JISEA Joint Institute for Strategic Energy Analysis

New Approaches to Energy Hardware Innovation and Incubation

David J. Garfield, Kate E. Moore, Richard Adams

The Joint Institute for Strategic Energy Analysis is operated by the Alliance for Sustainable Energy, LLC, on behalf of the U.S. Department of Energy's National Renewable Energy Laboratory, the University of Colorado-Boulder, the Colorado School of Mines, the Colorado State University, the Massachusetts Institute of Technology, and Stanford University.

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The Joint Institute for
Strategic Energy Analysis

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NOTICE

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Executive Summary

Leadership in energy innovation depends on the ability of entrepreneurs to develop and successfully bring innovative technology solutions to market. In the past five years, novel approaches have emerged to support the early-stage cleantech development of physical systems, improving the path from invention to scale-up in the marketplace. Building on a Joint Institute for Strategic Energy Analysis (JISEA) white paper from 2016, we provide additional details, updates on progress, and analyses of these maturing programs and organizations, as well as discuss several new initiatives that have been created since 2016. These enterprises differ from traditional business incubators both in their commercialization methodologies and in the combined resources leveraged from founding organizations and partners. This paper provides a general landscape of these innovative programs and begins to identify metrics of success to help quantify the impact of these various approaches.

The following table summarizes the programs we evaluated, which fall into three categories as indicated by color. Light green represents the most mature innovation organizations that focus primarily on access to technology development facilities and expertise. Dark green are those organizations that were established more recently and were inspired by the successes of those in light green. (Both light and dark green provide non-dilutive funding.) Blue represents innovation organizations that provide equity-based financial resources, some of which also provide access to physical resources.

Energy Innovation Organizations Evaluated, with Organizational Focus and Strategy

Organization/ Program	Organization Founders	Year launched	Tech Focus	Funding type	Lab/ equipment access	Technology testing/ validation/ demonstration support	Faciliated investor and industry introductions
Wells Fargo Innovation Incubator (IN^2)	Wells Fargo Foundation, National Renewable Energy Lab	2014	commercial buildings, agriculture	non-dilutive	x	x	x
Cyclotron Road	Lawrence Berkeley National Lab	2014	advanced manufacturing, clean power, electronics	non-dilutive	x	x	x
Lab-Embedded Entrepreneurship Program (LEEP) Nodes	Argonne National Lab & Oak Ridge National Lab	2017	energy	non-dilutive	x	x	x
Shell GameChanger Accelerator Powered by NREL (GCxN)	Shell, National Renewable Energy Lab	2018	long-duration energy storage, controls for the grid of the future	non-dilutive	x	x	x
Women in Cleantech Challenge	MaRS, Natural Resources Canada	2018	cleantech	non-dilutive	x	x	x
The Engine by MIT	MIT	2017	tough tech	equity	x	x	x
Carbontech Labs	Carbon 180	2018	CO_2 removal and/or utilization	equity		x	x
PRIME Coalition	Public charity that partners with philanthropists	2014	energy	equity		x	x
Breakthrough Energy Ventures	Bill Gates, Investor-led	2017	energy	equity		x	x

The following are key findings from this study:

1. **Technology-focused innovation organizations show early signs of success in aiding startups across the Valleys of Death.** Started in 2014, the Wells Fargo Innovation Incubator (IN^2) at the National Renewable Energy Laboratory (NREL) and Cyclotron Road at Lawrence Berkeley National Laboratory (LBNL) have five years of track record in helping innovative startups gain footing in the marketplace. Through a series of interviews with key stakeholders, including program staff, entrepreneurs, and investors, we find that these organizations produce a marked increase in the success rate of the companies that participate. Thus far, 100% of the companies participating in both programs are still in existence as of the publication date of this report, a key metric given the early stage and technological risk of the companies involved.

2. **The success of energy technology innovation depends on a multitude of support approaches.** The diverse approaches that these innovation organizations take is a display of both the complexity and diversity of the challenge. IN^2 gives technology startups access to the facilities at NREL through its staff scientists and engineers. Cyclotron Road allows entrepreneurs two years of access to the facilities at LBNL, while providing entrepreneurial training. PRIME Coalition and The Engine focus on the early financing hurdles of a technology company that has yet to develop a tangible product. All of these approaches and more are needed to fully support innovative and disruptive hardware technology development.

3. **Success begets success.** Many of the programs explored in this report exist as expansions of the earlier approaches or were directly inspired by the earlier programs. In 2017, the U.S. Department of Energy expanded the Cyclotron Road model to both Argonne and Oak Ridge National Laboratories, collectively deemed the Lab-Embedded Entrepreneurship Program (LEEP) nodes. Shell GameChanger Accelerator Powered by NREL (GCxN) applies the IN^2 model to technology areas of interest to the Shell Corporation. The Women in Cleantech Challenge was inspired by the success of both IN^2 and Cyclotron Road and adopts aspects of each in a Canadian cleantech program focused on female entrepreneurs. These programs stand as a testament to the success of the early programs on which they are modeled.

The programs in this report address a plethora of hurdles: providing trusted third-party validation and demonstration, facilitating early customer and industry engagement, leveraging existing physical assets to develop new technologies, and/or providing financing with early-stage risk-tolerant capital. These functions are complementary, not competitive; a single company would benefit from the services or capital of multiple programs, named here or otherwise. While even the most mature of these organizations is still relatively nascent, early data suggests there is both a high demand for their services, and that their services provide meaningful impact for the startups involved. Detailed in the report below are descriptions of the mentioned organizations—how they function, what challenges they address, and some early metrics of their successes.

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Introduction

The cost of renewable energy technologies such as wind, photovoltaics (PV) and lithium-ion batteries have fallen precipitously over the past decade. PV module prices have dropped an order of magnitude, from $3.42 per watt in 2008[1] to $0.30 per watt in 2018[2], and renewable energy generation capacity has grown commensurately[3]. In fact, utility-procurement executives are reporting that the cost of adding new renewable generation capacity is now less than the marginal cost of running existing fossil fuel assets[4], resulting in record global investments ($333 billion in 2017) in clean energy over the past several years[5]. Despite these tremendous strides, however, estimates from Bloomberg New Energy Finance and others[6–9] project that at current growth rates and projected levels of investment, global society will not achieve the emissions reductions targets set forth in the Paris Climate Agreement, and that in order to meet these targets a host of new technologies need to not only be discovered[10], but to be brought into the market and deployed at scale within the next 30 years[11] to meet those goals.

Stages of Innovation Addressed by Organizations Studied

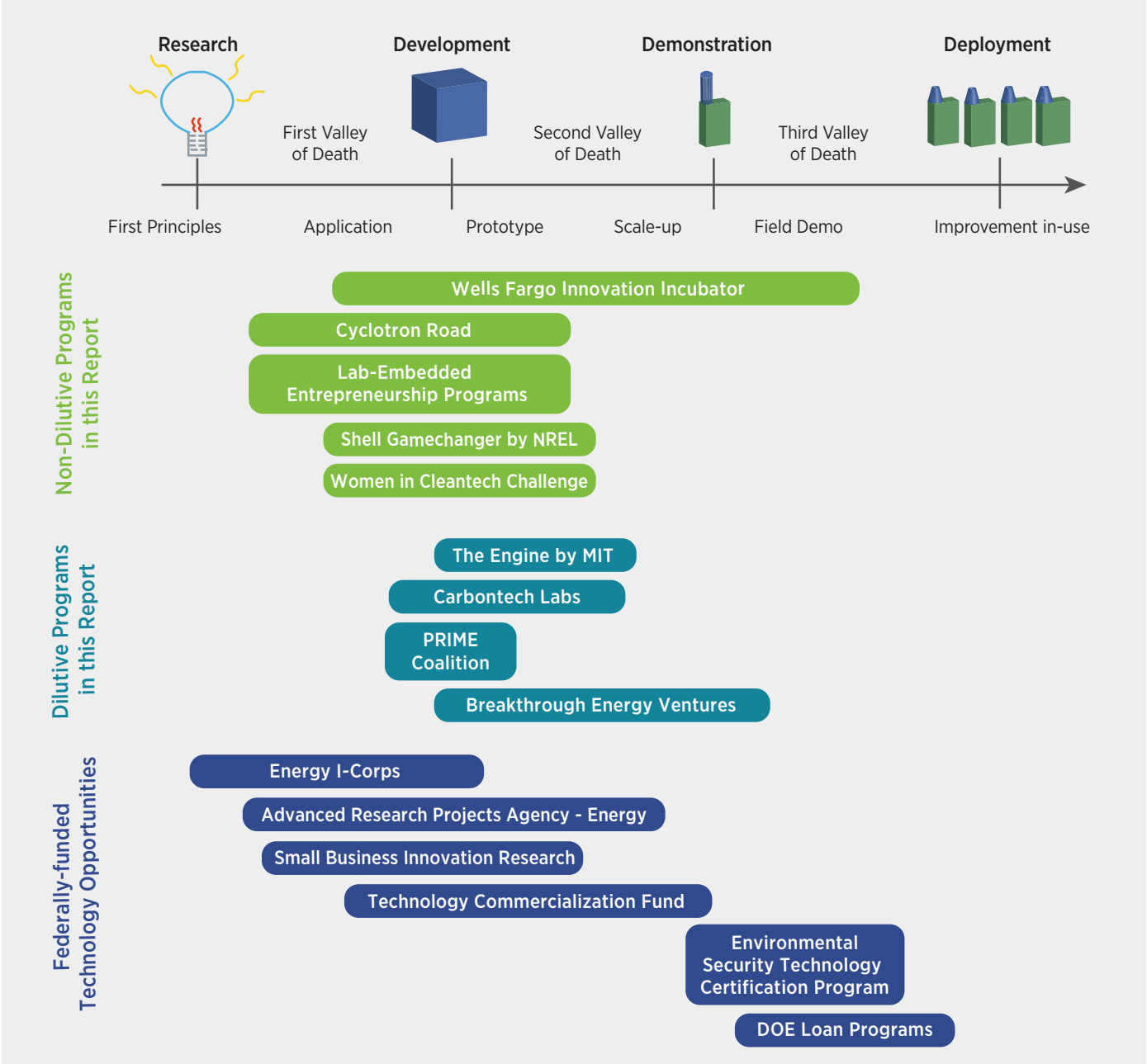


Figure 1: The pathway to market is not uniform or linear but all innovations must pass through these stages.

Compounding the problem, innovation in what Bonvillian and Weiss deem "legacy sectors"*[12] is both time- and capital-intensive, and heavily regulated. The energy sector, particularly hardware technologies, certainly fits this bill. Incumbent businesses tend to lack the risk tolerance needed to yield transformative innovation[13,14], while startups attempting to make inroads in these markets face many well-documented challenges[12,15–17]. Collectively and ominously deemed the Valley[s] of Death, these difficulties contributed to large energy sector losses seen after the influx of venture capital (VC) investment in the 2000s, and led to a dearth of investment in energy innovation through the recession and into the economic recovery[5,18–20].

Today, many savvy investors seek to limit their exposure to technological risk. As one venture capitalist (VC) shared as input for this paper, "If I have to put in $30 million to find out if the technology will work, it's a no-go." No longer interested in funding science projects, many investors now expect startups to have proven their technologies' fundamental viability before raising capital. However, de-risking physical technologies without the proper resources can prove insurmountable. Innovation organizations[12,21] have therefore been created to help promising technologies down the risk curve[9] and across the Valley of Death, helping them navigate the nuanced innovation process (see Figure 1) and ready them for third-party investment. According to Rafael Reif, President of the Massachusetts Institute of Technology (MIT), these organizations are needed to accelerate the process from "idea to investment… to impact."[15]

In this paper, we explore several innovative technology incubation models that have been created to address these challenges. The suite of programs described herein is by no means comprehensive, but rather attempts to convey the diversity of approaches to address the hurdles faced by startups in these spaces. These organizations tend to specialize in specific areas of the technology innovation process, focusing on prototype development, demonstration of those prototypes, financing of these technical endeavors with patient, risk-tolerant capital, and/or introductions and engagement with potential customers and end-users. This paper will lay out fundamental aspects of the following programs, based on a series of interviews with both founders and program staff. It will also attempt to quantify early successes in two of the more mature programs, though it should be noted that these innovation organizations are themselves startups and it remains too early for them to be definitively judged. The following section will discuss in more detail the difficulties in attempting to quantify metrics for these programs.

Measuring the Success of Innovation Organizations

Like the startup ventures themselves, the innovation organizations described in this report and elsewhere are experiments, constantly iterating and improving their programs in order to better fulfill the goals they set out to achieve. Measuring the success of these organizations depends, of course, on the goals with which they judge success. For the sake of clarity, we will focus on one general goal that is universally shared across all the programs described below—allowing and accelerating the path from idea to scaled market adoption for the ventures that participate in the programs.

Many metrics tangentially address this goal: jobs created, introductions made, partnerships created, pivots and technology development milestones achieved, and others. These early success indicators and de-risking activities attempt to convey the overall viability of the ventures as they work towards profitable enterprise status, and to some degree they achieve this goal. The most ubiquitous metric tallies the amount of money raised by the participating ventures. For two of the more mature programs described below, IN^2 and Cyclotron Road, we report the latest of these metrics at the time of publication.

We also propose a slightly more nuanced metric. By measuring the rate of money raised, both before and after joining a program, we are better able to quantify the goal of acceleration. Using data from IN^2, the incubator housed at NREL, we plot money raised versus time, for both participating and rejected ventures. While it can be argued that the positive correlation between money raised and program acceptance is simply a result of selection bias, the slope change (see Figure 2a) at the time of program entry is strong evidence of causation, at the very least due to signaling and/or publicity, and quantitatively verifies acceleration. Due to the proprietary nature of this data, we were only able to produce this plot for the IN^2 program. While we acknowledge the shortcomings of measuring money raised in general, we find this approach a valuable addition to the repertoire of quantitative metrics of success for innovation organizations.

* Legacy sectors, as defined by Bonvillian and Weiss, are those market sectors in which an established industry already exists, such that market entry by a new innovation is impeded by economic, political, and social paradigms.

Catalogue of Innovation Organizations†

We catalogue the organizations in this report into two general categories: those that primarily provide access to physical resources (laboratories, equipment, research staff) and those that primarily provide access to capital.

Of those that primarily provide access to physical resources, IN² and Cyclotron Road are the most mature innovation organizations in this report. They were both established in 2014.

Wells Fargo Innovation Incubator (IN²): The National Renewable Energy Laboratory (NREL), partnered with the Wells Fargo Foundation (WFF) in 2014 to create the Wells Fargo Innovation Incubator (IN²), a technology-focused initiative that leverages the physical and intellectual resources of NREL to accelerate market acceptance for new energy companies in the commercial buildings space, and in 2017 announced it will expand into agriculture, housing and smart mobility.

Cyclotron Road: Lawrence Berkeley National Laboratory (LBNL), in conjunction with the U.S. Department of Energy (DOE) created Cyclotron Road, an entrepreneurial research fellowship that allows very early-stage hardware innovators the time and resources to de-risk their technologies in order to attract more traditional forms of capital.

The following programs also provide access to physical resources, and were inspired by the successes of IN², Cyclotron Road, or both.

Lab-Embedded Entrepreneurship Programs (LEEP): The DOE Advanced Manufacturing Office (AMO) recently expanded the Cyclotron Road commercialization model to Argonne and Oak Ridge National Laboratories. Named Chain Reaction Innovations and Innovation Crossroads, respectively, the programs together with Cyclotron Road are collectively named Lab-Embedded Entrepreneurship Program (LEEP) nodes.

Shell GameChanger Accelerator Powered by NREL (GCxN): The IN² methodology was recently adopted by the Shell GameChanger Accelerator Powered by NREL (GCxN) accelerator program. NREL will manage the program, and its first cohort is focused on long-duration energy storage and technologies that enable the electricity grid of the future.

Women in Cleantech Challenge: A partnership between the MaRS Discovery District and Natural Resources Canada (Canadian federal government), the Women in Cleantech Challenge provides select women entrepreneurs with financial, technological, and business resources to accelerate their companies' development.

The following programs primarily provide access to capital rather than physical resources. This is an imperfect classification, and the following programs are ordered by the amount of access to physical resources, from most to least.

The Engine by MIT: Spurred in part by the MIT President's call to action, MIT launched its version of an innovation orchard deemed The Engine, a unique venture fund with laboratory space for technological development.

Carbontech Labs: Based at the University of California at Berkeley, Carbontech Labs combines a technology accelerator with an investment fund focused on CO_2-negative technologies.

PRIME Coalition: PRIME pools philanthropic grant money into an early-stage, highly risk-tolerant VC fund that focuses only on technologies with the potential to mitigate gigaton-scale CO_2-equivalent emissions.

Breakthrough Energy Ventures (BEV): This venture fund is noteworthy in its size and fund life ($1 billion initial fund over 20 years), its limited partners including Bill Gates, Jeff Bezos, and several other notable individuals, and its focus only on technologies with the potential to reduce more than half a gigaton of annual CO_2 emissions if deployed at scale.

† The list of programs in this report was compiled based on a series of discussions with various stakeholders, including program directors, investors, and entrepreneurs.

Wells Fargo Innovation Incubator (IN^2)

Introduction

A collaboration between the Wells Fargo Foundation (WFF) and NREL, the IN^2 program leverages the financial capital and market knowledge of WFF combined with the technical expertise and world-class facilities at NREL to help promising startups gain traction in the marketplace. In its very design, the program alleviates the typical disjuncture found between technologists and business managers by pairing a leader of financial services with a leader of renewable energy technologies[22]. It is this strategic public/private partnership that makes IN^2 unique, allowing it to comprehensively accelerate cleantech commercialization.

Program History and Structure

IN^2 was conceived and implemented in a collaboration between the Innovation and Entrepreneurship Center (IEC) at NREL and the WFF and aims to provide market acceptance and market traction for early hardware technology companies. In 2014, the WFF granted the Alliance for Sustainable Energy L.L.C. (the operator of NREL) $10 million over a five-year period to create the IN^2 program. Administered by the IEC, the program began with a technical focus in the commercial buildings space. Based on the success of the model, IN^2 received an additional $20 million from the WFF in 2017, enabling the program to expand its focus and grow its ability to support innovations and partnerships. In 2018, IN^2 announced its expansion into the food-energy-water nexus and a new partnership with the Donald Danforth Plant Science Center in St. Louis, MO to develop, test and validate promising agricultural technologies addressing critical sustainability challenges.

Companies applying to the program must be referred by one of its channel partners (of which there are more than 50, see Figure 2b), ranging from universities to incubators to economic development entities in the United States and Canada. While the channel partners recommend companies to IN^2, IN^2 supports them in return through a $5 million Channel Partner Awards Program. This symbiotic relationship among ecosystem partners is a defining feature of IN^2.

Applicants then enter a series of down-selection rounds, first with NREL technical staff, followed by Wells Fargo executives from across the bank, and finally, to a board of external industry experts for final selections. Companies are awarded up to $250,000 of non-dilutive funding to be used on technical services at NREL or the Donald Danforth Plant Science Center, as well as additional funding to support the company in program-related costs. After being accepted into IN^2, each company is assigned a principal investigator, and together the parties determine the scope of work that will most benefit the technical needs of the company. The funding has been used to pay for a variety of services utilizing the research staff and facilities, including demonstrations at Wells Fargo locations and on the NREL campus, as well as testing and validation of technologies in the various labs at NREL.

Within the technical focus area, IN^2 accepts companies across all levels of maturity, clustering them into Tiers 1-3. Tier 1 companies are classified as bench-scale, with proof of concept but no physical prototype. Tier 2 companies have made a physical prototype that is available for testing and validation. And Tier 3 companies are classified as commercially ready, potentially with pilot-scale production and a small revenue stream. The tiered structure, along with NREL's focus in both basic and applied research, allows IN^2 to incubate technologies across a wide breadth of maturity. It also builds a structure for advancement within the program. For example, a Tier 1 company, upon successful completion of initial milestones, can apply for follow-on funding within IN^2, enabling further technology progress and advancement. Furthermore Tier 3 companies in IN^2 have the opportunity, upon completion of milestones, to pilot their technologies. This real-world field validation provides companies valuable insights regarding end-user experience while serving as an important de-risking signal to prospective customers, investors, and partners.

Hurdles Addressed

When entering an established industry such as commercial buildings components or agriculture, a new technology must work from day one. Working out the shortcomings of a new product based on client feedback is not a possibility in this space. For this reason, industry incumbents are traditionally wary of startups, and seek certainty of product viability before money ever changes hands. Through IN^2, startups gain access to decades of industry-specific know-how and state-of-the-art testing facilities to develop and prove out their technologies. In addition, cohort members benefit from the credibility that NREL (and Danforth) has earned with major industrial partners over decades of working together. Promising technical data taken at NREL gains a trusted seal of approval from an independent third party. These relationships between industry and NREL can then be extended to the startups, helping them to make inroads early on.

"Our design and modeling results weren't questioned by potential industry partners because of the reputation NREL brings to the table."

—Mike Pintar, COO of NETenergy

While the services provided through the IN^2 program vary widely depending on the needs of the company, some examples for how IN^2 companies have used the resources thus far include integrated systems-level modeling and design, trusted third-party technical validation, and field-site demonstrations. IN^2 companies have used the broad skillsets of NREL researchers to refine initial prototypes, integrate proprietary components into market-ready devices, and model system-level return-on-investment based on projected costs. As addressed above, the third-party validation performed by NREL can be vitally important. Similar to how the Food and Drug Administration validates pharmaceutical technologies through clinical trials, positive results from NREL testing sends a powerful market signal to would-be stakeholders. Perhaps most valuably, IN^2 offers the opportunity to commercially demonstrate technologies, moving them beyond lab curiosities to tangible products that add value. These demonstrations have varied from smart electric vehicle charging stations at NREL's National Wind Technology Center to energy-metering sensors at a Wells Fargo branch bank, and act to further reassure traditionally risk-averse customers.

"Through the pilot at the National Wind Technology Center, IN^2 gave us validation and credibility in the difficult, early period of building the company."

—Steve Low, Co-founder and Chairman of the Board, PowerFlex

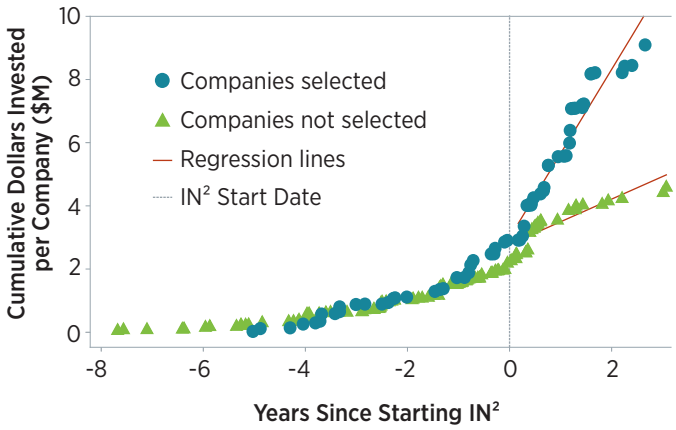
The partnership between NREL and Wells Fargo acts as a key differentiator for the IN^2 program. Because Wells Fargo operates approximately 90 million square feet of commercial real estate globally, accepted companies have already been vetted by a potential future customer. By having this marquee first customer co-administer the program, IN^2 helps open doors into the relevant commercial space from the very beginning. Furthermore, the perspective from Wells Fargo can help shape product development to better address market needs. One example comes from a stick-on energy-metering device company that uses proprietary deconvolution algorithms to save 90% in hardware costs and 75% on installation costs over comparable systems. When this company was determining the most compelling value proposition for their technology, its conversations with Wells Fargo revealed an opportunity to automate the overnight monitoring of essential power systems at bank branches, adding significant value in avoided labor expense. It is this kind of insight, from a commercial buildings operator in partnership with a commercial buildings technology incubator, that makes Wells Fargo's relationship with IN^2 supportive of innovation to commercialization.

As IN^2 expands into agriculture and other sectors, it will expand its network of strategic partners commensurately. Just as Wells Fargo provides insight as a potential customer, as well as an opportunity for real-world demonstrations, IN^2 plans to add analogous industry partners relevant to the new technology focus sectors.

Metrics

- The 20 companies of the first three cohorts have raised over $114 million in outside funding since entering the program (cohort 4 was announced in late 2018 with an additional five companies), amounting to a roughly 19× capital multiplier.
- So far, Tier 1 companies have raised $11 million, Tier 2 companies have raised $57 million, and Tier 3 companies have raised $46 million.
- Companies entering IN² saw a 4.8× increase in dollars-per-year-raised upon entering the program (see Figure 2a).
- Four companies have had mergers or acquisitions since entering IN²: EdgePower, J2 Innovations, SmarterShade, and Whisker Labs.
- Six companies have advanced to the next technical Tier within the program: Maalka, Polyceed, PowerFlex, simuwatt, ThermoLift, and Whisker Labs.
- Five companies have performed β-demonstrations either on NREL campus or at a Wells Fargo branch: Ibis Networks, LiquidCool Solutions, Powerflex Systems, simuwatt, and Whisker Labs.
- The Wells Fargo Foundation expanded funding for IN2 from $10 million to $30 million in 2017, with the intent of expanding the program focus from solely commercial buildings into agriculture, smart mobility and housing.
- Shell emulated the IN² structure in a new partnership with NREL: Shell GameChanger Accelerator Powered by NREL, or GCxN (see below for details).

a. **Rate of Investment in IN² Companies versus IN² Applicants**



b. **IN² Channel Partners**

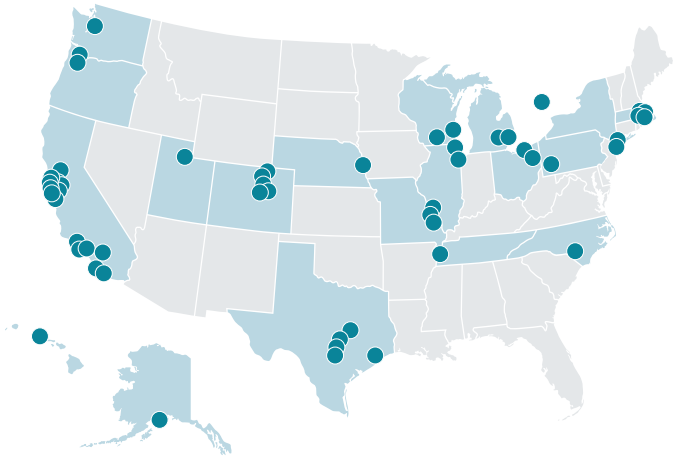


Figure 2: a. Cumulative investments across companies in IN² plotted versus time (blue circle), versus companies that applied to IN² but were not accepted (green triangle), each normalized by the total number of respective companies. To the left of zero shows money raised (either through grants or equity rounds) before the respective company entered (or would have entered) the IN² program. To the right of zero are monies raised after entering. On average a company's rate-of-investments-received increases upon entering the IN² program; slope for non-IN² companies remains relatively constant‡. Fitting linear regressions to IN² companies versus those who were not accepted (for positive values of x) yield slopes of 2.66 and 0.72 $million / company-year, respectively. Companies in IN² raised $550 thousand per year per company before entering IN² on average.

b. IN² channel partners by geographic location

‡ One company from those not selected was removed from the data. This company raised $80M before applying to IN2 (left of zero), and this created a step-wise function for the non-IN² companies. Including this data, however, does not change the slope to the right of zero for companies not selected.

Cyclotron Road

Introduction

Cyclotron Road began in 2014 as an attempt to bridge the divide between proof of principle and reduction to practice for energy hardware technologies[16]. Housed at Lawrence Berkeley National Laboratory (LBNL), Cyclotron Road is designed to provide a path for scientists and engineers from academia to entrepreneurship[23], affording not only technical but also business resources to its cohort members. It is this comprehensive approach to technical company building that makes the program unique.

Program History and Structure

Cyclotron Road was founded in 2014, based on the realization that scientists or engineers interested in translating their scientific breakthroughs into applied technologies did not have a well-defined pathway. The idea to provide these entrepreneurial scientists two-year access to the assets of LBNL was approved by the laboratory directorate, and through a Laboratory Directed Research and Development[§] initiative, the program was born. Six months later the Advanced Manufacturing Office of the Department of Energy (DOE) agreed to support Cyclotron Road. It is now funded collectively by DOE's Advanced Manufacturing Office, the California Energy Commission, the Defense Advanced Research Projects Agency, and a small group of philanthropists, and is currently considering applications for its fifth yearly cohort.

Cyclotron Road has a yearly call for new fellows, and applicants go through a rigorous application process including a series of pitch-formatted interviews and other review processes. Once accepted, fellows are granted access to LBNL and University of California at Berkeley facilities for two years, while receiving a generous stipend, extensive mentorship, entrepreneurial training, and networking opportunities. They are required to locate in Berkeley for the duration of the program in order to take advantage of the laboratory and program resources. The fixed two-year duration is intentional; fellows are expected to use their time at Cyclotron Road to prepare for and source external funding. As several Cyclotron Road fellows have iterated, "Two years is great when you get into Cyclotron Road, but it goes by quick." Because it can easily take five to six years to get from bench to commercial scale, Cyclotron Road provides an initial runway.

Many Cyclotron Road companies incorporate only upon being accepted, and typically do so before entering the program. A specially designed Cooperative Research and Development Agreement (CRADA) allows the founders to either own or co-own any intellectual property (IP) created during the two years. All fellows come from technical research backgrounds, with the majority holding Ph.D.'s; this allows them to either perform the research and technology de-risking themselves or to direct employees they have hired. The Cyclotron Road program team also provides business development support, offering services such as technoeconomic modeling, market entry strategies and market forecasting, as well as myriad introductions to a network of contacts and advisors across the relevant communities. The program is designed as much to be an immersive training for scientific entrepreneurs as it is a hardware technology incubator, and several fellows have referred to their time in Cyclotron Road as a mini-MBA.

Hurdles Addressed

A dearth of financial sources exists to fund prototype development. Federal agencies traditionally view the endeavor as too applied for government funding, while VCs typically want to see a prototype before making an investment. This leaves scientists and engineers who aspire to bring their promising discoveries out of the lab and into the world in a conundrum, and it is this hurdle that Cyclotron Road addresses.

The two-year fellowship attempts to give scientists-turned-entrepreneurs the time, resources and freedom to develop their prototypes, spanning the gap between federal grant dollars and traditional early-stage investment.

> **"Investors wanted a prototype. But without investment we didn't have the resources to build one. It's a chicken and egg problem that Cyclotron Road solves."**
>
> —Kendra Kuhl, Co-founder and CTO, Opus 12

[§] Representing a small portion of a national laboratory's research budget, Laboratory Directed Research and Development initiatives are discretionary funds that allow a laboratory's leadership to fund creative and innovative work in line with the mission of DOE but outside the general scope of the laboratory's current work.

"For me, the community aspect is the strongest resource of Cyclotron Road."

—Chris Kaffer, Co-Founder and CEO of Mallinda

In addition to providing the time and resources needed to overcome this funding gap, Cyclotron Road is designed to build the skills, knowledge, and community that fellows require to become business leaders. Most of the fellows have strong technical backgrounds but little business experience or contacts. Through the program, they participate in quarterly meetings modeled after board meetings, and attend weekly sessions ranging from how to hire the right people to how to write pitch proposals. The program also creates a community of like-minded individuals willing to mentor and share.

The quality of fellows is universal, and those already enjoying success from government grants or VC rounds are eager to share their approaches and lessons learned. In addition to the internal community, Cyclotron Road constantly brings potential investors and partners through the labs—on average over 300 per year, ranging from corporate research and development (R&D) directors to VCs to philanthropists to government program managers—to help ensure cohort teams get well-aligned funding that keep the projects going beyond their tenure at LBNL. This collective training and networking have contributed to the positive outcome that to date, all Cyclotron Road teams remain in business.

Metrics:

- 30 companies have been supported by the program to date, with a majority of these companies being created only after acceptance into Cyclotron Road.
- Over 140 employees are currently employed by Cyclotron Road member companies and alumni (see Figure 3).
- Five out of six companies in the first cohort have raised traditional VC rounds, with the 6th currently funded by a multi-million-dollar DOE demonstration grant.
- Approximately $80 million in follow-on funding has been raised across all cohorts—with roughly half coming from grants and half from equity rounds.
- Around 150 applicants apply for five to ten slots each year.
- The AMO expanded the program in 2016 to two other national laboratories: Chain Reaction Innovations at Argonne and Innovation Crossroads at Oak Ridge.
- In 2017, Cyclotron Road expanded laboratory access to include the University of California at Berkeley.
- In 2019 Activation Energy, the nonprofit affiliate of Cyclotron Road, announced plans to expand the program geographically, beginning with a new program office in Boston focused on Microsystems.

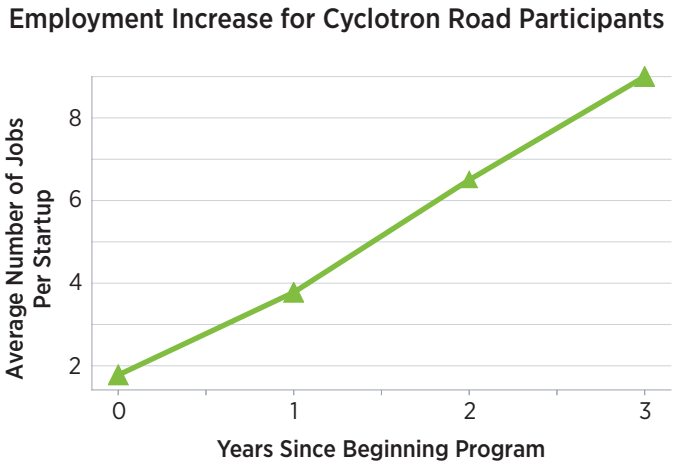


Figure 3: Employment per company has increased steadily for all participating companies thus far. Jobs numbers were calculated based on individual startup websites and interviews with startup founders.

Laboratory-Embedded Entrepreneurship Programs (LEEP)

In 2016, the Advanced Manufacturing Office expanded the Cyclotron Road model to both Oak Ridge and Argonne national laboratories. These new programs, named Innovation Crossroads and Chain Reaction Innovations, respectively, operate very similarly to Cyclotron Road, offering very early-stage energy hardware entrepreneurs a two-year laboratory fellowship to de-risk their technologies while determining a pathway to market. Because the program requires physical presence, the expansion allows the LEEP fellowships greater geographic reach. Indeed, a majority of cohort members from all three programs hail from the regions surrounding the respective labs. In this sense, the LEEP nodes, as they are referred, help to accomplish the long-standing goal of turning the national labs into regional innovation and growth hubs[24], leveraging immense laboratory resources to launch disruptive innovation into local economies.

While all three programs were similarly modeled, they do offer some distinct attributes, mostly a reflection of the local ecosystems. Cyclotron Road and LBNL have strong ties to UC Berkeley. Thus, beyond offering access to UC Berkeley facilities, the program also leans on Berkeley's Haas School of Business for some business development of the Cyclotron Road projects. In particular, the Cleantech-to-Market Program (C2M) at Haas, which tasks M.B.A. and Ph.D. students with developing a pathway to market for nascent technologies, has had several Cyclotron Road companies participate in the program. Due to its proximity to Silicon Valley, Cyclotron Road also attracts many VC investors to tour the program and its companies. Chain Reaction Innovations at Argonne National Lab leans heavily on the Polsky Center for Entrepreneurship and Innovation at the University of Chicago. For instance each Chain Reaction Innovation team participates in the Innovation Corps (I-Corps) program at the Polsky Center and has access to other resources at Polsky, from a legal bootcamp to Small Business Innovation Research (SBIR) consultants. Finally, Innovation Crossroads has formed strong ties with the University of Tennessee (UT) as well as Launch Tennessee, a state-wide entrepreneurial resource center. The UT's Bredesen Center, an interdisciplinary Ph.D. program, sends energy entrepreneurial students through the UT I-Corps program while paired to Innovation Crossroads technologies. Teams at Innovation Crossroads also get *pro bono* legal advice from the UT Law School, and they are also paired with an energy mentor from Launch Tennessee at the start of their fellowship.

The new LEEP nodes are an experiment in and of themselves; only time will tell the success of these programs. Furthermore, the definition of success depends on perspective, and aligning the interests of the various stakeholders will be challenging. For instance, the Advanced Manufacturing Office seeks to seed young startups that will graduate from their residency within the national lab to create domestic manufacturing jobs. The national labs seek fresh ideas and entrepreneurial excitement, as well as new projects and funding opportunities. And according to a senior staff member of one of the LEEP nodes, their goal is to shorten the maturation time to a Series A from as long as seven years down to 18 months, while lowering the capital requirement from $10 million to $1 million all-in.

Shell GameChanger Accelerator Powered by NREL (GCxN)

In 2018, Shell announced it would partner with NREL through the Shell GameChanger program. The resulting program, Shell GameChanger Accelerator Powered by NREL (GCxN) will extend Shell's efforts to reposition itself as the energy company of the future, helping the world decouple energy consumption from carbon dioxide output. GCxN will be administered by the Innovation and Entrepreneurship Center at NREL, the same department that administers the Wells Fargo IN^2 program, with which it will share many attributes.

As in IN^2, companies must be referred to the program by GCxN channel partners, many of whom are shared with IN^2 (see Figure 2b). Selected companies will receive up to $250,000 of non-dilutive funding, to be used on a scope of work agreed upon by both Shell, NREL, and the respective company. GCxN will focus on technologies in Tiers 1 and 2 on the IN^2 development scale, or Technology Readiness Levels 2–5[‖], to focus on high risk, high reward technologies. Initially, NREL will support projects in two technical focus areas: long-duration energy storage and technologies that enable the power grid of the future. The long-duration energy storage call seeks technologies that deliver electricity at less than $0.10 per kWh with preferably more

[‖] Technology Readiness Levels were developed at the National Aeronautics and Space Administration (NASA), in order to systematically judge a technology's level of development or validation for space applications. While real-world technological development does not fit so neatly on a linear scale, TRLs are still useful for quantifying the relative maturity of a technology.

than 16 hours of discharge duration at the rated power. Technologies that fulfill these requirements would allow intermittent renewables to perform more like baseload sources for the majority of use cases; however by some estimates, upwards of 200 hours of storage capacity at the rated power will be needed to store enough excess generation without curtailment, while having enough energy to deploy during production lulls (see Figure 4). Even at 16 hours, these requirements preclude ubiquitous battery chemistries such as lithium ion. Technologies that fall within the "grid of the future" call will provide services required to manage the increasingly complex electricity grid as our energy system evolves. Increasing penetration of renewable generation and the proliferation of batteries and electrification (of transportation and heating for example) will create the need for real-time optimization controls, highly-accurate weather forecasting, and related technologies to effectively manage a safe, reliable electricity grid. These two initial technology areas are potentially the first of many that will be housed at GCxN, and highlight the unique synergies between Shell's vision for the future of energy[25,26] and the unique capabilities of NREL.

Women in Cleantech Challenge

Funded by the Canadian Government's Department of Natural Resources (NRCan), and supported by the MaRS Discovery District, an urban innovation hub based in Toronto, the Women in Cleantech Challenge is an entrepreneurial support program and C$1 million prize competition. Six women entrepreneurs in cleantech have been selected as finalists, and after 30 months of support, a winner will be selected in the winter of 2020/21.

In 2017, representatives from MaRS's cleantech program pooled together best practices collected on several entrepreneurial program visits, including to IN[2] and Cyclotron Road. Combined with the Canadian Government's initiatives in creating cleantech grand challenges and in bringing more women into STEM (science, technology, engineering and math) fields, MaRS and NRCan started the Women in Cleantech Challenge with an open call to female entrepreneurs in Canada. From over 150 applicants, ten semi-finalists were selected to pitch their ideas in front of a panel of experts. From that ten, six finalists were selected to join the program. These six women are receiving a C$115,000 annual stipend for 30 months, along with extensive technical and business development support. The technical development will come from Canada's national laboratories. Each entrepreneur will be paired with a relevant lab scientist and will receive up to C$250,000 in technical assistance, a model which closely mirrors that

Increased Renewable Use Will Require Massive Storage Capacity

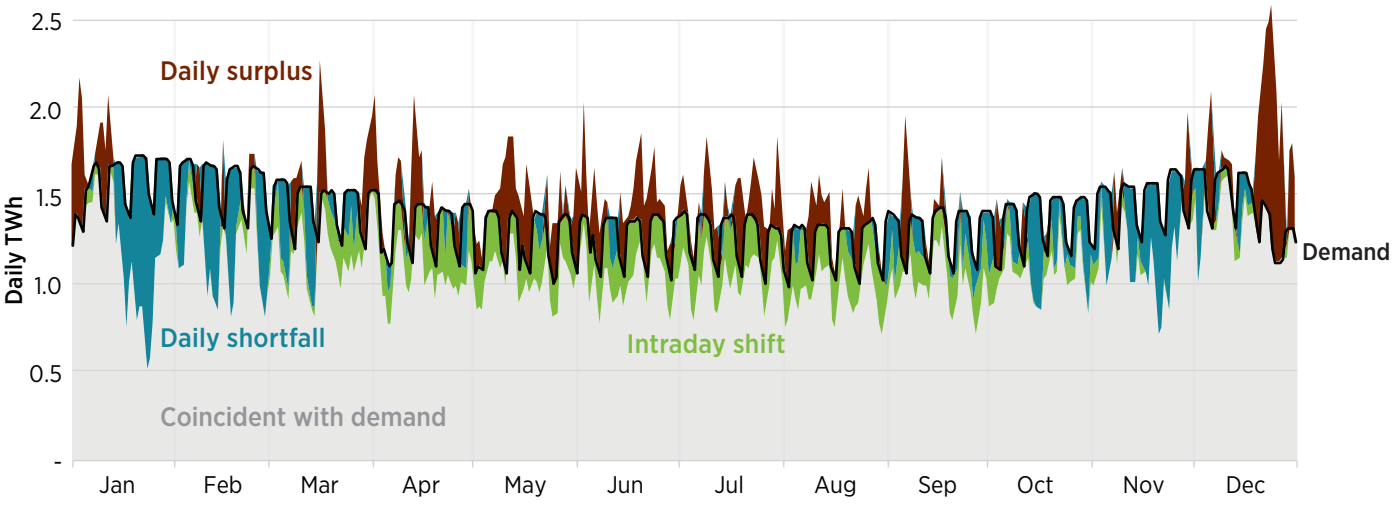


Figure 4: The Shell GCxN program is focused on storage because power use in Germany (which has heavy renewable buildout) shows the need for significant energy storage. Demand (black) is plotted against renewable generation, showing a production shortfall (blue) that can be met with intraday shifting from storage (green). (Reproduced with permission from Pierpont et al.[27])

of IN[2]. In tandem, the MaRS Discovery District will provide venture services in the form of "market intelligence, talent, communications and educational support"[28]. At the end of the 30 months, the six finalists will again make their pitches to the panel of judges. Because the finalists are starting from very different levels of technical maturity spanning Technology Readiness Levels 2–5, companies will be judged on their progress during the program, both in terms of quarterly metrics as well as a final determination by the judging panel. The winner will receive an additional C$1 million to further accelerate her company's growth.

The Women in Cleantech Challenge is currently planning to extend the model to other underrepresented groups. Applying the best practices from a variety of innovation organizations to female entrepreneurs, who are traditionally underserved in the community[29], NRCAN and MaRS aim to not only catalyze cleantech innovation, but create a more equitable ecosystem in the process.

The Engine by MIT

As stated above, in 2015 Rafael Reif, President of MIT, encouraged the formation of "innovation orchards" to "accelerate… idea to investment" for science innovators[15]. The Engine was MIT's realization of Reif's concept. Launched in 2016, The Engine takes a hybrid approach to commercializing what it deems "Tough Tech", combining a long-term venture fund with access to well-equipped labs and entrepreneurial guidance. The Engine aims to provide an example for how universities with powerhouse research facilities can turn those bench ideas into groundbreaking innovations that benefit society.

Started by MIT, The Engine now exists as an independent, for-profit venture capital firm that invests in early-stage Tough Tech companies in the Boston area. The Engine Fund, the primary vehicle to serve this purpose, is a $200 million investment fund, to which MIT contributed $25 million. With an 18-year fund life, the fund provides patient seed-stage capital in exchange for an equity stake in the company to ventures that hold potentially prohibitive technical risk for the traditional investor[30]. While startup companies do not need to have an affiliation with MIT in order to participate, as of early 2019, 12 of the 16 companies do have an affiliation, with the remaining four coming from Harvard University, MIT's neighbor in Cambridge. The Engine does require companies to locate in Boston if they are to accept funding, an attempt to strengthen the local innovation ecosystem and ensure that they take full advantage of the programmatic offerings beyond financial capital.

The Engine is somewhat unique as a venture capital firm, combining not only an investment fund but physical office and lab space, facilities partnerships, and entrepreneurial mentorship as well. Its headquarters include both office and lab space in Cambridge, which portfolio companies (and non-portfolio companies) can rent for as long as they need. Thus far companies typically reside for one to two years before outgrowing the space. Several facilities in and around the Boston area also have agreements with The Engine to provide portfolio companies access to specialized equipment, including The Broad Institute, the Department of Defense's MIT Lincoln Laboratory, and several research institutes within MIT. The Engine also provides tailored professional development and business services for its portfolio companies. Investments at The Engine are made on a rolling basis, a condition that restricts the uniformity of these ancillary services but according to Engine staff is meant to allow for a more hands-on, tailored approach to best address the development needs of the founders.

With its longer fund life than the typical VC firm, The Engine is designed to provide patient capital that lacks technical-risk aversion, allowing founders the time to tackle the key development hurdles facing their technologies while spanning the gap between government grants and traditional venture capital. Further, the concentration of ready-to-use resources with the injection of meaningful capital early on allow the founders to accelerate their development times by going all-in on their technologies, without having to worry about converting warehouse space into a scientific development lab.

> **"Without the resources that The Engine provided, the technical progress we achieved in 14 months would have taken five years."**
>
> —Shreya Dave, CEO at Via Separations

Beyond affording the means and freedom for technical development, The Engine seeks to ensure that the technical founders successfully navigate the entrepreneurial process. Some portfolio companies have founders who are experienced entrepreneurs. For others, The Engine will run workshops with invited experts to target the needs of the specific companies, from hiring decisions to managing capital expenditure. The requirement that startups are physically located in Boston allows valuable interactions

with The Engine staff, fellow founders, as well as curated visitors like potential investors or corporate partners. The visibility and connectivity are designed to ensure that portfolio companies seamlessly transition beyond The Engine as they grow.

Less than two years after starting up, the companies funded by The Engine are already seeing some early success. An initial investment in a nuclear fusion company utilizing high-temperature superconductors just closed a Series A with outside investors[31]. An energy storage MIT-spinout aiming for name-plate durations in the thousands of hours also recently closed its Series A[32]. A quantum computing software company partnered with Google[33]. And a startup focused on space data has launched its first satellite[34].

Carbontech Labs

Recognizing that the world will not be able to achieve climate change targets merely by reducing emissions, Carbon180, formerly the Center for Carbon Removal, focuses on technologies that can remove CO_2 from the atmosphere. Carbon180 strives to achieve meaningful market penetration by convening key stakeholders, advocating market-based policy, and running a technology accelerator focused on carbon-negative technologies, known as Carbontech Labs. Potential technologies in the accelerator could do many things: remove CO_2 from the atmosphere; convert captured CO_2 into value-added products such as plastics, building materials, fuels, pharmaceuticals, or anything else involving carbon atoms; utilize biomass as an input into product streams; design new systems to increase the carbon sequestration processes in farming practices; and likely many others. The accelerator pools best practices from several disparate programs, focusing them on carbon technologies, or carbontech.

The program at Carbontech Labs is broken into three phases, with a progressively-narrowing filter at each phase. The first phase mirrors the regiment of National Science Foundation I-Corps in many ways. Approximately 20 companies in this phase are granted $40,000 to define their value propositions, perform customer-discovery interviews, and refine their paths to market. In addition, each of these startups are expected to perform life-cycle and techno-economic analyses of their technologies, prepare a ten-page white paper ready for potential investors, and have their technology assessed by Carbontech Labs staff. The investor advisory network at Carbontech Labs then chooses eight Phase-One companies to bring to Phase Two. These eight companies receive between $200,000 and $600,000 of equity investment from the Carbontech Impact Fund to build a physical prototype. If need be, Carbontech Labs will help Phase Two companies gain access to a lab from one of their partners in the New Carbon Economy Consortium, a collection of universities and national laboratories across the United States. Upon completion of Phase two, startups can receive additional equity funding from the Carbontech Fund, or source capital from other investors, including potentially with the partners of Carbontech Labs. Several demonstration sites offer Phase Three companies the opportunity to build pilot demonstrations of their technologies. Thus far these sites include the Wyoming Integrated Test Center for carbon capture technologies, as well as two sites for testing farmland, rangeland, and biomass conversion practices and technologies.

Carbontech Labs attempts to compile the best incubation practices across all levels of company maturity and focus them onto a single technological focus. In doing so, they are creating a one-stop shop for startups to determine their business plans and mature into presentable enterprises, source funds and laboratories to build working prototypes, and partner with real-world test sites in deploying demonstrations. At the same time, through their focus on this one (albeit broad) technology area, Carbontech Labs can also curate a more relevant network of investors, foundations, large corporations and others interested in carbon-negative technologies for its startups. These ventures will gain both exposure and recognition within this network, further strengthening the merit of the program.

PRIME Coalition

PRIME Coalition mobilizes philanthropic dollars to de-risk early-stage companies addressing climate change. As stated above, there is a tremendous gap in funding between scientific research and commercial technological development, especially for hardware-based technologies. Using vehicles such as recoverable grants and program-related investments (PRIs), the goal of PRIME is to help fill that gap. PRIME acts as a non-profit investment syndicate for philanthropic organizations, identifying companies and technologies with tremendous potential to mitigate greenhouse gas emissions while pooling charitable asset owners to support them.

Private foundations governed by the U.S. federal tax code must give away 5% of their assets annually, and historically these have been made as grants to nonprofit causes with no financial return. While the other 95% (the endowment)

is sometimes invested in socially-impactful assets, fiduciaries generally attempt to preserve the social mission of the foundation in perpetuity, and therefore prioritize financial returns over social impact when investing the endowment. Program-related investments (PRIs) allow foundations to make disbursements that count towards the 5% in grants, but can be structured as equity or debt to nonprofit or for-profit entities[35]. PRIs must meet three criteria in order to be lawful, according to the U.S. Internal Revenue Service[36]:

1. The primary purpose is to accomplish one or more of the foundation's exempt purposes,
2. Production of income or appreciation of property is not a significant purpose, and
3. Influencing legislation or taking part in political campaigns on behalf of candidates is not a purpose.

With U.S. foundations giving away more than $60 billion in grants annually[37], PRIs have the potential to fund high-risk but transformative innovations both patiently and substantially. However, a list of hurdles makes charitable investing to science and engineering innovation prohibitively difficult for private foundations, and as a result, very few use PRIs to advance energy hardware innovation. PRIME Coalition acts to lower these educational, operational, and perceived regulatory barriers.

PRIME taps a team of internal and external investment experts to vet portfolio companies based on three criteria: the potential to reduce gigaton-scale CO_2 equivalent emissions, significant commercial promise that would bring them to scale, and fitness for charitable capital (i.e. an inability to raise sufficient financial support without philanthropic intervention). From 2014-2018, PRIME vetted promising startup companies and showcased them to prospective philanthropists: foundations, donor-advised funds, individuals, family offices and trusts. Since the end of 2018, PRIME has also led financing rounds via the PRIME Impact Fund, a seed fund with pooled resources from philanthropists, investing in companies that fit the criteria listed above.

Because of the rules of charitability, PRIME must invest in transformative companies with significant technical risk. This early capital injection enables technical proofs of concept in order to bring the risk profile in line with more traditional follow-on investments. From the standpoint of foundations, its grant dollars can not only "accomplish [their] exempt purposes" by bringing transformative clean energy technologies into the world, but also have the potential to earn returns, multiplying the reach of the initial grant. From the standpoint of the startup, it now has access to significant flexible capital to validate the key proof-points necessary for later commercial investment rounds.

> **"The VCs understood the concept, but wanted to see more technological de-risking. PRIME funding bridged this gap, so that we could go into the field and demonstrate key elements of our technology in order to raise the Series A."**
>
> —Startup founder supported by PRIME

Since 2015, PRIME Coalition has mobilized $48.8 million and supported eleven companies, ranging from grid-scale energy storage to electric airplanes to cradle-to-cradle composite materials. These investments have helped companies build prototypes, fund pilot demonstrations, obtain grants from the Advanced Research Projects Agency - Energy and/or raise follow-on rounds of capital. While it is clearly too early to fully evaluate the success of PRIME's model, the quality and potential impact of the 11 companies thus far, along with the immense pool of untapped grant dollars, add up to a promising idea.

Breakthrough Energy Ventures

In late 2015, on the eve of the United Nations Climate Change Conference in Paris, Bill Gates spurred a collaboration called the Breakthrough Energy Coalition focused on supporting new technologies to prevent the impacts of climate change. The collaboration includes several corporations, as well as 30 of the richest and most influential people in the world, including Jeff Bezos, Richard Branson, and Michael Bloomberg. Breakthrough Energy Ventures (BEV) was created as an offshoot of the Coalition, in order to inject patient capital into the technologies needed to address climate change.

BEV is unique from other VC firms in several ways. The LPs consist of a majority of the individuals in the Coalition, allowing BEV to be set up like a family office. The fund life is 20 years, with $1 billion of initial capital. The added time horizon over a typical VC fund allows BEV to invest in transformational technologies still in their nascency, while the size of the fund allows BEV to place many bets across various sectors and levels of development. Breakthrough

Energy has laid out five grand challenges that together capture nearly all sources of greenhouse gas: electricity, transportation, agriculture, manufacturing, and buildings—and will only invest in those technologies which have the potential to reduce global GHG emissions by at least half a gigaton of CO_2-equivalent. They have assembled a team of 26 people to run the fund, consisting of prominent scientists, entrepreneurs and industry experts, among them one Nobel Laureate and one National Medal of Science Laureate. BEV is willing to span very-early seed to late-stage scale-up, and typically takes one board seat in its investment companies.

BEV, as with many venture firms, is quite secretive about its deal-flow and process. It has announced investments in fourteen startup companies, spanning technologies from nuclear fusion to CO_2-light concrete, several of which tackle various forms of energy storage. It is unclear how much of the $1 billion fund they have invested so far, but they likely have a large portion still untapped. Again, only time will tell if BEV is successful—that success hinges on its ability to quickly transform disruptive innovations into global companies that will simultaneously reduce greenhouse gas emissions and earn handsome profits in order to scale.

Discussion and Conclusion

Based on the research performed for this report, we briefly provide some areas in which these and other organizations could further improve the innovation pathway for energy hardware technologies.

Strengthen the Entire Ecosystem

The path from invention to diffusion in energy and related markets is both challenging and long. The programs and institutions described above contribute vital functions in this energy technology innovation ecosystem, and as in any ecosystem, the various components allow the system as a whole to function. Some effort has been expended to connect the components, and yet they still exist largely as silos, both geographically and functionally. These connections need to become stronger, such that any individual entrepreneur can benefit from the suite of capabilities across the ecosystem. It should be recognized that this is not a zero-sum game, and that creating a stronger ecosystem benefits all parties.

Certain ecosystem functions deserve more attention. For instance, many early-stage innovators do not consider the manufacturing processes by which their products will be made. Several innovation centers are designed to focus on this, such as mHUB in Chicago. Not only do they provide physical resources to test manufacturing processes, but these centers also partner with outside corporations to gain expert insights as well as foster connections with future customers. These relationships with the market players who are already at scale, similar to those relationships that IN^2 and GCxN have with Wells Fargo and Shell respectively, allow startups to scale more rapidly.

Market demand presents another key component to this ecosystem that is sometimes institutionally suppressed. Part of the difficulty in bringing disruptive innovation to legacy sectors such as energy lies in the magnitude of the incumbents[12], the inertia against change, and risk-aversion in general. Some programs are beginning to add divisions focused on policy solutions to encourage market movement. For instance, Imagine H_2O, a water technology accelerator, recently partnered with the Milken Institute in California to launch a water policy accelerator[38].

Designed to encourage market-based water technology adoption, the Water Innovation Policy Program convenes stakeholders within the policy and research communities to develop solutions that enable innovations to penetrate markets organically. While this program is focused on water, the structure is generalizable to technologies across the legacy sectors.

Embrace the Rejected

Ryan Kushner, author of *Accelerate This*[39], and others[12,40] advocate that programs should also consider methods to highlight deserving applicants who did not receive awards, in order to strengthen and preserve goodwill in the community. For instance, Y-Combinator maintains a discussion board where everyone in the community (including rejected applicants) can post ideas, and the Advanced Research Projects Agency—Energy allows top applicants who did not receive an award a booth at its annual summit. These offerings provide the opportunity for rejected applicants to learn from their mistakes, in order to succeed in follow-on attempts. Many high-quality ventures will initially be rejected. By providing some amount of consolation prize, programs can build a community of advocates broader than its awardees, and further strengthen the ecosystems in which they work.

Conclusion

Each of these programs offers a targeted approach to addressing the challenges on the road from scientific invention to market disruption. Rather than competing with one another, these approaches are complementary; a single startup company could benefit from Cyclotron Road, followed by IN^2, with investments from PRIME and Breakthrough Energy Ventures. Also, this list is by no means sufficient or comprehensive. These and many other organizations are needed to enable the coming energy transformation, combining the best attributes of the programs above as well as entirely new approaches.

Through innovation, the world's energy system and by extension nearly every sector of the economy will see dramatic change in the 21st century. The organizations and programs described in this paper are designed to fill the existing gaps that prevent entrepreneurs from commercializing disruptive technologies. The early results are promising and exciting, but they are just the beginning.

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