Boston University Institute for Sustainable Energy

Still Charging

Energy Storage Commercialization in Massachusetts

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Executive Summary

With the mutually reinforcing trends of climate change mitigation and transport electrification, the opportunity for energy storage innovation has never been more apparent. Massachusetts supports a robust community of entrepreneurs who develop and commercialize their inventions in the state. Recognizing this, Boston University's Institute for Sustainable Energy and Greentown Labs conducted 25 interviews with a wide array of participants involved in the energy storage innovation ecosystem. These interviews focused on barriers, gaps, and strengths of Massachusetts in getting energy storage technologies from lab to the first sale.

Our interviews identified three key barriers:

- **Resource Barriers:** Developing a new energy storage technology is not only capital intensive, but requires infrastructural resources that are difficult to locate in the state.
- **Knowledge Barriers:** Energy storage entrepreneurship needs a particular mix of business and technical knowledge that are present but siloed in Massachusetts.
- **Policy/Regulatory Barriers:** New technologies take time for regulations to adapt and align. In Massachusetts, several regulatory barriers were identified, including the lack of clear permitting pathways, and the risks of lithium-ion lock-in.

From the suggested improvements, we distilled the following strategic goals that should guide ecosystem participants:

- **Catalyze More Interactions between Ecosystem Participants:** Knowledge silos hamper progress and prevent successful commercialization. One way to tackle this is to encourage ecosystem members to work together meaningfully, as through a centralizing organization and state policy.
- **Improve Testing in Massachusetts by Improving Testing Infrastructure**: Rapid iteration is the key to innovation. However, in battery development, resource challenges make testing difficult and expensive, hampering innovation. Bringing these small scale testing resources in state, and improving the ease of piloting are key.
- **Lower Barriers to New and Different Types of Participation:** The energy storage ecosystem requires deep technical knowledge, limiting the pool of potential participants.

With these three strategic goals in mind, Massachusetts could cement its place as a global energy storage hub, drawing innovators from across the world to the state.

1. Introduction

The climate change challenge is driving profound shifts in two bedrock industries of modern society: energy and transportation. For decades, these industries relied on fossil fuel-based energy; today, more renewable energy sources are replacing natural gas, coal, or petroleum fuels and globally, renewable energy accounts for 9.3% of generation.[1] The United States has doubled its share of renewables since 2000 and is expected to continue growing renewable energy resources, especially intermittent renewables such as wind and solar. [2,3]

Massachusetts, a climate policy leader in the United States, committed to a statewide greenhouse gas emissions reduction of 85% below 1990 levels by 2050 and has an aspiration to exceed the goal and be carbon neutral by 2050.[4,5] Massachusetts is already among the lowest-emitting states in the nation, and per capita emissions have fallen by 28.7% since 2005.[6] In addition to significant solar installations, the state is moving forward with offshore wind deployments, setting targets for 3,200 megawatts by 2035.[7]

Inherently intermittent, wind and solar cannot totally replace fossil fuels without energy storage. With limited exceptions, the electricity grid was developed over the past century without energy storage for economic reasons: it was far cheaper to oversize the capacity of the electric system to meet peak needs. Recent improvements in storage technology, especially batteries, have made grid-scale energy storage possible.

Massachusetts is taking steps to realize this new possibility. The state created new programs adding financial incentives for storage to the Solar Massachusetts Renewable Target (SMART) program, passing a clean peak requirement, and introducing storage deployment targets of 1

[1] BP. (2019). Statistical Review of World Energy: Electricity. Retrieved June 12, 2019, from https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/electricity.html

[2] Energy Information Administration. (2018). U.S. Battery Storage Market Trends. Washington DC. Retrieved from www.eia.gov

[3] Energy Information Administration. (2018). Renewable Energy Sources - Energy Explained, Your Guide to Understanding Energy - Energy Information Administration. Retrieved July 24, 2019, from https://www.eia.gov/energyexplained/index.php?page=renewable_home

[4] Massachusetts Executive Office for Energy and Environmental Affairs Letter of Determination. (April 2020) https://www.mass.gov/doc/final-signed-letter-of-determination-for-2050-emissions-limit

[5] Massachusetts Executive Office for Energy and Environmental Affairs press release. (April 2020) https://www.mass.gov/news/baker-polito-administration-issues-letter-establishing-net-zero-emissions-target

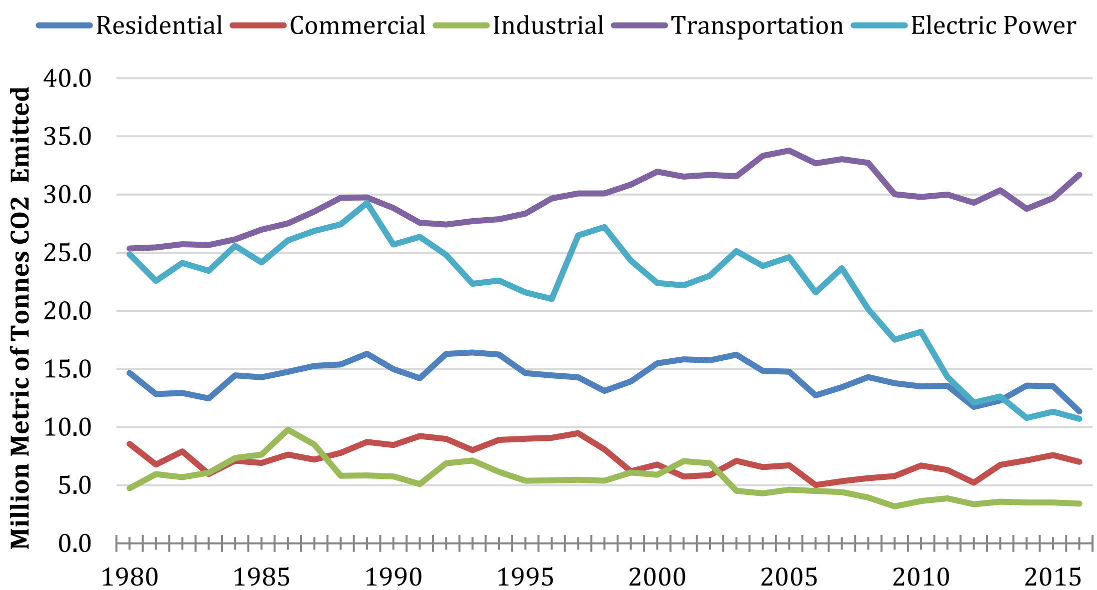
[6] Energy Information Administration (2005). Energy-Related Carbon Dioxide Emissions by State, 2005–2016. Retrieved from www.eia.gov

[7] Gerdes, J. (2018, December 17). Record-Breaking Massachusetts Offshore Wind Auction Reaps $405 Million in Winning Bids. Greentech Media. Retrieved from https://www.greentechmedia.com/articles/read/record-breaking-massachusetts-offshore-wind-auction

GW by 2025.[8,9,10,11,12] ISO New England (the authority responsible for the high-voltage electricity grid within New England) also supports storage by allowing market participants to bid energy storage capacity, energy, and ancillary service into the regional wholesale markets.[13]

The above discussion has focused solely on the electricity industry, in which carbon emissions have already substantially fallen across Massachusetts. However, the next frontier of decarbonization is in the transportation sector (see Figure 1). As the carbon intensity of electricity generation falls, electrification of the vehicle fleet could reverse the recent trend of increasing transportation emissions. While electric vehicles (EVs) have yet to achieve widespread adoption and economic parity with fossil fuel vehicles, improvements in battery energy density are reducing the costs and improving the range of EVs. Many leading companies in the oil, electricity, and auto industries are anticipating the likelihood of a future more reliant on EVs by investing massively in electric vehicle battery technology.

Figure 1: Massachusetts Carbon Emissions by Sector 1980-2016[14]



[8] Mai, H. (2019). Massachusetts' multipronged policy approach spurs distributed energy storage. Retrieved June 12, 2019, from https://www.utilitydive.com/news/massachusetts-multipronged-policy-approach-spurs-distributed-energy-storag/554208/

[9] Department of Energy and Environmental Affairs. (2018). Guideline on Energy Storage. Boston, MA. Retrieved from https://www.mass.gov/files/documents/2018/09/13/Energy Storage Guideline FINAL 091318.pdf

[10] Climate Change Adaptation Advisory Committee. (2011). Massachusetts Adaptation. Boston. Retrieved from https://www.mass.gov/files/documents/2017/11/29/Full report.pdf

[11] Executive Office of Energy and Environmental Affairs. (2015). Massachusetts Clean Energy and Climate Plan for 2020. Boston. Retrieved from https://nescaum-dataservices-assets.s3.amazonaws.com/resources/production/Clean Energy and Climate Plan for 2020.pdf

[12] Massachusetts Department of Energy Resources. (2016). State of Charge: Massachusetts Energy Storage Initiative. Retrieved from http://www.mass.gov/eea/docs/doer/state-of-charge-report.pdf

[13] Mai, H. (2019). Massachusetts' multipronged policy approach spurs distributed energy storage. Retrieved June 12, 2019, from https://www.utilitydive.com/news/massachusetts-multipronged-policy-approach-spurs-distributed-energy-storag/554208/

[14] Graph created from State Carbon Dioxide Emissions Data, US Energy Information Administration

While many issues about the future of energy storage remain unclear, there is widespread recognition that the decarbonization of both the electricity and transportation sectors is highly dependent on further improvement and deployment of energy storage products and services.[15,16,17]

Recognizing the need for continued advancement in energy storage technologies, the federal government recently launched an ARPA-E program to sponsor innovation in long-term (i.e. more than a few hours) energy storage.[18] Private investment is rising too, with recent blockbuster deals like Shell's acquisition of Sonnen, Ford's $500m investment in Rivian, and Daimler's investment in Sila Nanotechnologies.[19, 20, 21] Anticipated investments in the industry are massive and expected to exceed $620 billion by 2040.[22]

These forces provide an enormous opportunity for entrepreneurs. As recognized by a recent University of Massachusetts Amherst report, Massachusetts has the characteristics of a healthy innovation ecosystem: clustering, public investment, cooperation between ecosystem actors, and friendly culture.[23] Owing to these strengths, combined with the state's market leadership and its world-class scientific/technical resources, Massachusetts has an uncommonly strong innovation ecosystem to offer the energy storage community[24] and many of those entrepreneurs choose Massachusetts as their launchpad.

Recognizing Massachusetts' potential to be the global leader in energy storage development, it is interesting to consider what challenges face entrepreneurs in Massachusetts that are particular to the energy storage sector, and how those might be addressed. Boston University's Institute for Sustainable Energy and Greentown Labs collaborated to identify opportunities for energy storage industry leadership in Massachusetts. This report summarizes the findings gained through a series of interviews with ecosystem participants (see Table 1), including identification of barriers to further growth and improvement and recommendations for both policymakers and ecosystem planers.

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[15] Yang, Z., Zhang, J., Kintner-Meyer, M. C. W., Lu, X., Choi, D., Lemmon, J. P., & Liu, J. (2011). Electrochemical Energy Storage for Green Grid. *Chem. Rev*. *111*, 3577–3613. https://doi.org/10.1021/cr100290v

[16] Omar, J., Posada, G., Rennie, A. J. R., Perez Villar, S., Martins, V. L., Marinaccio, J., … Hall, P. J. (2016). Aqueous batteries as grid-scale energy storage solutions. https://doi.org/10.1016/j.rser.2016.02.024

[17] Gallo, A. B., Simões-Moreira, J. R., Costa, H. K. M., Santos, M. M., Moutinho, E., & Santos, D. (2016). Energy storage in the energy transition context: A technology review. https://doi.org/10.1016/j.rser.2016.07.028

[18] St John, J. (2018). ARPA-E funds research on energy storage that can last for days. Retrieved June 26th, 2019, from https://www.greentechmedia.com/articles/read/arpa-e-funds-research-into-energy-storage-that-can-last-for-days#gs.dfhyuGQ

[19] Spector, J. (2019, February 15). Oil Supermajor Shell Acquires Sonnen for Home Battery Expansion. *GreenTech Media*. Retrieved from https://www.greentechmedia.com/articles/read/oil-supermajor-shell-acquires-sonnen-for-home-battery-expansion

[20] Lacey, S. (2019). Watt It Takes: Creating a Battery Unicorn by Learning From Previous Cleantech Busts. Retrieved July 24, 2019, from https://www.greentechmedia.com/articles/read/watt-it-takes-sila-nanotechnologies

[21] Warren, T. (2019). Ford Invests $500M in Electric Truck Maker Rivian: Here's Why. Retrieved July 24, 2019, from https://fortune.com/2019/04/25/ford-is-making-its-own-electric-truck-so-why-is-it-investing-in-rivian/

[22] Brian Echouse. (2018). The Battery Boom Will Draw $620 Billion in Investment by 2040 - Bloomberg. Retrieved May 21, 2019, from https://www.bloomberg.com/news/articles/2018-11-06/the-battery-boom-will-draw-1-2-trillion-in-investment-by-2040

[23] Umass Clean Energy Extension. (2019). *Creating Opportunity: Building a Massachusetts Battery Energy Storage Innovation Ecosystem*. Amherst, MA. Retrieved from https://ag.umass.edu/sites/ag.umass.edu/files/pdf-doc-ppt/creating_opportunity_in_the_ma_battery_energy_storage_innovation_ecosystem_umass_cee_-_june_2019.pdf

[24] Klowden, K., Lee, J., & Ratnatunga, M. (2018). State Technology and Science Index. Retrieved from www.statetechandscience.org

Table 1: Interview Categories

Category	Number of Interviews
Universities - The source of many innovations. Interviews focused on understanding the research and spin out process.	4
Corporates - Interviews concentrated on how corporations view innovation ecosystems, and how they collaborate with the ecosystem to understand their needs.	3
Utilities - Key stakeholders in the electrical system. Interviews focused on understanding their needs and engagement with the innovation ecosystem.	3
Startups - The innovation engines of the ecosystem. The interviews focused on technical and commercialization needs.	4
Government Agencies - Interviews sought to understand the role of government in this ecosystem in providing financial and policy support.	3
Investors - Funders are key sources of capital for energy storage ventures. Conversations centered around understanding risks and opportunities.	3
Ecosystem Partners- From accelerators to incubators to mentors, many organizations have holistic perspectives on the commercialization process.	2
Customers and Developers - Final implementers of many energy technologies. Interviews focused on developers' perspectives on the final commercialization of technologies.	3

Massachusetts must both leverage its strengths and lower some barriers to become the premier home for innovative energy storage companies. Several common themes emerged from our interviews on nurturing a stronger energy storage ecosystem in the state. Specifically, our interviewees envisioned a strategic use of policy and resources to achieve the following:

Catalyze More Interactions between Ecosystem Participants

This summarizes interviews with a diverse group of ecosystem participants, from startups with very specific technical concerns to customers who are the ultimate market for these innovations. Because we were able to speak with the full spectrum of players, it became clear that there are many knowledge silos in the energy storage arena. A resolute effort through a series of conferences, working groups, and cohosted events would increase communication between ecosystem participants and break down these silos.

Facilitate Rapid Iteration by Improving Testing Infrastructure
The innovation process requires the translation of the theoretical to the real. Testing inherent assumptions early and often provides critical feedback and stage gates to startups and their investors. As our interviews indicated, difficulties with rapid and inexpensive iteration and testing abound in the current energy storage ecosystem, and implementing improved testing infrastructure would give Massachusetts a critical edge over other states.

Lower Barriers to New and Different Types of Participation in the Ecosystem
For a variety of reasons enumerated below, participation in the current energy storage ecosystem involves overcoming a variety of barriers, including lack of data access, high knowledge requirements, and lack of focus on adjacent markets. While the community is open and welcoming, often, the amount of knowledge required to participate meaningfully is difficult to obtain.

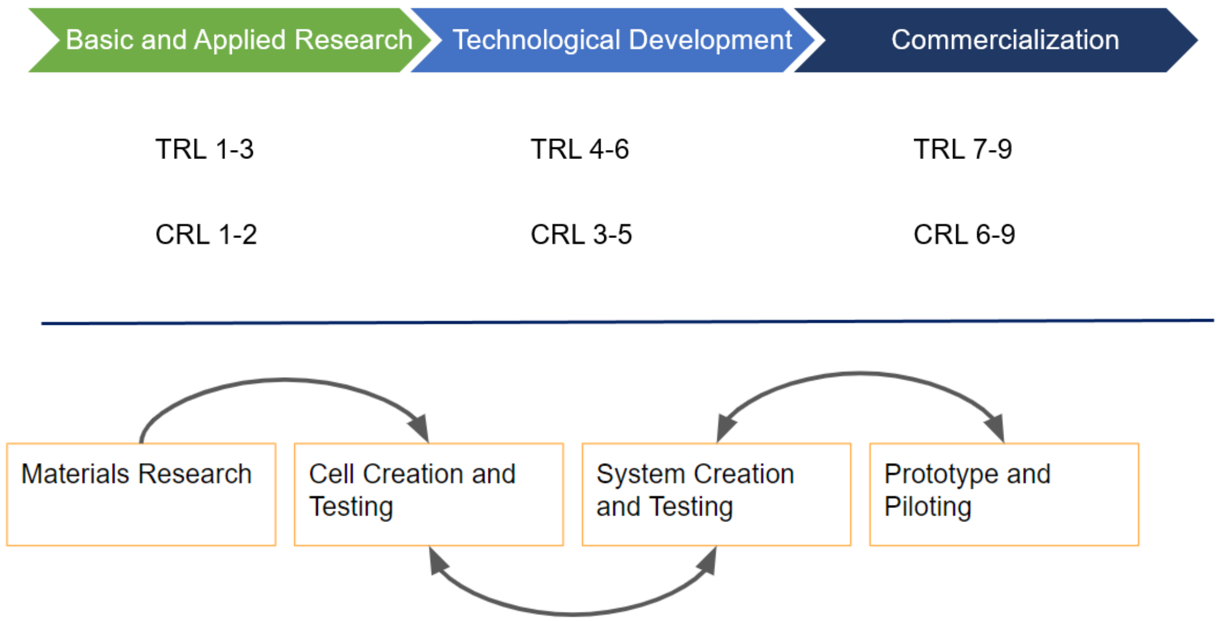
Energy Storage Commercialization in Context

Just as not all technologies are the same, no two companies working in a similar technology area are at the same stage of maturity – which in turn implies that they will have different needs for commercialization assistance from the ecosystem.

To discuss the distinct differences between company maturity, this paper uses two frameworks, developed by the Federal government: Technology Readiness Level (TRL) and Commercial Readiness Level (CRL), illustrated in Figure 2.[25] Both are used to evaluate a technology's potential at a certain point in time. TRLs answer the question, "will it work, and in what environment?" and CRLs answer, "How well does the product fit with markets and customers' needs?" Startups must develop both at the same time if they are to be successful.

[25] Mai, T. (2015). Technology Readiness Level. Retrieved June 12, 2019, from https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

Figure 2: Stages of Technological and Commercial Development in CleanTech



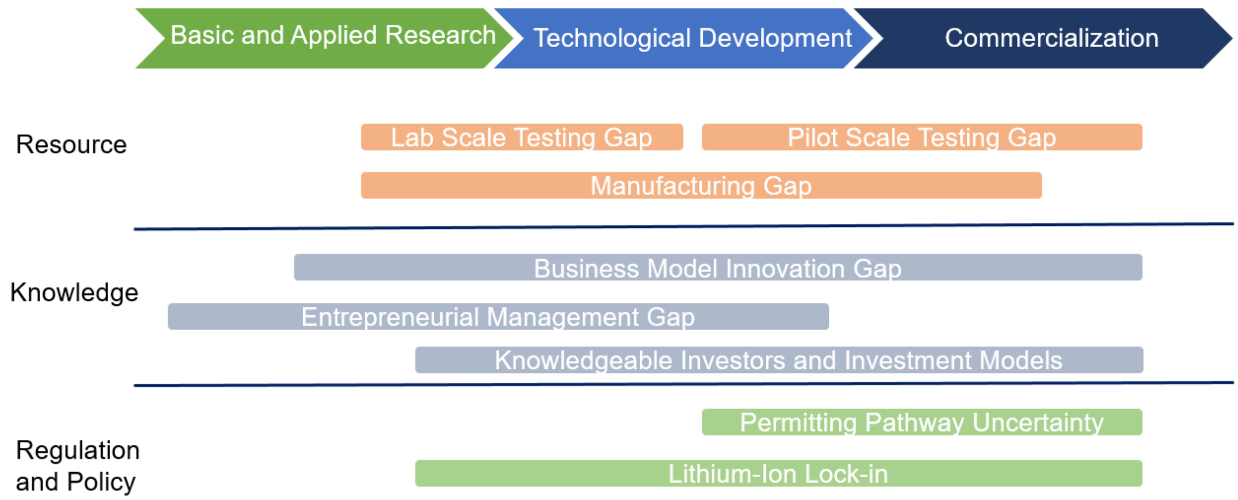
As is the case with many hardware innovations, battery chemistries advance by scaling from small to large, typically from a coin cell to an 18650 or pouch cell. Each step along the way involves rigorous testing, which drains resources from a startup. Risks rise with each successive step, with large-scale testing being exceptionally costly. Other storage technologies (i.e. not batteries) follow similar scaling tests.

Moreover, companies rarely move linearly through these development stages, with product designs often requiring backtracking to engineer the optimal configuration. Indeed, the natural course of product development can occasionally entail reverting to basics as new versions are developed and performance requirements change.

2. Barriers to Innovation in Massachusetts Energy Storage Ecosystem

After 25 interviews with energy storage innovation stakeholders, a variety of common themes began to emerge – particularly regarding barriers to commercial advancement of new energy storage technologies, products, and business models. The barriers identified can be grouped into three main categories: resource barriers, knowledge barriers, and regulatory/policy barriers, as shown in Figure 3.

Figure 3: Barriers to Innovation at various stages of Energy Storage Technology Development



2.1 Resource Barriers

Across the board, innovators emphasized the importance of testing new products quickly and inexpensively. Testing allows innovators to validate their ideas early, preventing more costly failures down the line. All the participants acknowledged iteration is especially difficult (and expensive) for all kinds of hardware, but affirmed its particular importance in energy storage commercialization. Test results, other than generating data, serve as key indicators to investors and/or strategic partners of technological readiness. It allows innovators to approach external partners with empirical data, a critical step to building lasting partnerships.

In an energy storage company, especially those advancing new chemistries, tests happen at a variety of scales, from the lab bench test of a new chemistry to the full field pilot of a storage system.

2.1.1 Lab Scale Testing

Having scaled a chemistry into something that can be commercialized, startups undertake pre-pilot scale tests on small devices, which must be prototyped on specialized equipment and then tested with different, also highly specialized, equipment. Not only is this equipment expensive, making it prohibitive for many companies to acquire, but it also is often not found in

Massachusetts. Many of the startups interviewed traveled to other states including Michigan, Arizona, and Indiana, to find micro-manufacturing and testing facilities. Others rely on what they called “vulture auctions,” purchasing equipment from startups that have gone out of business – a practice that cannot be relied upon to obtain exactly the right equipment or gain access in a timely manner.

One interview subject highlighted the variability that comes out of this ad hoc manufacturing process. Inventors are manually building and testing these prototypes on a wide variety of equipment, leading to increased variance between samples. Since the parts, machines, and manufacturing techniques used are not all equivalent, the associated lack of standardization makes it difficult to compare the relative advantages of one product to the other. This variance masks the benefits of new technology when compared to industrially produced batteries, increasing investor skepticism.

2.1.2 Pilot Testing

As difficult as testing is at the lab scale, pilot testing at customer sites at a commercial scale is yet more challenging. Pilot tests are the ultimate learning experiment, exposing technologies to real-world conditions for the first time. Many interview subjects highlighted the value and the risk of their pilots: a good one can set your company up for success, whereas a bad one can erode investor confidence. If Massachusetts is to be the premier place for hardware startups, solving the piloting problem is imperative. Our interviews revealed several barriers to piloting in Massachusetts.

It is highly preferable for pilot testing sites to be in close proximity to the innovating company. Travel costs can increase quickly, both in terms of time and money, the further staff has to travel to a test site. These constraints can reduce the frequency of staff interaction with the pilot unit and reduce the information learned from the pilot deployment. Therefore, for energy storage innovators to find Massachusetts a fertile environment, it is critical for organizations located within the state to be willing to serve as hosts for trial products.

In Massachusetts (and indeed anywhere), it is difficult to find a partner willing to be customer number one, creating a bottleneck in the commercialization process. Initial pilot customers are crucial partners, helping give feedback on the technology, helping product development efficiency and efficacy. However, few organizations have decision-makers willing to take on the technological risk. This perceived technical risk makes it difficult for startups to find partners to apply to demonstration grants offered in the state.

“No one wants to be the first customer; everyone wants to be the second.” - Potential Commercial Customer A

Alongside technological risk, interview subjects noted the financial risk of pilot projects. The capital intensity of many stationary energy storage systems makes paying for pilots with a startup’s internal sources of capital costly and/or difficult. Unlike larger companies, startups do not have balance sheets to leverage for test project financing and frequently rely on state and federal grants. From a customer perspective, the ambiguity of who owns and maintains a long-lived asset like a stationary storage system is a major factor. Others highlighted the risky nature of startups: they might change direction or go out of business, leaving the customer with expensive pre-commercial technology.

“It’s hard to convince people that you will be around in a year or two and that a 10-year warranty means anything."- Corporate Engineer A

Several storage technologies under development are designed for application in microgrid systems. Still, many stakeholders that pursue microgrids (such as hospitals and other emergency service departments) cannot afford unreliable electric service, eliminating many sites for pilot testing. Similarly, new storage products face the same perceived risk issues for customers with an uninterruptible power supply. Interview subjects maintained that customer interest in energy storage is high, especially with state subsidies. Still, their desire to participate in innovation is low: these customers need a commercially proven solution.

To circumvent these issues, several startups collaborated with established, often multinational, corporations although such relationships are hard to develop and maintain. The corporate and startup interviewees acknowledged the need for partnerships based on mutual understanding but also emphasized the difficulty of creating and managing those relationships. There are limited resources at the corporate level, both in terms of capital and in terms of time, to dedicate to projects outside the core business. If they are well run, these corporate collaborations are excellent ways to access resources. If poorly run, they offer only partial solutions to this ecosystem problem.

2.1.3 Support for Adjacent Markets as Storage Grows

These problems compound when related markets are considered. Should battery recycling be considered part of the state’s energy storage focus? What about battery management systems and other power electronics? And electric vehicle technologies?

Interview subjects struggled with these questions. Our subjects felt that these markets are clearly part of the energy storage ecosystem, but are poorly supported. A battery recycling startup will have radically different needs than a battery chemistry startup; the needs of these adjacent industries are generally unaddressed.

These adjacent industries are set to grow, piggybacking on the success of mainstream energy storage. Massachusetts could invest early, creating a positive feedback loop between the adjacent industries and the storage industry. This positive feedback would reinforce the clustering effects in the Massachusetts energy storage ecosystem, and bring more jobs, investment, and growth to Massachusetts.

2.1.4 Need for Niche Markets

More than the development of adjacent markets, many investors and interviewees pointed out a need for niche markets in which energy storage innovations can gain an early foothold. These are usually smaller markets willing to pay premium prices, or those with needs currently unmet by alternative products. Niche markets offer a chance for small and medium-sized companies to grow without the billion-dollar buy-in necessary to compete against large battery manufacturers. Not only is competition less intense, but the customer purchasing process is often faster, and based more on superior performance than a lower cost.

Many startups and investors pointed out the challenges that a new storage technology would face by needing to compete against lithium-ion batteries, which have had decades and billions of dollars of efforts in development, economies of scale and consolidation. Put another way by a startup CEO: “Battery markets are inherently commoditized, so new technologies still early in the tech development cycle have to find price-insensitive [performance based] markets." Furthermore, the necessity for start-ups to focus on a single technology means the limitations of that developing technology define the limitations of what is possible in the market place.

Cleantech history bears this out. The solar industry survived for decades, slowly growing from small niche markets like navigation buoys to broader markets before increased industry scale, expanded subsidies, and technical developments allowed prices to fall to levels where the mass market would buy.[26] Lithium-ion had a more consumer-focused development path, starting with camcorders, moving to laptops, and then cellphones, continually expanding to new applications as economies of scale drove prices down.

Small battery configurations can follow a similar path. However, large scale batteries face a more daunting challenge as they generally act as critical backup systems or grid suppliers. These large-scale batteries, as noted by our interviewees, are selling into limited markets, defined by their capitalization and risk tolerance.

`“Everyone wants to solve the cost problem, but someone has to buy the first 10 million bucks of product. Essentially someone needs to pay for the new technology to reduce costs” - Startup CEO B`

2.2 Knowledge Barriers

In a highly technical field selling to highly technical markets, energy storage entrepreneurs often view problems as purely technical. However, commercialization is a problem requiring both technical and business knowledge. Massachusetts needs to develop entrepreneurial and managerial resources alongside its technical strengths if it is to become a global hub of the emerging energy storage sector.

2.2.1 Entrepreneurial Management Gaps

While technical knowledge in the state abounds, investors and ecosystem support organizations repeatedly brought up gaps in the quantity and quality of entrepreneurial management. This observation is surprising, given Massachusetts’ relative entrepreneurial success. Our

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[26] Green, M. A. (2005). Silicon photovoltaic modules: A brief history of the first 50 years. Progress in Photovoltaics: Research and Applications, 13(5), 447–455. https://doi.org/10.1002/pip.612

interviewees spotted a common problem: founders active in energy storage rarely have both technical knowledge and entrepreneurial knowledge. Founders do eventually learn some business skills thanks to the tight-knit community built around organizations like Greentown Labs and entrepreneurial academic institutions. Still, formal capability-enhancement based on market feedback would increase the likelihood of successful commercialization.

2.2.2 Business Model Innovation / Non-Technical Innovations

Virtually all ecosystem members interviewed identified insufficient business model innovation as a major problem for energy storage, though what ‘business model innovation' means can vary. Some interviewees asked for new ways to sell storage, such as novel financing mechanisms and ownership structures. Others took a wider view of business model innovation, referring to the introduction of complementary solutions such as recycling, efficiency, or software. For these types of innovation, the energy storage ecosystem will need to offer different knowledge and support resources for another kind of entrepreneur.

The first umbrella, of new financing and ownership mechanisms, already has substantial support in Massachusetts. MassCEC’s ongoing ACES grant, as well as the broader InnovateMass grant, has provided funding to innovative use cases and business models for energy storage projects. Data gained from the ACES project will be crucial for improving storage bankability. Still, the market’s reliance on established technologies demonstrates an opportunity to support the development of business models involving earlier stage battery technologies.

Such supports could be in the form of customer use data sets or, for example, commercial customers who would improve innovators’ understanding of customer value propositions. Conversely, several innovators and investors themselves pointed out a lack of investor knowledge about energy storage and particularly the gaps between expectations and reality on both technical and commercial matters.

2.2.3 Knowledgeable Investors and New Investment Models

Investors offer critical resources for startups: not only capital but also hard-earned advice and industry connections. Finding the right investment partner, particularly the first significant one, is a critical step for startups. Unfortunately, the difficulties of the energy storage market make attracting investors difficult. Traditional venture capital timelines mesh poorly with energy storage hardware development.[27] Further, many investors cite knowledge barriers as a major reason they avoid energy storage opportunities. MassCEC’s work in this area was praised, but interviewees highlighted that more could be done.

Interview subjects pointed to the need for a more patient investment model incorporating sources of capital other than traditional venture capital, including family offices, debt-based instruments, or philanthropic investing. Our interviewees gave (or indeed were part of) some examples of patient investors willing to learn the complexities of energy storage, especially in

[27] Gaddy, B., Sivaram, V., & O’Sullivan, F. (2016). *Venture Capital and Cleantech: The Wrong Model for Clean Energy Innovation*. Retrieved from http://energy.mit.edu/wp-content/uploads/2016/07/MITEI-WP-2016-06.pdf

more mission-driven funds. Even so, a capital crunch at an early stage could prevent start-ups that develop valuable technologies from commercializing successfully.

2.3 Policy and Regulation Barriers

“It's a chain from idea to proof of concept, to funding; onto team building, intersecting tech, then what it takes to scale. If any link in the above chain is broken, it won’t go forward... If an investor sees a market barrier when it comes to commercialization, they will be scared of losing their exit.“ - Ecosystem Accelerator B

2.3.1 State Deployment Policy Risks Locking In Lithium-Ion

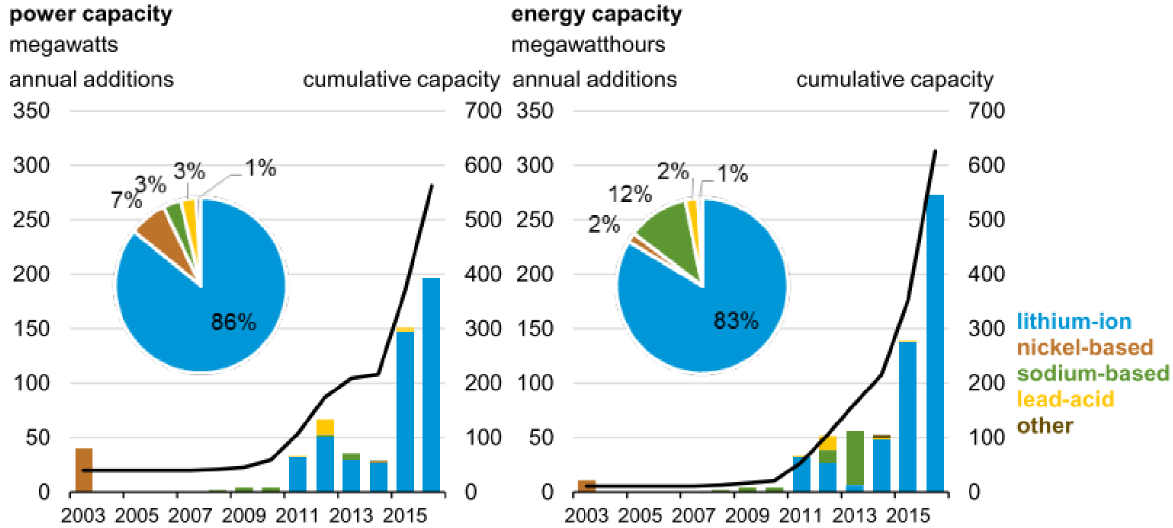
Massachusetts' efforts to set storage targets and the development of a clean peak standard were universally applauded by our interview subjects.[28, 29] The strong commitment of the state’s executive and legislature to storage deployment means startups, investors, and developers are less worried about policy risk when investing in Massachusetts than in most other locations.

Stationary storage developers interviewed made it clear that “developers will chase incentives” and that the current policy incentives reinforce technology risk aversion. Following national trends, almost all the deployments are from well-established lithium-ion chemistries (see figure 4 below). Much of this, our interview subjects pointed out, was due to the favorable economics of lithium-ion over other underdeveloped forms of energy storage. The desire to deploy already commercially available technology has a downside: technology lock-in, hindering the development of innovative storage technologies such as flow batteries.

[28] Spector, J. (2018, August 1). Mass. Lawmakers Set Storage Target, Raise RPS, Overturn Rooftop Solar Demand Charge. GreenTech Media. Retrieved from https://www.greentechmedia.com/articles/read/massachusetts-lawmakers-set-storage-target-raise-rps-overturn-rooftop-solar

[29] Kuser, M. (2019, January 6). Mass. Inaugurates Clean Peak Standard. RTO Insider. Retrieved from https://rtoinsider.com/massachusetts-doer-clean-peak-minimum-standard-108832/

Figure 4: Deployed Energy Storage Capacity by Battery Type



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

The solar industry experienced technology lock-in after aggressive policies focused on deployment, and the same thing appears to be happening in the stationary storage market.[30,31] While being the most commercially viable technology available for most storage applications, lithium-ion battery technology has significant drawbacks. Our interview subjects pointed out the well-documented supply chain risks (both in terms of quantity of supply and origin), the dangers of fires, and the concentration of the industry in a few large companies.[32,33,34] All these would be mitigated if other energy storage technologies were to successfully mature and achieve viability in the market place alongside lithium-ion.

"The fear is that the view of the energy system may be wrong, locking us into an undesirable future. A support ecosystem that pushes too strongly in one direction risks having unnecessary investments." - University Researcher A

Massachusetts' deployment policies are not as aggressive as in some other states but, given the long life cycles of storage assets, some consideration should be given to diversifying the technologies deployed over time to avoid the systemic risk of being reliant on a single technology.

30 Hoppmann, J., Peters, M., Schneider, M., & Hoffmann, V. H. (2013). The two faces of market support - How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry. Research Policy, 42(4), 989–1003. https://doi.org/10.1016/j.respol.2013.01.002

31 Hoppmann, J. (2015). The Role of Deployment Policies in Fostering Innovation for Clean Energy Technologies: Insights from the Solar Photovoltaic Industry. Business and Society, 54(4), 540–558. https://doi.org/10.1177/0007650314558042

32 Mozer, P., & Lee, S.-H. (2016). Samsung to Recall 2.5 Million Galaxy Note 7s Over Battery Fires. New York Times. Retrieved from https://www.nytimes.com/2016/09/03/business/samsung-galaxy-note-battery.html

33 Spector, J. (2019, April 23). What We Know and Don't Know About the Fire at an APS Battery Facility. Greentech Media2. Retrieved from https://www.greentechmedia.com/articles/read/what-we-know-and-dont-know-about-the-fire-at-an-aps-battery-facility

34 Zhong, R. (2019, April 22). Tesla to Investigate Car That Appeared to Burst Into Flames in Shanghai. New York Times. Retrieved from https://www.nytimes.com/2019/04/22/technology/tesla-explosion-shanghai.html

2.3.2 Permitting Pathway Uncertainty

For better or for worse, Massachusetts has a reputation as a regulation-heavy state. By adding costs and delays, bureaucracy hinders investment, throttling pilot scale deployment, and, consequently, energy storage in the state.

Our interviews revealed that commercial and startup companies desire improved service and communication from local and state regulators, as well as the utilities, to expedite and facilitate project deployment. Several interviewees cited permitting uncertainty as a major barrier to setting up pilot projects in Massachusetts. One startup near Boston described permitting uncertainty as a key reason that they pilot and test their developing energy storage products outside the state. The complexity of doing business in Massachusetts was baked into their growth plan, despite Massachusetts having all the indicators of a good market. The CEO, in his interview, indicated his small company could not afford the expensive consultants and lawyers required to do business in Massachusetts.

"Policy and fixed costs of policy are high and require a lot of strategizing. Outsourcing to a law firm is too expensive." - Startup CEO C

Regulatory barriers to energy storage also exist at ISO New England, which manages the high-voltage power grid and wholesale power markets. In many applications, stationary energy storage profitability remains dependent on the structure of the energy markets, which are undergoing a radical transformation, leaving energy storage startups prone to risks dependent on the direction of that change and making it more difficult for energy storage ventures to attract investors. (Other federal regulatory uncertainties under FERC jurisdiction were described by interviewees, but those fall outside the scope of this paper.)

3. Proposed Improvements to the Massachusetts Energy Storage Ecosystem

To improve the energy storage ecosystem in Massachusetts, interviewees made several suggestions that (if implemented) would deepen interactions between ecosystem participants, increase the speed and quality of iterative testing, and reduce participation barriers.

3.1 Foster More Interactions between Ecosystem Participants

3.1.1 Creation of an Energy Storage Center in Massachusetts

Key stakeholders: Government, Accelerators

Many of the challenges outlined in this paper are ones of coordination, information disparities, and business skill education. One way suggested by interview participants to improve on all these fronts is to create a stably funded energy storage center to act as a nexus between ecosystem stakeholders. This center could provide networking opportunities, educate investors, and new entrepreneurs, while continuously advocating for the energy storage community. As a centralizing force in the ecosystem, it should be collocated with startups, allowing for the serendipitous connections that are seen in the best ecosystems.

The center's mission must be broad, allowing for the rapidly evolving nature of energy storage technologies and market segments. For it to create the most value for ecosystem participants, the center must encompass the needs of adjacent markets, like recycling and software.

The center would have detailed knowledge (and in some cases, possession) of assets, equipment, and capabilities located in (or near) Massachusetts that would be available to energy storage innovators. Such a center could also provide help identifying niche markets for startups, connecting them to individual champions within organizations that are willing to undertake pilot projects. Finally, the center would ensure that energy storage startups transitioning to Massachusetts have a single point of information, lowering barriers and ensuring that startups from around the world want to move to Massachusetts.

Tackling these problems would have distributed benefits. This center would act as a focal point, advancing the state government's energy storage ambitions, and the seed funding could be provided by the state. This center could run related programing to draw additional funding from corporations, utilities, and developers. Another option is to integrate it into MassCEC, although there could be conflicts with that organization's technology-agnostic approach.

3.1.2 Improving Innovation Diffusion in Utilities

Key stakeholders: Utility, Startups, Government

Many of the members of the energy storage ecosystem pointed out that utilities walk a fine line when dealing with energy storage innovation. On the one hand, utilities control much of the data and access to systems and customers that startups need to work with. On the other hand, many acknowledged that utilities had an obligation to their ratepayers to minimize risks in the power grid, maintain reliability of electric service, and keep costs low. As a whole, interviewees described utilities as cautious, making a connection to the innovation ecosystem difficult.

"Utilities are slow, and like learning at a measured pace"- Utility B.

An employee of a major utility interviewed described a tentative willingness to experiment with energy storage, but only insofar as a *potential* tool to use in fulfilling RFPs. The main issue is the lack of institutional knowledge about energy storage inside the utilities, especially among utility system planners who make critical recommendations on future infrastructure deployment. This lack of familiarity, when combined with an understandable risk aversion, leads to a slow pace of change.

The outsourcing of various analyses to engineering procurement firms by utilities adds another layer of separation between the utility and new energy technologies, reducing the chance that utilities develop familiarity with new energy storage technologies – especially emerging products and applications.

One way to overcome this challenge may be for entrepreneurs to engage with an underutilized resource in Massachusetts: the Municipal Light Plants (MLPs). These small community-owned utilities may have more flexibility to innovate relative to the large investor-owned utilities in the state. They already are experimenting with energy storage to mitigate RNS fees.
By assuaging fears about new technologies, successful engagement by energy storage innovators with MLPs could prove crucial first inroads to critical constituencies inside the large utilities. Such work could fit into existing grant structures, reducing the need for new program creation.

“Big guys have the money to do things, but they have other things to focus on, can’t react as quickly. Surprisingly, the MLPs can put new tech on the grid faster than the big guys. Excellent middle ground.” - MLP Utility C

Instead of creating new incentive programs, innovation-focused state institutions and ecosystem members should increase efforts to connect with these organizations. This could be in terms of investments, pilot projects, sharing of resources, or other forms of engagement.

More than the ecosystem reaching out to the utilities, major utilities should consider the best way for them to connect with startups. The disruption of energy markets by storage is just beginning, and developing organizational innovation capabilities is critical to the core mission of delivering reliable and cheap electricity. Using meetings and networking events is an excellent way to allow innovative ideas to spread to operations focused utility engineers, lowering the barriers to adopting new technology. These events should be explicitly aimed at removing knowledge silos inside utilities.

3.2 Accelerating Iteration by Improving Testing in Massachusetts

3.2.1 Creating a Manufacturing and Testing Center

Key stakeholders: Universities, Government, Investors

The problem of testing is a tricky one that vexed many of our interview subjects. They came up with a multiplicity of ideas, of varying scales of ambition.

One proposal for lab-scale testing revolved around leveraging the tremendous strength of local universities to create a micro-manufacturing and testing hub, similar to ones in other states. Collocating the facilities to manufacture and test a lab-scale prototype allows companies to test different configurations based on test results rapidly.

This facility could be located inside a university (or perhaps a decommissioned power plant). Assuming confidentially of test findings can be maintained, such a testing hub would allow startups to avoid capital intensive investments in specialized equipment and consult with expert researchers around designing experiments using standardized methodologies. Results from an industry acknowledged center would improve investor and customer trust and reduce technology risk. This type of center would be excellent for pre-pilot development and prototyping, allowing rapid and reliable iteration without expensive transport of equipment and staff out of state.

It might also serve as a draw for energy startups, increasing Massachusetts' profile around the world as an energy storage hub. Using universities, already accustomed to patent issues, provides some protection from intellectual property concerns. The main challenge will be marketing the service to startups, although this challenge is mitigated since many of them are located here in the Bay State.

While a university-based testing and manufacturing hub would be adequate for many smaller-scale batteries, a pilot-scale testing capability for large batteries was also seen as necessary by interviewees. Three possible approaches to these challenges emerged from the interviews.

The first was a grant and obligation system for public and private universities to partner with energy storage startups to provide demonstration sites on campus. The public and private universities, due to their missions to catalyze the spread of knowledge, would partner with the state government to fund these demonstration sites. This would require quite some buy-in from university operations officials, as well as a mechanism for certification of results. Using the university as a living laboratory, one with both residential and various types of commercial buildings, is particularly appealing if the universities are allowed to share and publish papers on the unique results of such activities. It should be noted that Boston University and several other universities in the area are using campuses as living sustainability laboratories already. The number of universities with suitable microgrids requires study.

Another interview subject suggested incentivizing communities to become living laboratories themselves, using grid-scale energy storage systems. Such an approach could test the performance of the battery in a real situation, with real users and with a real client: a utility or municipal light department. The incentive for this living laboratory could come from a similar grant as the ACES program, or a Public-Private Partnership (P3) between the utilities and the state government. Several communities, due to geography, already have isolated microgrids and consequently face energy supply challenges, so this could solve two problems. There is a precedent for this in the state, with National Grid's Smart Energy Solutions grid in Worcester. Neighborhood electrical systems as testing grounds have been proposed with some success in Korea and Portland, Oregon.[35, 36]

The final suggestion was to build on the Moon Island facility in Boston Harbor and create a testing microgrid there. Moon Island is in Boston Harbor, connected to the mainland by road. MassCEC has already partnered with the City of Boston to build a fire training facility focused on energy storage. Expanding this facility to allow large scale testing would enable tests to happen in a safer location, already equipped for fire and safety, but still a real-world application with data that could be passed along to investors and clients. This would not have the benefit of a living laboratory, like the other two; however, it would act as a lure for energy storage and power electronics startups.

For any/all of these possibilities, the pricing of access to services could be lower for instate companies, further incentivizing companies to move to Massachusetts. A partnership between MassCEC and other clean tech investors could enable access to test data, providing investors with a dedicated staff and testing facility to test out potential investments.

3.2.2 A Platform or Organization Dedicated to Matching Pilot Projects with Startups

Key stakeholders: Government, Ecosystem, Utilities

Several interview subjects pointed out the need for an organization or website that connects pilot ready startups with internal champions at the potential host. While some interviewees suggested this as a focus for the energy storage center mentioned above, more than one participant suggested a website or web-based organization with supporting staff who help pair specific utility/customer problems with potential innovative solutions. One notable example of this type of site is REV Connect, New York's connection platform for new energy ideas.

The concept is simple: utilities can post business problems and run programming to get solutions without the need for the cumbersome RFP process.[37] While InnovateMass, a program focusing on promoting Massachusetts based pilot projects though grants, has a similar "technology spotlight," it lacks REV Connect's "innovation sprint" format. If a REV Connect-like

[35] McDonald, M. (2011, July 28). To Build a Better Grid - The New York Times. New York Times. Retrieved from https://www.nytimes.com/2011/07/29/business/global/to-build-a-better-grid.html
[36] Walton, R. (2018). Portland General Electric to develop "smart grids" in 3 Oregon towns | Utility Dive. Retrieved May 31, 2019, from https://www.utilitydive.com/news/portland-general-electric-to-develop-smart-grids-in-3-oregon-towns/539720/
[37] Walton, R. (2018). Project of the Year: REV Connect | Utility Dive. Retrieved June 2, 2019, from https://www.utilitydive.com/news/rev-connect-project-of-the-year/539951/

process is set up in Massachusetts, it could first focus on utility needs, but expand to the industrial and commercial sector as well.

This matchmaking service would probably need to be undertaken by an existing organization within the energy storage ecosystem. Given the similarity to many ecosystem support programs already run by accelerators and incubators, one of these organizations could host the site. As suggested by the REV Connect model, an organization such as Connecticut's Greenbank could be brought in as a partner to mitigate financial risks.

3.3 Lower Barriers to New Types of Participation in the Ecosystem

3.3.1 Enabling Business Model Innovation

Key stakeholders: Ecosystem, Startup, Government

Business model innovation was repeatedly identified as a major need by both start-ups and investors. Start-ups need to have more creativity around the ownership and finance side of their business, while typical venture funding sources are a bad fit for most energy storage opportunities.

Some key steps to improving energy storage business model innovation identified by our interviews are:

- Improving grid-scale data availability for startups to allow innovators to identify opportunities.
- Clearer articulation of pain points in storage financing combined with innovation sprints.
- Allowing greater input from the innovation community in RFPs and planning.

Of course, many of these proposals need more study.

3.3.2 Leveraging Universities as Knowledge Dissemblers

Key stakeholders: University, Startups, Investors

Repeatedly, interview subjects highlighted the gap in management acumen within energy storage start-ups, which are usually launched and managed by technically-gifted founders. Many of the ecosystem participants claim avoidable business errors lead to higher failure rates among startups. Many interviewees from startups described being surprised by the number of business decisions they have to make, relative to their original intent of simply developing a better product.

Many of these founders are from the Bay State's world-class universities. These universities have acclaimed business schools with entrepreneurship courses, often with specialized tracks for cleantech. Prospective entrepreneurs should be incentivized to take these classes through accelerator partnerships with universities or state programs, reducing the chance of simple business errors. Furthermore, business schools could be important resources to lower knowledge barriers among two key demographics: investors and customers. These schools could offer public-facing courses designed to foster internal champions willing to help grow the cleantech industry here in Massachusetts. Alternatively, innovation-oriented classes could be hosted in various incubators, with the option for members to join.

Interview subjects also highlighted a lack of analysis of the commercialization process for energy storage and specifically the lack of a universally accepted comprehensive framework for battery chemistry commercialization. The TRL and CRL models are useful generally but do not describe the specific difficulties of energy storage. Universities are ideal places to develop such a framework, especially if they can collaborate with Federal institutions like Sandia and Argonne National Laboratories.

3.3.3 Develop Permitting Guides for Energy Storage

Key stakeholders: Government, Ecosystem

More than one startup and potential customer described the difficulties of permitting an energy storage project in Massachusetts. Most of them seemed willing to undergo the process, but costs and frustration stemming from uncertainty and time expenditure were discouraging. This made securing pilot projects, and testing out new business models, much more difficult and expensive.

Reforming the permitting system for energy storage should be a long-term goal for Massachusetts based on knowledge gathered from these initial deployments. However, in the short term, more clarity and transparency in the permitting system would be welcome. The state should invest time into developing permitting guides for energy storage as well, to draw more interest in the state. These guides should give concrete steps and a timeline for a company to follow.

4. Conclusion

Massachusetts has been an early leader in energy storage, and its activities so far have established fertile ground for further advancement in both technology innovation and commercial deployment. With additional strategic investment and guidance over the next decade, Massachusetts could become the premier hub for the future of the energy storage sector.

To do this, Massachusetts must learn the emerging lessons from both the still-nascent energy storage arena and the technology innovation community more generally.

- **Innovation cannot be purely technological**. Novel ways of financing, owning, and investing in energy storage are as important as new battery chemistries in developing the market – and achieving the associated economic and environmental benefits that energy storage can bring to Massachusetts.
- **The storage market is larger than chemical batteries**. The focus in the ecosystem is often on storage technologies defined too narrowly and fails to include adjacent markets like power electronics or recycling.
- **Rapid testing is key to innovation.** Local prototyping and testing must be available at all levels of energy storage commercialization to shorten and improve product development cycles.
- **Energy innovation requires buy-in from all stakeholders.** In order to maximize the value of the network effects gained by ecosystem community members when they engage with each other, all stakeholders must participate actively.
- **An energy storage center will continue improving the ecosystem.** As suggested in this and other papers, an established advocate for energy storage can carry on the work of continuously coordinating and improving the ecosystem.[38]

[38] Umass Clean Energy Extension. (2019). *Creating Opportunity: Building a Massachusetts Battery Energy Storage Innovation Ecosystem*. Amherst, MA. Retrieved from https://ag.umass.edu/sites/ag.umass.edu/files/pdf-doc-ppt/creating_opportunity_in_the_ma_battery_energy_storage_innovation_ecosystem_umass_cee_-_june_2019.pdf

APPENDIX

A. Methodology

The information gathered in this paper consists primarily of insights gathered during interviews with 25 experts in the Massachusetts energy storage market conducted between January and April 2019. Literature research then supplements these insights. In order to maximize the diversity of viewpoints, the chosen interview subjects work in diverse fields, all relating to energy storage. In cases where subjects fall into multiple categories, researchers used their judgment to place them.

The study placed a premium on day-to-day experience with startups, or with energy storage deployments. Most of the interviewees were based in Massachusetts, though many had experience nationally. The interviews were conversational, though a set list of questions was kept in order to maintain focus.

When quoting interviewees, we avoid identifying information, instead listing them by category and letter when needing to identify them in order to encourage candid viewpoints. For example, a hypothetical interview subject at a regulatory agency would be identified as "*Regulator A*."

B. Technology and Commercialization Readiness Level Definitions

	Technology Readiness Level	**Commercial Readiness Level**
1	Basic principles observed and reported	Knowledge of applications uses, and markets are limited or incidental
2	Technology concept and/or application formulated	Cursory familiarity with potential applications, markets, and competing technologies. Market research is from secondary sources. Product ideas are speculative
3	Analytical and experimental critical function and/or proof of concept	Developed understanding of technology use cases, and the market allows a hypothetical product to be refined iteratively. Commercialization research is dependent on primary research and considers future market requirements
4	Component and/or breadboard validation in laboratory environment	Primary product hypothesis is refined through additional analysis of products and customers/users. Mapping technology/product attributes against market needs gives a clear value proposition. Cost performance model is created, and basic competitive analysis is carried out to find unique selling points. Suppliers, partners, and customers are identified and mapped. Regulatory requirements are identified.

5	Component and/or breadboard validation in relevant experiment	Deep understanding of market and target application leads to a defined product. Cost-performance model is refined and used to validate value proposition. Relationships with suppliers, partners, and customers are created and used to refine product. Basic financial model is built.
6	System/subsystem model or prototype demonstration in a relevant environment	Market/Customer needs are defined, documented, and used for product design optimization. Partnerships with key-value chain stakeholders are formed, and regulatory compliance is underway. Financial models are refined.
7	System prototype demonstration in an operational environment	Product design is complete, supply, and customer agreements are in place, stakeholders are engaged in product/process qualifications. Certifications and regulatory compliance are accommodated. Comprehensive financial models for early and late-stage production are complete.
8	Actual system completed and qualified in an operational environment	Customer qualifications are complete and initial products are manufactured and sold. Commercial readiness grows with scale. Market dynamics are continuously validated.
9	Actual system proven through repeated deployments	Widespread deployment.

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