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Energy Storage Roadmap for Northeast Ohio 2019: Full Report

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Energy Storage Roadmap for Northeast Ohio

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The findings, conclusions, and recommendations expressed are those of the authors. They do not necessarily represent the views of Cleveland State University or Team NEO.

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1. Introduction

Northeast Ohio's economic development leaders have, for some time, recognized the role that advancements in energy storage technology could play in the regional economy. By 2010, shifts in traditional models of energy consumption had become perceptible. These shifts — driven by the emergence of cheap renewable power generation, smart grid technology and increasing interest in electric vehicles — presented both a challenge and an opportunity for the Northeast Ohio economy. While the challenge of not knowing how the region would respond to potentially disruptive changes to our energy system was presented, so too was an opportunity for new and existing businesses and institutions in the region to develop technology in response to this challenge.

Economic development experts at NorTech Energy Enterprises (now part of, and hereinafter referred to as, "TeamNEO")[1] committed to investigating strategies for the region to best respond to these challenges and opportunities. The result was the preparation of a seven-year strategic plan published in 2011 by TeamNEO, "Developing Sector Roadmaps for the Advanced Energy Cluster in Northeast Ohio" (2011 Roadmap).[2] The goal of this plan was to create a "cluster development roadmap" for the energy storage sector that could establish a detailed vision and action plan to help accelerate job growth and economic impact in Northeast Ohio.[3]

In 2018, TeamNEO determined it was time to update the 2011 roadmap. The resultant study (2019 Roadmap) examines the current trends in the energy storage industry and identifies changes that have occurred since 2011 that may warrant course adjustments for the cluster. The 2019 Roadmap considers what strategies might be employed going forward to advance the energy storage industry in Northeast Ohio.

The 2011 Roadmap identified four target market segments to Northeast Ohio's growing energy storage cluster:

- Lead-acid batteries
- Lithium-ion cell materials
- Flow batteries
- Distributed energy storage systems

The 2011 Roadmap also considered Northeast Ohio's position with regard to each of these segments, comparing each with the position of competitors. This included looking at the concentration of regional players, strength of supply chains, local know-how and academic leadership, local project

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[1] For more on Team NEO's role as a business development organization and its work to enhance the economy of Northeast Ohio, visit https://www.clevelandplus.com/teamneo

[2] The 2011 Roadmap for the Energy Storage Cluster can be downloaded at http://www.clevelandplus.com/wp-content/uploads/sites/2/2018/01/Energy-Storage-Roadmap-Brief_FINAL.pdf

[3] *Id.* at 3.

activities and the cost of skilled labor within the region. Similar competitive regions (Reading, PA, and Holland, MI) were identified within the United States,[4] and compared with Northeast Ohio. The authors found that Northeast Ohio held a competitive advantage in lead-acid technology development, while Holland, MI, held a competitive advantage in lithium-ion cell material development. Further, the authors found that, as of 2011, no area in the United States had developed a competitive advantage for flow battery development or distributed energy storage systems.

The 2011 Roadmap thereafter recommended a series of actions to enable the development of a Northeast Ohio energy storage cluster. These included, among other activities, pursuing grant opportunities, enabling financing for energy storage projects, and communicating to the industry and general public the opportunities resulting from the cluster development. The 2019 Roadmap will revisit these recommendations in light of new developments.

While the 2011 Roadmap identified energy storage as a developing cluster, Northeast Ohio has another interest in energy storage: The region has among the highest demand charges in the United States. Batteries could play an important role in constraining regional electricity costs. According to National Renewable Energy Laboratory (NREL), Northeast Ohio is among those regions with as many as 100,000 customers with demand charges exceeding $15/kW (although most of Ohio has as few as zero). Indeed, Northeast Ohio experiences demand charges similar to those found in the most populous and congested regions of the U.S., such as New York City, Chicago, Detroit and California (*see* Figure 1).[5] Demand charges in these areas can range from 30% to 70% of the customer's electric distribution bill. Such areas are candidates for early adoption of grid-based energy storage systems: NREL has determined that peak demand charges are the most reliable predictor of battery economic viability, and that the break-even point for grid-based energy storage is $9/kW.[6]

The 2019 Energy Storage Roadmap would not be possible without the generous support of the Burton D. Morgan Foundation. While this report was prepared by Team NEO and Cleveland State University, we gratefully acknowledge the following organizations and institutions that contributed to its development – The Great Lakes Energy Institute at Case Western Reserve University, the CSA Group, GLX Power Systems Inc., NASA, Rockwell Automation, Schneider Electric, and the Tech Belt Energy Innovation Center (TBEIC).

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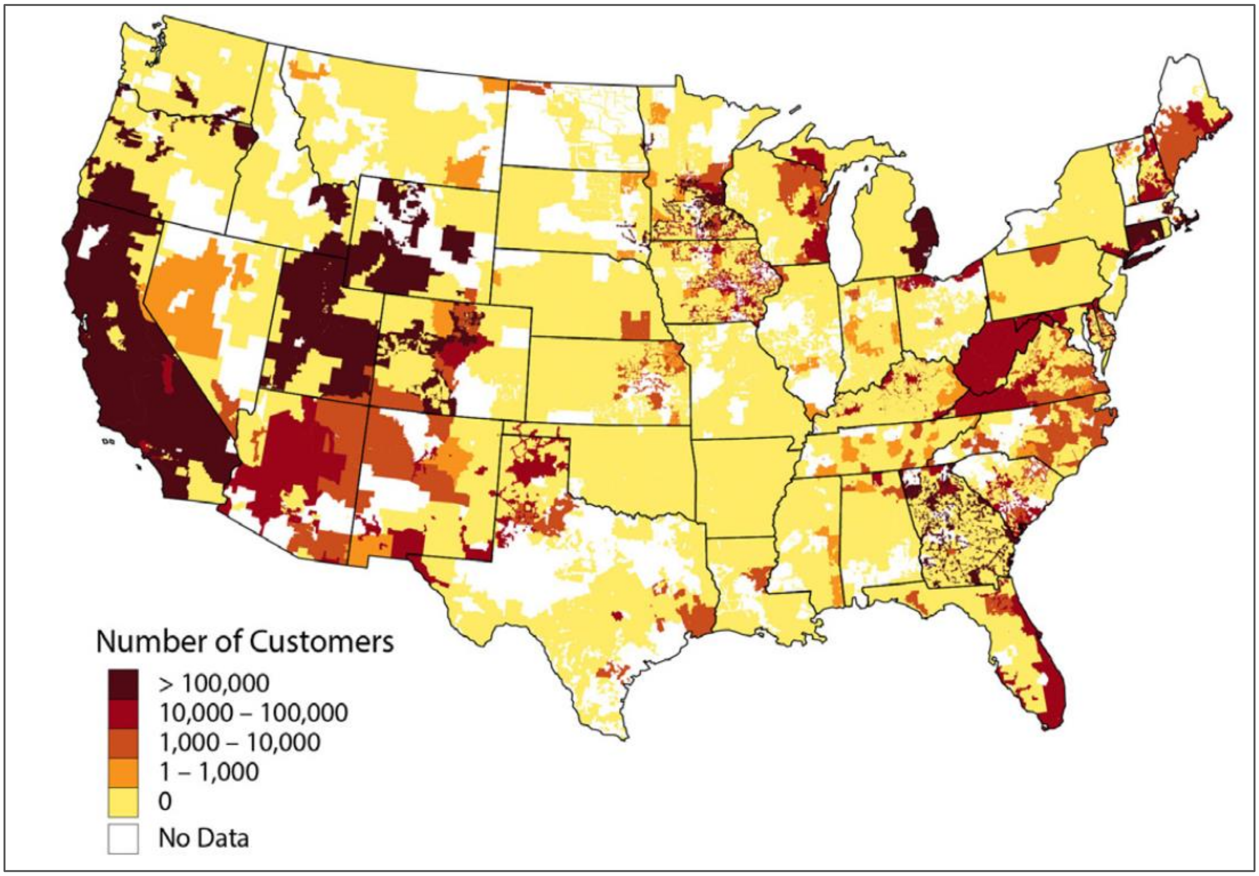
[4] *Id*. at 26. The 2011 Roadmap also considered locations outside of the United States, such as Germany, China, Japan and South Korea, but determined that the U.S. locations were most likely to compete for federal dollar support, labor and venture capital.

[5] McLaren, J. (2017). "Identifying Potential Markets for Behind-the-Meter Battery Energy Storage: A Survey of U.S. Demand Charges." *National Renewable Energy Laboratory*. https://www.nrel.gov/docs/fy17osti/68963.pdf

[6] *Id*. at note 2.

Figure 1. Estimated Number of Commercial Customers Who Can Subscribe to Tariffs with Demand Charges in Excess of $15/kW



Source: NREL

This consideration — local demand for grid-based energy storage — is particularly relevant to energy storage system integrators. As will be discussed herein, Northeast Ohio is home to several well-established companies already engaged in grid control systems and storage integration. Policies that enable or encourage local demand can help drive the cluster development and economic growth.

This 2019 Roadmap examines the status of the four segments identified in 2011, and considers other new segments that may be emerging. As with other nascent industries, the players frequently change. Accordingly, the 2019 Roadmap also re-examines the state of the energy storage industry in Northeast Ohio, and compares this with current industry trends and the expectations for market development from industry experts. Finally, the 2019 Roadmap reconsiders the 2011 action recommendations in light of these changes and suggests what changes could be made to further the continued development of the energy storage cluster in Northeast Ohio.

2. Defining Energy Storage and Energy Storage Opportunities

2.1 What Is *Energy Storage*?

Energy storage, as used in this Roadmap, may be defined as the capability to retain chemical, mechanical, thermal or electrical potential energy for an extended duration that can in turn be converted into usable electric power when needed.[7] Without a storage medium, electrical energy must be used as soon as it is produced and produced as soon as it is needed on an instantaneous basis, which requires a complex balancing act that utility companies must perform for nearly all of the electricity generated in the U.S.[8] On any given day, utilities across the country try to predict how much electricity people will want to consume based on historical patterns and then deliver this amount to every single customer at the precise combination of 120 volts with 60 Hz frequency — the standard for electric alternating current (AC) in the U.S. Over-delivery can lead to waste and damaged equipment, while under-delivery results in service disruptions such as brownouts.[9]

Energy storage allows energy to move through time. Energy generated at one time — whether from natural gas, solar, wind or any other power source — can be used at another time through storage. Decoupling the linkage between the production and consumption of electric power enables greater flexibility in balancing fluctuations in electricity generation and demand that can otherwise lead to inconsistent, inefficient and poorer-quality power.[10] Energy storage technologies absorb electrical power during periods of excess generation so that it can be released later in a measured, controlled manner, reconciling the differences between variable electrical sources and consumption. Energy

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[7] *See* Baxter, R. (2006). *Energy Storage: A Nontechnical Guide*. PennWell: Tulsa, OK. The 2011 Team NEO study defined energy storage as follows: "the capability of purposely storing various types of energy for use within electricity-based systems, and controllably releasing it for use at another time when a specific demand is to be met." This definition comports with the Baxter definition. Principally, the goal is to exclude oil- and gas-related storage from this analysis. These can, of course, also be converted to electricity, but they have pre-existing, well-established models and technology. We will, however, consider hydrogen and ammonia storage with this analysis, since they are new.

[8] Energy storage currently represents approximately 2% of U.S. generation capacity. *See* "Frequently Asked Questions." (n.d.). *Energy Storage Association.* http://energystorage.org/energy-storage/faq

[9] *See* Energy Storage Association. (n.d.). "Unleashing the Power of Energy Storage." http://energystorage.org/energy-storage

[10] *Supra fn* 7 and 8.

storage enables the control of the electrons flowing through the electrical infrastructure so that they provide the most resilient, superior power quality and efficiency.[11]

2.2 Application-based Framework (Market Segments)

Creating a roadmap for the development of energy storage requires a framework for analysis that considers different technologies and markets. A common and useful approach is to categorize types of energy storage by application.[12] This is especially appropriate within the context of economic development given that the "best" technology (i.e., the most economically efficient one) is dependent on where and how a given technology is deployed to meet a specific storage need.[13] A given technology is more or less cost-effective based on the needs of a particular application, such as whether a high *cycle life*[14] is required. The nature of an energy storage application precedes what technologies will be utilized.

Within this framework, we can distinguish between three general areas of energy storage applications:

- *Grid Storage*. Also known as stationary storage, this refers to storage technologies applied to the network of substations, transformers, and transmission and distribution (T&D) power lines that together make up what is known as the *grid.*

- *Transportation Energy Storage*. Storage technologies support a number of transportation modes, including passenger cars, trucks, trains, boats, planes, drones, carts, motorcycles and forklifts. In some cases, electrons may flow not only from grid-to-vehicle, but also from vehicle-to-grid during times of electric supply shortage.[15]

- *Consumer Electronics Energy Storage*. Energy storage for portable applications includes the use in smartphones, web-connected wearables, tablets/laptops, medical devices and power tools.

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[11] *See* Port Authority of Long Beach. (2016). "Energy Storage Technologies White Paper." http://www.polb.com/civica/filebank/blobdload.asp?BlobID=13596

[12] For examples, *see* U.S. Department of Energy. (2017). "Electrical Energy Storage Factual Status Document." https://science.energy.gov/~/media/bes/pdf/reports/2017/EES_BRN_Factual_Doc.pdf

[13] *Supra fn* 11. Economic efficiency can, and sometimes does, include environmental costs and benefits. Oftentimes, however, environmental costs are controversial and held external to the calculation of the most efficient system.

[14] *Cycle life* is an energy storage metric that describes the number of times a technology can be charged and discharged before it fails to deliver sufficient energy and power during discharge in relation to its initial rated capacity.

[15] *See* Energy Storage Association. (n.d.). "Electricity Storage and Plug-in Vehicles." http://energystorage.org/energy-storage/technology-applications/electricity-storage-and-plug-vehicles

All three of these general areas are relevant to this Roadmap. As we will see from the analysis ahead, the grid storage markets may offer the most significant opportunity for Northeast Ohio's energy storage cluster.

2.3 Energy Storage Technologies

It can also be useful to understand how different types of storage are classified based on their underlying technology. These assorted technologies are generally grouped based on the form of energy they store. Along these lines, energy storage technologies broadly fall into one of the following five categories:[16]

1. *Mechanical Energy Storage.* Under this technology, electricity is converted into either potential or kinetic energy. One example of stored potential energy, seen in Figure 2a, involves water storage facilities at two different elevations: Water is held in an upper reservoir (initially pumped there using an electric motor) and then released to a lower reservoir, with a turbine placed between the two facilities to produce electricity when water runs through it.[17] A similar form of storing potential energy uses compressed air: Air is pressurized within a container, and then later released to drive a turbine when power is needed.[18] Generally, Northeast Ohio does not have the necessary geographical relief for cost-effective stored hydropower. However, it may have some locations, such as abandoned underground salt mines, that could be used for compressed-air technology.

   An example of storing energy kinetically can be seen in the rotational kinetic energy of a flywheel, represented in Figure 2b.[19] This sort of technology uses a motor-generator power conversion system to convert AC power delivered by the grid or other generating unit into the rotational energy of the rotor. The energy is later released by applying resistance to the spinning rotor, which is typically surrounded by a vacuum to minimize the frictional loss of energy.

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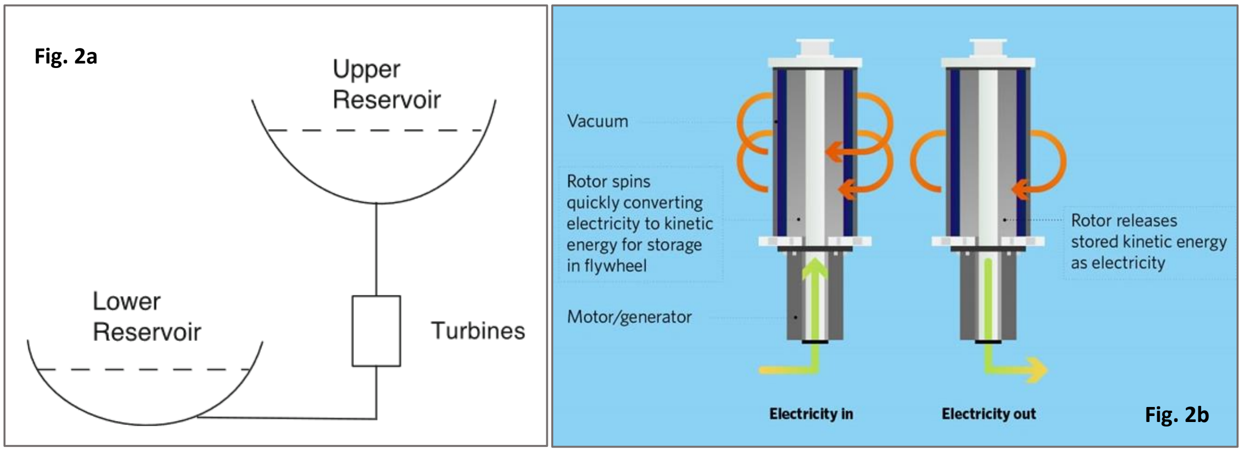
[16] *See* U.S. Department of Energy. (2017). "An Evaluation of Energy Storage Options for Nuclear Power." https://www.osti.gov/servlets/purl/1372488

[17] Huggins, R. (2016). *Energy Storage: Fundamentals, Materials and Applications*, 2nd ed. Springer International Publishing: Switzerland.

[18] *See* Energy Storage Association. (n.d.). "Compressed Air Energy Storage (CAES)." http://energystorage.org/compressed-air-energy-storage-caes

[19] Image Source: *Independent Electricity System Operator (IESO) of Ontario*. http://www.ieso.ca/en/Powering-Tomorrow/Technology/High-Performance-Flywheel-Energy-Storage-Systems-Temporal-Power

Figure 2. Examples of Mechanical Energy Storage

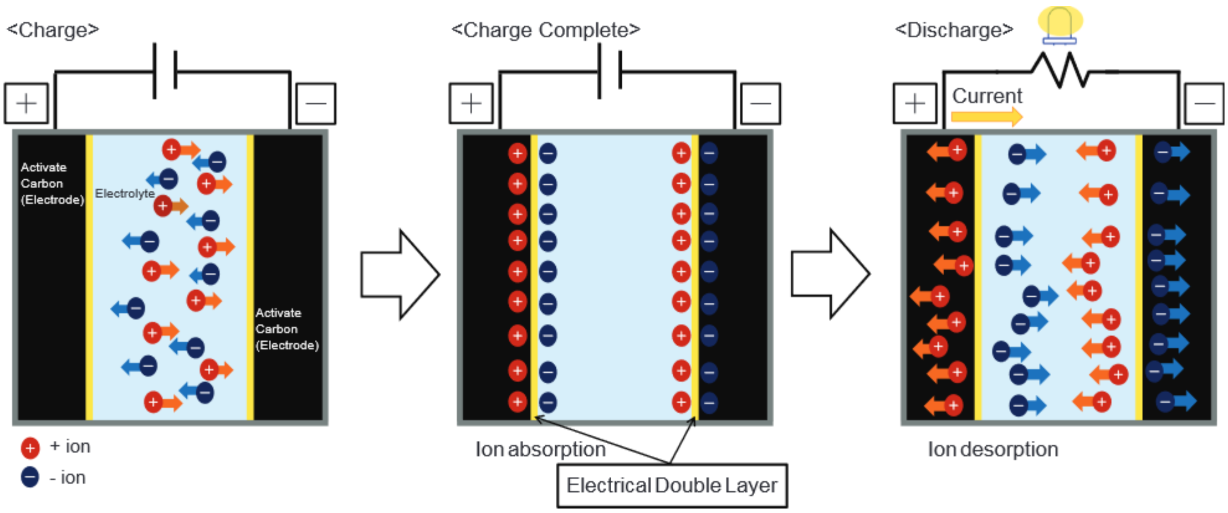


2. *Electrical Energy Storage.* These technologies can store electrical energy directly in one of two ways: electromagnetically, where energy is stored in a magnetic field generated by current running through a superconducting wire; or electrostatically, where energy is stored in an electric field between two charged electrode plates separated by an electrically insulating material.[20] The latter of these, illustrated in Figure 3, is known as an electrical double-layer capacitor, or supercapacitor. When a current is introduced to the supercapacitor, ions build on either side of the insulator to generate a double layer of charge.[21]

[20] Rasmussen, C. et al. (2013). "Electromagnetic and Electrostatic Storage." *DTU International Energy Report 2013*. http://orbit.dtu.dk/files/60269062/DTU_International_Energy_Report_2013.pdf

[21] Image Source: *Mouser Electronics (Murata Manufacturing).* https://www.mouser.com/pdfDocs/Murata-DMF-DMT_TechnicalGuide.pdf

Figure 3. Structure of a Supercapacitor



3. *Electrochemical Energy Storage*. The most common form of electrochemical energy storage is the battery, which can be further subdivided into the categories of conventional batteries and flow batteries. The difference between these two types is that conventional batteries store charge in solid electrode systems, while flow batteries rely on storing charge in at least one liquid.

   Figure 4 illustrates how the conventional lithium-ion battery works.[22] The electrodes (i.e., the anode and cathode) store the lithium. The electrolyte[23] carries positively charged lithium ions from the anode to the cathode and vice versa through the separator.[24] The movement of the lithium ions creates free electrons in the anode, which creates a charge at the positive current collector. The electrical current then flows from the positive current collector, through the device being powered by the battery, to the negative current collector.[25] While the battery as illustrated in Figure 4 is structurally similar to a supercapacitor, it is important to note that in the case of the battery, energy is indirectly stored in a *chemical* form where a chemical reaction is required to release charges that can perform electrical work.[26]

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[22] Image Source: *Stanford University Department of Physics (Wikimedia Commons).* http://large.stanford.edu/courses/2016/ph240/werner1/.

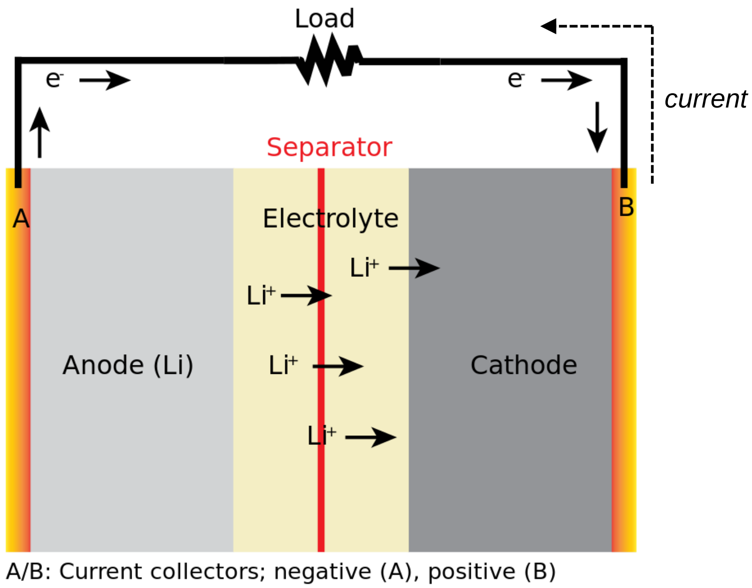
[23] The *electrolyte* is a nonmetallic liquid or solid that conducts ions to carry electrical charges.

[24] The separator, typically a polymer or ceramic, blocks the flow of electrons inside the battery.

[25] See U.S. Department of Energy. (2017). "How Does a Lithium-Ion Battery Work?" https://www.energy.gov/eere/articles/how-does-lithium-ion-battery-work

[26] Conway, B. (1999). *Similarities and Differences between Supercapacitors and Batteries for Storing Electrical Energy*. In: Electrochemical Supercapacitors. Springer: Boston, MA. https://link.springer.com/chapter/10.1007%2F978-1-4757-3058-6_2

Figure 4. How a Lithium-ion Battery Functions

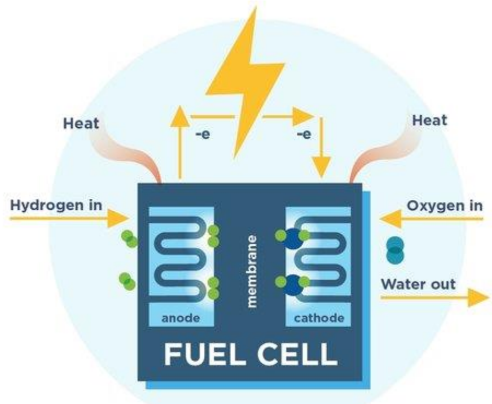


4. *Hydrogen Energy Storage.* Under this form of energy storage, electricity that has been generated by a power plant can be used to produce storable hydrogen through electrolysis, where water molecules are split into their constituent hydrogen and oxygen gases by an electric current. The chemical energy stored in the hydrogen bonds can then be used later in a fuel cell to produce electricity, as illustrated below in Figure 5.[27] While electrolysis offers a long-term strategy for developing renewable hydrogen, the common method of making hydrogen today, and for the near term, is through a process of stream reformation of natural gas. As a result, storage of hydrogen has become of increasing interest for Northeast Ohio, which sits adjacent to the large Marcellus and Utica natural gas fields.

   A fuel cell works by passing hydrogen through the anode of a fuel cell and oxygen through the cathode. At the anode site, the hydrogen atoms are split into electrons and protons. The protons pass through the electrolyte membrane (e.g., a polymer or metal oxide), while the electrons are forced through a circuit, generating an electric current and excess heat. At the cathode, the protons, electrons and oxygen combine to produce water molecules. Fuel cells do not need to be periodically recharged like batteries, but instead continue to produce electricity as long as a fuel source is provided.

[27] Image Source: *Fuel Cell & Hydrogen Energy Association.* http://www.fchea.org/fuelcells

Figure 5. Fuel Cell Basics



5. *Thermal Energy Storage.* The most widely used form of thermal energy storage for electricity production sector is known as *sensible heat storage*. In a sensible heat thermal energy storage system, a storage medium (e.g., molten salts, sand, rocks or soils) is heated to store energy without undergoing a phase change over the temperature range of the storage process. The heat collected is used to generate steam that, in turn, drives a turbine generator.[28]

   Sensible heat storage is widely utilized in concentrated solar power (CSP) applications where the use of thermal energy storage enables a project to produce electricity after the sun has gone down. The medium of choice in CSP plants with thermal energy storage is usually molten salts, which can withstand extremely high temperatures.

   Figure 6 illustrates how a CSP plant could generate electrical power using heat collected from sunlight.[29] In this process, a heat transfer fluid is heated as it circulates through the receivers in the collectors. It runs through a heat exchange to generate high-pressure steam, which drives a conventional steam turbine. The spent steam from the turbine is condensed into liquid and re-heated in the steam generator, allowing the process to continue. The storage tank holds the heated medium, such as molten salts, enabling the system to produce electricity after sundown.[30]

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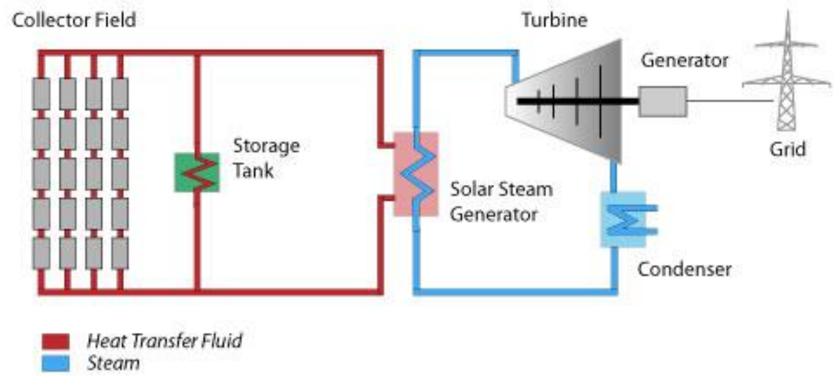
[28] Harvey, A. (2017. "The Latest in Thermal Energy Storage." *POWER Magazine*. https://www.powermag.com/the-latest-in-thermal-energy-storage/?pagenum=3. *See also* Dincer, I., and Rosen, M. (2011). *Thermal Energy Storage: Systems and Applications*, 2nd ed. Wiley: Hoboken.

[29] Image Source: "Concentrated Solar Thermal Systems." *Green Rhino Energy*. http://www.greenrhinoenergy.com/solar/technologies/cst_systems.php

[30] *Id.*

Figure 6. Solar Thermal System



2.4 Energy Storage Systems

While the technology by which energy is stored in various media constitutes the heart of an energy storage application, it nonetheless is but a part of a greater energy storage *system*. Such a system generally consists of three parts: the storage medium, a power conversion system (PCS) and balance of plant (BOP), also known as balance of system (BOS).[31] Figure 7 shows an electrochemical-based battery storage system for grid storage, although the same concept extends to other storage technologies and applications for energy storage.

While the storage medium essentially defines how an energy storage system is known (e.g., flywheel energy storage, battery energy storage), the BOS and PCS are crucial enablers of the core technology. These two sometimes neglected parts of an energy storage system represent from 25% to 40% of overall system costs.[32] Recently, cost reductions for these components have been the main drivers of falling battery prices, with this trend likely to continue.[33] Continued efforts to standardize the design and engineering for BOS and PCS should accelerate this cost decline, presenting opportunities for increased energy storage growth more generally.[34]

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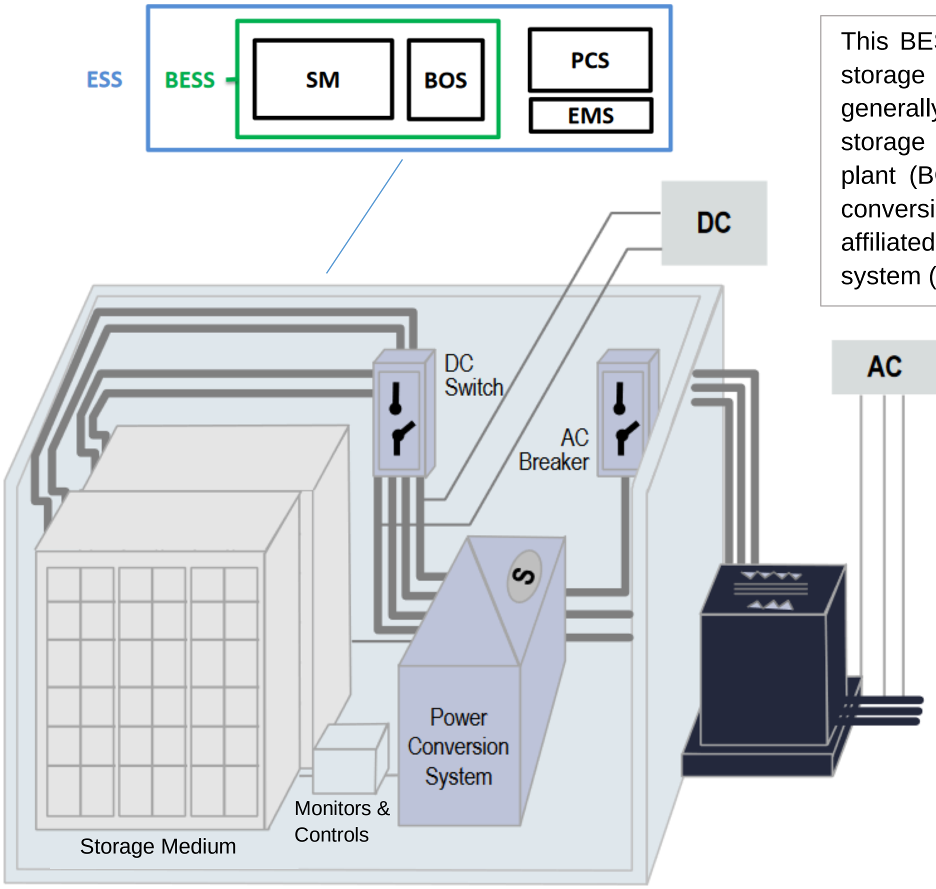
[31] *Supra fn* 7.

[32] *See the following*: (a) Maloney, P. (2018). "Not so Fast: Battery Prices Will Continue to Decrease, but at a Slower Pace, GTM Says." *Utility Dive*. https://www.utilitydive.com/news/not-so-fast-battery-prices-will-continue-to-decrease-but-at-a-slower-pace/518776/; (b) Kupper, D. et al. (2018). "The Future of Battery Production for Electric Vehicles." *Boston Consulting Group.* https://www.bcg.com/en-us/publications/2018/future-battery-production-electric-vehicles.aspx; and (c) Fu, R. et al. (2018). "2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark." *National Renewable Energy Laboratory*. https://www.nrel.gov/docs/fy19osti/71714.pdf

[33] *Id. See also* Munsell, M. (2016). "Grid-Scale Energy Storage Balance-of-System Costs Will Decline 41% by 2020." *Greentech Media*. https://www.greentechmedia.com/articles/read/grid-scale-energy-storage-balance-of-systems-costs-will-decline-41-by-2020#gs.vUgfJ2kj

[34] *See* Colthorpe, A. (2018). "GTM: Front-Of-Meter Cost Declines Will Slow as Industry Grows 6x Over by 2022." *Energy Storage News*. https://www.energy-storage.news/news/gtm-front-of-meter-cost-declines-will-slow-as-industry-grows-6x-over-by-202

Figure 7. Battery Energy Storage System (BESS)



This BESS, illustrating an energy storage system (ESS) more generally, is composed of a storage medium (SM), balance of plant (BOP or BOS), and power conversion system (PCS) with an affiliated energy management system (EMS).

Source: Sandia National Labs[35]

System Component	Subcomponents	
SM	• Battery Cells & Modules	• Racking Frame
BOS	• Battery Management System (BMS) • System Control Software • Monitors and Sensors • Thermal Management (HVAC Systems)	• Fire Suppression • Electrical Distribution & Control • Communication (wired or wireless) • Container
PCS	• Inverter • Rectifier • Electrical Protection (Switches & Breakers) • Power Conditioning	• Energy Management System (EMS) - Economic Optimization - Distributed Asset Integration - Data Logging

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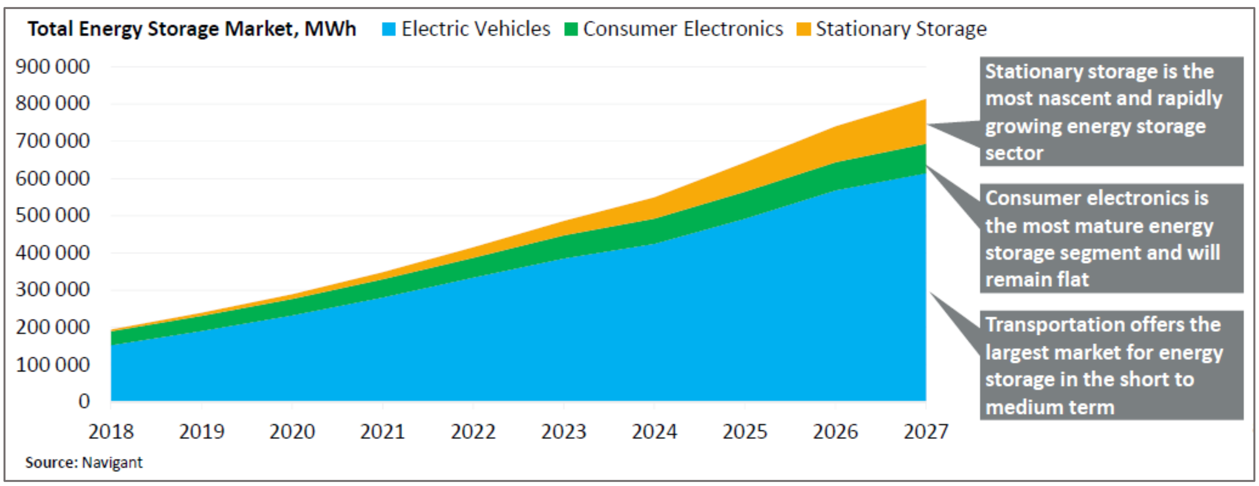
[35] *See* Sandia National Labs. (2016). "DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA." https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2016/169180.pdf
See also: (a) Sandia National Labs. (2017). "Energy Storage Project Financing (EESAT 2017)." https://eesat.sandia.gov/wp-content/uploads/2017/12/Richard_Baxter.pdf; and (b) and Sinovoltaics Group. (2017). "Balance of System (BOS): What Is It?" https://sinovoltaics.com/learning-center/basics/balance-of-system-*bos/*

3. Trends in Energy Storage Markets

The energy storage advantage stems from the flexibility it allows for *when* energy can be used. Within this broad view of energy storage benefits, a narrower set of factors have been recognized within the identified three application areas as key drivers that are likely to maximize value creation in the energy storage market. While the listing that follows of these demand- and supply-side considerations is not exhaustive, these particular energy storage value streams have been identified by academic researchers and industry analysts as offering high economic potential. [36]

Of the three identified general applications, Navigant has projected that while transportation offers the most near-term opportunity for storage, grid-based storage is the most rapidly growing, while consumer storage market growth will remain flat (*see* Figure 8).[37] For reasons set forth herein, however, there is reason to expect significant long-term growth in all three sectors.

Figure 8. Anticipated Total Energy Storage Markets, Near- and Mid-term



[36] *See* McLaren, J. (2016). "Batteries 101 Series: Use Cases and Value Streams for Energy Storage." *National Renewable Energy Laboratory*. https://www.nrel.gov/state-local-tribal/blog/posts/batteries-101-series-use-cases-and-value-streams-for-energy-storage.html. *See also:* (a) Frankel, D., and Wagner, A. (2017). "Battery Storage: The Next Disruptive Technology in the Power Sector." *McKinsey & Company*. https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/battery-storage-the-next-disruptive-technology-in-the-power-sector*;* and (b) U.S. Energy Information Administration. (2018). "U.S. Battery Storage Market Trends." https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

[37] Figure 8 obtained from Bushveld Energy. (2018). "Energy Storage & Vanadium Redox Flow Batteries 101. http://www.bushveldminerals.com/wp-content/uploads/2018/11/Energy-storage-101.pdf

3.1 Grid Storage Drivers

The factors driving grid storage usage and growth are as follows:

- *Frequency regulation* helps balance momentary differences between demand and supply, often in response to deviations in power line frequency from 60 Hz.

- *Arbitrage*, also known as electrical energy time-shift, involves purchasing inexpensive electric energy, available during periods when prices or system marginal costs are low, to charge the storage system so that the stored energy can be used or sold at a later time when the price or costs are high.

- *Load management*, or customer energy management, comprises several services, including protecting on-site customer loads against short-duration events that affect the quality of power, such as voltage surges and sags (i.e., brownouts); supporting customer loads with "islandable" capabilities when there is a total loss of power from the source utility; and reducing overall customer costs for electric service by minimizing demand charges. [38]

- *Backup power* provides an active reserve capacity of power and energy that can be used to energize transmission and distribution lines and provide start-up power to bring power plants on-line in the event of grid failure.

- *Transmission and distribution deferral* is due to storage's reducing the "peak" or maximum power draw (i.e., peak demand) by the loads that are using electricity.[39] By keeping the electrical loading of the transmission and distribution system equipment lower than it would otherwise be, storage defers the need to make large lump investment for capacity upgrades. The result is a reduction in overall cost to ratepayers, improvement in utility asset utilization and mitigation of the financial risk associated with large capital investments.

- *Renewable energy integration* is expected to depend significantly on the ability of energy storage to overcome challenges such as output variability and temporal mismatch between generation and demand that are associated with wind, solar and other renewable sources of energy that can fluctuate intermittently.

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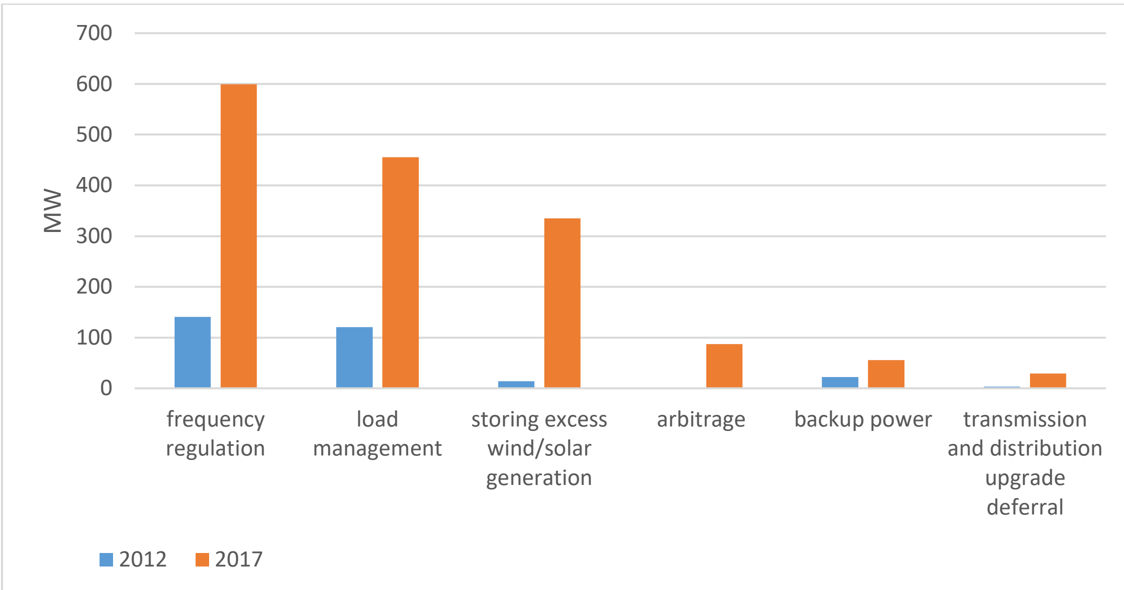
[38] Demand charges, based on a customer's highest average electricity usage occurring within a defined time interval during a billing period (e.g., 15 minutes), are associated with the cost of providing sufficient electricity generation and distribution capacity to customers. *See supra fn* 5.

[39] *See* Energy Storage Association. (n.d.). "Benefit Categories." http://energystorage.org/energy-storage/energy-storage-benefits/benefit-categories

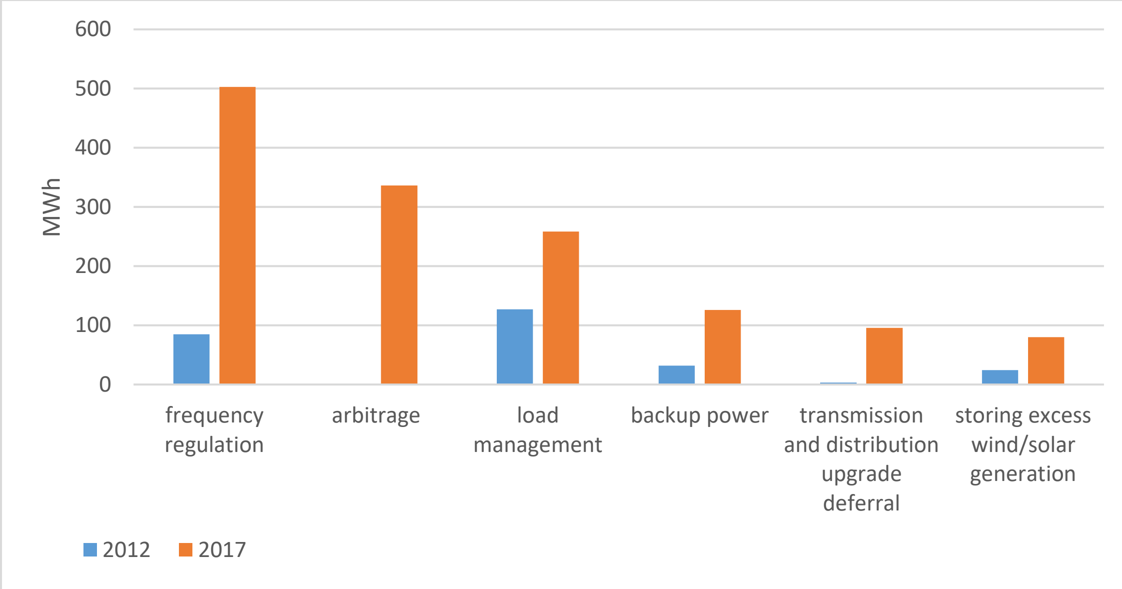
Figures 9 and 10 illustrate the change in the amount of grid-scale power and energy capacity available among these value streams in the United States from 2012 to 2017.[40] As can be seen from the figures, grid-scale storage power capacity has, over the past five years, been driven by frequency demand, load management and renewable generation system support. Arbitrage has, however, produced a significant amount of energy capacity.

Figure 9. U.S. Grid-scale Power Capacity by Value Stream, 2012 and 2017



[40] Power capacity, measured in megawatts (MW), is the maximum *instantaneous* amount of power output, while energy capacity, measured in megawatt-hours (MWh), is the *total* amount of energy that can be stored or discharged by an energy storage system.

Figure 10. U.S. Grid-scale Energy Capacity by Value Stream, 2012 and 2017



Source for Figures: U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report

3.2 Transportation Energy Storage Drivers

The factors driving transportation energy storage usage and growth are as follows:

- *Consumer demand* for more environmentally friendly vehicles that contribute to lower greenhouse gas emissions will continue to grow and impact energy storage trends. This expansion is expected to occur regardless of oil price fluctuations, similar to what has already been seen with past electric vehicle (EV) growth (*see* Figure 11). As executives with British Petroleum (BP) and Shell have noted, social desirability is important enough for consumers to ignore that battery-powered technology is currently more expensive than internal combustion engines.[41] According to BP's chief economist, this *cool factor* — what an EV says about buyers, how modern they are and their responsibility to the planet — could lead to faster penetration of zero-emission vehicles and spur EV fleet growth.[42]

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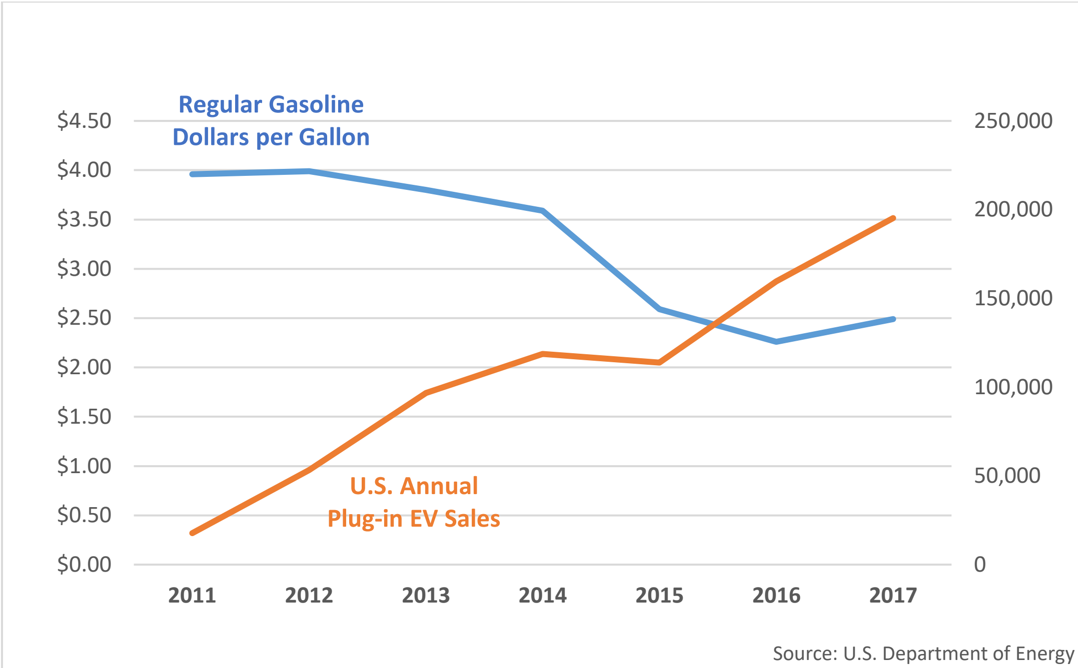
[41] *See* Khrennikova, D. (2018). "Passionate Electric Car Owners to Drive Growth, Shell Says." *Bloomberg*. https://www.bloomberg.com/news/articles/2018-11-27/-passionate-electric-car-owners-to-drive-growth-shell-says

[42] *See* Paraskova, T. (2018). "Shell: EV Demand to Grow Regardless of Oil Prices." *OilPrice.com.* https://oilprice.com/Energy/Energy-General/Shell-EVs-Demand-To-Grow-Regardless-Of-Oil-Prices.html

Figure 11. Price of Gasoline vs. Annual EV Sales, 2011-2017



- *Public policy*, in terms of both incentives and prohibitive regulations, is one of the strongest catalysts for EV market attractiveness and, by extension, general energy storage growth.[43] In the U.S., in addition to the federal tax credit of up to $7,500 for qualifying EVs, 45 states offer their own incentives ranging from tax credits, utility time-of-use rate reductions and high-occupancy vehicle (HOV) lane exemptions to promote EV adoption, with nine of those states' forming a coalition committed to having 3.3 million zero-emission vehicles[44] on their roadways by 2025.[45] Of significance to shaping the near- to mid-term future of transportation energy storage are the proposed outright bans on sales of vehicles with internal combustion engines in several countries with large consumer markets — including China, France, Germany and the U.K. — with 2030 being the most common target year among these countries.[46]

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[43] Accenture. (2016). "Electric Vehicle Market Attractiveness: Unraveling Challenges and Opportunities." https://www.accenture.com/_acnmedia/PDF-37/accenture-electric-vehicle-market-attractiveness.pdf

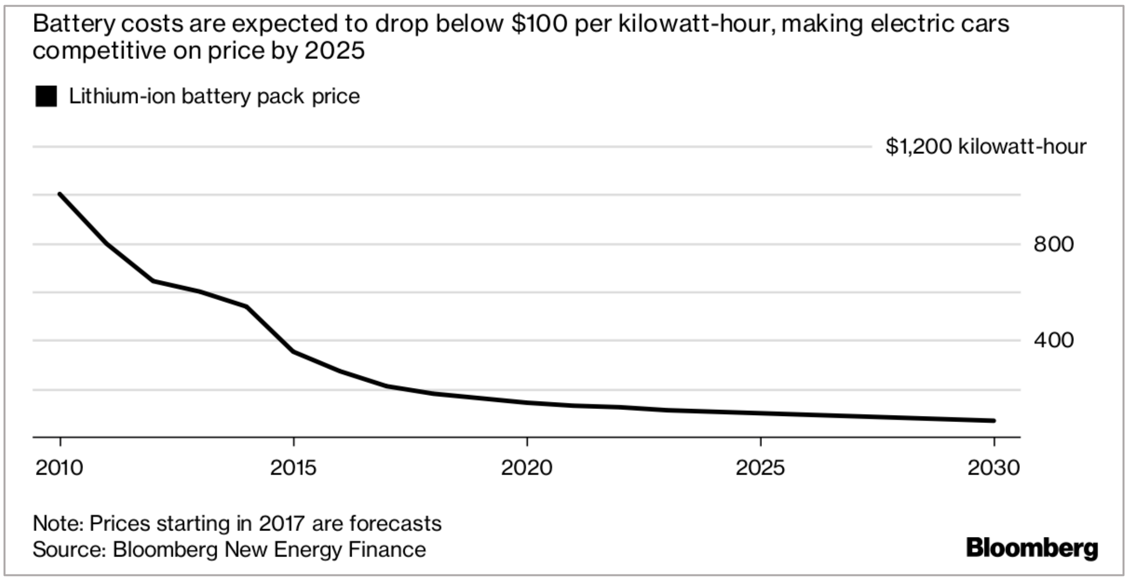
[44] Zero-emission vehicles (ZEVs) include pure battery-electric vehicles, plug-in hybrid electric vehicles and hydrogen fuel cell electric vehicles.

[45] *See* National Conference of State Legislatures. (2017). "State Efforts to Promote Hybrid and Electric Vehicles." http://www.ncsl.org/research/energy/state-electric-vehicle-incentives-state-chart.aspx. *See also* "About the ZEV Task Force." *Multi-State ZEV Task Force*. (n.d.). https://www.zevstates.us/

[46] *See* Thomson Reuters. (2018). "What's Driving the Electric Vehicle Revolution?" https://blogs.thomsonreuters.com/answerson/whats-driving-the-electric-vehicle-revolution/

- *Declining battery prices* are bringing EVs closer to price parity with internal combustion engine (ICE) vehicles. Batteries within the lithium-ion family, the dominant form of energy storage for passenger vehicles, currently represent around one-third of the cost of an EV.[47] The general consensus in the automotive industry is that for EVs to be competitive with ICE vehicles, costs for these batteries must fall to $100/kWh.[48] This threshold is projected to be reached by the mid-2020s due to increasing economies of scale that have already significantly reduced battery prices to around a fifth of what they were in 2010, as illustrated in Figure 12.[49]

Figure 12. Projected Decline in Battery Prices



- *Vehicle performance* associated with EVs is a value driver of energy storage in transportation that could arguably be as significant as environmental factors. Researchers at the University of California-Davis Institute of Transportation Studies, while investigating the adoption of Teslas among car buyers, found that the most prominent reason for purchasing a Tesla was not environmental concerns but rather the vehicle's high performance, particularly its fast acceleration and how this provided "visceral rewards" to drivers.[50] An EV's electric motor can produce maximum torque from a standstill, enabling it to accelerate faster than an ICE vehicle, in which this maximum rotational force or "turning power" is realized more gradually.[51]

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[47] *See* Flowers, S. (2018). "Electric Vehicles: Transportation Disruptor, Part 1." *Wood Mackenzie.* https://www.woodmac.com/news/the-edge/electric-vehicles-transportation-disruptor-part-1/

[48] *Id.*

[49] *See* Chediak, M. (2018). "The Battery Will Kill Fossil Fuels — It's Only a Matter of Time." *Bloomberg*. https://www.bloomberg.com/news/articles/2018-03-08/the-battery-will-kill-fossil-fuels-it-s-only-a-matter-of-time

[50] Richards, S. (2017). "How to Combine Three Revolutions in Transportation for Maximum Benefit Worldwide." *UC Davis Institute of Transportation Studies*. https://its.ucdavis.edu/blog-post/page/3/

[51] *See* Fernie, M. (2016). "How Do Electric Vehicles Produce Instant Torque?" *Car Throttle.* https://www.carthrottle.com/post/how-do-electric-vehicles-produce-instant-torque/. *See also* ScienceBlogs.

3.3 Consumer Electronics Energy Storage Drivers

The factors driving the usage and growth of energy storage in consumer electronics are as follows:

- *Energy density* is expected to remain the most important metric in all consumer applications with regard to energy storage.[52] Secondarily, yet still of great importance to end users, value creation in this area will depend on *longer cycle life*, *faster charging*, technology deployment that is *intrinsically safe*, and having enough *available power* to achieve peak computing needs.[53] As would be expected, users of energy storage within this space want to be able to do more, for a longer period of time and with less downtime. And they want to be able to do this with the confidence that the storage technology will not malfunction catastrophically.[54]

  Companies that develop electrical storage for consumer applications will differentiate themselves by effectively doubling current performance standards over the next five to seven years. This is illustrated in Table 1, which compares the performance of typical present-day lithium-ion technology and the market-driven performance needs that the industry is targeting for the more important consumer applications.

(2009). "What Does Torque in a Car Do?" https://scienceblogs.com/startswithabang/2009/04/21/what-does-torque-in-a-car-do. *Note*: Not all energy storage for EVs is necessarily batteries. Kinetic energy recovery systems (KERS) were originally developed for Formula 1 racing and are being implemented in passenger cars by Volkswagen and Mercedes. Heat from braking that would normally dissipate can be gathered and stored either in a battery or as kinetic energy with a flywheel; the latter form has offered seven seconds per lap of 80 hp boost in racing. For more information on KERS, visit http://large.stanford.edu/courses/2015/ph240/sarkar1

[52] *See supra fn* 12.

[53] *Id.*

[54] The release of the Samsung Galaxy Note 7 smartphone, for example, saw around 100 dangerous battery incidents, including fires and explosions, due to poorly constructed battery cells containing the flammable lithium-ion electrolyte. *See* Moynihan, T. (2017). "Samsung Finally Reveals Why the Note 7 Kept Exploding." *Wired*. https://www.wired.com/2017/01/why-the-samsung-galaxy-note-7-kept-exploding/

Table 1. Energy Storage Targets for Consumer Electronics

	Specific Energy (Wh/kg)		**Specific Power (W/kg)**		**Charge Rate[55]**		**Discharge Rate**		**Cycle Life**	
Application	*Status 2017*	*Target*	*Status 2017*	*Target*	*Status 2017*	*Target*	*Status 2017*	*Target*	*Status 2017*	*Target*
Internet of Things (IoT)	100	200	200	400	1C	2C	2C	4C	500	1000
Wearables	150	300	200	400	1C	2C	2C	4C	400-500	500-700
Cell Phones	150	300	200	400	1.5C	3C	2C	3C	500	800-1000
Tablet/Laptop	150	300	200	400	1.5C	3C	2C	3C	800	1000

Source: U.S. Department of Energy (DOE), Enovix Corp.[56]

- The emergence of *wearable technology*, including ingestible and implantable medical devices, will drive the need to develop not only new forms of energy storage technology that can deliver a given level of energy density, cycle life, etc. at this smaller scale, but also thinner, more flexible form factors that can deliver this performance. Importantly, wearable technology must be capable of being shaped to conform to end applications, rather than having the end product being built around the energy storage. As a result, the physical obtrusiveness of the energy storage powering a device must be minimized. Figure 13 shows some of these wearable technology applications that will drive what is projected to be a $100 billion industry by the mid-2020s.[57]

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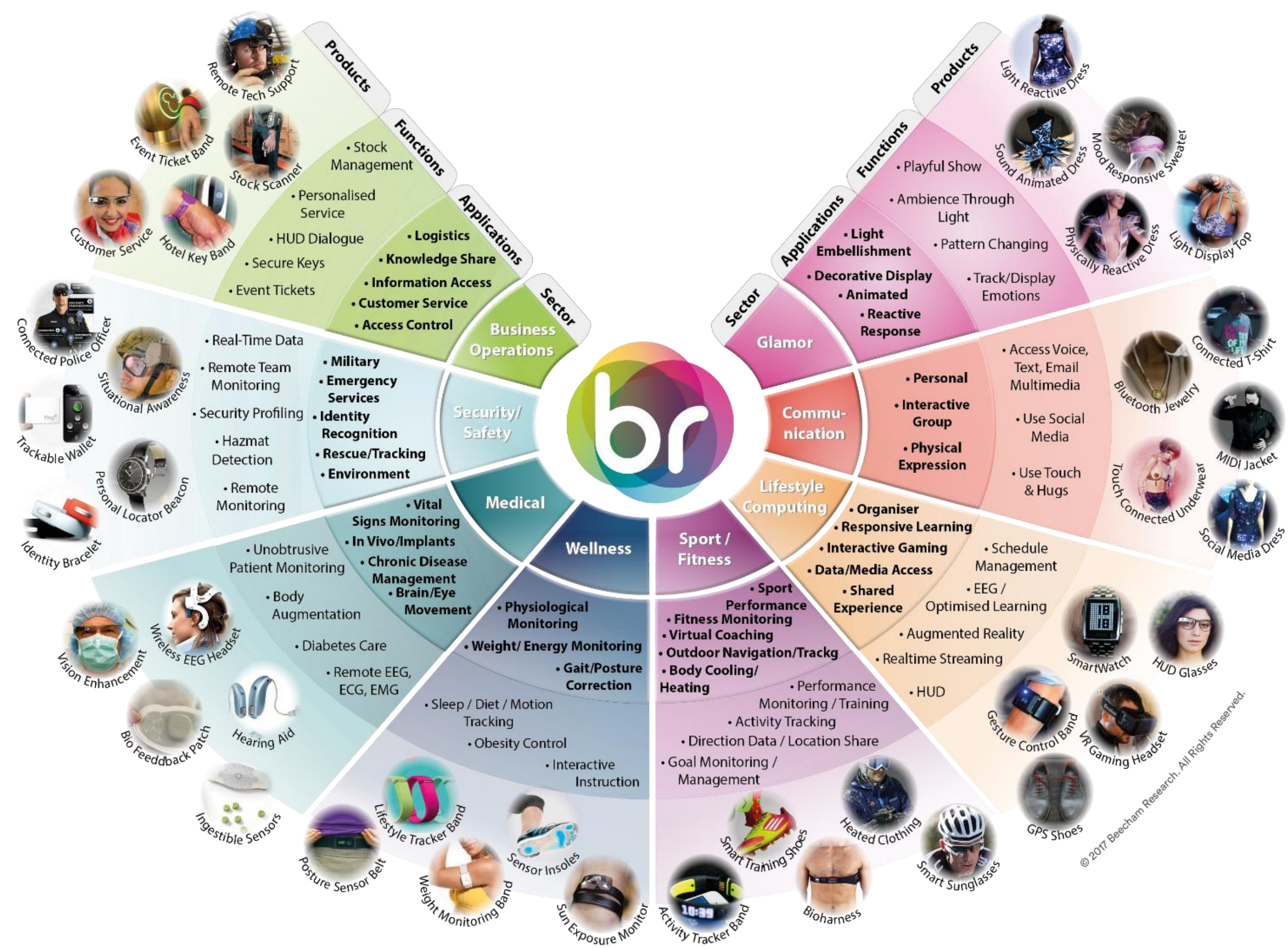
[55] Charge and discharge rates of a battery are governed by C-rates. The capacity of a battery is commonly rated at 1C, meaning that a fully charged battery rated at 1Ah should provide 1A for one hour. The same battery discharging at 0.5C should provide 500mA for two hours, and at 2C, it delivers 2A for 30 minutes. *See* Battery University. (2017). "BU-402: What is C-rate?" https://batteryuniversity.com/learn/article/what_is_the_c_rate

[56] *See supra fn* 12.

[57] *See* Hayward, J. (2018). "Wearable Technology 2018-2028: Markets, Players, Forecasts." *IDTechEx.* https://www.idtechex.com/research/reports/wearable-technology-2018-2028-markets-players-forecasts-000606.asp

Figure 13. Wearable Technology Applications



Source: Beecham Research.[58]

Figure 14 shows the likely market evolution for the flexible batteries that could power these wearable devices and the expected composition of form factors for this kind of bendable, stretchable, foldable and rollable energy storage. While this storage market segment is expected to experience substantial growth and reach $400 million in global sales by 2025,[59] one of the primary constraints in the wearables market is the pace of technology change for flexible, printed and thin film batteries.[60] New

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[58] Beecham Research Limited. (n.d.). "Wearable Technology Application Chart." http://www.beechamresearch.com/download.aspx?id=36

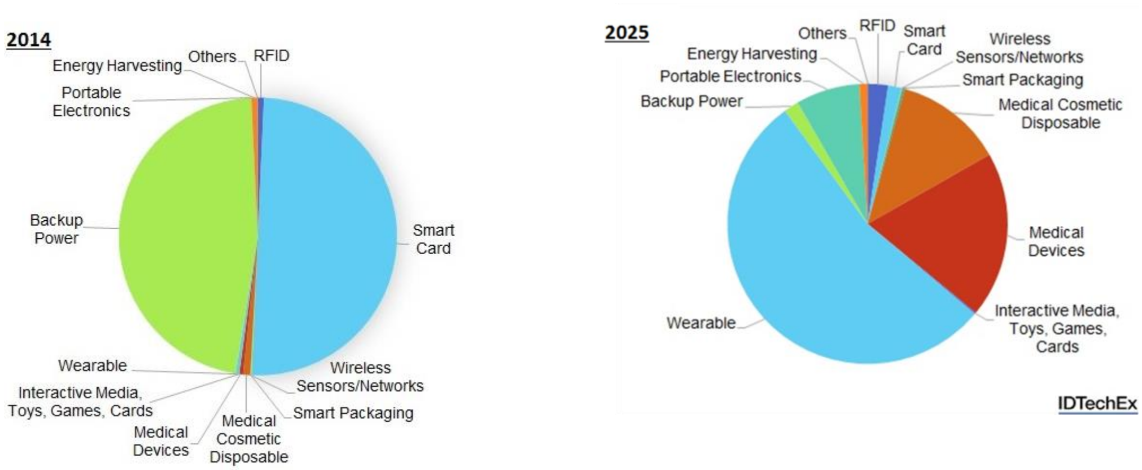
[59] Mulcare, J. (2015). "Flexible Battery Market to Increase to $400m by 2025." *Electronic Specifier.* https://www.electronicspecifier.com/around-the-industry/flexible-battery-market-to-increase-to-400m-by-2025

[60] He, X. (2018). "Flexible, Printed and Thin Film Batteries 2019-2029: Technologies, Markets, Players." *IDTechEx.* https://www.idtechex.com/research/reports/flexible-printed-and-thin-film-batteries-2019-2029-000634.asp

materials for electrodes and electrolytes, as well as new manufacturing methods including printing techniques, will have to be developed in order to provide the energy density, power and cycle life required for the wearable forms that consumers demand.[61]

While electrochemical battery technologies are the most commercially mature type of storage for meeting this demand, other storage technologies could provide opportunities for value-adding activities within this market space. Wearable woven supercapacitor fabrics with high energy density have been shown at the prototype demonstration stage (i.e., *TRL 6* according to NASA's technological readiness level system) to feature scalable fabrication, arbitrary form-factor designs, excellent flexibility and good mechanical stability as flexible power sources for wearable electronics.[62] Production costs for this kind of supercapacitor-based, fabric-like power source that can be cut, folded or stretched without losing its function are currently estimated at around $0.10 per square centimeter.[63]

Figure 14. Evolving Market Composition for Thin Film, Flexible and Printed Batteries



Source: IDTechEx Ltd.

4. Research Methodology and Literature

An energy storage roadmap for Northeast Ohio that identifies how local assets can be leveraged to capture maximum growth for the region requires that two questions be answered: 1) What are the

[61] *Id.*

[62] *See* Shen, C. et al. (2017). "Wearable Woven Supercapacitor Fabrics with High Energy Density and Load-bearing Capability." *Nature*. https://www.nature.com/articles/s41598-017-14854-3

[63] Nanyang Technological University. (2018). "Customizable, Fabric-like Power Source for Wearable Electronics." *ScienceDaily.* https://www.sciencedaily.com/releases/2018/01/180130094725.htm.

area's energy storage assets, and 2) what current trends and projected near- to mid-term future developments within the global market present opportunities that Northeast Ohio could capitalize on given these assets?

The first question was answered by compiling a list of local businesses and institutions found in Northeast Ohio that are engaged in energy storage technology development. The list of energy storage assets representing areas of strength for the region was compiled using a variety of third-party company databases and Team NEO partner lists. Databases used to assemble the asset list included Pitchbook, D&B Hoovers, Reference USA, Thomas Register, and the Ohio Manufacturers Directory. Among other search strategies, these databases were queried using the following codes under the North American Industrial Classification Systems (NAICS): 333613, Mechanical Power Transmission Equipment Manufacturing; 334419, Other Electronic Component Manufacturing; 335312, Motor and Generator Manufacturing; and 335911, Storage Battery Manufacturing.

Additionally, NASA Glenn Research Center had previously prepared an asset map of companies in Ohio to identify areas of high concentration of energy storage technology. Portions of NASA's asset map were incorporated into the asset list for the 2019 Roadmap. Final verification of this list was provided by an advisory committee that was tasked with providing market and technical guidance, connections to market participants, engagement during development of the work product, and a review of outcomes and recommendations.

The advisory committee was also consulted for opinions on likely near- to mid-term national and global trends.[64] Supplemental expertise on the current and projected future state of the market was gathered through a series of interviews with market participants and energy storage stakeholders, including, among others, those with GLX Power Systems, Eaton Corporation and Schneider Electric, as well as professors of electrical engineering and polymer sciences at the University of Akron. Publicly available research on emerging markets by firms such as Navigant, Greentech Media and IDTechEx, as well as reports from the national laboratories,[65] were also examined to identify potential opportunities in energy storage for Northeast Ohio.

[64] The study team would like to thank the following individuals for serving on the advisory committee (along with associated organizations in parentheses): Thomas Doehne (NASA), Ryan Franks (CSA Group), Jim Green (CSA Group), Grant Goodrich (Great Lakes Energy Institute at Case Western Reserve University), Kent Kristensen (GLX Power Systems), Dave Mayewski (Rockwell Automation), Rick Stockburger (Tech Belt Energy Innovation Center) and Don Wingate (Schneider Electric).

[65] In particular, Sandia National Laboratory, the National Renewable Energy Laboratory, and Idaho National Laboratory.

5. Sector Assets in Northeast Ohio and the Region's Competitive Position

Building upon the region's core strengths and established energy storage assets — i.e., the existing network of industry, academic, government and nonprofit stakeholders dedicated to building a regional energy storage ecosystem — Team NEO has led the creation of Northeast Ohio's Energy Storage Innovation Cluster.[66] This "center of gravity" is designed to attract new companies and investment into the energy storage cluster, and to provide a place where ideas, products, businesses and collaborations can grow.

5.1 Commercial Assets

Commercial assets are among those core assets, so it is appropriate to first look at the regional private-sector presence within energy storage. Following the 2011 Roadmap, we initially examined what were identified as *core* energy storage activities in the region. These activities, including both R&D and manufacturing, were defined as "core" due to the value they contribute to energy storage systems and how critical they are to making technologies work. Table 2 lists some of these core activities and materials for a sample of energy storage systems based on the classification of the asset inventory that was developed for the previous energy storage roadmap.[67]

Table 2. Core Activities and Materials for Energy Storage Systems

Energy Storage System	Core Materials
Li-ion cell	• cathode/anode • electrolyte • separator • packaging (cell, button, prismatic, or pouch)
Flywheel	• magnetic bearings • stator coil • enclosure • rotor assembly
Automotive and Non-Automotive Battery Pack	• battery management system control circuitry • busbar

[66] For more information on Team NEO's activities in support of Northeast Ohio's energy storage cluster, visit https://www.clevelandplus.com/teamneo/services/clusters/energy-storage/

[67] Team NEO maintains the asset list from the 2011 and the 2019 Roadmaps. Related questions should be directed to Team NEO's Energy Storage Innovation Cluster administrator.

The 2011 asset list was updated for 2019, and each private-sector firm on it was categorized according to the following dimensions:

- Number of employees
- Core vs. BOS (BOP)/PCS
- If core, which storage technology
- If BOP/PCS, what application area and subareas
- Place on the value chain (e.g., R&D, manufacturing, distribution and sales)

The number of employees for each local business establishment within energy storage was estimated using company profiles from third-party databases such as D&B Hoovers and Mergent Intellect. Categorization for the other three dimensions was based on a series of interviews with a number of the local companies, as well as industry experts, guidance from the advisory committee, direct email correspondence with local firms, examination of investor presentations and company websites, and internet searches for news on local energy storage businesses.[68]

Figure 15 shows the number of employees working for companies in each of the energy storage technologies in Northeast Ohio. There is some overlap in these numbers given that some companies are involved in more than one technology. Altogether, we estimated 36 unique companies and 1,063 employees currently involved in core energy storage in Northeast Ohio.[69] This represents a compound annual rate of growth in energy storage employment for the region over the past seven years of about 4.1%. For energy storage companies in Northeast Ohio with product lines in electrochemical technology, around 50% of employees work for firms focused on materials science and improving items such as electrodes and electrolytes. Another 25% do work related to battery management systems, and 20% are employed in battery cell or battery module production.

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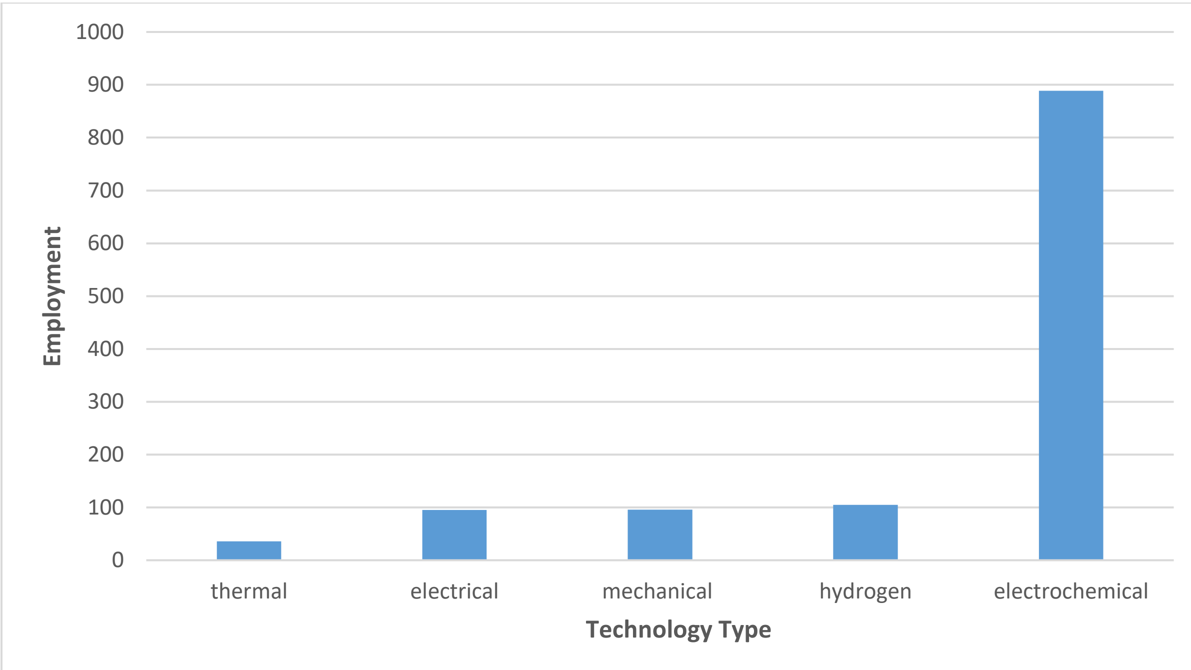
[68] *Id.*

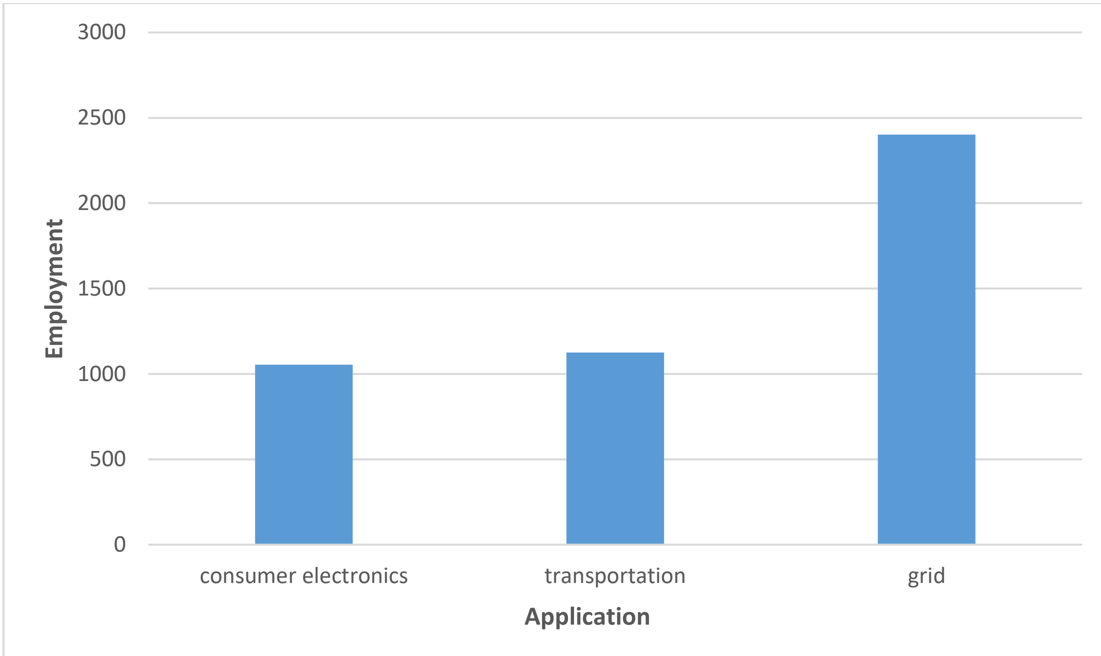
[69] Crowne Battery Corporation, located in Fremont, Ohio, was included in this analysis, even though Sandusky County is outside of the traditional Northeast Ohio county footprint. However, it was deemed to be close enough that it should be considered part of the Northeast Ohio energy storage cluster.

Figure 15. Employment for Core Energy Storage in NE Ohio



Employment in "non-core" energy storage activities is considerably greater. Approximately 2,850 workers are employed across 41 companies that produce components or subcomponents for energy storage BOP and PCS within the region. Figure 16 shows the number of employees working for companies in each of the energy storage applications in Northeast Ohio. Similar to core energy storage, there is overlap in what firms produce with regard to storage applications for BOP and PCS. Since the 2011 Roadmap did not identify non-core employment, we are unable to report the rate of growth for non-core activities here. However, given the relevance of non-core activities to the energy storage cluster, growth rates should be ascertained in a future study.

Figure 16. Employment for Combined Energy Storage
Balance of Plant and Power Conversion Systems in Northeast Ohio



The most active energy storage market segments for BOP and PCS in Northeast Ohio (22% of employees) are the production of either plastic or metal containers and housing for energy storage systems. An additional 15% of BOP- and PCS-related employees work in printed circuit board production, while another 15% produce flywheel BOP products such as motors, generators and associated coil wires. The printed circuit board's importance as the "heart" of a battery pack should not be understated,[70] as evidenced by its role in battery management for electric vehicles such as the Chevy Volt, seen in Figure 17.

[70] *See* AA Portable Power Corp. (n.d.). "PCM for LiCo/LiMnNi/LiNiCoMn Battery Packs." https://www.batteryspace.com/pcmforli-coli-mn-nibatterypacks.aspx

Figure 17. Chevy Volt Battery Management System

Source: EDN Network[71]

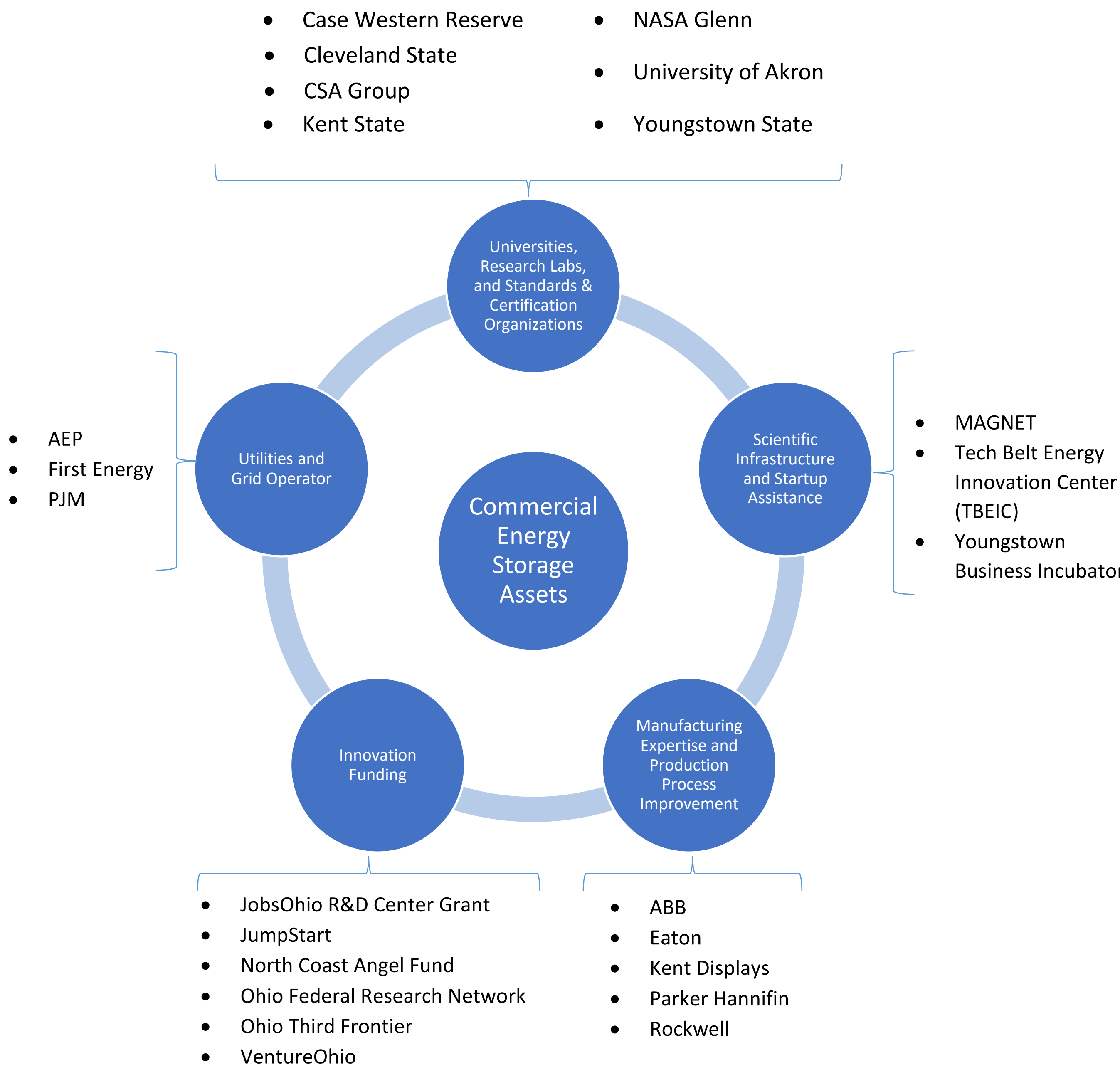
Expanding the scope of energy storage to include non-core activities risks diluting the understanding of the industry's economic impact in the region. However, given that so much of the work done in the U.S. energy storage industry today relates to applications and system integration, this appears to be an appropriate extension. In 2019, the Northeast Ohio Energy Storage Innovation Cluster is in large part driven by applications and system integrators.

5.2 Structural Assets

Northeast Ohio energy storage companies, whether core or BOP, do not exist within an ecological vacuum. Rather, they occupy a space within an ecology that is dedicated to more efficient management of energy generation and usage. This regional energy storage ecosystem, of which commercial assets are part, is represented below in Figure 18.

[71] *See* Evanczuk, S. (2012). "Teardown: High-voltage Li-ion battery stack management — the drive for safe power." *EDN Network.* https://www.edn.com/design/systems-design/4391497/Teardown--High-voltage-Li-ion-battery-stack-management---the-drive-for-safe-power

Figure 18. Structural Assets for Energy Storage in Northeast Ohio



5.2.1 Universities, Research Labs and Standards & Certification Organizations

The universities and research institutions within a geographic area together form a regional factor that is a cornerstone of cluster competitiveness, playing a key role in innovation-based economic development.[72] They collectively comprise an asset that increases the quality of both producers and inputs through the dissemination of knowledge and upgrade of human capital. This asset further promotes economic diversity by generating new opportunities out of the old.[73] Some of these sources of basic and applied research in Northeast Ohio are as follows:

- *Case Western Reserve University (CWRU).* CWRU's involvement in energy storage is a direct result of its legacy as a leading research institution in the fields of electrochemistry, materials science and polymers. University researchers are actively working on advanced flow batteries using non-hazardous electrolytes, new battery chemistries for higher power and energy density, novel electrodes, and structural batteries. Facilities within the Case School of Engineering specifically designed for energy storage research include the Case Electrochemical Capacitor Fabrication Facility, the Center for Dielectrics and Energy Storage, and the Electrochemical Engineering and Energy Laboratory.[74]

  CWRU is currently leading the $10.75 million Department of Energy-funded Energy Frontier Research Center on Breakthrough Electrolytes for Energy Storage (BEES).[75] BEES was established to help researchers develop an understanding of how the transport mechanism and electron transfer reactions occur in deep eutectic solvents and soft nanoparticle systems, and how they can be controlled to advance electrochemical performance.

  The Partnership for Research in Energy Storage and Integration for Defense and Space Exploration (PRESIDES) Center of Excellence, is one of six centers of excellence established by the Ohio General Assembly's Federal Research Network (FRN) to advance the commercialization of developing technology, with the focus of PRESIDES being on advanced energy storage solutions.

  PRESIDES is part of the Great Lakes Energy Institute (GLEI) at CWRU, the multimillion-dollar interdisciplinary research institute dedicated to translating research on energy generation, storage and distribution into the next generation of advanced energy technologies.[76] GLEI maintains active relationships with members of the energy industry across Northeast Ohio, and

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[72] *See* Wessner, C. W. (Ed.). (2013). *Best Practices in State and Regional Innovation Initiatives: Competing in the 21st Century*. Washington, DC: National Academies Press. https://www.nap.edu/catalog/18364/best-practices-in-state-and-regional-innovation-initiatives-competing-in

[73] *Id.*

[74] Case School of Engineering. (n.d.). "Facilities." http://energy.case.edu/Facilities

[75] Case School of Engineering. (n.d.). "Center for Breakthrough Electrolytes for Energy Storage (BEES)." http://engineering.case.edu/research/centers/breakthrough-electrolytes-for-energy-storage

[76] *See* Ohio Department of Higher Education. (n.d.). "Great Lakes Energy Institute: Case Western Reserve University." https://www.ohiohighered.org/coe/advanced-energy/cwru-glei

connects faculty to partnerships and funding opportunities. While CWRU does not have a specific energy-related degree program, GLEI offers a co-curricular *ThinkEnergy Fellows* program for CWRU graduate and undergraduate students, introducing them to career and research opportunities in the energy sector, and contributing to Northeast Ohio's educated workforce in energy.

- *Cleveland State University.* The Center for Rotating Machinery Dynamics Control (RoMaDyC) interacts with industry and the community to educate as well as to increase the productivity of advanced rotating machinery. It also performs research to provide technical innovations that solve complex problems in engineering systems involving rotor dynamics and vibration control through active magnetic bearings. Flywheel energy storage systems (FESS) require high rotational speed [77] for optimal energy storage, with magnetic bearings representing a fundamental technology for reducing friction and minimizing parasitic energy loss. Control of rotor dynamics is also achieved via magnetic fields of the bearings, to dampen vibrations that can otherwise lead to rotor failure.

  RoMaDyC's facilities include a rotor crack detection test rig; an active magnetic bearing test rig; a multipurpose rotor dynamic test rig; an MBC500R magnetic bearing system to explore advanced control strategies for AMB systems with flexible rotors, as well as disturbance rejection algorithms for rotating machinery; and various vibration analyzers, signal processing instruments and rotor dynamic simulation software that includes a magnetic bearing module to meet the demands of industrial magnetic bearing applications.[78]

- *CSA Group*. This global organization is dedicated to safety, social good and sustainability, and is a leader in safety and environmental certification around the world, including in Canada, the U.S, Europe and Asia. CSA Group's mandate is "to hold the future to a higher standard."[79] Its 54,000-square-foot, state-of-the-art Cleveland laboratory has comprehensive primary and secondary battery testing capabilities to help manufacturers produce safer, more reliable products that are compliant with all applicable safety, environmental and operating performance standards for markets around the world.[80]

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[77] Currently operational FESS grid storage systems operate at rotational speeds of greater than 10,000 RPM. *See* Tweed, K. (2015). "Quantum Energy Storage Redesigns the Flywheel for Microgrids." *Greentech Media.* https://www.greentechmedia.com/articles/read/quantum-energy-storage-redesigns-the-flywheel-for-microgrids#gs.L18eK73b

[78] *See* Cleveland State University Washkewicz College of Engineering. (2018). "Our Facilities." https://academic.csuohio.edu/romadyc/facilities/index.html

[79] *See* PR Newswire. (2018). "CSA Group Publishes New Bi-national Standard for Photovoltaic Module Testing." https://www.prnewswire.com/news-releases/csa-group-publishes-new-bi-national-standard-for-photovoltaic-module-testing-300769647.html

[80] *See* CSA Group. (n.d.). "About CSA Group." https://www.csagroup.org/about-csa-group. *See also* PR Newswire. (2015). "CSA Group Expands Cleveland Laboratory Adding New Services." https://www.prnewswire.com/news-releases/csa-group-expands-cleveland-laboratory-adding-new-services-506936151.html

- *Kent State University*. The Fuel Cell, Clean Energy and Sustainability Lab is focused on the research and development of fuel cell technologies, with capabilities in materials processing and fuel cell fabrication. The Fuel Cell Lab's current research includes anode materials development for improved performance, dip coating for the fabrication of dense electrolyte films and porous electrode layers, and manufacturing fuel cells using additive manufacturing techniques (i.e., 3D printing). Among other fabrication equipment, the Fuel Cell Lab's facilities include an EOS M100 industrial 3D printer for the production of complex metal parts.[81]

- *NASA Glenn Research Center (GRC)*. NASA Glenn's core energy storage expertise includes design, development and testing of Li-ion and "beyond Li-ion" batteries, proton exchange membrane (PEM), and solid oxide fuel cells, electrolysis systems and flywheels. GRC also integrates these technologies, as well as supercapacitors, into integrated systems to mature the technologies for final product development for ground testing, and aeronautics and space flight missions. There are several labs and facilities that support assembly, integration and testing of energy storage technologies, including space simulation chambers (thermal/vacuum), environmental test chambers, mechanical and structural performance test labs, a dry room for fabrication and assembly of battery cells, testing facilities for mid- and large-scale polymer electrolyte and solid oxide fuel cells, and a spin pit and air bearing rig to assess the rotor life cycle and qualification testing of a flywheel. GRC also performs research, development and testing of new materials that support the development of the energy storage technologies. Capabilities include specialized laboratories for synthesis, processing, fabrication and analysis of ceramic, metal and polymer materials, and individual components of fuel cells, supercapacitors and batteries.

  NASA Glenn employs multiple partnership mechanisms to achieve the greatest flexibility and ensure that its technologies, facilities and expertise are broadly available to the public, ensuring the greatest national benefit. Partnership opportunities include:

  - Access to NASA's growing portfolio of intellectual property
  - Access to world-class subject matter experts (SMEs)
  - Utilization of unique facilities and test services
  - Opportunities for joint research, development, test and evaluation efforts

- *University of Akron (UA)*. The Akron Functional Materials Center (AFMC) is an initiative designed to facilitate engagement with industrial partners where the ultimate objective is to accelerate research discoveries toward commercialization through projects in five industry-driven theme cluster areas, each of which has two regular faculty members dedicated to project coordination.[82] One of these theme areas is Energy & Electronics, where key aspects include:

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[81] *See* Kent State University College of Aeronautics and Engineering. (n.d.). "Fuel Cells, Clean Energy, and Sustainability." https://www.kent.edu/fuelcell

[82] *See* University of Akron. (n.d.). "Overview of the Akron Functional Materials Center (AFMC)." https://www.uakron.edu/afmc/

- Examining a variety of battery technologies (e.g., Li-ion, Li-air, Li-sulfur and Na-ion)
- Innovative processing for scalable fabrication of active materials for battery electrodes
- Expertise in ion-containing polymers

Faculty expertise in the Energy & Electronics theme extends from the design and synthesis of new materials to fundamental device characterization and long-term performance evaluation of materials. AFMC's capabilities within this theme include:

- Testing battery components (e.g., electrodes, separators, electrolytes and additives) as well as electrochemical characterization for evaluating the electrochemical properties of newly developed materials
- Novel routes to conductive coatings, both transparent and non-transparent
- Customized polymers for binders, separators and additives within a battery system, including nanocomposites with carbon nanotubes or graphene

Commercialization of energy storage technologies is further supported through the I-Corps Sites Program, which provides resources and support to develop the proof needed to transform UA technology into a validated prototype or process that can be licensed to a scalable startup company.[83]

- *Youngstown State University.* The Center for Innovative Additive Manufacturing (CIAM) advances research, education, workforce development and industry partnerships in the emerging field of 3D printing. CIAM has undertaken fabrication and performance analysis of 3D printed fuel cells. Current work includes the analysis of different binder concentrations and the performance of a fuel cell with varying porosity.

  CIAM also has membership access to nearby America Makes, the national accelerator for additive manufacturing and 3D printing, whose facilities include selective laser melting printing for metals, selective laser sintering of polymers and industrial-sized fused deposition modeling printing.[84] Such facilities could also be used to develop additive manufacturing methods for improving the core technology of other kinds of energy storage. New techniques for 3D printing porous electrodes, for example, have been shown to vastly improve the charge capacity and charge-discharge rates for lithium-ion batteries.[85]

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[83] *See* University of Akron Research Foundation. (n.d.). "I-Corps: NSF Innovation Corps." https://www.uakron.edu/research/icorps/

[84] *See* Youngstown State University. (n.d.). "Center for Innovation in Additive Manufacturing." https://ysu.edu/center-for-innovation-in-additive-manufacturing. *See also* https://www.americamakes.us/about/

[85] Carnegie Mellon University. (2018). "3D Printing the Next Generation of Batteries." *ScienceDaily*. https://www.sciencedaily.com/releases/2018/07/180730160351.htm

5.2.2 Innovation Funding

The investment of sustained funds — at the state and federal levels, as well as by entities such as banks, angel investors and venture capitalists — is essential for regional innovation initiatives to thrive.[86] Following are some of the funding sources that could be used to catalyze energy storage technology and cluster growth in Northeast Ohio.

- *The JobsOhio R&D Center Grant program* provides qualified companies with an incentive to establish new R&D centers in Ohio and position the state favorably to win production facilities after R&D products and services are commercialized. The R&D Center Grant program allows JobsOhio to make strategic investments in new R&D centers that support targeted industries, one of which is energy storage/fuel cells.[87]

- *JumpStart* deploys $40 million in pre-seed and seed venture capital to help entrepreneurs in Northeast Ohio turn innovative early-stage companies into successful, mature firms, with a particular focus on technology markets.[88]

- *North Coast Angel Fund (NCAF)* is a contributed capital and "sidecar" pre-seed investment fund with a focus on early-stage technology investments. Membership consists of more than 180 of the region's leading investors, entrepreneurs and business leaders. NCAF was Northeast Ohio's first professionally managed angel fund and to date has invested $30 million in 40 portfolio companies.[89]

- *Ohio Federal Research Network (OFRN)* organizes and provides resources for collaborative research initiatives within the University System of Ohio that align with and support priority mission requirements at Ohio's federal labs (e.g., NASA Glenn, Air Force Research Lab [AFRL]) to grow the existing research talent base. Focus areas include energy storage, attracting outside public and private investment, and retaining and creating new jobs. [90] Central to this mission are the Centers of Excellence (CoE), such as Case Western's PRESIDES CoE, which continue to receive funding for aligned research projects with high commercialization potential. PRESIDES most recently was awarded $1.65 million by OFRN, along with additional matching funds from industry

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[86] *See supra fn* 72.

[87] JobsOhio. (n.d.). "R&D Center Grant: Funding the Innovation and Commercialization You Need to Make a Home in Ohio." https://www.jobsohio.com/about-jobsohio/services-programs/research-development-grant/

[88] JumpStart considers fuel cells and energy storage as qualifying "technology" markets. *See* JumpStart Inc. (2018). "JumpStart Investment Funds Overview and FAQ." https://www.jumpstartinc.org/wp-content/uploads/2018/03/JumpStart-Fund-Overview.pdf

[89] *See* North Coast Angel Fund homepage at https://www.northcoastangelfund.com. *See also* JumpStart Inc. (n.d.). "North Coast Angel Fund." https://www.jumpstartinc.org/funder/north-coast-angel-fund/

[90] Ohio Department of Higher Education. (2017). "I-Corps@Ohio Partners with the Ohio Federal Research Network: Announces Teams for Pilot Program to Accelerate Ohio Technologies to Market." https://icorpsohio.org/wp-content/uploads/2017/01/OFRN-Announcement-2.0.pdf

partners, to research and develop energy storage resources for defense and aerospace technological needs.[91]

- *NASA*, like other federal agencies, has funding available for technology research and development programs for small businesses and research institutions, including colleges and universities. The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs fund the research, development and demonstration of innovative technologies that have significant potential for successful commercialization or infusion into a NASA mission. The SBIR and STTR programs are potential sources of seed funding for small businesses with 500 or fewer employees as well as for nonprofit research institutions tied to a small business of this size.[92] The amount and duration of this potential funding includes:

  - SBIR Phase I contracts lasting six months and STTR Phase I contracts lasting 13 months, both with maximum funding of $125,000
  - Phase II contracts lasting 24 months with maximum funding of $750,000
  - Phase III contracts for the commercialization of innovative technologies, products and services resulting from either a Phase I or Phase II contract. Phase III contracts are funded from sources other than the SBIR and STTR programs. There is no limit on the number, duration, type or dollar value of Phase III awards made to a business concern. The small business size limits for Phase I and Phase II awards do not apply to Phase III awards.[93]

- *Ohio Third Frontier* is a $2.3 billion initiative funded by voter-approved, state-backed bond sales that supports applied research and commercialization, entrepreneurial assistance, early-stage capital formation and skilled technical workforce development that can support technology-based economic growth. Among the portfolio of programs supported by Ohio Third Frontier, energy storage is a preferred area within Advanced Energy.[94] Funds available for value chain development, commercial acceleration and venture loans, entrepreneurial services, and talent development and attraction are intended to create an ecosystem that supports the efficient and seamless transition of innovative ideas from the laboratory to the marketplace.[95]

- *VentureOhio* is a nonprofit entrepreneurial facilitator that works to increase access to capital by fostering interaction and engagement between early-stage companies and private equity.

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[91] Wright Patterson Air Force Base. (2017). "Ohio Federal and Military Jobs Commission Support: Ohio Federal Research Network — Improving Ohio's Economy Through R&D." https://www.wpafb.af.mil/Portals/60/documents/afrl/Ohio_Federal_Research_Network_HughBolton.pdf

[92] *See* NASA. (n.d.). "NASA SBIR/STTR Basics." https://sbir.nasa.gov/content/nasa-sbirsttr-basics

[93] *Id.*

[94] The Ohio Manufacturers' Association. (n.d.). "Ohio Third Frontier Program." http://www.ohiomfg.com/grip-assets/resource_library/tax_management/ohio_third_frontier_program_overview.pdf

[95] *Id*.

VentureOhio advocates on behalf of promising Ohio startups to increase their visibility and attract investment. Its membership includes more than 25 angel investors and venture capital funds.[96]

5.2.3 Scientific Infrastructure and Startup Assistance

Scientific infrastructure and knowledge-based entrepreneurship play a key role in developing local innovation clusters.[97] Along these lines, the following are resources in Northeast Ohio that can support entrepreneurs in successfully bringing energy storage products to market:

- *Manufacturing Advocacy and Growth Network (MAGNET)*, part of the Ohio Manufacturing Extension Partnership, is a nonprofit with offices in Cleveland and Akron that offers consulting services to small and mid-size manufacturers to help them improve:

    - Sales and marketing
    - Product design and development
    - Cybersecurity
    - Process innovation
    - Product quality
    - Workforce engagement and operations

    MAGNET also offers incubation services to help startups:

    - Build a working prototype
    - Construct a persuasive pitch
    - Create a data-driven financial model
    - Develop a manufacturing process
    - Design a go-to-market plan[98]

- *Tech Belt Energy Innovation Center (TBEIC)*, located in Warren, Ohio, is an energy incubator that can help energy storage startups and organizations with new products navigate from innovation to commercialization. TBEIC's services include an Entrepreneur-in-Residence program that connects client companies to mentors with industry expertise and fundraising experience, as well as offering coworking space, private office space and access to conference rooms.[99]

    TBEIC's facilities also include an Energy Innovation Lab, which provides access to specialized, state-of-the-art equipment, including a grid simulator that enables companies to test a power

[96] *See* VentureOhio homepage at https://ventureohio.org
[97] *See supra fn* 72.
[98] *See* MAGNET homepage at https://www.manufacturingsuccess.org
[99] *See* TBEIC. (n.d.). "Facilities & Programs." https://www.tbeic.org/facilities-and-programs

source and simulate how it would react in a variety of scenarios, including blackouts, brownouts and lightning strikes.[100] The lab also maintains a fleet of battery testing devices that enable businesses to test batteries in several different ways, including predicting the life cycle of a battery and testing its capacity. Current tenant MegaJoule Storage Inc., a developer of lead-acid batteries and electrochemical capacitors for grid storage, describes how TBEIC "understands the needs of energy startup companies," in terms of both acquiring funding and business-to-business networking.[101]

- *Youngstown Business Incubator's* campus is home to the previously mentioned America Makes National Additive Manufacturing Innovation Institute, the nation's leading and collaborative partner in advanced manufacturing and 3D printing technology research, discovery, creation and innovation.[102] Experts in mechanical engineering and advanced manufacturing describe how additive manufacturing "will lead to a revolution in the way energy storage components are designed, integrated and utilized in electronic devices."[103]

  The Youngstown Business Incubator also offers entrepreneurial support services, including market validation studies and subsidized student workers through Youngstown State University.[104]

5.2.4 Manufacturing Expertise and Production Process Improvement

For energy storage companies to lower their prices while sustaining their margins and increasing market share, employing economies of scale and introducing novel products to the market are not likely to be enough. Boston Consulting Group describes how the most effective way for energy storage manufacturers to be cost-competitive in a challenging market is to improve operational performance.[105] For energy storage producers to achieve operational excellence, they must implement "Industry 4.0" technologies and processes.[106]

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[100] Kromer, C. (2018). "TBEIC to Unveil Energy Lab." *Tribune Chronicle.* http://www.tribtoday.com/news/local-news/2018/10/tbeic-to-unveil-energy-lab
[101] Nelson, G. (2018). "As TBEIC Grows, So Does Its Mission." *The Business Journal.* https://businessjournaldaily.com/as-tbeic-grows-so-does-its-mission/
[102] Youngstown Business Incubator. (n.d.). "America Makes Youngstown — The Hub of Additive Manufacturing." https://ybi.org/america-makes/
[103] Cobb, C., and Ho, C. (2016). "Additive Manufacturing: Rethinking Battery Design." *Electrochemical Society Interface.* https://www.researchgate.net/publication/303532082_Additive_Manufacturing_Rethinking_Battery_Design
[104] Youngstown Business Incubator. (n.d.). "YBI Entrepreneur Education & Training." https://ybi.org/programs/
[105] Kupper, D. et al. (2018). "The Future of Battery Production for Electric Vehicles." https://www.bcg.com/en-us/publications/2018/future-battery-production-electric-vehicles.aspx
[106] *Id.*

Industry 4.0, synonymous with the "Industrial Internet of Things" (IIoT), stands for the "fourth industrial revolution." PricewaterhouseCoopers describes it thusly: "While Industry 3.0 focused on the automation of single machines and processes, Industry 4.0 focuses on the end-to-end digitization of all physical assets and integration into digital ecosystems with value chain partners."[107] The value proposition of Industry 4.0 lies in its ability to effectively integrate flows of digital information from many different sources and locations that can drive the physical act of doing business.[108] Figure 19 illustrates this iterative physical-to-digital-to-physical process that will drive customer value creation while improving process efficiency and productivity in smart factories that implement Industry 4.0.[109] This digitization of the entire supply chain is expected to increase annual revenues by 2.9% while reducing costs by 3.6% on average for manufacturers across all industries by the early 2020s.[110]

An advantage for energy storage companies looking to implement Industry 4.0 solutions in Northeast Ohio is the significant presence of companies that are global players in developing smarter manufacturing — e.g., ABB, Eaton, Parker Hannifin, and Rockwell. Their products and platforms facilitate the integration of information and operational technologies across an enterprise's entire value chain, leading to enhanced value creation through intelligent, self-optimizing and autonomous processes.[111] Additionally, Team NEO offers a complimentary IIoT readiness assessment that companies can use to evaluate their readiness for Industry 4.0 implementation.[112] Team NEO has recently published a roadmap for IIoT cluster development that sets forth in detail the opportunities for that industry in Northeast Ohio.[113]

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[107] PricewaterhouseCoopers. (2016). "Industry 4.0: Building the Digital Enterprise." https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf

[108] Deloitte. (2018). "On the Board's Agenda: The Dawn of Industry 4.0." *Risk & Compliance Journal* (The Wall Street Journal). https://deloitte.wsj.com/riskandcompliance/2018/07/11/on-the-boards-agenda-the-dawn-of-industry-4-0/

[109] *Id*. *See also* Singla, V. (n.d.). "Industry 4.0 is Key to Modernise Business and Increase Competitiveness." *Oracle UK*. https://www.oracle.com/uk/industries/features/modernise-business/

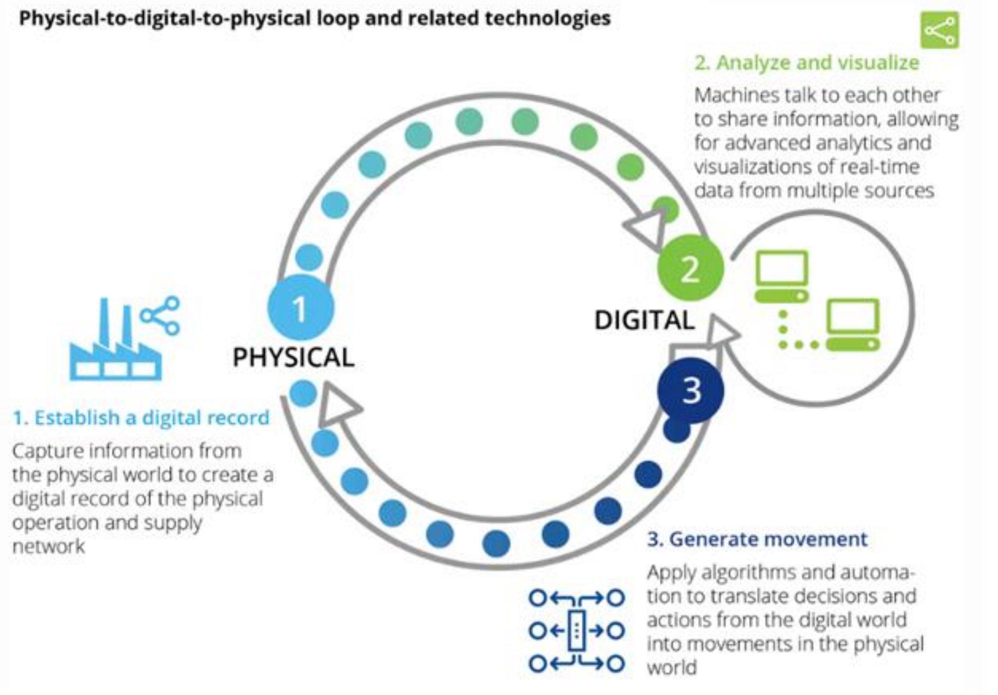
[110] *Supra fn* 106.

[111] Examples include ABB's Ability™, Eaton's Smart Factory solution, Parker Hannifin's Voice of the Machine platform, and Rockwell's Connected Enterprise.

[112] *See* Team NEO. (n.d.). "IIoT Readiness Assessment." https://www.clevelandplus.com/teamneo/iiot-readiness-assessment/

[113] Team NEO. (2018). "Smart Manufacturing: Industrial Internet of Things (IIoT) Roadmap for Northeast Ohio (Executive Summary)." https://drive.google.com/file/d/1nQ-hl5-vLdx2lQyMpWoQu3qTdhdnTxhU/view. *See also*: McCafferty, R. (2018). "Team NEO Releases New 'Roadmap' on the Industrial Internet of Things." *Crain's Cleveland Business*. https://www.crainscleveland.com/manufacturing/team-neo-releases-new-roadmap-industrial-internet-things.

Figure 19. How Industry 4.0 Works



Source: Deloitte Center for Integrated Research/Deloitte Insights. Copyright © 2018 Deloitte Development LLC. All rights reserved.

While Kent Displays might not be considered to be an "energy storage" company, it does have expertise in roll-to-roll manufacturing, which is likely to play a significant role in future energy storage system manufacturing. The company has installed the world's first roll-to-roll line for mass-producing flexible plastic liquid crystal display (LCD) material.[114] Besides flexible displays, this printing-like process can be used to produce advanced batteries, fuel cells and supercapacitors.[115] A technology assessment by the U.S. Department of Energy suggests that the successful application of roll-to-roll processing to these energy storage technologies would result in dramatic cost reductions.[116] A local company with knowledge and experience in this manufacturing process could engender cluster-enhancing knowledge spillover effects for energy storage.

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[114] Mezger, R. (2008). "Kent Displays is on a Roll with New LCD Process." *Cleveland.com.* http://blog.cleveland.com/business/2008/10/kent_displays_is_on_a_roll_wit.html

[115] Belharouak, I. (n.d.). "Advancing Battery and Energy Storage Research." *Oak Ridge National Laboratory.* https://www.ornl.gov/division/etsd/rtr

[116] U.S. Department of Energy. (2016). "Quadrennial Technology Review 2015: Innovating Clean Energy Technologies in Advanced Manufacturing — Technology Assessments." https://www.energy.gov/sites/prod/files/2016/02/f30/QTR2015-6K-Roll-to-Roll-Processing.pdf

5.3 Assessing Northeast Ohio's Competitive Position

A central issue to cluster development is a region's *capacity* for innovation.[117] Human capital plays a central role in determining this innovation capability.[118] Firms are increasingly viewing skilled labor as the crucial *natural resource* of sorts that drives their competitiveness. As *The Wall Street Journal* put it, "Fifty years ago, companies opened new locations to be near lumber, copper or resources needed for their business. Today, people are the resources." [119] Indeed, the availability of skilled labor as a site selection factor is essentially *as* important as the cost of labor among company executives across all industries, according to surveying performed by the corporate site selection publication *Area Development*.[120]

We sought to determine Northeast Ohio's competitive position in terms of its capacity to attract skilled labor relevant to energy storage compared with other areas that are considered hubs within the emerging energy storage industry. According to the energy industry press, the following regions have been identified as being where "the energy storage industry is happening now": [121]

- San Francisco, CA, is home to multiple companies focused on grid storage, including Primus Power, a maker of flow batteries, and startups such as Advanced Microgrid Solutions, Stem, and Green Charge networks, which are working on using lithium-ion batteries for grid storage solutions. The region is home to three national laboratories: Lawrence Berkeley, Lawrence Livermore and the SLAC National Accelerator.
- Reno, NV, is the location for Tesla's Gigafactory 1, where 20GWh of lithium-ion battery production for transportation and grid energy storage occurs annually through a partnership with Panasonic.

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[117] European Commission of the European Union. (2016). "Clusters and Workforce Development (Discussion Paper)."
https://www.clustercollaboration.eu/sites/default/files/eu_initiatives/discussion_paper_skills_development.pdf
[118] *Id.*
[119] Weber, L. (2016). "Companies Flock to Cities with Top Talent." *The Wall Street Journal.*
https://www.wsj.com/articles/companies-flock-to-cities-with-top-talent-1460482766
[120] *See* Gambale, G. (Ed.). (2018). "32nd Annual Corporate Survey & the 14th Annual Consultants Survey." *Area Development.* https://www.ncleg.gov/DocumentSites/Committees/JLEDGEOC/2017-2018/Meetings/2018-04-05%20EDPNC%20Annual%20Report,%20Chambers,%20Rural%20ED,%20Deographic%20Trends/003_EDPNC_2018_Corporate_Survey_2018-04-05.pdf
[121] Ferris, D. (2017). "Where the Energy Storage Industry is Happening Now." *E&E News*.
https://www.eenews.net/stories/1060052447. New York State was also listed as an area, but we determined that this was more prospective than "now." Clearly, however, portions of that state will emerge as a hub for storage technology. Note also that in the 2011 Roadmap, three areas were considered as in competition: Holland, MI; Reading, PA; and Northeast Ohio. Neither Reading nor Northeast Ohio are on the list identified by *E&E News*.

- Holland, MI, is where LG Chem and Johnson Controls produce more than 3 GWh of transportation energy storage per year for automotive manufacturers including GM and Ford.
- Detroit, MI, and the surrounding area are home to primarily transportation energy storage, where the likes of Ford and GM have large battery pack assembly plants. Also, the University of Michigan Battery Lab is nearby.
- Charlotte, NC, where companies such as Celgard, Parker Hannifin, Alevo, SGL, FMC Lithium and the German conglomerate Saft either supply parts and materials for, or are integrators of, lithium-ion batteries, especially for grid storage. Also, ABB has an energy storage research center in this region.

To measure how competitive Northeast Ohio is in possessing the human capital required to drive an energy storage cluster, we compared location quotients (LQs) for a selection of engineering occupations in the Cleveland and Akron metropolitan statistical areas (MSAs) to LQs for the same occupations in the MSAs corresponding to the energy storage hub regions.[122] LQs measure the relative concentration of an occupation in a given place, with the United States being the basis of comparison in this instance, and can be used to identify regional specialization in an area. A general rule of thumb is that an LQ of 1.2 indicates specialization.[123] Tables 3 through 7 show the LQs for engineering occupations in Northeast Ohio compared with LQs for the areas identified by *E&E News* as energy storage hubs.[124]

[122] Bureau of Labor Statistics data used for this analysis was not available for Holland, MI. Data for Grand Rapids, MI, the nearest MSA, was used instead.
[123] Nolan, C. (n.d.). "Occupation Clusters." *Indiana Business Research Center at Indiana University Kelley School of Business.* http://www.incontext.indiana.edu/2010/jan-feb/article3.asp
[124] Bureau of Labor Statistics. (2018). "Occupational Employment Statistics." https://www.bls.gov/oes/current/oessrcma.htm

Table 3. LQs for Chemical Engineers

Area Name	Occupation	LQ
Cleveland, OH	Chemical Engineers	1.64
Akron, OH	Chemical Engineers	1.31
San Francisco, CA	Chemical Engineers	0.96
Detroit, MI	Chemical Engineers	0.62
Grand Rapids, MI	Chemical Engineers	0.62
Charlotte, NC	Chemical Engineers	0.52
Reno, NV	Chemical Engineers	N/A

Table 4. LQs for Electrical Engineers

Area Name	Occupation	LQ
Detroit, MI	Electrical Engineers	2.69
Akron, OH	Electrical Engineers	1.95
Grand Rapids, MI	Electrical Engineers	1.30
San Francisco, CA	Electrical Engineers	1.21
Charlotte, NC	Electrical Engineers	0.93
Cleveland, OH	Electrical Engineers	0.93
Reno, NV	Electrical Engineers	0.55

Table 5. LQs for Materials Engineers

Area Name	Occupation	LQ
Akron, OH	Materials Engineers	2.36
Cleveland, OH	Materials Engineers	1.48
Detroit, MI	Materials Engineers	1.32
Grand Rapids, MI	Materials Engineers	1.18
San Francisco, CA	Materials Scientist[125]	1.05
Charlotte, NC	Materials Engineers	0.53
Reno, NV	Materials Engineers	N/A

Table 6. LQs for Industrial Engineers

Area Name	Occupation	LQ
Detroit, MI	Industrial Engineers	3.99
Grand Rapids, MI	Industrial Engineers	3.29
Cleveland, OH	Industrial Engineers	1.39
Akron, OH	Industrial Engineers	1.28
Charlotte, NC	Industrial Engineers	1.02
San Francisco, CA	Industrial Engineers	0.45
Reno, NV	Industrial Engineers	0.43

Table 7. LQs for Mechanical Engineers

Area Name	Occupation	LQ
Detroit, MI	Mechanical Engineers	7.42
Grand Rapids, MI	Mechanical Engineers	3.32
Akron, OH	Mechanical Engineers	1.29
Cleveland, OH	Mechanical Engineers	1.16
Charlotte, NC	Mechanical Engineers	0.99
Reno, NV	Mechanical Engineers	0.70
San Francisco, CA	Mechanical Engineers	0.45

From the above tables, we see that Northeast Ohio has the highest occupational concentration of chemical and materials engineers among the regions analyzed. For industrial and mechanical engineers, LQs approaching or greater than 1.2 for both Cleveland and Akron MSAs indicate regional specialization, though not quite as high an occupational concentration as for chemical and materials

[125] Materials scientists and materials engineers have similar training and perform similar tasks. *See* Study.com (n.d.). “Difference Between Material Science & Material Engineering." https://study.com/articles/difference_between_material_science_material_engineering.html

engineers. Electrical engineers are highly concentrated over a smaller part of Northeast Ohio compared with the other occupations.

Northeast Ohio’s ability to attract additional skilled labor to further strengthen its position in developing a storage cluster depends on several factors, the most important of which is the cost of living. The economic development firm Development Counsellors International (DCI) found, in a survey accompanying its *Talent Wars* brief on what people look for in jobs and locations, that cost of living was the most important factor for relocation decisions.[126] DCI reported, "Even locations with the highest salaries (e.g., Seattle) are losing talent because sky-high rents are outpacing paychecks."[127]

To better understand Northeast Ohio’s cost of living in comparison with the energy storage hub regions, we gathered Bureau of Economic Analysis data on Regional Price Parity (RPP) data for the corresponding MSAs. Regional price parities give a sense of how much higher or lower effective prices are in an area relative to the nation overall as well as between cities.[128] RPPs are determined by the average prices paid by consumers for a mix of goods and services (including housing) consumed in each region. Since RPPs are constructed as indices, with the national average set at 100, they allow for easy comparison of prices between a given area and the nation overall. As seen in Table 8, the RPP index suggests that Northeast Ohio has the lowest cost of living among the regions that were examined.

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[126] Development Counsellors International. (2017). “Talent Wars: What People Look for in Jobs and Locations.” https://aboutdci.com/wp-content/uploads/2017/03/TalentWars2017.pdf

[127] Handy, E. (2018). “How Cost of Living Affects Talent Attraction.” *Livability Media.* https://livability.com/topics/business/how-cost-of-living-affects-talent-attraction

[128] Sen, E., and Scavette, A. (2017). “Regional Spotlight: Purchasing Power Across the U.S.” *Federal Reserve Bank of Philadelphia.* https://www.philadelphiafed.org/-/media/research-and-data/publications/economic-insights/2017/q4/rs_purchasing-power.pdf?la=en

Table 8. Cost of Living by Metro Area

Area Name	Price of Goods, Services and Housing Compared to National Average
Akron, OH	10% lower
Cleveland, OH	9.8% lower
Charlotte, NC	6.5% lower
Grand Rapids, MI[129]	6.5% lower
Detroit, MI	4.1% lower
Reno, NV	1.3% lower
San Francisco, CA	24.7% higher

Source: Bureau of Economic Analysis[130]

6. Market Opportunities for Northeast Ohio Businesses

Harvard Business School's Clayton Christenson describes how companies wanting to build new growth are most successful in doing so through *disruptive innovations* rather than through incremental refinements of established products.[131] These kinds of innovations help "create a new market and value network" that disrupts the status quo.[132] Disruptive innovation can also spur growth within regional economies, often led by regional innovation clusters.[133] The academic literature on the subject also describes how disruptive technological life cycles can "initiate the emergence of new regional industrial clusters or create opportunities for further development of existing ones."[134]

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[129] Bureau of Economic Analysis data used for this analysis was not available for Holland, MI. Data for Grand Rapids, MI, the nearest MSA, was used instead.

[130] Based on the Bureau of Economic Analysis' most recent index of Regional Price Parities by Metro Area. *See* Bureau of Economic Analysis. (2018). "Regional Price Parities by State and Metro Area." https://www.bea.gov/data/prices-inflation/regional-price-parities-state-and-metro-area

[131] Christensen, C., Raynor, M., and Anthony, S. (2003). "Six Keys to Building New Markets by Unleashing Disruptive Innovation." *Harvard Business School.* https://hbswk.hbs.edu/item/six-keys-to-building-new-markets-by-unleashing-disruptive-innovation

[132] Christensen, C. (2013). "Disruptive Innovation." Chapter in *The Encyclopedia of Human-Computer Interaction, 2nd Ed.* https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/disruptive-innovation

[133] *See* National Academy of Sciences. (2012). "Clusters and Regional Initiatives." https://www.ncbi.nlm.nih.gov/books/NBK100322. *See also* National Academies of Sciences. (2012). "Overview: The New Federal Role in Innovation Clusters." https://www.nap.edu/read/13249/chapter/3#16

[134] Dalum, B. et al. (2005). "Technological Life-Cycles: Lessons from a Cluster Facing Disruption." *European Urban and Regional Studies.* https://journals.sagepub.com/doi/abs/10.1177/0969776405056594

Christenson identified companies that are disruptively innovative by comparing the compound annual growth rate (CAGR) of their stock's investment return with the CAGR of stocks for incumbent companies.[135] He found that financial return growth rates for disruptive companies are appreciably greater than for incumbent companies.[136] We accordingly identified innovative energy storage technologies based on the average forecast of their market's CAGR relative to the incumbent energy storage technology's average market CAGR, as predicted by a variety of market research firms. Lithium-ion was treated as the incumbent technology and used as the basis for comparison given its characterization by the MIT Energy Initiative as the "market leader in energy storage."[137] We similarly identified as potentially disruptive those energy storage technologies that have predictable, medium-term market CAGRs that are higher than that forecasted for lithium-ion batteries (*see* Table 9).

Table 9. Potentially Disruptive Energy Storage Technologies Represented in Northeast Ohio

Energy Storage Technology	CAGR Forecast (through 2026)	Market Size Forecast (in billions by 2026)	Representative Northeast Ohio Assets
Solid-state Batteries	63.1%	$1.5	University of Akron; Akron PolyEnergy
Graphene	36.9%	$0.6	NeoGraf Solutions[138]
Supercapacitors	21.0%	$5.0	Gotion; PolymerPlus LLC
Silicon-based Batteries	29.4%	$0.9	Case Western Reserve University (CWRU); NASA
Fuel Cell (hydrogen)	19.6%	$14.3	CWRU; Kent State University; Yanhai Power LLC
Flow Battery	30.5%	$1.0	CWRU; Coventya, Inc.
Flexible, Printed & Thin Film Batteries	34.8%	$1.6	Blue Spark
Lithium-ion Batteries	*16.3%*	*$99.3*	*(incumbent technology)*

This is not to say that Northeast Ohio lacks the capability to be competitive in the anticipated near-term $100 billion market for lithium-ion energy storage. While East Asia has hosted more than 80%

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135 *Incumbent* companies supply established products to the market.

136 Feinzaig, L. (2008). "Investing in Disruptive Innovation." *Forbes.* https://www.forbes.com/2008/08/12/google-digitalequipment-disruption_leadership_clayton_in_lz_0813claytonchristensen_inl.html#298dff94272d

137 Maloney, P. (2018). Lithium-Ion Domination Could Block Promising Storage Technologies, MIT Finds." *Utility Dive.* https://www.utilitydive.com/news/lithium-ion-domination-could-block-promising-storage-technologies-mit-find/522536/

138 While NeoGraf does not currently produce graphene, instead focusing mainly on graphite, they do hold a patent related to graphene production and employ scientific staff with expertise in graphene.

of the manufacturing capacity for core lithium-ion materials across all applications,[139] the demand for increased energy density, power density and cycle life will present opportunities for Northeast Ohio to capture a larger share of the market by leveraging its existing *advanced* lithium-ion assets.

The market research firm IDTechEx summarizes how some of the more critical materials that will go into the next generation of lithium-ion technologies include silicon, polymer electrolytes and graphene,[140] all of which are represented in Table 9 of potentially disruptive energy storage technologies found in Northeast Ohio.[141] These disruptive energy storage technologies would therefore not necessarily supplant the incumbent lithium-ion technology, but rather could serve as important complements that enable a shift in added value away from areas such as Japan, China and South Korea that currently dominate the market.

The nickel-manganese-cobalt (NMC) blended cathode is another material expected to drive the growth of advanced lithium-ion technologies.[142] Developed by Argonne National Laboratory, NMC is considered a major leap in lithium-ion technology and has become a prominent cathode material in the transportation market due to its higher energy storage capacity and improved safety compared to conventional cathode material.[143] BASF is one of only four companies licensed to produce NMC; it does so at its 70,000-square-foot plant in Elyria, Ohio.[144]

7. Framework to Capture Market Share

7.1 Cluster Development Frameworks

Technology innovation has a disproportionately powerful impact on job creation. Accordingly, Northeast Ohio's ability to capture its share of the developing energy storage market is important. Experts estimate that for each new high-tech job created, five additional jobs are created outside the high-tech sector.[145] Technology innovation has the largest multiplier of all industries — three times

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[139] Chung, D. et al. (2016). Automotive Lithium-ion Cell Manufacturing: Regional Cost Structures and Supply Chain Considerations." *National Renewable Energy Laboratory*. https://www.nrel.gov/docs/fy16osti/66086.pdf

[140] *See* Grande, L., and He, X. (2018). "Advanced Li-Ion & Beyond Li-Ion Batteries 2018-2018 (webinar slides)." *IDTechEx.* https://www.idtechex.com/research/reports/advanced-li-ion-and-beyond-li-ion-batteries-2018-2028-000566.asp

[141] The solid-state batteries being developed locally incorporate polymer electrolytes.

[142] *Supra fn* 136.

[143] Argonne National Laboratory. (n.d.). "Argonne's NMC Cathode." https://access.anl.gov/projects/nmc/

[144] *Id. See also* Remington, K. (2012). "BASF Unveils New Plant for Lithium-Ion Battery Material in Elyria." *The Morning Journal.* https://www.morningjournal.com/news/basf-unveils-new-plant-for-lithium-ion-battery-material-in/article_fa848ff3-7cf2-52a3-b455-77fb5bb372ee.html

[145] Moretti, E. (2012). *The New Geography of Jobs. Moretti, E. (2012). The New Geography of Jobs.* Houghton Mifflin Harcourt: New York, NY.

higher than manufacturing. Further, high-tech jobs offer higher salaries. It is not surprising, then, that state economic development groups invest significant resources into technology innovation clusters: They recognize the nexus between technology innovation and standard of living, and accordingly make this a priority.[146]

The 2011 Roadmap identified an emerging energy storage cluster in Northeast Ohio around four market segments: advanced lead-acid batteries, lithium-ion cell materials, flow batteries and distributed energy storage systems. The 2011 Roadmap further identified visions and goals for each of these sectors, and strategies for how Northeast Ohio could capture its share of the anticipated market opportunities and jobs. A number of those strategies have been and continue to be deployed, with varying degrees of success. Some have been incorporated into this analysis.

In developing a roadmap for cluster development, it is useful to consider what strategies economic development experts have found to be effective. In 2013, the National Academy of Sciences published the *Best Practices in State and Regional Initiatives: Competing in the 21st Century.*[147] The publication was supported by grants from the Department of Energy, the National Institutes of Health, the National Institute of Standards and Technology, and the Economic Development Administration. It identified several themes for successful cluster development:

- *Investment of substantial public funds* by the states over a substantial period of time, along with the development of intermediating institutions, provides the foundation for progress. These investments also often have a catalytic effect, attracting private investments as well as support from foundations and the federal government.

- *Sustained support by states for educational institutions* can be important for long-term economic development, as these institutions provide the research facilities, a trained workforce, a flow of ideas for commercial development, and the branding that characterize successful regions.

- *Community colleges* play an essential role in providing a trained workforce able to adapt to changing technologies and to enable new opportunities.

- *Public-private partnerships* facilitate the collaboration needed to develop the necessary workforce, provide and enrich research facilities and agendas, help develop new ideas, and support bringing the resulting products to the market.

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[146] *Id*.
[147] *Supra fn.* 72.

- *Funding from philanthropic foundations* can play a significant and often catalytic role in initiating, complementing and sustaining action by regional and state authorities.[148]

Research institutions were identified by the Academy as particularly important to innovation-based regional economic development, and as "the cornerstone of U.S. international competitiveness."[149] University faculty recruitment, including the creation of endowed chairs, has emerged as an important tool for innovation-based economic development. Additionally, research institutions that own, operate and share laboratories and state-of-the-art equipment with the private sector can enable cluster development. Cooperative research among universities and private companies is especially critical to fostering innovation.[150]

The culture of entrepreneurship was also identified by the Academy as critical to cluster development. This includes readily available funding from angel investors and early-stage finance companies. It also includes local economic development organizations and philanthropies that encourage regional innovation, such as through SBIR grant application support. Finally, policy continuity and stable political leadership are important to the development of a healthy entrepreneurship culture.

7.2 Application to Northeast Ohio

Northeast Ohio has the research institutions and entrepreneurial culture necessary for the sustained development of an energy storage cluster. These include:

- *Research Institutions*. Northeast Ohio is home to three major research institutions that are involved in energy storage. These include two universities (Case Western Reserve University and Akron University) and one National Laboratory (NASA Glenn). Cleveland State, Kent State and Youngtown State Universities also conduct research in energy storage or related areas.

- *Entrepreneurial Culture*. Northeast Ohio has several organizations that provide support for energy storage entrepreneurship. More notable organizations include JumpStart,[151] which provides seed funding for innovative startup companies in high-tech industries, and Team NEO, which provides market research, thought leadership and other support for cluster development (including funding the 2019 Roadmap). In addition, Northeast Ohio has an incubator geared specifically for energy

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[148] *Id*.

[149] *Id*.

[150] *Id*.

[151] *See* JumpStart Inc. (n.d.). "Fostering Entrepreneurs, Buildings Ecosystems and Impacting Economies." https://www.jumpstartinc.org/#1

storage related startups: The Techbelt Energy Innovation Center (TBEIC) in Warren, Ohio. TBEIC provides office space, shared conference rooms, mentoring, and grid and battery test facilities.[152] These assets will play an important role in the emergence of an energy storage cluster in Northeast Ohio. And while it is critical that they continue to be funded, it is worth noting that these institutions have enjoyed considerably greater funding in the past. Most notably, the universities and JumpStart enjoyed considerable support from the Ohio Third Frontier program beginning in 2002. That program invested some $2 billion into university and private company technology innovation that ultimately led to successful programs such as Akron's polymer and materials cluster.[153] Ohio's Third Frontier program continues in 2019, but does not enjoy the levels of support that it once had.

Northeast Ohio also enjoys some additional advantages that are not among those listed by the Academy of Sciences but which may be important specifically to the development of an energy storage cluster. These include the following:

- Northeast Ohio has a workforce that is consistent with cluster development in energy storage. In particular, the region has a relatively high number of engineers working in fields related to energy storage compared with other parts of the United States, as indicated by the location quotient analysis in Section 5.3.

- Feedstock for polymer-based electrolytes and balance of plant equipment should be relatively cheap in Northeast Ohio due to its location close to Appalachian shale. This may become an even bigger advantage as new crackers and other petrochemicals are developed in the region. For current storage technology, such as lithium-ion batteries, this means a cost advantage for battery parts, such as separators and binders, which make up as much as 15% of the cost of the battery. As polymer-based solid-state electrolyte technology is developed, this cost advantage will increase to as much as 30%. A significant cost advantage in feedstock could make Northeast Ohio a candidate for manufacturing.[154] Battery manufacturing has largely moved to Asia, where workforce costs are lower. Ohio may be able to reverse this trend by exploiting cheap Appalachian natural gas and natural gas liquids.

- Northeast Ohio is located near most of the major metropolitan areas in the Midwest, Mid-Atlantic and Northeast regions. This could lead to a savings in transportation costs for materials manufactured in Northeast Ohio.

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[152] *See* TBEIC's homepage at https://www.tbeic.org. There are other incubators in Northeast Ohio that are not necessarily energy-specific but that energy storage startups could make use of, such as the Bounce Innovation Hub in Akron. *See* Bounce's homepage at https://bouncehub.org

[153] Agtmael, A. (2016). "How Cities Can Use Local Colleges to Revive Themselves." *The Atlantic*. https://www.theatlantic.com/business/archive/2016/03/cities-colleges-akron-polymers/472881/

[154] Interview with polymer experts at University of Akron, January 2019.

- Northeast Ohio's cost of living is modest compared to other regions in the United States, which is an important consideration for cluster development.

7.3 Roadmap Recommendations

Given the current assets that exist in Northeast Ohio and the market trends for energy storage, the following are strategies that could be adopted to further the energy storage cluster.

1. *Development of a culture of entrepreneurship*. These strategies could help maintain or materially improve the culture of entrepreneurship in Northeast Ohio as it relates to energy storage:

   - Obtain JobsOhio R&D grant. The JobsOhio R&D grant program was created to facilitate new strategic corporate R&D centers in Ohio. Energy storage is expressly included among the industries contemplated. A center must be a newly created (or repurposed) physical space dedicated to technology innovation.[155] Total initial funding available for this program is $100 million. It requires an investment of at least $3 million from a corporation. Applicants must have a five-year operating history and annual revenue of greater than $10 million. Because JobsOhio is looking for a company with a pre-existing critical mass, the best candidates for this might be Northeast Ohio's system integrators.

   - Increase available seed or early-stage capital funding. Currently JumpStart is the leader in Northeast Ohio for this. Additional state or philanthropic funding for JumpStart or other venture capital organizations would significantly help local entrepreneurship.

   - Re-fund Third Frontier. Established in 2002 to seed technology research and attract private investment, this program was refunded by a $700 million bond in 2010. Around $200 million remains unspent. As of April 2019, it is unclear what the new DeWine administration has planned for the Third Frontier. Accordingly, economic development groups and mayors are closely watching how this develops, and making their preferences known.[156] The Third Frontier program was critical to the success of the medical technology cluster in Northeast Ohio, infusing over $160 million into the region.[157] Such a program could likewise have significant benefits for the energy storage cluster.

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[155] JobsOhio. (n.d.). "JobsOhio Research & Development (R&D) Center Grant." https://jobsohio.com/why-ohio/incentives/jobsohio-loan-and-grant-programs/jobsohio-research-and-development-grant/

[156] Miller, J. (2019). "Could DeWine Mean Business for Cleveland?" *Crain's Cleveland Business*. https://www.crainscleveland.com/node/717491/printable/print

[157] *Supra fn.* 72.

- Develop and fund incubators. Incubators can have a significant effect on entrepreneurial culture. The role of an incubator is to increase the chances of success for young firms by de-risking entrepreneurial activity.[158] This type of business support program provides a multitude of services that are critical in helping startups grow, including:[159]

  - Coworking space, including access to conference rooms and private offices
  - Access to specialized equipment (e.g., technical/testing facilities)
  - Access to funding through angel investors and venture capital
  - Networking and collaboration opportunities
  - Business skills training (e.g., in accounting)
  - Mentorship, either directly or by connecting clients/tenants to external parties (individuals or mature companies) with industry expertise, as well as business and fundraising experience.

An energy incubator faces a unique challenge in connecting young companies to adequate funding. The investment funds that startups in Northeast Ohio have access to generally provide $25,000 or less in early-stage funding. Capital-intensive energy storage startups typically require more than $100,000 to get started.[160] On the other hand, energy storage is a relatively bigger, yet perhaps safer, bet compared to other early-stage investment opportunities (e.g., computer software) that likely have more uncertain product development life cycles and less pervasive demand.

The Opportunity Zones program created through the Tax Cuts and Jobs Act of 2017 could possibly provide a deeper pool of funds needed to finance energy storage startups. The program is designed to encourage investment in *Qualified Opportunity Zones* — census tracts designated as economically distressed by the U.S. Treasury — by providing federal tax incentives to invest in *Qualified Opportunity Funds* (QOFs), which, in turn, invest directly or indirectly in the Opportunity Zones.[161] No QOFs have made investments in Northeast Ohio's more than 100 Opportunity Zones as of April 2019. The program, however, is in its infancy. There are currently two QOFs with a geographic focus that includes Ohio (with a combined size of $550 million). Energy storage companies could potentially take advantage of these funds, which target a mixture of economic

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[158] *Id.*

[159] *See* Madaleno, M. et al. (2018). "Incubators, Accelerators and Regional Economic Development." *IZA Institute of Labor Economics.* http://ftp.iza.org/dp11856.pdf

[160] March 2, 2019 conversation with Rick Stockburger, CEO of TBEIC. Mike McKay, director for the Ohio Pre-Seed Fund Capitalization Program, had a similar observation: Energy storage's relatively high capital costs represent a challenge to early stage financing.

[161] *See* Internal Revenue Service. (2019). "Opportunity Zones Frequently Asked Questions." https://www.irs.gov/newsroom/opportunity-zones-frequently-asked-questions. *See also* Ohio Development Services Agency. (n.d.). "Opportunity Zones." https://development.ohio.gov/bs/bs_censustracts.htm

development, community development, small business development and renewable energy investment.[162] The establishment of an Ohio-based Energy Storage/Clean Energy Technology opportunity fund would be a more useful source of financing for early-stage energy storage business support.

- Develop Centers of Excellence. "Center of Excellence" is a term of art commonly used by federal grantors. Federal grants are available from federal sources for Centers of Excellence. For instance, CWRU has NSF planning grants for industry-university collaborative research centers (one for industrial energy efficiency and one for energy materials data analytics). Similarly, the Ohio Chamber of Commerce has proposed that Ohio develop four hubs of innovation: data analytics, health, advanced manufacturing and smart infrastructure. If the state adopts (and funds) this strategy, Northeast Ohio could be the hub for smart infrastructure, which would include energy storage. Indeed, CWRU has already established itself as a leading research institution on smart infrastructure, including its recent academic collaboration with Siemens (creating a digital grid lab and curriculum for the new energy workforce).[163]

2. *Programs that spur project investment into, and deployment of, energy storage technology*. Frequently, the best way to develop a cluster is to incentivize local deployment of technology developed by companies operating within the cluster. The following are strategies for enabling such deployment through local adoption of energy storage technologies:

   - Develop a Cleveland Green Bank. A more robust local market for intermittent, renewable power might enable Ohio-based energy storage companies to increase deployment of their technologies. Green Banks can provide an effective strategy for development of renewable power, and thereby trigger more demand for storage. Ohio enjoys among the lowest electricity prices in the country, averaging around 9-10 cents/kWh for commercial power. This makes renewable power more difficult to finance. Green banks make funding available to support loans for renewable energy projects through guarantees and gap financing. Connecticut provides a notable successful green bank model.[164] Cuyahoga County's Office of Sustainability and the Cleveland Foundation are collaboratively developing a similar program in Northeast Ohio.[165]

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[162] National Council of State Housing Agencies. (2019). "Opportunity Zone Fund Directory." https://www.ncsha.org/wp-content/uploads/2018/11/Opportunity-Zone-Fund-Directory-Current.pdf

[163] Scott, M. (2018). Siemens and Case Western Reserve University Form Academic Partnership to Train Next Generation of Digital Grid Experts." *Case Western Reserve University.* https://thedaily.case.edu/siemens-case-western-reserve-university-form-academic-partnership-train-next-generation-digital-grid-experts/

[164] For more information on green banks and facilitating investment into domestic low-carbon, climate-resilient infrastructure, visit the Green Bank Network homepage at https://greenbanknetwork.org

[165] Interview with Cuyahoga County Director of Sustainability, Mike Foley, April 2019.

- Maintain Ohio renewable/energy efficiency portfolio standards. In 2008, Ohio passed both a renewable portfolio standard and an energy efficiency standard. Both have since been under attack, at one time being frozen for several years. The Ohio General Assembly sought to make this permanent in 2017, but failed to receive enough votes to override the governor's veto. This may change in 2019. The renewable and energy efficiency portfolio standards are important to the deployment of grid-related energy storage, which will be triggered by the introduction of more renewable power into the grid. Those companies engaged in energy storage system integration will be the benefactors of these standards. The development of clean fuel standards would have a similar catalytic effect on electric and fuel-cell electric vehicles, both of which rely on batteries.

- Develop regulatory laws that encourage energy storage deployment. Ohio is a deregulated electricity market state, meaning that generation markets are competitive, but distribution remains fully regulated. Energy storage can be valuable on either side — as support for generation or for distribution. In either case, regulatory frameworks should be developed or maintained to encourage a rapid deployment of energy storage technologies in Ohio. This includes the following:

    - Maintain net metering. Ohio currently has net metering rules, but they are under threat of erosion. The utility-owned distribution companies (electric distribution utilities, or EDUs) have raised concerns that net metering will eventually lead to higher rates for those who do not have on-site generation, yet still bear the cost of maintaining infrastructure to such locations elsewhere. As a result, the EDUs have asked the Public Utility Commission of Ohio (PUCO) to increase their demand charges, which generally cannot be net metered. High demand charges can spur grid-based energy storage deployment, but these can also constrain distributed renewable projects that rely on net metering. Currently Northeast Ohio is among those areas nationwide that have relatively high demand charges. The PUCO will have to consider policies that will encourage both grid and behind-the-meter storage.

    - Allow utilities to recover grid-related storage costs. Even though many engineers believe that energy storage is more akin to grid regulation and stabilization than generation, most deregulated jurisdictions have found that storage is more akin to generation, and therefore should fall on the deregulated side.[166] This is the best strategy for behind-the-

[166] In Texas, for example, where the generation of electric power was deregulated at the turn of the 21st century through a series of amendments to the state's Public Utilities Code, energy storage qualifies as generation by law. The rationale for this classification is that while batteries do not actually generate electrical energy, the way in which they discharge power resembles generation. Utilities in Texas are therefore not allowed to own energy

meter storage, since regulatory approval for storage projects tends to be cumbersome, and as history has shown, more expensive. However, deregulation should not discourage utilities from developing large-scale storage in front of the meter. Storage that is used for frequency or voltage control will increasingly be part of a well-regulated grid, but it is unclear if or how utilities can recover such costs in deregulated jurisdictions like Ohio. Texas regulators have passed this issue on to the Texas legislature.[167]

Maryland, another deregulated state, is taking a more deliberate approach, recently passing legislation that requires the Maryland Public Service Commission (PSC) to investigate multiple models for how grid-scale energy storage might be encouraged. Under Maryland HB 650, the Maryland investor-owned utilities must solicit at least two of four possible models for storage: utility-owned, third-party owned, joint utility- and third-party owned, or a virtual power plant. The PSC is required to submit reports in 2024 and 2026 on the results of this investigation, including recommendations as to whether utilities can and should own grid-scale energy storage. The more deliberate approach has been justified by Maryland's abundant access to fossil fuels, its non-curtailment of grid-scale wind and solar, and its relatively modest increases in transmission and distribution costs.[168]

Ohio legislators and regulators will need to consider the Maryland, Texas and other deregulated state strategies. The PUCO will be pondering this issue in 2019-20 through its Power Forward[169] initiative. The energy storage community should engage in this effort and develop policy recommendations for the PUCO.

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storage assets in this regulatorily bifurcated energy industry since they are not allowed to function as a power generator. However, one of the principal benefits of energy storage is that it can allow utilities to defer costly transmission and distribution upgrades, which can, in turn, lower customer rates. Such costs should be recoverable by the utilities. Deregulated states should therefore prioritize the development of clear guidelines on the use of energy storage by utilities for non-generating applications. This is currently an issue before the state legislature in Texas. *See the following: (a)* Maloney, P. (2019). "Texas Regulators Defer to Legislature on Utility Ownership of Energy Storage. *Utility Dive.* https://www.utilitydive.com/news/texas-regulators-defer-to-legislature-on-utility-ownership-of-energy-storag/546366; *(b)* Spector, J. (2018). "Why is the Texas Market So Tough for Energy Storage?" *Greentech Media.* https://www.greentechmedia.com/articles/read/why-is-the-texas-market-so-tough-for-energy-storage#gs.54znk1; (c) Baddour, D. (2016). "Texas' Deregulated Electricity Market, Explained." *Houston Chronicle.* https://www.houstonchronicle.com/local/explainer/article/texas-electric-deregulation-ERCOT-TCAP-7971360.php

[167] *See Utility Dive, id*.

[168] *See* H. Mai, "Maryland passes energy storage pilot program to determine future regulatory framework," *Utility Dive*, April 2, 2019, found at: https://www.utilitydive.com/news/maryland-passes-energy-storage-pilot-program-to-determine-future-regulatory/551769/.

[169] For the 2018 Power Forward Report, *see*: https://puco.maps.arcgis.com/apps/Cascade/index.html?appid=59a9cd1f405547c89e1066e9f195b0b1

- Design electric vehicle (EV) rates and infrastructure to encourage EVs. Currently the PUCO has set up a working group within its Power Forward initiative to look at infrastructure and rate design for electric vehicle recharging stations.[170] This analysis is likely to have a significant impact on the rate of adoption of electric vehicles in Ohio. Because Ohio has relatively low-cost electricity, special rates may not be required to encourage early electric vehicle adoption. The Energy Storage Community should engage in this process and develop policy recommendations for the PUCO.

3. *Recruitment/Retention of energy storage faculty and researchers*. Technology-intensive companies tend to locate near the best universities in certain fields of science and engineering to enable their internal research departments to work with "star" scientists and recruit promising students.[171] Additionally, startup companies spun off from universities very often establish operations near these institutions.[172] A key driver in perpetuating this virtuous cycle is the attraction of top academic talent. The development of Northeast Ohio's biomedical cluster was partly a product of dedicating a significant share of funds to luring nationally recognized scholars to the region.[173] In a similar vein, cluster-inducing activities for energy storage could include leveraging the Ohio Eminent Scholar Program and Third Frontier (should it be re-funded) to endow energy storage-specific faculty chair positions at Northeast Ohio universities, to be filled by eminent researcher-entrepreneurs recruited from throughout the country who would likely bring a retinue of highly skilled research staff and scientists with them.

4. *Organizational structure.* A successful energy storage cluster requires some formal organization to take leadership, enable communication as well as collaboration, and identify opportunities.

    - Jobs Ohio/TeamNEO/Chambers of Commerce/TBEIC. TeamNEO has, to date, assumed formal organization of the Northeast Ohio energy storage cluster. However, support from JobsOhio and the local chambers of commerce will be important. TBEIC, as the principal energy incubator in Ohio, is also positioned to take on leadership for the cluster.

    - Energy Storage Association and other trade organizations. Energy storage is critical to a broad range of industries in Ohio. The IIoT/smart manufacturing cluster, for instance, will rely heavily upon new energy storage technology to achieve success. However, trade and

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[170] *See* Demeter, T. (2018). "What Does PowerForward Mean for Ohio's Clean Energy Future." *Ohio Environmental Council.* https://theoec.org/blog/ohpowerforward. "Electric Vehicle Charging Infrastructure" is one of five areas for which working groups are being developed. Rate design is a separate area, but there will inevitably be some crossover between the two areas.

[171] *Supra fn.* 143.

[172] *Id.*

[173] *Id.*

engineering associations from different industries often do not communicate well with one another. Organizations that provide more general technical networking opportunities, such as the Cleveland Engineering Society, could be a clearinghouse for cross-industry collaboration that helps connect new industries that depend upon energy storage advancement.

- Synergistic outreach. Energy storage systems are often application-specific. Applications will set the market for local system integrators, so the energy storage community should establish ties with new, emerging technology development groups that rely on electricity uptime. Some of these already exist within the local community at universities, NASA and TeamNEO. This sort of cross-industry dialogue should be formalized rather than ad hoc to obtain the best results. These include efforts such as:
    - Internet of Things/Data Processing
    - Cryptocurrency
    - Flexible and Wearable Electronics
    - Microgrids
    - Clean Fuel Technology
    - Material Sciences

8. Conclusions

The combination of unique energy-related assets found in Northeast Ohio has furthered the evolution of an energy storage cluster that, through continued collaboration and inter-asset support, may enhance the region's position as a leader in the development and production of energy storage technologies. This may, in turn, attract the investment and high-income jobs associated with concentrated high-tech innovation. There are opportunities for the region to not only capture a larger portion of the predominant lithium-ion storage technology as a result of novel products' being developed by area companies, but also be at the leading edge of transformative new technologies, such as solid-state and wearable/flexible batteries, in the not-too-distant future. Included among the assets Northeast Ohio can bring to a cluster, in addition to its existing institutions and businesses, are the relatively high location quotients for engineering occupations and the low cost of living found in the region. These compare favorably to other energy storage clusters found around the United States.

To realize this potential, local stakeholders will have to closely examine energy storage applications and integration strategies. Creative thought to applications can enable the region to leverage the presence of other regional innovation clusters, including additive manufacturing and smart manufacturing. Regional strengths in these other clusters can enable energy storage production in

Northeast Ohio to be more efficient in terms of cost, customer satisfaction and optimal resource management than competing areas in other parts of the country and the world.

The region will also have to mobilize significant financial resources for sustained investment into new technologies and early-stage companies if it wants to grow its energy storage cluster. The Third Frontier program has been a critical source of funding that has fueled the growth of other innovative industries in Northeast Ohio, particularly the thriving biomedical cluster.[174] However, most of the available funds for this state-backed initiative have been previously allocated. The nascent Opportunity Zone program may prove to be a supplemental or an alternative pool of funding to cover the relatively high capital costs that are often a challenge to early-stage financing in energy storage.

Northeast Ohio possesses the necessary intellectual and human capital to be competitive in energy storage. It also possesses a support structure in the form of organizations such as Team NEO and the Tech Belt Energy Innovation Center to help bring new technologies and early-stage companies along as they progress on the path toward commercialization. Working in concert, the assets within this energy storage ecosystem can accelerate innovation, capitalize on market opportunities, and drive economic growth through the deployment and adoption of novel energy storage products and services.

[174] Northeast Ohio's biomedical sector captured over $160 million during the early stages of the Third Frontier program, enabling the region to additionally secure substantial private sector investments. *See supra fn* 72.

Appendix

Table 10. Core Commercial Energy Storage Assets in Northeast Ohio

Company	Energy Storage Employees in NE Ohio	General Storage Technology	Specific Technology if Electrochemical
Akron PolyEnergy Inc.	1-19	Electrochemical	Lithium-ion; Solid-state; Active/Inactive Materials
Akron Polymer Systems Inc.	1-19	Electrical; H_2	---
AMETEK Technical & Industrial Products Inc.	50-99	Electrochemical; H_2	Battery Management Systems (BMS); Systems Control
APV Engineered Coatings (Akron Paint & Varnish)	1-19	Electrochemical	Lithium-ion; Active/Inactive Materials
BASF Catalysts LLC	50-99	Electrochemical	Lithium-ion; Active/Inactive Materials
Blue Spark Technologies Inc.	1-19	Electrochemical	Zinc-Manganese Dioxide; Thin Film
City Machine Technologies	20-49	Mechanical	---
Controllix Corp.	1-19	Electrical	---
Coventya Inc.	1-19	Electrochemical	Zinc-Bromine Flow; Active/Inactive Materials
Cratus Energy	1-19	Electrical; Electrochem.; H_2	---
Crown Battery	200+	Electrochemical	Lead-Acid
Echogen Power Systems	20-49	Thermal	---
Electromotive Inc.	1-19	Electrical	---
Energizer Battery Inc.	50-99	Electrochemical	Zinc-Manganese Dioxide (Zn/MnO2); Lithium-Iron Disulfide
Energy Technologies Inc.	50-99	Electrochemical	Lithium-ion; NiCad; NiMH; Lithium Polymer; Lead-Acid; BMS
Erie Industrial Products	1-19	Electrochemical	Automotive Battery Pack
GES-AGM (GES Graphite)	20-49	Electrochemical	Lithium-ion; Other Chemistries; Active/Inactive Materials
GLX Power Systems	1-19	Electrochemical	BMS; Systems Control
Gotion	20-49	Electrochemical; Electrical	Lithium-ion; BMS
Graywacke Engineering Inc.	1-19	Electrochemical	BMS; Systems Control
HV Coil LLC	20-49	Mechanical	---
JME Inc.	1-19	Electrical	---
Kalt Manufacturing	50-99	Mechanical	---
MegaJoule Storage Inc.	1-19	Electrical; Electrochem.; H_2	Advanced Lead-Acid; BMS; Systems Control
Modtech Corp.	1-19	Electrochemical	Lithium-ion; BMS
Orbital Research Inc.	20-49	Electrical	---
Pace Converting Equipment	1-19	Electrochemical	Thin Film
Polymer Plus LLC	1-19	Electrical	---
Powdermet Inc.	20-49	Electrical; Electrochem.; H_2	Lithium-ion; Active/Inactive Materials
Power & Grounding Solutions	1-19	Electrochemical	Automotive Battery Pack
SKF Solution Factory	1-19	Mechanical	---
Southwire Company LLC	50-99	Electrochemical	Automotive Battery Pack
Technology Management Inc.	1-19	H_2	---
UPE Inc.	1-19	Electrical	---
Valtronic Technologies Inc.	20-49	Electrochemical	BMS; Systems Control
Yanhai Power LLC	1-19	H_2	---

Table 11. Balance of Plant and Power Conversion System Assets in Northeast Ohio

Company	Energy Storage Employees in NEO	Application Area	Subarea
Advantage Circuits Ltd.	1-19	Transportation; Grid	Printed Circuit Boards
AT&F Advanced Metals	100-199	Grid	Containers; Tanks
C.E.C. Electronics Corporation	1-19	Consumer Electronics; Transportation; Grid	Printed Circuit Boards
Cleveland Circuits Corp.	20-49	Cons. Elect.; Transport.; Grid	Printed Circuit Boards
Darrah Electric Company	20-49	Grid	Power Conversion
DCM Manufacturing Inc.	50-99	Grid	Thermal Management
DECA Manufacturing Inc.	100-199	Cons. Elect.; Transport.; Grid	BOP; Wire Harness Assem.; Interface/Communication Cable
Delta Systems Inc.	200+	Cons. Elect.; Transport.; Grid	Printed Circuit Boards
Die-Matic Corp.	50-99	Grid	Container/Housing
Dimension Engineering LLC	1-19	Cons. Elect.; Transport.; Grid	Monitors and Sensors; PCS
Eaton (Cleveland Satellite)	1-19	Grid	Power Conversion
Vertiv Co.	200+	Grid	Thermal Management; PCS
Energizer Battery Inc.	1-19	Cons. Elect.; Transport.	Container/Housing
Essential Research Inc.	1-19	Cons. Elect.; Transport.; Grid	Monitors and Sensors; PC Boards
Euclid Universal (Imperial)	1-19	Grid	Flywheel BOP
Ferro Corp.	100-199	Cons. Elect.; Transport.; Grid	Materials (battery seal)
Gorman-Rupp Industries	200+	Grid	Pumps for Flow Batteries
Ideal Electric Co.	20-49	Grid	Flywheel BOP
IPAK Services LLC	1-19	Grid	Flywheel BOP
Johnson Matthey Process Tech.	20-49	Transportation; Grid	Hydrogen BOP
LaGrange Electrical Assemblies	20-49	Grid	Wiring Harnesses & Cable Assem.
LayerZero Power Systems Inc.	20-49	Grid	Container/Housing; PCS
LTI Power Systems	20-49	Grid	Power Conversion System
MK Enterprises Inc.	20-49	Transportation; Grid	Electric Wire & Interface Cable Assem.
Multilink Inc.	100-199	Grid	Container/Housing; Interface Cable
NeoGraf Solutions	50-99	Transportation; Grid	Thermal Management
PanelTech LLC	1-19	Grid	Container/Housing
Parker-Hannifin Corp.	100-199	Grid	Flywheel BOP
Powermetrics Inc.	1-19	Cons. Elect.; Transport.; Grid	Power Conversion System
Precision Design	1-19	Grid	Power Conversion System
Premix Inc.	200+	Cons. Elect.; Transport.	Container/Housing
Quality Switch Inc.	20-49	Grid	Power Conversion System
RTD Electronics Inc.	1-19	Cons. Elect.; Transport.; Grid	Wire Harnesses; Electromechanical Interconnect Assemblies
Sovereign Circuits Inc.	100-199	Cons. Elect.; Transport.; Grid	Printed Circuit Boards
Swiger Coil Systems	100-199	Grid	Flywheel BOP
The Hannon Co.	50-99	Grid	Flywheel BOP
Thermtrol Corp.	20-49	Transportation; Grid	Cable and Wire Harness; Thermal Mgt.
Unifrax Corp.	20-49	Grid; Transportation	Thermal Management
Vexos	50-99	Cons. Elect.; Transport.	Printed Circuit Boards