


Intelligent Switchgear | Storage | Clean Energy | Cogeneration

Microgrids

Technology Development, Market Applications, and Policy

White Paper - May 2018

GREENLEAF ADVISORS, LLC

Greenleaf Communities

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About Greenleaf

Greenleaf Advisors (greenleafadvisors.net) is a consulting and transaction-services firm that builds sustainable enterprises and communities by bridging them to the resources and strategies they need to develop in a healthy way. Greenleaf Advisors engages at the intersection of capital, business, science, and policy to serve organizations that address the sustainable use of natural resources to become leading enterprises.

Greenleaf Communities (greenleafcommunities.org) is a nonprofit 'sister' organization to advance a healthy and sustainable world by recruiting and organizing multi-disciplinary teams of scientists to investigate environmental influences on health and inform industrial practices and policies.

Our Energy Partners

Greenleaf and its energy partners collaborate to develop and deploy integrated, intelligent microgrid solutions to multiple markets looking for clean, economic, and resilient power.

Intelligent Generation is a software-as-a-service company pairing energy storage with solar. IG generates revenue in wholesale power markets, saves on energy and power expenses, and protects critical systems with battery backup.

GreenCity Power delivers electricity, heating, and cooling to building owners economically and securely through natural gas sourced cogeneration and thermal systems. Their systems offer customers increased profitability and power resiliency, greener buildings, and flexible fee structure.

G&W Electric uses the latest technologies in load and fault interrupting switchgear, reclosers, system protection equipment and distribution automation to create custom solutions for their clients. G&W is bringing expertise to the renewable energy market with their LaZer automation system and switchgear technologies.

ENGIE, in North America, manages a range of energy businesses in the U.S. and Canada, including retail energy sales, electricity generation, cogeneration, and comprehensive energy management solutions to help customers run their facilities more efficiently and optimize energy and other resource use and expense. They offer integrated management solutions—including on-site solar, battery and cogeneration design, installation, and financing. Globally, ENGIE is the largest independent power producer and energy efficiency services provider in the world, with operations in 70 countries employing 150,000 people, including 1,000 researchers in 11 R&D centers.

Introduction

Microgrids have been a hot topic in the energy sector lately in a variety of applications both for developed and developing countries. This paper is a brief overview of microgrids, the market and opportunities, and policy and regulations followed by a few selected case studies.

A microgrid is a local energy grid with control capability that can island itself from the traditional grid.[1] It operates with its own power sources (e.g. solar photovoltaic (PV), generators, wind, battery storage). This provides additional resiliency and reliability to users in the system when outages or other issues arise in the traditional grid while also improving energy efficiency and lowering carbon footprint.[2] Microgrids offer local solutions to a global issue and have applications in urban and rural settings.

The nascent microgrid industry is developing rapidly. The market for microgrids is evolving with regulations and technological changes, especially as more standardized options develop. Drivers of growth include aging infrastructure of the traditional grid, increased extreme weather events, protection of critical systems, economic benefits, technological advancements and cost reductions, consumer demand, and policy developments. The microgrid business model is still developing, and each project tends to be custom designed. These systems are at an early stage in many respects, so it is difficult to predict how the market will develop profitably. The current customer landscape includes remote off-grid, campus and institutional, military and government, commercial and industrial, utilities, and communities. These segments place value on reliability, resiliency, and security. [2]

The medical sector is becoming increasingly interested in microgrids on its campuses. On May 7th, 2018, our energy partners will be presenting at CleanMed in San Diego, California on “Resiliency through Cogeneration and Microgrids” (Available on greenleafadvisors.net/CleanMed2018). CleanMed is the premier national environmental conference for leaders in health care sustainability who are on the leading edge of greening the health care sector.

Clean Energy Technologies

Combined Heat and Power

Combined heat and power (CHP or cogeneration) is a proven and longstanding technology that utilizes waste thermal energy from the generation of electrical power to produce heating and cooling services. Traditional generation technologies (e.g. diesel-fired engines, natural gas fired engines, and cogeneration) can be integrated into a microgrid. CHP is highly reliable, profitable, and environmentally-friendly. It addresses both heating and cooling requirements. CHP technologies can operate at 65 – 85% efficiency, a significant improvement over the 45 - 55% efficiency when power generation and boilers are separate. [3]

Solar PV and Wind

Solar PV systems are beneficial in a microgrid as they provide energy from free and infinite fuel. Solar photovoltaic devices convert sunlight into electricity via a semiconductor diode. The power that a PV system can generate depends on the installed capacity of the system (area and efficiency) and the intensity of sunlight (time of day, cloud cover, geographic location). For more information on solar PV systems within a microgrid see NREL’s “Microgrid-Ready Solar PV” (link). Wind turbines convert kinetic energy in the wind to electricity. There are utility-scale turbines, offshore turbines, and small residential turbines.[4] Wind turbines tend to generate more electricity overnight and not during the day when electricity demand is higher. As with solar, energy storage can provide benefits to wind to help capture electricity for use during peak periods.[5]

Energy Storage

Energy storage is an important component of the microgrid: it prevents excess renewable energy generation from being wasted and allows for the microgrid to support loads when islanded.[6] Intelligently managed storage allows assets to contribute to wholesale markets (e.g. frequency regulation, energy arbitrage, demand charge management) and generate additional revenues.[5] Energy storage technologies include flow batteries, flywheels, compressed energy air storage, thermal, pumped hydro (see appendix), and hydrogen fuel cells. Through renewable electrolysis, hydrogen can store energy until it is converted by a fuel cell back to electricity.[7]

Market and Opportunities

The microgrid business model is still developing as most projects need to be custom designed. These systems are early stage in many respects, so it is difficult to predict how the market will develop profitably. To reduce uncertainty and optimize performance, it will take the integration of talents and resources requiring collaboration among service/product partners. As the market, policy, and technology develops in this space, the risks and uncertainty will likely decrease. Navigant expects that this market will continue to develop and become less expensive once turnkey solutions are readily available.

Opportunities in this space have been driven by the aging infrastructure of the traditional grid, increased extreme weather events, need for protection of critical systems and loads, economics, technological advancements and cost reductions, consumer demand, and policy developments. [2] U.S. energy infrastructure is aging; many operating power plants were built in the 1960s and 1970s and many electric transformers have exceeded their expected useful lifetimes. It is estimated that outages cost U.S. businesses $150 billion per year. Severe weather events are the largest impact to the electrical grid and have continued to become more common in recent years. [8]

Microgrids can aggregate resources to provide additional economic values. Approaches include demand response capacity, load management, energy arbitrage (time-of-use pricing), and frequency regulation.[9] Demand response compensates customers for reducing their electrical load during times of high power prices.[10] Energy arbitrage is based on charging a battery when energy is low (off-peak) and utilizing that electricity when prices are high (on-peak).[11] Frequency regulation is a wholesale market that keeps the grid stable; battery operators can bid into this market and they are effective in maintaining this stability.[12]

Renewable energy costs are declining[13], and technologies are developing so they have become an attractive option to include in microgrids. Combined heat and power has been a leading technology choice in microgrids globally for many years. But by 2026, Navigant expects solar PV (and battery storage) to take the lead. Energy storage has been growing rapidly and advancing technically. Both CHP and solar plus storage are being used in microgrids today to complement each other in their service provisions.[14]

In North America, campus and institutional microgrids have been the largest market segment due to their large electrical demands and reliability needs.[2] Utility distribution microgrids are likely to increase. Globally, commercial, and industrial (C&I) customers have been gaining momentum.[15] Utility scale projects can provide economic benefits and address the aging grid.[2] Typically, C&I customers are interested in reducing costs and continuing operations for critical loads during an outage. These customers want to protect against lost data or production interruptions. The community and utility segment looks to meet emission requirements and improve critical infrastructure. University and business campuses have high heating and cooling needs and require high reliability of power to maintain research operations. Hospital and institutional networks also require secure and reliable electricity to prevent loss of research, lab tests, and to continue operations. Microgrids help protect against cybersecurity risks due to its ability to separate from the grid. In remote communities, microgrids can help protect against volatility in petroleum supply.[9]

Policy and Incentives

Regulatory drivers will be critical in wider adoption of microgrids. It is suggested that regulatory authorities acknowledge trends in microgrids and develop rules that allow for easier implementation.

Incentives that will encourage renewable development include energy tax credits, renewable portfolio standards, grid modernization grants, and net metering.[9] Renewable portfolio standards (RPS) require that a certain amount/percentage of energy is produced via renewable sources. Similarly, Energy Efficiency Resource Standard (EERS) policies encourage a reduction in energy usage each year. Renewable energy standard (RES) requires utilities to sell energy generation from renewable sources. Feed in tariff, tax rebates, renewable energy certificates, grants, rebates, and tax credits are other incentives offered by states and utilities.[16] With investment tax credits (ITC), solar energy, fuel cells, and small wind turbines are eligible for a 30% tax credit. [8]

States and local governments can promote renewable and resilient energy by providing support and planning assistance. It is important to engage stakeholders early to share information about programs and to receive feedback. This also includes informing and educating municipalities and government officials. To reduce the imbalance between wealthier communities and low-income communities (wealthier communities tend to be early adopters of technology), states can target funding and support to low-income and vulnerable populations. These populations are also most affected by natural disasters and power outages. Programs should avoid being too narrow in scope, by allowing flexibility, communities can build projects that fit their needs.[17]

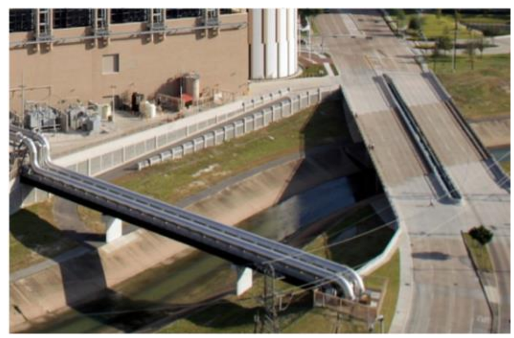
Technical assistance can help applicants as many solutions are not turnkey. High up-front costs and lack of experience with new technologies make financing projects difficult. States can help reduce this burden by providing information on financing options and allow for value stacking to improve project economics.[17]

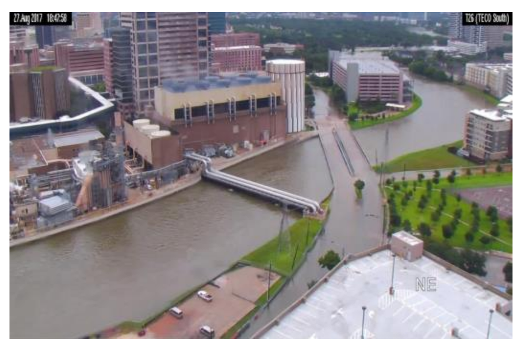
Selected Case Studies

The Texas Medical Center and TECO case study showcases how their microgrid and storm infrastructure allowed for continued operations during Hurricane Harvey. In Boston, ENGIE provides critical energy for Harvard Medical School and Harvard Medical School-affiliated hospitals. The Illinois Institute of Technology and Bronzeville case study highlights the utility-grid pilot project and its connection to an existing campus microgrid. The Stone Edge Farm case study also presents a microgrid that maintained operations during extreme weather events, in this case, California's wildfires.

Texas Medical Center and Thermal Energy Corporation

Hospital operations are critical in disasters. The Texas Medical Center (TMC) is the largest medical complex in the world at over 50 million square feet and with 9,200 patient beds. Institutions at the center include research universities, medical centers, and children's hospitals.[18] During Hurricane Harvey, TMC and the Thermal Energy Corporation (TECO) in Houston were able to continue operations due to their advanced planning and infrastructure. Just a few years earlier in 2001, they were less prepared for Tropical Storm Allison, causing flood damage, loss of power (including generators), and losing $2 billion in research.[19] TMC and TECO used this experience to build resiliency upgrades including a new combined heat and power generator, floodgates, and developed emergency protocols.





Many lessons from TMC can be applied to hospitals across the nation. TECO, the provider of cost-effective and energy-efficient cooling and heating to many hospitals in TMC, stresses that reliability and redundancy is critical to the healthcare sector especially during storms or power interruptions. TECO has a 48 MW combined heat and power (CHP) plant that operates at 68% efficiency compared to a traditional power plant which operates at about 33% efficiency.[20] This plant allows TECO to provide all their own electricity and to continue chilled water and steam service in the case of an electrical grid failure. The CHP plant provides between $6 – 12 million of energy savings a year.[21]

TECO is well prepared for emergencies; they test and maintain equipment to ensure it is ready and operational when needed and conduct emergency preparedness drills. In the case of Hurricane Harvey, TECO responded proactively and called in staff to work shifts, closed floodgates in anticipation of the flood, and utilized their combined heat and power plant to not risk any loss of power from the utility grid. Due to their emergency preparedness, Hurricane Harvey was essentially a "non-event" and did not halt operations. When vehicle traffic could not reach the hospital due to street flooding for about

36 hours, helicopters were able to transport patients. They were able to handle clean water requirements, food, and sanitation and waste management.[22]

A Brief History of TECO's Sustainability and Emergency Preparedness Efforts[23]

- In 1969, Houston Natural Gas Corporation (now TECO) completed a central steam and chilled water plant on the Texas Medical Center Campus.
- In 1980, they converted to natural gas, utility electric power, and emergency power production.
- In 2003, the floodwall was built and other storm/disaster infrastructure upgrades were made.
- In 2010, a 48 MW CHP was completed and operational.

Medical Area Total Energy Plant – Boston, MA

ENGIE provides critical energy for Harvard Medical School and five Harvard Medical School-affiliated hospitals. Some of the most prestigious clinical and research institutions depend on the reliable energy services enabling them to treat 103,000 inpatients and 2.4 million outpatients annually. Cumulatively, ENGIE serves more than 12 million square feet of space in 74 buildings. Due to the critical and life saving measures of these institutions, energy redundancy and uninterrupted service is critical to the operations of these hospitals.

As a combined heat & power plant, heat and electricity is generated from a single fuel source. At times, the plant is a tri-generation plant, creating chilled water in addition to steam and electricity from a single fuel source. This highly efficient process requires significantly less fuel, reduces emissions, and creates energy independence for the designated area. The system is designed with multiple layers of redundancy so that it can operate and remain fully functioning during power outage, ensuring critical operations at the hospitals and research centers served by MATEP can continue without interruption.[24]

Bronzeville and Illinois Institute of Technology

In February 2018, ComEd was approved to build a utility-based microgrid in Chicago. ComEd is expecting this project will provide knowledge on how utilities and microgrids can recover from extreme weather and protect against physical - and cyber-attacks. It will be in Chicago's Bronzeville neighborhood and serve 1,060 customers once operational including facilities such as the Chicago Public Safety HQ, educational facilities, public works building, health clinics, and other public use buildings. Another benefit to the location is that it will connect to the Illinois Institute of Technology campus existing microgrid - providing additional insight into how a microgrid cluster will operate and how to operate two systems to provide value and efficiency.[25] The Bronzeville ComEd project is innovative in that a majority of microgrid projects have been behind the meter.[26]

Initial concerns over the project arose specifically on ComEd's owning of the generation as that is forbidden in the Illinois electrical market; the proposal has been altered to now bid out the distributed energy assets. Critics have questioned ComEd's role in the project as they will earn a guaranteed rate of return while spreading costs among ratepayers across their territory.[27]

To address concerns, ComEd is working with the Environmental Defense Fund and Citizens Utility Board to develop a pilot tariff that allows for third parties to own and manage microgrids with ComEd's wires. [26] This project is unique as it allows non-utility owned microgrids to use utility's infrastructure which has previously been limited.[28] Insight will be gained on how microgrids can be integrated into utility systems and how generation assets can be shared among customers (e.g. a microgrid cluster).[26]

Phase I is about providing solar PV and battery storage for 2.5 MW of local load. Phase II will add 4.5 MW of load. Once complete (expected in 2019), peak electricity demand of the 1,060 ComEd customers in the system will be met.

The Illinois Institute of Technology microgrid was built to improve power reliability on campus and to reduce problems with energy outages. They were experiencing power outages a few times a year which could cost $500,000 annually due to repair, lost productivity, and lost research.[29] Generation sources are from a gas-fired generator, solar PV, and wind turbines with battery storage (which can also be charged by the traditional grid during off-peak hours). The microgrid generates approximately 2/3 of peak summer demand.[30]

Stone Edge Farm

Near Sonoma, California, Stone Edge Farm sustainably produces heirloom vegetables, fruits, wines, olives, honey, and more. The farm is also home to a microgrid that integrates solar, microturbine, tri-generation (combined cooling, heating, power plant), hydrogen fuel cells, and storage. Critical load is backed up by solar-power battery storage which allows continuous operation of critical operations of the farm. The microgrid utilizes Heila Technologies which allows autonomous smart operation and switches the grid to different resources.[31]

While the farm was evacuated during Sonoma's wildfires in 2017, critical operations were able to continue for 10 days due to the microgrid.[32] Stone Edge Farm is looking to incorporate knowledge gained for microgrid application in their expansion plans. [33]

Conclusion

The microgrid and renewable energy industries are developing rapidly. They provide additional resiliency and reliability to customers during grid outages while also improving energy efficiency and lowering carbon footprint. They are being used globally in a variety of applications including campus and institutional, C&I, remote off-grid, utility, community, and military settings.

Greenleaf Advisors brings together leading energy developers, integrators, providers, and EPC firms to optimize operational and financial benefits for customers through integrated microgrid services.

For more information, or to discuss possible projects, please contact Katie DeMuro, kdemuro@greenleafadvisors.net at Greenleaf Advisors.

References

[1] **U.S. Department of Energy**, "The Role of Microgrids in Helping to Advance the Nation's Energy System," [Online]. Available: https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/role-microgrids-helping.

[2] **Navigant Consulting**, "Microgrid Multi-Client Study," 2015.

[3] **U.S. Department of Energy**, "Combined Heat and Power Technology Fact Sheet Series," 2017. [Online]. Available: https://www.energy.gov/sites/prod/files/2017/12/f46/CHP%20Overview-120817_compliant_0.pdf.

[4] **U.S. Department of Energy**, "How Do Wind Turbines Work?," [Online]. Available: https://www.energy.gov/eere/wind/how-do-wind-turbines-work.

[5] **Clean Energy Group**, L. Milford, R. Sanders, S. Mullendore and T. Olinsky-Paul, "Jump-Start: How Activists and Foundations Can Champion Battery Storage to Recharge the Clean Energy Transition," Clean Energy Group, 2018.

[6] **Microgrid Knowledge**, C. Evanich, "The Value of Energy Storage in Microgrids," 10 April 2017. [Online]. Available: https://microgridknowledge.com/value-energy-storage-microgrids/.

[7] **NREL**, J. Thomas, "Hydrogen: A Promising Fuel and Energy Storage Solution," 2013. [Online]. Available: https://www.nrel.gov/continuum/energy_integration/hydrogen.html.

[8] **Pew Charitable Trusts**, "Distributed Generation: Cleaner, Cheaper, Stronger. Industrial Efficiency in the Changing Utility Landscape," 2015.

[9] **SEPA and EPRI**, N. Enbar, D. Weng, R. Edge and J. Sterling, "Microgrids: Expanding applications, implementations, and business structures," Smart Electric Power Alliance and Electric Power Research Institute, 2016.

[10] **PJM**, "Demand Response," [Online]. Available: http://www.pjm.com/markets-and-operations/demand-response.aspx.

[11] **GreenTech Media**, J. St. John, "Energy Storage on the Grid Edge," 11 November 2013. [Online]. Available: https://www.greentechmedia.com/articles/read/energy-storage-on-the-grid-edge.

[12] **Armada Power**, "What is Frequency Regulation?," [Online]. Available: http://www.armadapower.com/frequency-regulation.html.

[13] **NREL**, R. Fu, D. Feldman, R. Margolis, M. Woodhouse and K. Ardani, "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017," *National Renewable Energy Laboratory,* 2017.

[14] **Navigant**, P. Asmus, "What Will the Microgrid of the Future Look Like?," 6 March 2018. [Online]. Available: https://www.navigantresearch.com/blog/what-will-the-microgrid-of-the-future-look-like.

[15] **Navigant**, P. Asmus, "Tracking Blackouts: Validation That C&I Microgrids Are the Next Big Thing?," 10 April 2018. [Online]. Available: https://www.navigantresearch.com/research/microgrid-deployment-tracker-4q17.

[16] A. Ali, W. Li, R. Hussain, X. He, B. W. Williams and A. H. Memon, "Overview of Current Microgrid Policies, Incentives and Barriers in the European Union, United States, and China," *Sustainability,* vol. 9, no. 7, 2017.

[17] **Clean Energy Group**, T. Olinsky-Paul, "What States Should Do: A Guide to Resilient Power Programs and Policy," June 2015. [Online]. Available: https://www.cleanegroup.org/wp-content/uploads/Resilient-States.pdf.

[18] **Texas Medical Center**, "About TMC," [Online]. Available: http://www.tmc.edu/about-tmc/facts-and-figures/.

[19] **Health Care Without Harm**, "Safe haven in the storm: Protecting lives and margins with climate-smart health care," January 2018. [Online].

[20] **Thermal Energy Corporation**, "System Benefits," [Online]. Available: http://tecothermalenergy.com/system-benefits/.

[21] **U.S. Department of Energy**, "Texas Medical Center and TECO," 2015. [Online]. Available: http://www.southwestchptap.org/data/sites/1/documents/profiles/Texas_Medical_Center-Project_Profile.pdf.

[22] **Thermal Energy Corporation**, "Emergency Preparedness," [Online]. Available: http://tecothermalenergy.com/operations/emergency-preparedness/.

[23] **Thermal Energy Corporation**, "TECO History," [Online]. Available: http://tecothermalenergy.com/about-teco/history/.

[24] E. Wood, "Engie and Axium Acquire Microgrid and District Energy System in Boston," Microgrid Knowledge, 4 April 2017. [Online]. Available: https://microgridknowledge.com/microgrid-and-district-energy-system-engie-axium/.

[25] **ComEd**, "ComEd proposal would create one of the first microgrid clusters in the world," 12 September 2017. [Online]. Available: https://poweringlives.comed.com/comed-collaborates-with-iit-to-create-one-of-the-first-microgrid-clusters-in-the-world/ .

[26] **Environmental Defense Fund**, C. Hicks, "Illinois blazes new trail in anticipation of private microgrids using utility wires," 10 April 2018. [Online]. Available: http://blogs.edf.org/energyexchange/2018/04/10/illinois-blazes-new-trail-in-anticipation-of-private-microgrids-using-utility-wires/.

[27] **Microgrid Knowledge**, E. Wood, "ComEd's Much-Watched Bronzeville Microgrid Wins Key Backing," 18 January 2018. [Online]. Available: https://microgridknowledge.com/bronzeville-microgrid-chicago/.

[28] **D. Munson**, "This Cleantech Hotspot Is Giving New York and California a Run for Their Money," 12 April 2018. [Online]. Available: https://medium.com/the-fourth-wave/this-cleantech-hotspot-is-giving-new-york-and-california-a-run-for-their-money-3a825cafc3f4.

[29] **Illinois Institute of Technology**, "Illinois Institute of Technology Microgrid," [Online]. Available: http://www.iitmicrogrid.net/microgrid.aspx.

[30] P. Caine, "Exploring the Technology Behind IIT's Microgrid," November 20 2017. [Online]. Available: https://chicagotonight.wttw.com/2017/11/20/exploring-technology-behind-iit-s-microgrid.

[31] **Stone Edge Farm**, "Stone Edge Farm Microgrid," [Online]. Available: http://sefmicrogrid.com/.

[32] L. Cohn, "Microgrid kept power on even as the California wildfires caused outages," 27 October 2017. [Online]. Available: https://microgridknowledge.com/islanded-microgrid-fires/.

[33] E. F. Merchant, "Fire-torn Northern California Becomes 'Living Lab' for Microgrids," 23 February 2018. [Online]. Available: https://www.greentechmedia.com/articles/read/fire-torn-northern-california-becomes-living-lab-for-microgrids.

[34] **Lazard**, "Levelized Cost of Storage Analysis - Version 3.0," November 2017. [Online]. Available: https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf.

[35] **Energy Storage Association**, "Energy Storage Technologies," [Online]. Available: http://energystorage.org/energy-storage-1.

Additional Resources

Clean Energy Group - cleanegroup.org

U.S. Department of Energy, Combined Heat and Power (CHP) Resource Guide for Hospital Applications - energy.gov/sites/prod/files/2013/11/f4/chp_hospital_guidebook_2007.pdf

GreenTech Media Microgrid Market Update - greentechmedia.com/research/report/gtm-research-note-us-microgrid-market-update-q2-2016

Health Care Without Harm - noharm.org

Microgrid Knowledge - microgridknowledge.com/

NREL, Microgrid-ready Solar PV - nrel.gov/docs/fy18osti/70122.pdf

Navigant Research - navigantresearch.com/research/energy-technologies/microgrids-energy-technologies

International District Energy Association, Schneider Electric and Microgrid Knowledge, Think Microgrid: A Discussion Guide for Policymakers, Regulators and End Users - blog.schneider-electric.com/wp-content/uploads/2014/06/Think-Microgrid-Special-Report.pdf

Appendix

Table 1 – Energy Storage Technologies Overview – Adapted from Lazard [34]

	Description	Size	Lifetime [1]	Pros	Cons
Compressed Air	Electricity is used to compress air which is then stored. The air is released to drive a turbine.	150 MW+	20 years	• Low cost • Flexible sizing • Large scale • Safe • Uses existing tech.	• Requires suitable geography • Difficult to implement small scale • Relies on natural gas
Flywheel	Store electricity as rotational kinetic energy, energy is released by decelerating the flywheel	30 kW – 1 MW	20+ years	• Low maintenance • Long life • Bridge gap between short-term ride-through power and long-term storage	• Low energy capacity • High heat generation • Sensitive to vibrations
Pumped Hydro	Pumps water from lower elevation to higher elevation reservoir, water is released through turbines.	100 MW+	20+ years	• Uses existing tech. • High capacity • Large scale	• Low energy density • Limited site availability • Limited cycling
Flow Battery	Flow batteries contain liquid electrolytes that store a charge. Types include redox flow, iron-chromium, vanadium redox, zinc-bromine [35].	25 kW – 100 MW+	20 years	• Scalable • High cycle/lifespan • No degradation in energy storage capacity • No potential for fire	• Reduced efficiency due to rapid charge/discharge • Relatively high balance of system costs
Lead Acid Battery	Lead-acid batteries are common and the oldest type of rechargeable battery. Advanced batteries use ultra-capacitors to increase efficiency and lifetime.	5 kW – 2 MW	5 – 10 years	• Mature technology • Low cost • Many uses	• Poor ability to operate in a partially charged state • Poor depth of discharge and short lifespan
Lithium Ion Battery	Li-Ion are solid state batteries replacing lead-acid batteries in many applications. They are an established technology used in electronics and advanced transportation industries.	5 kW – 100 MW+	10 years	• Declining costs • Efficient power and energy density • Low self-discharge	• Cycle life limited • Overheating issues • Requires advanced manufacturing capabilities for high performance
Sodium Battery	High temperature batteries have high power and energy density for large commercial and utility scale projects; low temperature batteries are an emerging technology for residential and small commercial applications.	1 MW – 100 MW+	10 years	High temp • Mature technology • High energy capacity • Long duration Low temp: • Smaller scale • Low-cost potential • Safe	• Higher costs • High temp – potential flammability issues • Poor cycling capability
Zinc Battery	Zinc batteries (include metal-air derivatives) are non-toxic, non-combustible, potentially low-cost.	5 kW – 100 MW+	10 years	• Deep discharge capability • Designed for long life • Designed for safe operation	• Currently unproven commercially • Lower efficiency • Poor cycling/rate of chare/discharge

[1] General range of useful economic life. Varies in practice (e.g. type of technology, intensity of use/cycling)