CASE STUDY 1:
ALASKA, U.S., ISLAND/OFF-GRID FREQUENCY RESPONSE

PROJECT DESCRIPTION

Xtreme Power, acquired by Younicos, delivered a 3 MW/750 kWh advanced lead-acid solution to the utility KEA. This was to integrate additional wind power into an island system in Alaska. The KEA system has a peak load of about 27 MW and baseload of around 11 MW; 4.5 MW of wind power capacity had already been integrated into the system and an additional 4.5 MW was soon to be added. In addition to the installed wind capacity, the utility's existing power capacity consisted of 23 MW hydropower and 33 MW diesel generation. Studies showed that existing power assets would not be able to provide sufficient frequency response to help compensate for the additional 4.5 MW of wind to come on stream.

One conventional option for KEA was to bring additional diesel generation on stream as spinning reserve. This would require curtailing wind generation and adding fossil fuel consumption. This would mean higher electricity costs, less integration of the renewable wind resource and more pollution from additional diesel fuel generation. Instead, the advanced lead-acid battery solution was introduced.

The project did not receive governmental support, and the utility's decision was based on a desire to improve sustainability and reduce operating cost. This benefit was quickly realised. In the first six months, KEA integrated another 8 million kWh of wind power into the grid. This displaced diesel generation that would have cost USD 560 000 of equivalent operation.

Several separate containers were used for shipping the system. One container could be used to ship one of the two 1.5 MVA power conversion systems, the battery rack structure, control system and other auxiliary equipment. These containers weighed around 45 tonnes (100 000 pounds). Batteries were shipped in on pallets in other containers, and a variety of transport was needed – truck to port, ocean freight and trucks to the site. A crane was employed to lift and set containers onto the site.

3 MW battery storage system by Xtreme Power on Kodiak Island, Alaska

Photo courtesy of Messe Dusseldorf North America

PROJECT TECHNOLOGY CHARACTERISTICS

KEA selected Xtreme Power's battery system to provide frequency response. The system monitors grid conditions 100 times per second and can instantly deliver 3 MW of power within 50 milliseconds if grid frequency falls significantly. The system responds to an average of 285 of these events throughout each day. This enables much fuller use of the wind resource. Though a large amount of power may be needed (up to 3 MW), these events often only last a few minutes. DoD is expected to be less than 20% and on average around 5%, though this has not been measured directly.

The advanced lead-acid battery solution was considered well-suited to this application. This is because the system remains at a high state of charge and can discharge quickly for very short periods. Given that lead-acid benefits from better economics than lithium-ion, this type was also seen as relatively cost-effective. The company states that temperature is the most important operating condition. The inside of the container must remain at 20-30°C. Maintenance costs are driven by travel expenses, given the remote location. These visits are conducted every quarter or less often, and monitoring occurs throughout the year. The other major variable cost is auxiliary losses from parasitic loads. The advanced lead-acid batteries are almost 100% recyclable and will be submitted to recycling at end of life.

Selected technical and cost installation statistics are presented below. Cost information does not include costs incurred by the utility, including a step-up transformer and MV switchgear.

Younicos lead-acid battery installation, selected technical and cost information

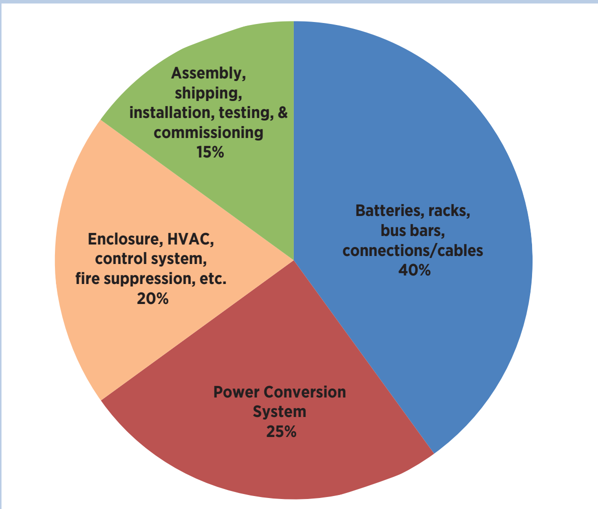
Expected Average Depth of Discharge	Expected Number of Discharges per Day	Efficiency[1] (AC)	Cycle Life[2]	Lifetime of Installation	Cost (US $)[3]
Approx. 5%	>250	80%	1000 cycles	3-5 years	$1 million / MW $ 4 million / MWh

1 Measured at 480 V AC.
2 At 80% depth of discharge assuming a C/3 rate per cycle. The frequency by which system is used poses stress on battery life.
3 Pricing assumes a nominal power capacity of 3 MW and usable energy capacity of 750 kWh. Cost is for a turnkey storage system including batteries, PCS, enclosures, environmental controls, fire suppression, control system, and auxiliary equipment.

Information provided by Younicos

The figure below presents an approximate breakdown of the various cost components for the installation.

Estimated project cost breakdown



Case study sources: Younicos; St. John (2012).

CASE STUDY 2: ANGOLA, ISLAND/OFF-GRID SCHOOL LIGHTING

PROJECT DESCRIPTION

AllCell provided 200 Watt/1 300 Wh in lithium-nickel-cobalt-aluminium batteries for a school in Angola, Africa. This was for off-grid lighting coupled with electricity generated from solar PV. The school had previously lacked any lighting and electricity. By adding lighting, it can stay open later and provide more services. The estimated cost of lighting four classrooms for up to eight hours per day is USD 2 per day. The project was commissioned by a non-profit focused on energy solutions in developing nations. The organisation was investigating whether lithium-ion is better value than lead-acid in off-grid, remote and hot lighting applications. According to AllCell, lithium-ion is more resilient to high temperatures than lead-acid, making it better suited to hot conditions. AllCell also has proprietary thermal management material. This helps prevent the battery from overheating, a particularly important problem given the hot weather in Africa.

Renewables were a key motivation. They avoided charging the batteries with diesel-generated electricity, thus using more of the solar resource instead of expensive diesel power. To AllCell's knowledge, no public funds were used. Shipping regulations were the main barrier affecting the project, and AllCell worked with foreign trade offices and embassies to ship lithium-ion batteries from the U.S to Angola. A small, commercially available inverter/charge controller was used to interface with the battery, solar panels and loads.

AllCell off-grid solar and battery storage at a school in Angola.

Source: AllCell

PROJECT TECHNOLOGY CHARACTERISTICS

Battery installation characteristics as provided by AllCell are presented below. External temperatures were the most important operating condition for battery performance. These are not controlled through any external measures. The battery pack is in the shade, and ambient temperature is expected to remain below 40°C. The simple battery management system in place does not control maximum charge voltage.

Ideally, the company expects the battery to require no maintenance. Given the remote location, replacing the battery would be more cost-effective than carrying out maintenance. AllCell did not have any information on how the battery would be decommissioned. In the U.S, lithium-ion batteries can be profitably recycled, which helps minimise environmental impact.

Performance and cost statistics, provided by AllCell, are laid out in table 3 and figure 2. Given the small size of the installation and unique operating environment, statistics presented here are probably not representative of all lithium-ion installations. For instance, larger installations have more complex and expensive control management systems, accounting for a larger percentage of cost.

Performance and cost statistics, AllCell off-grid lithium-nickel-cobalt-aluminium battery installation

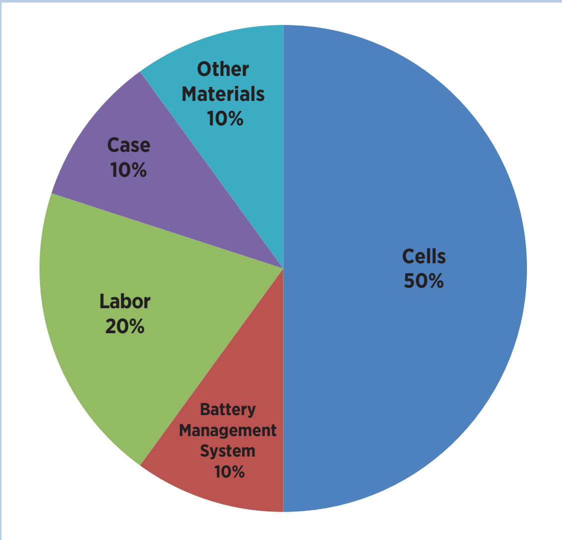
Expected Average Depth of Discharge	Round Trip Efficiency (DC-DC)	Cycle Life	Calendar Life	Annual Capacity Loss (calendar effects)	USD/Wh	USD / Wh at Higher Load	USD/W
50%	>95% not including inverter	>3000 cycles[1]	6 years[2]	Approx. 4%	$0,80	$0,40	Approx. $5

1 Does not include calendar degradation of cells.

2 Could vary depending on battery usage.

Source: AllCell.

Estimated battery pack cost breakdown for AllCell off-grid lithium-nickel-cobalt-aluminium battery installation



Source: AllCell

Case study sources: AllCell

CASE STUDY 3: HAWAII, U.S., WIND SMOOTHING

PROJECT DESCRIPTION

NEC Energy Solutions provided a lithium-iron phosphate (Nanophosphate®) battery in Maui, Hawaii, to smooth ramp rates in a 21 MW wind farm. The battery has a capacity of 11 MW/4 300 kWh. It was installed to manage wind farm ramp rates to comply with local interconnection requirements. The ramp rate limitation on Maui is in place to ensure local power grid stability by limiting feed-in variability of generating resources. The project was not directly subsidised but as part of the wind farm qualified for a 30% investment tax credit. The battery was chosen for its durability and safety for the smoothing application, and the technology has been utilised successfully before in many locations around the world.

Equipment was delivered by trucks from Massachusetts to California, then shipped directly to Maui where trucks carried it to the project site. After delivery, a crane was used to position the containerised units onto their footings. Nine battery containers, three inverters and three transformers were involved in the project, along with switchgear and thermal management units.

Auwahi project site in Maui, Hawaii.

Source: NEC Energy Solutions.

PROJECT TECHNOLOGY CHARACTERISTICS

The lithium-iron phosphate battery is designed to run in any environment. The equipment has been successfully installed and run in desert, tropical, mountainous and coastal locations under a wide variety of temperature and humidity conditions. The power electronics used in the installation were commercially available but were custom built for the project by Dynapower Corporation of Vermont. The actual nameplate capacity utilisation for this particular project was not disclosed, but the battery system is designed for and capable of discharging to 100% DoD. Nanophosphate® lithium-ion battery technology does not have limitations on DoD or extended periods at low state-of-charge, unlike lead-acid battery technologies.

Overall project costs were driven by equipment cost. The largest component cost for the battery itself was the lithium-ion cells. An exact percentage breakdown was not provided. Operational/variable costs are driven by energy losses (round trip efficiency losses). This occurs during electricity conversion and storage via inverters and in battery cells. Thermal management equipment (chillers) consumes the most electricity as part of auxiliary power consumption. Round trip efficiency is about 80%. This includes losses due to power conversion from AC to DC and back to AC, the energy storage cells, busbars, battery management systems and thermal management systems.

Maintenance costs are primarily made up of labour and travel costs to the Maui area. They consist of routine equipment inspections. Extended warranties provided for manufacturer parts, labour and travel form another portion of maintenance costs. This extended warranty cost is typically a single digit percentage of the original equipment and project development cost. The system is designed so that the customer can easily access and service it. This includes replacing common parts and responding to alarms. Not all maintenance is performed by NEC. The operator may also maintain some of the systems' components, including the battery management systems, battery modules and other recommended spare parts. NEC customers typically employ their existing staff to carry out ordinary maintenance. These employees must be qualified to carry out basic electro-mechanical maintenance on industrial equipment.

NEC project and battery technical information

Roundtrip Efficiency (AC-AC)	Cost Estimate (per MW)[1]	Cell Cycle Life[2]	Expected Installation Lifetime[3]	Container Shipping Weight (2MW / 500 kWH)	Inverter Shipping Weight
80% to 85%	$800 000 to $1.2 million	8 000 cycles	20 years	59 000 pounds (26 762 kilograms)	50 000 pounds (22 680 kilograms)

1 Depends on size and location of project.

2 100% depth of discharge over 1 hour before reaching 80% of initial capacity.

3 Includes two battery additions constituting 5% of original nameplate capacity expected over the lifetime.

Source: NEC Energy Solutions

Case study source: NEC Energy Solutions

CASE STUDY 4: YAP STATE, FEDERATED STATES OF MICRONESIA, SOLAR PV STORAGE AND ENERGY SHIFT

PROJECT DESCRIPTION

This project was implemented by the secretariat of the Pacific Community and funded by the European Union. It consisted of five flooded lead-acid battery installations with a total capacity of 1593 kWh[1]. These were installed on the island archipelago of Yap combined with solar photovoltaics (PV) systems. The total solar PV capacity is 270 KWp on five outer islands of Yap State, encompassing ten mini-grids. Hoppecke, a German company, manufactured the batteries.

The goal was to provide access to electricity in some areas and displace diesel generation in others, estimated to cost USD 1.2/kWh. This battery type was chosen because it was considered the most cost-effective solution for the application. It was designed to last for at least for ten years at 30°C if DoD was limited to 20%, to maximise battery lifetime.

Several containers were shipped from the factory in Germany to Yap main island, where a small state-owned ship then brought the batteries to individual islands. The cells were carried by hand to the battery houses. The inverter used in all the projects was manufactured by SMA, known as Sunny Island.

PROJECT TECHNOLOGY CHARACTERISTICS

For the flooded lead-acid battery installations the most important decision criteria was the depth of discharge (DoD). Another important consideration was that high temperatures drastically reduce life time. Furthermore, ventilation is necessary to avoid hydrogen building up in the battery house. Distilled water must be added to the cells regularly due to evaporation during the charging process. The quantity of water has been significantly reduced with the use of recombination caps.

Project cost breakdown depends on the site and application for which the battery is used. Schools had a much smaller battery cost (*e.g.* less capacity was needed for daily load) compared to rural villages. For the same capacity of PV, villages needed much more storage to serve their evening lighting load.

For decommissioning, the supply contract required a commitment to ship the used battery back to a recycling facility in Germany at the suppliers' cost. An alternative solution would be that the local power utility sells the lead to a nearby recycling facility.

1 At ten hours of discharge (C10) and 20 ° C.

Flooded lead-acid battery installations, selected technical information

Maximum Depth of Discharge	Estimated Calendar Life [1]	Estimated Cycle Life [1]	Estimated Cost ($ / kWh) [1]	Individual Cell Weight
20%	15 years	8 000	1340	221 kg

1 At 20% depth of discharge.

Case study source: SPC North-REP project: http://www.spc.int/northrep

CASE STUDY 5: CALIFORNIA, U.S., OFF-GRID SOLAR PV POWER SUPPLY

PROJECT DESCRIPTION

Aquion Energy installed a 54 kWh aqueous hybrid ion (AHI™) battery with a 10.8 kW solar PV array at a ranch in California. This was for continuous access to reliable power without the use of diesel fuel. The ranch is located outside the area serviced by the utility. There were few options for sourcing power. It meant either extending grid power service to the ranch location or constructing a comprehensive commercial-grade microgrid. Extending grid service to the ranch was too expensive. The ranch owner therefore invested in a microgrid operation with the aim to minimise or eliminate diesel generation for daily power supply. Diesel generation was expensive due to the high cost of fuel and transportation to the ranch. The energy storage system was sized appropriately to provide several days of autonomous power delivery without the use of diesel generation. A 30 kW diesel generator was installed for backup. No incentives were available but the return on investment was attractive enough for the ranch to install the system without public funding. The battery's performance, environmental footprint and cost profile was found to be better than that of lead-acid and other options. Aquion's cost analysis is presented below.

Solar PV power generation (left) coupled to aqueous hybrid ion battery storage pack by Aquion Energy (right).

Source: Aquion Energy

The system consists of three Aquion M100 battery modules. Each module weighs roughly 1 285 kg (2 833 pounds). A forklift truck was used to place and install the battery modules in the garage. No special equipment was required as the Aquion AHI battery chemistry is considered a non-hazardous shipping material.

PROJECT TECHNOLOGY CHARACTERISTICS

The Aquion Energy aqueous hybrid ion products use a water-based electrolyte with multiple ions (including sodium and lithium), a manganese oxide cathode, and a carbon/titanium phosphate anode. This innovative electrochemistry combines the attributes of other aqueous systems (cost, safety, ease of integration and self-balancing) with the strong and robust cycling attributes of intercalation-based batteries. These have deep discharge and partial state of charge cycle life. Deep discharge cycle life is at least 3 000 cycles, and these batteries have been specifically formulated to provide high efficiency (more than 85%) for long periods (at least four hours). The electrochemistry is safe and uses non-toxic, non-flammable materials.

The final system consists of the following:

- Three Aquion M100-HV battery stacks (54 kWh)
- Power conditioning system from Dynapower Corporation
- 40 SolarWorld 270 W PV modules
- Unirac SolarMount
- Outback FWPV-8 roof-mounted combiner box
- MidNite solar wall-mounted MNPV4HV-Disco-3R combiner box
- Crouse-Hinds CCB6SL F15 combiner box
- 30 kW backup diesel generator

Aquion used HOMER, a common microgrid modelling tool, for cost estimates. Diesel cost, including transportation, was estimated at USD 1.32 per litre (USD 5 per gallon). The results demonstrated that adding AHI energy storage and solar panels would drastically reduce diesel consumption and therefore system LCOE. The upgrade to a battery-based system cost an additional USD 64 000. However, it was projected to save over USD 27 000 per year in diesel fuel costs, a payback period of less than three years.

Cost analysis conducted by Aquion Energy for off-grid generation

	Capital expenditure USD	Diesel (L/yr)	Diesel (USD/year)	Renewable %	LCOE (USD)
Diesel-only	20 000	20 300	26 800	0	4.51
AHI*+solar+diesel	80 500	65	90	97	0.77
PbA+solar+diesel**	73 300	170	230	92	0.87

* *Aquion's aqueous hybrid ion (AHI) battery,*

** *PbA is a generic lead-acid battery. The AHI battery is 55.5 kWh of energy, while the lead-acid is 90 kWh and has a maximum 50% DoD. The calculation is over a 20-year life time.*

Source: Aquion Energy

Aquion batteries require no maintenance throughout their whole life, so maintenance costs are not relevant. The batteries can be installed and operate in ambient temperatures of -5°-40°C with minimal impact on performance. They have no dangerous failure modes and do not require active or thermal management. The ranch could therefore install the batteries in a small corner of the garage without the need for complex or costly fire suppression or air-conditioning systems to maintain system life. The batteries are environmentally benign and can be easily recycled or disposed of at end of life. Additional technical information is presented below.

Aquion battery installation – selected technical characteristics

Maximum Depth of Discharge	Average Depth of Discharge	Roundtrip Efficiency (DC-DC)	Expected Operational Lifetime (Cycles)	Expected Lifetime (Years)
100%	45%	Approx. 85%	>6 000	>10

Case study source: Aquion Energy

CASE STUDY 6: NEW MEXICO, U.S., SOLAR PV SMOOTHING AND ENERGY SHIFT

PROJECT DESCRIPTION

Ecoult (acquired by East Penn Manufacturing in 2010) supplied PNM, a large utility in New Mexico, with its advanced lead-acid battery solution. The battery provides 500 kW of smoothing capability and 250kW/1 MWh of energy shifting for a 500 kW solar photovoltaics (PV) plant owned by the utility. According to Ecoult, the battery installation allows better alignment of PV output and system peaks. It also smoothes the volatile ramp rates of the solar PV resource and demonstrates a dispatchable renewable resource. Along with EPRI, the site collects data. This is to optimise control algorithms for best performance and to understand the benefits such a system can bring to grid stability.

Ecoult describes its Ultrabattery as a "completely new class of lead-acid technology" able to operate efficiently and effectively even during partial, continuous charge and discharge. Components are recycled by the company at the end of the project's life. The New Mexico battery installation was partly funded by ARRA. The development of this type of battery was supported by the Australian government. The solar PV plant did not receive any government funding.

One of eight containers consisting of 160 cells.

Delivery of eight battery containers, August 2013

Battery container.

PNM Prosperity Energy Storage Project

PROJECT TECHNOLOGY CHARACTERISTICS

Selected technical characteristics of Ecoult's UltraBattery Energy Resource (UBER) 320/500 kW are presented below. The blocks consist of battery cells, management and monitoring, integrated temperature management and other components to integrate the system. This system may be delivered in two 20-foot shipping containers (see picture above) and can be scaled up to various power and output levels. For instance, one block can provide 100 kW for 3.5 hours or 250 kW for 1 hour. Two blocks in parallel can provide 100 kW for 7.8 hours or 250 kW for 2.6 hours. See Ecoult (2013) for further technical information.

Ecoult's UBER 320/500 kW-selected technical information

Number of Cells	Total Energy Available Before Replacement	Shipping Weight	Operating Ambient Temperature	Dimensions
160 cells / container	2GWh[1]	1 container = 50 000lb (22 680kg)	-25°C to 45°C	6.06m L x 2.44m W x 2.59m H

1 At recommended operating conditions. Considers both containers.

Source: Ecoult (2013).

Case study sources: Ecoult (2013), EPRI (2012)

CASE STUDY 7: ROKKASHO, AOMORI, JAPAN, WIND ENERGY TIME SHIFT AND FREQUENCY RESPONSE/SPINNING RESERVE

PROJECT DESCRIPTION

NGK Insulators provided 34 MW/204 MWh of sodium-sulphur battery capacity connected to a 51 MW wind farm in northern Japan. The project was commissioned in 2008. The batteries provide greater wind integration for electricity produced at night during periods of low demand, subsequently sold during the day and times of higher demand. The batteries can also be used to provide spinning reserve and frequency response. To protect them from corrosive salty air in the area, they are kept in suitable housing and consist of 17 sets of 2 MW battery units (pictured below). They are monitored from a single control centre at the site, using smart grid monitoring and controls provided by Yokogawa Electric Corporation.

34 MW (204 MWh) NAS Battery System Rokkasho in Japan since 2008

NGK Proprietary and Confidential *© 2008-2013 NGK Insulators, Ltd. All rights reserved*

Source: Abe, H. (2013)

PROJECT TECHNOLOGY CHARACTERISTICS

The following table presents the technical characteristics of NGK Insulators sodium-sulphur batteries.

NGK Insulators sodium-sulphur battery technical characteristics

Calendar Life	Cycle Life	Hours of Storage	Efficiency (DC-DC)	Minimum Discharge Time	Energy Density	Maintenance	Operating Temperature (°C)
15 Years	4 500	6 Hours	85%	2 milli-seconds	Approx. 1500 ft^2 / MW	Minimal planned maintenance, no pumps, valves, or heat exchangers	300 to 350

Source: Abe, H. (2013)

Case study sources: Abe (2013); Clean Energy Action Project (2014).

CASE STUDY 8: TEXAS, U.S., WIND ENERGY TIME SHIFT, SMOOTHING, AND FREQUENCY RESPONSE

PROJECT DESCRIPTION

Duke Energy incorporated 36 MW/24 MWh of advanced lead-acid batteries provided by Xtreme Power[1] into its Notrees 153 MW wind farm in West Texas. This was part of a testing and demonstration programme funded by ARRA. This provided half the funds (around USD 22 million) and Duke Energy matched with the other half. Thus the total project budget was USD 44 million. The primary objectives of the project are to store energy for a number of purposes when it is not needed. This is to meet demand at later times, quantify the value of wind storage, and assess commercial viability in the Texas ERCOT market. Another function is to provide fast frequency response for this Texan pilot programme. Achieving these goals is expected to reduce congestion, optimise dispatch, reduce energy costs, improve grid reliability, reduce carbon emissions and improve knowledge of wind and battery storage resources. A final report on the results of the project by the U.S. DOE is expected in October 2015.

36 MW advanced lead-acid battery system by Xtreme Power connected to a wind farm in Texas

Source: DOE (2013)

PROJECT TECHNOLOGY CHARACTERISTICS

Limited technical information is available. Reports on project results are expected in the coming months and years. Some relevant project information is presented below.

Duke Energy wind and battery storage project details

Location	Heat Management	Space Needed	Maximum Discharge Duration
At the substation and tied on the distribution side	Cooling pump skids, air/ water heat exchangers	Battery modules housed in approx. 6 000 sq. ft. building	15 minutes

Source: Gates, J. (2011)

1 Xtreme Power was recently acquired by Younicos.

Case study sources: DOE (2013b; 2013c), Gates (2011).

CASE STUDY 9:
ZHANGBEI, CHINA, WIND ENERGY TIME SHIFT AND ANCILLARY SERVICES

PROJECT DESCRIPTION

Prudent Energy supplied China's Wind Power Research and Testing Centre with a 500 kW/1 MWh vanadium redox flow battery. The project is collaboration with the China EPRI. It was commissioned in 2011 and is currently operational. The centre has 78 MW of wind capacity and 640 kW of solar photovoltaics (PV). The battery is used to integrate more of this energy into the grid. It does so by storing electricity during periods of low demand and excess wind production and discharging when demand is higher. The installation can also provide services over a shorter timeframe, including load following and voltage support. The facility is further meant to test the battery's operation so that the local utility, the State Grid Corporation of China, can test the technology compatibility with China's system.

Vanadium redox flow battery by Prudent Energy connected to a wind testing facility

Source: Prudent Energy (2012)

PROJECT TECHNOLOGY CHARACTERISTICS

The vanadium redox flow battery uses storage tanks to contain the electrolyte, a proprietary mixture. The electrolyte is circulated via pumps through the systems' cell stack, causing vanadium ions to react and create a charge. This then flows through to a DC circuit, which creates the conditions for electricity discharge. This process is reversible, and the electrolyte can be pumped back into the tanks. Unlike sodium-sulphur batteries, this system runs at room temperature and is also low pressure. Unlike cell-based batteries, the flow battery does not degrade over time due to the partial state of charge. Air conditioning units may be included so that electrical equipment does not overheat. In very cold climates heat exchangers can be installed so that the electrolyte retains its fluidity.

Prudent Energy vanadium redox flow technical characteristics

Cycle Life (full-depth charge / discharge)	Cycle Life (partial charge / discharge)	Calendar Life	Fastest Response Time	Efficiency (DC-DC)	Dimensions (250kW Module)	Dry Weight (250kW Module)	Electrolyte Required per Hour of Rated Discharge
10 000	100 000	10 years	<50 ms	Up to 85%	9.3m x 2.0m x 2.8m	13 900 kg	15.4 m^3

Source: Prudent Energy (2012)

Case study sources: DOE (2013d), Prudent Energy (2012a; 2012b; 2013)

CASE STUDY 10:
MARYLAND, U.S., SOLAR AND BATTERY STORAGE FOR CUSTOMER AND ANCILLARY SERVICES

Solar Grid Storage LLC provided a 500 kW AC storage and inverter combination to the headquarters of real estate developer Konterra in Maryland. The storage comprises 300 kWh of lithium-ion batteries provided by AllCell Technologies. The storage and inverter system was connected to solar photovoltaics (PV) panels with a capacity of 400 kW. Solar Grid provided two PowerFactor 250™ installations. The intention is to provide both the customer and the grid with multiple benefits. This includes backup emergency power during grid outages and reduced system cost through additional revenue from regulation and fast-power balancing support to the local grid. Other ancillary services like spinning reserve and black start capability are possible but not easy to monetise in the present market and regulatory structure. The systems are connected to the local utility and can thus provide a range of ancillary services when required by the utility or grid operator through normal dispatch.

The provision of ancillary services to the local grid is key to Solar Grid's business model. The company's standard service is to provide the inverter and storage system (PowerFactor™) at a very low cost. It pays for its installation, whereupon Solar Grid owns and operates the system for ten years. The company recovers these costs plus a profit margin through ancillary services provided to the grid and paid for by the grid operator. This business model thus utilises battery storage to capitalise on new regulatory markets for ancillary services in the U.S. At the same time, it brings down the cost of the PV system and provides both customer and grid with greater resilience.

Lithium ion battery system by Aquion Energy for providing ancillary services

Location of the battery storage site. Source: Cook, C. (2013)

PROJECT TECHNOLOGY CHARACTERISTICS

The following table presents technical considerations for the PowerFactor500™, a 500 kW/250 kWh lithium-ion battery system that contains a 500 kW inverter.

PowerFactor500 technical details

Container Size	Weight	Nominal Battery Capacity	Battery Operating Voltage (V)	Peak Efficiency
20 foot ISO Container	27 000 pounds	235 Ah	922-996	95,3%

Based on Solar Grid Storage

Source: Based on Solar Grid Storage

CASE STUDY 11: GERMANY, BATTERY STORAGE SUPPORT FOR HOUSEHOLD SOLAR PV

Since May 2013 the German government has supported the installation of household battery storage systems coupled with solar photovoltaics (PV) panels. In the first year, around 340 systems were installed every year. However, since July 2014 this number has increased to 600 systems per year. Battery systems are supported by a grant amounting to 30% of the battery system's cost. The remaining sum may be eligible for low interest loans provided through KfW bank's Programme 275. In order to receive programme support, the solar panels must be 30 kWp or less, and they must have been installed after 31 December, 2012. Total subsidies are capped at EUR 600/kWp for PV systems operating within the previous six months. A maximum of EUR 660/kWp is applicable for retrofitted systems commissioned after this period. The size of the battery storage systems has been increasing since May 2013, and on average subsidies are in the range of EUR 3 300 per system. The programme received EUR 25 million, and it is unclear if further funding will be available. The following conditions also apply.

- The PV system may not feed more than 60% of its installed capacity into the grid. This provision is intended to promote grid-optimal PV feed-in coupled with battery system charging.
- The battery must have at least have a seven-year manufacturer warranty. Battery defects must be replaced within the warranty time frame.
- Manufacturer batteries must be certified in the market, guaranteeing quality and performance.
- Remote control of inverters supported by the programme must be possible. They must take into account active and reactive power as a function of grid voltage and frequency, if needed. Control by the local utility requires the prior agreement of the owner.
- Around 6 500 systems have been installed thus far under this subsidy programme. Another 4 000 that do not receive the subsidy have also been installed. Eligible systems include lithium-polymer, lithium-titanate, lead-acid and lead-acid gel compositions. The seven-year warranty provision may limit the availability of lead-acid systems given their generally lower cycle life. The 60% feed-in provision also limits the FiT the system may receive. This may be a disincentive for some German consumers. BNEF calculates a payback period of around 11-18 years for the PV and battery system even with this subsidy. However, this will improve as battery costs decline.

Case study sources: KfW (2014), Goldie-Scot (2013), BMU (2013), BNEF (2014).

CASE STUDY 12: DOHA, QATAR, ISLAND/OFF-GRID SOLAR PV INTEGRATION AND ON-GRID ANCILLARY SERVICES

PROJECT DESCRIPTION

As a climate change conference got under way in late 2012, BYD launched its lithium-iron phosphate battery solution at the Qatar Science and Technology Park. The battery is 500 kWh and is charged by an adjacent solar PV installation and diesel generator. The project represents an interesting hybrid of benefits for both on and off-grid applications. These include voltage/reactive power support, frequency regulation and black start capabilities if the grid goes down.

Containerised energy storage system by BYD.

Source: BYD Energy (2012)

PROJECT TECHNOLOGY CHARACTERISTICS

Summarised below are the selected technology characteristics of the BYD 500 kW/500 kWh lithium-iron phosphate solution. This may not be the exact solution provided in the case study above but has similar characteristics.

Technical overview BYD 500 kW/500 kWh lithium-iron phosphate battery

Container Size	Standard Warranty for Battery and Power Control System[1]	System Efficiency	Permissible Humidity	Permissible Altitude	Response Time
40 ft.	2 years	<90%	5%-95%	≤2000m	<100 ms

1 Can be extended according to customer requirement.

Source: BYD Energy (2014)

Case study sources: BYD Energy (2012; 2014).