Energy I-Corps Program: 2017 Case Studies

Final Report

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Notice

Table of Contents

ACKNOWLEDGEMENTS I
NOTICE II
TABLE OF CONTENTS III
ACRONYMS AND ABBREVIATIONS V
GLOSSARY VI
EXECUTIVE SUMMARY I
PURPOSE OF CASE STUDY PROJECT I
SELECTED CASE STUDY TECHNOLOGIES I
KEY FINDINGS AND LESSONS LEARNED II
SECTION 1 INTRODUCTION 1
1.1 ENERGY I-CORPS PROGRAM OVERVIEW 2
1.2 OVERVIEW OF TECHNOLOGY TRANSFER RESEARCH 6
1.3 METHODS 10
SECTION 2 STARS 13
2.1 TECHNOLOGY OVERVIEW 13
2.2 PROGRESSION ALONG THE COMMERCIALIZATION CONTINUUM 18
2.3 CONCLUSION 26
SECTION 3 SONICLQ 28
3.1 TECHNOLOGY OVERVIEW 28
3.2 PROGRESSION ALONG THE COMMERCIALIZATION CONTINUUM 33
3.3 SUMMARY 41
SECTION 4 WISDEM 43
4.1 TECHNOLOGY OVERVIEW 43
4.2 PROGRESSION ALONG THE COMMERCIALIZATION CONTINUUM 47
4.3 SUMMARY 53
SECTION 5 RWEDI 55
5.1 TECHNOLOGY OVERVIEW 56
5.2 PROGRESSION ALONG THE COMMERCIALIZATION CONTINUUM 60
5.3 SUMMARY 67

SECTION 6 LESSONS LEARNED AND FACTORS CONTRIBUTING TO SUCCESS 68

6.1 FACTORS CONTRIBUTING TO SUCCESS 68

6.2 LESSONS LEARNED 72

6.3 ENERGY I-CORPS AS A TECHNOLOGY 73

APPENDIX A INSTRUMENTS A-1

A.1 PRINCIPAL INVESTIGATOR AND ACTIVE TEAM MEMBERS GUIDE A-1

A.2 INDUSTRY EXPERT GUIDE A-11

A.3 PARTNERS/FUNDERS GUIDE A-13

A.4 RESEARCH SUPERVISOR GUIDE A-15

A.5 TECH TRANSFER OFFICE REPRESENTATIVE A-17

Acronyms and Abbreviations

ANL	Argonne National Laboratory
CEO	Chief Executive Officer
CRADA	Cooperative Research and Development Agreement
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EERE	DOE Office of Energy Efficiency and Renewable Energy
IP	Intellectual property
MMPT	Micro- and Meso- channel Process Technology
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
NWTC	The National Wind Technology Center
OEM	Original Equipment Manufacturer
OSU	Oregon State University
PI	Principal Investigator
PNNL	Pacific Northwest National Laboratory
RAPID	Rapid Advancement of Process Intensification Deployment
RWEDI	Resin Wafer Electrodeionization
SonicLQ	Sonic Leak Quantifier
SaaS	Software as a Service
SMR	Steam-methane reforming
STARS	Solar Thermochemical Advanced Reactor System
TCF	Technology Commercialization Fund
TRL	Technology Readiness Level
TTO	Technology Transfer Office
WISDEM	Wind Plant Integrated Systems Design and Engineering Model

Glossary

This glossary defines terms whose usage may be specific to Energy I-Corps. The glossary also serves as a primer on key Energy I-Corps concepts and activities.

Business model canvas	A framework used in lean startup practices; the business model canvass is a summarized business model that lets one look at nine building blocks of a business on one page. Essentially, this is a diagram of how a company creates value for itself and its customers. The business model canvas is a key component of the Energy I-Corps training curriculum.
Cohort	A term used to designate one group among many in a study. In this study, Cohort 1 is the group of lab scientists and engineers that participated in the first Energy I-Corps training in Fall 2015, and Cohort 2 is the second group, which received training in Spring 2016.
Cooperative Research and Development Agreement (CRADA)	A collaborative agreement that allows the Federal Government, through its labs, and non-federal partners to optimize their resources, share technical expertise in a protected environment, and access intellectual property emerging from the effort. CRADAs offer both parties the opportunity to leverage each other's resources when conducting mutually beneficial research and development.
Customer discovery	A process in which innovators (in this case, participating technology teams) conduct in-depth interviews with potential customers and other market contacts to obtain feedback relevant to how their innovation might be received in the market. In response to such feedback, innovators can refine their innovations to increase their market appeal. This process is the core of the Energy I-Corps curriculum; it takes the teams out of the building and perhaps out of their comfort zone. Teams are challenged to conduct about 75 interviews during the course of the training.
Entrepreneurial Lead	Leads the technology team's investigation, through interview research, into customer requirements and the commercial landscape, and assists in development of commercialization next steps.

Entrepreneurial leave	The breadth and depth of Entrepreneurial Leave Programs at the national labs differ. The program enables lab employees to take a leave of absence (or establish the terms of separation) to start or join a company commercializing a new technology. The programs may be structured to reduce some of the job security risks facing employees considering entrepreneurship by guaranteeing a job at the lab if returning within well-defined constraints. The programs establishing terms of separation typically provide only partial assurance that the employee can return to a job.
Industry Mentor	Provides business and commercialization guidance to the technology team's Principal Investigator and Entrepreneurial Lead. Selected Industry Mentor's had extensive industry experience directly or indirectly related to the team technology and may have been a lab employee or been employed by industry.
Innovations	See "technology"
Intellectual property (IP)	Intellectual property (IP) refers to creations of the mind, such as inventions, literary and artistic works, designs, symbols, names, and images used in commerce. Lab IP that transfers to the commercial sector is commonly patented and licensed.
Lab	A DOE national laboratory.
Lean LaunchPad®	A technology and startup development approach codified by Steve Blank that uses the business model canvas to develop a minimum viable product and customer discovery to explore market receptiveness and conditions.
Minimum viable product	In product development, the minimum viable product is a product sketch with just enough features articulated to gather validated learning about the product's market potential to inform its continued development.
National Science Foundation (NSF)	The National Science Foundation (NSF) is the primary Federal agency supporting research at the frontiers of knowledge, across all fields of science and engineering (S&E) and all levels of S&E education. It developed and conducts I-Corps training, which trains university-affiliated innovators.

Pivot	A term from Lean LaunchPad that describes a substantial change made to a business model canvas in response to customer discovery interviews.
Principal investigator (PI)	Serves as a technology team's technical lead and overall project manager.
Startup	A company in the first stage of its operations. Typically, an organization started by entrepreneurs attempting to develop and capitalize on a product or service for which they believe there is a demand. Lean LaunchPad provides a more limited definition: a temporary organization used to search for a repeatable and scalable business model.
Technology	In this study, "technology" refers to the innovations developed by the Energy I-Corps training teams and encompasses hardware, software, and methods.
Technology Commercialization Fund (TCF)	The TCF is a nearly $20 million competitive funding opportunity that leverages the R&D funding in DOE's applied energy programs to mature promising energy technologies with the potential for high impact. Projects require matching non-Federal funds of at least 50% of the total project cost. Funding authorized in section 1001 of the Energy Policy Act of 2005.
Technology Readiness Level	Technology Readiness Level (TRL) is a widely-used indicator of degree of development of a technology toward validation at commercial scale in the actual operating environment; degree of development is described on a scale of 1-9, with 9 being fully deployment ready.
Technology team	The team of lab innovators that participate in the Energy I-Corps training.
Technology transfer	The process by which technology or knowledge developed in one place or for one purpose is applied and used in another place for the same or different purpose.

Technology Offices (also known as Program Offices)	EERE develops research agendas and directs and funds research through its Technology Offices (TO): Advanced Manufacturing Office (AMO), Bioenergy Technologies Office (BETO), Building Technologies Office (BTO), Fuel Cells Technologies Office (FCTO), Geothermal Technologies Office (GTO), Solar Energy Technologies Office (SETO), Vehicle Technologies Office (VTO), Water Power Technologies Office (WPTO), and Wind Energy Technologies Office (WETO).
Technology Transfer Offices (TTO)	Offices in federal labs staffed with highly competent technical managers who are full participants [along with the innovating scientist or engineer] in the technology transfer process. They are empowered to develop and promote the key partnerships necessary for technology transfer.
Value proposition	Articulation of the value—in words and, ideally, in dollars—the technology offers the target market, including an identification of the bundles of products and services being offered to the potential customer and the problems solved or benefits offered.
Viable product	Viable products are products anticipated to yield a positive revenue stream. The participating labs selected technology teams to participate in Energy I-Corps for technologies they believed showed promise of being, after further development, viable.

Executive Summary

PURPOSE OF CASE STUDY PROJECT

This report provides case studies of early outcomes for four technologies whose teams participated in one of the first two Energy I-Corps training cohorts (late 2015 and spring 2016). Other assessments of early Energy I-Corps outcomes relied on survey research to describe training outcomes such as trainee knowledge gains and post-training commercialization-spectrum activities. These survey studies are unable to provide insight into how the trained researchers applied Energy I-Corps principles to advance their technologies toward commercialization. The current case study research aims to fill those gaps and provide a more nuanced presentation of Energy I-Corps effects.

SELECTED CASE STUDY TECHNOLOGIES

We sought to select technologies that had progressed along the commercialization continuum since training based on such indicators as follow-on funding received, industry partnership established, and startup launched. We obtained information from the NREL Energy I-Corps program manager, participating lab managers, and the DOE program lead that helped us identify candidates for the case study investigation. We identified six technologies as constituting the best candidates for the study and gathered additional information on these six. We selected four technologies to pursue for the case studies that follow (Table 1-1).

Table ES-1: Selected Labs, Teams, and Technologies

Lab	Team	Technology
ANL	SonicLQ	A hardware and software technology designed to identify air infiltration or leakages in buildings. SonicLQ is short for Sonic Leak Quantifier.
ANL	RWEDI	A separation technology that uses electricity to remove ions from aqueous streams. RWEDI is short for Resin Wafer Electrodeionization.
NREL	WISDEM	An open-source, software-based framework that creates a “virtual,” vertically integrated wind plant to optimize wind turbine and plant design, control, and operation. WISDEM is short for Wind Plant Integrated Systems Design and Engineering Model.
PNNL	STARS	A technology platform that efficiently converts solar and other forms of energy and natural gas into chemicals, fuel, and power. STARS is short for Solar Thermochemical Advanced Reactor System.

We conducted in-depth interviews with six or seven key individuals for each project team: these included the technology's Principal Investigator, other key team members, their lab research manager, funders or industry partners, and an industry expert.

KEY FINDINGS AND LESSONS LEARNED

Our analysis revealed the following key factors that contributed to these technology teams' successes in progressing along the commercialization continuum.

- **Professional and Personality Factors of Team Members:** Teams comprised of both members with commercialization expertise and members with technology expertise enabled a collaborative division of labor. Team members confident in public speaking helped win follow-on funding.
- **Energy I-Corps Training:** Customer discovery interviews led teams to pivot and enabled them to redirect their efforts toward the most viable near-term market. Teams learned how to develop and deliver value propositions effective in enticing investors and securing follow-on funding.
- **Follow-on Funding:** Winning funding enabled continued research and development and the demonstration of projects in operational environments.
- **Technology Factors:** Having a strong comparative advantage over existing technologies, being able to benefit multiple market actors, and having multiple potential applications contributed to the case study technologies' successes.
- **Target Market Characteristics:** Our case study teams identified near- and long-term markets for their technologies and those markets were either primed for or open to adopting new technologies. Three teams also had industry partners that expressed interest in the technology soon after training.

The teams had to be careful to avoid the appearance of conflict of interest as lab researchers worked with their respective startup. They accomplished this by invoking entrepreneurial leave policies, activity agreements, or by making it clear to investors that they were supporting *either* the lab or the startup company.

In summary, the business training provided by Energy I-Corps was essential to these teams' commercialization progress. The expertise and personality characteristics of the team members, characteristics of the technology, and market conditions appear to be equal contributors to progress. Follow-on funding is important to TRL advancement, and lab policies concerning startups and conflict of interest influence the ease of technology transfer.

Section 1 Introduction

Energy I-Corps, one of several U.S. Department of Energy (DOE) Technology-to-Market Programs, is intended to accelerate the commercialization of clean energy technologies from DOE national laboratories (labs). DOE launched Energy I-Corps (then termed Lab-Corps) as a pilot in August 2014 with a request for lab participation, and it continues as a program with annual funding. Seventy-one technology teams from 10 national labs have participated in six trainings held from fall 2015 through fall 2017.

Energy I-Corps trains selected lab scientists and engineers in techniques to accelerate technology commercialization. The intensive training occurs in a group setting with extensive individual coaching and feedback provided by experienced instructors and industry experts paired to the technology teams. DOE intends for researchers to return to the lab with a framework for industry engagement to guide their future research across multiple projects and technologies and to inform a culture of market awareness within the labs.

This report provides case studies of early outcomes for four technologies whose teams participated in one of the first two Energy I-Corps training cohorts (late 2015 and spring 2016). It contributes to an assessment of Energy I-Corps' value through in-depth qualitative investigations – case studies – of selected Energy I-Corps technologies.

This report joins other assessments of Energy I-Corps, including a first-year process and early impacts investigation and a second-year impacts investigation, both of which assessed outcomes from surveys of participating and, for comparison, nonparticipating technology teams.[1,2] The survey research describes such outcomes as trainee knowledge gains and post-training commercialization-spectrum activities (such as follow-on funding obtained) but is unable to provide insight into how the trained researchers applied Energy I-Corps principles to advance their technologies toward commercialization nor explore the influence of such factors as technology type on activities pursued and early results attained. The current case study research aims to fill those gaps and provide a more nuanced presentation of Energy I-Corps effects.

[1] Energy I-Corps Program: Year 1 Process and Impact Evaluation, Final Report. November 28, 2016. DOE/EE-1575.

[2] Energy I-Corps Program: Year 2 Impact Evaluation, Final Report. February 2018. DOE/EE-1736.

To this end, this report provides short case studies of four technologies that startups had licensed to pursue commercialization.[3] To date, it is our understanding that neither these four technologies nor any of the other Energy I-Corps technologies have attained commercialization as of the beginning of 2018.[4]

1.1 ENERGY I-CORPS PROGRAM OVERVIEW

"In general, the process of commercializing intellectual property is very complex, highly risky, takes a long time, costs much more than you think it will, and usually fails," as characterized by the U.S. Congress Committee on Science and Technology (1985, p.12).

Responding to the daunting commercialization process, DOE developed the Energy I-Corps training program specifically tailored to the needs of researchers in national labs who have developed potentially marketable technologies they are interested in commercializing.

"Technologies" refer to the innovations developed by the training teams and encompasses hardware, software, methods, and processes. Through Energy I-Corps, participating labs support entrepreneurial-focused technology teams to identify and pursue market applications for their technologies through direct engagement with industry, entrepreneurs, and investors.

During the two-month training, participating teams work to define value propositions for their selected technologies, conduct customer discovery interviews with prospective customers as well as potential market partners, suppliers, distributors, and so on. Teams also sketch viable market pathways for their technologies or conclude that they need to explore new markets if the markets they initially targeted are not viable (Figure 1-1).

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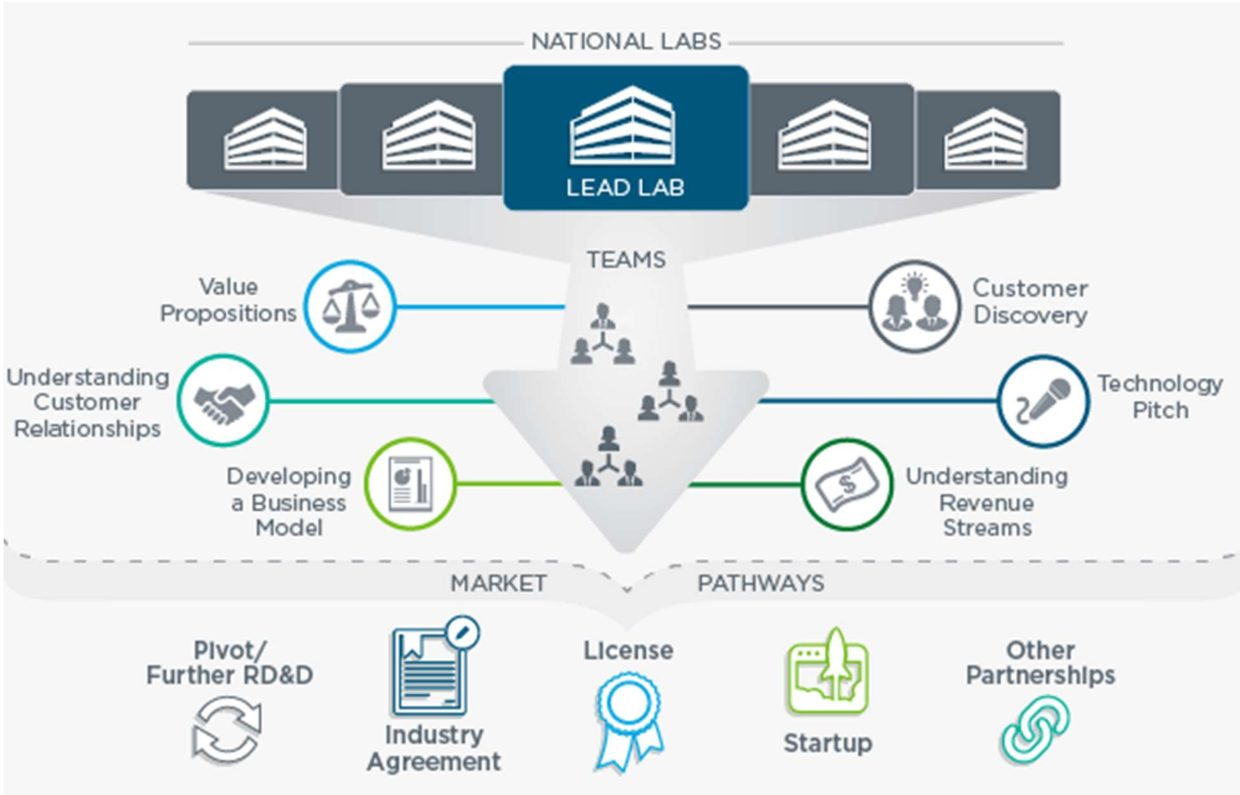
[3] During the course of the research, the team identified additional technologies which a startup had licensed, or which were posed to yield a startup. We are unaware of any statement by DOE announcing startups to date among Energy I-Corps technologies. In addition to technologies with startups or poised for startup, other technologies for teams participating in the training had received follow-on funding and attained other markers of advancement on the commercialization spectrum.

[4] EERE defines a commercialized technology as an invention or intellectual property that is developed into a technology and enters the market as "first sale," "in-use in a production application," or "sale of a commercial license."

Figure 1-1: Energy I-Corps Process



Source: Department of Energy, https://energy.gov/eere/technology-to-market/energy-i-corps, accessed December 20, 2017.

The training takes, in effect, a quasi-scientific approach to commercialization by guiding teams in developing and testing key hypotheses relating to the technology's commercialization. The training consists of a multi-day onsite opening session, weekly web-based sessions, and a multi-day onsite closing session. The onsite sessions include a mixture of lectures, workshops, team presentations, and group and individual feedback; the web-based sessions are primarily team presentations with feedback. Throughout this training, teams also engage in an experiential customer discovery process – "get out of the building!" is a refrain of the training – through which teams test their commercialization hypotheses by talking with (as a goal) at least 75 industry contacts.

Energy I-Corps implements a commercialization training model that modifies the respected Lean LaunchPad® entrepreneurship curriculum, building on a foundation established by the National Science Foundation's (NSF) Innovation Corps™ (I-Corps) training for NSF-funded researchers.[5] DOE and its program Lead Lab, National Renewable Energy Laboratory (NREL), tailored the Energy I-Corps curriculum to the

[5] See Steve Blank, "Why the Lean Start-Up Changes Everything," *Harvard Business Review,* May 2013. https://hbr.org/2013/05/why-the-lean-start-up-changes-everything.

unique features of the labs to enable lab researchers to pursue a variety of commercialization pathways that extend beyond startup development to include industry agreements, technology licensing, and other partnerships with the private sector.

Energy I-Corps uses the team structure employed by NSF I-Corps. All training teams are composed of three team roles:

- Principal Investigator (PI) – Serves as technical lead and overall project manager.
- Entrepreneurial Lead – Leads the investigation, through interview research, into customer requirements and the commercial landscape, and assists in development of commercialization next steps.
- Industry Mentor – Provides business and commercialization guidance to the PI and Entrepreneurial Lead.[6]

True to its Lean LaunchPad roots, Energy I-Corps instructs and critiques training participants (hereafter, trainees) as they examine nine elements of a business model considered necessary to commercialize a new technology:

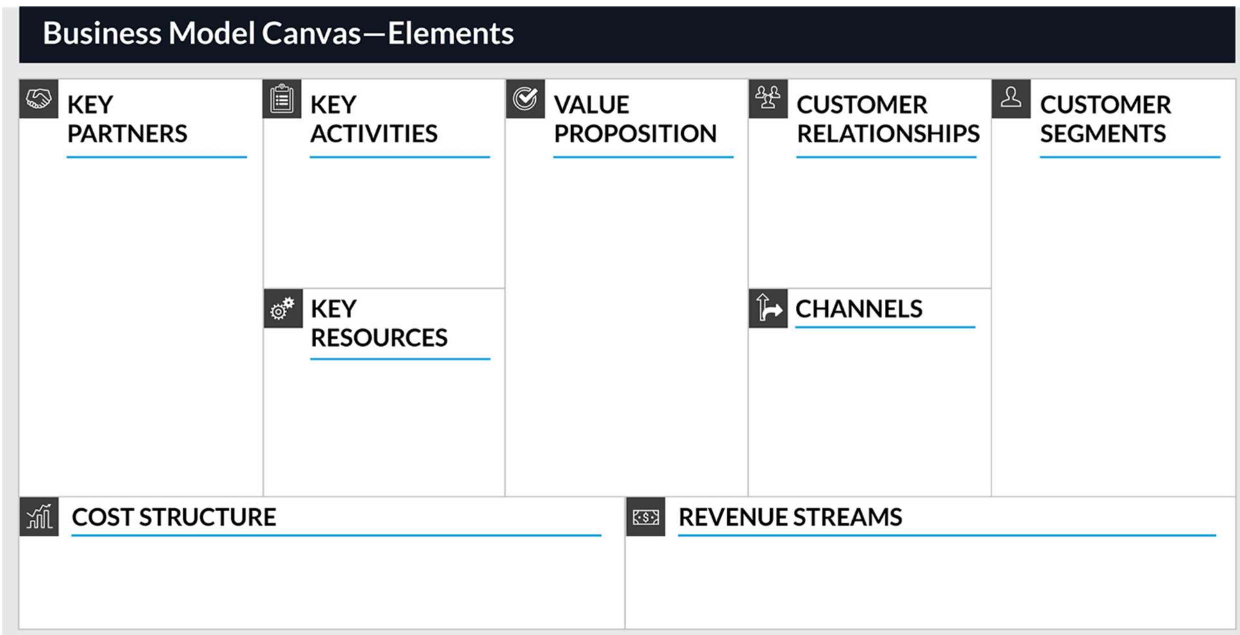
1. **Key Partners:** Identification of key partners, suppliers, their activities, and the resources acquired from them.
2. **Key Activities:** Identifying distribution channels, revenue streams, and customer relationships.
3. **Value Proposition:** Articulation of the value—in words and, ideally, in dollars—the technology offers the target market, including an identification of the bundles of products and services being offered to the potential customer and the problems solved or benefits offered.
4. **Customer Relationships:** Articulation of how to attract and keep new customers, how customers are integrated into the business model, and how costly the relationships with customers are.
5. **Customer Segments:** Identification of customer types for whom the technology creates value.
6. **Key Resources:** Identification of key resources required, their distribution channels, and revenue streams.
7. **Channels:** Identification of the channels through which customers are reached, which work best, and which are most cost-effective.

[6] Selected Industry Mentors have extensive industry experience directly or indirectly related to the team technology and may be a lab employee or employed by industry.

8. **Cost Structure:** Identification of most important costs and which key resources and activities are most expensive.
9. **Revenue Streams:** Development of the revenue model, pricing tactics, and estimation of customers' willingness to pay for the technology.

Together, these nine elements comprise what is termed the *business model canvas* (Figure 1-2). They also comprise a minimum viable product: a product sketch with just enough features articulated to gather validated learning about the product's market potential to inform its continued development.

Figure 1-2: Business Model Canvas



In its initial formulation, the business model canvas contains a series of hypotheses specific to the technology about market players, needs, and conditions. Through a process termed *customer discovery* (with "customer" broadly denoted to encompass all relevant market players), teams seek to confirm the hypotheses. Teams adjust (small and large adjustments, the latter known as "pivots") the business model canvas in response to findings. Throughout the process, teams identify new hypotheses in response to their increasing understanding of the market, in line with the adage, "the more you know, the more you know what you don't know."

NREL manages the Energy I-Corps program, serving DOE as Lead Lab. It leads curriculum development and ongoing refinement, recruits program instructors and industry mentors, assembles teams from participating national labs, and manages training activities. The following labs participate in the program and assemble and support training teams:

- Argonne National Laboratory (ANL)
- Fermi National Accelerator Laboratory
- Idaho National Laboratory
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- National Renewable Energy Laboratory (NREL)
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory (PNNL)
- Sandia National Laboratories

DOE's Energy Efficiency and Renewable Energy (EERE) division initiated and manages Energy I-Corps and every EERE technology office has supported teams through the training. Subsequent to the pilot period, DOE expanded participation to include teams supported by its Fossil Energy, Nuclear Energy, Electricity and Energy Reliability, and Environmental Management offices. The sixth cohort also featured a team sponsored by an external industry partner, IP Group. Energy I-Corps has had six cohorts of research teams to date, with the last cohort completing training in November 2017. The seventh cohort is planned to launch in April 2018.

1.2 OVERVIEW OF TECHNOLOGY TRANSFER RESEARCH

The enactment of public policy directing technology transfer from the nation's national laboratories (the Stevenson-Wydler Technology Innovation Act of 1980, Pub. L. 96-408) and universities (the Bayh-Dole Act of 1980, Pub. L. 96-517) has given rise to many and varied studies of technology transfer activities and effectiveness.[7,8] Much of this literature, however, focuses on university technology transfer, and many of the studies of government research institutions investigate other countries.

[7] The Stevenson-Wydler Act, among other provisions, had federal laboratories to establish technology transfer offices (TTOs) and to set aside funds for technology transfer.

[8] The Bayh-Dole Act said, among other provisions, that universities can retain title to innovations funded by the federal government and take the lead in patenting and licensing the innovation.

The Science and Technology Policy Institute provides a key exception with its 2011 study *Technology Transfer and Commercialization Landscape of the Federal Laboratories* (IDA Paper NS P-4728; henceforth referred to as the IDA study).[9] The study begins with a definition of technology transfer and commercialization as activities that result in the transfer of technology from a federal laboratory or agency (the producer or, equivalently, the transfer agent) to a commercial organization (the user, or transfer recipient) that can improve technologies by undertaking the technical, manufacturing, and business research to bring them to market.

The IDA study, based on a literature review and extensive interviews, identified nine factors or conditions that affect technology transfer and commercialization at federal labs. These factors include such items as laboratory mission and resources, researchers, and coordination of technology transfer and commercialization activities.

The IDA study also identified strategies believed by contacts to increase the speed and extent of technology transfer leading to commercialization. The strategies include two that DOE incorporated into Energy I-Corps: Enhance education and incentives for researchers to engage in technology transfer; and Increase visibility and access to federal laboratories by increasing outreach and use of partnership intermediaries.[10]

Bozeman and his colleagues have tackled the extensive technology transfer literature through two review papers that focus on U.S. technology transfer from both national laboratories and universities.[11,12] Although the 2015 review does not include the IDA paper, the Bozeman and IDA concepts are fully compatible.

To synthesize the literature reviewed, Bozeman developed an organizing model he terms the Contingent Effectiveness Model of Technology Transfer. With the term “effectiveness,” Bozeman describes the outcomes of the technology transfer endeavor, anticipated to be comprised largely of benefits but necessarily including unintended (negative) consequences. Bozeman codifies these outcomes into seven spheres: “out-

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[9] Institute for Defense Analysis, Science and Technology Policy Institute (IDA STPI). 2011. Technology transfer and commercialization landscape of the federal laboratories. IDA Paper NS P-4728. Washington, DC.

[10] Energy I-Corps trains researchers; by paying researchers for their time spent in Energy I-Corps activities, it provides a type of incentive. Trainee activities include outreach and exploration of potential partnerships, and the participating labs support Energy I-Corps in part through outreach to the industrial sector.

[11] Bozeman, B., 2000. Technology transfer and public policy: a review of research and theory. *Research Policy 29* (4) 627-655. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.197.3112&rep=rep1&type=pdf

[12] Bozeman, B., H. Rimes, and J. Youtie, 2015. The evolving state-of-the-art in technology transfer research: Revisiting the contingent effectiveness model. *Research Policy* 44, 34-49. http://www.sciencedirect.com/science/article/pii/S0048733314001127?via%3Dihub

the-door," market impact, economic development, public value, scientific and technical human capital, political, and opportunity cost.[13]

"Out-the-door" provides the simplest measure of technology transfer activity effectiveness, indicating that the technology has transferred from the originating institution (the lab) to a recipient organization (for the case studies here, the startups). As Bozeman notes, this effectiveness criterion reflects a bureaucratic approach that equates transfer itself as success. Despite the limited notion of effectiveness described by the "out-the-door" criterion, the criterion recognizes that whether and how an innovation is used is typically beyond the control of the innovators or innovating institution. Although the metric does not provide an assessment of the benefits assumed by policymakers to accrue to technology transfer, researchers use the "out-the-door" criterion of effectiveness far more often than any other criterion, principally due to the availability of information.

In the current study, we use the "out-the-door" criterion of effectiveness due to the short amount of elapsed time (relative to commercialization processes) since the Energy I-Corps training. Subsequent studies of Energy I-Corps might investigate additional outcomes, such as market impact. Per this criterion, the transfer of all of the case study technologies has been effective; they are "out the door," having passed from the lab to a startup (see Section 1.3.1). This report examines factors that led to these technologies' out-the-door success and describes conditions suggesting that these technologies are likely to continue to develop through commercialization readiness and to achieve sales or use in the case of open-source software.

Bozeman terms his model "contingent" effectiveness to acknowledge the multitude of factors that influence the effectiveness of the technology transfer endeavor; that is, the many factors on which success of technology transfer is contingent. He groups these contingencies into five categories, and elaborates each with subcategories to illustrate the many variables that can influence technology transfer success:

1. **Transfer agent.** Transfer agents are the innovating institutions. The national laboratories (the subject of this report) vary widely, and are characterized by such factors as technological niche, mission, sector, scientific and technical human capital, resources, geographic location, organizational design, management style, and political constraints.
2. **Demand environment.** Demand environment describes the nature of the target market's demand for the innovation. Markets vary widely and are characterized

[13] It may interest the reader to note that the IDA study did not use or propose a comprehensive set of success metrics, but concluded that a versatile set of metrics needed to be developed to accommodate the wide-ranging research activities of the federal labs.

by such factors as existing demand for a comparable technology (if any), potential for induced demand, and economic characteristics of the innovation.

3. **Transfer recipient.** Transfer recipients are the entities acquiring the innovations. Transfer recipients vary widely, as no two organizations are the same, and are characterized by such factors as scientific and human capital, resources, manufacturing expertise, marketing capabilities, geographic location, diversity, and business strategies.
4. **Transfer object.** Transfer object denotes the innovation being transferred, including one or more of the following technology types: scientific knowledge, physical technology, technological design, process, know-how, and craft.
5. **Transfer media.** Transfer media denotes the source by which recipients acquire the innovations, including one or more of the following source types: open literature, patent and copyright, license, absorption, informal, personnel exchange, on-site demonstration, and spinoff.

Energy I-Corps operates in this complex environment comprised of diverse laboratories, diverse technologies, diverse target markets, and diverse uptake entities. Only the transfer media is somewhat simplified in these case studies of Energy I-Corps technologies, as the studies focus on cases of transfer via licenses to startups that have either spun out of the labs or out of the training teams sponsored by the labs.

It is precisely this enormous variability in contexts – in factors that influence technology transfer success – that led DOE to request that we develop case studies to better understand Energy I-Corps effectiveness. In this report, we define technology transfer "success" as progression along the commercialization continuum including receiving follow-on funding, forming industry partnership(s), founding a startup, and high likelihood of continuing progress as described by Technology Readiness Level (TRL). The following case studies explore the context in which each selected technology has moved from the lab to the startup, touching on each of the five categories of contingency in Bozeman's Contingent Effectiveness Model of Technology Transfer (as given in the above numbered list).[14]

As for transfer effectiveness, we limit the discussion to "out-the-door," transfer from the lab to another party, as none of the technologies has attained market sales. However, we broaden the lens in one respect.

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[14] In addition to the Bozeman analysis, we were guided in our development of interview guides by unpublished papers prepared by Dr. Gretchen Jordan. These include *Template for Case Studies of Technology Commercialization*, July 2017, and a paper for the October 2013 *NAS Team Science Workshop*.

1.3 METHODS

1.3.1 Selection of Technologies Teams for Case Study Investigation

We obtained information from several sources to identify candidates for the case study investigation. We asked the NREL Energy I-Corps program manager to identify technologies developed by any of the participating labs that had progressed along the commercialization continuum and might be appropriate for the case study research. We similarly asked the program managers at each participating lab to identify any of their technologies that might be appropriate for this case study research. Finally, we obtained from the DOE Energy I-Corps program lead a list of all participating technology teams that had received follow-on funding subsequent to training.

From these sources we identified six technologies as constituting the best candidates for the case study, based on follow-on funding received, industry partnership established, and (possibly) startup launched. Startups had licensed three of the six technologies. We gathered additional information on these six technologies and selected four to pursue for the case studies that follow (Table 1-1), including the three technologies with startups, industry partners, and follow-on funding and one with partners and funding but no startup at time of selection but now, at the time of reporting, with a startup launched.

Table 1-1: Selected Labs, Teams, and Technologies

Lab	Team	Technology
ANL	SonicLQ	A hardware and software technology designed to identify air infiltration or leakages in buildings, informing decisions on the energy efficiency of the building. Can work for large buildings and occupied buildings, which other technologies cannot do. SonicLQ is short for Sonic Leak Quantifier.
ANL	RWEDI	A separation technology that uses electricity to remove ions from aqueous streams. In its application in cooling towers, removes minerals from water, reducing the amount of water and chemicals normally used in the process. RWEDI is short for Resin Wafer Electrodeionization.
NREL	WISDEM	An open-source, software-based framework that creates a "virtual," vertically integrated wind plant to optimize wind turbine and plant design, control, and operation. WISDEM is short for Wind Plant Integrated Systems Design and Engineering Model.

Lab	Team	Technology
PNNL	STARS	A technology platform that efficiently converts solar and other forms of energy and natural gas into chemicals, fuel, and power. In its application in hydrogen production, produces hydrogen with lower carbon emissions and/or lower cost than alternative technologies. STARS is short for Solar Thermochemical Advanced Reactor System.

All four of these technologies had attained out-the-door success at the time of this study. Startups have acquired licenses to use the STARS and RWEDI technologies. WISDEM, an open-source software, has been downloaded, including download by a startup intending to offer WISDEM on a software-as-a-service basis. SonicLQ has spawned a startup which plans to license the technology when it receives a patent that is pending.

The startups need to further develop the technologies to take them to TRL 9 (commercialization ready) and on to sales.

1.3.2 Selection of Interviewees and Interview Guide Development

We identified contacts to interview consistent with the Bozeman Contingent Effectiveness Model (Table 1-2). We obtained contact information from each lab's Energy I-Corps program manager and from each team's Principal Investigator. Using five guides tailored to the individual contact (denoted by the letters A-E in Table 1-2), we sought to interview up to seven contacts for each case study and completed interviews with six of those contacted for three studies and with seven contacts for one study. The interview guides, presented in Appendix A, explore many of the contingency elements in Bozeman's model (given in the numbered list in the previous section). We discussed the transfer object (the Energy I-Corps technology) and transfer media (licensed to spinoff startup) with most contacts.

Table 1-2: Types of Contacts Interviewed and Guides Used

Contingency Category	Sub-Category	Type of Contact	Guide
Transfer Agent	Innovating researchers	Principal investigator (PI)	A
		Engineers, other researchers	
	Innovating institution	Lab's Technology Transfer Office (TTO) manager supporting the technology	B
		Research manager of group in which PI works	C
Transfer recipient	Startup	Startup Chief Executive Officer (CEO)	A
	Partner/funder	Partner/funder supporting the technology	D
Demand Environment	--	Industry expert	E

1.3.3 Analysis

With the contacts' permission, we recorded and transcribed the interviews for our note taking. We used qualitative analysis software to thematically code the interview data into emergent themes. We specifically sought to trace the commercialization progression over time, key activities undertaken, challenges faced and their resolution, and the influence of Energy I-Corps on these aspects. The case study technology teams reviewed their respective chapters to ensure accuracy of technical details and to ensure no proprietary information was shared.

Section 2 STARS

STARS (Solar Thermochemical Advanced Reactor System), also referred to as Dish-STARS when paired with solar energy parabolic dish concentrators, participated in the first U.S. DOE Energy I-Corps training cohort, which started October 2015.

Robert Wegeng, a scientist at Pacific Northwest National Laboratory (PNNL) was the Principal Investigator (PI) for the research that led the predecessors of the STARS technology to obtain more than 150 patents. The Entrepreneurial Lead was Chris Klasen and the Industry Mentor was Peter Brehm.

In early 2017 the PI and the Industry Mentor on the STARS Energy I-Corps team incorporated STARS Technology Corporation in the State of Washington, acquired the license to STARS-related patents, and received funding from DOE, with cost share from Southern California Gas Company (SoCalGas) and others, and signed two cooperative research and development agreements (CRADAs) related to that funding.

The STARS Technology Corporation is currently pursuing applications for the technology in hydrogen production for fuel-cell vehicle refueling stations and to reinject hydrogen into natural gas pipelines, increasing the renewable content and reducing the carbon intensity of the gas. A demonstration project is on track for the first application, establishing hydrogen refueling stations in Palm Desert, California in 2019.

This is STARS' story of its path into Energy I-Corps and onto startup and early commercialization activity.

2.1 TECHNOLOGY OVERVIEW

2.1.1 Brief Description

Dish-STARS efficiently converts solar energy, water and methane, usually from natural gas, into chemical energy. Dish-STARS integrates two technologies, the STARS chemical reactor system and the solar energy parabolic dish concentrator; Figure 2-1 shows this pairing. The Dish-STARS technology is versatile and can create such products as hydrogen and synthesis gas (syngas).[15] STARS builds upon years of development at PNNL of the Micro- and Meso-channel Process Technology (MMPT), in particular, micro- and meso-channel chemical reactors and heat exchangers.

Dish-STARS replaces natural gas combustion with renewable energy. PNNL summarized the science of the Dish-STARS technology as follows:[16]

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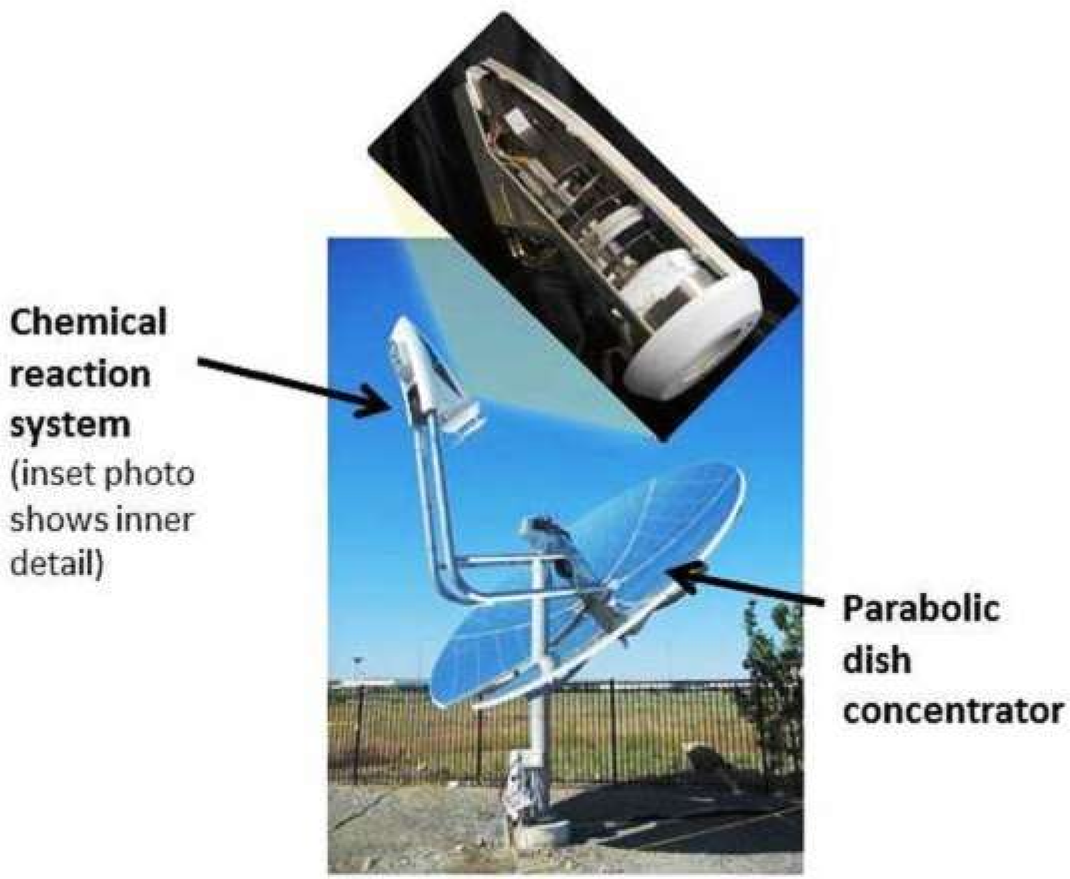
[15] Syngas is a combustible fuel gas mixture consisting primarily of hydrogen, carbon monoxide and, often, carbon dioxide. Syngas is more energy-rich than natural gas.

[16] https://availabletechnologies.pnnl.gov/technology.asp?id=395

Concentrated sunlight heats up the natural gas flowing through the [chemical] reactor's channels, which hold a catalyst that helps turn natural gas into [hydrogen, syngas, or other products]. The heat exchangers' channels help recycle heat left over from the chemical reaction gas. …STARS has set a world record with 69% of the solar energy that hit the system's mirrored dish converted into chemical energy contained in the syngas.

Figure 2-1: The Dish-STARS Technology



The STARS technology accomplishes this efficiency on a very small scale. The reactor and heat exchangers have narrow MMPT channels that are only as wide as six dimes stacked on top of each other.

The PI, making an analogy with computer process chips, describes STARS as chemical process "chips." "A chemical process chip that might be the size of a book has the same capability as a chemical plant that is much bigger."

"A chemical process chip that might be the size of a book has the same capability as a chemical plant that is much bigger."

In typical chemical production, plant economies come from building very big. The MMPT chips get economies by building small and exploiting some physics and chemistry advantages that make them powerful and fast.

STARS is a technology platform that can be configured for multiple applications and users. These MMPT chips can be highly specialized for different needs and integrated with other chips to create a system with specific properties. Thus, the STARS platform can serve a wide variety of applications, including applications ranging in size from a single chip to hundreds or thousands of chips.

Although Dish-STARS is currently not commercialized, its commercialization is expected to offer affordable production of low-carbon intensity (renewable) fuels, chemicals, and power. As the startup scales up production to meet demand from successful commercialization in the refueling and reinjection markets, production costs will fall, opening opportunities for the technology's use in other applications that have a lower price-point.

2.1.2 Current Market Targeted

There are significant market opportunities for STARS and Dish-STARS in the next three to five years. To attract investors, the startup team has chosen to concentrate first on a module configured for hydrogen production for two applications. One is fuel cell vehicle refueling stations, both distributed production at the station and centralized production with shipping to stations. This application will require a small but sufficient number of Dish-STARS to be manufactured and sold, enabling scale up and lowering costs of production. The second application is to reinject the hydrogen produced back into natural gas pipelines, increasing the renewable energy content, and reducing the carbon intensity of the gas. This technology has a reasonably high cost target ($8-10/MMBTU) and would justify the production and deployment of potentially tens of thousands of Dish-STARS units.

The competitors to STARS in its initial hydrogen production applications are entities producing hydrogen, which have very large central production facilities. The current dominant state of the art for hydrogen production is steam-methane reforming (SMR), where about 25 percent of the natural gas is burned to convert the rest of the natural gas into hydrogen. In SMR, natural gas (or another methane source) reacts with high-temperature steam in the presence of a catalyst. SMR is very cost effective but has substantial negative environmental impacts. Today, the US produces 95% of its hydrogen by natural gas reforming in large central plants.[17]

[17] https://energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

Electrolysis, a newer approach to hydrogen production, is low-carbon but is not cost effective and thus in limited use.

STARS use in hydrogen production for its first applications meets or beats the costs of these existing technologies, can provide distributed production, and has reduced environmental impacts.

The STARS team identified through its Energy I-Corps activities multiple potential products and applications. The team focused during the training on developing value propositions and a product application strategy for the sequential rollout of STARS systems for the identified applications. The next three opportunities the team intends to pursue after hydrogen for refueling stations and reinjection into natural gas pipelines are:[18]

- Co-production of liquid hydrocarbons (such as methanol) and hydrogen. The market potential here is very large, "considering that methanol is one of the world's largest commodity chemicals, with global production of about 100 million metric tons per year, and that methanol could be used as an additive that enables gasoline to meet the California Low-carbon Fuel Standard for 2020." Central and distributed power generation from the syngas product that the STARS technology platform can produce as an alternative to hydrogen production. This application for power generation has a large market potential.
- Distributed production of liquid hydrocarbon fuels from bio-gas and/or associated gas at landfills, anaerobic digesters, oil fracking sites, etc. The cost targets may be similar to that for hydrogen production for refueling stations and so may be more readily achieved than for some of the more challenging applications.

2.1.3 Comparative Advantage and Benefits

Dish-STARS has economic as well as environmental comparative advantages. The team expects Dish-STARS to meet the price of hydrogen produced by SMR and is less expensive than producing hydrogen by electrolysis.

The projection made in the team's proposal for follow-on funding and reiterated in interviews for this case study is that when Dish-STARS is manufactured at volumes where economies of scale are achieved, the unit production costs, not including compression, will be less than \$2/kg hydrogen production (a competitive price) with carbon emissions (carbon intensity) of 49.4 g CO2/MJ (based on lower heating value), which is about 45 percent less than hydrogen conventionally produced through SMR.

Dish-STARS can produce hydrogen efficiently on a very small scale. Because that small scale can then be scaled up by individual units, it can satisfy many markets without the

[18] Dish-STARS Commercialization Proposal to the DOE Technology Commercialization Fund, 2017.

large capital costs of current refineries and high transportation cost required with the large refineries using the traditional SMR process.

Dish-STARS can replace SMR with renewable energy in the production of hydrogen from natural gas, achieving 20% lower carbon emissions. There is increasing societal pressure to reduce the amount of carbon released into the atmosphere. Low-carbon production of hydrogen helps meet societal goals.

Dish-STARS can transform carbon into chemicals such as methanol, which is used to lower emissions from gasoline, and chemicals used to produce plastics. Creating products of value from carbon provides incentives to not release it into the atmosphere, even when there is no requirement or regulation to do so.

There is an abundant supply of natural gas in the United States and its price has been decreasing; thus, STARS is assured of a reasonable methane source. Areas of the country have excess renewable energy power that could serve as the energy source needed for the methane conversion.

2.1.4 Current State of Development

The STARS technology has over 150 patents and was well developed prior to its involvement in Energy I-Corps, although that development (discussed in section 2.2.1) did not target the application of hydrogen production. The PI estimates that the technology got to Technology Readiness Level (TRL) of about 5 during Energy I-Corps (from TRL 3 at the beginning of the SunShot funding) and is at about TRL 6 at the end of 2017.[19,20] The team expects to get to TRL 7 or 8 during the two years with funding from the Technology Commercialization Fund (TCF).[21, 22, 23]

STARS is also currently supported by the Rapid Advancement of Process Intensification Deployment (RAPID).[24] The team's work on the RAPID project will improve the

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[19] TRL 5 corresponds to initial development and verification of an integrated system.

[20] TRL 6 corresponds to validation of system prototype in a simulated operating environment.

[21] TRL 7 corresponds to integrated system prototype demonstrated in an operational environment.

[22] TRL 8 corresponds to validation in a commercial operational environment.

[23] TCF is a DOE competitive funding opportunity designed to mature promising technologies to advance commercialization and lab-industry partnerships. https://energy.gov/technologytransitions/services/technology-commercialization-fund

[24] In December 2016, DOE established the RAPID Institute with federal and private funding to focus on developing breakthrough technologies to boost domestic energy productivity and energy efficiency by 20 percent in five years through manufacturing processes in industries such as oil and gas, pulp and paper, and various domestic chemical manufacturers. RAPID is coordinated by the American Institute of Chemical Engineers. To date, RAPID consists of 75 companies, 34 academic institutions, seven national laboratories and other organizations. https://energy.gov/articles/energy-department-announces-american-institute-chemical-engineers-lead-new-manufacturing

"manufacturing readiness" of the STARS technology by improved additive manufacturing design to decrease manufacturing costs and improve performance.[25]

2.2 PROGRESSION ALONG THE COMMERCIALIZATION CONTINUUM

2.2.1 Prior to Energy I-Corps

Initial funding for MMPT development at PNNL came from NASA. NASA wanted to develop a method for carbon capture to make rocket fuel on Mars. The STARS PI was the PI on that early work. The phrase "developing fuel from thin air," while sounding like science fiction, is still the ultimate goal for the technology development: to capture CO_2 and water from the atmosphere and from them make valuable fuel and chemicals. The current technology development is a preliminary step.

Development funding was received from the DOE Fuel Cell program and the American Recovery and Reinvestment Act of 2009 (ARRA). More recently, the PI and PNNL team received funding for development from the DOE Energy Efficiency and Renewable Energy (EERE) SunShot Initiative from 2014 to 2017. That research led to a version of STARS optimized for syngas production, intended to be consumed in a combustion turbine for electricity generation. The effort advanced the technology from TRL 3 to TRL 6 relative to syngas production for the Energy I-Corps team.[26]

The original TRL 3 version of the system accomplished a 63% solar-to-chemical energy conversion efficiency, based upon the ratio of the increase in the higher heating value of the reacting stream to the direct normal sunlight incident on the dish (independent of what is produced from the conversion). The TRL 5 version achieved its target of 70% during on-site testing in FY2015. These are world record efficiencies for solar-to-chemical energy conversion and are a part of the rationale for why STARS received an R&D 100 Award from R&D Magazine during 2014.

PNNL was also involved in the initial development of the dish parabolic solar receiver with a Stirling engine. PNNL had contracts with Infinia Technology Corporation for dish receivers to test the development of Dish-STARS that brought these two developing technologies together.

2.2.2 Energy I-Corps Experience

The PNNL Technology Deployment Office is responsible for technology transfer at the Laboratory. The office was active in the management of the lab's involvement in Energy I-Corps and created a pipeline of clean energy technologies and had identified technical staff associated with the technologies that they thought would be good potential Energy

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[25] Additive manufacturing builds a component in layers by dipositive material as governed by digital 3D design data.

[26] TRL 3 corresponds to proof of concept for components.

I-Corps trainees. In addition to an enthusiastic STARS PI, there was a lot of energy and support from the primary program offices that had and were supporting STARS – the SunShot program and Vehicle Technologies Office.

The STARS Energy I-Corps team had not worked together before, although the PI and Industry Mentor knew each other from earlier work between their two organizations. Both the Entrepreneurial Lead and the Industry Mentor were chosen by the PNNL Energy I-Corps manager, although the PI had some input when an initial choice for Industry Mentor did not work out.

Each member of the team had deep expertise in their areas. The PI had been instrumental in the development of the team's technology and its predecessors for more than 15 years. The Entrepreneurial Lead had a MBA and experience in project management at the lab, and in previous employment had used tools like the Lean LaunchPad methodology to learn the segments and industries various technologies were playing in. He did not have a technical degree as most Entrepreneurial Leads did.

The Industry Mentor had experience with forming energy businesses and raising venture capital, initially with a company startup from PNNL many years ago. He is a seasoned, well-known Washington business leader and entrepreneur. He was president of Infinia Technology Corporation (ITC), which had supported the PNNL PI with the solar dishes that integrated the reactors with solar energy.[27]

The team "worked really well. The chemistry is perfect together."

The team members appreciated what each member brought to the effort and found themselves to be very compatible. The Technology Deployment Officer said in the interview that the "incredibly strong Entrepreneurial Lead, [a PI] who was incredibly enthusiastic about his technology and an advocate for seeing it get applied… and senior experience and knowledge base from the Industrial Mentor… worked really well. The chemistry is perfect together."

During the six-week Energy I-Corps training, team efforts were focused on populating and validating the business model canvas. Team members described their activities developing value propositions for the applications identified through the customer discovery process as particularly important. The initial business model for Dish-STARS provided the basis for testing key assumptions with external experts through interviews with 77 subject matter experts. These experts were a mixed group of potential customers, competitors, regulators, and trade associations.

The Energy I-Corps training emphasized that the minimum viable product was the lowest cost product to develop that also made the most compelling commercial sense.

[27] The parent of ITC, Infinia Corporation, had started out as Stirling Energy Systems, a firm looking to commercialize solar Stirling engines.

Refining the minimum viable product helped the team refine its business model canvas, which in turn helped the team attract capital, as well as management, to the process.

The validation/customer discovery process showed the team that a pivot from the power generation funded by SunShot to solar-based hydrogen production resulted in a minimum viable product for which the team found a lot of market interest. Hydrogen, especially renewable hydrogen, or quasi renewable hydrogen, was very much of interest to the State of California and some of its key and strategic industries, such as oil refineries and hydrogen fuel cells. The pivot to hydrogen production did not pose the team technical challenges. As the technology was already making hydrogen, simply adding a water-gas shift reactor produces a lot of hydrogen with 20% lower carbon emissions than from SMR production.

The Energy I-Corps experience gave the PI and other team members confidence they had a minimal viable product ready for commercialization. When they completed the training, they began the dialog with PNNL management and staff in the Technology Deployment Office about leaving the lab and starting a business to pursue commercialization. All three team members were interested in remaining involved, even the Industry Mentor, who saw the huge promise in the pivot to low-carbon hydrogen production.

Everyone interviewed agreed that none of this would have happened without the Energy I-Corps experience. One person described Energy I-Corps as "the catalyst that got the reaction going." Another said, "Everything changed the next day [after Energy I-Corps]. We were not the same people the next day." Also, the positive feedback received from people interviewed during Energy I-Corps as well as from the course faculty really mattered to lab management.

Energy I-Corps was "the catalyst that got the reaction going."

Spending time out in industry, doing customer discovery, and starting to put it all together in their heads was important "because often researchers spend all their time programmatically thinking about answering questions and solving problems related to their projects, but never thinking about what is it going to take or mean to actually get that technology valuable in some industry space". There is no time in the normal work week to dedicate to customer discovery.

Team members agreed that "when you can validate all the elements of the business model canvas, you have a much better chance of having an executable business model, because you did your homework. You learn that you have to continue doing your homework as the technology and context evolve." Team members have stayed in contact with members of the Energy I-Corps faculty and continue to seek advice from various technology and small business experts and to be open to pivots.

2.2.3 Building on the Energy I-Corps Experience

2.2.3.1 The Startup Company

The PI and Industry Mentor co-founded the STARS Technology Corporation (a C Corporation)[28] in the State of Washington in early 2017. The company is located in Richland, Washington to be close to PNNL.

The PI and Industry Mentor were soon joined by the Entrepreneurial Lead. The Entrepreneurial Lead coincidentally had a job offer to work for an early stage technology investment firm focused on getting technologies out of national labs and top tier universities, building startup companies, and getting technologies through the valley of death. After getting an agreement that he could also work with STARS, he left the lab. A retired PNNL employee who had worked on the technology as a consultant also joined the startup.

The team's Industry Mentor serves as the Chief Executive Officer, spending one day per week on the project the first year.[29] The PI serves as the Chief Technology Officer, spending about half time, and the Entrepreneurial Lead is the Chief Operating Officer, spending 10-20 hours per week on the startup. The fourth member is a hydrogen expert who continues to do the techno-economic analysis for STARS. At PNNL, staff continue to work on STARS-related projects, and as needed, the team calls on their and other expertise from within the lab, as well as outside contractors. An external contractor does the additive manufacturing of the heat exchangers, for instance.

2.2.3.2 Partners/Funders

The Energy I-Corps team continued development of the technology until Spring 2017 through the contract with EERE's SunShot program. At the same time, they submitted a winning proposal to the DOE TCF, receiving $1 million over two years with additional cost share of $500,000 from SoCalGas and $500,000 from the startup company STARS Technology Corporation. Several of those interviewed said that had it not been for Energy I-Corps they would not have be able to write such a strong proposal to the TCF or secured so much money.

The TCF project aggressively supports the cooperative development of Dish-STARS with two goals: ramping up production (to hundreds and possibly thousands of units per year) to reach economies of scale in hardware production and implementing several major deployments by 2020. The TCF project will also directly support the near-term application identified through Energy I-Corps training, the distributed hydrogen production at a fuel-cell vehicle refueling station in Palm Desert, California. The plan is

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[28] The profits of a C corporation are taxed separately from the income of its owners.

[29] The CEO's previous company, Infinia Technology Corporation, was sold in September to American Superconductor.

for a multi-fuel station that provides compressed natural gas, hydrogen, and methanol. The STARS solar thermochemical process will be designed to co-produce hydrogen and methanol, with hydrogen production to be up to 100 kg H2/day. Methanol production rate will depend on the requirements of the refueling station.

The DOE program office funding the TCF award reviews the project regularly and holds monthly meetings to ensure the project is delivering what was promised. According to the current PNNL PI for STARS, the project is on track to meet its milestones.

The STARS technology also receives funding under RAPID, one of the first projects to be funded by the institute, which was established mid-December 2016. RAPID is an outgrowth of the collaboration between Oregon State University (OSU) and PNNL through the Microproducts Breakthrough Institute, which began in 2001. The success of that partnership has evolved into the new, five-year, $70 million Advanced Technology and Manufacturing Institute, located on the Hewlett Packard campus in Corvallis. OSU and PNNL co-direct the institute's module manufacturing focus area. The module manufacturing focus area addresses manufacturing and supply chain issues associated with modular chemical process intensification, which, according to OSU "is the development of chemical manufacturing equipment that is smaller, lighter-weight, and more energy efficient."[30]

Through its RAPID funding, the team is working to increase efficiencies in the additive manufacturing of the STARS reactor, key to lowering production costs. The RAPID project will develop prototype assembly lines to build small quantities of reactors over the next one or two years, initially tens to dozens of units and ultimately hundreds. STARS Technology Corporation also provides cost share for this project through a CRADA with PNNL.

PNNL has a long history of collaboration with OSU. The OSU Engineering Department, in addition to its RAPID involvement, will continue to provide the cost models that predict system cost at various production levels. System costs drive the STARS technical economic model, which provides the economic metric that guides development of the technology.

In addition to PNNL and OSU, two businesses have served and continue to serve as resources to the STARS team. The team calls on Diver Solar LLC, which has deep expertise in solar technology, for assistance with design issues. Barr Engineering is well equipped to take designs to engineering scale and actual construction. A PNNL colleague now works there.

SoCalGas has been a partner in STARS development since 2014. A technology development expert at SoCal Gas read an article about STARS while scanning the

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[30] http://oregonstate.edu/ua/ncs/archives/2016/dec/osu-pnnl-lead-part-major-national-program-%E2%80%98chemical-process-intensification%E2%80%99

horizon for interesting technologies. He met with the STARS team and was impressed with its potential for distributed, cost-competitive, low-carbon intensity hydrogen from natural gas and sunlight. SoCalGas ended up providing cost share for the SunShot project and now the TCF project.

There are several benefits that the STARS technology could offer SoCal Gas. It offers hydrogen at potentially the lowest cost available. It offers low-carbon hydrogen and is much less expensive than the alternative low-carbon generation method, electrolysis. It uses natural gas (SoCalGas' product).

A SoCalGas technology expert thinks that the STARS projection is very realistic of hydrogen at two dollars per kilogram or two dollars per gasoline gallon equivalent and so believes STARS is a valuable pathway to pursue. SoCalGas is also funding a project at the Jet Propulsion Lab using different technologies to convert natural gas into hydrogen. More recently, SoCalGas has been investing in research to reform natural gas in such a way as to co-produce hydrogen and high-value forms of carbon. The company anticipates that different forms of carbon might scale to the point where it makes sense to reform natural gas in large quantities and use the hydrogen for energy generation and thermal applications and use the carbon for other things. "The STARS technology is a platform, it doesn't really have an end point from where we're at now."

"The STARS technology is a platform, it doesn't really have an end point from where we're at now."

2.2.3.3 Technology Transfer

The PNNL Technology Deployment Office worked to develop the required CRADA after STARS received its TCF funding commitment. All CRADA partners, DOE/PNNL, SoCalGas, and STARS Technology Corporation had to agree on the same scope of work, and the field of use and other intellectual property issues. Not only was information that would result from the project protected, but SoCal Gas and STARS have the opportunity to secure the intellectual property rights going forward.

PNNL was just developing an Entrepreneurial Leave program and the PI was the first employee to engage in the process. PNNL designed the entrepreneurial leave process to vet candidates in a way that PNNL Battelle could identify the risks, conflicts of interest, and other things that the lab would be committing to, but also to enable participating entrepreneurs to determine the best path for them. Had the STARS PI been more junior at the lab, entrepreneurial leave would have been a good fit for him. But he happened to be in the right position to retire from the lab to join the startup and be rehired at the lab part time.

There were challenges in the PI's change in position, and the Technology Deployment Office worked with the PI to make sure that transition was as smooth and seamless as possible. PNNL has a diverse, laboratory-wide group involved with Entrepreneurial

Leave: the project manager oversight office (which represented the sector managers), the line managers, legal staff, and Human Resource staff, and compensation staff. For example, the PI's line management helped sort out conflicts of interest, in particular identifying the projects on which the PI could still work once he divested himself of management responsibilities. The lab developed an outside activity agreement to help everyone understand what activities the PI was going to do and how any conflicts will be managed. The agreement underwent multiple revisions by a PNNL attorney, other stakeholders, the PI, and line management. The Technology Deployment Officer interviewed concluded that "we got it right, and everybody seemed very comfortable with it."

The large intellectual property portfolio involved in this transfer, much of which the PI had helped create, was very beneficial for future technology development. It was also a challenge for the PI to work with the PNNL commercialization manager to identify, based on what he and the startup wanted to accomplish, the intellectual property protection that needed to be secured through a licensing arrangement. This sorting out was done after the startup's incorporation. Because the technology had over 150 patents, identifying exactly which patents and patent options the startup wanted took time, because the more patents licensed, the greater the cost for the license.

PNNL's Lead Patent Counsel was very helpful in this process because he had been involved throughout, from the CRADAs, to the licensing executions, to figuring out the entrepreneurial leave strategy. The Technology Deployment Officer interviewed summed up the lab support for the transfer of STARS as "great support from a lot of people at the lab." These people faced challenges with an open mind, saying "yes, we can do this, but let's just take care of this." The industry mentor said that the commercialization group and PNNL "were very reasonable to work with and very knowledgeable. They were good partners in this process."

> The PNNL commercialization group and others "were good partners in this [technology transfer] process."

2.2.4 Marketing Context

STARS has hit a window of opportunity for this type of technology.

STARS is a technology platform with multiple applications. It can produce fuel or chemicals and has multiple ways to generate economic value, in addition to the environmental benefits of low-carbon production, including the capture of carbon in materials such as plastics. Given worldwide pressures to reduce the amount of carbon released into the atmosphere, anyone who has a carbon-based fuel in any location serious about decarbonizing is a potential customer for the STARS technology.

Worldwide, hydrogen is a $150 billion dollar a year market. Currently, fertilizer production and petroleum refining are the largest users of hydrogen. The hydrogen market has been growing because hydrogen is used to make cleaner gasoline and cleaner diesel. Producing low-carbon hydrogen is a benefit in itself.

The Hydrogen Council, launched in 2017, is a global initiative of leading energy, transport and industry companies with a united vision and long-term ambition for hydrogen to foster the energy transition.[31] The council came together for a report on the future of the hydrogen market, developed with support from McKinsey. The study, entitled *Hydrogen, Scaling Up*, outlines a comprehensive and quantified roadmap to scale deployment and describes its enabling impact on the energy transition.

> *"Deployed at scale, hydrogen could account for almost one-fifth of total final energy consumed by 2050. This would reduce annual CO2 emissions by roughly 6 gigatons compared to today's levels and contribute roughly 20% of the abatement required to limit global warming to two degrees Celsius. On the demand side, the Hydrogen Council sees the potential for hydrogen to power about 10 to 15 million cars and 500,000 trucks by 2030, with many uses in other sectors as well, such as industry processes and feedstocks, building heating and power, power generation and storage. Overall, the study predicts that the annual demand for hydrogen could increase tenfold by 2050 to almost 80 EJ, meeting 18% of total final energy demand in the 2050 two-degree scenario."*[32]

The energy sector itself is challenging, however. There are many incumbents, including regulated utilities, and large capital investments. For a new technology to break in requires "a combination of engineering, economics, and politics," as one person interviewed described it. To the extent the market for STARS is hydrogen refineries, these refineries are very good at what they do; their margins are razor thin. As a consequence, they do not often make changes to their systems. Thus, although it is a great market, getting into the refinery business will be challenging.

Considerations such as these led the STARS team to develop the strategy of starting with niche markets, such as distributed hydrogen refueling stations.

2.2.5 Current Challenges

There are no remaining technical challenges to commercialization of STARS in its first two applications. The PI stated, "There are no new discoveries to be made. The current performance and cost is good enough." He added that no conventional methods can deliver hydrogen to the distributed refueling stations at a reasonable price. "We just have to execute our plan."

The largest challenge in execution is finding investors interested in partnering with STARS Technology Corporation in this early stage of demonstrations at increasing

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[31] http://hydrogencouncil.com

[32] http://hydrogencouncil.com/hydrogen-scaling-up-new-roadmap-launches-at-cop-23

scale. Production of the equipment is expensive. Finding more investors consumes a great deal of time at a time when staff work for the startup just part time and there are many other demands on their time.

2.2.6 Looking Forward

Although the attainment of technology development and commercialization milestones can seldom be reliably predicted, the PI estimates that the STARS technology of hydrogen production for refueling stations and reinjection into natural gas pipelines will be commercialized (TRL 9) shortly after a successful demonstration, the aim of TCF and SoCal Gas funding.

Given that STARS is a technology platform and the team identified and prioritized during Energy I-Corps five other applications with large potential markets, there is no discussion of ending PNNL's involvement in technology development for these other applications. STARS Technology Corporation is not setting up a technology development company.

The startup team, particularly the Chief Technology Officer, is actively soliciting investment from pre-venture capital firms, venture capital firms, and strategic investors. They welcome government investment also but consider that source more as sponsorship. The team has already raised money and made its cost share payments for the two CRADAs. At the time of this case study in late 2017, there are signs that a venture capital firm intends to invest in STARS.

The STARS Chief Technology Officer imagines an established company might acquire the startup, but the team would be reluctant to sell without assurance that the purchaser would take the technology to its full potential to make a difference in the world.

2.3 CONCLUSION

The STARS technology is poised to be commercialized by 2020 in its initial application of using solar energy to turn natural gas into hydrogen for fuel-cell vehicle refueling stations. It is a technology platform with world record-setting energy conversion efficiencies that can be configured for other applications, particularly once an improved design of its additive manufacturing process lowers production costs.

Energy I-Corps helped the team realize that a pivot to production of low-carbon hydrogen meant they had a minimum viable product. In addition, the training helped the team develop a strategic sequencing of other applications in a roll-out designed to attract investors. Follow-on funding has been secured and the startup continues to raise capital.

The STARS technology offers much promise, both economic and environmental. Dish-STARS can transform carbon into chemicals such as methanol that is used to lower emissions from gasoline, and other chemicals that are used to produce plastics. The creation of valued carbon products decreases the likelihood that the world's industrial economies will continue to waste large quantities of carbon by releasing it into the atmosphere.

Section 3 SonicLQ

SonicLQ, short for Sonic Leak Quantifier, is a hardware and software technology designed to identify and measure air infiltration or leakages in buildings so that more informed decisions can be made about sealing any leaks. Ralph Muehleisen, a scientist at Argonne National Lab (ANL) and SonicLQ Principal Investigator (PI), led the research that culminated in SonicLQ. The PI, along with Industry Mentor Bill Shadid, a consultant in the building energy industry, and Entrepreneurial Lead Cathy Milostan, a business analyst on staff at ANL, participated in the first U.S. DOE Energy I-Corps training cohort, which started October 2015.

After the Energy I-Corps training, in the spring of 2016, the Industry Mentor launched SonicLQ LLC, became the Chief Executive Officer (CEO), and continued some of the research and business development responsibilities performed by the Entrepreneurial Lead, who left the team due to workload and funding constraints. In 2017, Kanthasamy Chelliah, a postdoctoral appointee at ANL, joined the team as a technical assistant.

The current SonicLQ team is continuing to guide the development of SonicLQ toward commercialization. The team is currently awaiting patent approval so that the SonicLQ technology can be transferred from ANL to SonicLQ LLC; once approved, the latter can pursue applications in the markets for building energy professionals and air leak detection technologies. While there are no sales of SonicLQ at the time of this case study (late 2017), the technology has received follow-on funding from DOE and the Department of Defense (DoD) for further development and testing.

This is SonicLQ's story of its path into Energy I-Corps, onto startup and follow-on funding, and early activity toward developing a minimum viable product for early adopters in the target market.

3.1 TECHNOLOGY OVERVIEW

3.1.1 Brief Description

SonicLQ (initially called the Acoustic Building Infiltration Measurement System, or ABIMS) is a technology that detects and quantifies air infiltration leakages in buildings and other enclosures.[33] The technology consists of a low-frequency speaker, a lightweight, specialized microphone array, and a software package (Figure 3-1).

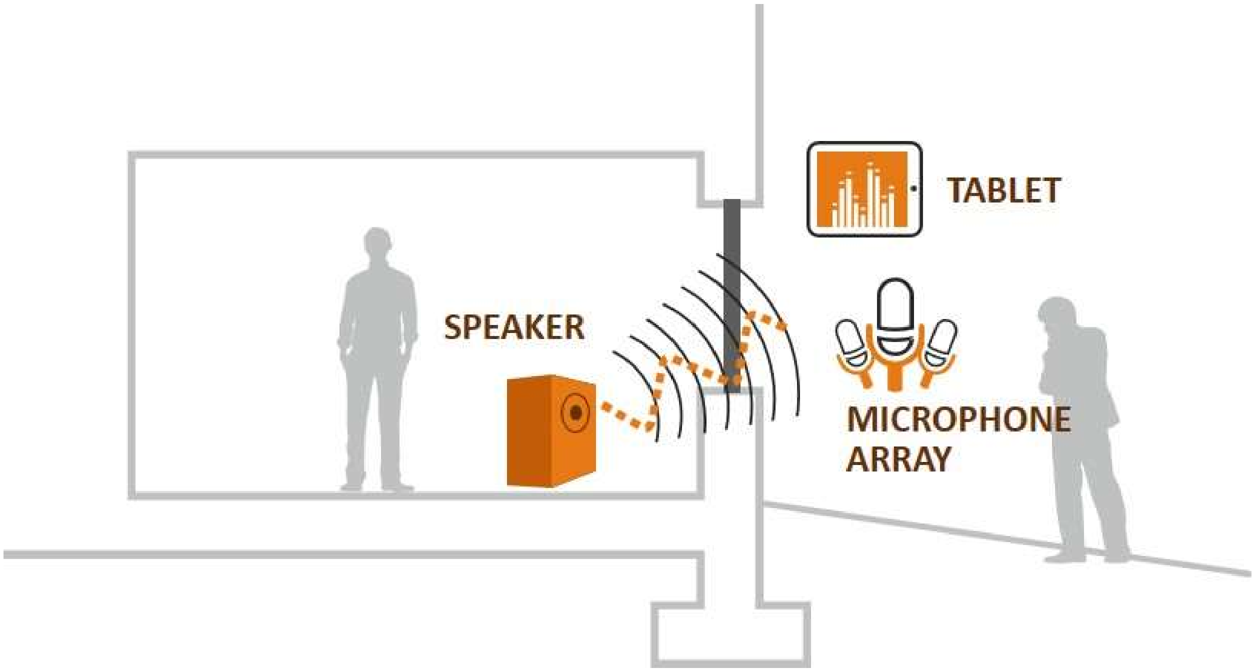
[33] https://www.anl.gov/energy-systems/project/acoustic-building-infiltration-measurement-systemsonic-leak-quantifier

Figure 3-1: SonicLQ Speaker, Microphone Array, and Software*

* Source: Yost, Peter. August 24, 2017. "SonicLQ: Reconnecting Acoustics and Airtightness," Building Science: The Nuts and Bolts of Building at GreenBuidingAdvisor.com. Accessed November 26, 2017 at http://www.greenbuildingadvisor.com/blogs/dept/building-science/soniclq-reconnecting-acoustics-and-airtightness.

SonicLQ works by placing the speaker inside the building or enclosure facing a wall or surface, and placing the microphone array, connected wirelessly to a laptop or tablet with the software package, directly opposite the speaker on the other side the wall or surface, typically on the outside of the building or enclosure (Figure 3-2). The speaker emits low-frequency sound waves that the microphone array receives, and then sends to the laptop or tablet. The software interprets the sound waves to produce an image of the wall or surface that shows and quantifies any air leakages. A person manually moves the speaker throughout the building, and the microphone array can be moved by a person or an attached drone (which is a necessity for multi-story buildings) to produce images of the entire space being tested.

Figure 3-2: SonicLQ Configuration*



* Source: Yost, Peter. August 24, 2017. "SonicLQ: Reconnecting Acoustics and Airtightness," Building Science: The Nuts and Bolts of Building at GreenBuidingAdvisor.com. Accessed November 26, 2017 at http://www.greenbuildingadvisor.com/blogs/dept/building-science/soniclq-reconnecting-acoustics-and-airtightness.

As reported by the Industry Mentor and CEO, "the images and output produced by SonicLQ can then be used to identify where and how much air infiltration occurs in buildings or enclosures so that more informed decisions can be made toward addressing and sealing any leakages." Sealing air leakages is important because it can reduce the amount of energy used to heat, cool, and/or ventilate a building or enclosure, or prevent air, sound, and/or other materials, like toxic materials, from leaking into or out of buildings, enclosures, or vessels.

> "The images and output produced by SonicLQ can be used to identify where and how much air infiltration occurs in buildings or enclosures so that more informed decisions can be made toward addressing and sealing any leakages."

3.1.2 Current Market Targeted

According to the PI, when he was first developing the idea for SonicLQ, the target market he envisioned was building energy professionals, which reportedly is a large and growing market and aligns well with his expertise in building acoustics and building science. Building energy professionals include those who conduct building energy audits, commission or weatherize buildings, perform building maintenance and operations, and/or work on the construction or retrofitting of buildings.

Among such professionals, the current target is specifically those working in large commercial, industrial, and institutional buildings. Through customer discovery interviews, the SonicLQ team found more interest in and demand for a technology like SonicLQ from professionals working with larger buildings compared to those working in smaller commercial and residential buildings due to several limitations with current infiltration-detection technologies in larger buildings that are reportedly not as challenging in smaller buildings (see next section for more details).

Also, during the early development of SonicLQ, and through customer discovery interviews, the team found that SonicLQ could have applications in other similar markets where leakage or infiltration is a concern. These include smaller residential and commercial buildings, storage containers, hazardous materials containment rooms, acoustic rooms like studios, and transport vessels like airplane fuselages and ship hulls. The team plans to explore these in more depth when SonicLQ is closer to commercialization.

3.1.3 Comparative Advantage and Benefits

The current building energy professional industry standard for detecting air infiltration or conducting energy audits in buildings is the blower door test. This test consists of sealing the exterior of an unoccupied building, placing a fan in the building's exit to pull air out of the building (or pull air in, either depressurizing or pressurizing the building), measuring changes in air pressure, and physically identifying leaks. Another, newer air infiltration technology is an infrared camera that produces a thermographic image of the building showing where cool or warm air is leaking from or into the building.

According to the SonicLQ team, funders, and an industry expert, SonicLQ has several potential advantages compared to these existing technologies. One of the most significant advancements is SonicLQ's ability to quantify air infiltration, which neither the blower door nor infrared camera can do.[34] This feature reportedly would enable building owners to reduce the time required to identify leaks and estimate their energy impacts, to better prioritize leak sealing.

Another potential advantage commonly reported in interviews with the SonicLQ team and an industry expert is that SonicLQ may be more versatile, as it is able to operate under more conditions than existing technologies. For example, SonicLQ can be used to test partially constructed buildings and buildings that are occupied. In contrast, blower door tests require the whole building to be constructed (which results in missed opportunities to eliminate leakage during construction) and unoccupied (which is inconvenient for building owners and occupants, and requires more time for the energy

[34] Professionals can quantify how much air is leaking from/into the entire building with a blower door but have to use a type of aerosol spray, like canned smoke or a fog machine, and/or advanced (and expensive) gauges to get a rough estimate of the size of the individual leak(s).

professional). SonicLQ can also perform tests when temperatures inside and outside the building are similar or different, while the infrared camera only works well when the temperatures are different, making the camera difficult to use during the spring and fall.

In addition to the time and costs savings that could result from a more versatile technology, SonicLQ could also be quicker to set up and easier to use when performing a test compared to current technologies, particularly in large buildings. An industry expert reported that some buildings can require up to 50 blower doors to test the whole building in a reasonable amount of time, which is very laborious and costly. A DoD project funder reported that some of their military installations are so large and old, building energy professionals have been unable to conduct blower door tests within the allocated budget and timeframe. The expert and funder both thought SonicLQ has the potential to overcome these limitations.

Beyond the advantages that SonicLQ could provide to building energy professionals, interviewees reported a few benefits that could accrue to builders, building owners and occupants, manufacturers, and society at large. For example, SonicLQ could reportedly help builders more easily meet building codes during construction of new buildings or retrofits of existing buildings, saving time and money on their projects.

If SonicLQ can result in quicker and cheaper infiltration tests or building audits, building owners may also be less reluctant to have an audit performed at their buildings. Greater uptake of energy audits would likely increase the uptake in building improvements that lower utility bills, energy usage, and greenhouse gas emissions and other pollutants, and increase occupant comfort and health. For example, the PI reported that the amount of energy wasted through air infiltration in buildings in the U.S. is estimated to be 20% of an average building's heating and cooling usage; across all buildings in the U.S., it is the equivalent of about 4% of total U.S. energy consumption. As he stated, "reducing the amount of wasted energy in buildings is thus not trivial but quite significant."

> "The amount of energy wasted through air infiltration in buildings in the U.S. is estimated to be 20% of an average building's heating and cooling usage; across all buildings in the U.S., it is the equivalent of about 4% of total U.S. energy consumption."

In addition, increased demand for building audits due to the use of SonicLQ could also have positive employment effects. It could increase both the demand for energy professional's services as well create jobs in manufacturing SonicLQ's components (speakers and microphone arrays).

3.1.4 Current State of Development

The PI estimates that SonicLQ is currently at a Technology Readiness Level (TRL) of about 5 (from TRL 3 pre-Energy I-Corps), which corresponds to initial development and verification of an integrated system. SonicLQ is reportedly very close to the next level (TRL 6), in which a system prototype will be validated in a simulated environment, as the PI and his team are beginning testing in an acoustic isolation chamber and on buildings at ANL.

A startup for SonicLQ (SonicLQ LLC) and website was recently created by the Energy I-Corps team's Industry Mentor, who became the startup's CEO.[35] The intellectual property for SonicLQ still resides at ANL, and the team is currently deciding when and how to transfer the intellectual property to the startup.

An industry expert with a background in physics recently reported through an industry newsletter that, "[SonicLQ] is definitely real. The math holds up. …for big existing buildings, this has real promise."[36] However, he added that SonicLQ still needed to be tested in an operational environment to determine whether the technology is ready for the market, if it needs further improvements, or if it is not currently possible to translate the math and physics underlying SonicLQ into a viable, competitive technology.

"[SonicLQ] is definitely real. The math holds up. …for big existing buildings, this has real promise."

Testing the SonicLQ in an operational environment will reportedly occur in 2018, as SonicLQ was selected by and awarded funding from DoD to perform its first demonstration project at two large U.S. military bases. The SonicLQ team plans to use results from the DoD demonstration project to develop a minimum viable product that they will market to early adopters – a few building energy professionals working in large commercial buildings under construction – and use the adopters' feedback to improve SonicLQ so that it is ready for the broader market of building energy professionals.

3.2 PROGRESSION ALONG THE COMMERCIALIZATION CONTINUUM

3.2.1 Prior to Energy I-Corps

The PI has a "unique mix" of expertise he developed over the course of his career. He started his career in building acoustics and, after a few years, began studying building science with a focus on energy efficiency. His professional background in these areas

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[35] www.soniclq.com

[36] Nadav Malin & Peter Yost. August 2017. "Mind the Gaps: Making Existing Buildings More Airtight" in The BuildingGreen Report (26, 8: 1-9). Accessed November 21, 2017 at https://www.buildinggreen.com/sites/default/files/ebn/TBGR_26-08.pdf

led him to the idea for a technology that identified and measured infiltration in buildings using acoustics.

In 2011, the PI took a position at ANL as the Principal Building Scientist. In 2013 he won a three-year award to begin development of the SonicLQ technology from a funding opportunity announcement from the Building Technologies Office. On the project he leveraged his adjunct faculty position at the Illinois Institute of Technology to partner with the school's faculty and graduate students on the project. The award funding let the PI continue development of SonicLQ during Energy I-Corps.

The team reached a TRL of about 3, corresponding to having a proof of concept for components, in 2014, at which point the PI applied for a patent for SonicLQ's hardware and software from the U.S. Patent Office. The PI thought this was a necessary step towards commercialization that would protect the intellectual property and would help in the future transfer of the technology from ANL to a startup or other business.

The team was reportedly completing TRL 3 around the time it participated in the first Energy I-Corps cohort, which started October 2015. The PI stated that, before training, his team had made progress in developing good estimates of costs but did not know much or anything about several other facets of the business model canvas important for the commercialization of SonicLQ, including:

- Identifying the market segment for which SonicLQ would create value
- Clearly articulating the value proposition for the identified market
- Developing a good estimate of what the target customer is willing to pay
- Identifying inputs/resources needed to deploy SonicLQ
- Identifying suppliers of needed inputs or resources
- Establishing relationship with key partners necessary for commercialization

3.2.2 Energy I-Corps Experience

To form the SonicLQ team for Energy I-Corps, the PI recruited from his staff and other ANL colleagues. The PI recruited one of his ANL staff members, who had a background in business analytics and consulting, to be the Entrepreneurial Lead. The PI also brought on board another of his ANL staff members with a business background, to serve as a backup to the Entrepreneurial Lead if she became too busy with her other projects.

A colleague at ANL recommended to the team a potential Industry Mentor who had previously worked with the staff members in another ANL Division. The Industry Mentor had a background in sustainable architecture, worked as an independent consultant in the energy efficiency industry with his own consulting firm, and had business experience and many contacts in the potential target market. The PI reached out to the Industry Mentor, and he agreed to join the team to participate in Energy I-Corps program and provide mentorship to the SonicLQ team.

Interviewed team members reported several key training activities that contributed to advancing the commercialization of SonicLQ.[37] The team learned about and conducted the customer discovery process, which led to the team to discover that the market they were initially targeting – residential building energy professionals – was unlikely to be among early adopters. While the residential building market is very large, professionals in this market were less interested in SonicLQ because of the adequacy of competing technologies. Instead, the team discovered that building energy professionals working in large commercial, industrial, and institutional buildings were much more interested in SonicLQ due to the substantial limitations of the existing technologies in these types of buildings.

The team developed and refined a value proposition for SonicLQ aimed at the newly discovered target market and gained experience in giving pitches for potential SonicLQ funders, investors, and/or partners. According to the PI, these activities, combined with his and the Industry Mentor's outgoing personalities and confidence in public speaking, greatly enhanced the team's success in securing follow-on funding and generating interest in the technology and the services it could provide.

In addition, the team discovered a limitation with SonicLQ during the Energy I-Corps training that was of concern to target market actors and required what the PI described as "not so much a pivot as an add-on feature." SonicLQ was originally designed to identify and measure infiltration in a building at distances close to the wall of the building, which could require users to take multiple measurements of a single wall (that is, narrow snapshots). Market actors reported preferring to take accurate measurements of an entire wall at once (that is, a broader snapshot), which led the team to work on improving SonicLQ's capabilities.

Another key Energy I-Corps activity reported by the team was learning what resources were available through ANL and other entities, networking with ANL staff, market actors, and potential investors or partners, and identifying what resources and channels they would need to deploy SonicLQ. For example, the Industry Mentor mentioned that although he had worked with ANL before Energy I-Corps, he had little knowledge of what resources, funds, and expertise were available or how to successfully leverage them.

[37] https://energy.gov/articles/progress-president-obama-s-lab-market-initiative

In sum, at the end of the Energy I-Corps training, the SonicLQ team had made significant progress in multiple facets of the SonicLQ commercialization process that were lacking before the training. The team was also on track to move SonicLQ to a TRL of about 4, corresponding to proof of application of system components. As the PI put it, "without Energy I-Corps, I am very confident that SonicLQ would have likely died on a shelf [in the lab]."

"Without Energy I-Corps, I am very confident that SonicLQ would have likely died on a shelf [in the lab]."

3.2.3 Building on the Energy I-Corps Experience

After completing the Energy I-Corps training, the Industry Mentor entered SonicLQ in the 2016 Clean Energy Trust competition. According to both the PI and Industry Mentor, the Energy I-Corps training contributed to their making a good showing at the competition, particularly in giving an effective pitch about the technology, target market, and value proposition. Even though SonicLQ did not win the competition, their participation in the competition reportedly was instrumental in generating useful investor feedback on and market interest in SonicLQ.

The PI and CEO established a good, collaborative relationship through the Energy I-Corps training and subsequent activities and learned to work well together as a team. However, the Entrepreneurial Lead and her backup left the team soon after the training due to funding and workload constraints. The PI was planning to hire graduate students at ANL or the Illinois Institute of Technology, but the Industry Mentor committed to staying on the team to perform some of the customer discovery and business development activities the Entrepreneurial Lead had been doing.

After launching a startup and securing follow-on funding (see next section for more details), the PI hired a postdoctoral technical assistant from the Illinois Institute of Technology to work on further developing and improving SonicLQ's software algorithms to overcome the limitations the PI learned about during the Energy I-Corps training and Clean Energy Trust competition. The technical assistant has a background in engineering and experience with developing acoustical hardware and software. He and the PI have been testing SonicLQ in an acoustical isolation chamber at ANL and on buildings at ANL and Illinois Institute of Technology, and have moved SonicLQ to a TRL of about 5, corresponding to initial development and verification of an integrated system.

3.2.3.1 Funders and Potential Partners

The PI investigated several different funding opportunities after the Energy I-Corps training, primarily looking through funding opportunity announcements listed in DOE and DoD communications. When SonicLQ's three-year seed funding contract expired, ANL provided between $5,000 and $10,000 of internal funds for the PI to continue working on SonicLQ and for the Industry Mentor to enter it in the Clean Energy Trust competition.[38]

The PI then applied for the Technology Commercialization Funds (TCF) for SonicLQ through the DOE's Building Technologies Office and was awarded $275,000 in additional research and development funding.[39] He also applied for funding through the DoD's Environmental Security Technology Certification Program, a project demonstration and validation program. SonicLQ was awarded an approximately $1 million demonstration project contract, in which funds would be made available as SonicLQ reached certain development milestones toward a TRL in which it was suitable to perform a demonstration.[40] The DOE and DoD funds enabled the team to make sufficient progress on SonicLQ to begin the demonstration projects on two large U.S. military base installations in 2018.

For both the DOE and DoD follow-on funding opportunities, the PI submitted a proposal and gave a pitch to the funding committee. According to the PI, the Energy I-Corps training experience and the team's good showing at the Clean Energy Trust competition contributed to the team's success in being awarded the funds, especially in "learning to effectively and confidently describe the target market and value proposition [of SonicLQ to funding committee]." An interviewed DOE funder who also sat on both the DOE and DoD funding committees mentioned that, "Energy I-Corps was not a necessary condition for being awarded the follow-on funding, but was viewed as a net-positive in the committee's decisions and likely helped the [SonicLQ] team create a successful proposal and pitch."

"Energy I-Corps was not a necessary condition for being awarded follow-on funding, but was viewed as a net-positive in the committee's decisions and likely helped the team create a successful proposal and pitch."

Interviewed funders also mentioned that the funding committees had some reservations about whether SonicLQ was technically ready for demonstration project funds, since the team was still improving the technology. However, the committees ultimately decided to award the funding, contingent upon the SonicLQ meeting certain development milestones, due to SonicLQ's potential and the team's progress toward commercialization. For example, an interviewed DoD funder reported that it was well worth the risk to fund the SonicLQ because many DoD facilities could stand to greatly

[38] The PI and other interviewees could not recall the exact funding amount.

[39] TCF is a DOE competitive funding opportunity designed to mature promising technologies to advance commercialization and lab-industry partnerships. https://energy.gov/technologytransitions/services/technology-commercialization-fund

[40] https://www.serdp-estcp.org/Program-Areas/Energy-and-Water/Energy/Conservation-and-Efficiency/EW-201719

benefit from the service that SonicLQ could provide, particularly in “identifying ways to reduce the DoD’s very large electricity bills.”

3.2.3.2 Startup and Technology Transfer

After the Clean Energy Trust competition in 2016, the PI and Industry Mentor decided that the Industry Mentor should launch the SonicLQ LLC startup and try to license the SonicLQ technology from ANL. Although SonicLQ was not yet ready to transition out of ANL, they wanted to get an early start on the technology transfer process and, borrowing from information provided in the Energy I-Corps training, ultimately decided that a startup would be the best way to achieve the transition. The Industry Mentor launched the startup in Minnesota and became the CEO, focusing primarily on developing the business for SonicLQ, including conducting additional customer discovery research, reaching out to potential partners or investors, creating marketing materials, and establishing plans to collaborate with the PI and ANL through joint projects, subcontracts, and cooperative research and development agreements (CRADAs).

Before licensing the SonicLQ technology to the startup and CEO, the PI, and ANL’s technology transfer office preferred to have a patent in place that will secure the intellectual property and to use the results from demonstration projects to get closer to the development of a minimum viable product and of marketing materials geared toward early adopters. The PI and CEO expect the patent process and DoD demonstrations projects to be completed during 2018, at which time they will decide how best to transition SonicLQ out of ANL. If a patent is awarded for the acoustic leak detection technology and the demonstration projects results are a success, they reported that they expect to license the technology to the startup. However, if the patent process is still ongoing and/or the demonstration projects results indicate substantial improvements need to be made to SonicLQ, the team may have to establish a CRADA with SonicLQ LLC, in which the startup would work as a partner with ANL. The PI mentioned that this flexibility in the technology transfer process was very helpful toward maintaining progress on commercializing SonicLQ.

3.2.4 Market Context

The PI, CEO, and an industry expert reported that their target market is typically open to change and innovation, particularly to overcome the limitations of current technologies. As described above, current technologies like the blower door and infrared cameras are reportedly difficult to use in large buildings and do not quantify air infiltration. SonicLQ has the potential to do both, and a few building energy professionals are reportedly very interested in testing it on their new construction projects. Others have expressed interest in the technology but are waiting to see to see the performance and cost-effectiveness results from the demonstration studies.

The broader construction market, however, is somewhat resistant to change and innovation, according to interviewees. The PI, CEO, and an industry expert thought the current building infiltration technologies have been mostly meeting the needs of building energy professionals and others working in smaller commercial and residential buildings. The team's current goal is to try to enter this broader market after they develop a viable product for use by early adopters in larger buildings.

3.2.5 Current Challenges

Interviewed SonicLQ team members, industry expert, and funders identified three overarching challenges SonicLQ needs to overcome to continue progress toward commercialization. First, improving SonicLQ's technical capabilities has proven to be difficult, especially given the reportedly limited testing facilities available at ANL. The PI mentioned that his team needs "more and different types of buildings on which to test SonicLQ," particularly for testing the SonicLQ under different conditions and increasing the distance from the surface the SonicLQ has to be placed to produce accurate measurements.

An industry expert reported that those in the industry who have followed SonicLQ are also very curious as to whether SonicLQ can work well in many different types of buildings and conditions. As he stated,

> *SonicLQ has real potential but there are a lot of aspects of the it that have not yet been tested, such as what types of walls or surfaces it can accurately measure, like concrete, metal, glass, wood, and others, whether it can detect leaks in long circuitous pathways through buildings (as opposed to a surface), and whether it works effectively when under different weather conditions, such as high winds, extreme cold and heat, particularly with the microphone array attached to a drone. Even though the theory underlying SonicLQ is sound, there's a lot SonicLQ has yet to prove and we [in the industry] are excited about the demonstration projects and an opportunity to test it.*

Anticipating these concerns from the target market, the PI reported, "based on early results from what we can use for testing [SonicLQ at ANL facilities], we have high confidence that the DoD demonstration projects on U.S. military bases will enable us to resolve the remaining major technical limitations and get us close to a minimum viable product for early adopters."

"We have high confidence that the [upcoming] DoD demonstrations projects will enable us to resolve the remaining major technical limitations and get us close to a minimum viable product."

Second, launching the SonicLQ startup and establishing a relationship between the startup and ANL required more time than anticipated, particularly for the CEO. Since the startup was very new, the CEO has "unexpectedly" spent a lot of time acquiring all the information necessary to work with ANL as a subcontractor under SonicLQ's follow-on funding contracts.[41] The CEO reported he is close to finalizing the sub-contract between the startup and ANL for the purposes of working on the DoD demonstration projects, but the challenges involved resulted in some delays since the CEO was too busy with this process to help on other facets of SonicLQ commercialization.

Third, according to the PI, conflict of interest policies at ANL has limited the amount and types of collaborations and engagements that can occur between the PI and CEO, especially after the launch of the startup. The PI strongly stated that he and the CEO are very supportive of the ANL conflict of interest policies, but have been challenged to maintain a division of labor that is both collaborative and avoids conflict of interest. For example, the PI reported that he is unable to consult with the CEO regarding the technology transfer process and that he must be very careful in how he discusses his role on the SonicLQ project when he gives pitches to potential investors and partners.

However, the PI also mentioned that SonicLQ was a "special case" in regard to avoiding conflict of interest at ANL. He reportedly could resign as PI of the SonicLQ project and work more closely with the CEO and startup while still being an employee at ANL. He stated this was not a viable option since he is the only person at ANL with the expertise needed to commercialize SonicLQ (given his mix of expertise in acoustic and building science). While the PI could reportedly train someone to take over as PI on the project, he was concerned that this would require too much time and resources, potentially resulting in stalling the SonicLQ commercialization process and jeopardizing follow-on funding.

The PI recommended that more information about launching a startup and how conflict of interest can influence projects, particularly in anticipating potential project delays during certain stages of commercialization, be included in Energy I-Corps training. He reported that Energy I-Corps has responded by providing more training to subsequent participating cohorts about creating startups and working toward commercialization under DOE labs' conflict of interest policies.

3.2.6 Looking Forward

Although attainment of technology development and commercialization milestones can seldom be reliably predicted, the PI estimates that SonicLQ will be at a TRL of about 6, corresponding to the validation of system prototype in a simulated operation environment, in early 2018, before they begin the DoD demonstration projects. After the DoD demonstrations that are scheduled to occur in 2018, the PI anticipates the technology will be at a TRL of about 7, corresponding to demonstrating an integrated

[41] The PI and CEO reported that the CEO plans work with ANL and DoD through the startup on the demonstration projects, which requires a subcontract with ANL.

system prototype in an operational environment, by around March 2019. The next step, according to the PI, is to enable early adopters to test SonicLQ in their new construction projects and use their feedback to develop a minimum viable product, thereby reaching in quick succession in late 2019 and early 2020 TRLs of about 8 and 9 (validation in a commercial operating environment, and validation of viability at commercial scale, with costs understood). If all goes as planned, the PI anticipates production and sales of the SonicLQ around summer of 2020.

The PI anticipates ANL will end its involvement with SonicLQ at a TRL of about 7, expected around March 2019. If the team decides to use a CRADA to continue research and development with the startup, SonicLQ could remain at ANL through TRL 8 or 9. Current follow-on funding from the DOE is expected to be exhausted after TRL 6 in early 2018 and follow-on funding from the DoD is expected to end after results from the demonstration projects are finalized in early 2019, at TRL 7.

The PI also stated that he and the CEO identified a few interested investors or partners including utilities and energy service companies that would benefit from using SonicLQ to help reduce energy consumption in buildings. The PI mentioned that the DoD and other related organizations have expressed interest in SonicLQ for identifying infiltration in containment rooms and transportation vessels. Aside from the upcoming DoD demonstration projects, the interested parties have yet to invest in or partner with the SonicLQ team, but are reportedly poised to do so when the team completes the demonstrations and gets closer to full commercialization.

3.3 SUMMARY

The SonicLQ team is making steady progress toward commercialization of the technology. SonicLQ reportedly has several potential advantages over existing technologies as well as many potential benefits for multiple actors, including reducing energy usage, utility bills, and pollution. It also appears to be in demand from prospective early adopters in the target market and is generating interest from possible funders and partners.

The SonicLQ team has a mix of expertise and background that aligns well with the target market and the technical capabilities of SonicLQ, and the team also reported having access to several key resources at ANL and the Illinois Institute of Technology.

Through Energy I-Corps, the team learned more about the target market and its needs and interests, developed a value proposition aimed at the target market, and identified technical improvements that were requested by target market actors. The Energy I-Corps experience reportedly contributed to the team making a good showing at the Clean Energy Trust competition and securing additional follow-on funding from the DOE and DoD.

The Industry Mentor has also recently launched a startup in preparation for transferring SonicLQ out of ANL, and the team is preparing for DoD demonstration projects that they reported will likely result in the feedback and results they need to create a minimum viable product ready for early adopters to start testing in the field.

Section 4 WISDEM

The WISDEM technology is short for Wind Plant Integrated Systems Design and Engineering Model. It is an open-source, software-based framework comprising multiple models that examines all wind plant system aspects to estimate the overall cost of energy. It is an innovative way of viewing wind plants that shifts away from an individual turbine-centered view to a holistic view of the wind plant operations. It serves as a research and planning tool that can inform the design of the wind plant and how changes in operations affect the energy load and cost of energy. A beta version of the software is available for download and has reportedly been downloaded 1,000 times.[42]

Katherine Dykes, a senior engineer at the National Renewable Energy Laboratory (NREL) and Principal Investigator (PI), led the research and participated in the first U.S. DOE Energy I-Corps training cohort, which started October 2015 – along with colleague and Senior Engineer Rick Damiani. In the training, they met their current industry partners, NextEra Energy Resources and Ystrategies.

In 2016, the WISDEM team won a competitive funding award from the DOE Technology Commercialization Fund (TCF) and is currently executing a demonstration project at a wind plant to validate the models' predictions for a wind plant controls application in an operational environment.[43]

What follows is an overview of the WISDEM technology and then the story of its path into Energy I-Corps and how that experience provided a foundation for subsequent activities leading toward commercialization.

4.1 TECHNOLOGY OVERVIEW

4.1.1 Brief Description

Research and development work on WISDEM is a part of a larger DOE Wind Energy Technologies Office research initiative called Atmosphere to Electrons. The initiative seeks to lower the cost of wind energy through an improved understanding of wind plant physics to optimize a plant's energy output. The U.S. has 82 gigawatts of wind power capacity[44] and it is estimated that WISDEM-informed optimization of wind plant controls for wake steering could increase a plant's energy output by 2 to 3%, or about 2 gigawatts.

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[42] https://nwtc.nrel.gov/WISDEM

[43] TCF is a DOE competitive funding opportunity designed to mature promising technologies to advance commercialization and lab-industry partnerships. https://energy.gov/technologytransitions/services/technology-commercialization-fund

[44] https://energy.gov/eere/wind/downloads/2016-wind-technologies-market-report

Making these sorts of operational changes are one way a wind plant operator with mature wind technology can improve its bottom line. For example, a typical project at a 100 megawatt plant with a capacity factor of 35% and revenue of $0.04/kilowatt hour, that 3% increase in performance translates to an annual revenue increase of about $400,000. That is a potential of $300 million in increased revenue across the U.S. wind industry.

This larger Atmosphere to Electrons effort, and the WISDEM technology, are a fundamentally new way of looking at wind plant operations. The business-as-usual approach controls each turbine independently through its own internal controller and sensors. The new approach, simulated by WISDEM, enables the optimization of a network of turbines by incorporating fluid dynamics analyses to characterize how each turbine interacts with other turbines and other components at the wind plant. For example, the wake caused by an upstream turbine can reduce downstream turbines' energy production. WISDEM enables an operator to model how to enhance the downstream turbines' energy production and overall plant performance by adjusting the upstream turbine positioning.

WISDEM brings physics modeling into an economic environment. It leverages of the models of other NREL Wind Energy Science Group scientists whose research addresses questions of fundamental science. WISDEM translates the physical impacts of innovations and operating changes into the economics of wind plant performance to understand the cost of energy and inform the plant's profitability.

4.1.2 Current Market Targeted

The WISDEM team identified private sector wind plant operators as its nearest-term target market. Plant operators can use WISDEM models to see how proposed changes would affect their operating costs and energy generation, key factors driving their bottom line.

The team anticipates that WISDEM could potentially be used by a range of stakeholders across the wind industry value chain, in particular developers, consultants, and owner/operators, who want to design, plan, or operate more effective wind plants. Original equipment manufacturers (OEMs) may also be interested in this research tool to evaluate how changes to their components can impact a plant's cost of energy.

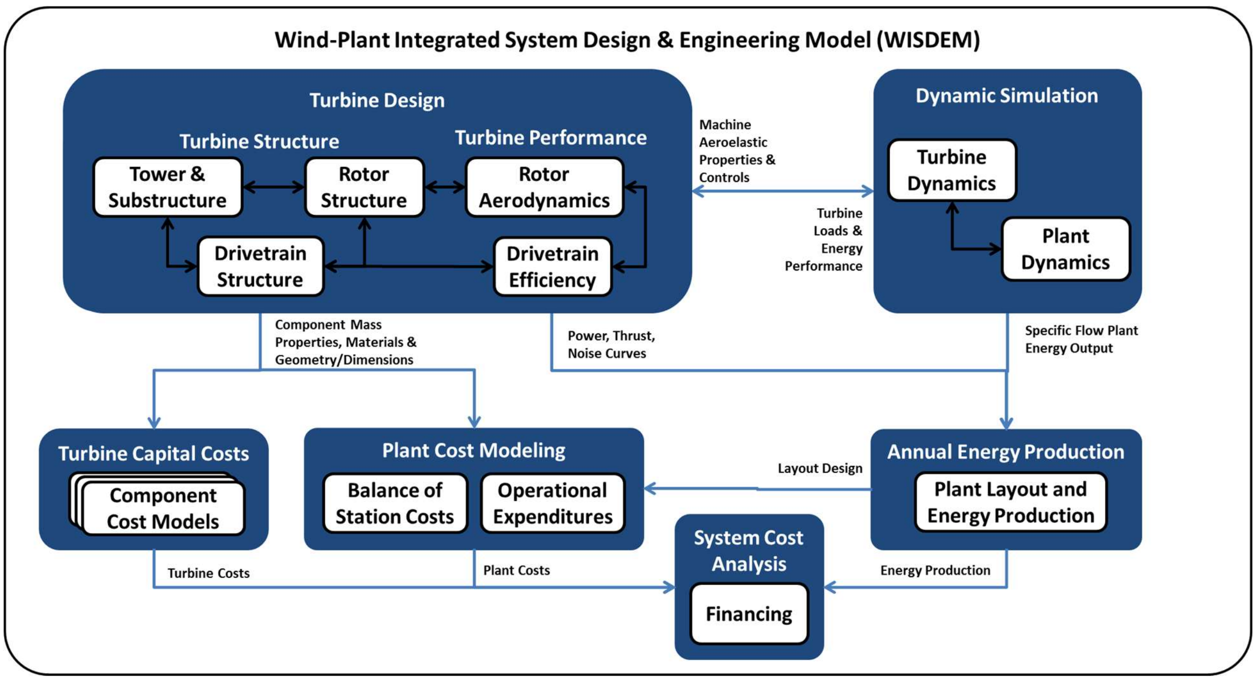
Two interviewees also mentioned how other researchers will be able to use the WISDEM tool moving forward. The National Wind Technology Center (NWTC) chief engineer reported that other groups in the wind program will use the tool to estimate impacts of technology changes on technology deployment.

The wind industry expert we spoke with added that the WISDEM tool gives researchers an opportunity to test models they have developed and modify their models to "fit within the framework of optimizing wind plants." For example, an atmospheric scientist may develop a new model for the wind industry, but needs to demonstrate their model will have a positive impact if it is to be adopted. Putting the new model into the WISDEM framework would enable the scientist to produce actionable outputs that clarify the positive impact.

4.1.3 Comparative Advantage and Benefits

WISDEM contains several interdisciplinary modules – one for each aspect of the wind plant that influences the plant's overall performance and cost of energy. These modules include the turbine design, including the turbine structure and performance, turbine capital costs, plant costs including operational expenditures, simulations of turbine and plant dynamics, and the plant layout design (see Figure 4-1).

Figure 4-1: WISDEM's Interdisciplinary Modules*



* Source: Dykes, Katherine, Rick Damiani, and Sandy Butterfield. 2015. Team WISDEM Final Energy I-Corps Presentation.

Incorporating these multidisciplinary modules enables WISDEM to translate operational or structural inputs into economic outputs. That is, how operational or structural changes affect the plant's cost of energy. Thus, the coupling of physics and economic models makes WISDEM valuable for planning and operation decisions because the operator can understand the financial impact of operational or structural changes.

WISDEM's advantage over other modeling systems is its flexibility, as it can incorporate modules from various sources. WISDEM can integrate proprietary codes and open-source codes to customize its framework for a particular use case. For example, a wind plant operator may choose to use OEM-supplied proprietary code for the turbines, its own financial model developed in-house, and someone else's atmospheric model. This flexibility makes WISDEM suitable for a variety of applications, as "the module framework can be easily reconfigured for different applications," according to the PI.

Due to its integrative ability, WISDEM is not a majorly disruptive technology. WISDEM does not require the plant operator to completely replace its modules with WISDEM modules. Operators can continue to use modules they have been using but now have the ability to integrate them into a more comprehensive system optimization framework.

All interviewees reported they were unaware of another software product capable of integrating these various aspects into a coherent mechanism for understanding how altering the components impacts overall plant performance and cost. Other software reportedly can break down when attempting to perform such a complex optimization task. This is not true for WISDEM because of the particular way in which the software modules in WISDEM have been developed for optimization applications.

Ultimately, if WISDEM proves successful and is widely adopted, it will enhance wind plant performance, increasing power production while controlling operation and maintenance costs. This innovation promises to lower the cost of wind-generated energy, potentially increasing wind energy adoption and the share of renewable energy on the electric grid.

4.1.4 Current State of Development

The state of WISDEM at the time of writing is akin to a "consulting process." WISDEM engineers run the software on behalf of a wind plant operator and interpret the results to provide advice and direction on how to modify the plant's operation. Additional development that would need to be done on WISDEM to make it a commercial product and usable by operators independently includes creating a user interface, developing database management capabilities, and adding functionality to set it up on various computing platforms. For now, the WISDEM senior engineers are focused on advancing their research and building a library of high-fidelity modules before they turn to creating the functionality necessary for it to be used independently by wind plant operators.

The WISDEM team has assessed the load effects and economic benefits of optimizing the operations of NREL-owned turbines using WISDEM models and are ready to apply WISDEM to a commercial windfarm to achieve a proof of concept in an operational environment. While the PI cautioned against applying Technology Readiness Levels (TRLs) to a software product, this stage of development corresponds by analogy to approximately a 6 or 7.[45]

[45] Other WISDEM applications on which the team is working are at lower TRLs.

4.2 PROGRESSION ALONG THE COMMERCIALIZATION CONTINUUM

4.2.1 Prior to Energy I-Corps

The two interviewed senior engineers working on the WISDEM technology had limited business experience prior to the Energy I-Corps training. One reportedly had helped startup companies get into the market with turbine-specific models. The other senior engineer had a dual undergraduate degree in business and engineering, which led to some business experience as an independent consultant in graduate school. Both asserted that they had not been exposed to Energy I-Corps concepts prior to the training.

The chance to apply for the first Energy I-Corps training cohort came at an opportune time. The WISDEM PI had been thinking about the potential to commercialize WISDEM and approached NREL's technology transfer office (TTO) to ask about commercialization opportunities and learn about commercialization more generally. A lab manager alerted her to Energy I-Corps, which she said, "seemed to fill the void I was looking for," providing an opportunity to learn more about commercialization pathways. She added that, beyond the Energy I-Corps training, she was unaware of much opportunity for research scientists to learn about commercialization.

WISDEM was ripe for the PIs to take to the commercialization training. Innovative thinking about wind plant operations as a system was well-supported by DOE and the WISDEM team had a strong theoretical foundation for their software. The WISDEM engineers also had upwards of 20 software records for the technology.[46]

The team wanted to use the training to test multiple ideas they had. They wanted to investigate what it would take to bring WISDEM from a research tool that is not user-friendly to a successful commercial tool.

The senior engineers reported they had some idea going into the training of the market segment for which WISDEM created value but had not developed a clearly articulated value proposition for that market. They did not have solid estimates of what potential customers would be willing to pay for WISDEM nor did they have good estimates of product costs. They had some understanding of what inputs and resources were needed to deploy WISDEM but had not yet established relationships with key partners or suppliers of inputs necessary for commercialization.

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[46] Software records are the way lab researchers submit a record of invention to their lab and must be filed prior to distribution of the software.

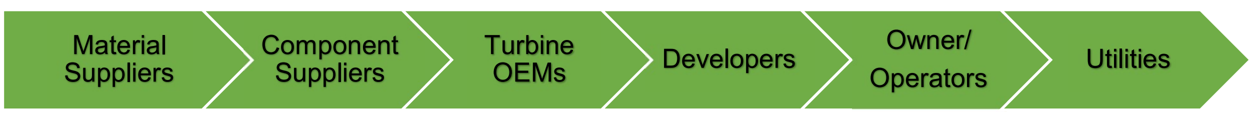
4.2.2 Energy I-Corps Experience

The interviewed WISDEM team members who participated in the Energy I-Corps training said the training was instrumental in their exploration of the marketplace and learning how WISDEM would be relevant and impactful for industry. Energy I-Corps provided the financial support to cover their time to conduct customer discovery interviews with potential industry partners. They used the training to build relationships with and awareness in industry of this innovative way of thinking holistically about wind plant operations. Through this market exploration, the team learned what industry was looking for and how to develop their software to meet those needs. One of WISDEM's Energy I-Corps participants said that the training was "the main channel to get this tool to commercialization and to bring it to the attention of the industry."

The training was "the main channel to get this tool to commercialization and to bring it to the attention of the industry."

The Energy I-Corps training strongly influenced the WISDEM team's target market thinking. Their customer discovery interviews included a broad cross section of people from developers, operators, consultants, and OEM suppliers (see Figure 4-2).

Figure 4-2: Wind Industry Actors



* Source: Dykes, Katherine, Rick Damiani, and Sandy Butterfield. 2015. Team WISDEM Final Energy I-Corps Presentation

When the team entered training, they imagined themselves working with customers spanning the industry, but especially anticipated working with OEM suppliers to improve design aspects of wind plant components.

Through conducting the customer discovery interviews, they learned that "owner-operators would be the most likely party interested in adopting the technology as a first customer segment" and the most willing to work with the WISDEM team, according to the PI. This led the WISDEM team to pivot and focus their early commercialization activities on the operation of wind plants by targeting wind plant operators.

This pivot is what led the WISDEM team to engage in conversations with NextEra Energy Resources. Reportedly, by the end of the training, the WISDEM team had successfully navigated to a proof of concept with NextEra, roughly corresponding to a TRL 3.

The interviewed WISDEM members agreed that the training focused on the typical commercialization pathways of patenting and licensing, and they did not learn much directly applicable to commercializing an open-source technology. Open-source software technologies are those for which the original source code is freely available and modifiable by any user, unlike licensing which grants use rights to a specific party.[47] NREL's TTO advised the WISDEM team during and after the training on how to continue to submit software records so the TTO could offer open-source licensing to WISDEM, according to a TTO representative with whom we spoke.

At the completion of the training, the WISDEM engineers had identified a market segment for which WISDEM creates value and had a well-developed value proposition for that market. They reportedly continue to refine the value proposition as they gain experience using the software and learn what advantages it can offer.

By the end of the training, the WISDEM engineers also established relationships with key partners and identified the inputs and resources needed to pursue the commercialization of WISDEM. They were less confident about product costs, what customers would be willing to pay for WISDEM, and who the suppliers of needed inputs would be, but said nonetheless that their understanding of those three business aspects had increased as a result of the Energy I-Corps training. After testing their multiple ideas, the WISDEM engineers felt empowered to pursue the primary goal they identified in training, which is the goal they continue to work toward today.

4.2.3 Building on the Energy I-Corps Experience

The WISDEM engineers completed their Energy I-Corps training in late 2015, and in early 2016, DOE released the solicitation for the inaugural TCF funding opportunity. The WISDEM team credited their Energy I-Corps training and the partnerships developed in the training as important reasons why they won follow-on TCF funding to continue the development of WISDEM.

4.2.3.1 Current Partners/Funders

WISDEM's two main industry partners are NextEra Energy Resources and Ystrategies, each of which emerged during the Energy I-Corps training. The relationship with NextEra began during the customer discovery interviews; the founder of Ystrategies was an Energy I-Corps instructor and was impressed with WISDEM's potential. Ystrategies saw strong value in optimizing wind plant operations and liked how WISDEM was applying systems engineering to an open-source software to model impacts.

Topic 2 proposals under TCF required a private industry partner to share 50% of the cost. WISDEM applied for $250,000 in TCF funding with NextEra Energy Resources committing $225,000 and YStrategies committing $25,000. TCF selected the proposal,

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[47] Others can modify any open-source software's code. The senior engineers with whom we spoke did not elaborate on plans to keep track of third-party code.

and the PI credits the Energy I-Corps training with making WISDEM well-positioned to win the TCF funding for two main reasons.

First, having committed industry partners was important to winning the TCF funding. The WISDEM PI reported that having NextEra and Ystrategies' support enabled them to demonstrate in their TCF proposal that there was "industry interest in the commercialization of WISDEM."

"It was really the experience in Energy I Corps that gave us the foundation to apply for TCF and be successful with it."

Second, the engineers leveraged what they learned during the training to lay a strong foundation for a winning TCF proposal. In particular, having clearly articulated a value proposition with quantified components for its target market enabled the team to demonstrate they understood the market. Finally, being able to report that the technology went through the Energy I-Corps training also reportedly made WISDEM a more attractive candidate for TCF funding. As the PI said, "All of those factors tied together, but it was really the experience in Energy I-Corps that gave us the foundation to apply for TCF and be successful with it."

Winning TCF funding was an opportunity to pursue a strategic partnership with NextEra. The WISDEM team is using the NextEra funds to execute a demonstration project at one of NextEra's wind farms, which should advance this application to a TRL 7. The demonstration project will validate and prove the viability of WISDEM's models to show that the technology works in practice. The demonstration project should produce tangible, quantifiable results demonstrating that wind plants achieve the improved performance the software predicts.

4.2.3.2 Technology Transfer and Startup

The fact that WISDEM is an open-source technology makes it different from the other technologies in this case study report.

Reportedly, before the WISDEM team entered the Energy I-Corps training, WISDEM had already been deployed as an open-source technology. Almost all software developed at the NWTC is in the open-source domain. A chief engineer for the NWTC who we spoke with explained that the Center encourages open-source software because it facilitates their ability to create partnerships and collaborate with industry since the industry partner has full visibility of and free access to the codes. The alternative would be for NREL to market proprietary software and license it for an income stream, but that puts the lab in competition with industry. A TTO representative added that open-source software is available to the community of users, who can further develop aspects of the technology.

The two typical pathways of transferring technology out of the lab include the formation of a startup company or a license to industry. A TTO representative reported, "For something like an open-source software, a startup becomes difficult because you're looking to provide competitive advantage to somebody on the other end. There's not specific rights that you can grant to them that could provide them with any type of competitive advantage." The WISDEM engineers, leveraging NREL expertise, reportedly positioned WISDEM as a unique and valuable tool that can be deployed via software as a service (see Section 4.2.6 for more details).

Because of the open-source nature of WISDEM, the TTO representative does not anticipate there will be a full transfer of intellectual property; even so, technology transfer is occurring. The open-source codes are available for use on the website. The senior researchers reported that they have technical service agreements with industry to enable industry partners to use WISDEM. The team noted that multiple groups have already adopted the software for different purposes.

The TTO at NREL helped manage the relationships between the WISDEM engineers and their industry partners. The TTO assisted WISDEM with securing the required letters of support from NextEra and Ystrategies for the TCF proposal. Once the team was awarded TCF funding, the TTO helped negotiated a multi-party cooperative research and development agreement (CRADAs) with the two organizations.

The TTO was closely involved with making sure all parties to the CRADAs had the same understanding and agreed to the contractual language. NREL will continue to be involved in the development of WISDEM through these working relationships.

Ystrategies has a CRADA with NREL and will be using the WISDEM software through an open-source license. In December 2017, YStrategies announced the launch of WindWISDEM Corporation – a cloud-based computing platform that will position WISDEM as an Internet of Things – Software as a Service (SaaS).[48] The platform will enable Ystrategies to charge a fee to access the website, which enables users to leverage "smart" modern turbines' SCADA (Supervisory Control and Data Acquisition) capabilities.

4.2.4 Marketing Context

The WISDEM tool has broad market appeal, according to interviewees, and has potential benefits for multiple actors in the wind energy generation market. For wind plant operators, adopting the WISDEM technology does not pose a threat of disrupting their ongoing operations, but does requires a shift in operators' thinking. All interviewees agreed that owner-operators of wind farms are risk averse, so new innovations need to be thoroughly validated to be adopted. An unproven technology requires a big commitment from an operator to work with the engineer pitching the technology.

[48] Ystrategies. 2017. "Ystrategies Corp. Announces WindWISDEM Corp. Launch and Investment." https://docs.wixstatic.com/ugd/2243d0_cf16ed5fe002437f8d291f01359b6af4.pdf

As the PI said, “With anything that changes the technology or the turbines, you really have to prove that you’re not going to adversely affect the plant before you do anything.” To promote WISDEM under such conditions requires educating and fostering a certain level of trust on the part of the wind plant operators.

Wind plant operators have been aware of the myriad factors influencing plant performance, but have been making decisions using their best judgment rather than robust modeling frameworks. As the NWTC chief engineer put it, WISDEM “introduces a level of system optimization complexity” to improving wind plant performance and “getting operators to adopt a more quantitative approach to optimization is probably the biggest challenge.”

Consequently, the demonstration project with NextEra will be critical to the future of WISDEM. Validating the models in the real world will provide assurances to the operators that the changes recommended by the models will not damage the equipment and will lower the cost of energy.

Wind plant operators have an incentive to adopt WISDEM once its models are validated, according to interviewees. As one of the interviewed senior engineers described, wind turbines are a mature technology and the development of the hardware has “plateaued.” Thus, wind plant operators are seeking to enhance profitability with the same hardware, which places the emphasis on improving the wind plant operations – precisely what WISDEM optimizes.

The interviewed WISDEM engineers also noted that there is increasing competition in analysis software for the wind plant space. The competition is coming from consultancies, other researchers, and from private industry. For example, KEMA DNV-GL, AWS Truepower, and GE Energy each have software tools for optimizing wind plant design. The PI said that while she is seeing more development and offering of multidisciplinary codes and modules for wind plant analysis, she is confident the competing technologies do not have the scope or particular design features that the WISDEM toolset does.

4.2.5 Current Challenges

At the time of writing, WISDEM is primarily a research tool and is not readily usable by wind plant operators who are not researchers. There is further work needed to make WISDEM a commercial software package. Additional development that will need to be done on WISDEM to make it a commercial product includes creating a user interface, developing database management capabilities, and adding functionality to set it up on various computing platforms.

4.2.6 Looking Forward

If the demonstration proves successful, the validation of WISDEM's models to improve overall wind plant performance will increase WISDEM's appeal to investors and other wind plant operators and "enable the pathway for commercialization and industry adoption of the technology," according to the PI.

> Validation of WISDEM's models will "enable the pathway for commercialization and industry adoption."

The interviewed engineers plan to continue learning about commercialization opportunities beyond a typical "patenting-licensing framework." They anticipated the possibility that another entity might acquire the WISDEM technology in the future, but had no elaboration to offer.

Ystrategies' has a go-to-market plan for WindWISDEM. In 2017 and 2018, they anticipate completion of a proof of concept and to "productize" the existing WISDEM system. In 2018, they plan to implement the SaaS platform with machine learning and expect their first revenues in the third quarter of 2018.[49]

The NWTC chief engineer noted that through WISDEM's partnerships, NREL staff are learning about working with industry partners that they can use for future research activities. The CRADA with NextEra may generate additional research and collaboration leading to them becoming a longer-term partner for wind research. "All of that is building a good foundation that will hopefully be useful for future NREL research activities" the chief engineer said.

A TTO representative corroborated this sentiment, adding that a measure of WISDEM's success has been the fact that commercial parties have entered into sponsored research activities with NREL and that NREL scientists are creating value for industry. Thus, benefits the team accrued from Energy I-Corps activities continue to reverberate in ongoing lab-industry interactions.

4.3 SUMMARY

The WISDEM technology is well-poised to be commercially successful. Based on what the WISDEM engineers learned in the Energy I-Corps training, the team found a viable near-term market, made fruitful industry partnerships, and won follow-on funding. One commercial partner granted access to an operational wind farm for the team to conduct a demonstration project and validate their models.

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[49] Ystrategies. 2017. "Ystrategies Corp. Investor Presentation: Acceleration and Innovation for Disruptive Early-Stage Technologies in Cleantech and Renewable Energy." https://docs.wixstatic.com/ugd/2243d0_f50211b56fe34fe18e9513709c9a9007.pdf

The team's multiple technical service agreements with industry and its partnership with NextEra will lead to further collaboration with industry and continued use and improvement of the WISDEM tool. In 2018, WindWISDEM Corporation may generate its first revenue.

If WISDEM continues on its promising path, wind plants in the near future will be better designed, better operated, and more profitable, paving the way for greater penetration of wind energy on the grid.

Section 5 RWEDI

At its core, Resin Wafer Electrodeionization (RWEDI) is a separation technology that uses electricity to remove ions from aqueous streams. RWEDI is a platform technology with multiple applications that may be of use to multiple markets. These applications include, but are not limited to, water purification for use in cooling towers, power plants, biorefineries, and the processing of sugars. This chapter focuses specifically on the water application of RWEDI and its use in cooling towers, as this application is furthest along the commercialization continuum.

The RWEDI team participated in the second U.S. DOE Energy I-Corps training cohort, which started March 2016. The team included, among others, Dr. Yupo Lin (the Principal Investigator), Dr. Jessica Linville (the Entrepreneurial Lead and, subsequently, the Chief Executive Officer (CEO) of the ensuing startup) and Dr. Michael Gurin, the Industry Mentor. Dr. Seth Snyder, the research group leader and an expert in the RWEDI technology, provided technical support to the Entrepreneurial Lead during the training. At the time of the training, all were associated with Argonne National Laboratory (ANL).

In February of 2017, the former Entrepreneurial Lead established and became CEO of a startup based on the RWEDI technology, RWEDI Solutions, Inc., which focuses on using RWEDI to purify water for use in cooling towers. The company was incorporated in the state of Delaware on February 10, 2017. RWEDI Solutions currently operates under a license option, which it signed with ANL prior to company formation.[50] The RWEDI technology platform has 14 patents, of which the CEO has licensed the five pertinent to water purification. While there are no sales for RWEDI at the time of this case study in late 2017, the technology has received follow-on funding from several sources, discussed below. The team is using some of that funding to build a demonstration unit to test the technology in a real-world environment.

Below is the story of RWEDI, as it makes its way toward commercialization, including its path into Energy I-Corps, the resulting startup, and future projections.

[50] RWEDI Solutions must meet specific milestones to convert to a full license agreement.

5.1 TECHNOLOGY OVERVIEW

5.1.1 Brief Description

RWEDI is a platform technology that has multiple applications. RWEDI itself is a separation technology that removes ions from aqueous streams. ANL summarized RWEDI's foundational science as follows:[51]

> *"Ion-exchange resin wafer electrodeionization (RWEDI) is an energy-efficient, low-cost separation technology that directly utilizes electricity to remove ions from aqueous streams. It integrates commercially available components of ion-exchange resin material, membranes, and electrically driven separation devices to increase the energy efficiency and reduce the cost of processing aqueous streams. The technology offers enhanced fluid and flow distribution; higher conductivity; superior pH control; ease of materials handling and system assembly; and a porous solid support for incorporation of catalysts, biocatalysts, and other adjuvants."*

RWEDI Solutions, the first company to use the RWEDI technology, applies the technology to the purification of water used in cooling towers. Cooling towers are heat rejection devices used to provide cooled water for air conditioning, manufacturing, and electric power generation. Water (or fluid) heated by those processes is cooled by flowing water over a labyrinth of coils or other "fill" providing an extensive air-water interface that enables the heat to transfer from the water to the air through evaporation.

Water is a solvent and thus to varying degrees contains dissolved mineral content, the elements that make water "hard." As we know from distillation, the evaporation of water separates pure H_2O from its mineral and other containments. In cooling towers, the mineral content the evaporating water leaves behind builds up on the fill, a process termed scaling. The scaling on the fill is corrosive and compromises its performance. The scaling also results in higher concentrations of dissolved minerals in the water, in the same process that gives us both salty shorelines (due to precipitates) and salty oceans.

To cope with scaling, cooling tower operators have to periodically drain, dump, and replace the water. The term "blowdown" describes the portion of the circulating water flow that cooling tower operators remove to maintain an acceptable amount of dissolved solids and other impurities.

RWEDI "purifies water before it reaches cooling towers, allowing cooling towers to waste less water."

As a cooling tower application, RWEDI is a water-saving technology. RWEDI substantially reduces the amount of blowdown. RWEDI also

[51] https://energy.gov/eere/technology-to-market/energy-i-corps-cohort-2-teams#anl-resin

substitutes for the chemical treatment of water to soften it for cooling tower use, described further below.

According to the RWEDI Solutions website, “the system is built from commercially available components and Argonne’s patented modification to enhance system performance and flexibility” (Figure 5-1).

Figure 5-1: The RWEDI System and its Components

Photo credit: George Joch, Argonne National Laboratory

5.1.2 Current Market Targeted

RWEDI is a platform technology and the underlying process could be attractive for a variety of markets. Through the Energy I-Corps experience, the Entrepreneurial Lead (subsequently, CEO) discovered that cooling towers are the most viable market at this time.

While a large benefit of the RWEDI technology will ultimately be reaped by cooling tower owners, who will see reduced costs, the RWEDI Solutions’ team has chosen to first target water treatment services companies that operate and maintain the cooling towers. By using the RWEDI technology, water treatment service companies can offer owners a cheaper service for a longer term, giving the service providers a competitive edge when bidding for contracts to service a cooling tower and, presumably, driving increased market share for RWEDI over time.

As described by the CEO:

> *“Our plan is to be an original equipment manufacturer and we're going to partner with the water treatment services companies that are managing the cooling towers today as our sales channel. This will give them (the service company) a technical advantage against competitors because we will set up the agreement is we're only going to partner with one water treatment service company per geographical location.”*

> *"Right now, the chemical contracts, the Master Services Agreements, are typically three- to five-year agreements. And so, every three to five years they're fighting to keep their customers, typically by lowering their cost of chemicals and reducing their margins. But our equipment has a 10-year lifetime. And so, we can lock in their customers for 10 years and offer them a way to gain more customers by installing the RWEDI Water System and offering those customer savings that other competitors can't."*

5.1.3 Comparative Advantage and Benefits

The RWEDI technology has many comparative advantages over the current practice for managing water use by cooling towers. By reducing water and chemical use, RWEDI reduces their associated costs, and reduces the environmental and social costs of water and chemical production, deployment, and use.

Currently, cooling tower operators manage the water hardness through two methods: adding water-softening chemicals and blowdown. These methods exist in trade-off; increased chemical use substitutes for increased water use, and vice versa. Both chemical and water use constitute substantial operating costs and environmental burdens.

Cooling towers use a great deal of water to operate. They consume water continually through the evaporative process and periodically from dumping the circulating water. According to the RWEDI Solutions website, the nation's half million cooling towers annually use more than 5 trillion gallons of drinking water, about four percent of all freshwater consumption.

And the cost of water is rising. Since 2010, rates have nearly doubled on average in 30 major U.S. cities. Rising water costs reflect increasing water scarcity, as some water agencies, particularly in the southwest, manage demand by increasing costs. According to a recent Newsweek article, "water managers in 40 states expect water woes over the next decade."[52]

Some governments (state, city, or municipality) are encouraging cooling towers to use non-potable sources of water. These waters have higher levels of impurities and are more likely to cause scaling and corrosion than potable water. With RWEDI, cooling tower operators can use less pure water, saving purer water for other use, an important societal benefit. In addition, owners in some areas are eligible for government-offered economic incentives provided for using non-potable water.

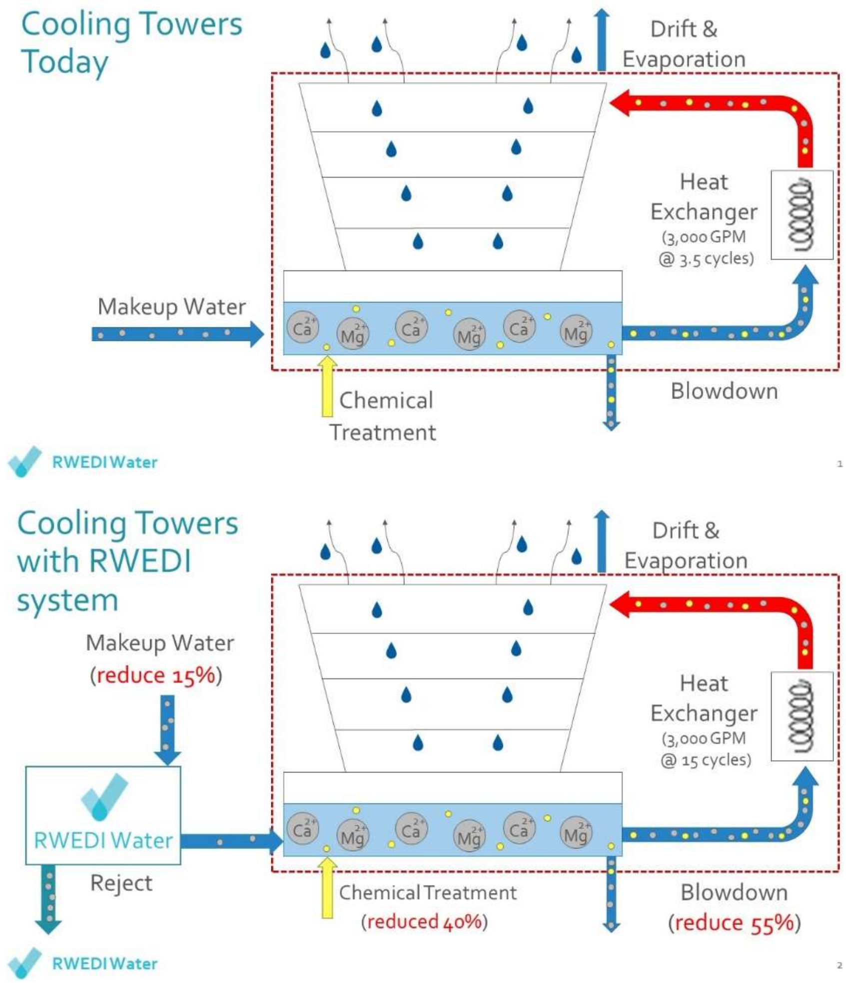
> The "technology makes it possible to use less water to operate a cooling tower, as well as to use water you normally couldn't use."

[52] http://www.newsweek.com/2017/12/01/what-happens-world-without-water-jordan-crisis-717365.html

According to an industry expert, RWEDI Solution's application "essentially makes it possible to use less water to operate a cooling tower, as well as to use water that you normally couldn't use because it is too hard or too contaminated."

Figure 5-2 illustrates the advantages of the RWEDI system. The startup's website states the RWEDI reduces blowdown by as much as 55 percent, in turn reducing water costs by up to 15 percent and sewer costs by 55 percent. RWEDI reduces chemical usage by 40 percent, and overall operating costs by 20 percent.

Figure 5-2: Cooling Towers Today vs. Cooling Towers with RWEDI System



In terms of concrete benefits other than cost-savings, the RWEDI Water system has a modular design enabling it to be sized for all commercial cooling towers. The system can also be installed along with traditional chemical treatment equipment, with RWEDI providing the primary means of treating the water, and standard chemical treatment available for emergencies. The only ongoing maintenance required for the RWEDI Water system is an annual replacement of the membrane packs.

In addition to the cost saving advantages of RWEDI and the ease of its installation and maintenance, RWEDI has larger environmental and societal benefits. RWEDI Water has been recognized for its environmental benefit and is listed as one of the 10 Illinois Green Tech Startups to Watch.[53]

> "Cooling towers are the second-leading consumer of freshwater in the world."

Worldwide, water shortages are of increasing concern. Technologies that reduce water waste are increasingly essential. According to one industry expert and confirmed by other sources,[54] cooling towers are the second-largest consumer of freshwater in the world. RWEDI Water conserves this vital resource.

5.1.4 Current State of Development

The CEO of RWEDI Solutions estimates that the technology is currently at a Technology Readiness Level (TRL) of about 6, which indicates that there has been validation of a system prototype in a simulated environment. Once they finish the demonstration unit, the CEO expects the technology to reach a TRL 7 or 8, which corresponds to having a demonstration of a system prototype in an operational environment (TRL 7) or demonstrating incorporation of the technology into a pre-commercial or commercial design (TRL 8).

5.2 PROGRESSION ALONG THE COMMERCIALIZATION CONTINUUM

5.2.1 Prior to Energy I-Corps

As Dr. Linville's postdoctoral fellowship at ANL ended in January 2016, she spoke with her group leader at the lab multiple times about finding a next job. She was interested in starting a company but was unsure how to go about it. Fortuitously, one team accepted to the Energy I-Corps training dropped out and RWEDI's application was chosen to replace it. The research group leader had been listed in the application as the Entrepreneurial Lead, but was no longer able to participate.[55] He thought Dr. Linville might be a good replacement and invited her to join the training team. Reportedly the group leader said, "I can pay you. But you have to start within the next half hour." Because the initial webinar was starting, they had to have their final team in place in a matter of minutes. Though the notice was short, Dr. Linville was presented with an enticing opportunity.

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[53] https://www.americaninno.com/chicago/10-clean-energy-green-tech-startups-to-watch-in-illinois/

[54] www.ce.utexas.edu/prof/mckinney/ce385d/Papers/Shiklomanov.pdf

[55] Dr. Snyder subsequently participated in Energy I-Corps training for other projects.

Due to her interest in the technology, her trust in her team members, and her motivation and desire for the opportunity, Dr. Linville accepted the offer and jumped whole-heartedly into the role of RWEDI Entrepreneurial Lead. In addition to the Energy I-Corps training, a knowledgeable and motived team, and a strong Entrepreneurial Lead, fortunate timing also appears to be a factor in RWEDI's progress toward commercialization.

5.2.2 Energy I-Corps Experience

From the beginning of Energy I-Corps participation, the Entrepreneurial Lead embraced the Lean LaunchPad methodology at the foundation of the training, quickly identifying what she needed to know to make RWEDI commercially successful. She "read the books, watched the videos, did numerous customer discovery interviews, and embraced the whole process." Importantly, over the course of the training, she developed a strong business model for the initial application of the RWEDI technology.

Entering the training, RWEDI was approximately at a TRL 6, corresponding to having demonstrated a prototype in a simulated environment. Identifying the most compelling, commercial-ready application was a process for the RWEDI team, a process they honed through the Energy I-Corp training. The RWEDI Water technology application came after multiple pivots; in the words of one RWEDI expert, "it's been one long pivot."

> Finding the most compelling application was "one long pivot."

Another interviewee noted that during the Energy I-Corps training, the team "looked at a pretty wide swath of potential applications." According to him:

> *"At one point, they were even looking at using the technology to filter water specifically for coffee shops – so they would have the exact flavor profile for their water and a much more repeatable coffee. And that is only one of many markets they tried to chase down. They realized that what they had was unique when it came to minimizing water use in these large cooling towers. Given the amount of water these towers use and the challenge owners have with their equipment, RWEDI would be much more valuable in that application. It was through Energy I-Corps that they realized that."*

As part of the customer discovery interviews, the Entrepreneurial Lead spoke with power plant facility managers and learned they are risk averse and have long field cycles. As a result, she decided to pivot away from power plant managers as an initial market. Cooling towers seemed to the Entrepreneurial Lead to be the more viable market and offer a stronger path toward commercialization.

The Entrepreneurial Lead, a chemical engineer by undergraduate training, reached out to her contacts "on Facebook, of all technical places," she joked, many of whom also have chemical engineering backgrounds. Asking if anybody knew anything about cooling towers, it turned out that a couple of her friends worked with cooling towers in manufacturing facilities and were able to provide her with insight into whether the technology might be useful or appealing to cooling tower owners and water treatment service companies. After some refinement, customer discovery interviews, and further study of the market, the Entrepreneurial Lead identified cooling towers as the best market fit for the technology.

By the end of the Energy I-Corps training, the Entrepreneurial Lead had found the product market fit, which was different from the power plant application initially anticipated by Principal Investigator and the RWEDI research group leader.

When asked if she thought RWEDI would be as well-positioned for commercialization if she had not participated in the Energy I-Corps training, her response was a decided "No. Not even close." She credits Energy I-Corps for, among other things, engendering a strong understanding of the importance of customer discovery interviews. Customer discovery interviews, according to the Entrepreneurial Lead and now CEO, are vital to understanding the market and creating a strong, viable, business model. She has noted specifically, "it's painfully obvious when you find a company, a startup, that's done a good job at doing customer discovery interviews and looking at the market versus ones that haven't. Being part of the Energy I-Corps program taught me how to do this."

Both the CEO and the Principal Investigator, as well as those familiar with their Energy I-Corps experience, indicated that prior to training they did not have as strong a grasp on how to commercialize RWEDI. They indicated that now, because of the training, the team identified the customers for whom RWEDI will provide the most value and the appropriate market context. They have a clearly articulated value proposition for the target market, developed an appropriate product price, identified the appropriate suppliers of those needed resources, developed a good estimate of business costs, have the resources needed to deploy RWEDI, and established a relationship with key partners necessary for commercialization. All interviewees indicated that Energy I-Corps was instrumental in advancing the technology on its commercialization journey.

As noted by a funder:

> *"They came out with a much better idea of what their technology looks like, how to find a home in the marketplace and the level of work that's ahead of them... And also having spoken to 100 individuals in the marketplace, we have some comfort that they're not barking up the wrong tree. They have a better handle of what their potential customers are really going to want to see."*

Another element of training that a RWEDI team member attributed to its success is the "fail fast approach" – testing the technology idea quickly. If that idea fails, then the team has the opportunity to try again. One RWEDI expert and team member expressed:

> *"Most people who are researchers will apply for a grant with the National Science Foundation, DOE, whoever, and they'll have a 36-month project, and they will essentially go to prove their hypotheses around month 32. But if your hypothesis is wrong, you're too late. You have no alternatives. So, what I've developed in every project I've worked on since the Energy I-Corps training is a fail-fast mode. Don't give me the perfect experiment. Is this technology going to solve this customer's need? How do we figure that out in two months, not in two years? Because if it's not going to and [the funder] still wants to work with me and I find that out in two months, then I still have time to try many other things. That's become a cornerstone of how I do my work now."*

In sum, the Energy I-Corps training was instrumental in bringing RWEDI to commercialization in many of ways, and the information the team learned through the training has also carried forth in other projects.

5.2.3 Building on the Energy I-Corps Experience

5.2.3.1 Partners/Funders

During and after the Energy I-Corps experience, the CEO won several competitions and received follow-on funding from several sources.[56] This funding includes a $250,000 award for RWEDI Water from the University of Chicago Innovation Fund, a pitch competition. The CEO also won a variety of competitions in 2017 including: a VentureWell Stipend ($2,500) to facilitate ASPIRE (Accelerating Startup Partnerships and Investment Readiness) program participation, and prizes from the Global Midwest Alliance ($1,000), the Build 312 Midwest Pitch Competition ($1,000), and the Clean Tech Open Midwest Region 90 Second Pitch Competition ($2,500).

The CEO identified several factors as contributing to her success in securing funding, one of which was an apparent skill at presenting. In addition, being good listener was necessary to get the most out of customer discovery interviews, as the customers talk about, and reveal, problems they are having with business-as-usual operations.

"They don't fund the tech. They fund the people"

The CEO credited Energy I-Corps for honing her skills in presenting, conducting customer discovery interviews, and creating a solid, viable business model. Through Energy I-Corps, she learned how to pitch the technology, and convey its value and its ability to solve problems to potential customers.

[56] http://rwedisolutionsinc.com/achievements.html

She learned to avoid the technical jargon and the science behind the technology, and focus on what the customer cared about – ways to address their problems and the real solutions that RWEDI affords to them. These skills ultimately enabled the CEO to win pitch competitions and earn follow-on funding for the technology. As she noted:

> *"A lot of what you hear is that people who fund startups, they don't fund the tech, they fund the people. I am confident presenting, and I can give a clear and focused presentation. I can articulate the market size and the revenue for the company and entire business model and don't get too deep in the weeds on the technology."*

This sentiment was echoed by one of the funders, who said that the decision to fund the RWEDI technology was due, in part, to the Energy I-Corps training and the personal qualities it conferred, qualities the funders believed would lead to success and the eventual commercialization of the technology. The funder specifically noted:

> *"From the Innovation Fund standpoint, the Energy I-Corps training gives us comfort in a couple of ways. One, that the team is really dedicated and excited about commercializing their technology. [The training is] a pretty intense experience and they know that going in. So, if they're willing to sign up for it and put in that level of effort and to be recognized as having done an excellent job [in the training], that says a lot about their level of enthusiasm for the process and that they're prepared to do what it takes."*

> The training is "a pretty intense experience… If they are recognized as having done an excellent job, that says a lot."

The CEO learned about different sources of funding from ANL, as was the case of support from the Chicago Innovation Fund. Reportedly, the Innovation Fund works closely with ANL as they try to spur scientists and post-docs to be more entrepreneurial.

The CEO is using the funding she has won mostly to build a demonstration unit and its requisite components, including the electrodeionization stacks, membranes, and pumps, and to pay an engineer to build it. She also uses some funds to pay her salary and to cover costs of traveling to conferences and presenting to water utilities and other interested stakeholders.

Some members of the RWEDI team also later received funding from the DOE Technology Commercialization Fund (TCF) for its application to biorefineries.[57] The team for that project, all at ANL, was led by the Principal Investigator and the ANL research group leader.[58] By this point, the Entrepreneurial Lead turned CEO had

[57] TCF is a DOE competitive funding opportunity designed to mature promising technologies to advance commercialization and lab-industry partnerships. https://energy.gov/technologytransitions/services/technology-commercialization-fund

[58] Other team members included Michael Gurin and Erik Hawley.

already begun applying RWEDI for use in cooling towers (not included in the TCF award).

5.2.3.2 Startup and Technology Transfer

Due to the Energy I-Corps training, the Entrepreneurial Lead was well positioned to venture RWEDI toward commercialization. In early 2017, she established RWEDI Solutions, focusing exclusively on using RWEDI technology to treat water for the use of cooling towers. As noted above, this resulting startup came after a pivot away from applying this technology for use in power plants, the anticipated target market at the outset of the team's Energy I-Corps training.

The Entrepreneurial Lead left ANL to become CEO of the RWEDI startup. Some team members noted that the process for technology transfer took a considerable amount of effort, reportedly due to ANL requirements. Despite some challenges, the CEO acquired a license to RWEDI for the targeted applications and subsequently launched the startup. RWEDI Solutions is now incorporated in Delaware as a C corporation.

5.2.4 Market Context

Nearly all experts and those familiar with the RWEDI technology indicated that actors in the cooling tower market tend to be risk averse.

As described by interviewees, RWEDI solves a problem for cooling tower operation and maintenance, but in this case, the power of the status quo looms large. As is typical, there is some risk to adopting new technology, and unless there are pressing motivations to change, cooling tower operators may be less interested in adopting this technology in favor of continuing their usual protocol. As one expert noted specifically "the industry is very conservative and risk averse. It takes a long time to adopt new technology."

Further, water service treatment companies have had some negative experiences with previous technologies purported to solve their problems, which may inhibit their desire to adopt future technologies. As one RWEDI expert noted, "they have been burned a little by other technologies that promise a lot of things and then don't deliver... And part of that is that those technologies try to solve all of your problems." However, because the CEO is specifically focused on what the technology can solve – that is, corrosion and scaling – she is more likely to deliver the results she promises. She noted, "and so being very upfront and honest about what I can and can't do instead of being, you know, a miracle machine, helps reduce some of their hesitations."

Related to their risk aversion, the market also seems to be slow to adopt new technologies. As one RWEDI expert described the market, "They're like dinosaurs. In molasses." The ANL research group lead, himself a RWEDI expert and advisor to the

CEO, has published a paper outlining some of the key opportunities and current challenges to accelerating and adopting technologies in the wastewater sector.[59]

Despite these potential challenges, particularly the risk averse nature of this market, this technology, as it is pitched, does have comparative benefits to other methods, including not treating the water at all, or using chemicals, as discussed above. Further, while this market is acknowledged to be risk averse, the CEO notes that, based on a great deal of research, this market does indeed seem to be the best market fit for the technology. As previously stated, RWEDI can be applied to many markets but as the interviewed team members and experts indicated, the best way to get RWEDI commercialized is to break into a more manageable (in scale) market for now, rather than for example, power plants, which are larger in scale and even more risk averse.

5.2.5 Current Challenges

The startup team has been unable to advance the TRL since the Energy I-Corps training. They are currently building the first demonstration unit to test and illustrate RWEDI's use for cooling towers. The CEO recently submitted a proposal to install the demonstration unit in Nevada, although this proposal was not funded. Ever planning and identifying contingencies, the CEO mentioned that she has leads in Texas and Alabama for other pilot projects. She expects that by March, she will have an opportunity to demonstrate use of the technology and advance the TRL.

5.2.6 Looking Forward

Although the attainment of technology development and commercialization milestones can seldom be reliably predicted, the CEO estimates that the technology will be at a TRL of about 7, corresponding to demonstrating an integrated system prototype in an operational environment around March 2018, at TRL 8 and 9 (validation in a commercial operating environment, and validation of viability at commercial scale, with costs understood) around Spring 2019. If all goes well, the CEO anticipates sales around Spring of 2020.

In terms of more distant projections, RWEDI is a scalable technology, which also reportedly opens other potential markets aside from cooling towers. These markets may range from the small scale, such as in-home units, to a much larger scale of water treatment at centralized power plants. As one RWEDI expert noted "there's an opportunity to build multiple businesses based on the end user, which would have a different supply chain and different customer relationships." While not a near-term goal for RWEDI Solutions, these multiple markets also present an exciting future potential for this technology.

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[59] http://pubs.acs.org/doi/pdf/10.1021/acs.est.6b05917

5.3 SUMMARY

RWEDI is a promising technology that has rests on a strong foundation of years of research and development. If successful, cooling towers with RWEDI will use considerably less water, and if the technology is adopted on a larger scale, a substantial amount of water will be conserved, providing an important environmental and societal benefit.

After intensive Energy I-Corps training, a great deal of research into markets, and a set of experienced, dedicated mentors, the CEO has thoroughly prepared RWEDI for commercialization. While RWEDI has some hurdles ahead of it, as any technology does at this stage, the training and preparation for the startup has positioned it to have a strong potential for commercialization.

Section 6 Lessons Learned and Factors Contributing to Success

6.1 FACTORS CONTRIBUTING TO SUCCESS

6.1.1 Professional and Personality Factors of Team Members

A business adage is “invest in people, not ideas.” This concept came through in our interviews with the lab researchers. In each of the case studies, the professional makeup of the teams and personality characteristics of the startup CEOs or PIs emerged as a contributing factor in progress toward commercialization, and winning funding from investors and/or interest from partners. While technical expertise in a technology is necessary for pursuing commercialization, three of the four teams also mentioned that having team members with professional expertise and experience in other facets of commercialization was a huge benefit. For example, the Industry Mentors and Entrepreneurial Leads contributed to developing the business side of their technologies, including conducting customer discovery research, launching the startup, reaching out to investors and partners, and/or transferring the technology out of the labs, which freed up other team members to focus on the facets more suited to their strengths. Overall, the mix of areas of expertise members brought to each team enabled them to establish a collaborative division of labor that utilized their unique skill sets to pursue various aspects of the commercialization process that would be very difficult for any single team member to perform on their own.

In addition, not all research scientists are willing or able to speak publicly in a confident manner, but having someone on the team to act as a public face for the technology and engage with investors increased the likelihood of winning further investment. At least one person on each of the case study teams was a clear and confident speaker who was good at communicating to investors. As further elaboration, interviewees credited the “high energy level” of one PI with her ability to both maintain relationships with multiple industry partners and pursue more at the same time.

6.1.2 Energy I-Corps Training

We identified six key ways the Energy I-Corps training supported progress toward commercialization for the case study technologies. The synergy generated by addressing the following interrelated components simultaneously focused the teams’ activities, enabling them to travel the path most likely to lead to commercialization.

1. **Customer discovery activities:** The training provided the structure in which customer discovery interviews could occur and helped teams conduct customer discovery research more effectively. The researchers were able to bill some of

their time to the training, allowing them to fully participate. In all four cases, the customer discovery interviews would not have occurred without the Energy I-Corps training. The interviews with market actors to gauge interest in the technology were instrumental in uncovering near-term market opportunities.

2. **Learning in training led to pivots:** Teams entered the training with their best guess as to what market actors would be interested in their technology. Yet, through the customer discovery activities mentioned above, each one of them learned that there was a more viable near-term market that would be better to focus their energies on. The four case study teams pivoted and redirected their attention to the newly-discovered market.

   The STARS initially anticipated it would first pursue the power generation market, but found a lot of market interest for solar-based hydrogen production. SonicLQ started with residential building energy professionals but discovered that building energy professionals working in large commercial/industrial buildings were a better target market. WISDEM pivoted away from OEM suppliers to wind plant operators. The RWEDI team had expected to serve power plants and now is marketing to cooling tower operators.

3. **Value proposition development and delivery:** Once a viable near-term market was identified, the teams learned to develop a value proposition that would resonate with actors in that market. Training activities enabled teams to specify and quantify components in the value proposition, making them specific and actionable. They also learned how to deliver their value proposition and pitches in a way that demonstrated value for the investor without getting bogged down in too many technical details.

4. **Formation of industry partnerships:** The training put the teams in direct contact with industry partners and market actors. As a result, industry actors gained awareness of and learned about these promising technologies. Each case study team developed an ongoing relationship with a market actor they met during the Energy I-Corps training.

5. **Provided a foundation for winning further funding:** Identifying a viable near-term target market, refining a value proposition for that market, and clarifying the elements in the business model canvas gave the teams a strong foundation for winning follow-on funding. All four teams leveraged what they learned in the training to build strong proposals to win competitive funding awards.

6. **Empowered the team to pursue commercialization:** The training and its activities bestowed an entrepreneurial confidence in the teams. The teams left the training empowered to create a startup company or pursue a strategic partnership with an industry partner.

7. **Cultivated an entrepreneurial mindset and business acumen:** For all case studies, the researchers who participated in the Energy I-Corps training are extremely knowledgeable in their respective scientific disciplines. The Energy I-Corps training supplemented their knowledge by cultivating an entrepreneurial mindset and business acumen.

6.1.3 Follow-on Funding

The follow-on funding the teams earned enabled them to continue research to develop their technologies. The funding also facilitated demonstration projects at real-world sites, an essential step to proving the technology's viability to industry. As examples, SonicLQ is demonstrating the technology on military bases, and WISDEM is demonstrating at an operational wind plant.

While the teams have not yet generated revenues for their technologies, the follow-on funding they received demonstrates that outside actors view these technologies as promising. Much of the funding that teams received after the training were competitive funding awards, indicating the reviewers saw strong commercialization potential in these technologies.

Two of the teams (STARS and WISDEM) have received funding from private businesses, as well as government (these teams received TCF Topic 2 awards, for which cost-share between government and private companies is required). One team (SonicLQ) received funding from the Department of Defense, a potential customer and all four teams have won competitive funding awards. One team (WISDEM) has received venture capital funding and another team (STARS) anticipates such funding in the near term.

6.1.4 Technology Factors

Each of the case study technologies was either well-advanced or had a strong theoretical foundation at the time of the training. The core concept behind the technology was well-developed, which was a necessary pre-condition for the teams to investigate the business hypotheses built on that concept.

Each of the technologies had a clear comparative advantage over competing alternative technologies or business-as-usual. The technologies offered targeted market actors the potential to streamline operations, expand their business, improve performance, and/or save time, money, and other resources in their operations.

The case study technologies each have multiple potential applications. Two of the technologies (STARS and RWEDI) are technology platforms. SonicLQ can be used for buildings, but also in clean rooms, transport vessels, containment rooms, sound studios, and other enclosures.[60] Having multiple applications enables a technology to remain viable even if one of the potential applications proves to be of little commercial value. It also amplifies investor attraction because investors know there are other applications down the pipeline. Hence, investors are supporting a technology that can lead to multiple revenue streams and are not limited to one niche market.

Further, each of the case study technologies has the potential to benefit multiple market actors and the broader society, increasing the appeal to investors and expanding the number of market actor types that may be interested in what the technology provides. The more parties that are interested in using or supporting the technology, the greater likelihood that one of them will follow-through.

6.1.5 Target Market Characteristics

The markets targeted by the technologies were either primed for adopting new innovations or at least somewhat open to them. While some of the markets targeted by the case study technologies are risk averse or cautious about adopting new technologies, they nonetheless expressed openness to adopting a thoroughly tested innovation.

Each technology had identified a near-term and a long-term market for which their technology could be applied. That means the technology has current demand and anticipated future demand. Knowing that once the technology is introduced into the market that there will be new sources of demand also increases its attractiveness to investors.

For example, STARS is currently targeting hydrogen production for fuel-cell vehicle refueling stations but has identified and prioritized multiple additional applications. SonicLQ is currently targeting large commercial building energy professionals. It anticipates subsequently targeting all building energy professionals, facilities with clean or containment rooms, and transportation vessels.

Further, three of the four case study technologies had an industry partner interested in commercializing the technology soon after the Energy I-Corps training. Having industry partners interested in the technology yielded greater resources to advance the technology, whether that be funding or a test site to carry out demonstration projects. Having well-known industry partners interested in the technology lends credence that established commercial entities consider the technology promising.

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[60] WISDEM, while addressing the single application of wind turbines, has the flexibility to address all potential operating conditions and to work in tandem with user-provided modules.

6.1.6 Managing Relationships between Lab and Startup

Each team successfully negotiated the complex terrain of lab researchers working with the startup. One or more team members who went through the Energy I-Corps training left the lab to form a startup. The teams had to be careful to demonstrate that the person at the startup was not being compensated for their time in the training.

The researchers had to learn ways to avoid the appearance of conflict of interest issues. They accomplished this by invoking entrepreneurial leave policies, activity agreements to avoid conflicts of interest, or by making it clear to investors that they were supporting *either* the lab or the startup company, but not both simultaneously.

The lab and startup need to negotiate licenses for existing intellectual property and CRADAs. CRADAs between the lab, the startup and other partners ensured everyone agreed to a statement of work and rights to intellectual property generated during the CRADA.

6.2 LESSONS LEARNED

The business training provided in Energy I-Corps was essential. The researchers learned a tremendous amount in the training that they used to further the commercialization of their technologies. Most significantly, the customer discovery interviews led the teams to make pivots in their target markets, they developed attractive value propositions, they learned how to effectively deliver a pitch and communicate effectively in a business context, and they developed relationships with commercial partners.

People are as important as the technology. The expertise and personality characteristics of the team members were substantial contributors to the technologies' progression on the commercialization continuum. Pitching the technology to investors and gaining exposure for the technology require someone who is good at communication. Having a team member who can deliver a pitch, be a friendly face, and have enough energy to pursue partnerships is important to gaining industry support.

Ongoing support is important to TRL advancement. The case study teams earned ongoing support in the form of funding or strategic partnerships to further the development of their technologies. Not only does the support enable researchers to cover their time working on the technology, but partners can provide access to real-world environments in which researchers can test their technologies. The follow-on funding or industry partnership also enhances the credibility and visibility of the technology.

Lab policies and procedures concerning startups and transfer of intellectual property, such as conflict of interest and entrepreneurial leave policies, influence the ease of technology transfer. The four case studies varied in the staffing of the startups and the technology licensing. Two case study teams reported challenges arising from policies governing interactions between lab and startup staff. Technology PIs that continue to be employed by the lab have less ability to support activities related to advancing their technology's TRL than they had prior to the formation of the startup. One startup was hampered because it has not been able to license the technology, which has yet to be patented. This startup thus needed to work through the lab to advance the technology, yet within a process in which the lab-employed PI could engage. It takes time and energy for the PIs to navigate the technology transfer process for startups and lab policies influence the relative ease. An active, supportive technology transfer office within the lab was very helpful.

6.3 ENERGY I-CORPS AS A TECHNOLOGY

The commercialization approach taught by Energy I-Corps itself can be considered a technology that has been transferred from NSF to DOE, is being transferred from DOE to trained researchers, and is being transferred to some degree from trained researchers to others involved in the technologies profiled in the study, as well as more broadly to the trained researchers' colleagues, as documented elsewhere. [61,62]

Through the four technology case studies presented here, we explore the effectiveness of the transfer of the Energy I-Corps technology. With each additional cohort, the Energy I-Corps technology once again goes "out the door," as Bozeman termed the most basic indicator of technology transfer effectiveness. As evident from the case studies, Energy I-Corps has demonstrated effectiveness in getting participating technologies "out the door," as well as in the realm of increased scientific and technical human capital, a second effectiveness outcome. Subsequent studies would be needed to demonstrate Energy I-Corps effectiveness in the remaining five outcomes identified by Bozeman of market impact, economic development, public value, political, and opportunity cost.

[61] Energy I-Corps Program: Year 1 Process and Impact Evaluation, Final Report. November 28, 2016. DOE/EE-1575.

[62] Energy I-Corps Program: Year 2 Impact Evaluation, Final Report. February 2018. DOE/EE-1736.

Appendix A Instruments

A.1 PRINCIPAL INVESTIGATOR AND ACTIVE TEAM MEMBERS GUIDE

A.1.1 Introduction

Thank you for talking with me today. As I mentioned, my firm is working with the DOE's EERE Office to prepare short case studies on Energy I-Corps (formerly, Lab-Corps) project team technologies that have made progress toward commercialization.

We will seek your feedback on the accuracy of our notes and the draft case study we compose based on our interviews for your technology, should you desire.

[Can say if needed during interview] I am aware I may be asking for confidential information. We will preserve necessary confidences, but nonetheless would like to obtain a complete picture. Will it work for you to answer fully and then flag for us any details of your response that you do not want revealed in the case study? With a complete understanding of both the details and your concerns, we will be able to craft general statements that are informative for the reader yet not revealing for you.

I'll be taking notes as we talk, but I'd like to record this conversation to ensure the accuracy of my notes. Is that okay with you?

Any questions for me before we get started?

A.1.2 Team

[ASK PI WHEN FIRST SCHEDULING]

Q1. Who is currently on the team working on the development or commercialization of [TECH NAME] – including yourself [if STARTUP: and those involved in the startup]? And please address when they joined the team, what organization they work for (such as a [LAB] scientist), and their roles on the team.

Q2. [If we have names not mentioned] And what about [NAME]?

Q3. [Any folks not among [CONTACT INFO]? If so:] Can you provide us with contact information for [people named]?

Q4. To confirm, the current team composition IS THE SAME / IS NOT THE SAME as the group that participated in the Energy I-Corps training?

Q5. Thank you. We will email your team members about the study and seeking their participation. We will mention that we are scheduling with you to conduct an interview. Will that be all right?

[ASK PI FOR INTERVIEW]

Q6. When we spoke to schedule, we reviewed your team members. How did you all come together to form this current team working toward commercialization of [TECH NAME]?

Q7. [If needed:] Were any of you already working together, and if so, in what capacity?

[ASK ALL]

Q8. Please describe your current role in the development of [TECH NAME] for commercialization, and, briefly, the types of activities are you engaged in?

Q9. [If unclear] Prior to [TRAINING DATE], what experience did you have that was relevant to the commercialization process, such as specific technical or market expertise, technology transfer, commercialization, or entrepreneurial experience?

Q10. About how much time or percent of time are you currently spending on [TECH NAME]?

Q11. Is all of this time covered by the current funding awarded to the technology, or are you donating your own time as well? [If own time, clarify amount/percent of funded vs unfunded time]

Q12. In addition to the people you are working with on [TECH NAME], we would like to briefly interview an independent industry expert that might provide some context for the technology. Can you suggest anyone, or suggest how we might identify an appropriate expert?

A.1.3 Technology

Let's move on to talk about the technology.

Q13. My understanding of the [TECH NAME] is that it [BRIEF DESCRIPTION]. The target market is [TARGET MARKET] and they would use it for [RATIONALE]. Is that about right, or am I misunderstanding something?

[AS NEEDED, PROBE ON TECHNOLOGY BENEFITS]

Q14. Compared to the next best technology that [TECH NAME] replaces, what does [TECH NAME] offer, such as improved performance, increased functionality, reduced costs?

Q15. What benefits would occur from commercialization/adoption, such as reduced energy use, reduced emissions?

Q16. What benefits, if any, would accrue to the producer of the technology and the accompanying supply chain, such as increased revenue, skills, ability to meet requirements or standards, advantage in new markets?

[IF NEEDED, PROBE ON TARGET MARKET]

Q17. Will the technology be used in the private sector, the public sector (ex: government), or both?

Q18. Will the technology be open-source or proprietary?

Q19. Is the technology to be a commercial product, a component in a commercial product, or is it a process (such as production process, or a component of a process?

[ASK ALL]

Q20. Have you made any pivots, substantially changing its functions, purpose, or who might use it? [If yes:] Describe pivot and when (pre or post training)

A.1.4 Technology Transfer

Q21. Has Intellectual Property (IP) been transferred outside of the lab? (patents or trademarks, license agreement).

[IF YES, IP TRANSFER:]

Q22. When, and how was it transferred (CRADA or license)?

Q23. To whom [or type of entity]? [Explore: organization type, size, past experience with this Lab/Agency and with this or related technologies, etc.]

Q24. Did you run into any challenges you needed to solve to transfer this technology? If yes, please describe.

[IF NO, IP TRANSFER:]

Q25. When do you foresee that the IP will transfer, and by what mechanism (CRADA or license)?

Q26. Have you run into any challenges attempting to transfer this technology? If yes, please describe.

[ASK ALL]

Q27. We understand that THERE IS / IS NOT a startup for this technology. Correct?

[IF STARTUP]

Q28. How are you defining startup? [ex: employer identification number (FEIN), president, employees, website, sales]

Q29. [If needed:] Have you had any sales or use? [If yes:] To whom? In what amount?

[IF NO STARTUP]

Q30. Do you anticipate a startup will emerge to take [TECH NAME] to market?

Q31. [If no] What entity do you anticipate will sell it first?

[IF IP TRANSFER AND/OR STARTUP]

Q32. What was the involvement of the Technology Transfer offices at your lab and the DOE agency in the [IP transfer and/or STARTUP]?

A.1.5 Funding and Other Resources

Q33. I understand that [TECH NAME] received follow-on funding from [INSERT FUNDER(S)]. Is that correct?

Q34. Have you received any other funding? [If yes:] Describe

Q35. [For each funding source] What are you using the [FUNDER] funds for?

Q36. [For each funding source:] What is the form of the agreement attached to the funding, such as DOE contract, CRADA, SPP [Strategic Partnership Projects, successor of Work for Others, (WFO)], something else?

Q37. [For each] Briefly, how did it come about that you received this funding?

Q38. [If unclear] How did you identify the funding opportunity? Did you have any prior relationships with the funders?

Q39. What were the key win points you think likely contributed to the funder's decision to back your technology. [Explore if the pitch varied by funding source]

Q40. Do you have any non-funding collaborators – such as other researchers in the Lab or industry, a green tech incubator, a private entity, small business assistance programs, that provided or are providing skills, resources or other support to the team? Are you in discussion with any others?

Q41. [If yes:] Describe with who, what is their involvement and what do they hope to get out of it?

Q42. What challenges have you encountered, if any, in establishing partnerships and obtaining funding? [If yes:] How are you addressing them?

Q43. What role, if any, did Energy I-Corps play in facilitating connections with those individuals/ companies, either during or after the training?

IF ENERGY I-CORPS TRAINING:

Q44. To what extent did the Energy I-Corps training prepare you for interacting with those parties?

Q45. In what other ways was the Energy I-Corps training helpful to the commercialization of [TECH NAME]?

Q46. I'd like to ask the counterfactual question: Do you think [TECH NAME] would be as well-positioned for commercialization as it is had you NOT participated in the Energy I-Corps training? Please explain.

Probe as necessary to get specific feedback on each of the following:

1. Usefulness of interviews with prospective customers that they conducted during training
2. Work on the technology's value proposition
3. Understanding the commercialization process
4. Understanding and accessing their lab's support for commercialization

ASK PI OR PRIMARY CONTACT

Q47. The case study methodology requires us to better understand the technology development from the perspective of funders and partners. We would like to briefly interview them. Can you provide me with contact information for [FUNDER(S)]? (Can send in email.)

Q48. [If non-funding collaborators mentioned:] And can you provide me with contact information for [collaborators mentioned]? (Can send in email.)

A.1.6 Technology Development

Q49. I'd like to understand the recent progression of [TECH NAME] in stage of technology readiness level per your current target market. I'll run through the TRLs in reverse order (from production and sales backward) for you to indicate your forecast of when you might hit that milestone, what stage best fits where you are now, and what stage the technology was in when you applied for the Energy I-Corps training. Your best assessments are fine.

Q50. Which of these TRL stages does current funding cover? A simple "yes, funding is for this stage" answer is what I'm looking for.

Q51. And how far, in terms of TRL, do you anticipate lab involvement will extend? [Alternative way to elicit answer: For rows with forecast dates, ask whether the contact anticipates the lab will be involved the activity.

[NOTES TO INTERVIEWER:

Ask for rows up until you hit the TRL at time of pre-training; omit subsequent rows.

Need only enter "Y"s (or any key stroke); blanks will be interpreted as N. Capture any respondent comments in last column. Ex: May have conducted validation testing and been dissatisfied; now engaged in reworking and/or testing.

Q52. TRL Progression Table

TRL	Description	Elaboration (if needed)	Forecast to reach TRL (mm/yy or yy)	Now at this TRL? (Y/N)	At this TRL at start of training? (Y/N)	Current funding for this TRL (Y/N)	Highest TRL w/lab involvement (Y/N)	Comments
10	Production and sales or open-source use	Includes use of technology in production processes						
9	Validation of viability at commercial scale; costs understood	1+ units produced; proven ready for full commercialization						
8	Validation in commercial operational environment	Incorporation into commercial design is demonstrated; pre-commercial demonstration						
7	Integrated system Prototype demonstrated in operational environment	Prototype demonstration in an operational environment (integrated pilot system level)						

TRL	Description	Elaboration (if needed)	Forecast to reach TRL (mm/yy or yy)	Now at this TRL? (Y/N)	At this TRL at start of training? (Y/N)	Current funding for this TRL (Y/N)	Highest TRL w/lab involvement (Y/N)	Comments
6	Validation of system prototype in simulated operation environment	Beta prototype system level						
5	Initial development & verification of integrated system	Lab testing of integrated or semi-integrated system; validation achieved in a relevant environment						
4	Proof of application of system components	Results based on projected or modeled systems suggest performance targets may be attainable; Alpha prototype						
3	Proof of concept for components	Research validate analytical predictions of separate elements of the technology						

TRL	Description	Elaboration (if needed)	Forecast to reach TRL (mm/yy or yy)	Now at this TRL? (Y/N)	At this TRL at start of training? (Y/N)	Current funding for this TRL (Y/N)	Highest TRL w/lab involvement (Y/N)	Comments
2	Concept definition	Potential of material or process to serve an application is identified						

Q53. Gazing into your crystal ball, are you applying for additional follow-on funding? Perhaps some of your current partnerships might continue. Perhaps you are eyeing potential new partners. What do you see going forward?

Q54. And do you anticipate that other entities will move to acquire the technology over time?

Q55. Now I'd like to discuss your technology progress in various business facets. Using a 5-point scale, where "5" indicates you've pretty much nailed this facet for [TECH NAME] and "1" indicates you haven't a clue, please indicate where you are now and where you were at the time you were accepted for the training.

Item	Now (1-5)	Prior to training (1-5)
Customers: Identified market segment or customer for whom [TECH NAME] creates value		
Value: Clearly articulated value proposition for identified market		
Pricing: Developed good estimate of what customer is willing to pay		
Costs: Developed good estimate of costs		
Inputs/Resources: Identified inputs/resources needed for to deploy [TECH NAME]		
Suppliers: Identified suppliers of inputs/resources needed		
Key Partners: Established relationships with key partners necessary for commercialization of [TECH NAME]		

A.1.7 Context

Let's discuss the broader context of your technology and the target market.

Q56. How does this market sector react to new technologies - are they quick to embrace them or more resistant to change? Why do you say that?

Q57. Are there other new technologies that [TECH NAME] must compete with to earn market share?

Q58. Are there any key technical or other limitations holding up the development or commercialization of your technology? Other limitations? [such as availability of capital, facilities, tools, talent]

Q59. Are there any legal, health, safety or environmental policies that are helping or hindering your progress?

Q60. Similarly, what benefits applicable to other work, if any, might accrue to those involved in the research and development and/or transfer of the technology, such as technical or business knowledge or lessons learned about the process?

Q61. Have there been any unanticipated outcomes from the technology development, transfer, and commercialization, either positive or negative?

A.1.8 Other Collaborators [IF TIME]

As our last topic, I'd like to explore whether there were any people or entities that we haven't discussed that might have played a role in the commercialization advancement of [TECH NAME]. This could include other scientists, potential funders, manufacturers, suppliers of raw materials, or potential customers of your technology.

Q62. After the Energy I-Corps training, who outside of your project team – that we haven't discussed – did you interact with to advance the commercialization of your technology?

[For each, as needed to understand:]

1. How did you identify them?
2. Did you have any prior relationships with them? [probe as needed to understand if they established the relationship during the training or prior to the training]
3. What was the purpose/nature of the interaction?
4. Why do you think those parties were interested in partnering/working with your team?
5. Did you encounter any challenges identifying or interacting with any of them?

Q63. [IF ANY:] So that we are able to trace the history of these collaborations, during the training did you explore collaborations with anyone you haven't just mentioned? [If yes, describe for each – the above probe questions]

Q64. And similarly, did you enter the training with some potential collaborators – either having already had interactions with them or with the intention of reaching out during the training? [If yes, explore]

A.1.9 Closing [ASK ALL]

Q65. [If needed] I am aware of [website, press releases]. Are there any other sources for an overview of [TECH NAME] that I should look at?

Q66. Those are all the questions I have prepared. Is there anything else you think is important for me to know about [TECH NAME], its commercialization journey, or Energy I-Corps?

A.2 INDUSTRY EXPERT GUIDE

Thank you for taking the time to talk with me today. As I mentioned in my email, my firm is preparing short case studies on promising technologies developed at Department of Energy National Labs. [TECH NAME] has been selected for a case study and [CONTACT NAME] suggested you would have a good perspective on the technology's potential impact in the market. We won't identify you by name in what we report.

I'll be taking notes as we talk, but I'd like to record this conversation to ensure the accuracy of my notes. Is that okay with you?

Any questions for me before we get started?

A.2.1 Introduction

Q1. How familiar are you with the [TECH NAME] technology and its application to [TARGET MARKET]?

1. Are there any other applications for this technology you're aware of?
2. (Ask for up to three applications in [TARGET MARKET]).

Q2. How did you first learn about [TECH NAME]?

A.2.2 Market

Q3. What does [TECH NAME] offer the [TARGET MARKET] market? (If needed: performance/function, cost, societal benefit)

Q4. What is the "business as usual" technology this technology would replace?

Q5. How many competing technologies are offering solutions to address similar problems in this market?

1. [If any:] How competitive is this technology market right now?

Q6. What are [TECH NAME]'s comparative advantages? (if needed, what advantages does it have over competing technologies or business as usual?)

1. Anything else? [repeat until "no" response]

Q7. Are you seeing the [TARGET MARKET] as a niche market, or broad market applicability?

1. Why do you say that? (Probe to understand market size in terms of number of potential customers and number of "units" demanded per customer)

Q8. And can you characterize the target market in terms of its maturity, risk aversion, and willingness to adopt new technologies? [Probe to address each element: maturity, risk, adoption]

Q9. Can [TECH NAME] be readily adopted or is it disruptive? (If needed: disruptive in that it needs supporting technology or infrastructure, disruptive in terms of its supply chain, or to the adopter's ongoing operations, or to the end user routines if they are not the adopter?)

1. (Probe on above factors, particularly disruption to ongoing operations)

Q10. What do you see are the main market challenges it will face as it moves toward commercialization?

Q11. How about economic challenges, including the supply chain, vested interests, and so on?

Q12. What do you see are the main technological challenges [TECH NAME] currently faces to meet and validate performance and cost requirements to enter the market?

Q13. Are there any other barriers that might limit target market adoption?

A.2.3 Energy I-Corps

We're almost done. Just a few questions left.

Q14. Are you aware that [PI] and his/her colleagues received training in commercialization for [TECH NAME] through a DOE program initially termed Lab-Corps and now known as Energy I-Corps?

Q15. [If yes and unclear:] How did you come to learn that?

Q16. Do you have any sense as to what ways, if any, [TECH NAME]'s participation in the I-Corps training has contributed to its developmental trajectory?

A.2.4 Closing

Q17. Finally, I'd like to better understand the context for your responses today. Would you describe yourself as having any conflicts of interest that may influence your opinion of the technology, or activities that might lead others to perceive a conflict of interest?

1. [If yes] what are they?

Q18. That's all of my questions. Is there anything else you think I should know that will help me to understand the path toward commercialization for [TECH NAME]?

A.3 PARTNERS/FUNDERS GUIDE

A.3.1 Introduction

Thank you for taking the time to talk with me today. As I mentioned in my email, my firm is preparing short case studies on promising technologies that have completed Energy I-Corps training through the DOE's office of Energy Efficiency and Renewable Energy. [TECH NAME] has been selected for a case study, and as part of that effort, we wanted to speak with you to understand your perspectives on the technology and its impact in the market. We won't identify you by name in what we report.

I'll be taking notes as we talk, but I'd like to record this conversation to ensure the accuracy of my notes. Is that okay with you?

Any questions for me before we get started?

A.3.2 Interview Questions

Q1. From talking with [CONTACT] I understand you've committed to provide [TECH NAME] with [$XX] amount of funding. Is that right?

Q2. Besides the funds, in what other ways are you supporting [TECH NAME]? (Probe to clarify current activities)

1. [If unclear] What is the nature of your current involvement with [TECH NAME]?

Q3. How and when did you first learn of [TECH NAME]?

Q4. And how did your current collaboration come about?

Q5. Are you aware that [PI] and his/her colleagues received training in commercialization for [TECH NAME] through a DOE program initially termed Lab-Corps and now known as Energy I-Corps?

1. [If yes and unclear:] How did you come to learn that?

Q6. [If aware of I-Corps] How did [TECH NAME]'s participation in the I-Corps training contribute to your decision to collaborate, if at all?

Q7. Why is your organization interested in [TECH NAME]?

1. What benefits does it offer your organization?
2. How is it a fit for your organization?
3. [If unclear] What benefit do you anticipate will result from your current collaboration?

Q8. Are there any concerns you have about the technology that might not make it a good fit for your organization?

Q9. What are the reasons you think [TECH NAME] might succeed commercially?

1. Anything else? [repeat until "no" response]

Q10. At the end of your collaboration, what additional technical development, if any, do you anticipate that [TECH NAME] will need to ready it for market sales?

Q11. At the end of your collaboration, what additional business or market development work, if any, do you anticipate that [TECH NAME] will need to ready it for market sales?

Q12. [Non-Lab funders and if unclear] Down the road, is it a possibility that your organization might acquire rights to the technology to produce yourself or purchase it when it its commercially available?

Q13. [Non-lab funder] Are there any other technologies you're keeping an eye on that addresses some of the same issues that [TECH NAME] addresses for you?

A.3.3 Closing

Q14. That's all of my questions. Is there anything else you think I should know that will help me to understand why your organization is supporting [TECH NAME]?

A.4 RESEARCH SUPERVISOR GUIDE

A.4.1 Introduction

Thank you for taking the time to talk with me today. As I mentioned in my email, my firm is preparing short case studies on promising technologies that have completed Energy I-Corps training through the DOE's office of Energy Efficiency and Renewable Energy. [TECH NAME] has been selected for a case study, and as part of that effort, we wanted to speak with you about [TECH NAME] as part of our exploration of its licensing and the startup. We won't identify you by name in what we report.

I'll be taking notes as we talk, but I'd like to record this conversation to ensure the accuracy of my notes. Is that okay with you?

Any questions for me before we get started?

A.4.2 Lab Background

First, I'd like to know a little about you.

Q1. What is your title at [Lab], your division or group, and how many PIs are in your group?

Q2. How long have you been in this role?

Q3. Does your group and its work have characteristics associated with development of commercial products or process and innovation, such as more applied research, more interdisciplinary investigations and/or cross functional teams than other groups?

Q4. To what extent is getting your group's innovations out of the lab a priority for you?

Q5. How common is it for the contracts your group works to require a market analysis or business plan, or otherwise begin to position them for technology transfer?

Q6. Compared to your peers, would you say you are more likely or less likely to encourage your PIs to pursue tech transfer?

A.4.3 Involvement with Technology

Q7. Has been your involvement with [TECH NAME] been limited to working with the PI, or did you help with the process of tech development or any tech transfer? (Describe)

1. [If any tech transfer] What has been your involvement, if any, in the licensing and startup of [TECH NAME]?

Q8. [If unclear] To what extent, if at all, has [PI] discussed with you any of the specifics around the fit between [TECH NAME] and potential markets? [possibly: honing the fit – tweaking the technology or the value proposition]

1. If yes: What have you discussed with them?
2. If yes: Is that part of your formal role, to discuss potential market applications with PIs?

Q9. [TECH NAME] participated in Energy I-Corps, then called Lab-Corps. What involvement, if any, did you have in the selection of [TECH NAME] to participate or in facilitating its participation during the training?

Q10. From your perspective, what benefit did [PI] gain from Lab-Corps participation?

A.4.4 Tech Transfer

Q11. What factors do you think contributed to the technology advancing to licensing and startup?

Q12. [If unclear] In your opinion, does the PI or [his/her] team have any characteristics that have contributed to the progression of [TECH NAME] from patenting through to startup?

Q13. Are there any other circumstances or conditions that you think set [TECH NAME] apart from some of the other technologies your PIs are working on, with respect to the progression from patenting through to startup?

Q14. Are you aware of any particular issues or challenges, from the progression of [TECH NAME] from patenting through to startup?

1. [If any]: What lessons learned came from that experience?

A.4.5 Closing

Q15. That's all of my questions. Is there anything else you think I should know in order to better understand the activities around the [TECH NAME] licensing and startup, including any implications of Energy I-Corps?

A.5 TECH TRANSFER OFFICE REPRESENTATIVE

A.5.1 Note to Interviewer

Many of the questions ask about licensing and/or CRADA negotiation. Depending upon the respondent's experience with licensing or CRADAs, please adjust the wording of subsequent questions. For example, if they were involved only in licensing, omit references to CRADAs and vice versa.

A.5.2 Introduction

Thank you for taking the time to talk with me today. As I mentioned in my email, my firm is preparing short case studies on promising technologies that have completed Energy I-Corps training through the DOE's office of Energy Efficiency and Renewable Energy. [TECH NAME] has been selected for a case study, and as part of that effort, we wanted to speak with you about the [TECH NAME] startup and the licensing of the technology. We won't identify you by name in what we report.

I'll be taking notes as we talk, but I'd like to record this conversation to ensure the accuracy of my notes. Is that okay with you?

Any questions for me before we get started?

A.5.3 Lab Background

Q1. First, I'd like to know your title at [LAB] and your division or group?

Q2. How long have you been in this role?

Q3. Does [LAB] have an entrepreneurial leave policy?

Q4. How common is it that researchers leave the lab to form a startup?

Q5. Approximately, how many startups have been among the licensees you've worked with?

A.5.4 Research Team

Q6. When did you first start working with [PI] and [TECH NAME]?

Q7. What were you working on when you first started working together?

Q8. What has been your role in negotiating CRADAs or licensing [TECH NAME]?

Q9. Please briefly describe what was entailed in negotiating the CRADA or the licensing of [TECH NAME]? (If needed: steps, activities)

Q10. What issues or challenges arose?

1. [If any] How did you solve them?

Q11. I'd like to understand what circumstances, if any, set the [TECH NAME] licensing or CRADA negotiation apart from others you've worked on.

Q12. What was the involvement of [PI] in negotiating the CRADA or licensing [TECH NAME]?

1. Was that involvement typical, or were there any particular issues?

Q13. Regarding the CRADAs, licensing, or startup, what have been topics on which you've had to educate or clarify policy for [PI or lab management]? For example, issues of conflict of interest. (Describe).

1. Anything else?

Q14. How about the CEO, what did you have to educate him/her on?

Q15. Did [PI] or [CEO] have any unique questions or concerns?

Q16. How challenging has this been for [PI] and [TECH NAME] CEO to master the nuances of issues concerning a startup?

Q17. What does [LAB] do, if anything, proactively or on an ongoing basis to educate researchers on issues regarding CRADAs, licensing, and startups, or is that more on a need-to-know basis?

Q18. What ongoing involvement, if any, have you or others at your office had with [PI] post-licensing?

Q19. What ongoing involvement, if any, have you or others at your office had with the startup post-licensing?

A.5.5 Energy I-Corps

Q20. [PI] and [TECH NAME] participated in Energy I-Corps, then called Lab-Corps. What involvement, if any, did you or others at your office have with [PI] during his/her Lab-Corps participation?

Q21. Were you involved in the selection of [TECH NAME] to participate in Lab-Corps?

1. [If Yes] What made [PI] and [TECH NAME] a good candidate for Lab-Corps?

Q22. [IF DON'T KNOW] Did Lab-Corps participants need to have already patented their IP? [If not required:] Had [TECH NAME] patented their IP prior to Lab-Corps?

Q23. What involvement, if any, did you or others at your office have with [PI] subsequent to Lab-Corps, but before the CRADA or licensing activities that we've already discussed?

A.5.6 Closing

We're just about done, I just a few questions left.

Q24. Have there been any issues unique to [TECH NAME] that we haven't discussed?

Q25. Finally, is there anything unique about [LAB] that influences how you work with PIs or CEOs as they negotiate CRADAs, license technologies, or form startups?

Q26. That's all of my questions. Is there anything else you think I should know in order to better understand the activities around the [TECH NAME] licensing and startup, including any implications of Energy I-Corps?

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