles in implementing grid-tied UDMs today, government-owned utilities serving rural and remote regions have already installed significant remote microgrid capacity in Alaska and Australia. Another hot spot is Canada, where provincial utilities work with the private sector to deploy hundreds of remote UDMs to reduce dirty (and increasingly expensive) diesel fuel consumption. Most of the remote power systems, which number in the thousands across the globe, are powered up by dirty diesel generation, hardly a technology platform of relevance to the smart grid and the fundamental networking advantages of the microgrid platform. Nevertheless, once renewable distributed energy generation (RDEG) is added to the mix, these remote systems (i.e., these microgrids) begin to look like the traditional microgrids that have been the focus of most of the U.S. Department of Energy (DOE) and DOD funding.

2.1.2.3 Military

Mobile military microgrids are the most radical interpretation of the microgrid paradigm shift. Not surprisingly, this segment is the least developed, yet it has had the most policy and financial support from the U.S. government. At present, these systems are being deployed in pilot projects in combat missions at forward operating bases (FOBs). These systems deploy yet another variation of enabling technologies due to the extremely small scale of system, cyber and physical security considerations, and the assumption that the structure is not permanent. As they grow in scale and sophistication, mobile military microgrids will likely become village power systems that serve humanitarian services once U.S. troops pull back from combat zones and other areas of conflict.

2.2 Energy Storage System Services for Microgrids

The services that energy storage systems (ESSs) deliver to microgrids are not dissimilar to the services that ESSs deliver to the traditional grid: resource optimization (fuel, PV, wind), resource integration (PV, wind), stability (frequency, voltage), and load management. Understanding the relative importance of each service to a microgrid customer is critical to building a compelling business case for energy storage for microgrids (ESMG), particularly in the face of cheaper alternatives, such as lead-acid batteries or diesel generators.

Grid-tied microgrids typically use combined heat and power (CHP) as the primary generation technology, and these CHP units will often use natural gas fuel. ESSs in a grid-tied microgrid will provide a variety of services to the microgrid itself and may provide ancillary services to the traditional grid in exchange for compensation from the grid operator. With UDMs specifically, in some cases, microgrids are being used by utilities as a platform for integrating smart grid infrastructure. ESMG may be able to make inroads with UDMs as a part of smart grid infrastructure. Energy storage can deliver a number of services and information that is useful to a utility, in addition to the software and controls that manage energy storage, which can also deliver information and operational flexibility to a grid system.

Table 2.1 ESMG Services by Microgrid Type

Microgrid	Grid-Tied Customer -Owned	Grid-tied Utility Owned	Grid-Tied Military	Remote Customer -Owned	Remote Utility Owned	Remote Military
Fuel Optimization				X	X	X
Load Management	X	X	X	X	X	X
Voltage, Frequency Services	X	X	X	X	X	X
DER Optimization	X	X	X	X	X	X
Smart Grid Integration		X				
Ancillary Services to the Centralized Grid	X	X	X			

(Source: Navigant Research)

2.3 Key Market Drivers

The business case for ESMG varies significantly between grid-tied and off-grid systems. Overall, the business case for ESMG is built around the ability of storage to maximize DER and minimize the "peakiness" of load. Secondary benefits include ensuring the stability of the microgrid overall. Ultimately, the operational objective of the microgrid and the technology composition of the system will determine which type of ESS is used in a microgrid, and to what degree. The technology composition of each microgrid is unique, as it is a response to a set of preferences and requirements set by each individual end user. As a result, it is more meaningful to discuss the business case for grid-tied and off-grid microgrids separately.

Generally, grid-tied microgrids will use natural gas-fueled CHP systems as a prime mover, along with other DER assets, such as solar PV. The ability to island is what makes a grid-tied microgrid a microgrid and not a virtual power plant (VPP). Overall, storage is perceived as an expensive resource, but the ability to extend islanding time – especially relevant to long-duration storage resources such as flow batteries – will be key to the business case for grid-tied ESMG. Another key driver for ESSs in a grid-tied microgrid is the amount of renewables penetration on the system: the larger the percentage of intermittent resources as a total percentage of the system, the better the business case for energy storage. Improving islanding time and renewables penetration on a grid-tied microgrid are primary drivers and applications for ESMG-tied systems. A secondary driver and application is ancillary services, both to the microgrid itself, but also to the centralized grid.

2.3.1 Improving Renewables Penetration in Microgrids

Whether a microgrid is grid-tied or remote, energy storage can influence the proportion of energy that is delivered from intermittent renewables (wind, solar). Virtually all microgrids will have a prime mover – either a diesel generator or a CHP unit (turbine, microturbine, engine, or fuel cell) for baseload generation. Although prime movers can be cycled up and down depending on load and the output of intermittent resources, this is fuel inefficient and degrades the prime mover.

Altogether, Navigant Research has identified 607 microgrid projects or company or country portfolios of microgrids in its Microgrid Deployment Tracker database. Of this total, 282 systems include solar PV and 158 include wind turbines. While this database is not fully comprehensive, it represents the most complete listing of microgrids available worldwide. Of the 607 systems, 46% include PV, 26% include wind capacity, and 30% include some type of energy storage, although many opt for different types of traditional lead-acid technology such as valve-regulated lead-acid battery. Though many systems include these technologies, renewables and storage make up a tiny fraction of total generation capacity of microgrids globally. There are 282 solar PV systems installed in microgrids globally, with a capacity of 132.6 MW, or 3.2% of the total microgrid system capacity. Wind fares slightly better, with 158 systems with 192.4 MW, or 4.6% capacity. Energy storage (including lead-acid) makes up 184 systems with a 107.3 MW, or 2.6% capacity. Overall, the market penetration of renewables and storage in microgrids is slightly higher than for the centralized grid, but it is still quite low.

Table 2.2 Technology Composition of Deployed Microgrids, World Markets: 4Q 2013

Metric	Diesel Generators	Solar PV	Wind	Energy Storage (includes Lead-Acid)
Systems	231	282	158	184
MW Capacity	448.7	132.6	192.4	107.3
% of Systems	38.1%	46.5%	26.0%	30.3%
% of Total Microgrid Capacity	10.8%	3.2%	4.6%	2.6%

(Source: Navigant Research)

Flywheels, lithium ion (Li-ion) batteries, flow batteries, and sodium sulfur (NaS) batteries are also installed in microgrids. Flywheels typically do not directly support renewables integration, although this technology does manage the frequency on the microgrid, including disruptions resulting from variable solar PV or wind.

Although a greater percentage of ESMG can improve the ability of the microgrid to support renewables, the maximum duration of discharge is also an important consideration. For systems that are 50% renewable energy, the minimum duration discharge is 1hour to 2 hours. For systems that are 75% renewable, a storage device capable of 4 hours to 5 hours is necessary, and for systems that are up to 85% renewable, at least 6 hours of storage is required.

Finally, for storage technologies that are used to improve renewables penetration in microgrids, efficiency is also important, particularly at low power output. Load on a microgrid will vary, and storage technologies that are efficient at low output will allow the system to benefit the most from the stored renewable energy in lieu of ramping up prime movers, such as CHP or diesel generators.

Storage is often cited as being an expensive technology for microgrids. Table 2.3 provides estimates for the installed cost across eight markets of five key components in a microgrid: PV, small wind, storage, CHP, and microgrid integration (which includes controls, software, and labor). On average, storage is competitive with solar PV, wind, and gas turbines. This only tells part of the story, however. Storage is a complementary technology, not a competing technology, as it improves the output of any generation technology including diesel, solar PV, wind, and CHP. As a result, the most compelling case for storage in a microgrid with renewables will be those instances where solar PV or wind are more expensive than storage on an installed basis, but they are considered more desirable than a prime mover technology (diesel, CHP).

The numbers in Table 2.3 were derived using cost data from Navigant Research reports, including *Renewable Distributed Energy Generation*, *Microgrids*, and *Combined Heat and Power for Commercial Buildings*. The installed energy storage costs represent an average of installed cost across advanced batteries and flywheels. Gas turbine CHP costs vary significantly and, therefore, there is a wide range for these costs. Microgrid integration costs are derived from Navigant Research's microgrids research, which includes cost data on microgrid-enabling technologies; integration costs were derived by taking a percentage of total microgrid costs per kilowatt.

Table 2.3 Estimated Microgrid Component Prices, Key Markets: 2013

Key Market	Units	Distributed PV, Installed	Large-Scale PV, Installed	Small Wind	Storage, Installed	Gas Turbine (CHP)	Grid-Tied Microgrid Integration	Remote Microgrid Integration
Australia	($/kW)	$ 3,100	$2,400	$2,675	$2,113	$800-$4,000	$1,150	$1,765
China	($/kW)	$2,200	$2,400	$1,580	$2,113	$800-$4,000	$1,150	$1,765
Germany	($/kW)	$2,600	$2,566	$1,650	$2,113	$800-$4,000	$1,150	$1,547
India	($/kW)	$1,700	$2,400	$1,200-$1,350	$2,113	$800-$4,000	$1,150	$1,765

Key Market	Units	Distributed PV, Installed	Large-Scale PV, Installed	Small Wind	Storage, Installed	Gas Turbine (CHP)	Grid-Tied Microgrid Integration	Remote Microgrid Integration
Italy	($/kW)	$3,100	$2,566	$1,941-$2,588	$2,113	$800-$4,000	$1,150	$1,547
Japan	($/kW)	$5,900	$2,400	$3,900	$2,113	$800-$4,000	$1,150	$1,765
United Kingdom	($/kW)	$2,700	$2,566	$6,100	$2,113	$800-$4,000	$1,150	$1,547
United States	($/kW)	$5,200	$3,745	$4,400	$2,113	$800-$4,000	$1,150	$1,629
Average	**($/kW)**	**$3,313**	**$2,630**	**$3,384**	**$2,113**	**$800-$4,000**	**$1,150**	**$1,666**

(Source: Navigant Research)

2.3.2 Ancillary Services to the Centralized Grid

Grid-tied microgrids have a unique opportunity to provide ancillary services to the grid. Frequency regulation, voltage support, and spinning reserves are the three most common services, and these are not dissimilar to the services that storage would provide the microgrid itself. In deregulated markets, resources (e.g., demand response [DR], power plants, and storage) may bid into the markets for these services, and, if called upon, are compensated. The primary factors that will influence this driver are the market structure and the minimum size of a resource in a market.

Markets in the United States will typically pay more for regulation delivered by an ESS (or any fast-response system), due to a mileage payment. This means that fast resources are compensated for the total amount of movement up and down in a given period. This usually equates to 3 to 5 times the amount paid to a traditional, slow resource, such as a coal-fired power plant. This will affect the rate of return of a storage system in a grid-tied microgrid that is bidding into the frequency regulation market. It will also influence the sizing of energy storage in such systems, because to participate more fully in the market, a customer may choose to oversize the ESS to capitalize on high payments and accelerate the return on the microgrid system as a whole.

The minimum size for a resource to bid into a market depends on each grid operator. In Germany, the minimum size of a resource delivering frequency regulation is 1 MW, whereas in the United States, the minimum varies with each independent system operator and can be as little as 100 kW. Therefore, in markets that have a high minimum power rating for services like regulation, only the largest grid-tied microgrids will be able to bid into the market.

Voltage support is typically procured using bilateral contracts. This is because a centralized grid system will typically require voltage support at specific physical locations on the grid, and, therefore, the market opportunity for energy storage in a grid-tied microgrid to deliver this service is limited to microgrids that happen to be situated where the operator requires voltage support. In addition, there are no market rules that prioritize energy storage delivering voltage support over any other technology. Therefore, the potential benefit of providing this service to the centralized grid is small.

Finally, the spinning reserve market may be relevant to energy storage in a grid-tied microgrid, but this service requires a longer time commitment from the resource than frequency regulation. If called upon, a resource is required to deliver energy for up to 120 minutes in some markets, such as the United States, but as little as 15 minutes, such as in the United Kingdom. There are two ways to participate in this type of market. Either the energy storage resource can provide the energy, or the microgrid system as a whole (a much larger resource) could island and remove load from the system. The latter is typically referred to as a tertiary reserve. Another way to participate in an ancillary market by islanding is to participate in a DR program, although in this case, the rules for each program again differ from grid operator to grid operator.

Players in the European market have indicated that to make a business case for energy storage in the frequency regulation market (as a unique application, not necessarily in a microgrid), the storage system must be $1.38 million (€1 million) per MW or less to have a return on investment (ROI) within 7 years. This assumes a maximum 80% depth of discharge and an average $38.28 (€28.15) per MWh of regulation. Within the context of a grid-tied microgrid, the maximum cost per MW constraint is lower because part of the value of the ESS is to provide stability and improve renewables penetration in the microgrid itself. For instance, if 30% of a 1 MW storage system is delivering grid services, this represents a potential income of $509,000 in the first 7 years – assuming a 1 MW battery, a maximum 80% depth of discharge, an average frequency regulation price of $38.28, and operation 90% of the year.

2.3.3 Remote Microgrids: Diesel Offset

Diesel gensets figure prominently in remote microgrids. All but one of the 231 remote microgrid entries in the Navigant Research Microgrid Deployment Tracker database are documented as having diesel generation. The business case for energy storage in a microgrid does not hinge on diesel displacement, but rather diesel reduction. Other prime movers, such as turbines, microturbines, engines, and fuel cells, also compete directly with diesel generators.

2.3.3.1 Diesel Costs

Diesel costs will be influenced by a number of factors, including native availability of fuel, transportation networks for fuels, weather conditions, safety conditions, fuel theft, subsidies, and taxes. For instance, theft and weather conditions are not an issue in Denmark, but the Danish government taxes fuels and energy heavily. The minimum EU tax on diesel is $0.45 (€0.33) per liter, and the tax in Denmark is slightly higher at approximately $0.54 (€0.39) per liter.

Taking into account that some markets, such as Denmark, are outliers, the average yearly savings per kilowatt of diesel genset that is offset is between $1,348 and $7,269. This refers to balancing a diesel genset using storage and does not include the benefits of solar PV, wind, or intelligent controls in a microgrid. Including European markets, where diesel prices are higher on average but are unlikely to hit the exceptionally high black market pricing seen in developing markets, the range of yearly savings per kilowatt of diesel genset offset is $1,708 to $8,348. The values in Table 2.4 represent the pump diesel prices reported by the World Bank. These prices are lower than prices reported by other organizations, such as the GSM Association.

On average, each marginal kilowatt of diesel generation will use between $3,820 and $10,460 in fuel, depending on fuel prices in a particular market. These prices are based on 8,000 hours of operation per year at an average efficiency of .30 L/kWh (50%-75% load). These figures do not account for the charge/discharge function of an energy storage asset, meaning that the storage asset will not be available for discharge 24 hours a day. However, the storage device will be balancing generation assets (charging) when there is surplus energy on the system, and thus will be useful for reducing fuel consumption.

Table 2.4 Remote Microgrid Diesel Prices, Key Markets: 4Q 2013

	Cost of Diesel for Remote Microgrid			Marginal Cost of Diesel Generation		Marginal Cost of Offsetting Diesel Generation with Energy Storage[a]	
Market	**Low ($/L)**	**High ($/L)**	**2013 Diesel Genset Installed Cost ($/kW)**	**Low ($/kW annually)**	**High ($/kW annually)**	**Low ($/kW)**	**High ($/kW)**
Canada	$1.30	$3.90	$500	$3,618	$9,853	$(1,505)	$(7,740)
Chile	$1.32	$3.95	$500	$3,658	$9,973	$(1,545)	$(7,861)
Denmark	$2.03	$6.10	$500	$5,377	$15,130	$(3,264)	$(13,018)
Greece	$1.93	$5.80	$500	$5,139	$14,418	$(3,027)	$(12,305)
India	$0.94	$2.83	$470-$590	$2,763	$7,290	$(651)	$(5,177)
Japan	$1.40	$4.19	$500	$3,855	$10,566	$(1,743)	$(8,453)
Russia	$1.10	$3.30	$500	$3,140	$8,420	$(1,027)	$(6,307)
South Africa	$1.32	$3.96	$500	$3,670	$10,011	$(1,558)	$(7,899)
Tanzania	$1.40	$4.21	$500	$3,865	$10,594	$(1,752)	$(8,482)
U.S. Military[b]	$1.09	$3.27	$540-$630	$3,116	$8,348	$(1,003)	$(6,235)
Average	**$1.38**	**$4.15**	**$500**	**$3,820**	**$10,460**	**$(1,708)**	**$(8,348)**

(Source: Navigant Research)

[a]First year cost of installing an additional 1 kW of energy storage versus 1 kW of diesel capacity, or installed cost of energy storage system minus marginal cost of diesel generation.

[b]Includes bases in the United States and FOBs.

2.3.3.2 Diesel Offset versus ESMG Capital Expenditure

First-year fuel savings, which include the marginal savings from not buying a generator and the marginal cost of purchasing storage in lieu, depend heavily on the fuel assumption and the amount of diesel generation that is being offset. For the purposes of this analysis, Navigant Research assumed a 15% offset of diesel generation in microgrids of four varying sizes. Microgrid systems that are greater than 10 MW are a subset of the number of systems greater than 1 MW, and similarly, microgrids that are less than 500 kW are a subset of the microgrids that are less than or equal to 1 MW.

Microgrids come in many flavors, and they are all designed to meet the demands and constraints of the customer. The following data is taken from the Microgrid Deployment Tracker database, which excludes all-diesel systems, of which a number are remote mining operations above 100 MW. In addition, some entries in the Microgrid Deployment Tracker database represent a company's country portfolio, which includes more than one microgrid. Therefore, the microgrid systems reported here underrepresent the actual market size.

The largest microgrids ostensibly have fewer budget constraints (for mining operations, for instance), and the assumption is that these are more likely to have more diverse generation assets than simply diesel generators (40% of the 79 microgrids above 10 MW include diesel generators). Similarly, 32.2% of the microgrids below 500 kW also include diesel generators. Table 2.5 illustrates the first-year savings of displacing 15% of a microgrid, at a variety of sizes, using energy storage. The average installed energy storage cost is $2,112 per kilowatt, and the average fuel cost in $1.38 per liter.

Table 2.5 Size Distribution of Deployed Microgrids and First Year Fuel Savings at Low and High Diesel Costs: 4Q 2013

Deployed Microgrids*	Total Microgrid Capacity (MW)	Microgrid Systems*	Average Capacity per System (MW)	15% Diesel Genset Offset per System (MW)	First Year Diesel Fuel Savings Using ESS (Low) per Microgrid	First Year Diesel Fuel Savings Using ESS (High) per Microgrid
> 10 MW	3,373.74	79	42.71	6.406	$10,941,157	$53,475,867
> 1 MW	4,049.65	253	16.01	2.401	$4,100,867	$20,043,347
< 0.5 MW	31.30	180	0.17	0.026	$44,544	$217,711
≤ 1 MW	94.86	268	0.35	0.053	$90,687	$443,238
No Information	N/A	86	N/A	N/A	N/A	N/A

(Source: Navigant Research)

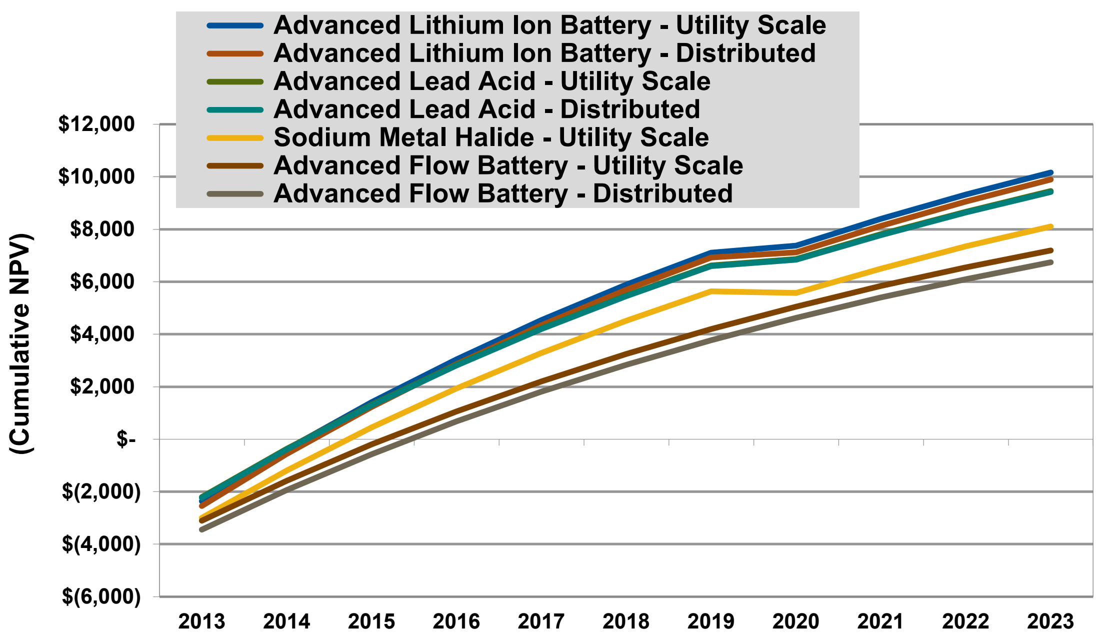
*Some entries in the Microgrid Deployment Tracker database represent a company's country portfolio, which includes more than one microgrid. Therefore, the microgrid systems reported here underrepresent the actual market size.

2.3.3.3 Diesel Offset versus ESMG Cost over Time

Chart 2.1 details the net present value (NPV) for four advance batteries assuming either utility scale or distributed-scale costs for three of the four technologies. This analysis compares the fuel savings of a diesel offset over time and on a per-kilowatt basis. The model assumes flow batteries have a replacement at 20 years and all other battery types have a replacement at 6.75 to 7 years.

The cumulative NPV chart shows the current cash position of each project (using the different battery types) during each of the 10 years. It shows the break-even point in which each project becomes net positive. All example projects broke even before 4 years, with half breaking even in the third year. The remaining projects break even in the second year. This NPV analysis is built using diesel offset assumptions, including diesel pricing of $1.09 per liter. Chart 2.1 assumes a discount rate of 10%. Additional assumptions are found in Table 2.6 in the accompanying Excel databook.

Chart 2.1 Cumulative Net Present Value of Energy Storage Technologies Integrated in Remote Microgrids by Battery Type, World Markets: 2013-2023*



(Source: Navigant Research)

*Net present value is assumed at a discount rate of 10%.

Section 3
TECHNOLOGY ISSUES

3.1 Introduction

The purpose of this section is to give an overview of two distinct but important sets of technologies that relate to energy storage for microgrids. This report does not cover all of the microgrid-enabling technologies, such as smart inverters or different kinds of distributed generation (DG), but focuses on energy storage types. Microgrid software and controls will interface with energy storage management systems, such as battery management systems for advanced batteries. Therefore, it is useful to understand the strategies for developing these primary controls. In addition, each storage technology has distinct operation, performance, and cost profiles that will come into play as customers decide on a storage technology.

3.2 Microgrid Software and Controls

Microgrid software and controls integrate and optimize the DER and loads in a microgrid. These components are critical to maintaining the fidelity of microgrid, and are especially important for more complex systems. Network system controllers, often a software solution, must allow all the diverse components that compose the remote microgrid to work in concert to preserve voltage and frequency, and perhaps protect critical loads. Because remote microgrids, generally speaking, operate in island mode all the time, microgrid control systems intentionally reduce the alternating current (AC) or direct current (DC) frequency of an islanded microgrid to coordinate the power balance between RDEG, loads, and storage devices.

One strategy to divide the controls approach is centralized versus distributed, but this can also be too simple. For example, vendors such as Lockheed Martin claim that the advantage of a hybrid controls approach is that it can initiate nearly instantaneous distributed responses from devices in the network, but it also incorporates a master controller that sits on top, and it is more focused on long-range resource planning and strategic commands.

On the surface, the self-regulating, distributed inverter-based system, such as those developed by the Consortium for Energy Reliability Technology Solutions (CERTS), seems particularly suited to remote microgrids. The CERTS system is based on the notion that generation and loads are sources of voltage, and that microgrids can be harmonized autonomously without a master controller. Not compatible with DC microgrid architectures, the CERTS system's reliance on CHP units and the phase angles of AC power may render it unsuitable for simple village power systems, but compelling for microgrids of approximately 100 kW in scale (the full capacity of a single Tecogen CHP InVerde unit).

Another major control challenge related to microgrids is the need to coordinate the variety of inverters in the system to facilitate parallel operation without loss of voltage and frequency stability. Techniques vary, resulting in a divergence in terms of the most applicable microgrid control system. This is the current focus of competition among microgrid vendors. To date, there are no clear leaders or alliances between vendors that are still, for the most part, in the exploratory phases.

Among the current options are centralized management systems that require high-bandwidth links between the inverters and central controller. Other prototype microgrids rely on distributed onboard controls, which reduce the bandwidth needed, but at the cost of synchronization difficulties. More recent work has investigated a hybrid control scheme in which proximate inverters operate in a master-slave arrangement. Still, others are sticking with common frequency droop methods, such as CERTS', or a voltage droop approach for DC grid architectures. Both of these options greatly shrink the need for any high-bandwidth communications across large distances. In general, roughly 70% of the control approaches relevant to an AC microgrid also apply to a DC microgrid. The balance is where customized solutions come in.

3.2.1 Flywheels

A flywheel is a mass rotating about an axis that stores energy mechanically in the form of kinetic energy. An electrical input accelerates the rotor with a built-in motor. When power is interrupted or needs to be supplied, inertia keeps the flywheel moving. The electrical energy is returned using this same motor as a generator that converts kinetic energy into electricity. Recent composite mechanical property advances have spurred interest in using the inertia of a spinning wheel to store energy, and flywheels have the potential to be a key contributor to future power needs of the utility grid.

Flywheels offer several important advantages over chemical energy storage. For one, the rate at which energy can be exchanged into or out of the flywheel is extremely rapid. Second, large amounts of power can be generated or withdrawn in a short time when compared to other energy storage technologies. Third, flywheels have a superior cycle life measured in the hundreds of thousands (for new models), particularly in comparison to advanced battery technologies. Finally, the technology is durable, typically requiring little maintenance over a 20-year period or longer.

The main issue with flywheels is their high upfront cost on an energy basis. Flywheels are approximately 85% efficient, clean and green, and extremely reliable. They are power storage devices rather than energy storage devices. Flywheels have an extremely short response time and offer what amounts to a surge of power for seconds and sometimes longer.

3.2.2 Advanced Li-ion

Li-ion batteries leverage the high reactivity of elemental lithium, the lightness of the metal, and its low density to create a lightweight, energy dense battery. While the overall cell and system design varies from manufacturer to manufacturer, the use of lithium compounds creates a high average cell voltage and high power and energy densities. Different Li-ion chemistries attempt to optimize energy density and lifecycle considerations through aspects such as more moderate thermal operating conditions.

Stability and thermal runaway are important concerns for Li-ion battery systems. A common attribute across Li-ion chemistries is the use of graphite for the anode (except in lithium titanate spinel technology), which helps the battery systems achieve a more level discharge curve. The cathode is typically made from one of three materials: a layered oxide, such as lithium cobalt oxide; a polyanion, such as lithium iron phosphate; or a spinel, such as lithium manganese oxide. Li-ion batteries are also high efficiency and have decent lifecycle expectations.

Controlling thermal runaway in Li-ion battery systems is a consistent problem, although grid storage applications have considerably fewer operating variables that can impact the thermal management of these systems. In contrast to the constrained spaces and mobile operating qualities of transportation applications, utility applications are stationary and can use a variety of thermal management considerations, from system architecture to advanced air or liquid cooling systems.

3.2.3 Advanced Lead-Acid

Lead-acid batteries, deployed extensively for backup power, have a more mature technology base than other advanced batteries, particularly for utility-scale applications. However, a shift toward advanced lead-acid batteries is occurring as environmental safety concerns mount globally. Additionally, advanced lead-acid batteries offer weight and operational advantages.

Innovation in advanced lead-acid batteries has focused on the addition of carbon to the negative electrodes of the battery cell. This provides several benefits. The addition of carbon, either in a split electrode or as a replacement electrode, enhances the battery's higher charge and discharge power characteristics by increasing the surface area on which the electrochemical reaction can take place. Furthermore, these batteries can operate on a broader depth-of-discharge range, increasing the functionality of the cells. The carbon replacement also enhances lifecycle qualities by reducing the development of extraneous materials, which precipitate out from the standard electron exchange reactions. This precipitation encourages self-discharge and diminishes capacity. These enhanced specifications have increased the interest in advanced lead-acid batteries for grid-scale applications.

Advanced lead-acid batteries offer high efficiency rates – on average around 90% – and these rates are enhanced with carbon additives in the cell design. What this technology offers in power density it lacks in energy density, particularly when compared to Li-ion batteries. As a result, although advanced lead-acid batteries offer significant improvements in performance, durability, and longevity over traditional lead-acid, this technology is typically best suited for energy-intensive applications, such as spinning reserves or load following. However, the Ecoult UltraBattery began providing 3 MW of frequency regulation in PJM Interconnection territory in the second half of 2012. There is enough diversity within this chemistry that it is difficult to exclude end-use markets.

3.2.4 Flow Batteries

Flow batteries are unique in the field of advanced batteries because of the use of liquid anolytes and catholytes. These are stored in tanks and are then pumped across a membrane to charge and discharge the battery. This design permits significant power and energy benefits as well as efficiency and reliability.

The design and operation of flow batteries is more similar to regenerative fuel cells than traditional advanced battery systems. Power and energy capacity are decoupled by the design of the system. The power (kilowatts) of the system is determined by the size of the storage tanks and can be augmented relatively easily. Likewise, the energy storage capacity (kilowatt-hours) is determined by the volume and concentration of the electrolyte; this too can be scaled up to provide systems with a few hours or several days' worth of storage capacity. These components are combined in a simple platform of cells and stacks, creating a modular design that is also intended to accommodate quick response.

Flow batteries are still in the commercialization stage of development, particularly for utility applications. As a result, the value proposition of this technology is not widely understood in the utility sector, and it will require significantly more demonstrations to convey its inherent advantages. Likewise, market forces are far from driving down the cost of this technology; volume sales, materials research, and design research and development will ultimately have to help bring costs down.

3.2.5 Sodium Metal Halide

Sodium metal halide (SMH) batteries offer some of the highest energy densities of any commercially available advanced battery. The technology boasts long lifecycle expectations – more than 4,500 cycles – as well as power density. SMH takes advantage of the abundance of elemental sodium and the volatility of the metal to create energy-dense batteries. The systems are designed based on a metal electrode, a sodium-based electrode, and a molten sodium electrolyte, with the latter contributing to high power density, due to its high conductivity. As with most other advanced battery technologies, power and energy density are a tradeoff with stability and thermal conditions; these batteries operate at high temperatures, exceeding 200°C, due to the need to keep the sodium electrolyte in liquefied form. The operating temperature is lower than it is for NaS batteries. The technology's energy density varies depending on the compounds used, but overall, the chemistry provides energy densities somewhere between flow batteries and lead-acid batteries.

SMH batteries generally contain no rare earth metals, and they are relatively simplistic in the sense that sodium is water-soluble. This has some strategic advantages for materials acquisition, safety, and lifetime operation and maintenance considerations, particularly compared to the more prolific NaS battery. Furthermore, SMH batteries have a lower vapor pressure and less metal corrosion than NaS battery systems.

Table 3.1 Operating and Cost Characteristics of Energy Storage Technologies in Microgrids: 4Q 2013

Technology	Temperature	Discharge Time	Total Cost ($/kW)	Cost ($/kWh)
Flywheel	Low	<1 hour	$1,300-$2,200	$7,800-$8,800
Advanced Li-Ion	Low	4-12 hours	$1,085-$1,550	$4,340-$6,200
Advanced Lead-Acid	25ºC	8 hours	$950-$1,590	$2,770-$3,800
Advanced Flow Battery	Modest	4-12 hours	$3,100-$3,700	$620-$740
Sodium Metal Halide	>200ºC	4-8 hours	$1,800-$5,000	$560-$1,650

(Source: Navigant Research)

Section 4
Key Industry Players

4.1 Introduction

This grouping of key industry players is not inclusive. The types of companies covered fall into one or more of the following categories: ESS companies that are installing storage systems in microgrids; ESS companies that are installing distributed ESSs of a size comparable to what is required in a microgrid; ESS controls and software companies that are working on solutions to maximize storage assets while improving durability and lifetime; and finally, microgrid integrators that have integrated ESSs into microgrids.

4.2 Energy Storage Technology and System Providers

4.2.1 A123 Energy Solutions

A123 Energy Solutions designs, develops, manufactures, and sells advanced, rechargeable Li-ion batteries and battery systems. In addition to work in a variety of commercial applications, the Westborough, Massachusetts-based company produces battery systems designed to improve the reliability and output of the electric power grid and enhance the efficiency and dependability of a utility's operations. A123 Energy Solutions leverages A123 Systems' proprietary Nanophosphate technology to deliver energy solutions for ancillary services, renewable integration, and transmission and distribution (T&D) support with its leading Grid Storage Solution (GSS) product line. The GSS includes advanced Grid Battery Systems, a proprietary control system called the A123 Energy Response Operating System (AEROS), and high-efficiency power inverters for DC-to-AC and AC-to-DC power and bidirectional energy flow to the grid.

A123 Energy has installed more than 100 MW of its grid storage solutions, spanning 20 different projects worldwide. To date, most of A123's installations utilize the high-rate version of the GSS and have had 15-minute durations. The company has also deployed its long-duration product, which is designed for multi-hour duration up to 4 hours at several sites, including in Hawaii and the United Kingdom. This will be crucial for the company as it continues to target wind integration applications, T&D deferral, and frequency regulation.

4.2.2 Aquion Energy

Started at Carnegie Mellon University (and spun-off) in 2008, Aquion Energy of Pittsburgh, Pennsylvania, produces aqueous hybrid ion batteries for use in microgrid support, off-grid generator optimization, and grid-level energy service applications. Aquion's batteries are expected to last for 5,000 charging cycles; they can withstand a wide range of temperatures without losing storage capacity, and they are safe and environmentally friendly. Aquion is focused on stationary applications, both small and large scale, where lower energy density can be an acceptable tradeoff for lower costs and longer life.

Target markets include integrated utilities, transmission operators, IPPs, centralized and off-grid renewables, industrial customers, and individual consumers. The company has received funding from the DOE, Bill Gates, and venture capitals such as Bright Capital, Foundation Capital, Kleiner Perkins, and Advanced Technology Ventures. It has yet to scale up its manufacturing to a commercial level, however, this is expected to happen in mid-2014. Most recently, Aquion has signed a memorandum of understanding with Siemens, under which both parties will test the integration of Aquion's AE12 Battery Module, an 18 kWh system, and Siemens' Sinamics S120 inverter solution.

4.2.3 EnStorage

EnStorage is a Yavne, Israel-based firm formed in 2008 to commercialize a proprietary hydrogen bromine flow battery technology originally licensed from Tel Aviv University. The company's core intellectual property is in the stack technology that charges and discharges the hydrogen bromine electrolyte. Unlike traditional flow battery technologies, the EnStorage system electrolyte flows in the same direction regardless of charge or discharge, resulting in a single electrolyte pump and tank. The energy is stored as hydrogen gas, which is consumed during the discharging cycle.

The company is currently testing its grid-connected technology demonstration unit (50 kW/100 kWh system) in the Israeli desert to test the technology's robustness, response time, and stack management. EnStorage is to commercialize a 150 kW/900 kWh system that would serve as a building block for turnkey systems targeted at renewables integration, load-leveling/peak-shifting, and distributed storage such as for a microgrid.

EnStorage has received funding from the following private equity and venture capital firms: Warburg Pincus, Canaan Partners, Wellington Partners, Greylock Partners, and Siemens Technology-to-Business.

4.2.4 Moixa

London, England-based Moixa Energy was formed in 2005 as a subsidiary of Moixa Group, which holds a significant portfolio of intellectual property on next generation mobile devices, which it commercializes through licensing, joint ventures, or the creation of new ventures. The company is competing in the nascent home energy storage market, rolling out an affordable ESS that shifts DC loads in the home off grid or off peak. Moixa's smart DC storage system, MASLOW, attaches to the meter and includes a small (1 kWh) deep cycle lithium iron phosphate battery. The system is designed to create a microgrid of DC devices in the home that maximizes energy efficiency by avoiding AC/DC conversions. The technology helps reduce peak demand and lower energy bills by shifting DC loads from lighting, communications, and electronic devices, to batteries charged during low tariff times, from local renewable sources, such as solar PV, or at times of excess wind supply.

As of July 2013, Moixa and a consortium of partners had put in a bid with the U.K. Department of Energy and Climate Change under its £21 million Energy Storage Generator Competition for a proposed Phase 2 project to deliver a 1 MWh-plus grid-scale storage demonstration of the

MASLOW system to 300 homes and sites in the United Kingdom. The project will end in March 2015. Moixa will receive $2.47 million (£1.5 million) for the Phase 2 demonstration.

4.2.5 ZBB Energy

ZBB Energy is based in Menomonee Falls, Wisconsin, employing about 80 people. The company has been offering zinc-bromine flow batteries and regenerative fuel cells since the summer of 2008. With its research and development facility in Perth, Australia, the company is well-positioned to tap global markets for remote microgrids. ZBB's primary product has been its Zinc Energy Storage System, which is a plug-and-play fuel cell that can operate in either DC or AC mode, is highly scalable, and requires no civil work. In 2010, ZBB began offering a modular Power & Energy Control Center, which features a configurable architecture that can connect multiple AC and DC power sources directly to DC energy storage units. This unique approach to microgrid development enables end-use customers to tap into a variety of storage devices to enhance microgrids because the aggregation occurs behind the meter. Having a DC bus means that diesel generators no longer have to follow load and, therefore, storage can serve as a shock absorber for the microgrid. The limitation is that the power flows only one way.

4.3 Microgrid Integrators with Storage Solutions

4.3.1 ABB

ABB is a major player in T&D grid infrastructure. Headquartered in Zurich, Switzerland, the company has more than 146,000 employees and logged revenue of $40 billion in 2012. ABB has traditionally offered an array of hardware products applicable to microgrids, including its Collaborative Production Management (CPM) plus and micro-SCADA offerings. Both were deployed in ABB's most noteworthy remote microgrid to date, which came online in 2011 and was billed as the world's first island to be 100% powered by renewable energy.

This physical island microgrid is on the smallest of the Canary Islands, El Hierro, and features more than 11 MW of wind power and 13 MW of pumped hydro storage. Combined, these sources provide roughly 80% of the total electricity. The remainder comes from both solar thermal and solar PV facilities. ABB provided automation and renewable integration services, including meeting the difficult challenge of maintaining stable frequency and voltage by sharing active and reactive power demand in the generators and tie lines.

ABB's purchase of Powercorp (Darwin, Australia) in 2011 signaled its increasing interest in remote off-grid systems. In terms of a key differentiator, ABB now relies on a patented flywheel as its preferred technology – instead of batteries – for stabilizing and storing variable renewable generation, which sets it apart from the pack (as does its emphasis on larger renewable remote microgrids). The PowerStore flywheel is coupled with a bidirectional inverter and can be scaled up from 500 kW to 1 MW in size. It provides peak shaving and frequency regulation, responding to changes in grid frequency in less than 5 milliseconds.

At present, ABB has the largest portfolio of remote microgrids of significant scale globally, with more than 15 wind/diesel hybrids installed in Australia, ranging in size from 1 MW to 14 MW.

ABB's recent acquisition of software vendor Ventyx also allows the company to offer enterprisewide management of microgrids, whether grid-connected or not, with other related products and services, including DC distribution network architectures for data centers, smart electric vehicle charging systems, and cyber security software offerings.

4.3.2 General Electric Digital Energy

General Electric (GE) Digital Energy, based in Atlanta, Georgia, is part of GE General Management. It employs 5,000 people and posted revenue of $7.4 billion in 2012. The company sees microgrids as a natural fit for its ecomagination program. GE has an existing commercial portfolio of tools and processes that it is currently adapting to a variety of microgrid architectures. The heart of GE's microgrid platform is the UR Relay system, which can manage multiple DER, each of which can be optimized, according to historical data and local usage profiles. Moreover, the company provides and integrates the microgrid controls system, including smart interfacing devices, communications networks, power switching devices, and so on. Unlike most microgrid developers and control system purveyors, GE can also provide the power generation technologies that will anchor microgrids, including renewable generation technologies, such as solar PV, as well as batteries. GE views islands, like those of Hawaii where it has helped develop solutions to variable wind and solar PV on small island grids, as one of its best near-term microgrid opportunities. In addition, GE has worked on village power systems funded through government grants in Dodaballapur, India, and several other districts impacted by a tsunami. The company also believes more than 300 remote communities in Canada alone could deploy its microgrid technology, with each of these communities representing smaller microgrid opportunities in the 100 kW to 5 MW range.

In addition, GE's Durathon battery, officially introduced in 2011, has already gained traction in global telecommunications and grid energy storage applications. Its SMH battery (formerly known as the ZEBRA battery) can size power and energy independently and typically without penalty from ambient temperature or environment. GE and FIAMM are commercializing this battery technology for grid storage applications. Currently, GE has a factory in Schenectady, New York, with capacity up to 1 GWh.

The company has identified three primary target markets for its Durathon batteries: remote off-grid telecommunications power systems, electric utility grid storage projects, and motive applications, including hybrid rail and industrial mining vehicles. Of those markets, GE has gained the most traction in the off-grid telecom market due to a 40 MW sale to a South African wireless provider.

GE's technology portfolio includes microgrid control systems (including smart interfacing devices, communications networks, power switching devices, etc.), solar PV and wind, and other key system components (power conditioning system, inverter) required to build complete wind and ESS or PV and ESS projects. This, along with GE's credit-worthiness as a firm, makes it less challenging for the firm to secure funding for turnkey solutions because all components come from GE, and the firm is solvent.

4.3.3 Raytheon

Raytheon Co., with 2012 sales of $24 billion and 68,000 employees worldwide, is a technology and innovation leader based in Waltham, Massachusetts. The company specializes in defense, security, and civil markets throughout the world. Raytheon has numerous technologies directly applicable to energy systems, including intelligent sensor technologies, sensor networks and architectures, command and control, data and information processing technology, cybersecurity, renewable energy technologies, and smart power management. With its vast array of competencies, Raytheon pursues multiple areas in the microgrid supply chain, such as balance of system design and integration, controls design and development, system fabrication, testing, and commissioning.

Raytheon is leading a project to integrate its Intelligent Energy Command and Control (IE2C) software and Primus Power's Zn/Br flow battery with the existing infrastructure of the Marine Corps Air Station in Miramar, California, using its Intelligent Power and Energy Management (IPEM) power system modeling and optimization tool in an effort to increase energy security, provide islanding capability, and reduce energy use and costs. Raytheon has also developed the R-Series Renewable Generator (ReGen), which is a self-contained hybrid power system designed for tactical use in remote locations. The system generates, stores, and manages clean renewable energy, such as solar and wind power. The ReGen has been deployed with the U.S. Marines in the Southwest United States, North Africa, and Afghanistan.

4.3.4 S&C Electric Co.

Founded in 1911, S&C Electric Co. of Chicago, Illinois, is a global provider of equipment and services for electric power systems. It is one of the most established of all hardware component suppliers selling into emerging microgrid markets. It offers a number of applicable solutions for the smart grid, such as improved service reliability, energy storage, operating efficiency, and renewable energy integration. S&C's service line includes analytical studies, design engineering, field service, project management, laboratory services, remote monitoring, and routine maintenance of power systems. Its products were integrated into the CERTS microgrid research and development testing, giving it a leg up on its competitors.

While S&C's initial claim to fame was an innovative power fuse, it has grown to become a clear U.S. leader in supplying smart switches and protection components that prevent power outages and minimize damage to equipment from power failures caused by circuit overloads. Its IntelliTeam SG Automatic Restoration System is a self-healing technology that uses excess generation from any alternate source (conventional, renewable, or storage) to restore service to un-faulted line segments, allowing for uninterrupted electricity service without manual intervention.

S&C holds a strong market share in grid scale energy storage, with claim to some of the first battery energy storage projects to be paired with wind power and used for islanding in North America. The company's 17 projects and 150 MWh of operational energy storage projects have helped pioneer the industry in North America and Europe. S&C's PureWave Storage Management Systems are used in utility-scale (1MW and up) applications to integrate a variety of battery chemistries for renewable integration, peak shaving, islanding, and frequency control. This system includes a 100% market share for NaS batteries in North America. Its PureWave® Community Energy Storage System provides another supplementary role of distributed stored energy at the commercial and residential level. This style of storage allows for significant improvements in peak shaving, load leveling, and reliability while reducing the impacts of grid events closer to the customer.

4.3.5 Sunverge Energy

One company that fully embraces the value proposition embedded with the concept of distributed energy storage is Sunverge Energy, a privately held company headquartered in Stockton, California, with 19 employees. The company has installed a total energy storage microgrid capacity of approximately 1.5 MWh in New Zealand, the United States, Germany, and South Korea. Soon it will be entering Australia. This total capacity represents literally hundreds of devices producing as little as 5 kW of power from containerized Li-ion batteries. Through its Sunverge Integration System (SIS), these batteries can be segmented for both behind-the-meter applications and utility grid ancillary services – simultaneously. Furthermore, the entire fleet of Sunverge systems, which can also integrate wind and fuel cells, can be remotely controlled from a single network operator, the essence of a VPP.

Perhaps one of Sunverge's most innovative microgrid projects has been developed in collaboration with the Pacific Housing, Inc. in California. The company is installing its SIS solutions at three low-income-affordable multifamily housing complexes located in three different ZIP codes and served by two different utilities: Southern California Edison and Pacific Gas and Electric. Financed, owned, and operated on a third-party basis, these residential microgrids are capable of islanding for a little as approximately 15 minutes, the length of time that would prevent most solar PV from tripping offline. They can also serve uninterruptible power system UPS functions for up to 2 hours. Another unique aspect of the Sunverge business model is the software-as-a-service approach, which limits upfront costs and can provide value streams for a variety of stakeholders. Other services supported by this platform are peak load shifting and demand charge reduction.

4.3.6 Toshiba

With roots that date back to 1875, Tokyo, Japan-based Toshiba has long been involved in both telecommunications and electric equipment manufacturing. Thanks to a product portfolio enhanced by the purchase of Landis+Gyr AG of Switzerland, which leads the world in smart meter deployments, Toshiba is now positioning itself in a variety of smart grid markets, including remote microgrids. Its unique advantage may be its ability to link home energy management systems (as well as commercial smart building technology) with optimized microgrid functionality.

Toshiba's flagship remote microgrid is located on Miyako Island in the south of Okinawa, Japan. Completed in October 2010, it features a number of cutting-edge technologies provided by Toshiba to the Okinawa Electric Power Company. Billed as the largest microgrid to be constructed in Japan, this system has been expanded from 4 MW to more than 9 MW. Primarily powered by solar PV, it also incorporates small wind, as well as natural gas turbines and other thermal power generation sources. The entire island has a load of more than 50 MW; thus, this is, in essence, a pilot project that could be expanded in the future. The primary purpose of this microgrid is to validate a next-generation supervisory control system, known as the Micro Energy Management System (MEMS), provided by Toshiba. The Japanese company is also providing DC/AC power conditioners with widespread applications in remote microgrids, as well as its rechargeable battery, known as SCiB.

4.4 Software and Controls Specialists: Microgrids and Storage

4.4.1 Ampard

Ampard is a Zurich, Switzerland-based startup focused on developing sophisticated controls and software for VPPs that are fast (10 hertz), reliable (units continue to operate even when communication lapses), and flexible (can be used for peak shaving, PV integration, frequency regulation, and voltage support). Ampard first developed controls around advanced battery technology; the company is also looking to develop controls for DR and thermal storage. Ampard specifically targets distribution system operators (DSOs) for its solution, citing the strain of distributed renewables on DSOs in Europe. The company has found that 50 kW to 100 kW systems with durations of 2 to 3 hours are ideal for DSOs. Ampard has positioned itself as an alternative to upgrading the distribution system and considers itself a player in the VPP space.

4.4.2 Green Energy Corp.

Based in Raleigh, North Carolina, Green Energy Corp. is a small, privately held company that offers an integrated solution for an array of microgrids via its GreenBus platform. An automation middleware based on open-source software, GreenBus aims to facilitate interoperability among disparate data and remote-sensing devices from multiple vendors – a key challenge facing all microgrids. Perhaps the most unusual aspect of Green Energy Corp.'s business model is that anyone can use the open licensed projects of GreenBus free of charge. The company then generates revenue by charging a subscription fee for the enterprise package of its platform.

In the spring of 2013, GEC merged with Horizon Energy and sister company Horizon Microgrid Solutions. Like Green Energy Corp., both are committed to an open source controls platform and have been working out a SaaS concept for microgrids. The combined company claims to have more than 100 projects on the drawing board, half of which are remote systems in the planning, design, or development phase in East Africa, Haiti, Hawaii, and other parts of North America. Virtually all of its microgrids incorporate some form of energy storage, with a clear preference for Li-ion technologies.

4.4.3 Greensmith Energy Management Systems

Greensmith is a Rockville, Maryland-based energy management systems integrator that launched in 2008. It has deployed several dozen systems throughout the United States and has begun to establish a global sales team. Its primary expertise is in systems integration for small energy storage units: community ESSs owned by utilities and building-sited systems owned directly by commercial building owners. The company is battery agnostic and works with several Li-ion cell manufacturers. Greensmith structures its systems around a three-tiered architecture: a battery management system that balances and monitors the cells, a CPU that controls the individual system through preset algorithms, and a fleet management software layer that allows a network of distributed devices to be controlled from a central location. The company expects continued growth to come from utility projects that aim to solve congested feeder issues due to high renewables penetration issues with energy storage devices. Growth will also come from commercial building owners that have power quality issues and can reduce demand charges and participate in time-of-use rate programs with energy storage devices.

The company currently has 14 customers, including eight major utility companies and solar developers. Greensmith holds several patents in the areas of intelligent control, integration, and storage of electricity. The company is in its fourth generation of battery operating systems software.

4.4.4 Growing Energy Labs Inc.

San Francisco, California-based Growing Energy Labs, Inc. (GELI) does not directly make batteries or power systems; instead, it makes software to control batteries connected to the grid. GELI's software allows utilities and commercial installations to integrate power more effectively from renewable energy sources with intermittent generation, such as wind and solar, by making operational decisions based on the price of power and energy in addition to the electrical status and activity of the grid and other system components. The GELI software can be optimized for microgrids or integrated ESSs. GELI licenses its software to developers, battery manufacturers, energy finance companies, and solution providers. What makes the software attractive is that it optimizes energy storage across multiple value streams, such as Demand Charge Management, TOU Energy Shifting, DR, making it more than just backup power. Utilities will benefit because the GELI system will help control peak shifting, load balancing, and frequency regulation by automating batteries connected to the grid. The software will also benefit renewable generation on the residential-scale by allowing the battery to communicate with the generation source and the end use. For example, a rooftop solar array producing electricity that is stored in a battery can be released with the smartest economics to various appliances as needed, increasing total system efficiency.

GELI intends to launch commercially in 2014. The company has collaborated with companies like Samsung, Dynapower, Aquion, Kokam, Coda, and Ideal Power, and it is meeting with developers regularly as they enter the market for microgrids or standalone ESSs.

4.4.5 HOMER Energy

HOMER Energy LLC is the world's leading source for the design and cost of remote power systems. It provides software, services, and community tools to professionals, researchers, and enthusiasts in the energy industry who desire to analyze and optimize distributed power systems and systems that incorporate high penetrations of renewable energy sources. Based in Boulder, Colorado, HOMER Energy was incorporated in 2009 to commercialize the Hybrid

Optimization Model for Electric Renewables (HOMER), which was developed by the National Renewable Energy Lab. In addition to the HOMER software, HOMER Energy offers additional services, such as web-based and in-person training and assistance in the use of HOMER. It also customizes the software for novel problems or types of equipment and provides a range of consulting services related to the policies, economics, and technologies of renewable and distributed power. Since its release, the HOMER software has been downloaded by more than 80,000 people in 193 countries. The company has developed a customized model for sizing flow batteries in remote microgrids with energy storage vendor ZBB Energy.

4.4.6 Spider9

Spider9 was founded in 2011 at the University of Michigan's School of Real-Time Computing by a team of Fortune 500 executives that were seeking solutions to increase the performance of renewable energy through the application of intelligent system controls. The Northville, Michigan-based startup has raised $10 million in private funding and leveraged patented technologies from the university to create a battery management software system called the Operating System for Energy (OSE). The system can remotely isolate degraded battery cells, allowing them to be replaced while the ESS as a whole is kept running at close to its nameplate voltage output without increasing system stress. OSE is integrated into Energy Vault, the company's Li-ion-based ESS, which is designed for residential and light commercial energy applications. Spider9 will be managing a 2 MWh Li-ion battery array that is connected to a solar farm being built by Greek solar developer EasyPower. The project is scheduled for completion in early 2014. Company executives expect the western United States and Germany will be key markets for the new products.

4.4.7 Spirae, Inc.

Started in 2002 in Fort Collins, Colorado, Spirae is a privately owned firm that is focused on VPP projects. Its technology and expertise are making some waves with microgrids designed to mesh with smart grid functionality. Spirae's BlueFin product is a distributed control platform that is highly scalable and allows custom integration of distributed generation, wind, solar, storage, thermal storage, flexible loads, and other dispersed resources. It also offers dynamic virtual generation and ancillary services management capabilities for the VPP and microgrid markets.

The firm can design and develop custom applications based on Spirae platforms and then perform the field engineering and data collection for modeling, simulation, and validation. Unique features of the BlueFin Microgrid Control include asset control, scheduling and dispatch, ramp rate control, energy and volatility forecasting, frequency and voltage control, ancillary services and market participation, and soft-islanding and automatic resynchronization. Spirae soft-islanding reduces export/import availability to zero before the breaker is opened, thereby islanding the microgrid without a power failure. Spirae currently has operations in North America, Europe, and India.

4.4.8 Xtreme Power

Founded in 2004, Xtreme Power is based in Kyle, Texas, with manufacturing facilities in Oklahoma and Texas. The company counts Dow Chemical, Fluor, Dominion Power, and BP as investors. Unlike most storage innovators, Xtreme Power is not an advanced battery purveyor. Instead, the company says it sells complete large-scale storage solutions. In January 2014, Xtreme Power announced it had filed voluntary petitions for relief under Chapter 11 of the United States Bankruptcy Code and that it is seeking a strategic buyer. According to a press release, the firm's core engineering, project development, and operations staff will remain at the company while it attempts to secure an acquirer.

Xtreme Power shifted toward large-scale wind and solar PV integration projects in 2011. It made major inroads on the Hawaiian Islands, where frequency issues can become major challenges due to the lack of interconnection with larger power grids. (Each island of Hawaii is not only a physical island but also an electrical island.) The storage systems from Xtreme Power are designed to firm up wind and solar farm power production, a market that includes more than three-quarters of the company's current business activity. Most recently, Xtreme Power made another shift, abandoning its own lead-acid battery to focus instead on its software and smart controls for a variety of storage chemistries, including Li-ion and flow batteries, with a renewed focus on remote applications.

The company's storage system controls feature a bidirectional, closed-loop, and water-cooled solid-state inverter/charger that features a microsecond response time and a real-time control system that can integrate customized algorithms for specific applications. Among the options are fixed or dynamic response, local or remote control nodes, and automated or manual operations.

4.4.9 Younicos

One of the most provocative vendors in the remote microgrid space is privately held Younicos of Berlin, Germany, which has the motto, "Let the fossils rest in peace." Younicos, with 70 employees, is among the companies purported to be able to create 100% renewable energy remote microgrids. The key enabling technology to achieve this feat is its software that can optimize smart bidirectional inverters, thereby displacing the need for a fossil prime mover within a microgrid, providing spinning reserves without the need for rotating mass. Embedded with advanced communications, the smart Younicos inverter can also help shed loads and help wind and solar PV devices run in parallel with diesel generators, if necessary. Its microgrid efforts are focused primarily on remote systems, and the company has recently marked several major milestones with grid-tied applications, some of which feature the ability to island. For example, Younicos deployed a 1.2 MW battery park for the utility Vattenfall in Berlin, Germany. The company has provided grid-balancing services since December 2012, making it the first grid-tied system prequalified to provide frequency response in Europe.

Younicos is currently pursuing another round of fundraising, seeking capital or a partnership with a larger company deeply involved in the microgrid/energy storage supply chain.

Section 5
MARKET FORECASTS

5.1 Introduction

This report includes detailed market forecasts by region, microgrid type, and technology. Three units are forecast: megawatts, megawatt-hours, and revenue in U.S. dollars. This section of the report discusses the high-level forecasts by region, technology, and microgrid type in terms of MW and revenue. The MWh forecasts by region, technology, and microgrid type are available in the Excel databook, as are the detailed region, microgrid type, and technology forecasts.

5.2 ESSs for Microgrids by Region

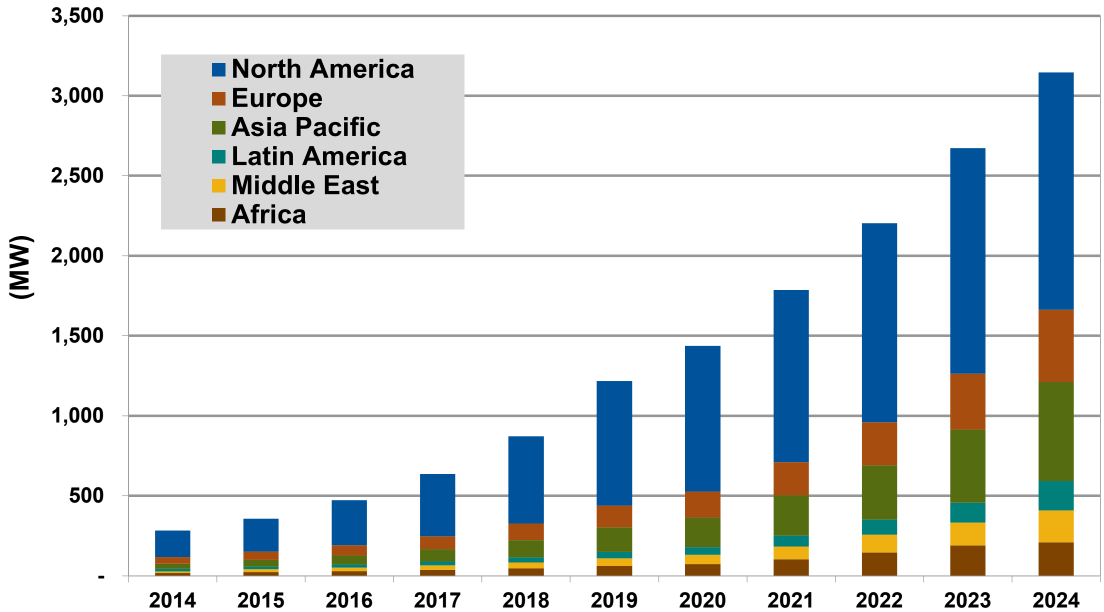
North America is the largest adopter of ESMG globally. This is largely because the ESMG market is derivative of the overall microgrid market. The North American market is the largest market for microgrids in each of Navigant Research's three scenarios (conservative, base, and aggressive), followed by Asia Pacific and Europe in terms of forecasted growth in overall microgrid deployments.

The following factors will affect the ESMG regional market shares:

- **Average microgrid size:** For example, African microgrids are typically less than 1 MW, whereas 181 of the 308 North American microgrids are more than 1 MW in size.
- **Ancillary revenue opportunities:** For example, the North American electricity market structure allows small resources to bid into and be compensated for delivering frequency regulation, whereas the minimum to bid into the German market is 1 MW.
- **Microgrid supplier strategies:** For example, ABB Powercorp uses flywheel technology while other developers are technology agnostic.

Asia Pacific is a prime candidate for remote microgrids of all types, with the exception of military, due to its many islands, fragile grid systems, and remote territories. Asia Pacific is the second-largest market for ESMG (both grid-tied and remote) with up to 620.3 MW and 2,796.9 MWh of installed ESMG capacity forecast in 2024. Cumulative installed capacity in the region is slated to be 2,323.0 MW and 9,311.7 MWh.

Chart 5.1 Installed Energy Storage Power Capacity in Microgrids by Region, World Markets: 2014-2024

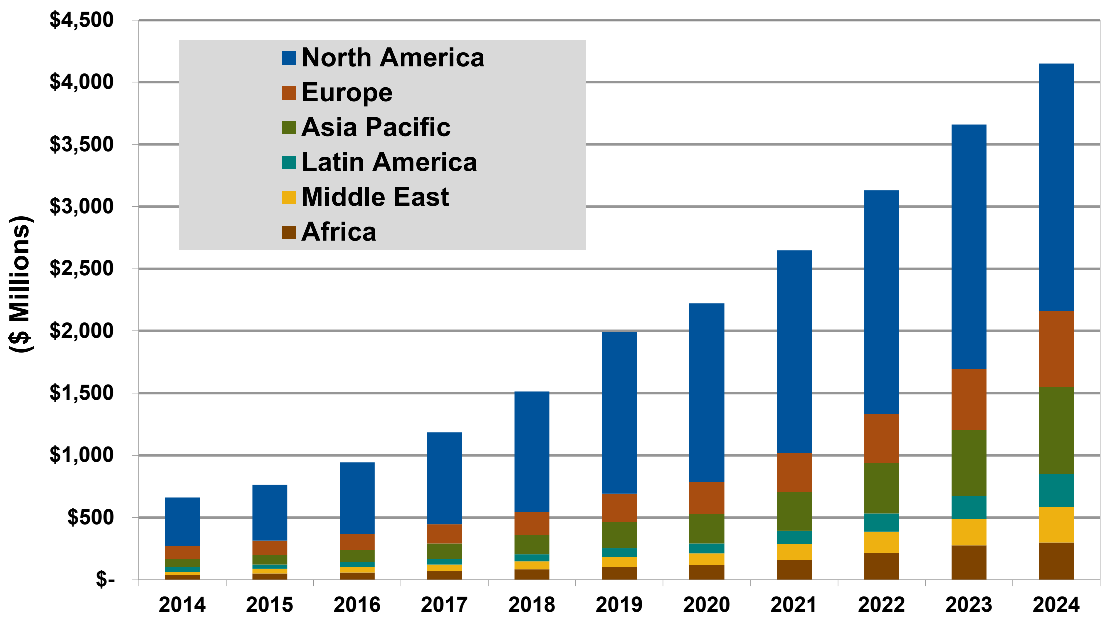


(Source: Navigant Research)

The North American market is by far the largest in terms of revenue, although most of this market is tied to customer-owned microgrids, where the emphasis will be placed on more robust islanding capabilities and the ability to participate in the ancillary services market. Technology that can do both is rare. Islanding plays well to the strengths of flow batteries, whereas flywheels and advanced Li-ion and lead-acid do better on the ancillary-service side.

All told, the North American market for ESMG is forecast to be $1,989.4 million, with the Asia Pacific and Europe markets valued at $697.7 million and $611.1 million, respectively. This difference in cost is attributable to the Asia Pacific region's heavy reliance on Li-ion batteries, which will drive down overall revenue significantly, as this technology is expected to have the most aggressive cost out of all five technologies in the forecast. In addition, native battery manufacturers that develop and install flow and SMH batteries, for instance, are well-positioned to penetrate the European microgrids market with a technology that offers overall good value for money on an energy basis.

Chart 5.2 Installed Energy Storage Revenue in Microgrids by Region, World Markets: 2014-2024

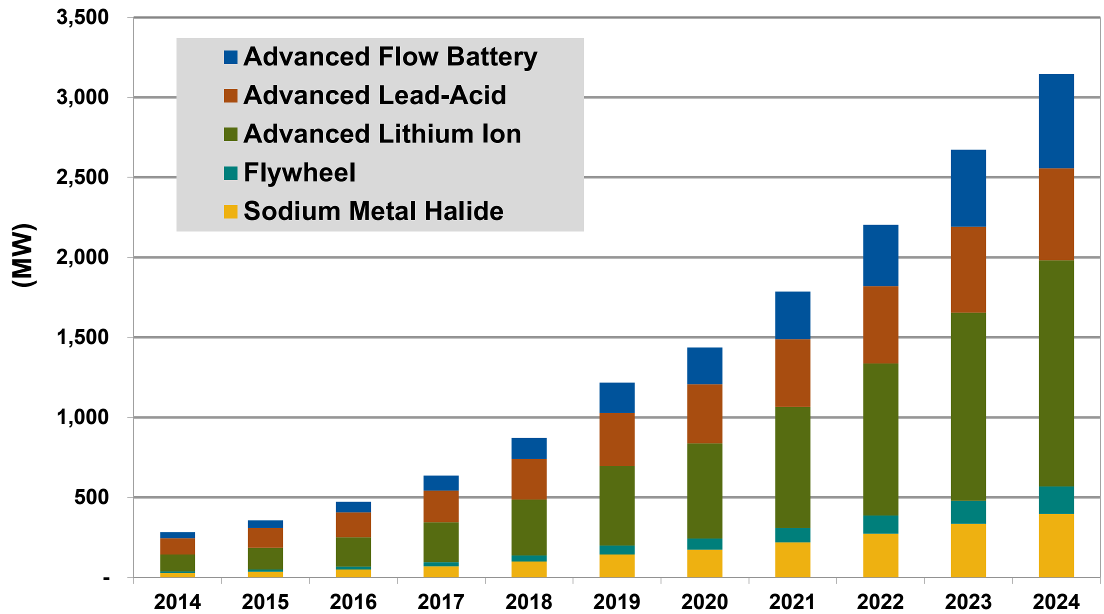


(Source: Navigant Research)

5.3 ESSs for Microgrids by Technology

Technology market share for microgrid applications depends on cyclability, flexibility, cost, and footprint. In the case of remote microgrid applications, durability is also a key characteristic in determining market share. The technologies forecast include advanced flow batteries, advanced lead-acid, advanced Li-ion, flywheels, and SMH. A key determinant of technology market share is the end-use application in the six microgrid types forecast in this report (grid-tied and remote microgrids of three types: customer-owned, utility-owned, and military). Purchasers of these six technologies will have different cost and performance concerns to balance when considering energy storage. In addition, some firms have distinctive strategies when it comes to incorporating energy storage in system. For example ABB's Powercorp uses flywheel technology in remote microgrids, such as the BHP Billiton nickel mine in Western Australia and the Coral Bay community in Northwestern Australia, even though these are remote diesel-led systems that typically require at least 2-3 hours of discharge.

Chart 5.3 ***Installed Energy Storage Power Capacity in Microgrids by Technology, World Markets: 2014-2024***

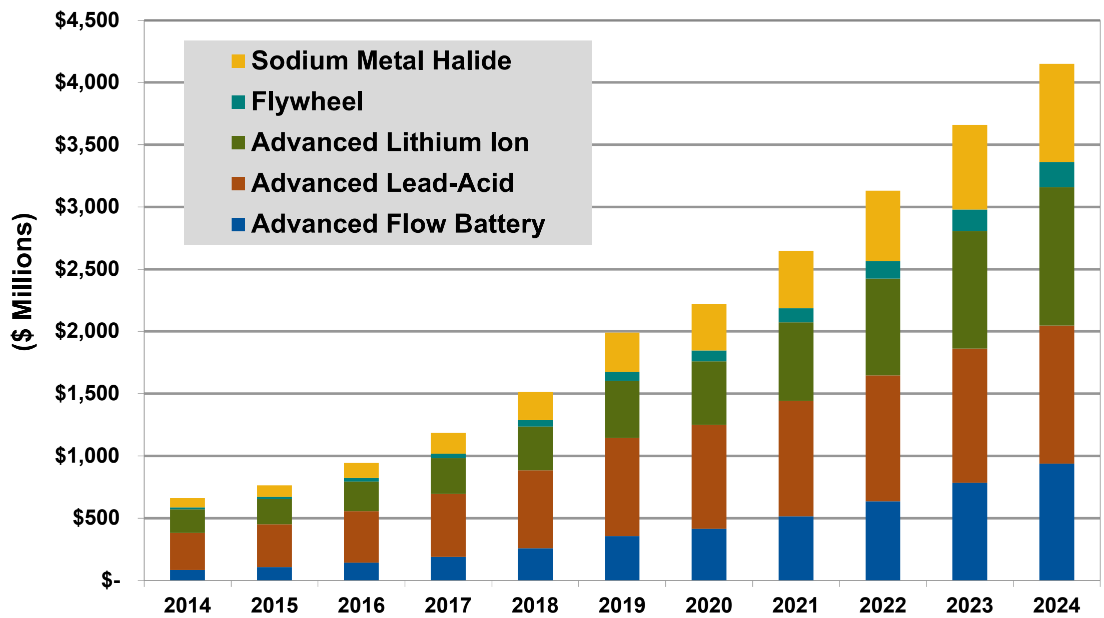


(Source: Navigant Research)

Revenue by technology is determined by multiplying the megawatt forecast by the current estimated costs in 2013 per technology. For the 2014-2024 period, downward cost curves are estimated for each technology based on supplier base, manufacturing developments, supplier experience with systems and project integration, and innovative financing mechanisms. Although Li-ion is a leading technology in the space, the downward cost curves for Li-ion are also the most aggressive out of all the technologies in this forecast with a compound annual growth rate (CAGR) of -12.5% in the 2014-2019 period and -6.4% in the 2019-2024 period.

This downward cost pressure reduces the overall revenue market share for Li-ion compared to the Li-ion megawatt market share. In fact, although the total Li-ion market for microgrids is 1.8 times that of advanced lead-acid (6,588 MW to 3,579 MW cumulative), the Li-ion market is only $29 million larger than the advanced lead-acid market in 2024 ($1,148 million for Li-ion compared to $1,109 million for advanced lead-acid). Although advanced lead-acid will be more expensive than advanced Li-ion (due to the manufacturing volumes of Li-ion that advanced lead-acid will be hard-pressed to match), advanced lead-acid will have advantages over Li-ion, including durability, which will be important in remote microgrid applications.

Chart 5.4 Installed Energy Storage Revenue in Microgrids by Technology, World Markets: 2014-2024



(Source: Navigant Research)

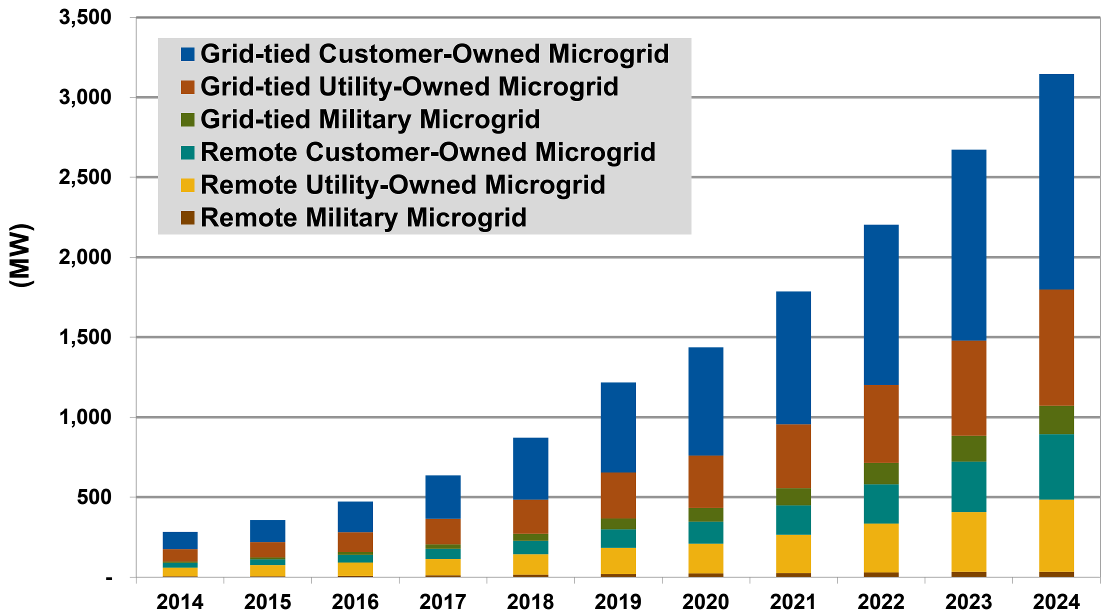
5.4 Microgrid Type

The microgrid type will have a significant influence on the best-choice technology. For example, remote systems must be more durable and robust than grid-tied systems because the opportunity cost of a failure is high, and there is typically only one backup solution (diesel) that may also be prohibitively expensive for any duration of time. According to one battery manufacturer, if a remote system cannot be serviced locally, it is likely to take at least 5 to 7 days for a qualified technician from the firm to reach the site, diagnose the issue, and repair the fault. As a result, a diesel generator will be running (cycling up and down, which is inefficient for fuel consumption) for the duration, if not longer, depending on the site and access to repair services from the systems integrator or ESS firm.

In addition, grid-tied microgrids are likely to have a greater choice in prime movers, and may use natural gas as a fuel instead of diesel, for example. These systems may also deliver ancillary services to the grid, may require extended islanding capabilities, and may have less stringent uptime requirements (since the grid will act as a backup system, in most cases).

Military microgrids are forecast based on the customer and not on the location of the microgrid. Although the U.S. military may have storage installed in microgrids outside the United States, the customer is the DOD, and as such, the capacity and revenue are accounted for as being part of the North American geography.

Chart 5.5 Installed Energy Storage Power Capacity in Microgrids by Microgrid Type, World Markets: 2014-2024

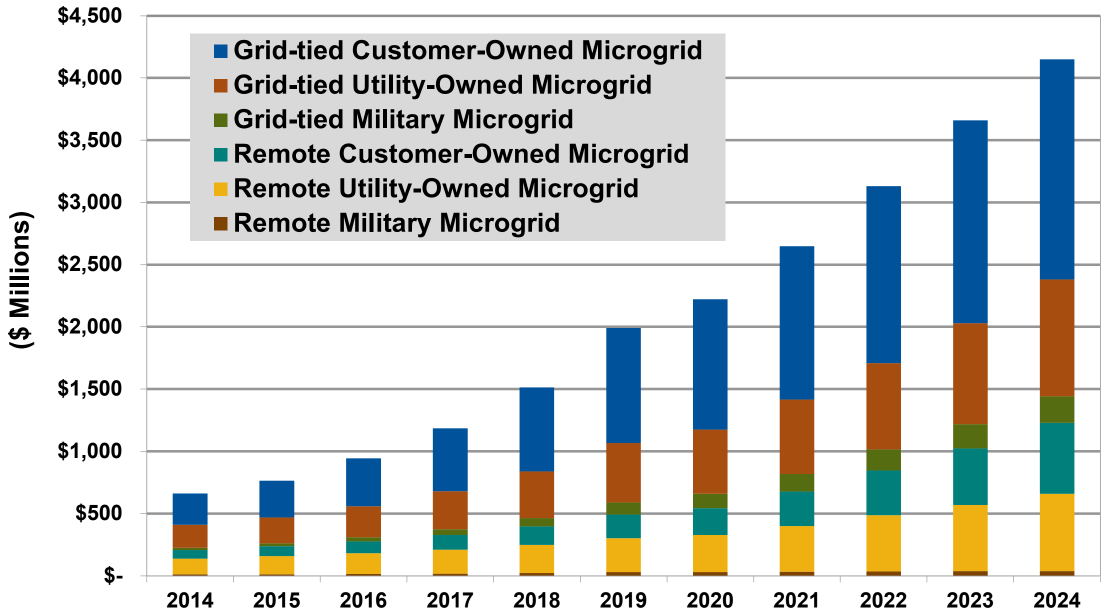


(Source: Navigant Research)

Customer-owned microgrids are the largest market for ESMG, this is largely a function of the North American market, where customer-owned microgrids will account for 71.2% of the North American market (see Navigant Research's *Microgrids* report for additional details). The campus/institutional market is particularly strong in North America. As such, technologies that provide a good balance between extended islanding, services to the microgrid, and allow for higher renewables penetration to accelerate the ROI for these microgrids will do well. In contrast, the market is more evenly split between grid-tied systems for utilities and remote systems for utility and customers. This is largely due to the Asia Pacific and European markets, where the distribution of microgrids is expected to be fairly evenly split between these types of systems, and as a result, ESMG.

The remaining markets, Latin America, the Middle East, and Africa follow the opposite trend as North America; these markets are heavily skewed toward remote microgrid systems. As noted in Section 2, the business case for ESMG in remote systems is built around diesel reduction. In Latin America and Africa, diesel prices are especially high.

Chart 5.6 Installed Energy Storage Revenue in Microgrids by Microgrid Type, World Markets: 2014-2024



(Source: Navigant Research)

5.5 Conclusions and Recommendations

Although the market forecast for energy storage being deployed within microgrids is set to grow during the forecast period, the key to entering these markets from the perspective of energy storage players is to focus on lowering costs for storage. In other words, these vendors must be able to make a compelling business case, even if diesel prices should decrease, and to develop a flexible market entry strategy.

The consumer of a microgrid will not approach a storage company for a solution. Instead, a customer is likely approach a one-stop solution provider that can assist with the engineering, procurement, construction, integration, permitting, and financing of a microgrid. Therefore, storage companies must either position themselves as microgrid experts and integrators, or they must partner with engineering, procurement and construction contractors, microgrid control and software developers, and other key microgrid players to get their products to the end customer.

Section 6

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Section 7

Acronym and Abbreviation List

Alternating Current .... AC

Capital Expenditure .... CAPEX

Combined Heat and Power .... CHP

Compound Annual Growth Rate .... CAGR

Consortium for Energy Reliability Technology Solutions .... CERTS

Demand Response .... DR

Department of Defense (United States) .... DOD

Department of Energy (United States) .... DOE

Direct Current .... DC

Distributed Generation .... DG

Distribution System Operator .... DSO

Distributed Energy Resources .... DER

Energy Storage for Microgrids .... ESMG

Energy Storage System .... ESS

European Union .... EU

Forward Operating Base .... FOB

General Electric .... GE

Gigawatt .... GW

Gigawatt-Hour .... GWh

Grid Storage Solution (A123 Energy Solutions) .... GSS

Growing Energy Labs, Inc. .... GELI

Hybrid Optimization Model for Electric Renewable .... HOMER

Independent Power Producer .... IPP

Kilowatt .... kW

Kilowatt-Hour .... kWh

Lithium Ion .... Li-ion

Megawatt .... MW

Megawatt-Hour .... MWh

Net Present Value .... NPV

Operating System for Energy (Spider9) .... OSE

Photovoltaic .... PV

Renewable Distributed Energy Generation .... RDEG

Research and Development .... R&D

Sodium Metal Halide .... SMH

Sodium Sulfur .... NaS

Sunverge Integration System .... SIS

Transmission and Distribution .... T&D

United Kingdom .... U.K.

United States .... U.S.

Utility Distribution Microgrid .... UDM

Virtual Power Plant .... VPP

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Scope of Study

Navigant Research has prepared this report to provide participants in the energy storage and microgrids market with a study of the global ESMG market, including a deeper analysis of the top driver for grid-tied and remote microgrids, respectively.

This report builds on the work of the Navigant Research Microgrids research and offers granular forecasts for ESMG adoption segmented by microgrid, customer, technology, and region. Participants include equipment and hardware vendors, utilities, software companies, installation and service providers, and other system component manufacturers.

The report's purpose is not to provide an exhaustive technical assessment of all of the technologies that may be related to ESMG. Rather, it aims to provide a strategic examination of the market that focuses on one to two key drivers, key technology issues, and the competitive landscape. Navigant Research strives to identify and examine new market segments to aid readers in the development of their business models. All major global regions are included and the forecast period extends through 2024.

Sources and Methodology

Navigant Research's industry analysts utilize a variety of research sources in preparing Research Reports. The key component of Navigant Research's analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Navigant Research's analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Navigant Research's reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

Navigant Research is a market research group that aims to present an objective, unbiased view of market opportunities within its coverage areas. Navigant Research is not beholden to any special interests and is thus able to offer clear, actionable advice to help clients succeed in the industry, unfettered by technology hype, political agendas, or emotional factors that are inherent in cleantech markets.

NOTES

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

CAGR = (End Year Value ÷ Start Year Value)$^{(1/steps)}$ – 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 2014 U.S. dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

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