Creating Opportunity:
Building a Massachusetts Battery Energy Storage Innovation Ecosystem

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The views and opinions expressed in this report are solely those of the authors.

Key Abbreviations & Acronyms

Abbreviation/Acronym	Meaning
BES	Battery Energy Storage
BMS	Battery Management System
BR	Battery Resourcers, Inc.
CEE	UMass Clean Energy Extension
CRF	Core Research Facility
DOER	Massachusetts Department of Energy Resources
E2STL	Electrochemical Energy Systems and Transport Lab
ECEL	Electro Chemical Energy Laboratory
GTL	Greentown Labs
Li-ion	Lithium-ion Battery
LMBC	Liquid Metal Battery Corporation
MassCEC	Massachusetts Clean Energy Center
MIT	Massachusetts Institute of Technology
MITEI	MIT Energy Initiative
NEC	NEC Energy Solutions, Inc.
R&D	Research and development
SBIR	Small Business Innovation Research Program
SEM	Scanning Electron Microscope
STEM	Science, Technology, Engineering, and Math
CEES	Skoltech Center for Electrochemical Energy Storage
TRI	Toyota Research Institute
TRL	Technology Readiness Level
UMass	University of Massachusetts
WCTI	Worcester Cleantech Incubator
WPI	Worcester Polytechnic Institute

Executive Summary

This report outlines the work, findings, and recommendations of a project undertaken by UMass Clean Energy Extension (CEE) over the course of the summer and fall of 2018 to evaluate and develop opportunities to enhance the emerging Massachusetts battery energy storage (BES) ecosystem. The originating scope of work was largely focused on developing a platform for battery storage ventures to access the technical resources and expertise of the Massachusetts academic sector.

During more than 20 hours of interviews and site visits, our work surveyed BES experts within the University of Massachusetts system, the Massachusetts Institute of Technology, and Worcester Polytechnic Institute, along with principals of a dozen of Massachusetts-based battery and energy storage ventures across a range of technologies and commercial readiness. We supplemented these communications with extensive secondary research sources including research reports, patent filings, technical journal publications, trade publications, market research resources, and web-based resources – and used the aggregated data as the basis for our findings and recommendations. Significantly, the study enabled us to identify additional opportunities to strengthen the Massachusetts BES innovation ecosystem.

In the course of identifying BES resources within the state's academic sector, it became clear that the need – and the opportunity – was greater than improving industry access to academic research resources alone. Accordingly, we developed a broad set of market recommendations and a prototype platform that address the core functionality of the study scope of work. In combination, these study outcomes are expected to be responsive to the broader market needs and opportunities identified in the course of our research.

> **"In the course of identifying battery energy storage resources within the state's academic sector, it became clear that the need – and the opportunity – was greater than improving industry access to academic resources alone."**

The Commonwealth is doing important work to support the critical *deployment* of new, advanced energy storage to enhance the efficiency, affordability, and resiliency of the electric grid, and for the ability to transition to a predominance of renewable energy generation. This report, in contrast, considers the opportunities for Massachusetts to better leverage its already active research, entrepreneurial and commercial sectors to *advance new battery technologies and business creation*. Supporting this advancement will expand economic development benefits of battery storage and strategically build on our state's advanced technology strengths.

It is clear from our research that Massachusetts has the makings of a vibrant energy and BES innovation ecosystem, which draws its strength in part through the strong coupling between the academic and private sectors that broadly underlies the robust Massachusetts technology economy.

Our primary findings and recommendations are summarized below and detailed in the main sections of the report.

Key Findings

Our research, interviews, and analysis reveal three overarching and related findings:

1. **The Commonwealth's colleges and universities have substantial technical, intellectual, and developmental BES resources that are of current and potential value to Massachusetts BES commercial ventures**. While we found that academic expertise applies to BES technologies at all scales, academic technical resources are largely concentrated at the level of bench-scale (up to 100 V) technologies. We identified limited equipment suitable for developing and testing medium-scale (>100V) systems, and little or no equipment suitable for large- or grid-scale

systems. It is notable that the surveyed companies did *not typically identify access to technical resources (e.g., fabrication, diagnostic, and testing equipment) as a primary limiting factor, and were more likely to note other needs as more significant, such as access to capital, workforce development, and manufacturing capacity*. We would expect that a broader survey of academic and industry players would further support this finding. Our industry surveys also revealed that, while a wide variety of technical resources is available at institutions across the state, no single institution has the core set of resources that an emerging commercial venture might need. Further, even when available, these academic resources may not be readily accessible to the commercial sector. Despite these challenges, it is clear that the Massachusetts academic sector is providing considerable technical expertise to state BES ventures at a broad range of system scales and developmental stages – and that the potential to foster and strengthen these working relationships is significant.

2. **Massachusetts is both generating BES ventures and attracting them from outside of the state**. The Commonwealth is functioning as a BES market engine and is arguably on the cusp of becoming a global locus of BES research and commercialization. This is in part due to the close coupling of the academic and commercial sectors that we observed (and that which more broadly underpins Massachusetts' broader technology sector). In fact, over 70% of the Massachusetts BES companies we surveyed were primarily direct spin-outs of Massachusetts academic institutions, including ventures of global significance. Additionally, we identified BES companies that have relocated to Massachusetts because of the recognized value of the Massachusetts technology ecosystem – and despite the lack of a dedicated BES facility, such as those that exist in other regions of the country. We also found that major multi-national corporations are establishing BES labs in Massachusetts, and are actively hiring technical talent from within the state's skilled workforce.
3. **The Commonwealth has the critical BES innovation ecosystem elements necessary for the state to become a global center of BES innovation and commercialization.** The strengths of the Massachusetts technology network were regularly cited by survey participants as critical to their success. Noted network elements include supportive state and NGO policies and programs, an active investment sector, a thriving and generative academic research community, and a growing commercial sector made up of new, mid-stage, and established global players. While the Massachusetts BES network is functional to an important extent, it is still emerging and finding traction: fostering greater ecosystem connectivity, efficiency, and impact is possible – and doing so would represent a significant opportunity for the Commonwealth. Our findings suggest that several key elements are necessary to support, grow, and fully capitalize on the potential of this emergent Massachusetts BES innovation and commercialization ecosystem. Strategies for doing so are described in **Section 4** below.

Recommendations

To most effectively build on the significant momentum in the state's BES industry, our recommendations focus on strategies to enhance the identification and connectivity the nascent Massachusetts BES innovation ecosystem. We recommend a multi-pronged BES initiative incorporating the following elements:

1. **Create a Massachusetts BES Leadership Consortium/Steering Group:** Primary functions of this Leadership Consortium will be to serve as a steering committee for strategic decision-making and related initiatives, and increase the profile and visibility of the Massachusetts BES industry. The leadership will create and steer actionable agendas for industry forums, advise and promote the functionality and peer participation in the web-based platform (described below), and provide identity and voice for public outreach in and beyond the Commonwealth. Our research underscored the high-degree of coupling between various stakeholders, and the importance of engaging all stakeholders to effectively understanding issues and opportunities.

2. **Convene and Facilitate BES Industry Events, Symposia, and Networking Opportunities:** The value of increased opportunities for networking was almost universally agreed upon across both academic and commercial sectors. We are recommending periodic face-to-face events and symposia to facilitate networking among Massachusetts BES academic, and private- and public-sector ecosystem stakeholders. While online platforms and searchable databases are important, the value of face-to-face connections cannot be overstated. This includes facilitated discussion between stakeholders on topics relevant to decision-making and policy.
3. **Develop and Disseminate a Massachusetts BES Innovation Ecosystem Brand:** We recommend that Massachusetts raise the profile and visibility of the state's BES sector by developing a "brand" identity that clearly communicates the Commonwealth's role as a global opportunity center for BES innovation and commercialization. One picture that emerges from our research is that the Massachusetts BES innovation ecosystem is arguably emerging as one of the global centers of BES research, innovation, and commercialization. This may in fact represent an under-appreciated opportunity for the Commonwealth with regard to economic development, as well as serving state commitments to carbon emissions reduction and renewables adoption. Our research found that Massachusetts is already attracting BES ventures – despite the lack of a national research laboratory or dedicated research and development (R&D) facilities – and we suggest that effectively communicating and leveraging this value proposition will further the awareness and attraction to the ecosystem and will advance the strength of the ecosystem and its economic development opportunity.
4. **Develop a Multi-functional Web-based Platform to Connect Ecosystem Resources and Activities:** We are recommending the development of an online "virtual platform" to host a range of functions related to the Massachusetts BES innovation ecosystem. We are proposing an ensemble of components, reflecting core themes that emerged through the findings of our research program. We also designed a prototype web-based academic database intended to increase the availability and accessibility of these resources and enable them to play a greater role in the ecosystem. Additionally, the web-based platform offers the potential to serve as a "brand" platform to connect and communicate the collective strength of Massachusetts energy storage sector, and the value proposition Massachusetts offers to prospective energy storage ventures within and outside the Commonwealth.
5. **Develop and Support Publicly Accessible R&D and Testing Facilities:** We recommend further consideration for the development of dedicated energy storage R&D and testing facilities. Our findings suggest that such core facilities would be very useful for early-stage emerging ventures, mid-scale technology validation, and larger grid-scale systems prototyping and demonstration. Such publicly accessible facilities would also help to further communicate the Commonwealth's BES brand identity and value proposition to current and prospective BES ventures. Based upon our findings, we believe that there are two distinct facilities worthy of further consideration:
    - Small and mid-scale (i.e., cell- and stack-level) R&D and validation facility
    - Grid-ready system prototype testing and validation facility

6. **Support the Massachusetts Academic Sector as the Engine of the BES Ecosystem:** Critical germination and advancement in BES technology occurs in academic research labs. It is important to emphasize the fact that *over 70% of the Massachusetts BES companies surveyed were spin-outs of Massachusetts academic institutions*. It was clear that the institutions themselves have resource needs relevant to BES R&D. We recommend:

"Over 70% of the Massachusetts battery energy storage companies surveyed were spin-outs of Massachusetts academic institutions."

   - Exploring state and industry mechanisms to further support academic research, including the ability to support graduate students; and
   - Supporting the capacity of academic researchers to facilitate commercialization of their research.

These recommendations are further detailed in **Section 4** below, along with a set of next steps to implement these recommendations.

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1.0 Introduction

1.1 The Promise of Energy Storage in Massachusetts

The U.S. energy storage market is poised for rapid growth and will be a $4.5 billion market in 2023 – and the value of the storage market is expected to double between 2019 and 2020.[1] Massachusetts is already beginning to reap the benefits of this expanding industry through both storage deployment and significant research, development, entrepreneurial, and commercial activities.

On the storage deployment front, there is significant potential and a recognized need in Massachusetts for "new advanced energy storage to enhance the efficiency, affordability, resiliency and cleanliness of the entire electric grid by modernizing the way we generate and deliver electricity. Increasing the amount of storage capacity on the power grid has the potential to transform the way we generate and consume electricity for the benefit of Massachusetts ratepayers."[2]

"The U.S. energy storage market is poised for rapid growth and will be a $4.5 billion market in 2023 – and the value of the storage market will double from 2018 to 2019, and then again into 2020."

While benefiting from the deployment of energy storage, there is an equally exciting opportunity to promote the growth of a Massachusetts energy storage industry, create jobs, and maintain and build a leadership position in this rapidly growing clean-tech industry. This can be achieved by enhancing the innovation environment for emergent battery storage companies within the state and as a means to attract new ventures to the state. Key components of this opportunity will be more efficient linking of companies to the energy storage expertise throughout Massachusetts' world-class academic sector, and investing in research and development and testing facilities. This will serve to solidify an energy storage industry cluster in Massachusetts that can help to grow a sustainable state BES sector and serve a competitive domestic and global export market. In short, a robust ecosystem of battery storage researchers, entrepreneurs, state agencies, financiers, advanced manufacturers, and industry players can offer the Commonwealth significant economic development and job-creation benefits.

1.2 Study Purpose, Scope, and Background

The intent of this study has been to investigate and articulate a platform to facilitate industry utilization of storage battery technology development capacity available across Massachusetts academic institutions. As commissioned by the Massachusetts Department of Energy Resources (DOER) and the Massachusetts Clean Energy Center (MassCEC), the specific scope of work requested that CEE:

1. **Identify relevant resources within the University of Massachusetts system, Worcester Polytechnic (WPI), and the Massachusetts Institute of Technology (MIT)**;
2. **Identify the relevant needs and resources of five to ten Massachusetts-based storage battery commercial ventures**; **and**
3. **Develop a platform to facilitate access to resources and opportunities between academic and commercial sectors**.

[1] https://www.woodmac.com/research/products/power-and-renewables/us-energy-storage-monitor/
[2] *State of Charge: Massachusetts Energy Storage Initiative*, 2016

The Commonwealth of Massachusetts has initiated significant legislation, programs, and policies to aggressively expand energy storage deployment and industry growth. High-performance storage batteries have been identified as an important factor in enabling the Massachusetts electric power grid to incorporate a significantly increased percentage of power from renewable sources.

This study is an outgrowth of a special Legislative Commission established in 2017 to consider means to enhance the success of energy storage entrepreneurship and business creation in Massachusetts. On behalf of the Commission, CEE completed a survey of Massachusetts energy storage stakeholders, and a benchmarking of national battery testing facilities, *Energy Storage and Battery Test Facilities: National Benchmarking Report*.[3] A key conclusion of this study, which led to the commissioning of the present effort, was "that access to technology testing equipment could greatly benefit battery entrepreneurs and emerging energy storage companies, and that substantial equipment and available capacity likely existed within the state university system, private universities, and private companies that can be useful to new ventures. Further, facilitating the connections between battery testing demand and supply may be an effective and low-risk means to advance emerging technologies, leverage academic research facilities, and maintain battery technology development and business growth in the state."

[3] https://ag.umass.edu/sites/ag.umass.edu/files/pdf-doc-ppt/energy_storage_and_battery_test_facilities_benchmarking_report.pdf

2.0 Study Design, Methods, and Limitations

As discussed above, CEE was charged with conducting an effort to facilitate and foster connections between the early-stage battery technology commercial sector and testing resources available within the University of Massachusetts system, as well as a small sample of private academic research institutions in the Commonwealth. The goals of this work were to:

1. Explore the capacities and interests in higher education and across a sample of industry members;
2. Examine alternative means to facilitate communications and connections between these sectors; and
3. Pilot a "matchmaking" process to inform the development of a long-term strategy.

To meet these objectives, CEE framed the study using two major elements:

- A **research component** in which a sample of BES academic and commercial resources were characterized and the status and nature of the ecosystem articulated; and
- A **design component** in which CEE utilized research findings to inform and design recommendations, including a multi-pronged initiative to leverage the collaborative potential of the state's emerging BES innovation ecosystem.

Figure 2.1 below provides the location of each commercial- and academic-sector BES entity engaged in the course of this research.

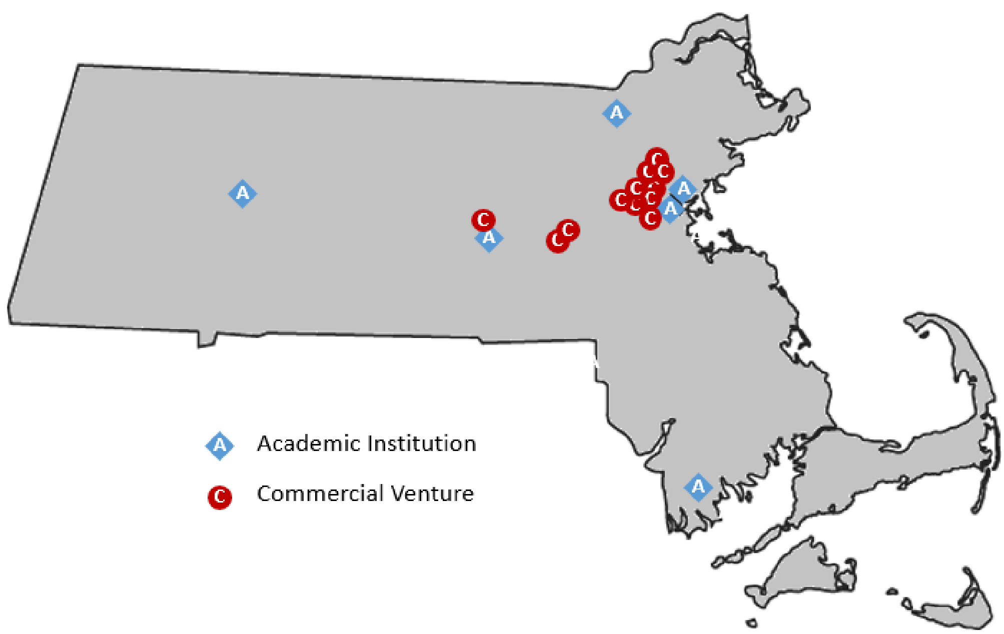

Figure 2.1: Location of the Massachusetts academic institutions and commercial ventures included in the study

2.1 Data Sources and Management

We pursued a systematic multi-pronged approach to identifying and characterizing available BES resources and needs. We undertook a comprehensive study through both primary and secondary sources.

Primary source research

Central to our primary source strategy was to conduct interviews with key individuals at each academic institution and company. Participant interviews were essential to integrating the dispersed and multi-variate nature of the information gathered. In short, interviews represent the primary information channel, and when compiled and synthesized with secondary source research, led directly to the key findings detailed in **Section 3**.

We conducted over 20 hours of face-to-face or telephone interviews, with the objectives of identifying and characterizing relevant BES resources, as well as specific needs and barriers to collaboration. Each interview was subsequently transcribed and stored to a central cloud-based project file system. The thrust of the interviews involved a discussion of the types and configurations of BES research tools and resources that were most relevant and important to the interviewee. Significantly, the interviews were also an excellent opportunity to gain direct insight into researchers' generalized perspectives on the BES innovation ecosystem.

"CEE conducted over 20 hours of face-to-face or telephone interviews, with the objectives of identifying and characterizing relevant BES resources, as well as specific needs and barriers to collaboration."

CEE endeavored to identify interviewees at each academic institution who were working in BES-relevant fields. One research challenge faced is the fact that relevant work in the field is dispersed across multiple disciplines and technical paradigms. In some cases, it was relatively easy to identify faculty focused on BES research. However, academic researchers did not always self-identify in this way. The important point here is that an essential technical resource may be connected to a researcher or a lab that is not explicitly associated with energy storage. A listing of research resources can be found in **Appendix A**.

Secondary research sources

The goal of secondary source research was to develop further knowledge of the Massachusetts BES innovation ecosystem needs and resources, and to identify how to best match the needs of emerging ventures with available academic resources. Secondary sources included research reports, patent filings, technical journal publications, trade publications, market research resources, web-based resources, internet searches, etc. For example, secondary source research included keyword searches of grant award databases for agencies such as the National Science Foundation (NSF) and U.S. Department of Energy (DOE). In another example, CEE searched employment databases to identify the hiring needs of Massachusetts BES companies. Search results provided insights into companies hiring and the types of expertise sought. Secondary sources also include discussion with individuals who had relevant direct knowledge of a company or academic institution, but whom themselves were not a direct representative of that company or institution.

Follow-up surveys

Subsequent to each interview, CEE prepared and anticipated providing participants with a standardized follow-up survey, pre-populated with findings from each interview. These follow-up surveys were designed to serve several functions: streamlining the collection follow-up information, enabling interviewees to correct errors and provide clarifications, and providing a template to enable ongoing gathering of information within a standardized format. However, time and data limitations prevented us from providing these surveys to study participants during the course of the study. Doing so may be an important follow-on step. An example follow-up survey is provided in **Appendix B**.

2.2 Participating Academic Institutions

CEE identified and interviewed individual researchers across the six pilot institutions specified in the scope of work. Academic sector study participants are shown in **Table 2.1** below.

Table 2.1: Academic-sector study participants and institutions

Institution	Study Participant(s)
Massachusetts Institute of Technology	Dr. Fikile Brushett Dr. Yet-Ming Chiang
UMass Boston	Dr. Niya Sa
UMass Amherst	Dr. Wei Fan Dr. D. Venkataraman Dr. Wei Fan Dr. James Watkins
UMass Lowell	Dr. Ertan Agar Dr. Fuqiang Liu
UMass Dartmouth	Dr. Patrick Cappillino
Worcester Polytechnic Institute	Dr. Yan Wang

CEE conducted approximately 30-60 minute Interviews with participants via phone or in-person. Interviews were loosely standardized and structured to address (1) participants' access to relevant BES resources, (2) current and planned research needs, and (3) general insights into the nature of the Massachusetts BES innovation ecosystem. A sample of interview questions is presented in **Appendix B**. Interview notes were transcribed, stored, and are available to support future research efforts.

2.3 Participating Commercial Ventures

CEE was charged with evaluating the needs of five to ten Massachusetts based energy storage companies. To identify these commercial ventures in coordination with MassCEC, we began by identifying a broad range of 20+ battery-related companies active in the state, based upon a review of several primary and secondary sources. We then selected a representative cross-section to study, based upon developmental stage, and technology basis. Commercial sector study participants are shown in **Table 2.2** below.

We placed emphasis on early and growth-stage ventures, as outlined in the scope of work. Based on information developed through our primary-source interviews, we also included ventures that moved to (or were considering moving to) Massachusetts. These range from early-stage start-ups to research labs affiliated with major multinational corporations (e.g., TRI).

We also interviewed individuals at relevant governmental and quasi-governmental entities, including MassCEC, DOER, and the Worcester Cleantech Incubator (WCTI). Input and support from these entities was invaluable.

This project did not undertake a direct assessment as to whether the resources available at Massachusetts academic institutions constitute an equivalency to the functionality of a dedicated R&D and validation center, such as those studied in the *Energy Storage and Battery Test Facilities: National Benchmarking Report*.[4] This would have been beyond the scope of this study.

[4] https://ag.umass.edu/sites/ag.umass.edu/files/pdf-doc-ppt/energy_storage_and_battery_test_facilities_benchmarking_report.pdf

Table 2.2: Commercial sector study participants

Company	Study Participant(s)
24M, Inc.	Dr. Yet-Ming Chiang
Ambri, Inc.	Phil Giudice
Battery Resourcers, Inc.	Dr. Yan Wang
Battrion, Inc.	(Katie MacDonald)* (Victor Marttin)*
Form, Inc.	Dr. Yet-Ming Chiang Mateo Jaramillo
Greentown Labs	Katie MacDonald Victor Marttin
Lionano, Inc.	Dr. Siyu Huang
Lithio Storage, Inc.	Dr. Anthony D'Angelo
NEC Energy Solutions, Inc.	Michael Hoff
Sparkplug Power, Inc.	Sean Becker
Titan Advanced Energy Solutions	Dr. Steven Africk, Ashish Sreedhar
Toyota Research Institute	Dr. Brian Storey
Vionx Energy Corp.	Dr. Shazad Butt

**Greentown Labs on behalf of Battrion, Inc.*

2.4 Research Limitations

It was anticipated that the outcome of this project could potentially be something along the lines of a web-based "AirBnB"-style tool for matching resources with needs. Based upon this interest, we designed a research program to generate relevant data, and insight into the usefulness and structural and functional organization of such a tool.

It is important to note, however, that this study was not intended to be a complete assessment of resources and needs. Instead, we used the collected information to develop a platform design for gathering, organizing and maintaining information. Because of the limited timeframe and budget for the project, it was understood that the specific technical and financial resources required to adequately implement and manage a platform could well be outside of available resources.

Time and budget constraints meant that we only interviewed and researched a targeted portion of the academic and commercial BES innovation ecosystem in Massachusetts. Even for the universities and companies we identified, we were not able to interview all of the individuals identified. That said, we are confident our outreach and findings are representative of the broader ecosystem. A challenge we faced was simply the logistics of tracking down and scheduling interviews during the summer 2018 travel season. A significant number of inquiries went unanswered and interviews were re-scheduled or delayed on numerous occasions. However, these challenges were mitigated by the willingness of nearly everyone contacted to participate in the study and general eagerness to making themselves available. Notably, the individuals interviewed were excited to discuss their work, resources, ideas, and plans for progress. While this in itself does not represent an objective "data point", we do believe that this is important to note.

3.0 Key Findings

The specific focus of our research was to identify relevant technical resources within the Massachusetts academic sector, and to develop means for improving commercial access to those research resources. Significantly, the context of this work enabled us to keep in mind the larger question of opportunities for improving the overall function of the Massachusetts BES innovation ecosystem.

While an initial underlying premise of the study was that access to testing and validation resources was a key factor to enhancing ecosystem performance and attracting BES ventures to Massachusetts, it became apparent that several other factors were also important to this goal. Additionally, it became apparent that Massachusetts is uniquely positioned to create, support, and capitalize upon a BES innovation ecosystem cluster.

Our research, interviews, and analysis reveal four overarching and related findings:

Finding #1: The Commonwealth's colleges and universities have substantial technical, intellectual, and developmental BES resources that are of current and potential value to Massachusetts BES commercial ventures

While we found that academic expertise applies to BES technologies at all scales, academic technical resources are largely concentrated at the level of bench-scale (up to 100 V) technologies. We identified limited equipment suitable for developing and testing medium-scale (>100V) systems, and little or no equipment suitable for large- or grid-scale systems. It is notable that the surveyed companies did *not typically identify access to technical resources (e.g., fabrication, diagnostic, and testing equipment) as a primary limiting factor, and were more likely to note other needs as more significant, such as access to capital, workforce development, and manufacturing capacity*. We would expect that a broader survey of academic and industry players would further support this finding. Our industry surveys also revealed that, while a wide variety of technical resources is available at institutions across the state, no single institution has the core set of resources that an emerging commercial venture might need. Further, even when available, these academic resources may not be readily accessible to the commercial sector. Despite these challenges, it is clear that the Massachusetts academic sector is providing considerable technical expertise to state BES ventures at a broad range of system scales and developmental stages – and that the potential to foster and strengthen these working relationships is significant.

Finding #2: Massachusetts is both generating BES ventures and attracting them from outside of the state.

The Commonwealth is functioning as a BES market engine and is arguably on the cusp of becoming a global locus of BES research and commercialization. This is in part due to the close coupling of the academic and commercial sectors that we observed (and that which more broadly underpins Massachusetts' broader technology sector). In fact, over 70% of the Massachusetts BES companies we surveyed were primarily direct spin-outs of Massachusetts academic institutions, including ventures of global significance. Additionally, we identified BES companies that have relocated to Massachusetts because of the recognized value of the Massachusetts technology ecosystem – and despite the lack of a dedicated BES facility, such as those that exist in other regions of the country. We also found that major multi-national corporations are establishing BES labs in Massachusetts, and are actively hiring technical talent from within the state's skilled workforce.

Finding #3: The Commonwealth has the critical BES innovation ecosystem elements necessary for the state to become a global center of BES innovation and commercialization

The strengths of the Massachusetts BES technology network/ecosystem were regularly cited by survey participants as critical to their success. While the BES ecosystem is comprised of many interrelated programs, people, and institutions, major facets include:

- A robust and engaged academic sector;
- A thriving commercial BES industry and broader technology sector;
- An active investment community;
- Progressive clean energy and energy storage policies and program; and
- Expanding state, national and global BES market outcomes that drive the ecosystem.

Figure 3.1 below illustrates these essential battery ecosystem elements.

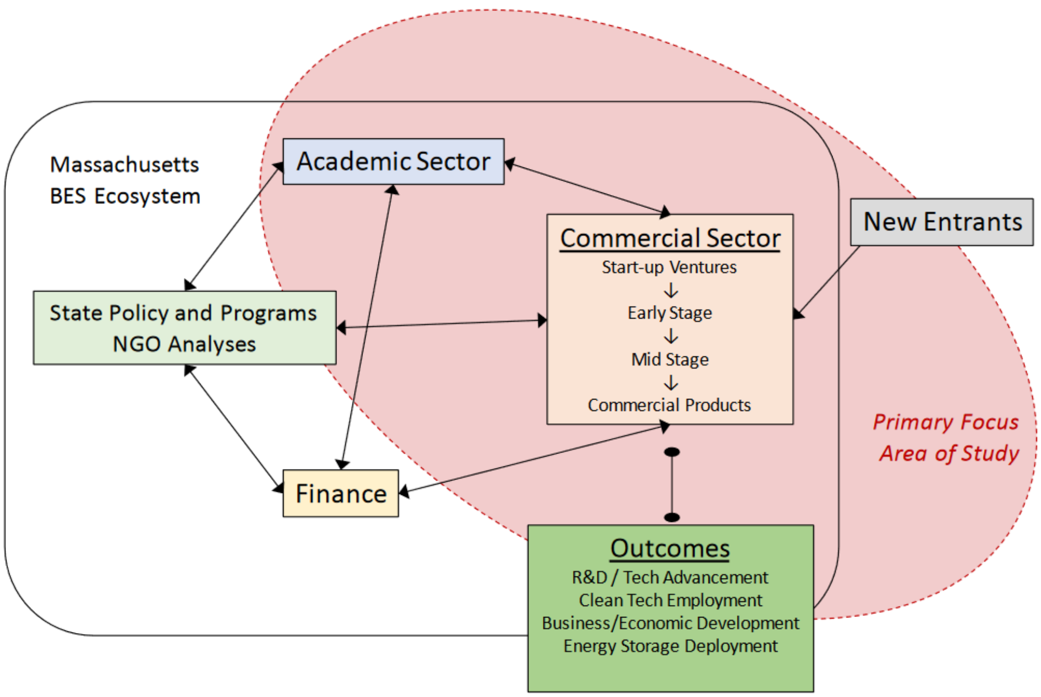

Figure 3.1: Massachusetts BES innovation ecosystem

While the Massachusetts BES network is functional to an important extent, it is still emerging and finding traction: fostering greater ecosystem connectivity, efficiency, and impact is possible – and doing so would represent a significant opportunity for the Commonwealth. Our findings suggest that several key elements are necessary to support, grow, and fully capitalize on the potential of this emergent Massachusetts BES innovation and commercialization ecosystem**.** Strategies for doing so are described **Section 4** below.

The following sections provide a basis and further explanation of the four main findings summarized above. We first examine findings from the academic sector, followed by the commercial Sector, and then describe current and potential synergies between these sectors and the opportunities and needs to enhance their connectivity.

3.1 Massachusetts BES Sector – Categories for Analysis

As anticipated, our research has shown that the state BES sector is not monolithic but is cast broadly across technologies, applications, and technology developmental stages. For the purposes of this study, we found it useful to consider the BES sector as broadly structured in terms of the following elements:

- **Technology Developmental Stage** (e.g., lab, scale-up, application/grid-ready)
- **Technology Basis** (e.g., Li-ion, Flow, other)
- **Market Application** (e.g., portable/personal, vehicles, grid integration)
- **Venture Developmental Stage** (e.g., start-up, growth/scale-up stage, revenue, established/corporate)

As might be expected, we found these categories to be somewhat dynamic and overlapping. For example, Lionano, Inc. is currently focused on the vehicle sector, but expressed interest in grid-scale applications. Lithio Storage began as a grid-storage venture but has pivoted to portable applications. UMass Boston chemist Dr. Niya Sa works with lab equipment most relevant to small (lab-scale) Li-ion systems but also has expertise that is relevant to advanced commercial applications, as well as to technical platforms beyond Li-ion.

We similarly broadly organized the scale of BES systems into three basic categories:

- Small-scale Systems (up to 100 V)
- Medium-scale Systems (greater than 100 V, and up to approximately 100 kW)
- Large- and Grid-scale Systems (ranges across residential, commercial, and utility scales)

These categories are based upon information generated in our research. While study participants referred to other system scale-related terminology (e.g., lab-scale, bench-scale, mid-scale), we feel that the above terms approximately capture the breadth of the technology size range. Scale roughly correlates with developmental stage with regard to grid-integration systems, but can also correlate with physical scale of application - such as a battery assemblage for portable devices - regardless of developmental stage. Accordingly, system scale is not necessarily an indicator of technical or commercial developmental stage.

3.2 Academic Sector – Resources and Needs

The Massachusetts academic sector holds considerable technical, intellectual, and developmental BES resources that are of current and potential value to Massachusetts BES companies. In our assessment, these technical resources are of greatest relevance to small-scale systems (up to 100 V). For example, it is conceivable that many of the technical resource needs of early-stage company Lithio Storage could be met by resources held by Massachusetts academic institutions, at least in principle.

We identified only very limited equipment suitable for scale-up or developing and testing medium-scale (>100 V) systems, and little or no equipment suitable for large, grid-scale systems. In fact, several academic BES researchers noted that medium-scale systems needed to be tested outside of the region (the Battery Fabrication and Characterization User Facility at the University of Michigan was often cited). In another example, the Sustainable Power and Energy Center testing facility at the University of California San Diego was repeatedly mentioned in the context of grid-scale systems validation. It is interesting to note that while “having to rush out to Michigan” for testing was noted as a burden by several academics, this was not noted in our conversations with commercial sector entities.

Significantly, the academic sector offers intellectual expertise as well technical as resources: in addition to equipment, the value of the expertise available within the academic sector was repeatedly remarked upon. For example, Loren Walker, Director of Research Development at UMass Amherst stressed that availability of UMass technical resources depends upon utilizing UMass expertise, “otherwise the business model doesn’t work.” In our assessment, the expertise available within the Massachusetts academic sector is exceptional, and holds the promise of relevance to systems of all scales.

Resources and expertise potentially relevant to BES R&D are typically spread across several technical domains and academic departments. Further, while fundamental science expertise may be highly applicable to BES, academic researchers may not necessarily associate themselves with the broader Massachusetts BES innovation ecosystem. Further, while academic technical resources are likely to be most relevant to smaller-scale systems, expertise is likely to be relevant across systems of all scales and developmental stages.

3.2.1 Structural Evaluation of the Academic Sector

Academic technical resources were found to be broadly organized into two basic categories:

1) Resources that are under the purview of an individual researcher’s lab or research group, and
2) Resources that are more institutional in nature, and less specifically associated with an individual researcher.

The Scanning Electron Microscope (SEM) lab at MIT, and the Roll-to-Roll Manufacturing Facility at UMass Amherst, are two examples of the latter. Resources that are more institutional in nature typically have well-defined access agreements and fee structures, typically involving fee-for-service arrangements. For example, MIT’s SEM lab charges $100/hour at the time of this writing. A number of academic researchers suggested that these facilities may be underutilized. UMass Lowell’s Core Research Facility (CRF) is another example of an outward-looking academic facility relevant to the Massachusetts BES industry. Dr. Siyu Huang of Lionano noted that they utilize the UMass Lowell CRF.

A considerable amount of BES-relevant equipment exists within the labs of individual researchers. The multi-channel battery characterization system in the lab of Dr. Niya Sa at UMass Boston is one example. However, accessibility of this type of equipment varies greatly, typically occurs on a case-by-case basis, and may not be considered generally available for commercial usage.

MIT’s Dr. Yet-Ming Chiang spoke to this restricted access as a potential factor negatively impacting the effective availability of research resources. Lithio Storage’s founder Anthony D’Angelo noted this as a challenge he had encountered as a start-up. Conversely, D’Angelo also noted that he still had access to a research group lab at Tufts University, where he conducted the Ph.D. research that would become the basis for his company.

Table 3.1 provides a summary of the BES resources identified at the academic institutions targeted in this study. Each of the resource categorizations are further defined and discussed below.

Table 3.1: Summary characterization of Massachusetts academic BES resources*

Academic Resource	UMass Amherst	UMass Lowell	UMass Boston	UMass Dartmouth	WPI	MIT	Other
BES-Relevant Resources							
Expertise	•	•	•	•	•	•	•
Equipment	•	•	•	•	•	•	•
Outreach/Policy	•	•	INS	INS	INS	•	•
Commercialization	•	•	INS	•	•	•	•
BES-Specific/Dedicated Resources							
Technical Resources		•	•	•	•	•	•
Researchers	•	•	•	•	•	•	•
Other	•	•			•	•	
Equipment Scale							
Small-Scale / Lab-Scale	•	•	•	•	•	•	•
Mid-Scale	•	INS			INS	INS	INS
Large- and Grid-Scale	INS						
Expertise Scale							
Small-Scale / Lab-Scale	•	•	•	•	•	•	•
Mid-Scale	•	•	•	•	•	•	?
Large- and Grid-Scale	•	INS	INS		INS	•	INS
Technology Basis							
Li-ion	•	•	•		•	•	•
Flow		•	•	•		•	•
Other	•	•	•		•	•	•
Technology Sector							
Portable Electronics	•	•	•		•	•	•
Vehicle	•	•	•		•	•	•
Grid-Scale	•	•	•	•	•	•	•
Resource Ownership							
Faculty/Research Group	•	•	•	•	•	•	•
Institutional	•	•			•	•	•
Collaborative Mechanisms							
Fee-For-Service	•	•	•	•	•	•	•
Sponsored Research	•	•	•	•	•	•	•
Co-PI/Grant	•	•	•	•	•	•	•
Consortium Membership	•	•	•	•	•	•	•
IP licensing	•	•	•	•	•	•	•
Individual Consulting	•	•		•		•	•
Other	•	•	•	•	•	•	•

*Data in table is based on best judgement given the available information from surveyed organizations.
INS = Insufficient Information.

BES-Relevant Resources

BES-Relevant Resources are broadly defined as technical and intellectual academic resources that support, facilitate and enable BES research and development in academic settings. They may not be directly identified as BES resources in the case of more basic research. These resources may also be relevant (and accessible) to the needs of commercial entities and other institutions through collaborative arrangements.

BES-Relevant Resources can be categorized as follows:

- **Expertise**: *Expertise* is defined as BES-related specialties and sub-specialties in the form of academic faculty, graduate students, and staff engaged in research that is (or could be) integrated into the BES innovation ecosystem. For example, UMass Boston chemist Dr. Niya Sa is involved in research related to Li-ion electrode chemistry, as well as multivalent systems. This research is highly relevant to both the academic and commercial sectors. Dr. Sa also expressed that she would value increased networking opportunities.

  It is important to note that academic BES expertise may be spread across several academic departments and even colleges within a single institution – and that expertise may not be directly or knowingly associated with BES. In fact, relatively few Massachusetts academic researchers surveyed self-identified as having a primary focus on BES. For example, while UMass Amherst's Dr. Wei Fan's work was not specifically identified as relevant to BES, he has collaborated extensively with both academic as well as industrial colleagues on BES related research, and his expertise and technical resources are directly relevant to BES. Academic expertise may also not relate directly to the development of BES technology hardware (e.g., battery chemistry, cell packaging) – but rather to very specific elements useful in growing and capitalizing upon a Massachusetts BES innovation ecosystem. Predictive computer modeling techniques are one example (Dr. Ertan Agar, UMass Lowell), as is grid-scale systems modeling (Dr. Prashant Shenoy, UMass Amherst).

- **Equipment***: Equipment* is defined as lab equipment and other technical resources that are relevant to BES R&D. For example, a SEM may not necessarily be identified as BES-related. The Roll-to-roll Manufacturing Facility at UMass Amherst is another example of a resource that is highly relevant to BES R&D, but is not a BES-specific resource.

- **Outreach/Policy:** *Outreach/Policy* is defined as resources and expertise that is relevant to broader contextual issues relevant to the adoption of BES technology and systems. UMass CEE at UMass Amherst and the MIT Energy Initiative (MITEI) are both examples.

- **Commercialization:** *Commercialization* resources and expertise within academia are relevant to the challenges of commercializing a BES technology. The entrepreneurial challenges of bringing a technology to market can often be more daunting than the technical challenges. The Massachusetts academic institutions targeted for this study vary greatly in the available resources and encouragement of commercialization of research activities. Further, the companies we interviewed typically cited business development challenges as greater than those associated with access to technical resources.

  We found that academic-industry collaborative mechanisms, agreements, and institutional business models for BES resource sharing across organizations is a critical aspect of a functional and efficient ecosystem. According to Loren Walker, Director of the Office of Research Development at UMass Amherst, it is difficult to make the business model of BES resource sharing functional without also accounting for the value of available expertise that almost always accompanies a hardware resource (e.g., testing equipment). In short, Walker indicated that the *software* of these sharing arrangements is at least as important as the *hardware*. UMass-Lowell's CRF is an example of an effort to develop an outward-facing collaborative model to enable outside entities to gain access to academic technical and intellectual resources.

BES-Specific/Dedicated Resources

BES-specific resources are defined as resources – expertise and/or equipment – that are dedicated and/or specific to BES R&D. The lab-scale equipment for vanadium electrolyte development in the lab of UMass Dartmouth chemist Dr. Patrick Cappillino is an example.

Equipment Scale and Expertise Scale

These categories refer to the relevance of equipment or expertise to the scale of a system, based upon the categories described above in **Section 3.1**. We differentiate between the scale relevance of equipment and expertise, as a researcher's lab may feature equipment relevant to small-scale systems, but the researcher's expertise may be relevant to systems that are larger scale or further along in their development. For example, Dr. Sa's lab at UMass Boston may be most appropriate for small-scale system hardware, but Dr. Sa's expertise is relevant to technologies at all scales. Similarly, Ambri's battery technology was relatively well developed, but encountered a technical challenge during scale-up that was addressed through tapping academic expertise in more fundamental materials science.

Technology Basis and Technology Sector

Our intent was to map academic resource availability onto the broad categories that we found best characterized the Massachusetts BES sector, so as to evaluate how the available academic resources might match the needs of the commercial sector. These assessments are based either upon direct knowledge of the relevance of a resource to a technology or technology sector (e.g., Dr. Agar's work at UMass Lowell with flow batteries), or our assessment of a resource's relevance (e.g., the relevance to Li-ion technology development of the coating capacity available at the Roll-to-Roll Manufacturing Facility at UMass Amherst.)

Resource Ownership

This category refers to whether an academic research resource is available at an institutional level, or is held in the lab of an individual researcher or research group within an institution. We found that the effective availability of a resource to the commercial sector can be significantly impacted by ownership.

Collaborative Mechanisms

We identified a wide range of academic-commercial collaborative mechanisms (e.g., consulting, sponsored research) being utilized between academic and industry players within the Massachusetts BES sector. Working arrangements between individual researchers and research groups exhibited the widest range of collaborative mechanisms. In one important example, the UMass system has established a voucher system to facilitate use of the CRF at its campuses, particularly by early-stage ventures. This system can help to reduce costs associated with utilizing the CRF.

3.1.2 Emergent Themes from the Academic Sector

As illustrated in **Table 3.1**, all six academic institutions surveyed have BES-related expertise and technical resources. In addition, we surveyed several other institutions, including Tufts University, Boston College and Harvard University, all of which indicated the availability of BES-relevant resources.

A common emergent theme from all of these surveys was a strong interest in extra-institutional networking and collaboration where it was not already occurring, and an interest in expanding collaborations in cases where it was beginning. For example, both WPI's Dr. Yan Wang and MIT's Dr. Fikile Brushett have independently explored developing outward-facing BES-related entities, and indicated an interest in collaborating with others to do so. More broadly, the idea of developing a platform for facilitating BES in the region received widespread support from the members of both the academic and commercial communities we interviewed.

It was widely agreed among study participants that an accessible database of BES-related academic technical and intellectual resources would be valuable. However, generally speaking, such information (that is, the data that would populate such a database) is not currently compiled into a single resource. Where is does exist, it is in widely varying forms, is often diffuse and inconsistent, and requires interpretation and normalization.

This is true for several reasons: The BES space is interdisciplinary, with resources and expertise often spread across many institutions, colleges, and academic departments. Further, relevant equipment and expertise may not be directly associated with BES. While relatively few Massachusetts academics self-identify as having a *primary* focus on BES, many work in areas that are of direct or indirect BES-relevance. For example, UMass Amherst chemist Dr. Dhandapani Venkataraman utilizes equipment for sophisticated surface characterization, yet his primary work may not be directly identified with electro-chemical battery research.

Accordingly, we developed several tools to facilitate the collection and normalization of this information. In **Section 4**, we present a database framework designed to be (1) responsive to the dispersed nature of the data, and (2) able to be regularly populated and updated by the academic institutions and researchers themselves.

3.2.3 Assessment of Academic Resources: Capacity and Need

A complete assessment of the capacity of academic resources to meet the developmental needs of BES ventures in Massachusetts was beyond the scope of this project. However, we can offer the following observations. Generally speaking, there are considerable R&D resources available at the small-system (<100V) scale. Academic resources decrease as systems increase in technical and development scale, and advance along the TRL level chain (described in **Appendix C**). We also found that as BES businesses evolve and advance, they are increasingly likely to purchase needed resources. For example, Ambri began using SEMs at MIT and Harvard University, but ultimately acquired their own instrument. This phenomenon is characteristic of many technology sectors and is not unique to the Massachusetts BES sector.

Capacity Assessment: Small-Scale Systems (up to 100 V)

The resources of the Massachusetts academic sector appear capable of serving many of the commercial needs of BES systems at earlier stages of development, or more advanced small-scale systems, up to approximately 100 V systems. For example, it appears that many of the scale-up equipment needs outlined by early-stage company Lithio Storage could possibly be met through the collective resources of the Massachusetts academic sector. However, the dispersed nature of the resources – and lack of clear collaboration pathways – are important limitations to companies such as Lithio Storage for making best use of these resources. (It should be noted, however, that Lithio Storage stated that access to capital was a more limiting factor to growth than access to scale-up facilities.)

Capacity Assessment: Medium-Scale Systems (>100 V – up to approximately 100 kW)

We did not identify any resources within the Massachusetts universities surveyed that were capable of testing mid-scale (>100V) BES systems. Several academic researchers mentioned this as a challenge for companies with which they had worked. Several researchers noted that there are no facilities of this scale anywhere in New England.

The University of Michigan's Battery Fabrication and Characterization User Facility was repeatedly mentioned as the facility of choice for Massachusetts BES companies with regard to testing medium-scale systems. It is important to note that researchers must drive to this facility as prototype battery stacks cannot travel by air.

Capacity Assessment: Large and Grid-scale Systems

We did not identify any resources within the Massachusetts universities surveyed that were capable of testing systems that were at this scale. There are also no facilities within the greater region. A testing facility at the Sustainable Power and Energy Center at the University of California San Diego was most frequently mentioned as the facility of choice for Massachusetts BES companies.

Academic Sector: The Engine of the Massachusetts BES Sector

An underlying premise of this study's original scope of work can be framed as "the academic sector has the resources, and the commercial sector has the needs – the provision of which will increase the likelihood of the state's BES sector's growth." During the course of our research, we found that the academic sector itself also has needs. For example, a recurring and specific theme among academics was how a relative lack of available funding for graduate students and post-doctoral fellowships in their research labs limits the progress they are able to make in advancing BES development. We feel that this is important to note, given the high proportion of Massachusetts BES companies we reviewed (70%) that are direct spin-outs of academic research labs, primarily at Massachusetts academic institutions. Put another way, Massachusetts academic institutions are one of the engines of the BES sector. If we are seeking mechanisms to improve the performance of the sector, it may be of considerable value to evaluate academic needs further.

Additionally, we found some evidence, anecdotal and otherwise, that Massachusetts academics are being pursued by other regions nationally and internationally, for their research expertise. For example, Dr. Deyang Qu, who had established a very active renewable energy research group and a well-equipped lab facility for electrochemical BES research and development at UMass Boston, recently relocated this lab and research group to the University of Wisconsin, where he was offered an endowed chair. Lithium-metal battery company Pellion, Inc.'s co-founder Dr. Gerbrand Ceder recently moved from MIT to a new position at University of California Berkeley. UMass- Boston chemist Dr. Niya Sa noted that she knew of several academics who have been recruited by universities outside of the U.S., to help support the BES development interests of those countries.

3.2.4 Overview of Surveyed Academic Institutions

University of Massachusetts System

Institution: University of Massachusetts at Amherst

Description: The University of Massachusetts at Amherst (UMass Amherst) is a major U.S. public Research 1 university. It is described as the "flagship" campus of the five-campus University of Massachusetts system. As a major research university, UMass Amherst has a primary orientation toward basic science and research within science and engineering, and has extensive research facilities and related expertise. We identified at least 12 researchers and a range of related R&D resources at the Amherst campus that are relevant to or engaged in the BES sector. In our assessment, the UMass Amherst campus has the potential to provide considerable relevant resources.

Resources and expertise potentially relevant to BES R&D are spread across several technical domains and academic departments, and are likely to be most relevant to small-scale (< 100 V) systems. Faculty expertise is likely to be relevant across systems of all scales.

UMass Amherst has noted cross-disciplinary research strengths in areas such as nano-materials, where the research is considered world-class. For example, the Facility for Advanced Roll-to-Roll Manufacturing has extensive resources of potential relevance to the BES sector. These resources are noted in the prototype database presented later in this report. UMass Amherst also has extensive facilities and technical expertise related to chemistry and chemical engineering, polymer science, nano-scale materials, and process engineering.

It is interesting to note, however that although several faculty are or have at some point engaged in research related to BES, none self-identified as having a primary focus on BES. For example, although Dr. Wei Fan (Associate Professor of Chemical Engineering) has expertise in carbon anode materials and surface characterization, and has collaborated with both academic and industrial colleagues in the BES sector, this information is not readily available, and only emerged through personal conversation.

As a public land-grant institution, UMass Amherst has a public outreach "extension" function that provides university resources and information to the public. UMass CEE is one example of this type of resource. This aspect of the university lends itself well to collaboration with the commercial sector, and to supporting the fulfillment of market development initiatives.

Institution: University of Massachusetts at Lowell

Description: The University of Massachusetts at Lowell (UMass Lowell) is a midsized public Research 2 university. It is located in the city of Lowell, about an hour north of Boston. UMass Lowell has particular strengths in science and engineering. The campus has worked actively to encourage technology innovation and commercialization – and engage with the commercial sector. For example, the University has established the Core Research Facility (CRF), to serve not only the UMass Lowell campus, but also regional technology businesses. The University's Office of Technology Commercialization may be the most pro-active technology-transfer office within the UMass system. UMass Lowell has also recently established a strategic relationship with clean technology incubator Greentown Labs Global Center for Cleantech Innovation (GTL).

In our assessment, the UMass Lowell campus has the potential to provide considerable relevant resources to early-stage BES research and commercialization activities. Several companies we interviewed mentioned having used the CRF at some point, and all of the UMass Lowell researchers we interviewed had multiple private sector collaborations.

UMass Lowell has an active core of researchers whose principal focus is energy storage R&D. UMass Lowell also has R&D facilities, notably the CRF, that are actively utilized by Massachusetts-based BES ventures. Companies are able to apply for and utilize a voucher system to pay for CRF services, through a system-wide UMass voucher program. University faculty have historically been actively involved in energy storage research and development, involving both electro-chemical storage batteries as well as fuel-cells. Two researchers in particular – chemistry professors Dr. Ertan Agar and Dr. Fuqiang Liu – are very active in the BES space, and have extensive academic and commercial collaborations. Together they have established the Electrochemical Energy Systems and Transport Lab (E2STL). Their collaboration with Dr. Patrick Cappillino at UMass Dartmouth is an example of cross-campus collaboration within the UMass system. Their work on flow batteries is of particular interest, because of the potential relevance of this technology paradigm to grid-scale applications. It should be noted that Dr. Agar has recently received a $500k funding earmark from the Commonwealth of Massachusetts, pending legislative approval, for continued development of flow battery systems.

Based upon our search of the scientific literature, UMass Lowell once had a battery testing facility. However, this facility appears to have ceased operation with the retirement of the associated faculty member.

Institution: University of Massachusetts at Dartmouth

Description: The University of Massachusetts at Dartmouth (UMass Dartmouth) is located in southeastern coastal town of North Dartmouth. This is near the city of New Bedford, and about 1.25 hours driving time south of Boston. It is a small Research 2 university and has active doctoral programs within engineering and the sciences.

UMass Dartmouth has a small but notable core of BES research activity, based around the lab of chemist Dr. Patrick Cappillino. This research work centers around stable electrolytes for vanadium redox flow batteries. Dr. Cappillino and his students have active research collaborations with academic and commercial partners, including UMass Lowell.

Institution: University of Massachusetts at Boston

Description: The University of Massachusetts at Boston (UMass Boston) is a "student-centered urban public Research 2 university" located just outside of Boston. As for all campuses within the University of Massachusetts system, it is a Research 2 university and has active doctoral programs within engineering and the sciences.

UMass Boston has a small but active core of research and development focused on BES. Chemist Dr. Niya Sa has recently arrived at UMass Boston, and has established a lab facility for BES research and development. Dr. Sa was previously at Argonne National Lab, where she was a chemist at the Joint Center for Energy Storage Research. Dr. Sa works in Li-on as well as multivalent and other battery technology paradigms. She has had extensive interaction with commercial BES ventures and holds several patents.

Dr. Sa's arrival follows the recent departure of chemist Dr. Deyang Qu, who had established a very active renewable energy research group and a well-equipped lab facility for electrochemical BES research and development. However, Dr. Qu has relocated this lab and research group to the University of Wisconsin, where he was offered an endowed chair.

Private Academic Institutions

Institution: Massachusetts Institute of Technology

Description: MIT is located in Cambridge, Massachusetts, a part of the Boston urban core. MIT is of international significance in BES research and commercialization. It can be considered one of the engines of BES not only in Massachusetts, but internationally. Several notable BES companies of international reach have spun directly out of MIT research. These include Massachusetts-based A123, NEC, Ambri, and more recently 24M and Form. MIT is also a source of graduates who have gone on to lead research programs at other Massachusetts institutions, as well as internationally, such as WPI's Dr. Yan Wang. These graduates also generate a ready source of highly-skilled employees for BES companies in the region. While MIT is not necessarily unique in expertise or resources, it is notable for the role it has repeatedly played in the BES sector.

MIT has considerable resources relevant to BES. These resources exist at both the broader institutional level, as well as the more localized level of research labs associated with individual researchers. Access to resources available at the more local level varies on a case-by-case basis. These resources are generally accessed through contact with individual researchers rather than with established collaborative mechanisms.

MIT has a very active core of both R&D and commercialization focused on BES. This includes a number of researchers and their associated research labs, such as Dr. Yang-Shao Horn's Electrochemical Energy Lab, as well as aggregate entities such as the Skoltech Center for Energy Science and Technology (CEST). MIT also has an extensive array of institutional-level resources, including the MIT Materials Science Center, the MIT SEM Laboratory, the MIT X-Ray Laboratory, the MIT Department of Chemistry Instruments, and so on. Dr. Fikile Brushett felt that MIT's institutional level resources were probably underutilized by the regional technology sector. Dr. Yet-Ming Chiang noted that resource availability varied depending on whether the resource was located at the institutional level, or within the provenance of an individual research lab. Phil Giudice, outgoing CEO of MIT spin-out Ambri, described how Ambri utilized the MIT SEM Lab prior to developing their own in-house SEM resources. The Ambri story also highlights MIT's deep connections to the regional technology sector and investment communities. For example, Ambri originally spun out of MIT in part through a relationship with Microsoft founder Bill Gates.

MIT also has a number of broader initiatives and resources of more general BES relevance. For example, MITEI is a broad aggregation of resources and individuals at MIT that reflects the interdisciplinary nature of the domain. In the context of BES resources, the MITEI infrastructure has the potential to serve as a useful point of central contact for access to MIT resources. For example, Energy Storage Research Center Director John Piret helped to facilitate contact with a number of key MIT researchers to support this study.

MIT is also at the forefront of commercialization activity and resources related to academic research. MIT is perhaps unique in the region for the degree of entrepreneurial support it provides to prospective commercial spin-outs. MIT is also deeply networked within the regional technology and venture capital communities. Resources such as the MIT Deshpande Center for Technical Innovation, and venture accelerator "The Engine", are examples of this. In 2017 "The

Engine" spun-out the new battery venture Form. This is undoubtedly one of the reasons that MIT is responsible for a high percentage of BES ventures that are academic spin-outs.

Institution: Worcester Polytechnic Institute (WPI)

Description: WPI is a private Research 2 university located in the central Massachusetts city of Worcester, about a 45-minute drive west of Boston. WPI is one of the first engineering and technology institutes in the U.S., and maintains strengths in engineering and the sciences.

WPI has a very active core of both R&D and commercialization focused on BES, centered around the Electro Chemical Energy Laboratory (ECEL) of Dr. Yan Wang. Dr. Wang did-post-doctoral work with Dr. Yet-Ming Chiang at MIT. In addition to Dr. Wang's ECEL, WPI has a number of institutional-level resources of potential relevance to the BES sector, particularly early-stage ventures.

Beyond basic research, Dr. Wang is very active in the commercial sector. For example, he has already spun-out two BES ventures in the Worcester area: Battery Resourcers, which recycles vehicle-scale Li-ion battery packs, and a new company focused on proprietary Li-ion electrodes.

Dr. Wang has also been exploring opportunities to create a regional platform to advance BES R&D and commercialization in the region. For example, he has received some support from WPI to explore creating a consortium of BES ventures.

3.3 Commercial Sector – Characterization and Needs

3.3.1 Characterization of the Commercial Sector

Table 3.2 below characterizes the BES companies that we surveyed across technology, scale, and commercial readiness. These companies were selected to provide a cross-section of BES activity in Massachusetts, but should not be considered a comprehensive selection. (See **Section 2.3** for a discussion of participant selection criteria.) It is important to note that these assessments do not represent any form of due-diligence, and are only provided here to illustrate general patterns and trends in the BES sector identified in the course of our (limited) research regarding technical resource needs. One characteristic to note is that several companies see their products as having potential to be scaled, and accordingly have relevance to several markets.

Table 3.2: Summary characterization of Massachusetts commercial BES ventures*

Commercial Venture	Lithio Storage	Battery Resourcers	Titan Energy	Battrion	Lionano	Sparkplug	24M	Form	Vionx	Ambri	NEC	Toyota Research Inst.	Greentown Labs
Technology Basis													
Li-ion	•	•	•	•	•	•	•				•	•	•
Flow						NA			•		•		•
Other						NA		•		•	•	•	•
Market / Scale													
Portable	•	•	•	•	•		•						•
Vehicle		•	•	•	•		•					•	•
Large- or Grid-Scale	•	•	•	INS	•	•	•	•	•	•	•		•
Technology Readiness Level (TRL)**													
	4-5	7-8	5-6	4-5	6-9	9	6-9	3-4	8-9	7-8	9	1-9	4-9
Venture Development Stage													
Early-Stage or Basic Research	•		•	•				•				•	
Scale-Up		•	•		•	•	•		•	•		•	
Revenue		•			INS	•	•		•	INS	•	•	•

*Data in table is based on best judgement given the available information from surveyed organizations.
**See Appendix C for a description of the TRL scale used in this study.
INS = Insufficient Information
NA = Not Applicable

Table 3.3 provides a summary of the technical, business, and financial needs of the companies that we surveyed. In the context of this study of access to R&D equipment, it is significant to note that access to R&D equipment was often ranked as less significant than other needs, such as access to capital.

The challenges of access to capital were a common theme among commercial study participants. This is hardly surprising, given that BES is still an emerging market sector, characterized by a relatively high percentage of emerging ventures. To this extent, we heard from early commercial ventures having a hard time raising capital in part due to the fact that investors are "shell shocked" with experiences of investing in battery start-ups in which "there hasn't been real ROI in 10+ years," as stated by one interviewee. It was mentioned that some start-ups have been able to raise some relatively significant early capital, in part through the strong reputation of founders. Another start-up was cited by one interviewee as a company that is identifying itself with the drone market more so than the battery market, in order to align themselves with what is perceived to be a more investible market sector than the storage battery market sector.

Table 3.3: Needs characterization of selected commercial BES ventures in Massachusetts*

Area of Need	Lithio Storage	Battery Resourcers	Titan Energy	Battrion	Lionano	Sparkplug	24M	Form	Vionx	Ambri	NEC	Toyota Research Inst.	Greentown Labs
							R&D / Validation Equipment						
Early-Stage or Basic Research	•			•				•					
Scale-Up	•	•	•	•	•		•	•					•
Large- or Grid-Scale	•	•		•	•	•	•	•	•	•	•		•
							Venture Development Needs						
Start-Up Resources	•		•	•									
Skilled Workforce	•	•	•	•	•	•	•	•	•	•	•	•	•
Manufacturing & Infrastructure	•	•	•	•	•		•	•	•	•			•
Partnership/Distribution	•	•	•	•		•	•	•	•	•	•		
							Company Needs, Ranked by Relative Priority† (1 = Greatest Need)						
Capital	1	1	1	1	2	2	1	1	1	1	2	3	1
Workforce	2	2	2	2	1	2	2	2	1	2	1	2	NA
Manufacturing	3	1	2	2	1	2	2	2	1	2	3	3	NA
Entrepreneurial Assistance	1	2	2	1	3	2	2	2	2	3	3	3	NA
Access to R&D Equipment	1	3	3	1	2	3	3	3	3	3	3	3	1
Access to Testing & Validation	1	3	3	1	2	3	3	3	2	2	3	3	1
Access to Expertise	1	3	2	2	2	3	2	2	3	2	2	1	3
Market Access	1	2	1	1	1	1	1	1	1	1	2	3	2

*Data in table is based on best judgement given the available information from surveyed organizations.
† Rankings are subjective assessments intended to characterize company needs relative to access to technical and validation resources, and do not represent a due-diligence assessment.
NA = Not Applicable

As further discussed in **Section 3.4**, the academic and commercial BES sectors are highly coupled in Massachusetts. **Table 3.4** demonstrates that within our survey sample, companies that were spun out from Massachusetts the academic sector are predominant, with others have relocated to Massachusetts in part due to the state's academic resources and highly trained workforce.

Table 3.4: Massachusetts-based commercial BES spin-outs from state academic institutions and re-locations

BES Company Origin	Lithio Storage	Battery Resourcers	Titan Energy	Battrion	Lionano	Sparkplug	24M	Form	Vionx	Ambri	NEC	Toyota Research Inst.	Greentown Labs
Spun Out from Massachusetts Academic Institution	•	•				INS	•	•		•	•	•[1]	•
Spun Out from Out-of-State Academic Institution				•[2]	•[3]	INS							
Relocated to Massachusetts from Out-of-State				•[4]	•	INS							
Massachusetts Non-Academic Origins			•			INS							
Out-of-State Non-Academic Origins									•				

[1] Located in Massachusetts because of academic collaborations
[2]ETH Zurich (Switzerland)
[3]Cornell University/NY BEST
[4]Currently in process of re-locating to Massachusetts
INS = Insufficient Information

3.3.2 Company Descriptions

In this section we briefly describe and characterize the participating BES companies listed in **Table 2.2**. We present them here in approximate order of their apparent developmental stage to best reflect the spectrum of BES companies in Massachusetts.

Lithio Storage, Inc, Somerville, Massachusetts (Greentown Labs)

Lithio Storage is an early stage company that is commercializing proprietary Li-ion battery technology developed at Tufts University by PhD student Anthony D'Angelo. The company continues to utilize lab facilities at Tufts University but would benefit from access to additional equipment. The company was originally focused on grid-scale storage solutions, but has recently shifted focus to wearable technology, in part due to the physically flexible nature of its technology. Lithio Storage won the 2018 $100k grand prize at the MIT Clean Energy competition, and has received some support from the MassCEC. The challenges facing the company in many ways epitomize those generally facing early-stage technology companies as they endeavor to make the bridge from academic research lab to commercial venture. Of all of the companies we interviewed, Lithio Storage is perhaps the venture that would benefit most from access to dedicated R&D and validation facilities. Having said that, other needs, such as access to capital and strategic partnerships were presented as more significant than access to technical resources. Lithio Storage recently moved to GTL in Somerville.

Battery Resourcers, Inc., Worcester, Massachusetts

Battery Resourcers, Inc. (BR) was founded in 2015 by WPI professor, Dr. Yan Wang, to commercialize a closed-loop process developed at his WPI lab for the recycling of Li-ion batteries. BR's proprietary process directly synthesizes new, low-cost cathode materials from exhausted Li-ion cells. BR sells these materials back into the Li-ion market. BR's process is considered the leading Li-ion battery recycling process, and BR has established significant strategic relationships with several Li-ion manufacturers, including A123. In June 2018, BR opened a Worcester pilot plant capable of recycling 500 kg of batteries per day. BR closed a $1.6M venture capital round in 2018, and is a MassCEC funding recipient. BR is now entering a growth phase. BR's primary challenges relate to issues of scaling manufacturing operations, establishing strategic market relationships, and growing sales. In addition to fundamental research, Dr. Wang is self-described as "very entrepreneurial" and is very interested in establishing an academic-industry BES consortium.

Titan Advanced Energy Solutions, Somerville, Massachusetts (Greentown Labs)

Titan is an advanced Battery Management System (BMS) technology start-up. Titan develops hardware/software solutions that meaningfully improve the daily performance, capacity, and overall life cycle of Li-ion batteries. Titan has developed novel technologies for monitoring charge status and performance of battery systems. Titan's systems apply across all BES sectors, including recycling. The company's primary scale-up challenges relate to developing strategic market relationships, and manufacturing and operations capacity. They indicated that a BES networking-based platform for Massachusetts would be valuable. Titan received $65k funding from MassCEC in 2018, and the company has reported sales. Titan is currently based at GTL. We met with principal scientist Dr. Steven Africk and engineer Ashish Sreedhar.

Battrion, Inc., Zurich, Switzerland

Battrion is a Swiss start-up that is actively seeking to re-locate to Massachusetts and has been in discussion with GTL about working together. Battrion is a spin-out of ETH Technical University Zurich. Battrion develops innovative fabrication technologies for Li-ion batteries that enable improvements in performance bottlenecks such as charging speed, energy density, and cost. Battrion has demonstrated its fabrication process at a pilot scale, and notes that its platform is fully compatible with current cell fabrication processes and materials. Based upon our conversations with GTL, Battrion is feeling the need to relocate because of a lack of capacity and opportunity in Europe to scale their venture. For example, Battrion has been repeatedly flying its engineers to the U.S. in order to pursue development. Battrion is specifically seeking to locate in Massachusetts due to the rich academic and entrepreneurial ecosystem for hardware start-ups, as they believe this to be one of the keys to developing as a company.

Lionano, Inc., Woburn, Massachusetts

Lionano, Inc. develops and manufactures proprietary Li-ion battery materials, including novel electrode and electrolyte technologies enabling high-performance and stable cells. According to COO Dr. Siyu Huang, Lionano is currently focused on the vehicle market. However, the company is interested in the grid-scale markets but "does not yet have the contacts there." Lionano was incorporated in 2013 in Ithaca, NY, and is a spin-out of Cornell University research. The company received "significant start-up support" from New York, which enabled the company to "launch and move through a proof-of-concept stage." Lionano was a member of the NY-BEST dedicated BES facility. However, Lionano made the decision to relocate to Massachusetts because of the perceived advantages of being located in the Massachusetts technology sector, despite Massachusetts not having a national lab or other dedicated BES facility. The company received a $22M series-B investment in 2017 led by a Boston venture capital firm.[5] The company is in a scale-up stage, and is aggressively hiring. According to Dr. Huang, Lionano is "widely [product] testing with global customers", and with "10 top U.S. companies." Primary challenges include capital investment to build out their manufacturing line, and the rapid pace of hiring. Dr. Huang indicated that they would like to see more government support for manufacturing and R&D. They are able to meet their needs for R&D testing and validation in-house. They also use the CRF at UMass Lowell, but would prefer a facility that was closer. They were very supportive of the idea of a BES "platform" to facilitate a broad range of networking, including talent recruiting.

Sparkplug Power, Inc., Somerville, Massachusetts (Greentown Labs)

Sparkplug Power, Inc. was incorporated in 2009, and is developing energy storage projects with the capability to provide 1-2 MW of grid regulation as well as backup power for host locations. The company utilizes a proprietary system for integrating solar generation with battery technology to create ancillary services for host sites with loads of more than 250 kW. Sparkplug is located at GTL, where it is installing a 280 kW/510 kWh system. Sparkplug is also a MassCEC grant recipient. A key challenge facing Sparkplug, according to GTL, is the slow pace of market adoption by prospective

[5] Kelly J. O'Brien, "Woburn start-up raises $22M to improve batteries in phones, electric cars", Boston Business Journal, 9/24/2018.

customers. Although market forecasts generally point to significant and widespread growth in demand for energy storage products like those offered by Sparkplug, market and policy factors rather than technology are combining to limit demand. This is not unique to Sparkplug, nor to the U.S. For example, UK Camborne Energy Storage has had similar market adoption challenges. We chose to include Sparkplug because it represents a systems-level application of the BES sector.

Form, Inc., Somerville, Massachusetts (Greentown Labs)

Form, Inc. is an early-stage company co-founded in 2017 by MIT chemist and serial BES entrepreneur Dr. Yet-Ming Chiang (associated with A123, NEC, and 24M), Mateo Jaramillo (ex-Tesla executive), Ted Wiley (Aquion), Marco Ferrara (IHI Energy Storage) and William Woodford (24M). The company was spun out through MIT's "The Engine" venture accelerator. The company is focused on developing long-duration grid-scale battery systems, based upon proprietary aqueous sulfur technology. The company is also pursuing a second, unspecified technology basis. The company currently has lab-scale prototypes. They have also been collaborating with the U.S. DOE's Joint Center on Energy Storage Research. The company recently raised $9M in Series-A VC funding. We met and briefly interviewed co-founders Dr. Chiang and Mateo Jaramillo.

24M, Inc., Cambridge, Massachusetts

24M manufactures Li-ion batteries for a range of applications, including vehicles and grid-scale storage – based upon a novel semisolid Li-ion battery technology and a unique manufacturing platform. 24M's platform is adaptable to both current and developing chemistries. 24M has established a number of strategic partnerships, including with NEC Energy Solutions (NEC), to produce grid-specific cells optimized for multi-hour duty cycles. The company was spun-out of Waltham-based A123 in 2010 by MIT chemist and serial entrepreneur Dr. Yet-Ming Chiang. The company was founded with $10.6M seed capital, and received an additional $6M in funding in 2011 through the U.S. DOE and ARPA-E. The company recently closed $22M D-round of venture capital funding and is currently generating revenue. We met and briefly interviewed Dr. Chiang.

Vionx Energy Corp., North Reading, Massachusetts

Vionx Energy Corp. was founded in 2002 as Premium Power, developing a technology that originated at United Technologies. Redeveloped in 2012 as Vionx Energy Corp., the growth-stage company manufactures long-duration grid-scale vanadium flow battery systems for a range of applications. The company also provides energy management systems, regenerative fuel cells with DC output power, and training and support services. Vionx is experiencing sales growth and has developed strategic partnerships with companies such as Siemens, Jabil, 3M and UTC. Vionx currently has two systems operating in Massachusetts: a 160 kW, 4-hour system at the U.S. Army's Fort Devens base, and a 500 kW, 6-hour system at the Worcester High School. The company has been successful in raising capital through multiple venture capital funding rounds, including $58M in 2015, $12.75M in 2017, and $6M in 2018. We chose to include Vionx because (1) the company offers technologies that provide longer-term storage (which may offer it competitive advantage over the currently predominant Li-ion technologies), and (2) Vionx represents a scale-up -stage company.

Ambri, Inc., Marlborough , Massachusetts

Ambri, Inc (formerly Liquid Metal Battery Corporation (LMBC)) is a scale-up stage company focused on commercializing proprietary battery systems for grid-scale power storage. The company was originally founded in 2010 to commercialize a novel liquid-metal battery technology originating from the lab of MIT's Dr. Roger Sadoway. The company has since developed additional novel battery chemistries and related systems. We interviewed outgoing Ambri CEO (and former Massachusetts DOER Commissioner) Phil Giudice. Ambri had an auspicious start, beginning when Microsoft founder Bill Gates was an anonymous enrollee in an MIT online-course offered by Dr. Sadoway, where Gates learned of the liquid metal battery. This led to Gates and Dr. Sadoway spinning out LMBC in 2010. (The attraction of Gates to MIT is an example of the strength of the Massachusetts technology sector, and the central role of the Massachusetts academic sector in the state's technology ecosystem.) LMBC experienced developmental challenges and redeveloped as Ambri.

Ambri currently has 35 employees and the company has raised over $75M in venture funding since its founding, in addition to grant awards. Giudice notes that in the company's evolution it utilized university R&D technology resources, such as SEMs at MIT and Harvard. However, over time the company found it valuable to bring such resources in-house, a common R&D capacity trajectory for evolving technology companies. Giudice noted that access to academic expertise was valuable throughout the company's development and that the underlying "scrappiness" of entrepreneurs enables them to find the resources they need. He also noted the "community" nature of the Massachusetts BES space in 2010, as well as the value of supporting (and not penalizing) academics in commercializing their research. Giudice made particular note of MIT in this regard.

NEC Energy Solutions, Inc., Westborough, Massachusetts

NEC Energy Solutions (NEC) designs, manufactures, and integrates megawatt-scale energy storage solutions for the grid. NEC's products are based on Li-ion technology from around the world including that of A123 Systems (A123). NEC is one of the more established BES companies. NEC participates in the global market of the large-scale energy storage sector, with systems in North America, South America, Europe, the UK, and Asia. NEC Energy Solutions was created by NEC Corporation of Japan, after it purchased the stationary energy storage division of Massachusetts-based Li-ion battery manufacturer A123 in 2014. A123 is presently focused on the automotive market. It should be noted that A123 was itself spun-out of the MIT lab of Dr. Yet-Ming Chiang. NEC Energy Solutions has headquarters and manufacturing in both North America and Asia with a majority of its R&D activities in Massachusetts. We included NEC in our survey because it represents the more established corporate end of the Massachusetts BES continuum, and is an example of the global reach of Massachusetts BES ventures. The company is a prime example of the capacity of the Massachusetts BES innovation ecosystem to generate and attract ventures of global significance.

Toyota Research Institute, Cambridge, Massachusetts

Toyota Research Institute Cambridge (TRI) emerged out of a collaboration with MIT and Stanford University. We interviewed materials scientist Dr. Brian Storey (who is jointly on the Olin College faculty) and TRI Director Dr. Eric Krotkov. TRI's location in Cambridge is a reflection of that relationship, and also "the strength of the Massachusetts technology innovation ecosystem," according to Dr. Storey. TRI is one of three research labs that Toyota has established, including TRI Headquarters in Los Altos, CA, and TRI Ann Arbor, MI. TRI Cambridge is primarily focused on artificial intelligence, robotics, and autonomous driving. However, TRI is involved in BES innovation "because of the need to power all of this," according to Dr. Storey. In particular, TRI is focused on methods for accelerating new materials discovery, which they see as important to innovation in the BES sector. Dr. Storey also noted that as part of a global corporation, access to outside technology resources "was not an issue". We chose to include TRI in our survey because: (1) their operational model is predicated upon extensive academic collaboration; (2) TRI chose to locate in Massachusetts because of the perceived strength of its academic and technology sectors; and (3) their presence in the state reflects an emerging trend of multinational corporations choosing to locate BES-related R&D facilities in Massachusetts (e.g., Samsung, Panasonic, LG).

Greentown Labs Global Center for Cleantech Innovation, Somerville, Massachusetts

The Greentown Labs Global Center for Cleantech Innovation (GTL) was founded in 2011, and since then has grown to become the largest, most comprehensive incubator in the world for hardware-focused cleantech start-ups. GTL provides the necessary facilities and resources that start-ups need to build physical products while also growing their businesses. GTL is a leading convener of cleantech innovation and entrepreneurs from around the world. GTL currently hosts over 80 ventures and has supported over 170 ventures since its founding (of which over 85% are still operational). Notably, GTL currently hosts several BES ventures, and is in discussion with a range of other prospective BES ventures. GTL is inarguably playing an effective role in building the capacity of the Massachusetts BES innovation ecosystem and incubating successful BES ventures. GTL's emergence as a global player in cleantech innovation commercialization is as an indicator of the collective strength and relevance of the broader Massachusetts technology sector to the clean technology sector, BES included. Based upon the emergence of the BES sector globally, and the perceived value of the Massachusetts technology ecosystem to the BES sector, GTL has been seeking to deepen its engagement with the BES sector. GTL has been pursuing a number of pathways to strengthen its capacity to attract and support emerging BES ventures. This includes (1) developing strategic partnerships with corporations operating in the BES space (e.g., Panasonic), (2) seeking support to add BES-specific R&D capacity to their existing in-house R&D resources, and (3) increasing capacity for strategic outreach to the BES sector. GTL interested in participating in the development of a multi-functional platform to support the Massachusetts BES innovation ecosystem. GTL was notably supportive of CEE's work on this study, including sharing their time, expertise, and contacts. We met and/or spoke regularly with GTL's Katie MacDonald and Victor Marttin during the course of this study.

3.4 Academic-Commercial Synergies and Needs

"Dr. Brian Storey noted that the Toyota Research Institute in Cambridge was established specifically because of the proximity to the Massachusetts academic research community."

An overarching finding is that the academic and commercial BES sectors in Massachusetts are highly coupled – and this connection can be expanded and deepened with a few strategic efforts. Based upon our research findings, we consider this to be one of the defining characteristics of the Massachusetts BES innovation ecosystem. Many of the companies we researched had utilized Massachusetts academic resources at some point in their development, and many were continuing to do so. For example, Ambri made extensive use of resources at both MIT and Harvard University, prior to developing their own in-house resources. Woburn-based Lionano currently makes regular use of the CRF at UMass Lowell. A related pattern we noted was that as companies scaled beyond early-stage ventures, they often bring R&D resources in-house. For example, Ambri CEO Phil Giudice (now retired) noted that early on the company made extensive use of MIT's SEM lab, but later acquired their own SEM. Several other companies also noted this trajectory. Our provisional assessment is that this occurs more because of convenience and speed of obtaining results, and less because of lack of availability of a resource. We have observed a similar pattern in other technology sectors. Nonetheless, this dynamic bears further research should Massachusetts consider developing dedicated publicly accessible R&D and validation resources for the BES sector.

A significant finding was the extent to which Massachusetts BES ventures originated from state academic institutes. In fact, over 70% of the companies we researched are in fact spin-outs of academic research, primarily from Massachusetts-based institutions. This includes ventures that are now of global significance, such as NEC. In short, the case can be made that the Massachusetts academic sector is one of the engines of the Massachusetts BES commercial sector. Illustrating this effect further, Dr. Brian Storey of TRI noted that the Cambridge location was established specifically because of the proximity to the Massachusetts academic research community. Notably, other multinational corporations are also opening BES R&D operations in Massachusetts based on the collective strength of the Massachusetts technology ecosystem – of which the Massachusetts academic sector is a key component.[6] These include Panasonic, Samsung, and others. We also noted that these corporate R&D facilities are doing significant hiring.

A majority of the academics that we interviewed had some degree of involvement in the commercial sector, and on the whole also expressed enthusiasm for collaboration. This ranged from occasional consulting work, to having founded multiple BES companies, including those of global significance in the case of Dr. Yet-Ming Chiang of MIT. As an anecdotal

[6] McSweeny, D. and Marshall, W., "The Prominence of Boston Area Colleges and Universities" Monthly Labor Review, 6/2009.

assessment, we would describe academics in the BES space as relatively entrepreneurial compared to academics in other disciplines we have experienced. Similarly, we would characterize many of the academics we interviewed as motivated by seeing their work translate into practical application, and providing social benefits. This was both a sentiment that we noted among many of the academics we interviewed, as well as something that was remarked upon by several whom we interviewed in the commercial sector. The importance of support for academics engaging in commercialization activities was also a common theme.

While the BES commercial sector holds considerable technical, intellectual, and developmental resources that are synergistic with Massachusetts BES academic institutions, it is less clear that these resources could be considered available to other *companies* in the BES space. However, it may well be that these resources are more available to *academics*, through the academic-commercial collaborations that are a characteristic of the Massachusetts BES innovation ecosystem.

Before examining our findings specific to the BES ecosystem, we provide below academic-industry drivers and mechanisms for collaboration unveiled during our survey. These demonstrate means by which the academic and commercial sectors in Massachusetts collaborate in other technology sectors. These mechanisms are relevant to the BES sector as well, and may be readily expanded or transferred to serve this sector.

3.4.1 Drivers for Academic-Industry Collaboration

There are numerous drivers for academic-industry collaboration. Academic expertise is an important resource for companies in addressing the challenges of technology development and commercialization, and these problems are often in turn a robust source of fundamental academic research questions. Interest on the part of academics to see their work translate from the lab into practical applications is also a driver, particularly when the work has potential social benefit. This commercial applicability and social benefit can also be an important driver for attracting students to research areas that could offer them attractive employment opportunities after graduation. Skilled workforce development is also an important factor, and is indeed one of the reasons that technology companies cite for locating in Massachusetts. Most science, technology, engineering, and math (STEM) graduates will go on to careers in the commercial sector, and academic-industry collaboration facilitates a valuable alignment between graduates and companies.

We observed a relatively high degree of academic-industry collaboration in the BES sector. However, a challenge noted by a number of those we interviewed was that the policies or culture of academic institutions are not always supportive or conducive to academic researchers engaging in translational research or work related to commercialization. This is particularly so for younger academics who are pre-tenure, or who have not yet been promoted to full professor. For example, a patent application is often not counted toward a tenure or advancement review, and indeed can be a liability. We know of cases where a patent application was cited as an example of a distraction from the traditional core academic research products of publication and grant awards. However, there are indications that academia is becoming more open to faculty engaging in work that may have a commercial path. Given that a significant number of BES companies we reviewed are direct spin-outs of academic research, this is of relevance to advancing the BES sector.

Greentown Labs (GTL) is an example of a venture that has intentionally created strategic relationships with academic institutions we studied across a range of clean energy research and entrepreneurship. These include both UMass Lowell and UMass Amherst (through GTL's not-for-profit arm, Greentown Learn), and MIT. GTL also has a relationship with Boston University.

3.4.2 Current Mechanisms for Academic-Commercial Collaboration in Massachusetts

From our survey and further investigation into academic institutions, we identify below key mechanisms by which academic and commercial collaboration are currently structured.

- Faculty Consulting: Academic researchers can be tapped by commercial ventures for limited term consulting to address technical challenges. Academic institutions vary in the extent they enable faculty to engage in these activities, but can lead to important collaborations and real-world problem solving.
- Core Facility Usage and State Voucher Program: Institutions may provide core research equipment and facilities on a pay-for-service basis for commercial users. Examples include MIT's broad range of shared research resources under its Core Facilities and Service Centers, and UMass Amherst Core Facilities in the Institute for Applied Life Sciences. The UMass system offers an Innovation Voucher Program, established by the state legislature, by which small to medium-sized businesses can access the university's leading-edge research facilities at reduced rates. This voucher program could be expanded or more directly targeted to battery research.
- Sponsored Research and Industry/Commercial Cooperative Research: Companies can sponsor research at academic institutions to address more fundamental science, engineering, and manufacturing challenges. The National Science Foundation offers a federal model through their Industry-University Cooperative Research Centers Program to develop long-term partnerships among industry, academe and government. This program leverages government funds with industry to support industrially relevant pre-competitive research. Under this model, the state could potentially pool industry funding and administer a program targeted to BES research with industry and academic collaborators to address common pre-commercial technical challenges.

3.4.3 Academic-Commercial Synergies and Needs Assessment

Below we summarize our findings below related to the synergies between the academic and commercial BES sectors in Massachusetts, followed by an evaluation of the key needs for these sectors to further enhance collaboration in the BES innovation ecosystem.

Academic-Commercial Synergies

- Academic and commercial sectors are highly coupled; a high percentage of companies surveyed are Massachusetts academic sector spin-outs, and some have grown to international significance.
- Many academics surveyed were engaged in some way with commercial sector, and all generally had high interest in engaging with companies.
- Many companies have used, or currently use, academic resources – both equipment and expertise.
- With this strong academic-commercial coupling, Massachusetts is attractive to BES commercial ventures, even despite lack of dedicated facilities. The Commonwealth is generating world-class BES ventures, attracting BES ventures from elsewhere domestically (e.g., Lionano) and internationally (e.g., Battrion), and large corporations are opening BES R&D lab facilities in Massachusetts (e.g., TRI).
- Taken in total, Massachusetts academic institutions have considerable technical resources of value to Massachusetts BES ventures, especially with regard to testing and validation of smaller scale (<100 V) systems.

Academic-Commercial Needs Assessment

- Massachusetts academic institutions hold considerable resources (technical, intellectual, developmental) that are of potential value to Massachusetts BES companies. While these resources are particularly applicable to testing and validation of smaller scale (<100 V) systems, there are far fewer resources available relevant to larger scale systems, including at the grid-scale.

For example, UMass Lowell’s Dr. Fuqiang Liu, who “works with many companies”, stated that a validation/testing facility would be very useful, especially for large grid-scale systems. Ideally, such a facility would be able to test at a range of scales from small to large. He also noted that “there is nothing in the New England area that can handle medium and large scale testing.”

- Massachusetts universities have technical intellectual expertise of considerable value to BES ventures, across a broad range of related sciences and system scales and developmental stages, though these experts may not necessarily be directly associated with the BES sector. Based upon our interviews, it was widely agreed that enhancing the connectivity between these sectors would be valuable.
- Our survey unveiled a number of comments and suggestions on means to enhance synergies and collaborations between the academic and commercial sectors. These include:
    - A searchable database of academic sector resources
    - Focused consortia, with emphasis on the importance of face-to-face discussions and networking
    - Collaborative commercial/academic research agenda setting and funding. Several interviewees mentioned as an example the NORA (North American Center for Research on Advanced Materials) Collaborative, which is a collaboration between BASF, UMass-Amherst, Harvard University, and MIT.
- Better coordination to pursue collaborative grant-funded federal research opportunities (e.g., SBIR, ARPA-E, DOE). To support and sustain a robust BES ecosystem, Massachusetts government and collaborators should consider how best to support the short-term needs of our existing set of battery companies, and the longer-term objective of sustaining leading edge battery research and new spin-out commercial ventures into the future.

4.0 Recommendations & Next Steps

In this section, we summarize our recommendations for next steps and continuing work for improving the performance of the Massachusetts BES innovation ecosystem, with regard to the Commonwealth's clean energy and economic development goals. These recommendations are based upon the findings and objectives presented in the sections above.

Principally, we are recommending a multi-pronged initiative based on our findings that we believe will significantly enhance the Massachusetts BES ecosystem. These recommendations are summarized as follows:

1. **Organize a Leadership Consortium/Steering Group**
2. **Convene and Facilitate BES Industry Events, Symposia, and Networking Opportunities**
3. **Strategically "Brand" the Development of the Massachusetts BES Innovation Ecosystem**
4. **Develop a Multi-functional Web-based Platform to Connect Ecosystem Resources and Activities**
5. **Consider the Need for Publicly Accessible R&D and Testing Facilities**
6. **Support Massachusetts Academic Sector as the Engine of the Ecosystem**

We articulate these recommendations in more detail in **Section 4.1** below.

The context of this study was the larger question of how to improve the overall function of the Massachusetts BES innovation ecosystem. In the course of identifying BES resources within the state's academic sector, it became clear that the need – and the opportunity – was greater than improving industry access to academic research resources alone. Accordingly, we developed a broad set of market recommendations and a prototype platform that address the core functionality of the study scope of work. In combination, these study outcomes are expected to be responsive to the broader market needs and opportunities identified in the course of our research.

Our recommendations are a direct reflection of the data and related information collected through our study. However, our study was limited in scope, and while our recommendations include further exploration of needs and opportunities through a leadership/steering group and forum, we do not attempt to present a comprehensive approach to addressing these and other industry gaps that should be addressed by policymakers and others for the ecosystem to reach its full potential.

Early in the study, it became clear that while we would have the resources to execute the research and conceptual design aspects of a web-based platform, we would not necessarily have the specific technical, financial and temporal resources to reasonably implement or manage such a platform.

While our recommended initiatives are focused on the energy storage community, we suggest that the professional connections and web-based platform deliberately cast a broader net. One finding was that researchers whom we identified as relevant to the energy storage ecosystem did not necessarily always self-identify as such, nor were they always readily identified by the energy storage community.

4.1 Recommendations for Enhancing Massachusetts' BES Innovation Ecosystem

Recommendation #1: Create a Leadership Consortium/Steering Group

We are recommending the formation of a Leadership Consortium composed of stakeholders who are representative of the Massachusetts BES innovation ecosystem. This would include representatives from the sectors identified in **Figure 3.1** above. We are recommending that the Leadership Consortium/Steer Group at a minimum include stakeholders from the following sectors:

- **Academic Sector:** Researchers and relevant administrators from public and private institutions
- **Commercial Sector:** Corporate representatives from across a range of applications, technologies, and corporate spectrum (both scale and maturity)
- **Finance Sector:** Private capital, equity and debt
- **Public Sector:**
    - NGO's and other stakeholder organizations; **s**uch as GTL and UMass CEE
    - State agencies, such as MassCEC, DOER, and the Executive Office of Housing and Economic Development
    - Legislators, policymakers, and public representatives

Primary functions of this Leadership Consortium will be to (1) serve as a steering committee for strategic decision-making and related initiatives, and (2) to increase the profile and visibility of the Massachusetts BES industry. The leadership will create and steer actionable agendas for industry forums, advise and promote the functionality and peer participation in the web-based platform, and provide identity and voice for public outreach in and beyond the Commonwealth. Our research underscored the high degree of coupling between various stakeholders, and the importance of engaging all stakeholders to effectively understanding issues and opportunities.

Recommendation #2: Convene and Facilitate BES Industry Events, Symposia, and Networking Opportunities

Broadly applicable events and symposia: We are recommending periodic face-to-face events and symposia to facilitate networking among Massachusetts BES academic, private- and public-sector ecosystem stakeholders. This includes facilitated discussions between stakeholders on topics raised, for example, by the Leadership Consortium, relevant to decision-making and policy. While online platforms and searchable databases are important, the value of face-to-face connections cannot be understated. As many have experienced, unexpected and generative connections are often made at conferences, symposia, and informal networking events.

The value of increased opportunities for networking was almost universally agreed upon across both academic and commercial sectors, for a wide range of reasons. It is apparent from our research that Massachusetts has a strong and passionate energy storage community. This in itself is an asset, and networking tools would further support this. These events would address such functions and topics as:

- Facilitated forums for discussion of key issues and questions
- Highlighting successful collaborations, perhaps with public engagement at, for example, the Museum of Science
- Networking opportunities to build and strengthen connections between stakeholders
- Forums to de-mystify the process for how industry can plug into academic resources and stimulate collaborations
- Identification of business development resources
- Opportunities for emerging ventures and investors to meet
- Discussion meetings to review state policy developments and needs, including incentive and motivation programs to support early stage commercialization

- Recruiting / "Job Fair" opportunities

Facilitated discussion between focused stakeholders: One finding of our research is that the issues related to progress in the BES space were multi-dimensional, and would likely benefit, for example, from a facilitated "focus group" discussion between stakeholders. The objective would be to articulate strategic opportunities to improve the performance of the Massachusetts BES innovation ecosystem. Examples of topics might include:

- The need for – and nature of – publically accessible research and testing facility(s) in Massachusetts
- How the Massachusetts BES innovation ecosystem could further attract prospective BES ventures to the state
- Challenges of developing (and providing) financing within an emerging market
- Funding and recruiting of new graduate students to support research labs
- Strengthening capacity of Massachusetts universities as sources of technology innovation and new ventures

Recommendation #3: Develop and Disseminate a Massachusetts BES Innovation Ecosystem Brand

We recommend that Massachusetts elevate the profile and visibility of the state's BES sector by developing a "brand" identity that clearly illustrates the Commonwealth's role as a global opportunity center for BES innovation and commercialization. One picture that emerges from our research is that the Massachusetts BES innovation ecosystem is arguably one of the global centers of BES research, innovation, and commercialization, and that the ongoing connections between academic and entrepreneurial activities are robust but under-recognized and under-leveraged. Effectively identifying, unifying, and communicating this important ecosystem represents an opportunity for the Commonwealth, and represents an attractive "value proposition" to BES researchers and ventures. Our research found that Massachusetts is already attracting BES ventures (despite the lack of a national lab or dedicated R&D facility) and we suggest that effectively communicating and leveraging this value proposition will further the awareness and attraction to the ecosystem. Doing so will further the strength of the ecosystem and its economic development opportunity, as well as serving state commitments to carbon emissions reduction and renewables adoption.

Recommendation #4: Develop a Multi-functional Web-based Platform to Connect Ecosystem Resources and Activities

We are recommending the development of an online "virtual platform" to host a range of functions related to a Massachusetts. We are proposing an ensemble of components, articulated below. The specific functionality of each of these components reflects core themes that emerged through the findings of our research program. Additionally, the web-based platform offers the potential to serve as a "brand" platform to connect and communicate the collective strength of the Massachusetts BES sector, and the value proposition Massachusetts offers to prospective energy storage ventures within and outside the Commonwealth.

We suggest that the web-based platform include the following components:

A. **Searchable Database Tool of Ecosystem Resources**
B. **Descriptive Outreach Pages for Energy Storage Ecosystem Stakeholders**
C. **Other Functionality, such as:**
    - **Recruiting / Employment tools**
    - **News / Announcements / Calendar**
    - **Policy and Programmatic News and Announcements**

These components are further described below.

A. Searchable Database of Energy Storage Equipment and Capabilities Available at Massachusetts Universities and Other Organizations

The searchable database component represents the original focus of this project. The value of a searchable resource database was also widely agreed upon among the constituents we interviewed in both the academic and commercial sectors. We developed a prototype framework, described below, for a searchable database of energy storage innovation resources available at Massachusetts academic institutions and other organizations. The structure of this database is a direct reflection of the data we collected during our research.

This resource, if properly structured and promoted, would serve as a platform to aggregate critical industry metrics and resources into a single, searchable tool. When made accessible to a broad audience, the database would serve to aid current industry players – and those considering entering the industry – in identifying and connecting with resources available in the Massachusetts BES market, as well as resource gaps. The platform would be expected to provide a clear demonstration to academic researchers and early ventures nationally and globally that Massachusetts has a world-class breadth and depth of opportunity.

Most fundamentally, we are recommending the database include institutional identifying information, BES personnel with their specific areas of research/expertise, a BES-related equipment inventory and availability for collaboration, and contact information. We are also recommending the inclusion of resources available at the private research labs for which Massachusetts is also known.

Prototype Academic Database Structure: Based upon our initial research at six academic institutions, we developed a prototype database structure that addresses academic BES resources, presented in **Table 4.1** below. We use, *for illustrative purposes only*, the resources of UMass/Boston researcher Dr. Niya Sa, and the Roll-to-Roll Manufacturing Facility at UMass Amherst.

We developed the above structure in order to provide a structure for both capturing as well as “normalizing” relevant data and information. This flexibility is important due to the fact that BES resource data to varies widely in structure, format and specific content. Significantly, this database format is intended to enable institutions themselves to upload (and update) information regarding resource availability that may not be tied to a specific researcher’s lab, and also enables *key word search* functionality for the database. Once the database is built, users can self-populate the database, promote their work, and raise the profile of their research and/or products. Doing so could serve to attract funding, collaborators, and customers.

Other Platform Databases: In addition to the development of an academic BES database, we also recommend the development of related non-academic commercial, financing, and policy resource databases. The need for easy access to this information was frequently raised during participant interviews – often as a priority above technology resources. The data structure of these databases would provide searchable information about resource availability and needs, collaboration opportunities, and contact information.

Table 4.1: BES academic resource database structure and example profiles

Database Parameter	Example Academic Profile 1	Example Academic Profile 1
Institution	UMass Boston	UMass Amherst
Lab	Sa Lab	Roll-to-Roll Manufacturing Facility
Researcher	Dr. Niya Sa	Dr. James Watkins, and others
Expertise Area	• Electro-Chemistry • Battery systems design and testing	• Functional Polymer Materials • Nano-materials • Manufacturing
Specific Expertise	• Mg, Zn systems • Multivalent systems • Advance Li-ion anodes • Surface Characterization	• Advanced nanomanufacturing • Manufacturing scale-up • Nano-imprint Lithography • Multi-functional materials
Research Functions	• Anode chemistry and fabrication • Surface chemistry • Battery testing, small scale	• Materials and process development • Manufacturing scale-up
Research Equipment	• Inert atmosphere box • Electrolyte development capacity • Interfacial study instrument • Micro balance (for studying mass deposition) • Many connections to other battery systems testing labs • Multi-channel battery testing system	• Material Preparation • Printing, Nanoimprinting, Coating, Laminating, Slitting • Battery assembly and testing • Characterization and testing
Specific Equipment Models	N/A	• Qsonica Q500 Ultrasonic Processor • Carpe Diem R2R - NIL300 • Maccor Model 4304 Battery Test System • Brookfield Ametek HBDV3T Rheometer
Contact Information	(Email address)	(Email address)

*Data in table is based on best judgement given the available information from surveyed organizations.

B. Descriptive Outreach Pages for Energy Storage Ecosystem Stakeholders

We are recommending that the web-based platform offer "pages" that enable stakeholders in the Massachusetts energy storage sector to post information about themselves and their work or services. These pages would serve both individuals, as well as larger public and private entities. One function is to provide a "face" to the data provided in the databases. It is also essential material to support the importance of connectivity identified in our findings. Examples of stakeholder categories of pages are:

- Institutions
- Individual researchers or entrepreneurs
- Private companies offering relevant services
- Energy storage companies
- NGOs, state agencies, and other entities
- Other

C. Additional Functionality

We are recommending that the web-based platform also include additional functionality, such as tools for recruitment, employment, and internships, industry news and announcements, state and federal news and announcements on policies and programs, on-line discussion forums, and so on. The point here is to enable the website to provide the functionality to support a high-performance state BES ecosystem.

Recommendation #5: Develop and Support Publicly Accessible R&D and Testing Facilities

We recommend further consideration for the development of dedicated energy storage R&D and testing facilities. Our findings suggest that such facilities would be very useful, especially for early-stage emerging ventures, mid-scale validation, and larger grid-scale systems prototyping and demonstration. Our research found that as ventures scale up, R&D resources are increasingly brought in-house. Therefore, testing facilities applicable at the early stage of technology development (and as final products emerge and need independent testing) may be particularly justified. Such publicly accessible facilities would also help to further communicate the Commonwealth's "brand" identity and value proposition to BES ventures.

Academic resources within the Commonwealth are concentrated at the level of bench-scale. Our industry surveys also revealed that, while a wide variety of technical resources is available at institutions across the state, no single institution has the core set of resources that an emerging commercial venture might need. Further, even when available, these academic resources may not be readily accessible to the commercial sector. The web-based platform and database described above is intended to increase the availability of these resources and enable them to play a greater role in the ecosystem.

Based upon our findings, we believe that two distinct facility types are worthy of further consideration:

- Small and mid-scale (i.e., cell- and stack-level) R&D and validation facility
- Grid-scale system prototype testing and validation facility

Small and Mid- Scale R&D and Validation Facility: This facility would enable early-stage BES ventures easy access to essential R&D equipment, such as the capacity to make and test 3 - 6 Ah pouch cells and 18-50 coin cell stacks. It would also enable testing of larger, mid-scale assemblies, such as the kW-scale batteries that many companies now must drive to for testing at the University of Michigan's Battery Fabrication and Characterization User Facility (a noted bottleneck). A dedicated facility would include equipment relevant to multiple technology platforms. Life-cycle testing capacity was also noted as an important capacity. Proximity to the companies clustered in the Boston area would likely be very important to the utility of this facility.

Grid-Scale System Prototype Testing and Validation Facility: This facility would enable the longer-term testing of stationary, grid-scale systems, and validation for early commercial units. There is currently no such facility in the region, and our findings suggest that many companies utilize the Sustainable Power and Energy Center testing facility at the University of California San Diego. This facility is less geographically sensitive. The opportunity to integrate an energy storage prototype testing and validation facility with the potential expansion of the Water Technology Test Facility at UMass Amherst and the Amherst Wastewater Treatment Plant should be explored further. The testing and validation across water and energy share common technical features, along with outreach and staffing needs, and a joint facility would be well positioned to address research and commercialization needs within the water-energy nexus. A joint facility is likely to be more attractive for state funding support and to attract diversified operational revenues and economic development opportunities.

We strongly recommend that further discussion and decision-making be sure to include a representative cross-section of ecosystem stakeholders. This would be an excellent topic to be examined at a facilitated face-to-face "focus" group, as recommended above. The BES sector is not monolithic and the needs of emerging ventures are nuanced and change with developmental and physical scale.

Recommendation #6: Support the Role of Massachusetts Academic Sector as the Engine of the BES Ecosystem

We recommend examining the role and needs of academic research in the Massachusetts BES innovation ecosystem, which provides the fertile ideas and talents needed for growth. Our findings suggest that there could be potential benefits to (1) further supporting academic research, and (2) supporting the capacity of academic researchers to facilitate commercialization of their research. A key finding of our study was the significant role that the Massachusetts academic sector plays in the BES innovation ecosystem. It is hard to overlook the fact that over 70% of the Massachusetts BES companies we researched are in fact spin-outs of the Massachusetts academic sector. This includes companies of global relevance. Critical germination and advancement in BES technology occurs in academic research labs.

If Massachusetts universities are indeed one of the "engines" of the BES sector, what more can be done to support the capacity of the universities in that role? For example, a common theme among researchers was how a lack of funding to support graduate students was limiting the progress and extent of their research. Relevant topics to consider might include:

- Support for faculty efforts to commercialize research
- Support networking between the academic and commercial sectors
- Identify how to retain and attract research talent, both faculty and graduate students
- Support academic researchers interested in commercialization activities

4.2 Next Steps

While this study provides important insights into the burgeoning Massachusetts BES industry, it represents only a beginning. By design, this study examined only a narrow slice of the industry and subset of those operating in it. Going forward, it will be critical to conduct additional research and surveys into the industry and academic institutions to gain both deeper and broader perspective on the resources, plans, needs, and opportunities within the Massachusetts BES innovation ecosystem. This broader and deeper research can be done in coordination with informing and implementing the above recommendations so as to assure they are useful and effective across the broader community of BES academics, innovators, and commercial and financial players.

To implement our recommendations, we suggest the following next steps:

1. **Establish Energy Storage Leadership Consortium / Steering Group**
    - Identify relevant entity to host and administrate
    - Recruit and convene consortium and develop key issues and work plan
2. **Host Face-to-Face Forum for Massachusetts Energy Storage Community**
    - Utilize Leadership Consortium and others to identify key topics for forum
    - Identify entity or entities to plan, organize, and sponsor forum
3. **Establish and Broadcast a Branding for the Massachusetts Energy Storage Ecosystem**

- Utilize Leadership Consortium and others to define and articulate brand
- Implement branding on web-based platform, forums, state programs, and others
- Utilize the branding to identify and broadcast Massachusetts energy storage innovation within the Commonwealth, nationally, and globally

4. **Develop and Launch Massachusetts Energy Storage Web-based Platform**
    - Create a scope of work to create and launch platform
    - Identify relevant entity or entities to host and administrate
    - Identify capital needs for both development and ongoing operations
    - Outreach and recruit academic and commercial stakeholders to populate databases and utilize platform
5. **Evaluate Industry Need and Funding for Public-Access BES Testing and Validation Facility**
    - Utilize Leadership Consortium and Face-to-Face Forum to investigate industry needs, facility specifications, and potential use and revenues of a facility
    - Explore benefits of integrating BES testing with other energy and water technologies, and opportunities for funding with water technology testing facility under consideration
6. **Convene Academic Sector and Explore Common Challenges and Opportunities to Sustain Robust BES Technology Development**
    - Discuss role of MassCEC and others to create programs to support/motivate BES entrepreneurship and address university barriers to applied research and commercialization
    - Discuss role of pooling and leveraging industry funds to support strategic pre-commercial research
    - Explore means to support more graduate students to support academic research and the technical workforce needed for spin-out companies

Appendix A – References and Selected Sources

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Cover photo: NEC Energy Solutions' 2-megawatt/3.9 megawatt-hour Li-ion battery storage system, Sterling Municipal Light Department in Sterling, Massachusetts. Credit: Clean Energy Group

Appendix B – Initial Interview and Follow-up Survey

1. Initial Interview Framework

The following is an example of the basic outline we followed for interviews. These questions were typically a starting point and catalyst for more varied discussion, which was valuable for both information as well as insight. Questions were adjusted for academic or commercial sector interviewees.

1. *Name:*
2. *Affiliation:*
3. *Contact info*
4. *Area of work:*
5. *Resources available (facilities and expertise)*
    - Facilities and equipment to offer:
    - Expertise to offer:
6. *Resources seeking access to:*
    - Equipment
    - Expertise
    - Other resources (please describe)
7. *Collaboration:*
    - Previous or current academic / industry collaborations in the BES Space
    - Availability and interest in collaborations with industry partners
    - Collaborative mechanisms
    - Other relevant info?
8. *Open-ended Questions:*
    - What would be most helpful to moving your work forward (bottlenecks / opportunities)?
    - What do you feel is needed most to advance battery research?
    - In your opinion, would Massachusetts benefit from a battery testing facility?
    - Why, and what would be its core functionality?
    - Would an academic/industry resource “match making” tool be helpful?

2. Follow-up Survey

The following is a sample of the Interview follow-up survey we prepared for each individual interviewed. The format is intended to facilitate ease of response on the part of the interviewee, and hence optimize return rate. The survey was designed to be populated with information gleaned from the initial interview, so that the interviewee could review for correctness, and supplement where needed. This survey was designed as a tool to support data collection going forward, and to facilitate "normalization" of the data. It also has an intentionally open-ended component, to capture potentially useful unanticipated information or insight.

Dear Study Participant

The information below was gathered during our recent conversation with you, as well as from websites and other sources. However, we acknowledge that this information may be incomplete, and may well contain inaccuracies based upon the transcription of handwritten notes, etc.

The data will be summarized within a report to the MA DOER and the MA CEC, and organized into searchable database tool that will be made available to those involved in the Massachusetts battery technology research and commercialization "ecosystem". Please note that the format below is simply a tool for data collection, and does not reflect the structure of a forthcoming database itself.

Could you please review the information below, and correct or add material as necessary?

Exemplary compiled interview example:

1. **Name:** *[Researcher name]*
2. **Institution:** *[Researcher institution]*
3. **E-mail:** *[Email address]*
4. **Tel:** *[Phone number]*
5. **Department:** *Chemistry*
6. **Lab:** *[Lab name]*
7. **Address:** *[Street address]*
8. **Relevant web links:** *[Lab website]*
9. **Areas of expertise:**

    Electrochemistry

    Analytical Chemistry

    Surface Chemistry

    Multivalent systems

    Mg and Zn systems (3 patents)

    Advanced anodes for Li-ion system, especially C-Si anodes;

    Surface characterization

    Extensive industry and national lab collaboration

10. **Facilities, Equipment and Capacities (specific make/model if possible):**

    Inert atmosphere box

    Micro balance (for studying mass deposition)

    Interfacial Study instrument (may be related to above)

    Electrolyte development capacity

Multi-Channel battery characterization system. Currently 3 channels, but can expand to 10 ch. (scale?)

I have many connections in battery systems testing, so can send samples out to various labs for testing...

11. Please indicate if any of these resources available to people outside of your lab, underutilized, have particular conditions of access (e.g. sponsored research contract, fee for service), etc.

12. Needs regarding facilities, equipment and capacities:

Access to SEM; have access through research relationships, but time-consuming and expensive

Funding for graduate students – largest bottleneck is limited funding to support graduate students, and hence the amount of research that can occur in my lab

13. Are there any "bottlenecks" you are experiencing concerning advancing your own work?

Lack of funding to support graduate students

14. Information regarding collaboration between the academic and private sectors.

Extensive collaborations with industry and national labs.

Seeking opportunities for interaction with regional colleagues; relatively few in the regional academic community involved in battery related research compared to other regions where have worked, such as the upper Midwest.

Expertise with advanced Li-ion anode would be helpful to Li-ion sector

15. What forms of collaboration do you currently use when working with the private sector? *(e.g., sponsored research agreement, fee-for-service, SBIR, do not work with private sector, etc.)*

16. How do colleagues in the applied sector typically find you (e.g., met at conference, your publications)

17. Do you feel that companies in the private sector who could benefit from your expertise and resources, are able to find you?

Not entirely – for example, my expertise regarding advanced Li-ion anode would quite likely be helpful to Li-ion sector

18. If you have worked with the private sector, what challenges have you encountered (e.g., IP, expectations regarding pace of work)

19. Questions regarding the MA Storage battery technology" ecosystem":

Massachusetts has some real strengths concerning battery technology development and commercialization (e.g., people like yourself).

- What do you feel are the strengths of the MA battery ecosystem?
- What kind of capacities, if they were available within Massachusetts, would help strengthen the capacity of the MA battery ecosystem?
- If you could pick just one of the above, which would it be?

20. Thank you for your generous participation. Anything else you would like to add?

Appendix C – Technology Readiness Level Scale Description

The Technology Readiness Level (TRL) scale is a widely used framework for assessing the relative development of a new technology in terms of commercialization – or deployment, if a non-commercial endeavor. For comparative purposes, we assigned a preliminary TRL range to the companies surveyed for this project.[7] It should be noted that it was not within the scope of the study to conduct a comprehensive TRL assessment, and that the preliminary assessment provided are in many cases inferentially drawn from information acquired in support of developing a resource access platform.

For purposes of consistency, we based our TRL assessment on a version of the scale used by the MassCEC, which is itself derived from a DARPA-E framework. The TRL scale was originally developed by NASA, for non-commercial purposes. We used guidance from Sandia National Laboratory for applying the TRL to commercial ventures. The list below illustrates how we applied the TRL framework to the commercial battery companies we reviewed.

Technology Readiness Levels

TRL 0: **Idea**. Unproven concept, no testing has been performed.

TRL 1: **Basic research.** Principles postulated and observed but no experimental proof available.

TRL 2: **Technology formulation**. Concept and application have been formulated.

TRL 3: **Applied research**. First laboratory tests completed; proof of concept.

TRL 4: **Small scale prototype** built in a laboratory environment ("ugly" prototype).

TRL 5: **Large scale prototype** tested in intended environment.

TRL 6: **Prototype system** tested in intended environment close to expected performance.

TRL 7: **Demonstration system** operating in operational environment at pre-commercial scale.

TRL 8: **First of a kind commercial system**. Manufacturing issues solved.

TRL 9: **Full commercial application**, technology available for consumers.

[7] Mitchell, John A." Measuring the Maturity of a Technology: Guidance on Assigning a TRL" SANDIA REPORT SAND2007-6733 10/2007.