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"Innovation Orchards": Helping Tech Start-Ups Scale

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EXECUTIVE SUMMARY

Federal support for R&D has fallen precipitously in recent years as a share of gross domestic product (GDP), and because of this, the United States risks slipping significantly as a global innovation competitor. More federal investment is needed to avoid falling behind. But it will be difficult to find political support for more funding, since Democrats are reluctant to reduce entitlement spending, and Republicans want to cut budgets, including science budgets. So America will likely be forced to make the best out of a bad situation. One way to do that is to focus more effectively on spurring innovation commercialization—and one emerging idea is the creation of "innovation orchards."

MIT President Rafael Reif coined the term "innovation orchard" in 2015, proposing a new mechanism to address a growing gap in the U.S. innovation system.[1] An "orchard" would bring together university, industry, and potentially government partners to create a space that provides start-ups with the know-how, access to technology, equipment, and bridge funding to scale up their new technologies. With existing gaps in innovation financing, the aim is to leverage strengths in a region's innovation system to help start-ups develop advanced prototypes, then demonstrate, test, and bring them to the manufacturing stage. In effect, the orchard would substitute space for capital.

Even with its decline, federal support for research at universities does continue to help create many new innovative technologies. New business start-ups have played a crucial role in translating innovative technologies into market-ready products, often with strong support from venture capital. The venture-capital system rose to prominence during the information-technology revolution, supporting computing and semiconductors, and has played a pivotal role in the U.S. innovation system for decades. Innovative start-ups, financed with venture funding, became a backbone of the U.S. economy during the second half of the 20th century. Some of the most successful firms to come out of this model, backed by early venture funding, include Apple, Microsoft, Genentech, and Google. However, starting in the second half of the 1990s, venture capital became more and more sector specific, coalescing around software and biotechnology, and in 2015 those two sectors received 53 percent of U.S. venture financing.

Venture capital has developed two different but successful models that have fostered the software and biotechnology sectors. Software start-ups have low initial costs, require minimal capital equipment, typically require a short period of time for development, and face low barriers to scaling online. This means software start-ups have the potential for very high profits on a smaller investment, though they are still high risk. Biotechnology differs from software in that the time to market tends to exceed a decade, and needed investments are substantially larger than those in software. However, the Food and Drug Administration approval process provides risk benchmarks for investment as a drug advances through the three phases of clinical trials. If a drug receives approval, its patent grants a short-term monopoly that is, in essence, assured by the FDA certification, enabling the high development costs to be recouped.

"Hard" technologies—in areas such as clean energy, materials, robotics, equipment, and others—that require long-term development, significant capital costs, and high risk, fall somewhere in between software and biotech and lack a well-defined venture-capital model. Start-up costs are much higher than for software, with a longer time to market, and they lack the FDA product certification and patent monopoly protections available to biotech. From 2006 to 2011, venture capital began investing heavily in the hard technology for new energy. A variety of factors made the sector appear promising for investment: high oil prices, growing environmental awareness, and an economy that had seen sustained growth in the years after the dot-com bubble. The onset of the recession proved damaging for cleantech; within a year, the price of oil had fallen by more than half, and Chinese government-subsidized low-cost solar panels flooded the market. Venture firms suffered major losses as a result and have largely withdrawn from the sector since. Other "hard" technologies face comparable challenges.

An ongoing effort to address these shortcomings has led to the creation of a number of new programs. Technology incubators and accelerators have been founded in a number of regions. Most cater to software start-ups, but a growing number are now focusing on start-ups developing hard technologies. However, most only have the resources to help with the early-development stages: low-cost office space, developing business plans, and first prototypes.

To fill this gap and focus on later-stage support, some new programs have emerged. Cyclotron Road, which is supported by the Department of Energy and its Lawrence Berkeley Lab, is one example. It offers newly-formed energy-technology groups advanced equipment, technology, and know-how to take on the technology-development stages of advanced prototyping, demonstration, testing, and production design. TechBridge, a program of the Boston branch of the Fraunhofer Institute organization—a nonprofit applied-research and development laboratory—links established start-ups with established firm partners for collaboration on late-stage development, with extensive lab support for new technology and product validation. It helps to certify new technologies through industry-driven validation and demonstration projects that Fraunhofer performs, rather than through the innovators themselves, as in the case of Cyclotron Road.

MIT's The Engine is another entrant that performs a similar "innovation orchard" role. The Engine builds on MIT's interest in bringing together technology start-ups, large companies, biopharma companies, federal labs, local incubators, and small- and medium-sized manufacturers in the region. It aims to fill a critical emerging gap in the innovation system, offering space, technology, and know-how as a substitute for initial financing, then de-risking and accelerating new technologies, so they can come into range of existing financing. The Engine will be regionally based but offer a new model for other universities and other regions interested in bridging this innovation gap. An experiment between the Massachusetts Manufacturing Extension Partnership and an area incubator, Greentown Labs, adds another element: creating collaborations between small area manufacturers and start-ups for production prototypes and pilot production.

Cyclotron Road, TechBridge, The Engine, and MassMEP-Greentown, then, all aim at helping start-ups commercialize their technology through new approaches to technology support. These and other innovation-orchard approaches aim to fill a growing gap in the U.S. innovation system, the start-up scale-up gap. As such, federal and state government programs should recognize the potential benefits of such efforts and more actively support their replication across the nation.

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FILLING GAPS IN EARLY-STAGE FINANCING AND SUPPORT

The U.S. innovation system is responsible for a wide range of technological wonders that are part of our daily routines. A combination of public and private investment in higher education and scientific research is the backbone of the U.S. innovation system. However, a large number of innovations based on new science or that require new production processes outside of the digital arena have not received adequate financial support. A gap for these non-digital technologies has formed between venture capital and earlier-stage government financing for R&D. Between the 1960s and 1990s, large companies with internal R&D shops helped fill that gap, perhaps most visibly in the rapid advancements in computing. But that era of massive industrial R&D labs is largely over. Large firms have cut back on their role, not only in basic research, but also in scaling up new technologies, and we haven't filled the gap. Moreover, venture capital is not structured to meet the challenge of advancing a wide range of technologies from new ideas to products that can be produced on a large scale. That is why many of the innovations of today, including those with IPOs, simply do not appear as important and transformational as innovations of the 1980s and 1990s.

The model aims to strengthen the innovation system around entrepreneurs and their start-up companies, to get a broader base of job-creating new firms underway and headed for success in regional economies.

A new approach, which MIT President Rafael Reif has called innovation orchards, is needed. These orchards would join the public, for-profit and not-for-profit sectors, to provide physical space, technology and equipment, mentoring, and bridge funding for new technology-oriented companies. This new kind of space would offer a system to help innovators develop advanced prototypes and de-risk their technologies, moving innovations through to a stage where venture capital or company partners could begin to play a role. This technology-rich innovation environment could also reduce the time to market by significantly advancing the technology. The aim is to create a more robust system where important innovations don't fall through the cracks.

The new model seeks to ally the public and private sectors to combine ingredients of know-how, technology access, and equipment for start-ups to help them scale up their products toward manufacturing and market entry. These nodes could link to other institutions that can provide secondary nodes, with particular technology expertise, to help the start-ups scale. These could include regional companies, consortia, and federal labs. Overall, the model aims to strengthen the innovation system around entrepreneurs and their start-up companies, to get a broader base of job-creating new firms underway and headed for success in our regional economy. The goal is to create a new model that is replicable.

This paper attempts to show that there is a real innovation gap that the country could benefit by filling. It looks at the state of funding, particularly venture funding, for start-ups trying to develop science-based innovations; at similar models that are now being tried to get over these barriers; and at ways to link small area manufacturers with the new generation of start-ups.

The federal government has been the main supporter of basic research for the last seven decades. The technologies that have grown out of this research have become indispensable to our daily lives, from the Internet to GPS.[2] But that support is falling as the federal government focuses largely on transfer payments to individuals, with programs like Medicare and Social Security continuing to grow. Declining federal support for research makes it critical to find more effective ways to translate this research into new technologies. The process tends to break down for innovations that are scientifically complex, requiring a longer timeframe to develop proof of concept and proof of product, and that require advanced manufacturing to scale up. These types of innovation rarely come to fruition under the current system. The failure to push toward this frontier in non-digital areas will mean much slower rates of innovation, productivity, and lower levels of U.S. competitiveness and job creation.

The process of taking an idea and turning it into a commercially viable product is no easy task. Basic research often creates the seedlings where new innovations take root. As the research becomes more applied, it moves out of the lab and into the private sector, though the transition typically requires outside financing. For some newly formed companies, assistance is available in the form of Small Business Innovation Research (SBIR) grants through federal R&D agencies, regional programs such as the Maryland Innovation Initiative and MassDevelopment Manufacturing Innovation Grants, or seed funding from family, friends, or angel investors. If the start-up company is able to create a prototype that is demonstrated to work using these funds, a larger source of financing may be provided by venture capital. Companies tend to rely on venture capital to support them through the final stages of product development and manufacturing before reaching the market.

This venture capital-driven model coalesced during the IT revolution of the 1970s and 1980s with remarkable success. Although early investments were in "hard" technologies, such as semiconductors and computing, the venture system's most visible successes today can be seen in the rapid innovation in software applications and in new pharmaceutical and biotechnology products.[3] Innovations that can't move from idea to market in just a few years, or lack the potential for the type of intellectual-property protection new drugs enjoy, face a much more challenging road. The capital costs and risks are even higher when development pathways are unfamiliar and manufacturing processes are new. Venture firms have become less and less willing to take on these costs and risks. Strategic industry partners offer a path for some technologies, but they typically require proof of product before investing, and the proposed new product generally needs to fit their existing business model. A gap then persists for science-based innovations with longer-term development requirements that represent new and unique advances, as opposed to incremental ones, and that are in more manufacturing-intensive sectors.

We need new models to help commercialize a wide array of technologies. One model to overcome this financing gap is the innovation orchard, exemplified by a number of public-private partnerships that have formed to support innovators as they begin applied research and work through product demonstration. For example, Cyclotron Road, Chain Reaction Innovations, and Innovation Crossroads are partnerships with the Department of Energy that allow start-up innovators to access technologies and expertise at Lawrence Berkeley, Argonne, and Oak Ridge National laboratories, respectively, to take advantage of the facilities and expertise. TechBridge in Boston connects larger companies with start-ups, offering a supporting technology-validation process to help de-risk the start-ups' potential products. MIT is now experimenting with another model, The Engine. Greentown Labs has partnered with the Massachusetts Manufacturing Extension Partnership (MassMEP) to aid in the scale-up process toward production, linking start-ups with small manufacturing firms. The concept of innovation orchards embraces these kinds of programs to supply assistance with not only product demonstration and validation but also the full range of resources and expertise necessary for innovations to make it to market.

THE DECLINE OF VENTURE FINANCING IN "HARD" TECHNOLOGY SECTORS

Historically high levels of federal support for basic research made the United States a world leader in innovation from the 1960s to the 2000s. But since then, this support has fallen behind many nations, at least as a share of GDP.[4] For more than half a century, economists have widely accepted that economic growth depends on a steady stream of innovations making it to market.[5] Commercializing innovations derived from basic research is a well-known challenge. For over two decades, this problem has been known as the "Valley of Death." While a range of investors provide funding to firms as they move toward commercialization, large gaps still exist for most start-ups. Technology at a very early stage carries a tremendous amount of risk. Ideally, an efficient market should still provide funding for many more of these start-ups, but the reality is that the uncertainty surrounding these new technologies has led potential investors to underinvest.[6] The continuous stream of new products and occasional breakthroughs during the IT revolution has led to a widespread belief that entrepreneurship is now just an inherent and pervasive feature of the U.S economy.[7] But it turns out to not be pervasive in most technology areas. This mistaken belief meant that for years the shortcomings in the U.S. innovation system were overlooked. The number of start-ups that never have an opportunity to bring their technologies to market dwarfs the number that succeed in the current system.[8]

Commercializing innovations derived from basic research is a well-known challenge. For over two decades, this problem has been known as the "Valley of Death."

The Status of "Growth" and "Quality" Entrepreneurship

Merely quantifying the number of new innovations that make it through the "Valley of Death" is a challenge. Organizations such as the Kauffmann Foundation tend to focus on small-business start-ups in general, which have been in modest decline for some years. Analysis that doesn't distinguish between types of entrepreneurs, however, can lead to the anomalous grouping of new "Mom and Pop" corner stores with biotech start-ups. Within the last few years, this has started to change, as academics have begun creating new indices to focus more explicitly on innovative, technology-based firms, which have much greater potential to scale up and grow than, say, a neighborhood dry cleaner. Starting in 2016, the Kauffman Foundation added "growth entrepreneurship" to its annual index. This new Kauffman index incorporates the rate of start-up growth, the share of scale-ups in the start-up mix (the percent of firms that have grown to employ more than 50 people in the first 10 years), and high-growth company density, to better measure trends in *growth* entrepreneurship in the United States.

Kauffman's growth-entrepreneurship index shows a deep decline from 2009 to 2013, a consequence of the Great Recession, but it is now close to the pre-financial crisis level.[9] However, nearly half of the high-growth firms fall into one of five industries: software, health, IT services, advertising and marketing, and business products and services.[10]

At MIT, Jorge Guzman and Scott Stern have worked in recent years to develop three new indices, the Entrepreneurial Quality Index, the Regional Entrepreneurship Cohort Potential Index, and the Regional Entrepreneurship Acceleration Index. These indices measure the quality level of firms within a cohort, the growth potential in a specific region, and their performance over time. Their research looked at data from 15 states totaling 51 percent of U.S. GDP and focused on a number of characteristics, including the legal structure and firm name, as well as any intellectual property held by the firm.[11] This analysis aimed to identify the innovative, technology-based firms with higher growth potential—"high-quality" firms. They found that after the dot-com bubble in 2001, growth potential for high-quality firms declined, which lasted throughout the 2000s. This reversed starting in 2010, and 2014—the last year included in the study—had the third-highest level of entrepreneurial growth potential in the last quarter-century. While the growth potential for high-quality firms is strong, the likelihood that these firms realize their potential fell starting in the late 1990s and only started improving slightly in 2009, the most recent year data is available for.[12] They found this to be a strong indication that the United States is still creating innovative start-ups, but that there is a failure for their associated technologies to make it to market. This is an important finding.

Sectors With Venture Support: Software and Biotech

During the last two decades, the software and biotech sectors have performed well, driven by widespread innovation. As discussed below, it seems start-ups in these sectors, particularly software, are more likely to succeed than start-ups that attempt to innovate in other areas. However, one would be hard pressed to say those two fields are substantially more capable of innovation than the other fields with lower scale-up success rates.[13] A better explanation is that over the last two decades, these two sectors have been unique in their ability to attract an increase in financing while others haven't.

The largest sources of financing for most start-ups in the United States are personal savings and credit, and investments from family and friends. While 38 percent of start-ups receive investments from people close to the entrepreneur—friends and family—the average amount invested is only $23,000. While this may be sufficient for some small businesses, it falls far short of the investment needed for a start-up to develop a new technology requiring a new manufacturing process. For these more capital-intensive start-ups, there are far fewer options. Bank loans backed by the Small Business Administration (SBA)—a standard resource for small firms—average only $143,899; this is in comparison to the average investment from venture capital of $5.94 million.[14] Part of the reason venture capital has played an outsized role in the funding of young firms is that with few or no assets, debt financing is not an option, leaving equity financing as one of the best options available.

This suggests that trends in venture capital play an oversized role in shaping the direction of innovation in the U.S. economy.

Venture capital hasn't been a panacea for all start-ups. One trend that stands out vividly in the venture-capital investment numbers is the increasing concentration of investment in the biotech and software sectors. In 1995, 61 percent of all first sequence funding—that is, new, as opposed to continuing VC investments—went to five industrial sectors. This jumped to 79 percent in 2015. The top two sectors in those years—software and biotech—saw their combined share jump from 33 percent in 1995 to 53 percent in 2015.[15] These numbers are also reflected in the broad economic shifts of the last two decades. Venture capital is often procyclical, as can be seen by investment patterns during the dot-com boom in the late 1990s and the most recent uptick in the software sector. On the other hand, the health-care sector has grown rapidly due to rising costs and an aging population, which may explain the increasing investments in the sector by venture capital. However, broad economic and demographic shifts are not enough to explain the allocation of venture-capital investments. A number of sector-specific traits have helped software companies and biotech firms gain a greater share of venture capital.

The Software Story

No other sector is as tied to venture capital as software. The software sector receives far and away the greatest share of investment from venture capital (VC) each year, with most of that centered on Silicon Valley. In 2015, 612 software start-ups received their first VC investment, compared with 122 biotech start-ups.[16] Software apps don't require expensive and sophisticated labs, and major equipment and infrastructure for development: The infrastructure is largely cloud-based, and no factory is required. Software can be rapidly tested and validated and doesn't require long and expensive prototyping and demonstration as do "hard" technologies. Additionally, software is generally much easier to scale up than hardware. This is because it can be distributed broadly and rapidly online, compared with the sales and distribution process for most manufactured goods. As a result, profit margins can reach as high as 50 percent.[17] The unique combination of low costs, with the potential for rapid scaling and large returns, has made software incredibly attractive to venture capital for more than two decades.

The same factors that make the software sector attractive to venture capital also make the sector incredibly competitive. This competition among software companies is steep, but the relatively quick movement between idea and market means the software firm either succeeds or fails quickly, which helps VCs reduce their risk and exit quickly. Ewens, Nanada, and Rhodes-Kropf have noted that the cost of starting a new business in the software and service sector has declined, prompting a change in how venture firms invest. The investment approach "spray and pray" is more common now, with much less guidance given to young start-ups than was previously common. This has resulted in investment shifting to start-ups that can demonstrate early successes and away from long-term more expensive innovations.[18] This investment approach places slower-moving hard technologies that require longer-term commitments at a disadvantage.

The manufacturing sector has experienced a growing integration of hardware and software.[19] This increasingly complex integration of hardware and software makes for a much more complex and expensive scale-up process than for stand-alone software. It remains to be seen whether these hybrids will lead to changes in the national portfolio of venture capital. At this time, it appears cheaper and less challenging to simply add software to an existing services sector than to fund predominantly hardware technologies that integrate software. Uber, for example, which represents one of the largest venture plays in recent years, simply uses software to restructure the established taxicab model; it does not require reinventing the automobile. Although both are complex new steps for VCs, software for established services will likely prove a more digestible model for VCs than software integrated into manufactured hardware.

The Biotech Story

On the other end of the spectrum from software lies biotech. Here, the role of the FDA, which is unique to this sector, offers a number of advantages and challenges. New pharmaceuticals have to move through a multiphase process of clinical trials before they can receive final approval from the FDA. Before it can be classified as an investigational new drug, a pharmaceutical first must pass through a preclinical stage. It must then make it through three clinical phases, which, if it's successful, allows the company to file a new drug application. With approval by the FDA, the drug can be promptly brought to market.[20]

This long and costly process would seem unattractive to venture capitalists compared with software. However, the rounds of venture capital can closely parallel the stages in the drug-approval process. Seed funding is raised for initial development work and is typically provided by angel investors. After that, venture-capital funds may step in with the first of three series of investment rounds, Series A, B, and C. After the Series C rounds, venture firms generally look to exit through an IPO, a merger and acquisition (M&A), or larger institutional investors coming on board.[21] The FDA approval process for each of the three stages of clinical trials allows investors to understand the risks at each stage and provides reliable benchmarking that can be linked to the corresponding venture-capital series.

The FDA's high level of oversight of the biotech industry sets it apart from nearly all other sectors of the U.S. economy. Regulatory changes can shift the makeup of the industry, just like technological breakthroughs. Following the 1962 Amendments to the FDA Act, large pharmaceutical firms were able to capitalize on increasingly stringent safety requirements, maintaining an advantage over small firms, while still conducting most of their R&D in-house. Rapid advances in biotechnology have also altered the landscape of the industry. The dramatic fall in the cost of DNA sequencing and more powerful computer modeling have enabled more and better early-stage research in a number of areas.[22] This fall in early-stage costs in some areas, however, has not been matched by a corresponding decrease in the cost to market.[23] In fact, the cost of complex clinical trials continues to grow. A study by the Tufts Center for the Study of Drug Development estimates the average out-of-pocket cost to bring a new drug to market at $1.4 billion.[24]

The biotech sector, like many other sectors in the economy, has high costs and a long duration to exit. The sector has been able to overcome these disadvantages in attracting venture capital in a number of ways. While stringent FDA regulations raise costs, they present a series of clear benchmarks for managing investment risks and therefore the development process. Perhaps most importantly, once a drug has been approved by FDA, the patent ensures other companies can't immediately put generics on the market. This makes blockbuster markets for drugs possible due to patents and FDA exclusivity, so that the years of development costs can be recouped. This FDA-staged approval process and product certification guarantees a market that is unique to this sector. It has also driven large pharmaceutical companies, which can better manage the high cost and complexity of clinical trials, to acquire or partner with promising start-ups, which have multiplied due to expanding research advances and declining early stage research costs. This provides a viable exit for venture capital and presents a clear path for start-ups to take that has proven successful in the past.

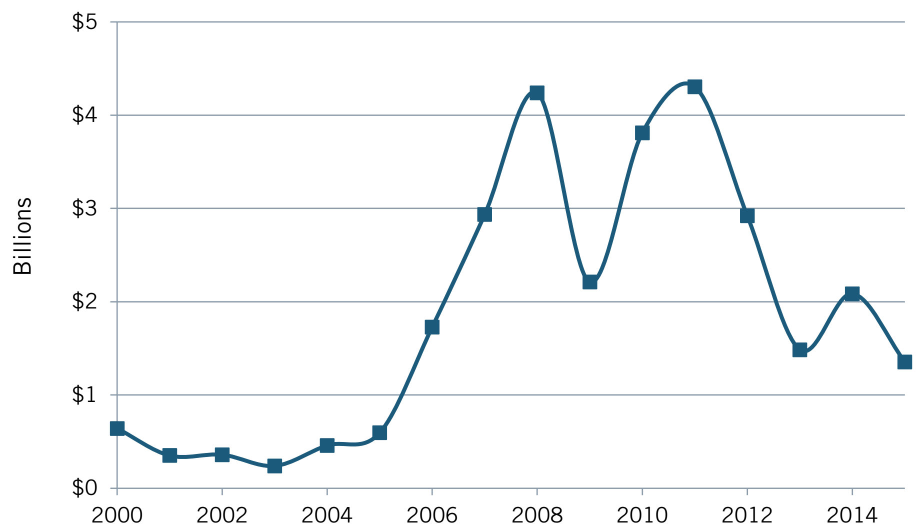
Sectors With Declining Venture Support: The Case of New-Energy Technology

One area that seemingly holds as much potential for innovation as biotech is "cleantech"—new-energy technologies, which are key to coping with climate change. So far, venture capital investments in clean energy have proven unsuccessful and unprofitable. From 2006 to 2011, venture capital firms invested extensively in clean-energy firms. At that time, rising gas and electricity prices (gas prices quadrupled from 1998 to 2008); the increasing awareness of climate change, stemming in part from Al Gore's *Inconvenient Truth* and UN climate reports; the prospect of carbon-pricing legislation; and corresponding new-energy policies, all led venture capitalists to believe that investment in clean energy could be both profitable and socially responsible. This optimism led to $25 billion of investment in clean energy from 2006 to 2011. Half of this sum was lost, while 90 percent of investments failed to break even in 2008, 2009, and 2011. No investment increased by a factor of two, even among the successes.[25] The timing of the clean-energy boom was lamentable; by 2008 the financial boom turned to crisis in the United States, while oil and gas prices fell. Congress's failure to pass carbon-pricing legislation hurt the competitiveness of clean energy, which was further compounded by a flood of cheap solar panels from China. At the end of the short boom, it was fossil fuels, not renewables, that were even more competitive.

Clean-energy technology is more likely to require large investments over the long term. The degree of risk and uncertainty can become too great for venture capital.

Political uncertainty is tied to the economic viability of clean energy. Due to narrow profit margins in the energy sector, changes in tax policy, regulation, and even geopolitical unrest can make the difference in whether a new technology is competitive. In addition, clean-energy technology is more likely to require large investments over the long term. The degree of risk and uncertainty can become too great for venture capital. One example of this uncertainty is the price of oil, against which clean energy competes: In August 2013, the price per barrel of oil was $109 (on the West Texas Intermediate standard benchmark for North American production). By January 2016, the price had fallen to $29 per barrel. Very few economic sectors face this kind of short term volatility, which makes the long-term viability of VC investments in cleantech difficult to assess. As can be seen in figure 1, volatility in energy markets passes through to venture capital investments. (The data on cleantech varies depending on the source: The estimates from the MoneyTree report are lower than those of Gaddy, Sivaram, and O'Sullivan.[26])

Figure 1: VC Investment in Cleantech[27]



The size of capital investments in the clean-energy sector can be massive. Solyndra, a thin-film solar-panel manufacturer, received approximately $970 million in investments as it attempted to scale-up.[28] Unfortunately, this coincided with an influx of cheap Chinese solar panels; the firm declared bankruptcy and shut down permanently in 2011. Other high-profile cleantech failures include HelioVolt, which received $200 million from VCs over 13 years, and Xunlight, a company that received government grants and tax credits but was never able to scale. The scale of these investments—and failures—have made the cleantech sector less attractive than other sectors. Typically, venture capitalists are comfortable investing $40 to $50 million leading up to a company's IPO or acquisition.[29] Ideally, this will take place within five years.

Clean-energy projects typically require a longer period of investment than the average software start-up. Venture-capital firms expect their investments to mature on a 10-year time scale.[30] The first five years involve stages of progressive investment and helping the projects scale, while the following five years are expected to return profits to the venture-capital firm. Most endeavors in clean energy take 10 to 15 years for the technology to mature, at the end of which there is no guarantee that the technology will be profitable or even have a market.[31] The low rate of successful exits for cleantech underscores this problem. Between 2006 and 2011, an average of 6.3 percent and 11.9 percent of medical and software companies, respectively, were acquired by other firms, while only 3.8 percent of clean-energy companies were acquired.[32] Clean-energy start-ups have often found themselves in a difficult position. With industry acquisition unlikely, clean-energy start-ups are more likely to have to scale up on their own. Venture-capital firms, preferring easy exits such as acquisition, are unlikely to make the large investments required for scaling up.[33]

Market forces at this point simply do not encourage the pursuit and development of scalable clean-energy solutions.

Cleantech provides a stark example of an innovative sector, needed to meet major societal challenges, that doesn't fit into a venture-capital business model and so is having trouble scaling up. But it is not alone: Other hard-technology sectors, such as advances in materials, photonics, or power electronics; or machinery and other capital equipment; or aerospace technologies, which require manufacturing and entry into complex markets, face similar challenges. Cleantech is representative of a larger "start-up scale-up" problem.

Venture Funding, IPOs, M&As, Crowdfunding, and Mini-IPO Options for Scaling Start-Ups

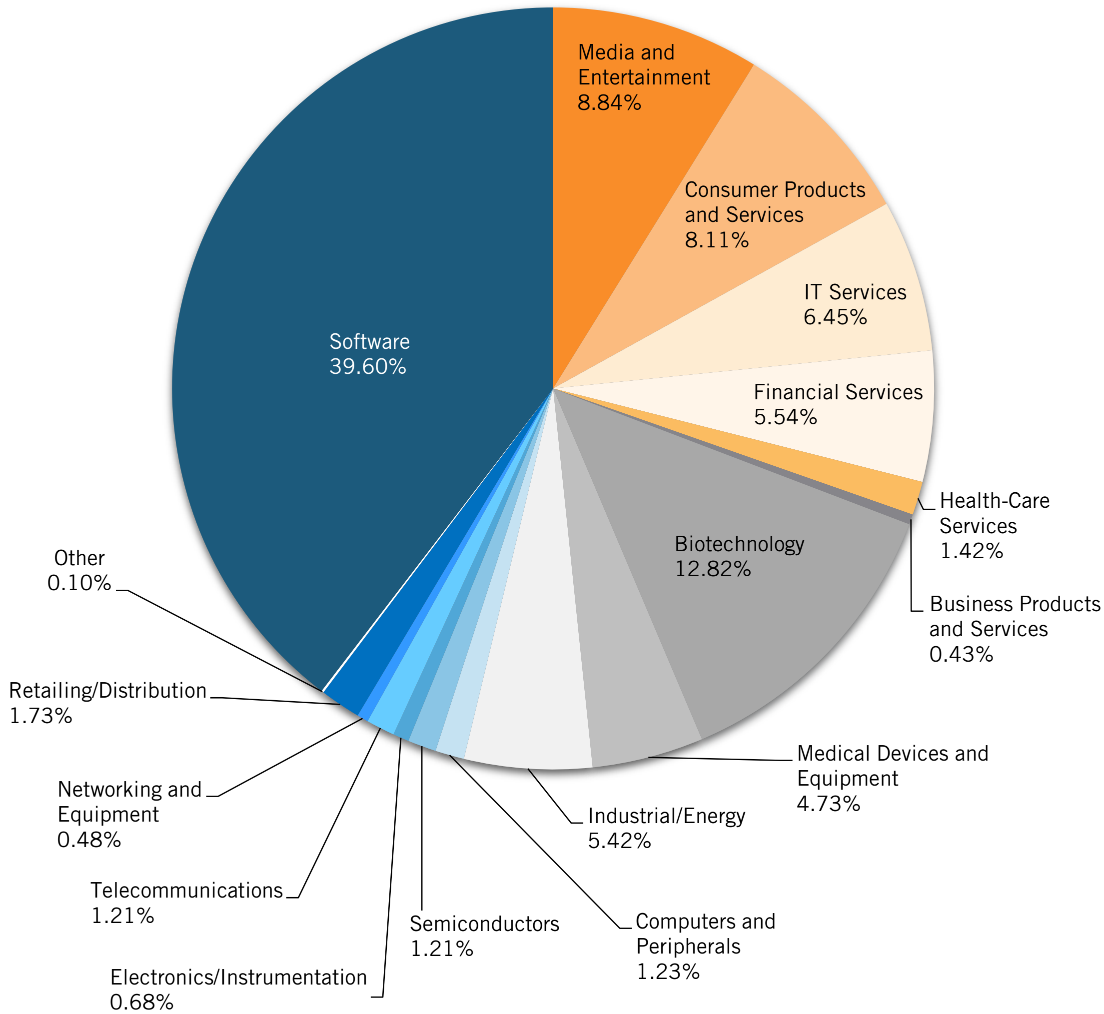
There are a number of potential sources that might be available for financing new firms, set out below.

Venture Funding Trends

As pressure to provide returns to investors has increased, venture-capital firms have tended to invest more in projects in later stages of development and already-proven technologies.[34] As a consequence, less than half of all venture-capital investments in the first quarter of 2016 were for seed and early-stage projects. However, since 2002, the aggregate of all seed and early-stage funding has risen steadily, with software and biotech assuming larger shares. The simple averages of investment per deal show that biotech and software receive nearly 7 and 2.5 times more, respectively, than hard industries.[35] This suggests companies that require manufacturing tend to have much less access to venture capital.

The chart below shows total venture investment in 2015 (nearly $60 billion) by sector. The dominance of the software and biotech sectors is evident. Perhaps surprisingly, most of the other large investments are in services, not hard technologies. The chart shows that software amounted to 40 percent of the 2015 venture total; biotechnology amounted to 13 percent; and various services categories (including media and entertainment) totaled 31 percent. In comparison, the industrial/energy category was 5 percent.[36]

Figure 2: Total VC Investment by Sector, 2015[37]



VC investments are also concentrated in just a handful of regions across the country. Nearly 47 percent of VC investments in the first two quarters of 2016 occurred in Silicon Valley. No other region comes close to this level of investment. Rounding out the top four are the New York metro area, Los Angeles/Orange County, and New England, with 11 percent, 9.7 percent, and 9.4 percent, respectively. The total investment made during these two quarters was just under $28 billion; every region other than the previously mentioned and the Southeast received less than one billion.[38] For start-ups outside these major areas, access to venture funding is severely limited, and, for some, relocating may be the only option.[39] These trends have been fairly consistent since the 1960s, with venture-capital investments centered primarily in California and Massachusetts.[40]

While we know which sectors receive venture capital and where they are located, it is more difficult to parse out how many firms are succeeding. Data exists for venture-backed firms that either have an IPO or merge with or are acquired by another company. Of course, these aren't the only options available to a firm, which could receive some other form of financing and remain privately held. Comparing the IPOs and M&As of companies that have received venture capital to all firms can provide some insight into the health of innovation in the economy at large.

IPOs: The Initial Public Offering (IPO) is no longer the common way to raise capital it once was. During the decade starting in 1990 there were 4,471 IPOs, but in the 15 years since then, ending in 2015, there were only 1,664.[41] Separating out growth-oriented start-ups from businesses in general, which includes large private companies going public and mergers between established corporations, is not a straightforward process, given currently available data sets. One somewhat imperfect method is looking at IPO and M&A trends among firms that receive venture capital, which in theory should be more likely to cover innovative start-ups. In this subset, venture-backed firms have fared substantially better than the market overall. While between 1995 and 2015, U.S. IPOs per year decreased from 578 to 183, for venture-backed firms, this decline was only 183 to 77.[42] The sector to see the largest increase in the number of IPOs was biotechnology, which increased from 16 in 1995 to 41 in 2015, making up 61 percent of all venture-backed firms to go public in 2015.[43]

M&As: Mergers and Acquisitions (M&As) are the other major exit strategy for venture-backed firms. The number of mergers and acquisitions in the United States, however, is not on the decline like IPOs, and has remained fairly consistent since 2000, hovering around 10,000 a year.[44] M&As are not only a signal of successful exits for venture firms, they also suggest partnerships that may enable technology scale-up by linking larger, established firms and start-ups. Again, as with the underlying venture funding, two sectors dominate. The software sector makes up the greatest share of annual M&As for venture-backed firms, totaling just over 50 percent in 2015. Even though over seven times as many software firms were acquired or merged in 2015 than biotech companies, the total value of the biotech deals was 23 percent higher.[45] As biotech companies move their products closer to market, their value increases rapidly and is indicative of the more monopolistic markets (based on the power of patents in the health sector) that they operate in compared with many software companies. This biotech M&A data seems to confirm the supposition noted earlier that established pharmaceutical firms are increasingly letting biotechs take on high-risk early R&D, then acquiring them.

Crowdfunding: In the last few years, the number of methods of financing a new start-up has increased. Crowdfunding garnered attention after it was legalized in the 2012 JOBS Act. Mini-IPOs were also a part of this legislation. The JOBS Act specifically legalized equity crowdfunding, enabling companies to sell ownership stakes.[46] From 2012 to 2013, online crowdfunding increased from $2.7 billion to $5.1 billion, although venture-capital funding in 2015 alone was nearly $60 billion.[47] The range of projects financed through crowdfunding is extensive, and on rare occasions it has been used to raise money for manufactured products. Pebble, for example, which makes a digital watch, raised $10.3

million and moved 400,000 units of its first-generation model. And a company making 3D printers raised $2.9 million in 2012.[48] Crowdfunding might have the potential over time to raise sums comparable to venture-capital firms, but the need to attract interest from thousands of people suggests crowdfunding is better suited for products that can be quickly brought to market and that can be understood by and appeal to consumers. This would likely preclude earlier-stage complex technologies. Financing for start-ups that are just starting and will require years of substantial investment are unlikely to have widespread success relying solely on crowdfunding.

Mini-IPOs: The other new financing mechanism to come out of the 2012 JOBS Act was the mini-IPO. Mini-IPOs have reduced legal and reporting requirements but are limited to issuing $50 million in securities. The SEC did not approve Regulation A+ (mini-IPO) until 2015, making a current assessment of the long-term potential difficult. In the first year, 94 companies filed, hoping to raise $1.7 billion. Of those 94, only 45 companies qualified to raise funds, and just a few were able to actually raise funds. Part of the reason for the low success rate was the failure to attract investors, and complications between SEC and state-auditing regulations have also slowed down the process.[49] Investments in mini-IPOs are not limited to accredited (wealthy) investors, which should theoretically expand the pool of available capital.

The reason to support tech entrepreneurship is to increase innovation to improve growth; if we limit funding access for entrepreneurs to only two sectors, too much innovation will fail.

Bank Lending and Other Options: Overcoming the "Valley of Death" is not solely an issue of increasing the total amount of investment in start-ups. Following the Great Recession, total credit to the nonfinancial sector, both businesses and households, decreased by nearly $1 trillion. Since that low in 2011, credit expansion has resumed, exceeding the prerecession high by the first quarter of 2014.[50] While this is a positive sign for the U.S. economy, bank lending to start-ups is difficult, given their lack of an income stream and collateral, meaning start-ups are essentially cut off from the largest source of credit in the country. Another positive sign is the overall increase in venture-capital funding over the last few decades; however, this is undercut, as noted, by its concentration on the software and biotech sectors. The degree of risk is high in all start-ups, but both software and biotech have financing models that assuage risk, while most other sectors have no corresponding risk-reduction system.

In summary, for start-ups, none of the other financing options appears to be a workable substitute for venture, and, as discussed, that source is now largely limited to certain sectors.

Implications

If technological innovation drives growth, and the current engine is being powered by only a few technological "cylinders," finding a way to ensure that more "cylinders" are firing will be important for stronger economic growth. The reason to support tech entrepreneurship is to increase innovation to improve growth; if we limit funding access for entrepreneurs to only two sectors, we will end up leaving too much innovation to fail. There may be an underlying rule here: We get the innovation we pay for; if we invest in certain kinds of innovation, that is the kind of innovation we will get. If we want to broaden the kinds of innovation entering the economy and society—for example, new-energy technologies that are cheaper than fossil fuels, we will need to find ways to broaden our innovation-support mechanisms.

A commonly used indicator of innovative success is productivity growth. The manufacturing sector has seen its multifactor productivity decline 0.5 percent from 2007 to 2014, with the last year reported by the Bureau of Labor Statistics seeing a decline of 1.0 percent.[51] For the private sector as a whole, multifactor productivity increased a mere 0.4 percent between 2007 and 2015.[52] This is compared with an average increase of 1.43 percent from 1996 to 2004. The increase in productivity during those years was a result of the IT revolution. Overall productivity is not where we need it to be; more innovation is required.

There is another reason to attempt to fill this innovation-system gap. Manufacturing is well known for its ability to serve as the economy's largest job multiplier.[53] Complex, capital-intensive, science-based technology goods require manufacturing. Manufacturing tends to create value chains of firms and accompanying jobs that reach, on the input side, from resources to R&D to suppliers and component makers, then to the production stage itself, and then on the post-production output side, from distribution to retail to repair to product life cycle.[54] If we are curtailing start-ups that make hard technologies, we are therefore slowing job growth. Both software and biotechnology are vital, for different reasons. But they are not enough. In recent years, America has been facing the consequences of what has been called a "jobless recovery" (a very slow job-recovery rate) following the Great Recession, along with growing income disparity. Ensuring a market with quality jobs is a significant societal challenge.[55] Part of the answer may be expanding the access of innovative start-ups to a broader spectrum of the economy, particularly in higher job-creating sectors.

THE "INNOVATION ORCHARD" APPROACH

If only limited financing is available for innovative start-ups to scale up outside of software, biotech, and services areas, how could this innovation gap be filled? One idea is to substitute space for capital. In other words, for start-ups that are moving past the early stages of technology development into product design, demonstration, testing, and initial production stages, spaces that offer advanced equipment, technologies, and accompanying expertise could help take the place of venture funding. These are the steps venture funding would typically support. Such innovation orchards might present an alternative way to scale up start-ups outside the current venture-support system; such technology-rich spaces might help fill the current innovation-system gap. Of course, financial backing will also be needed, but advancing the technology may be a way to de-risk the technology, to get it within range of the risks that the financing system is prepared to accept. It is possible that such a rich and supportive environment may be able to accelerate the development of the innovation in hard technologies faster than the 10-plus years it now takes—indeed, it may offer a better way of innovating.

Existing Technology-Development Programs

Obviously, there are numerous technology-transfer programs, at the federal and university levels in particular, that are relevant to this problem.[56] Universities and the federal government provide support for various aspects of early-stage technology development.[57] Universities typically have technology-transfer offices and many are teaching entrepreneurship. Increasingly, they support technology incubators, which typically offer start-ups office space and business plan-development support, and sometimes technology-development help; these now number several hundred, usually operating at early stages.[58]

For example, in a state faced with economic decline, the University of West Virginia is a land-grant school imbued with public purposes that, since 2014, has developed an interesting economic agenda at both early- and later-development stages to complement its longstanding education and research roles.[59] It has created a "launch lab" for training, assisting, and mentoring student entrepreneurs; some 40 student-organized firms have come through this pipeline since 2014. It also has a new testing and evaluation center for partnerships with industry. It is currently developing applied R&D centers, including an innovation center linked to its health-research programs, where start-ups can conduct translational research. Support to firms at various stages of development comes from three innovation funds; two are supported by private donors. Since West Virginia has no resident VCs, the university is planning a larger venture-capital fund with $20 million for initial investments; it is also planning a research park to support clinical-trial work and other applied work.

For start-ups that are moving past the early stages of technology development into product design, demonstration, testing, and initial production stages, spaces that offer advanced equipment, technologies, and accompanying expertise could help take the place of venture funding.

Other universities are developing comparable entrepreneurship programs with support from NSF's I-Corps program, which links NSF investigators with mentors to develop commercialization plans for their research results. Also at the federal level is the SBIR/STTR program, housed in major federal-research agencies, which offers up to approximately $1 million grants for technology development to small companies on a competitive basis. The program is funded by a small carve-out from federal R&D funding.

Some states have programs that operate at this early technology-development stage. For example, Michigan's Translational Research and Commercialization Program offers a fund for collaborations between universities and small firms for technology commercialization. Maryland has a Proof of Concept Alliance based on a cooperative agreement between Maryland's state universities and the Army Research Laboratory (ARL) to use ARL's Maryland facilities for research, prototyping, testing, and technologies that can be commercialized.

Elements in the private sector are also working to support start-ups at early stages of development. These accelerators can be found across the country. Perhaps the most well-known is Y Combinator, which aims to support companies through the earliest stages by providing seed funding to get them through the proof of concept stage. Each year Y Combinator funds two groups of start-ups for three months, during which time the start-ups are given seed funding, advice, and the opportunities to connect to later-stage investors, in exchange for equity in their company.[60] The company has expanded into other areas but estimates the total market cap of all the companies that participated in the program is over $70 billion.[61] Y Combinator is not limited to software companies, but the three-month turnaround may not be suitable for all start-ups.

The federal government also supports later-stage technology-development efforts. The Defense Department's "6.3" funding for "advanced technology development" totaled $5.69 billion in fiscal year 2016, available through the military services and DARPA's R&D programs. Of course, defense procurement funds can also be used to develop technologies. Although start-ups can participate, work supported through these programs must fit specific military needs. There are some federal programs that can help start-ups scale up besides procurement. NIH's National Heart Lung and Blood Institute has had a "Phase III" SBIR program that funds NIH health-science researchers for technology-commercialization efforts if they obtain additional matching funds from investors and strategic partners. The Army Research Laboratory has an "Open Campus Initiative" to promote breakthrough advances through sharing expertise, facilities, and technology infrastructure. The Obama administration's program to create 14 advanced-manufacturing institutes aims to link universities and companies in R&D and technology-development collaborations for emerging advanced-manufacturing technologies.[62] To date it has been aimed more at existing manufacturing firms, small and large, rather than technology start-ups.

Although all of these programs are relevant, none quite matches the innovation orchards model. However, there are now examples of organizations more comparable to the innovation orchards concept that can tell us about how that model can work. Several organizations, explored below, have formed recently in an effort to help get more innovations commercialized.

Innovation Orchard Models

Cyclotron Road[63]

The Lawrence Berkeley National Laboratory (Lawrence Berkeley Lab), a federal laboratory managed by the University of California, founded Cyclotron Road (CR) in July 2014, as a new form of technology accelerator. Its program is described as a "new early-stage energy technology incubation program."[64] The U.S. Department of Energy (DOE)'s Advanced Manufacturing Office (in the Energy Efficiency and Renewable Energy office—EERE) joined with Lawrence Berkeley Lab to fund CR as a pilot program in the fall 2014.[65]

Cyclotron Road is based on the assumption that both academia and corporate R&D are constrained in their ability to develop and deploy lengthy, risky research to the market. This has resulted in a gap in energy-technology innovation over the past decade. Cyclotron Road, with funding from Lawrence Berkeley Lab and DOE, aims to bridge the gap between emerging energy-technology ideas and the marketplace by providing entrepreneurial researchers with the resources they need to successfully commercialize their technologies.[66]

CR follows a five-element approach to find and develop the most promising energy-technology ideas; these are not strictly linear, and can proceed in parallel and in varied sequences:[67]

Recruitment of Talented Innovators: CR is committed to hiring the "best and most-driven innovators" and working closely with them in developing and nurturing their ideas. These entrepreneurial researchers typically come out of university research labs or smaller businesses. This stage aims at emerging technologies in the prefinancing phase. The first cohort of innovators consisted of six teams selected from a pool of 150 applicants; a second cohort of six teams was added in March 2016.[68] Thus, CR at its initial phase is more talent- than technology-oriented, reaching researchers before or just as they create companies. It thus operates at a somewhat earlier stage than contemplated by the innovation orchard model described above, but remains very relevant.

Selection of Scalable-Technology Solutions: Similar to ARPA-E, CR singles out those technological inventions that can be commercialized and scaled to ensure that they have a significant impact when implemented in the energy market. CR encourages entrepreneurs to identify potential markets and align their technologies to them. Since CR is an entrepreneur-driven model, it provides support throughout the entire process. Technology solutions that CR focuses on include:[69]

- Cheap, safe, and scalable energy storage for grid and mobility applications;
- Cheap, safe, and scalable nuclear-power generation;
- Disruptively economic, next-gen renewable-power generation;
- Technologies to capture, sequester, and utilize atmospheric greenhouse gases;
- Technologies to radically increase the efficiency of current power systems and production processes; and
- Sustainably produced fuels and chemicals.

Leverage R&D Possibilities of National Labs: By bringing project leaders together with Lawrence Berkeley Lab experts, CR aims to make use of existing R&D technology, equipment, and know-how. This rich access to technology is a key distinction between CR and most technology incubators. The scientists receive access to the lab's excellent research infrastructure within weeks, which allows them to promptly begin de-risking their technology as well as save a significant amount of time and money in developing advanced prototypes. Furthermore, the lab is known for its emphasis on teamwork, which enables project leaders to benefit from lab researchers with various fields of expertise.[70]

Support System for Innovators: Throughout the two-year program for each cohort, CR connects innovators with potential collaborators, mentors, and development partners, and provides networking opportunities and education to help them in developing their technologies.[71]

- *Funding*: Project leaders are paid a living stipend with benefits through an individual fellowship that focuses on entrepreneurial education from the U.S. Department of Energy for up to two years. In addition, CR can allocate a small amount of funding (less than $100,000 per project) toward initial R&D projects aimed at exploring collaborations with staff scientists at Berkeley Lab. Project leads are expected to raise additional R&D funds from private investors as well as federal research grants, for instance from EERE, ARPA-E, DARPA, and various SBIR programs, as well as state funding, for instance from the California Energy Commission (CEC).

- *Mentorship*: The program recruits entrepreneurs, R&D executives, investors, and government researchers to give project leaders technical and business guidance. Teams also participate in biweekly project reviews with the CR program leaders.

- *Networking*: Innovators get a chance to participate at a number of events and conferences, thought-leader roadshows, and entrepreneurship workshops. Networking is also important within the cohort community.

Connect Innovators With Commercial Partners: Throughout the program, CR works to connect innovators with the most appropriate commercial partners and investors, including:

- Corporations for possible joint-development projects, minority equity investment, or outright acquisition.
- Venture firms, which can provide funding for early-stage technologies, but also serve as leverage for non-dilutive grants.
- The growing area of "family offices," which can offer equity and debt financing.
- Possible nonprofit supporters.

Lab-Embedded Entrepreneurship Program (LEEP)—A Generalized Cyclotron Road Model From DOE: The Lab-Embedded Entrepreneurship Program is a generalized model inspired by Cyclotron Road that has been developed at DOE. Its Advanced Manufacturing Office, along with EERE's Tech-to-Market office, has generalized the framework and launched projects at two other labs—the Chain Reaction Innovations (CRI) program at Argonne National Laboratory, and the Innovation Crossroads program at Oak Ridge National Laboratory (ORNL). Innovators selected to participate receive a fellowship and seed funding, as well as access and support at the labs. Crossroads intends to leverage ORNL's strengths in additive manufacturing. At CRI, $4 million will fund the first cohort of cleantech entrepreneurs through joint efforts between DOE and Argonne; a similar figure will fund the first cohort for Innovation Crossroads through joint funding from DOE and ORNL.[72]

TechBridge[73]

The TechBridge program was founded in 2010 by the Fraunhofer Center for Sustainable Energy Systems (CSE), which is a nonprofit, applied-research and development laboratory based in Boston and a branch of Fraunhofer USA. This is a U.S. 501(c)(3) organization, and a subsidiary of Germany's Fraunhofer Institutes. CSE aims to advance economic development through the commercialization of clean-energy technologies. Research areas include energy generation, efficiency, and distribution technologies, with a specific focus on building energy efficiency, distribution-grid technologies, and solar photovoltaics. Since its foundation in 2008, Fraunhofer CSE has "filed and licensed several patents in photovoltaic and building energy technologies, and created over 170 job-years and hundreds of indirect jobs in the clean energy technology center."[74]

Fraunhofer is one of the world's leading organizations for applied research and development, with a professional engineering staff of 23,000 in more than 67 institutes and research units in Germany and worldwide. Fraunhofer's annual research budget is more than $2 billion, and is mainly used for the development and demonstration of innovative technologies in various industrial sectors. The organization obtains most of its funding through contract work for industry and the public sector.[75] TechBridge leverages the extensive resources of Fraunhofer CSE and the greater Fraunhofer network (including the Fraunhofer Energy Alliance of 18 Fraunhofer Institutes) to perform industry-driven validation and demonstration projects that de-risk disruptive technologies coming out of start-ups.

While TechBridge did obtain some initial funding from venture-capital firms, most venture-capital investors proved hesitant to fund the de-risking of technologies until the model was proven. Specifically, a rigid venture-investing framework, with limits on development time, funding commitments, and risk acceptance, tended to create barriers to spending money on such de-risking work. TechBridge, however, gained traction with an award from the Department of Energy in 2010, which provided $1 million in funding over three years.[76] The investment helped TechBridge test and refine its business concept and prove that the model could provide real value.[77] TechBridge was able to show, in a study it conducted, that companies at a similar stage and quality were nearly twice as likely to receive follow-on funding from the private sector within two years if they had received Fraunhofer validation services, relative to if they had not.[78]

In August 2015, Fraunhofer TechBridge also emerged as one of 80 winners of the 2015 Growth Accelerator Fund Competition, which was hosted by the U.S. Small Business Administration (SBA). The SBA Award provided TechBridge with $50,000 in capital to "expand its reach across the U.S. and connect with more innovative start-ups in new technology areas."[79]

Innovation Gaps TechBridge Aims to Address: TechBridge's objective is to evaluate the viability and performance of early-stage clean-technology start-ups for future investors and partners, as an independent third party. The program seeks to eliminate one of the most critical obstacles for energy entrepreneurs, the industry-readiness barrier. While many good ideas emerge at start-ups and universities, "in many cases the technology is not taken seriously in the industry context yet," says former Director Johanna Wolfson. This is in part caused by the fact that scientists develop prototypes under lab conditions without knowing how their technologies would fare once implemented in a company or an operating facility such as a power plant.[80]

Scientists develop prototypes under lab conditions without knowing how their technologies would fare in a company or an operating facility such as a power plant.

TechBridge supports energy technologies in multiple ways to mitigate this gap in the innovation pipeline. First and most importantly, Fraunhofer scientists design and execute customized validation and demonstration projects for the participating start-ups to test the viability of their new technologies. Because Fraunhofer is an applied lab driven by industry contracts, its researchers and engineers are uniquely positioned to design and execute work that will be considered both relevant and credible to potential investors and industry partners. This access to technology validation and the technical equipment and know-how to perform it is a key feature. As example of how this system works, one TechBridge-assisted start-up aimed to develop a flexible, thin-film photovoltaic solar module transparent to visible light. TechBridge validated the technology for use in standard windows in 16 different climate conditions, advised on manufacturing methods and on optimal product materials. With the validation of its technology, which made windows into solar panels, the firm gained two phases of DOE SBIR funding support and $6.2 million in series A venture funding.[81] In a review by independent experts, the TechBridge model was described as "surgical," and a tremendous accelerator for the right start-up.[82] But while TechBridge is one of the only models to focus on technology validation and demonstration, and forging partnerships with strategic industry partners, it does not address all aspects of start-up support. Therefore, TechBridge partners with other organizations to support start-ups in their fundraising efforts and connect them with investors.[83] This approach "significantly accelerates the commercial entry of many early-stage technologies across a wide set of domains, from water treatment and smart grid control to manufacturing, photovoltaics, and beyond."[84] TechBridge's target audiences extend beyond industry partners and government organizations to include philanthropic organizations and investors.

The particular focus on industry partners is noteworthy. TechBridge (and Fraunhofer CSE) worked to identify the specific barriers that prevent start-ups and industry partners from collaborating effectively, and tuned the TechBridge model to address those challenges for both start-ups and industry partners. These barriers have been broadly summarized by TechBridge to fit into two categories:

1. *The technology is underdeveloped by industry standards.* The limited scale-up capital available for technology developers, plus the relatively high demonstration threshold for "hard" technologies that must be manufactured, often prevents meaningful

progress on making technologies ready for industry uptake, even when the next steps are clear.

2. *Information disconnects exist between technology developers and potential adopters.* Technology developers focused on their core innovation often lack the expertise to analyze their technology in an operational, industrial context, and often have limited knowledge of the industry proof points that will be required. Simultaneously, potential adopters (customers, co-developers, supply-chain partners, etc.) lack access to data that demonstrates the performance of the new technology in its relevant industrial context, limiting the attractiveness of early partnerships or other support. As a result, industry actors are able to identify many promising technologies of interest to them, but those technologies are not sufficiently de-risked. These industry actors therefore take a wait-and-see approach. Meanwhile, promising early-stage technology concepts dry up, never overcoming the industry-readiness gap and achieving commercial impact.[85]

TechBridge posits that to overcome these barriers there must be a mechanism that both *correctly diagnoses* and then *directly addresses* the specific challenges facing the new technologies, from the perspective of established industry. It follows a four-step approach to carry out the validation work for emerging clean-energy technologies, "paving the way for groundbreaking energy companies to attract funding, partnerships, and customers."[86]

- *Define:* TechBridge works with program sponsors (i.e., private companies, generally large corporations) to determine the scope and goals of each program, focusing either on innovation in a particular region (through a government sponsor) or a topic of strategic interest (through an industry/investor sponsor). This step is key to TechBridge's approach: identifying a sponsor's concrete innovation need first, then working, in the next step, to tie a developing technology to the need.
- *Identify:* TechBridge then executes a comprehensive start-up search and selection process, taking into account expert technical and business expertise.
- *Design:* Fraunhofer scientists design a customized validation or demonstration project that aligns the goals of the program sponsor with those of the selected start-up(s). In the process, TechBridge tries to strike a balance between the feasible project and the ideal project, which could otherwise take years to complete and require more financial resources than available. Thus, a valuable project design needs to be useful, correspond with the client's needs, help start-ups in achieving their objectives, and respect potential budget-timeline constraints. Above all, the project must bring the technology to a relevant "Go/No-Go" decision point for the industry sponsor.
- *Execute:* The technical projects are executed at Fraunhofer research facilities and in real-world demonstration sites. Projects include optimizing and testing prototypes, conducting field demonstrations in real-world conditions, performing system integration work, and evaluating manufacturability. Engineers also evaluate

> practical concerns, such as the cost of maintenance and the feasibility and ease of operating and installing the technology.[87] This process of technology evaluation typically takes about four months.[88] By carrying out these projects, Fraunhofer takes on the role of an independent third party, preparing the start-up(s) for partnership and providing industry sponsors with trusted information on the relevant area of innovation.

TechBridge's system of tying a technology start-up to a sponsor that needs the technology enables a viable follow-up pathway for the start-up. The technology-validation process that TechBridge offers through the respected Fraunhofer system is particularly important. It readies the technology for implementation from a range of perspectives and provides assurance to the program sponsor that it is fully demonstrated, with a workable business model.[89]

The Engine

In October 2016, MIT led an effort to create another variation of the innovation orchard model called The Engine, located adjacent to MIT's Kendall Square campus. In justifying the project, MIT's president argued,

> [F]rom listening to entrepreneurs across the region, we are concerned that many new-science innovations with great potential for addressing humanity's most serious challenges are being stymied on the long trek to the marketplace. Why? Because turning a brand-new piece of science into a world-changing technology that is optimized, tested and ready for manufacture at scale can take more than a decade, longer than venture capitalists (VCs) can reasonably wait. The result is that our society's current system for funding and commercializing new ideas—so effective with relatively quick-to-market digital products—leaves many "tough technology" solutions permanently stranded.[90]

MIT created a 26,000-square-foot space in the heart of the Kendall Square innovation hothouse, to serve up to 60 start-ups, to be rich in technology, equipment, and know-how. While it will help some early-stage start-ups get off the ground (particularly from MIT), there are already numerous start-up incubators in the area for such firms. So The Engine could serve primarily as a kind of graduate school for area start-ups, assisting them after they have developed business plans and prototypes and are moving into product design with the advanced prototype, demonstration, testing, and perhaps pilot-production phases. The start-ups could be both resident and nonresident, using the equipment and assets. They would enter for one-year terms that could be extended. A series of advisory committees are to be set up with MIT faculty, as well as outside experts, to assist in different technology and other support areas.

The Engine will also serve as a staging area, so that as its start-up firms move toward production, it can link them to secondary nodes, which will include strong local companies interested in linking to start-ups in a range of technology areas, from medical devices to energy. Lincoln Laboratory, for example, a noted defense research and engineering lab administered by MIT, plans to be a node, offering access to its highly respected rapid-prototyping capability. Although The Engine is clearly following Reif's concept of substituting space for capital, it will also offer bridge funding (raised outside the university's academic budget and endowment) to help its start-ups scale. Launched with $25 million raised by MIT, it was also anticipated that area investors, more to help strengthen regional innovation than for gain, could pool resources at a larger scale to build the bridge fund, recognizing the high risk and not expecting VC-type margins. So there would be a high-risk but for-profit investment feature.

All these tools could accelerate the time for the technology scale-up, and help de-risk participating start-ups, so they could come in range of financing, from venture and corporate venture to alliances with existing firms. The Engine will be independent of MIT, and would help both start-ups coming out of MIT as well as from other regional sources.

The Engine, while still at the early start-up phase, is positioned to absorb lessons from other program models. It also represents a way universities could engage with this start-up challenge. Since university research has become a cornerstone for technology advance, universities are increasingly playing a regional economic role in addition to their historic education and research roles. While many universities have technology-transfer programs that help start-ups emerging from campus research, and have links to incubators that support start-ups at early stages of development, few have focused on the scale-up stage. The Engine, then, could be one model for how interested universities could operate at this stage.

In addition to a new role for universities, The Engine provides other new elements:

- the idea of *secondary nodes* to link start-ups to additional technology facilitators in the region, from companies to labs, that can help start-ups with specialized support and technology;
- including both *resident* and *nonresident* start-ups for support and technology access, which can broaden the number and kinds of firms helped; and
- a *bridge fund* for start-up scale-up, from contributors willing to treat helping start-ups as a new kind of charitable assistance, with the hope of an eventual upside return.

These are all possible contributions to the "orchards" model.

Greentown Labs-MassMEP Partnership[91]

The current generation of technology-based, innovative start-ups emerged largely from university research benches. These start-ups know their research well, but usually have no idea about how to manufacture products. The Greentown Lab-MassMEP partnership has attempted to get start-ups past this innovation gap, offering an instructive additional feature for the innovation orchards approach. Greentown is located in Somerville, adjacent to Cambridge, Massachusetts; MassMEP is the Massachusetts branch of the NIST-sponsored Manufacturing Extension Partnership program that operates in every state to bring optimal production processes and technologies to small U.S. manufacturers. In November 2014, these two groups partnered to launch a one-year pilot program called the Greentown Labs-MassMEP Manufacturing Initiative, aimed at linking start-ups with local manufacturing capabilities. The program has been developed and managed by Micaelah Morrill, a program director at Greentown Labs, and Peter Russo, the growth and innovation program director at MassMEP. Greentown Labs recognized that start-ups that have successfully received initial funding and produced a working prototype might still have difficulty becoming a commercial company if they are unable to move to production at scale. During their one-year pilot, members of Greentown Labs and MassMEP identified the existing barriers that prevent start-ups and established small- and mid-sized manufacturers from working together and developed a program to systematically address those challenges. The Greentown Labs-MassMEP Manufacturing Initiative offers a framework for start-ups in the later stages of incubation (or, if they have venture support, early stages of series-A funding) to connect to a manufacturer and take their prototype to a production-ready design.

Many start-ups do not understand the needs of the manufacturers they might be trying to partner with.

Barriers to Collaboration: Greentown Labs conducted a survey, which revealed that start-ups and manufacturers seeking to connect faced communication and cultural barriers, as well as difficulties finding each other.[92]

Even once they make contact, the two groups often approach each other from very different perspectives and cultures. Start-ups developing new technologies typically are founded by university researchers (including scientists, grad students, or postdocs), who come from research benches but have little or no experience with actual manufacturing and are often not aware of manufacturers in their region. In contrast, small manufacturers often have deep experience with production processes and technologies but do not conduct R&D. The two different groups communicate in different worlds but may be able to help each other. For start-ups, access to practical manufacturing experience is crucial as they move toward production. For manufacturers, who often serve as suppliers in various industry sectors, working with start-ups could give them access to innovations that could scale their production.

While small manufacturers seeking to work with start-ups tend to prefer making connections via word of mouth and face-to-face relationships, start-ups typically begin their searches online. These Internet searches frequently direct start-ups to contract manufacturers based outside the U.S.; venture capital sources may also refer them to such contract manufacturers abroad.[93] This often means they can't work in close proximity to resolve ongoing design problems collaboratively, and they may also lose control of important aspects of their innovations. But even once in contact with manufacturers, start-ups need more than just the fulfillment of a contract. Unfamiliar with designs for manufacturing, start-ups are out of their depth: They may not know what their needs are, or what questions to ask.

Finally, many start-ups do not understand the needs of the manufacturers they might be trying to partner with. Start-ups do not recognize the high overhead expenses that go into development and communication to complete a prototype, and how this translates into a need for most established manufacturers to secure a longer production run in order to make a profit. If start-ups cannot help a manufacturer make a profit, they need to find other ways in which they can be a benefit to the manufacturer. According to Greentown Labs' survey, many manufacturers begin working with start-ups because they are looking to gain exposure to new markets, or because many want to give back to their communities.

The Program: To bridge these gaps, Greentown Labs and MassMEP developed a three-part program that educates start-ups and facilitates connections with local Massachusetts-based manufacturers. Broadly, the program comprised 1) a survey, 2) a series of "office hours" meetings, and 3) a set of workshops and face-to-face sessions in which start-ups received one-on-one advice and guidance for effective communication with manufacturers, along with general design for manufacturing information.

1. *Survey:* Two initial surveys, one sent to start-ups and one sent to manufacturers, helped Greentown determine each group's understanding of and expectations for the other. The survey was mandatory to gain entry into the initiative.

2. *"Office Hours":* Office hours were opened to Greentown Labs start-ups, along with other hardware start-ups from across Boston and eastern Massachusetts and hosted by Peter Russo from MassMEP, along with other manufacturing experts and Greentown Labs staff. Start-ups would often come in with the goal of finding a manufacturer, but Russo would quickly determine that many were not actually ready to meet with anyone. They might not know what type of manufacturing capabilities they needed, were unfamiliar with important processes, or their design would be flawed.[94]

   In cases where start-ups were not yet ready to begin manufacturing, Russo would conduct an initial walkthrough of their plan, help alter or simplify the design, and provide feedback in a 30- to 40-minute session. Start-ups might ask for feedback on their bill of materials, subassembly, or more generally, for background on manufacturing processes. After incorporating the feedback, the start-ups would come back for a second, shorter meeting. Once start-ups knew what their needs were and their design was ready, Russo and Morrill would help connect them to a manufacturer.

3. *Workshops:* To educate start-ups about manufacturing processes, Greentown Labs hosted workshops and "lunch and learns," which they opened to both Greentown start-ups and the broader Boston-area hardware start-up community concerned about manufacturing their proposed products. These workshops brought manufacturers to Greentown for half-day informational panels, after which start-ups

were able to speak one-on-one with manufacturing representatives and start to build relationships.[95]

Greentown's involvement formally ended after the first connection was made; the process of negotiating and signing a contract was left entirely to the manufacturer and the start-up. Yet Morrill and Russo continued to provide mentorship and advice to both start-ups and manufacturers as they progressed in their relationships.

Outcomes: In all, 32 start-ups were interested in receiving assistance from the program, and 83 manufacturers were interested in working with start-ups. The program facilitated at least 140 connections between start-ups and manufacturers and resulted in 19 signed contracts.

Greentown received a large amount of interest from both start-ups and manufacturers: Of the manufacturers surveyed, about 75 percent had an interest in working with start-ups. Manufacturers saw the potential to generate revenue long-term but also had a desire to gain exposure to new markets and technologies. Others saw working with start-ups as an opportunity to enhance their internal processes and capabilities, as well as to bring an exciting and entrepreneurial spirit to their employees.

The Greentown Labs/MassMEP partnership is not the same as the "innovation orchard" concept, but it could be complementary. One is pursing the full scope of the innovation process through technology scale-up; the other enables start-ups to link to the initial production stage of the innovation process. But this initial production stage is clearly part of the innovation process; missing it creates an innovation-system gap. The Greentown/MassMEP project represents an important innovation phase that could enhance the orchards model. In effect, both approaches seek to integrate the manufacturing process into start-ups to increase the odds that their prototypes can become be commercially viable.

Complementary Models: Lessons From Each Approach

Each of the models explored above provides a different menu for an innovation orchard approach, and each provides potential complementarity.[96] Although it is still early times for The Engine, Cyclotron Road, TechBridge, and Greentown Lab/MEP, each offers lessons.

Cyclotron Road (CR) creates a home for early-stage innovators forming start-ups, including technology, equipment, and a know-how rich space. It draws on a top DOE lab, putting talented teams of scientist and engineer-led start-ups, picked through a highly competitive selection process, into an outstanding R&D facility, where they also receive business mentorship. In economic terms, CR represents the efficient deployment of an existing asset—a strong energy lab. Despite the discouragement the new start-ups have faced from the sharp decline in VC support for cleantech, CR gives them a working home, pays their salaries for two years, and removes many of the barriers to product design. An important measure for CR's success is that, no matter what happens to the start-up itself, CR is retaining strong talent in cleantech. It shows that top-notch innovators will flock to an intense, "all-in" setting that offers significant support. It shows that linking lab scientists to start-ups to share expertise can work. It demonstrates that modest funding and an existing technology asset—the lab—can potentially leverage additional outside funding. The major challenge for CR is having its start-ups show tangible relevance to potential industry partners who can assist in implementing the technology as they emerge from their term at CR. Because its energy-lab partner lacks expertise in commercial manufacturing design and scale-up, it must also bridge this space.

CR is now in its third cohort of start-ups and looks quite promising. CR's approach has already spread to two other DOE labs. This approach could scale to other DOE labs but also to the even more numerous Department of Defense labs and research centers. DOD's Lincoln Laboratory, for example, is already exploring this space as a node of The Engine. This is a way of repurposing existing facilities already rich in technology and know-how to serve new aims at relatively modest additional cost, since the technology and know-how have already been invested in. It could be an important way the innovation orchard model spreads.

Universities are increasingly playing a regional economic role, supplementing their longstanding education and research roles.

TechBridge brings a different set of lessons. The challenge that TechBridge is trying to solve is that without deep industry applied knowledge and support, start-ups have great difficulty showing the industrial viability of their new technologies to investors, customers, and, particularly, potential industry partners. TechBridge works in a different way from CR. It goes to established industrial firms and asks them to consider innovations they need and will fund, then it shops these requests to qualified start-ups that can offer to undertake the innovation. TechBridge is an expert, quality matchmaker between the two sides, and helps protect each—particularly helping the start-up manage its IP. TechBridge's Fraunhofer Lab system then validates the start-up's technology innovation, certifying how the technology can best be optimized and produced—a key third-party validation role that helps both sides move ahead toward a working partnership. TechBridge leads both parties to field demonstration projects that can de-risk the new technology, so they can move toward production. The key features that TechBridge offers are technology validation, demonstration, refining the prototype, and developing manufacturing feasibility. It is a different role than CR, but potentially highly complementary—you could attach this step to a CR-like space. Interestingly, of 17 start-up companies that have come through TechBridge's process, TechBridge data shows that 100 percent have survived, and obtained $136 million in follow-on funding and 19 new industry partnerships.[97]

The Engine is still at an early start-up phase, but hopes to build on lessons from the other models. Importantly, as noted above, it represents a way universities could engage in the start-up scale-up problem. Universities are increasingly playing a regional economic role, supplementing their longstanding education and research roles. Most research universities have technology-transfer programs that help their researchers with implementation, and many now connect to incubators that support early stage start-ups. The Engine could demonstrate how universities could extend their reach to operate at the start-up scale-up stage, offering another means to build the innovation orchard model. It also explores approaches for specialized secondary nodes at area firms and labs, for serving resident and nonresident start-ups, and for a bridge fund for its start-ups.

The Greentown Lab-MassMEP program for linking start-ups to capable small manufacturers offers a third complementary element. The problem it addresses is that innovative start-ups emerging from university labs know their research but generally lack manufacturing knowledge. The program helped equip start-ups with basic manufacturing knowledge, alerted them to gaps and issues in their manufacturing designs, then facilitated a highly-personal, face-to-face system for linking and building trust between small regional manufacturers and start-ups at area incubators for production scale-up—creating advanced prototypes and pilot production of initial products. This, too—linking start-ups to strong local manufacturers to scale up to production—is a complementary piece that can snap into an innovation orchard model to help it work.

All these models offer a way out of the dilemma posed in Part I, that a major gap in the U.S. innovation system has opened up because of the decline in venture-capital funding for entrepreneurial start-ups focused on "hard" technologies. The innovation orchard concept of aggregating promising start-ups within a technology, equipment, and know-how rich space presents a way to close that gap. It aims to substitute space for capital to accelerate and de-risk start-ups' new technologies and move them into range of capital support for implementation. It is a novel innovation-system experiment.

POLICY PROPOSALS

To further these new approaches, we have a series of suggestions:

Seed Innovation Orchards in More Federal Labs

Federal defense and energy labs interested in gaining access to the next generation of innovators and innovations should consider nurturing innovation orchard models such as DOE's Lawrence Berkeley, Argonne, and Oak Ridge laboratories are now doing, and as DOD's Lincoln Laboratory and Army Research Laboratory are working on.

Leverage the Technology and Know-How of Universities

Many universities are already linked to early-stage start-up incubators. They should consider taking the next step by using their technology equipment and know-how to create new orchard spaces for start-ups, as MIT has now done for The Engine. In addition, the National Science Foundation, NIH, and other federal agencies funding scientific research should review their policies to ensure that their funding creates opportunities and avoids barriers for grant recipients undertaking these kinds of follow-on innovation orchard efforts.

Link Small Manufacturers to Start-ups Through MEPs

Manufacturing Extension Partnerships, jointly supported by NIST and every state, should emulate the Greentown-MassMEP model of linking the small manufacturers in their regions to start-ups for the benefit of both sides in scaling new technologies to pilot production.

CONCLUSION

We now have a serious gap in our innovation system: Because venture capital can't manage the risk of "hard-technology" start-ups that manufacture, most areas of science-based future innovations simply will not be able to scale up. They will die on the innovation vine, with major implications for future job creation. We have mechanisms already at hand—government labs, universities, and the MEP program—poised to be able to fill this gap. The costs would be modest because these existing assets could be readily repurposed, consistent with their existing missions. The early experiments set out above suggest the results could be powerful.

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J. Chazen, “Venture Capital and Research Centers: Facilitating Innovation” (paper, MIT Washington Office, August 2016), accessed March 14, 2017, http://dc.mit.edu/resources/policy-resources.

90. Rafael Reif, “Introducing the Engine,” *Boston Globe*, October 26, 2016, accessed March 14, 2017, http://www.bostonglobe.com/opinion/2016/10/26/reif/o0I3OhgX8B1HYjYi04PzJL/story.html. For disclosure, the authors of this paper were involved for MIT in analyzing “Innovation Orchards” models as background for The Engine.

91. Section drawn from, Katherine W. Nazemi, “From Startup to Scale-Up: How Connecting Startups with Local Manufacturers Can Help Move New Technologies From Prototype to Production” (paper, MIT Washington Office, July 2016), accessed March 14, 2017, http://dc.mit.edu/sites/default/files/doc/Connecting%20Startups%20to%20Small%20Manufacturers%20Nazemi%20July%202016.docx.

92. Communication from Micaelah Morrill to W.B. Bonviliian, February 4. 2016; Nazemi, “From Startup to Scale-Up”, 6-8.

93. Elizabeth B. Reynolds, et al., “Learning by Building,” in R. Locke and R. Wellhausen, *Production in the Innovation Economy* (Cambridge, MA: MIT Press, 2014).

94. Micaelah Morrill and Peter Russo, interview by Katherine Nazemi, June 20, 2016.

95. Greentown Labs, 2015.

96. This section draws on Johanna Wolfson, “DOE, Emerging Models for a Better Innovation Pathway” (presentation, DOE Office of Energy Efficiency and Renewable Energy, Washington, DC, August 25, 2016), and discussions with Wolfson, August 25, 2016.

97. Fraunhofer TechBridge Program, Impact, accessed March 14, 2017, http://www.cse.fraunhofer.org/techbridge/impact.

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