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WHITE PAPER

Building the Business Case for Hybrid Battery Platforms

Optimizing High Penetration Renewable Energy Microgrids

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Section 1
EXECUTIVE SUMMARY

1.1 Microgrid Market Drivers Spur Energy Storage Innovation

Navigant Research projects that commercial and industrial (C&I) microgrids will be the fastest growing market segment over the next decade. C&I projects, whether connected to a grid or not, are benefiting from the declining costs and increased functionality embedded in advanced batteries, including technologies such as zinc-air (ZnAir). Ten years ago, many microgrids were designed to avoid including battery technologies due to the high cost. In 2019, the opposite is true. Not just one but two kinds of batteries can be integrated into microgrids to optimize the distributed energy resources (DER), and balance frequency and voltage. Along with C&I customers such as data centers, other microgrid segments are gaining momentum, including microgrids deployed by utilities themselves.

A number of global programs, such as World Bank's $1 billion energy storage initiative, are increasing interest in advanced battery technologies. As the world shifts to greater reliance on variable renewable energy resources, the need for low cost, long duration, and largely maintenance-free battery options is increasing dramatically. Though lithium ion (Li-ion) batteries have historically been the battery solution of choice for many microgrids, the need for longer duration energy storage is becoming more important as the variable renewable content of microgrids and the overall grid continue to climb. As the impacts of global climate change continue to stress the grid, digital economy, critical facilities, and communities, energy storage will play an even more vital role in our energy future.

Many assume that energy technology innovation typically starts in the industrialized nations and then ultimately gets exported in some form to the developing world. For DER solutions, that is not always the case. Take the example of energy storage system (ESS) solutions. Remote microgrids, which require strong resilience since they must operate in island mode 24/7, have spurred major advances with controls and ESS optimization, allowing for higher penetrations of renewable energy. These advances are often nurtured by economic necessity, not policy incentives or subsidies.

ZnAir battery technologies are one example. When coupled with Li-ion, the resulting hybrid battery solution offers a compelling story for which the business case will grow over time. One potential use is in data centers, which drive much of today's digital economy. These end users are C&I customers that require extremely reliable energy. A single minute loss of power can result in a million dollar loss. Data centers have historically depended on diesel generators paired with lead-acid batteries. There must be a better way.

1.2 Defining Hybrid Battery Platforms

Hybrid power systems have traditionally been defined as a blend of fossil and renewable energy technologies. This hybrid approach to power generation has been at the core of the microgrid value proposition. This is especially true in remote power applications, where the cost of diesel is so high that integration with renewable energy resources—whose fuel is free—reduces ongoing operating costs. As the proportion of renewable energy increases beyond certain thresholds, longer duration batteries capable of storing renewable energy over several hours are required to optimize the entire DER portfolio to realize the resiliency and reduced cost value propositions inherent with the microgrid platform.

NantEnergy is a new company that incorporates a long duration, low cost battery solution inherited from Fluidic Energy combined with the Li-ion ESSs previously sold by Sharp Electronics, now also part of the NantEnergy offering. This hybrid battery solution fits the theme of a greater hybridization of grids, whether one is focusing on power generation, alternating current (AC) and direct current (DC) infrastructure, or battery solutions. NantEnergy is integrating battery chemistry configurations (ZnAir and Li-ion) to provide optimal value for end users.

Hybrid battery platforms to date have been led by remote microgrid applications, including energy access and telecom sites. These hybrids come in many forms. Batteries married with flywheels or ultracapacitors are among the more common. The latter two hybrids fail to address some of the challenges in project design when integrating two forms of storage, taking into consideration primary and secondary applications. At present, few, if any, battery hybrids incorporated into multi-resource microgrids or other power networks include a viable long duration technology that can serve as a resilience insurance policy.

Navigant Research recognizes that the same value streams captured in remote power applications can be applied to grid-connected projects, whether developed by third-party developers or utilities. Among the lowest cost (and longest duration) battery chemistries on the market, ZnAir battery technology's value increases when integrated with other batteries (such as Li-ion) as well as other DER (solar PV, wind, hydro, etc.).

In this white paper, Navigant Research focuses on the specific characteristics of ZnAir batteries. It discusses the value proposition that integrating Li-ion batteries with ZnAir provides a powerful, long-lasting, and dynamic ESS configured to meet the challenges associated with two pressing market needs: longer term resilience services for C&I clients, communities, and utilities; and high penetrations of variable renewable energy systems installed at customer sites and on the grid in general.

A ZnAir/Li-ion battery hybrid system offers several synergies for customers seeking resiliency, lower technology and energy costs, and capture of grid service revenue streams.

Section 2
THE ZINC-AIR BATTERY VALUE PROPOSITION

2.1 Putting Zinc-Air Batteries on the Energy Storage Map

While first commercial applications date back to 1920s, zinc-air (ZnAir) battery applications were focused on remote railroad signaling and harbor buoy lighting. In 2019, however, the characteristics of the battery are ideal for stationary energy storage applications such as microgrids, telecom towers, and as a low cost and creative backup power solution for utilities thinking outside of the box on resilience.

ZnAir batteries are designed with a fundamentally different architecture than most conventional batteries. Typical rechargeable batteries consist of an anode and cathode at opposite sides of the cell with a conductive electrolyte in between. The key difference in a ZnAir battery is its use of air as the cathode opposite a zinc anode. During the battery's charging phase, electrical current converts zinc oxide into zinc and oxygen. When energy is required, the discharge phase oxidizes the zinc with air, and the process can repeat.

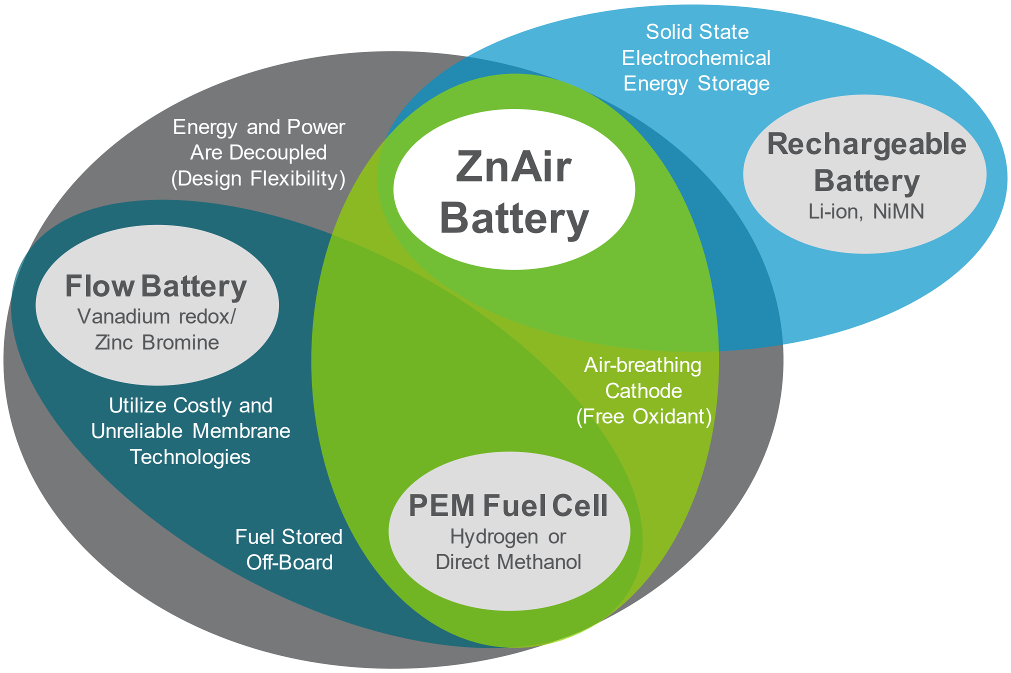
The relatively simplistic design of ZnAir batteries offers the potential for lower cost manufacturing compared to other battery chemistries with less supply chain risk and environmental impact. A primary reason for this is the lack of expensive and potentially volatile compounds found in other batteries including lithium, cobalt, and vanadium.

ZnAir batteries offer technical specifications and operational characteristics that straddle the line between conventional Li-ion batteries and flow batteries. An important advantage of ZnAir technology is the design flexibility enabled by the decoupling of power and energy capacities. ZnAir batteries can be configured in a variety of full power discharge durations ranging from 2 to over 24 hours. The technology generates a lower round-trip efficiency between 50% and 65%. This compares to flow batteries which average 65%-80% efficiency, and Li-ion batteries, which can achieve 90% or higher. However, ZnAir batteries offer efficiency advantages at the system level by operating in a wider temperature range and not requiring external active heating or cooling which reduces the round-trip efficiency of other battery technologies including Li-ion.

ZnAir technology also benefits from a long lifetime with little to no degradation of capacity based on usage. The technology runs for 3,000 cycles at full power, on average, and unlike Li-ion batteries offers a full 100% depth of discharge. ZnAir batteries can be readily recycled and replaced with new electrodes for continued usage. The technology is also advantageous due to the lack of moving parts and minimal maintenance which makes it well suited for microgrid and remote applications where maintenance service is challenging and expensive.

A comparison of this technology with the portfolio of similar DER options is illustrated in Figure 2-1.

Figure 2-1. Attributes of ZnAir Batteries Are Shared with Other Energy Storage and DER Options



(Sources: Navigant Research, NantEnergy)

2.2 A Comparative Analysis: Unique Attributes of ZnAir Batteries

ZnAir is a newer energy storage technology that does not neatly fit into the traditional categorization of energy storage options. It is not a flow battery, though its distinguishing feature is longer duration storage. It is not a power application, such as flywheels or ultracapacitors (and to a lesser extent Li-ion). It also does not match up with large-scale pumped hydroelectric or compressed air. This conundrum of not being able to fit ZnAir batteries into a conventional map of energy storage options has led to unfamiliarity with its specialized attributes. As a result, many of those looking for advanced energy storage applications for new DER platforms such as microgrids do not have this battery option on the radar, especially in markets such as North America, where the prime focus has been peak shaving, demand response, and frequency regulation. This allowed the technology to slip under the radar.

The value proposition standing behind ZnAir centers around its cost, its lack of environmental impacts throughout the mining and manufacturing life cycle, and its suitability for meeting the changing needs of an energy market marching toward increased reliance upon variable renewable energy. Specific advantages include:

- ZnAir's raw material costs are up to 20 times less expensive than Li-ion (or 5% of the cost)
- ZnAir's raw material costs are up to 4 times less expensive than lead-acid batteries (or 25% of the cost)
- ZnAir offers more cost-effective longer duration storage than either Li-ion or lead-acid
- It has lower operating costs since it can operate in a wide range of temperature environments without additional fans or heaters (-20 degrees C to 50 degrees C)

These advantages in standalone applications are enhanced when deployed in a hybrid platform, as will be discussed in detail throughout the rest of this white paper.

2.2.1 Decoupling Power from Energy

Typically, energy storage can provide two basic services: power and energy. Up until recently, power applications were more cost-effective. This application was a more pressing need to integrate renewable energy resources with onsite fossil fuel generation. Power applications were well served by more conventional battery technologies, including lead-acid and Li-ion. These technologies offer relatively high power densities; however, they have limited design flexibility to customize the amount of power and energy capacity. This type of customization ability is known as decoupling. The architecture of certain battery technologies, such as flow and ZnAir batteries, offers the ability to modify the power output and energy capacity of an ESS independently.

Decoupling power output and energy capacity in an ESS allows for flexibility in designing a project to fit the needs of a customer more accurately and can lead to a more profitable investment. Certain battery technologies, such as lead-acid and Li-ion, have a limited ability to decouple power from energy due to the operational characteristics of the technology and system architecture. This can result in projects with an excess of either power output or energy capacity that drives higher system costs. By comparison, ZnAir and flow battery technologies that allow for decoupling can be sized to both the power and energy requirements for a given project.

Flow batteries operate by pumping liquid electrolyte through an ion exchange membrane to generate an electric current. In these systems, the power output of the system is determined by the area of the exchange membrane/electrode while energy capacity is based on the volume of liquid electrolyte. Power and energy are therefore decoupled as the volume of electrolyte can be increased for longer duration discharge with the same size membrane/electrode and power output.

ZnAir batteries operate on a similar principle, though with different specifications. In these batteries, the air electrode acts like the engine in a car, determining the maximum power out of the storage system. The zinc anode then serves as the fuel, powering the system and determining its energy capacity. The battery container can be developed in a variety of sizes to allow for different energy capacities while keeping the same electrode area, resulting in the ability to decouple energy from power and provide long duration discharge operation.

The ability to decouple energy from power is a key advantage of ZnAir battery technology. ZnAir batteries are compared with other leading battery and distributed energy technologies in the following sections.

Table 2-1. ZnAir Battery SWOT Analysis

Strengths	Weaknesses
• Low cost material inputs • Ability to decouple power output and energy capacity • No thermal runaway or fire safety risk • 100% depth of discharge capability	• Low round-trip efficiency • Limited manufacturing capacity currently available compared to incumbent technologies
Opportunities	**Threats**
• Long duration storage applications such as emergency resiliency and displacing diesel generation in microgrids • Combining with Li-ion or other technologies in hybrid designs • Relatively low cost manufacturing can be scaled up faster than other technologies	• Increasingly long duration designs for Li-ion batteries • Flow batteries achieving cost reduction breakthroughs • Achieving broad market acceptance on par with Li-ion • Bankability of warranties

(Source: Navigant Research)

A variety of zinc-based battery technologies that take advantage of zinc's abundance and resulting low cost are being developed and actively deployed. Using low cost inputs will allow ZnAir and other zinc-based technologies to decrease costs rapidly as manufacturing scales, bringing down balance of system costs. The ability to scale manufacturing presents another advantage. Unlike Li-ion and certain flow battery technologies, ZnAir batteries do not require clean rooms and the use of toxic chemicals. This allows for new manufacturing facilities to be built relatively quickly in local markets close to customers.

2.2.2 Flow Batteries (Vanadium/Zinc Bromine)

Flow batteries remain an emerging technology in the energy storage industry, although progress toward commercialization has accelerated. Flow batteries are generally defined as single-celled batteries that transform the electron flow from activated electrolyte into electric current. They achieve charge and discharge by pumping a liquid anolyte (negative electrolyte) and catholyte (positive electrolyte) across a membrane. Flow batteries are naturally flexible and expandable by design and able to store energy for long periods of time simply by adding additional tanks of electrolyte. While there are many different flow battery chemistries, two have emerged as the most attractive in this market: vanadium redox and zinc bromine.

Table 2-2. Flow Battery SWOT Analysis

Strengths	Weaknesses
• Design flexibility to decouple energy and power • No fire safety/thermal management risk • Long cycle life without degradation	• Low round-trip efficiency • High upfront costs • Few bankable vendors
Opportunities	**Threats**
• Chemistries with lower materials costs (e.g., zinc-based, iron-based) • Absorbing excess generation that would otherwise be wasted	• Emerging long duration technologies with lower materials costs • Reputable vendors offering reliable warranties for competing technologies

(Source: Navigant Research)

2.2.3 Fuel Cells

Fuel cells are commercially viable in 2019. Some companies, such as Bloom Energy, are actively marketing themselves as microgrid vendors. The issue continues to be cost, though low natural gas prices makes them an appealing alternative to diesel generators in regions with air quality constraints. Fuels cells currently rank among the most expensive distributed generation options for microgrids, and their notorious sensitivity to fluctuations of power quality means they are not yet ready for mixed-resource microgrids. However, Bloom Energy and others are figuring out how to use a DC bus backbone to attach energy storage devices to help smooth out performance.

Table 2-3. Fuel Cell SWOT Analysis

Strengths	Weaknesses
• Extremely modular • Very low emissions • Few moving parts, so low maintenance	• Poor load following ability • High cost of fuel cell and hydrogen fuel production • Sensitive to small frequency deviations for microgrids in island mode
Opportunities	**Threats**
• Data centers looking for diesel alternatives • Clean baseload power for microgrids	• Declining solar PV and battery prices • Historic variability in natural gas prices • Lack of hydrogen infrastructure

(Source: Navigant Research)

2.3 The Value Proposition of Li-Ion Batteries

Li-ion batteries have emerged as the leading technology for new deployment of utility-scale energy storage not only because of their flexibility, but also largely because they are already available in mass production and further down the experience curve than many other newer technologies. The Li-ion category includes a variety of different chemistries and architectures, but they all operate on the core principle of Li-ion intercalation.

Li-ion batteries have excellent energy and power densities, high round-trip efficiency, and decent life cycle expectations, making them well suited for grid applications, particularly power-intensive applications often necessary within a microgrid. However, stability and thermal runaway remain a significant concern. Li-ion systems require complex thermal management and safety systems.

Table 2-4. Li-Ion SWOT Analysis

Strengths	Weaknesses
• High power and energy density • High round-trip efficiency • Mass production, reputable vendors, low cost	• Safety concerns due to thermal runaway • Need for active cooling in high heat environments • Inability to provide very long duration discharge
Opportunities	**Threats**
• Continued improvement in energy density • Continued improvements and system design for safety • Long duration designs up to 8 hours	• Alternative technologies for long duration storage • Raw material costs and availability: lithium and cobalt have faced recent supply constraints and volatile prices

(Source: Navigant Research)

2.4 Why 1 Plus 1 Can Equal 3: The Hybrid Energy Storage System

The combination of multiple energy storage technologies with complementary operating characteristics and technical requirements can provide many advantages for customers and project developers. Hybrid ESSs (HESSs) are a relatively new class of energy storage solutions. They combine two or more stationary energy storage technologies with supplementary operating characteristics that deliver energy for short-, mid-, and long-term applications not achievable by any one technology. HESSs can address the power and energy needs of a wide range of customers.

HESSs have several advantages in the market:

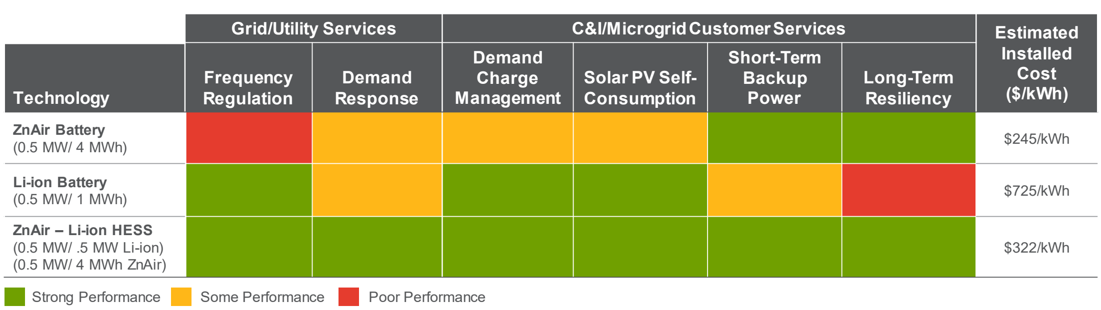
- The ability to operate under dynamic conditions and multiple use cases without compromising system health.
- The reduction of total investment costs relative to a single pure-play technology due to the decoupling of energy and power.
- An increase in total system efficiency by operating at algorithmically optimized points, resulting in less thermodynamic losses.
- Increase of storage system lifetime due to reduction of dynamic stress the system endures per cycle. HESS design allows each storage technology to be operated in its optimal way which reduces risk of failure and low performance.

Combining two or more battery chemistries in a hybrid configuration can be an effective way to showcase a battery chemistry's best performance attributes. Technologies such as Li-ion batteries are ideally suited to higher power, short duration applications that require frequent cycling. While the technology can be configured for longer discharge duration and backup power, the need for frequent cycling is such that the additional cost to extend the duration makes Li-ion batteries a poor fit for standby power and long duration resiliency applications. Combining Li-ion batteries with long duration technologies such as ZnAir batteries provides advantages by using each technology in the optimal way.

An HESS configuration combining Li-ion and ZnAir batteries can provide high power frequent cycling services such as demand charge management and frequency regulation with a cost-effective, short duration Li-ion battery. The ZnAir system is then used as additional storage when required for resiliency during outages and other services that require a longer duration discharge. Given the complementary nature of these hybrid systems and their greater flexibility, why not make hybrid battery solutions the centerpiece of new project developments, squeezing the most value out of all DER assets both for long-term and short-term value creation?

Figure 2-2 compares three energy storage technologies based on their suitability for the services provided to C&I and microgrid customers. This shows the services which the technology can optimally perform. While Li-ion batteries can be designed for long-term resiliency, the higher cost and self-discharge make the technology a poor fit for this application. Alternatively, while ZnAir batteries can provide some grid stability and ancillary services, lower round-trip efficiency makes this a suboptimal application for the technology. Figure 2-2 notes the estimated installed cost for each technology. Installing both a long duration ZnAir battery and a short duration Li-ion battery would require a total investment of $1.71 million. However, an HESS combining both ZnAir and Li-ion in a single system would cost approximately 15% less (estimated $1.45 million installed) while still providing both short-term power services and the benefit of long-term resiliency as the Li-ion battery can have a smaller capacity. Compared to a standalone Li-ion battery, the HESS solution has a 56% lower cost while providing twice as many grid and customer services.

Figure 2-2. Energy Storage Technologies Capabilities Comparison, Estimated Fully Installed Costs: ZnAir, Li-Ion, ZnAir/Li-Ion Hybrid



(Source: Navigant Research)

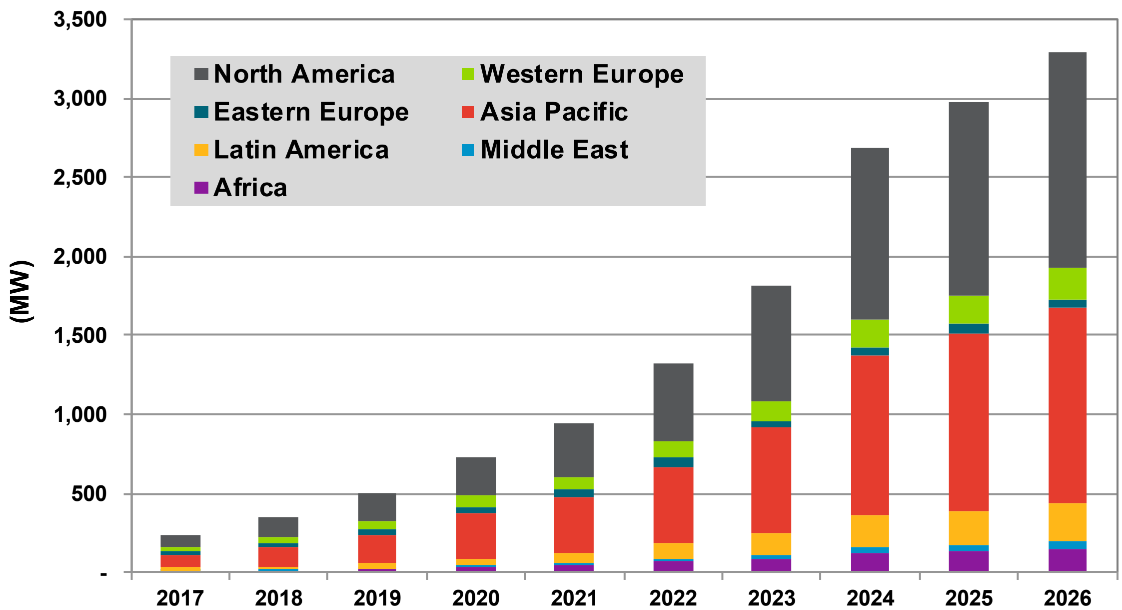
Section 3

KEY MARKET TRENDS SUPPORTING HYBRID ENERGY SOLUTIONS

3.1 Energy Storage in Microgrid Trends

A decade ago, the goal of most microgrids was to limit the size of energy storage due to the high cost. In 2019, the vast majority of microgrids use some form of energy storage due to the shift away from reliance upon fossil fuels. The more diverse the generation resources of a microgrid, the more resilient it becomes, assuming an adequate controls scheme is in place. One can also make the argument that an HESS also increases resilience by leveraging the different internal and external grid services such hybrids can provide. The key to success of this strategy is integrating the right battery chemistries at the right price.

Chart 3-1. Annual Installed Energy Storage for Microgrids Power Capacity by Region, World Markets: 2017-2026

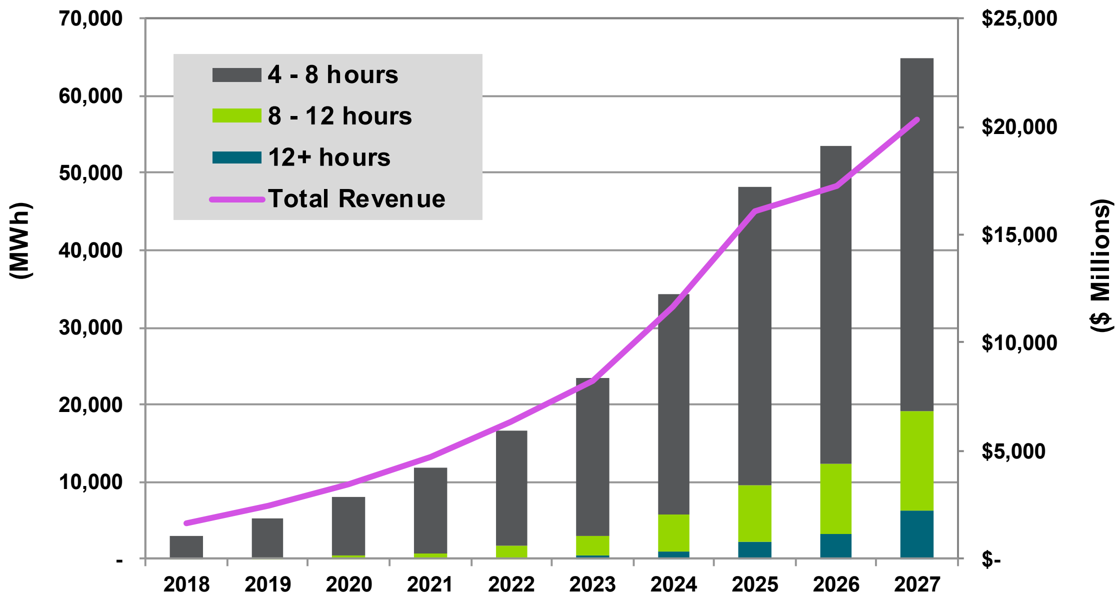


(Source: Navigant Research)

3.2 Forecasted Growth in Long Duration Energy Storage Technologies

Navigant Research also expects consistent growth in the demand for longer duration energy storage technologies driven by three overarching factors: the growing penetration of variable renewable energy, government support, and the limitations of existing storage technologies. Chart 3-2 illustrates Navigant Research's forecasts for the growth of long duration energy storage markets globally, segmented by the duration of projects.

Chart 3-2. Annual Installed Long Duration Storage Energy Capacity and Deployment Revenue by Duration, All Applicable Technologies, Applications, and Regions: 2018-2027

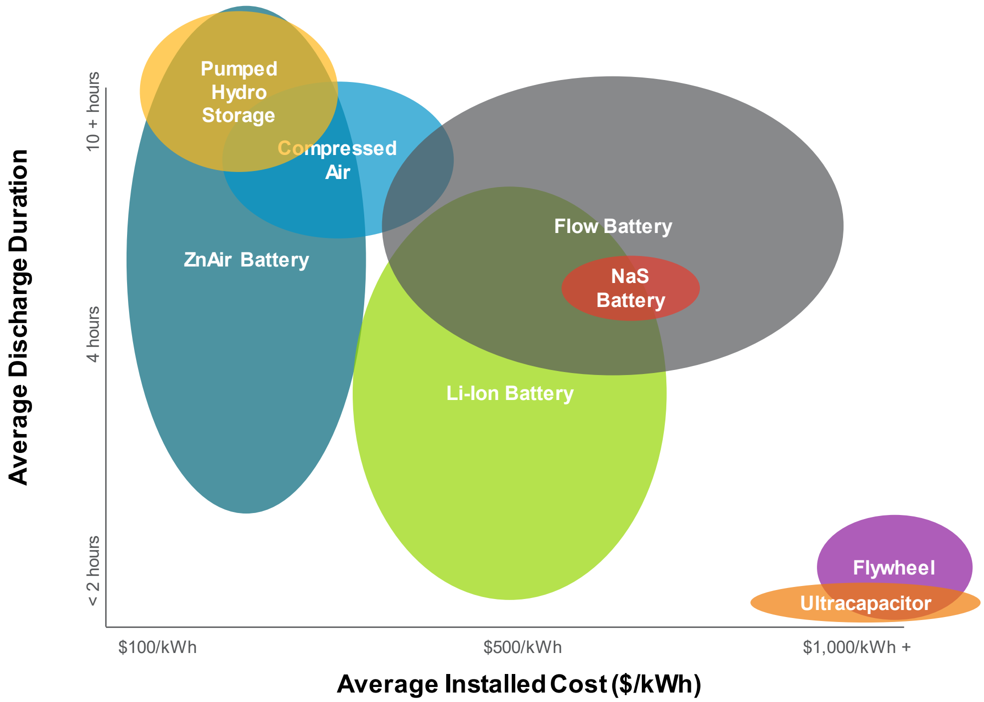


(Source: Navigant Research)

As shown in Chart 3-2, the majority of new long duration storage projects installed in the coming decade are expected to fall in the 4-8-hour range. While there may be value in longer duration projects in the near-term, there are currently few market mechanisms and regulatory constructs that reward such long duration operation. Additionally, in an electrical network that has already been built on the foundation of conventional fossil fuel plants, there is typically little need for ESS projects to discharge at full capacity for longer than 8 hours. The 4-8-hour duration range is currently served by existing technologies including Li-ion, flow batteries, ZnAir batteries, and others.

There are multiple technologies capable of providing long duration discharge within the 4-8-hour range. Figure 3-1 compares 8 leading energy storage technologies based on the average discharge duration and average installed cost. Multiple technologies are capable of hitting the 4-hour duration market. However, fewer technologies are able to meet the requirements for 8+ hour durations or longer. ZnAir is one of the most flexible and lowest cost technologies currently available due to its ability to decouple power from energy for flexible system designs and installation locations, and the ability to scale from several kilowatt-hour to multiple megawatt-hour installations with a low cost relative to other battery technologies.

Figure 3-1. Energy Storage Technology Comparison by Average Discharge Duration and Average Installed Cost ($/kWh)



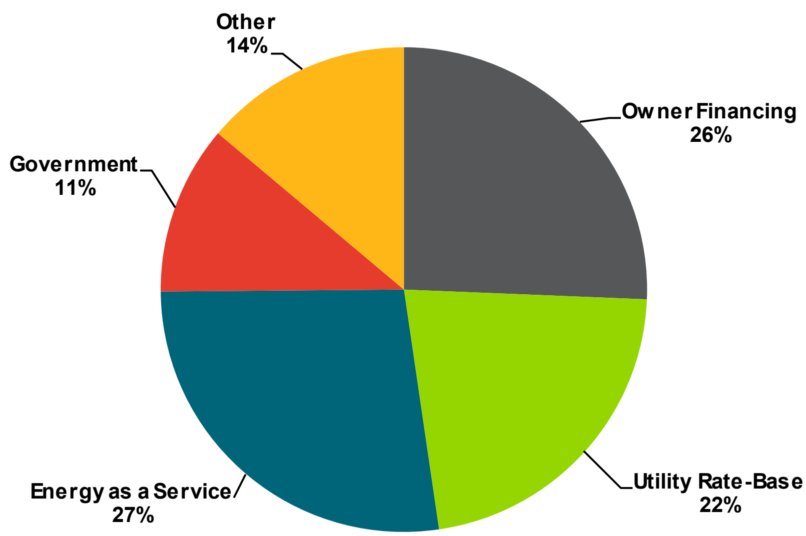
(Source: Navigant Research)

3.3 Energy As A Service

Navigant Research also tracks business model trends across DER platforms. Here, a trend that started in the developing world—energy as a service (EaaS)—is finding its way into more mature and industrialized markets. The two most popular approaches to financing microgrids globally are EaaS and utility rate base. Both approaches are gaining significant momentum in North America and carry important implications for hybrid battery solutions.

The advent of a hybrid battery solution offering may only enhance the value propositions of these business models for future microgrid deployments. For example, NantEnergy's SmartStorage behind-the-meter microgrids were installed at six sites within the Santa Rita Union School District in Salinas, California. The systems provide up to 7 hours of power at each school during a grid outage and also offset the school's energy and demand usage resulting in substantial savings on its utility bills. These innovative multi-campus systems will enable the schools to support the local Salinas community as Powered Emergency Response Centers in the event of disasters that cause prolonged outages. This project was deployed under an EaaS model and is ideally suited for other schools and community assets owned by local governments.

Chart 3-3. Market Share of Known Microgrid Business Models, World Markets: 2015-2018



(Source: Navigant Research)

Section 4
A GLOBAL VIEW: CASE STUDIES, LESSONS LEARNED, AND FUTURE OPPORTUNITIES

4.1 Importing Innovation from Remote Developing World Applications

Instead of exporting advanced energy technologies from a centralized grid model to what has often been seen as a more primitive distributed model made necessary due to a lack of modern grid infrastructure, one could argue the opposite is now true. Remote power applications face even more challenging technical and business model issues, given that there is no traditional grid backup. Often, government incentives favor incumbent technologies—such as diesel generators—rather than new, more advanced, and cleaner technologies such as advanced batteries. These systems operate as power islands 24/7. A more distributed intelligence approach to development and optimization has been nurtured due to practical necessity.

ZnAir battery systems—over 3,000—have been deployed across several regional markets worldwide: Costa Rica, El Salvador, Guatemala, Honduras, Malaysia. Papua New Guinea, and the US (including Puerto Rico.) The majority support off-grid applications: either energy access initiatives (130 villages in Africa and Asia Pacific) or powering up remote telecoms infrastructure (over 1,000 sites worldwide). Both of these market segments are vital for economic development in these developing world markets. Access to electricity supports not only economic activity but the fundamental services necessary for life, including access to clean water, lighting, and cooking. Mobile phone technology enables billing and reconciliation, creating the necessary infrastructure for small local enterprises to conduct basic business functions. The following statistics sum up both the scope and value that ZnAir batteries have provided to date for these off-grid deployments:

Perhaps the best way to grasp what is possible in industrialized nation markets in North America is to examine lessons learned from projects recently completed by NantEnergy in Asia Pacific, Africa, and Puerto Rico. These markets are characterized by strong value propositions but daunting logistics and business model challenges. These lessons are then compared with how utilities in the US are following a path for microgrids based on similar value propositions but tailored to a grid-connected world: the concept of non-wires alternatives (NWA).

4.1.1 Case Study: Indonesia

The Republic of Indonesia is made up of more than 17,500 islands, approximately 6,000 of which are inhabited, spread out across 1.9 million square acres of land and sea. While there are areas of high population density, much of Indonesia's population is scattered among the nation's 75,000 rural, often isolated, villages. With no unified electrical grid, some 12,600 Indonesian villages have no access to traditional utility grade electricity. In fact, more than 2,500 of these villages have no source of electricity at all. Working with the Indonesian government, NantEnergy's local licensed regional manufacturer has installed ESSs in 120 villages as of March 2019, capturing electricity generated by solar PV panels during the day to be released over extended periods of time at night, lighting homes and streets and providing power communications for 182,000 people. ZnAir battery technology and solar PV panels make the entire program possible, eliminating the need for diesel generation and lead-acid battery storage, the latter of which are often mismanaged, need frequent replacement, and represent long-term toxic management challenges.

4.1.2 Case Study: Madagascar

Madagascar, the world's fourth largest island, is home to nearly 26 million people, most of whom have no electricity. Located approximately 250 miles off the southeast coast of Africa, Madagascar is one of the world's least developed countries. According to World Bank, just 23% of the population has access to electricity; in rural areas, only 5%. This situation is beginning to change, however, with forward-thinking entrepreneurs developing new EaaS market models. In the village of Belobaka in 2017, NantEnergy partnered with a local Caterpillar dealer to develop a solar plus storage microgrid designed to generate and deliver electricity for the first time to up to 400 households and local businesses. The microgrid reduces diesel emissions and creates surplus electricity for homes and businesses in the village, creating local economic development benefits.

4.1.3 Case Study: Puerto Rico

In partnership with non-profit Empowered by Light, NantEnergy is delivering a 361 kWh hybrid Li-ion/ZnAir ESS paired with 49 kW solar PV to the Metro Fire Station in San Juan, Puerto Rico. The microgrid is designed to deliver up to 55 hours of backup power and eliminate the station's dependency on a diesel generator. Following the success of the Metro project, NantEnergy and local engineering, procurement, and construction company AIREKO plan to develop a microgrid to provide fail-proof power to the island's Emergency Operation Center where emergency operations and disaster recovery efforts are coordinated by the governor, fire department, police, and coast guard.

When the grid is down, whether due to a major storm or hurricane, or scheduled or unscheduled power outage, the system will operate off-grid and continue powering critical services. When the grid is operational, the system can provide supplemental services to the grid and help stabilize it. One benefit of microgrid projects such as this one in Puerto Rico is the speed with which they can be deployed. Microgrid developers are now offering plug-and-play systems that can be sized to meet a customer's needs economically and be installed rapidly. These solutions can provide resiliency far faster than major grid infrastructure upgrades from incumbent utilities, which often take years to permit and develop.

4.2 Lessons Learned from Global Microgrid Deployments

The increasing sophistication and decreasing costs for battery-backed microgrids are opening new opportunities for third-party developers to improve resiliency of energy supplies for both end-use customers and, in North America and the industrialized world, for the grid as a whole. This dynamic is perhaps most evident in the state of California, where wildfires have been upending centuries-old utility business models. The recent bankruptcy of the state's large utility Pacific Gas & Electric (PG&E), considered one of the first climate change bankruptcies, is highlighting the potential value in microgrids and other DER.

PG&E's bankruptcy has been primarily driven by the liabilities the company faces for its equipment starting multiple massive wildfires in the past 3 years. Microgrids backed with battery energy storage can be an important tool to reduce the risk posed by wildfires. These systems provide customers with power in the event of outages caused by damage to power lines or preemptive de-energizing of lines to reduce fire risks. California is far from the only location experiencing grid infrastructure due to extreme weather damage. The impacts of increasingly powerful hurricanes in the Caribbean and Southeast US are also presenting opportunities for microgrids to enhance the resiliency of energy systems.

Microgrids focused on resiliency, renewable energy integration, and economic optimization in developing world off-grid applications share essential traits with use cases in North America. The link between these two different microgrid markets is energy storage. It can serve as a bridge to optimize across DER portfolios, while also extracting as much value as possible specifically from low carbon renewable energy resources.

4.2.1 Non-Wires Alternatives Include Utility Distribution Microgrids

The utilities that have been most successful in gaining regulatory approval for rate-basing of microgrids followed the precedent set by San Diego Gas & Electric's Borrego Springs. The microgrid is justified as an NWA. In the case of Borrego Springs, the cost of extending a traditional utility transmission line was more expensive than building a microgrid, so all ratepayers benefit. While the ratepayer benefits attached to NWA projects typically total single digit million dollar savings, some projects can net substantial cost reductions. For example, Con Edison saved $800 million by deferring traditional transmission and distribution upgrades via NWA resources that included advanced batteries.

The utility that has had the most success with regulated investment in microgrids in North America is Duke Energy, which discovered the key is the NWA approach. An obstacle to rate-basing microgrids is justifying customer dollars going to infrastructure whose primary benefits only flow to a small pool of customers located inside the microgrid. In October 2018, the company filed for approval of an NWA microgrid consisting of 2 MW solar PV system coupled with 4 MW Li-ion battery in North Carolina. Along with localized resiliency, the microgrid will provide energy and grid support to all Duke Energy customers while deferring ongoing maintenance of an existing distribution power line that serves the remote town. Duke Energy has also found an application for long duration batteries offered by NantEnergy that echoes developing world applications.

Duke Energy also used the NWA rationale to create an off-grid 10 kW solar plus storage microgrid to power up a 60-foot tall remote telecoms tower, which provides electricity to a radio repeater relay at the top of Mount Sterling in the Great Smoky Mountains National Park. On the surface, this installation looks very similar to NantEnergy's deployments in the developing world. The difference is that it was determined that this microgrid featuring long duration energy storage was a lower cost alternative than a 3.5-mile long distribution line of the type which historically has operated in steep terrain. The safety issues associated with maintaining this power line for such a small bit of electricity did not make sense. In the past, Duke Energy had to pay to keep vegetation away from the power lines and occasionally replace poles. These upgrades would often require a helicopter. Furthermore, special permits were required every time maintenance needed to be performed. The microgrid, which came online in spring 2017, consists of 10 kW of solar PV and the 95 kWh ZnAir battery. Among the primary benefits of this microgrid are reduced operations and maintenance (O&M) expenditures over time.

4.2.2 Three Takeaways from Off-Grid Applications

North America's grid challenges have been exposed by recent extreme weather-related events, which are likely to increase over time due to global climate change (these events include hurricanes, wildfires, rains and extreme flooding). Here are three takeaways from off-grid applications of ZnAir batteries of particular relevance:

- **Reduced reliance upon diesel generation can save money and improve overall O&M challenges.** Though the cost of diesel in North America's lower 48 is generally much lower than in developing world markets (as well as remote markets such as Alaska, Hawaii, and parts of Canada), the declining costs of solar PV, wind, and new advanced batteries means that limiting reliance upon diesel generators for backup power may no longer be a valid value proposition. Within a grid-tied application, the drivers for limiting diesel generation include new emission limits in many key markets, high failure rates for backup diesel generators, and availability of fuel during emergencies due to availability and logistics.
- **Reduced reliance upon lead-acid batteries echo same arguments applied to diesel generators.** Though a well-established energy storage technology, lead-acid batteries have also historically been mismanaged, requiring sooner than expected change-outs resulting in both increased costs and environmental liabilities. Lead-acid batteries are a better fit for off-grid applications than grid-tied applications since they are not ideally suited for the quick cycling required for the provision of grid services.
- **Increased reliance upon variable renewable energy resources requires longer duration energy storage technologies**. As microgrids downsize fossil generator contributions to the overall resource mix, longer duration energy storage technologies

become necessary. Tapping these renewables to help provide grid services, however, also requires power applications able to respond quickly to grid or price signals. This makes hybrid long duration/power ESSs particularly attractive.

4.3 Future Opportunities for HESS Deployments

Power infrastructure is becoming diversified in different ways. Diversifications include fossil and renewable energy, as well as generation and load optimization, with batteries serving as a bridge between the two. Increasingly, AC and DC hybrids are emerging too, as an emphasis on modularity and efficiency rise in importance. As the penetration of renewable power generation increases, new grid services are required to ensure that new generation resources can be integrated effectively, and the overall operation of the grid is as efficient as possible.

Interest in long duration energy storage is rising around the world as the rapid growth of variable output renewables continues and issues with grid stability and efficiency become more tangible for grid operators.

These same drivers affect microgrid designs, especially as microgrids seek to sustain themselves in islanding mode over longer periods of time.

Hybrid storage solutions such as ZnAir batteries paired with Li-ion batteries can be an ideal technical solution for these microgrid projects. This combination of technologies allows a microgrid to have the flexibility to serve short duration, high cycle rate grid services and energy cost management operations for customers with Li-ion batteries, while ZnAir batteries are well suited for standby operations providing additional energy capacity. The ZnAir battery then offers a long duration storage asset capable of providing resiliency during an outage, regardless of the state of charge of the Li-ion system being used for grid services.

4.3.1 Future Trends Merge Energy, Mobility, and Other Critical Infrastructure Needs

Hybrid battery systems are not only a strong fit for high penetration renewable energy microgrids also seeking to provide grid services, but a much wider spectrum of market opportunities evolving under an Energy Cloud paradigm shift[1].

The projected growth in plug-in EVs (PEVs) offers both challenges and opportunities to distribution utilities. If not managed in an intelligent way, these PEVs can pose a threat to overall grid reliability. Yet if aggregated and optimized with smart controls and integrated with new hybrid battery platforms offering both endurance and power, they can create

[1]Navigant Research, *Energy Cloud 4.0*, 1Q 2018.

synergy with other DER. The advent of automated vehicles speaks to the rapid advances occurring with sensors, artificial intelligence, and transportation. Here, too, advanced batteries, especially HESS, can serve as a bridge. In this case, between realms of electricity and mobility.

These mobility applications can also be married with other essential infrastructure services, including telecoms and clean water. The focus of energy services has traditionally been power generation. Modulating load came next. In 2019, with the emergence of better batteries and distributed intelligence controls, hybridized systems can be commercially deployed across a wide spectrum of C&I and utility applications in North America and around the world. Why not make hybrid battery solutions—centered around the clear advantages of ZnAir—the centerpiece of new DER project developments, squeezing the most value out of all DER assets both for long-term and short-term value creation?

Section 5
ACRONYM AND ABBREVIATION LIST

AC ..... Alternating Current

C ..... Celsius

C&I ..... Commercial and Industrial

DC ..... Direct Current

DER ..... Distributed Energy Resources

EaaS ..... Energy as a Service

ESS ..... Energy Storage System

EV ..... Electric Vehicle

HESS ..... Hybrid Energy Storage System

kW ..... Kilowatt

kWh ..... Kilowatt-Hour

Li-ion ..... Lithium Ion

MW ..... Megawatt

NWA ..... Non-Wires Alternative

O&M ..... Operations and Maintenance

PEV ..... Plug-in Electric Vehicle

PG&E ..... Pacific Gas & Electric

PV ..... Photovoltaics

SWOT ..... Strengths, Weakness, Opportunities, and Threats

US ..... United States

V ..... Volt

ZnAir ..... Zinc-Air

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This white paper provides a description of ZnAir battery technologies, details for the value proposition of hybrid energy storage systems—specifically ZnAir and Li-ion—and why longer duration batteries will become necessary as renewable energy penetrations grow. It also provides market forecasts on energy storage deployments—both in microgrids and for long duration technologies—as well as case studies from around the world. The white paper concludes with lessons learned from the developing world that can shape solutions in North America and the rest of the industrialized world.

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