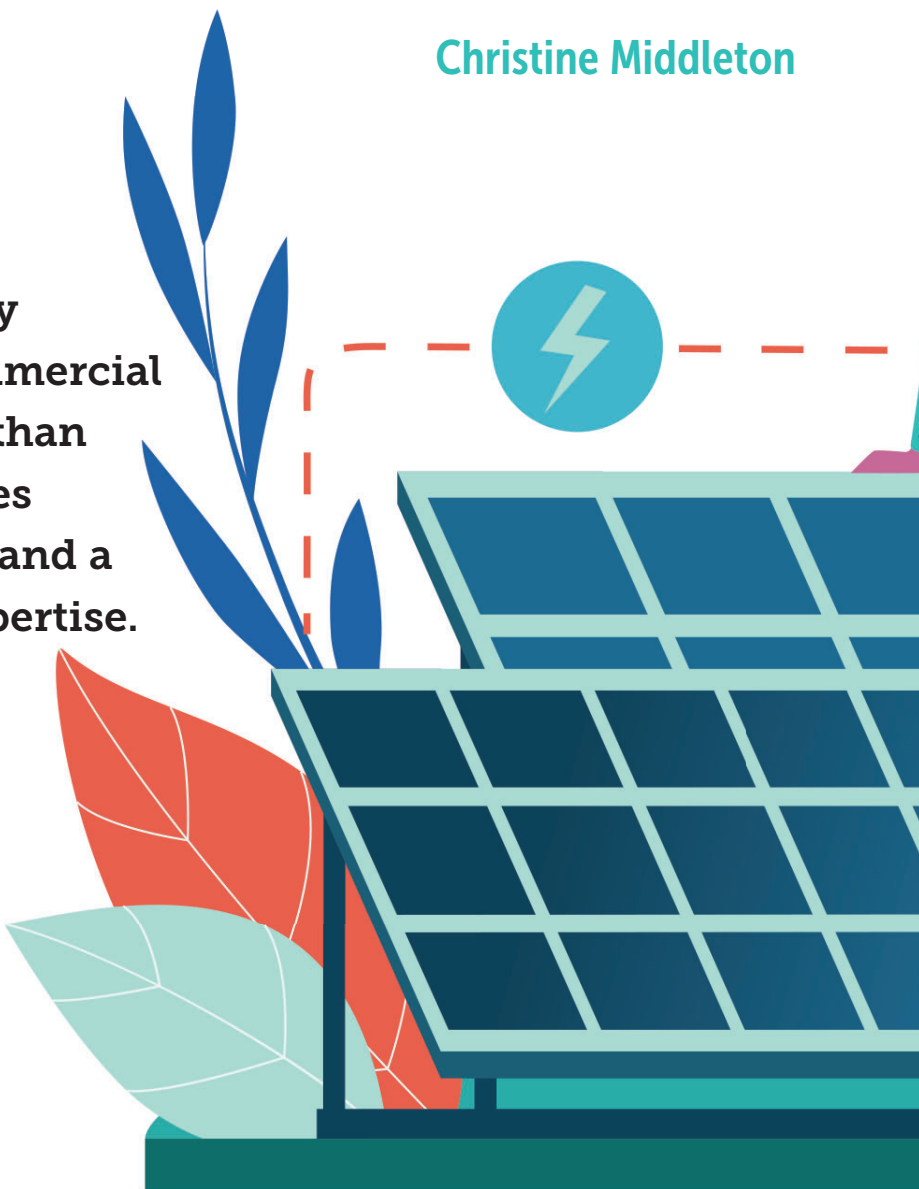


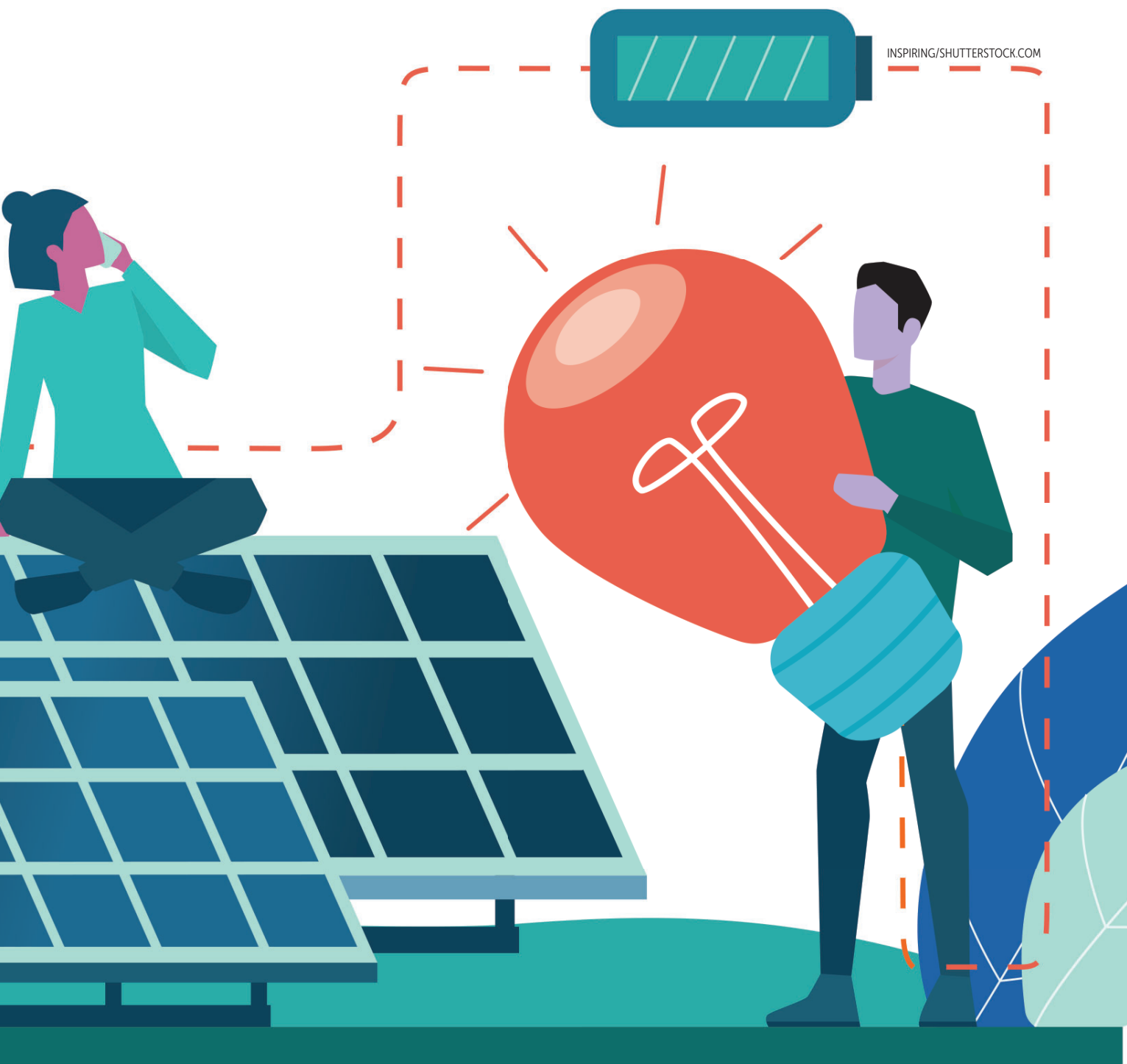


The road from **academia** to **entrepreneurship**

Christine Middleton

Developing laboratory innovations into commercial products takes more than a great idea. It requires financial investment and a team with diverse expertise.







niversity researchers are responsible for nearly half of all basic research performed in the US¹ (see figure 1). But what happens when that research yields a discovery or invention that could have practical applications? If a technology is going to be of use, it has to make its way out of academia and into a company that can bring it to market.

Startups are an increasingly popular route for commercializing academic research; more than 14 000 startups based on academic research were formed from 1996 to 2017, and more than 1000 per year were added^{2,3} in 2018 and 2019 (see figure 2). But pursuing that route requires expertise in areas such as business, marketing, development, and manufacturing that are likely not covered in most scientists' PhD programs. It also requires money. For a potential first-time entrepreneur, it can be difficult to envision what the process entails—who should be involved, what funding sources are available, and how to handle intellectual property—or where it begins.

Early days

Any new invention or discovery should be discussed early on with the university's technology transfer office (see figure 3), which helps researchers pursue intellectual property protection and commercialization (see PHYSICS TODAY, February 2021, page 24). The first step is usually to complete a disclosure form or notice of invention. That information will help the office's staff decide whether the concept is novel enough to be patented and whether it might have some commercial value.

If an invention or discovery passes both tests, the tech transfer office facilitates the patent process. An attorney, likely one who specializes in the appropriate scientific area, will handle the filing process, which can require multiple exchanges with the patent office and take more than a year. The tech transfer office also typically covers patent filing fees, which can be \$10 000–\$20 000, and the maintenance fees due every three to four years. Disclosures based on federally funded research must be reported to the funding agency within two months, another task the office usually handles.

Tech transfer offices need money and experts to run, which is why considerable disparities in resources can be found across academic institutions. Large universities with a history of successful tech transfer and commercialization are able to provide more specialized guidance and may even host their own startup incubators or entrepreneur training programs. Researchers from smaller universities that don't generate many patents may need to look for additional support from people and programs outside their institutions.

The patent process highlights an important difference between the incentives for academics and for entrepreneurs. University researchers are generally excited to share their new work with others in the community through seminars, conference presentations, journal articles, and other means. That sharing, however, can be a death knell for the patenting process. Once the information has been presented or published, it may no longer be eligible for patent protection. Consulting the tech transfer office at the first inkling that a discovery might be patentable can help prevent disqualifying disclosures.

The current system for protecting university-developed intellectual property was born out of the Bayh–Dole Act of 1980. Prior to its enactment, the federal government owned the rights to technologies developed with federal funding. At the time, however, less than 5% of the government's 28 000 patents from federally funded research had been licensed for commercial use, compared with nearly 30% of patents that the government had allowed companies to retain.⁴

Bayh–Dole allows universities to retain ownership of the intellectual property developed in their laboratories with federal funding. It was intended to help research results progress into useful products. By giving universities a financial stake in the successful licensing of their patents, the government incentivizes both universities and researchers to patent their work and to pursue and facilitate the licensing of those patents. Universities are required to give inventors a share of any royalties generated by the patent, but the percentage varies widely between universities; it typically falls in the 25–75% range and may decrease when profit thresholds are reached.⁵

Has the Bayh–Dole Act been successful? It depends on the metric. For most university tech transfer offices, the revenue they bring in through licensing doesn't cover their operating costs. In 2019, however, more than 7500 patents were issued based on academic research and close to 10 000 licenses and options were executed for the use of existing university patents.² Such licensing can be credited with creating hundreds

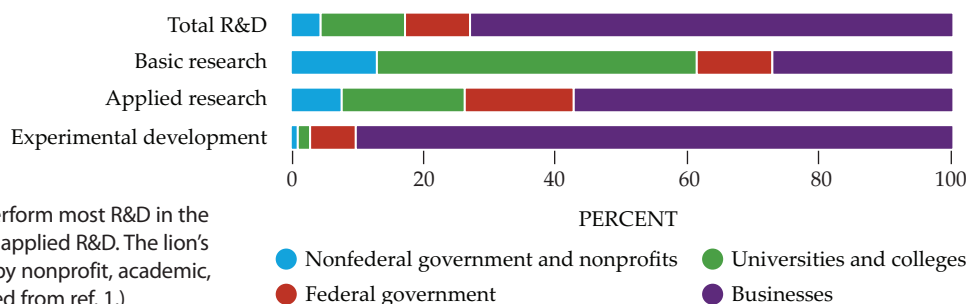
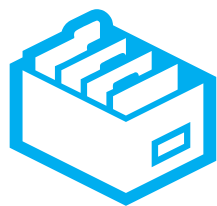


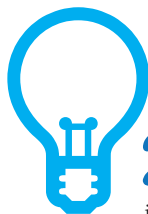
FIGURE 1. PRIVATE COMPANIES perform most R&D in the US. Much of that work, however, is in applied R&D. The lion's share of basic research is performed by nonprofit, academic, and government institutions. (Adapted from ref. 1.)

**15 972**

US patent applications filed

7528

US patents issued

**25 392**

invention disclosures

**77.2**
billion

research expenditures

6725startups still
operating**1040**

startups formed

**FIGURE 2. TECHNOLOGY TRANSFER**

continues to bring ideas from academic labs to commercial settings. These numbers reflect the state of tech transfer in 2019. (Adapted from ref. 2.)

of thousands of new jobs and adding up to \$30 billion to the annual US GDP.

Diving in

When a new technology based on academic research is patented, it typically has a technology readiness level (TRL) of around a 1 or 2. A widely used measure of how mature a technology is, the TRL scale ranges from 1 (a basic principle is observed) to 9 (operational in a target environment), as shown in figure 4. The new technology is cutting-edge research, which makes it exciting, but that novelty also means that it's not quite ready for prime time. A large company is therefore unlikely to swoop in and license a new patent. It will want to see that the science works, which can take time, and that the technology has an application for which there is a market.

Startups can help bridge the gap between basic research and commercial readiness, sometimes referred to as the "valley of death."⁶ (See the article by Orv Butler and Joe Anderson, *PHYSICS TODAY*, December 2012, page 39.) From 1996 to 2017, about two-thirds of university patent licenses went to startups and small companies with fewer than 500 employees. A so-called deep-tech startup—one based on advancing a scientific or engineering innovation rather than, say, delivering a service or developing software—would typically get an exclusive license for the patent so it could use the technology for a potential product. (The term "product" is used loosely here; it could mean a standalone device or something that gets incorporated into a consumer product. See the box on page 46 for examples.)

The people who found startups are typically those who know the underlying technology intimately: the researchers who developed it. In that case, they're likely also named on the patent and therefore have a preexisting financial stake in the startup's success. More importantly, however, researchers' deep understanding gives them a clearer picture of what the technology could be used for; they're likely to be the first to see its potential and the most excited about sharing it with the world.

Even if the founders of a startup are the inventors of the underlying technology, they generally still have to license any relevant patents from the university. A 2018 update to the Bayh-Dole Act requires researchers to assign ownership of federally funded inventions to the university where the research was performed. An inventor usually has no guaranteed right to a license. But individual rights vary depending on the re-

searcher's contract with the university, and an inventor may, for example, retain some priority status over third parties in licensing negotiations. The updated act also generally requires that licensing preference be given to small businesses.

Deciding whether and how to pursue commercialization requires more than just vision and excitement. That's where incubators come in—they provide researchers with the mentorship and tools needed to set and refine development goals, create a business plan, and take other essential steps. Not all incubators target deep-tech startups, which have different needs than companies based on, say, services or algorithms. But many do, and they're often hosted by universities or potential investors.

NSF's Innovation Corps (I-Corps) is an incubator-stage federal program designed to help researchers evaluate the market opportunity for their technology and fill any skills or knowledge gaps associated with turning their basic research into a commercial venture. Piloted in 2011, the program is based on the Lean LaunchPad methodology developed and taught by Steve Blank at Stanford University. It applies the scientific method to starting a business and pushes participants to quickly test their ideas in the "real world." Applicants must have previously received an NSF grant for related research or have participated in local I-Corps training.

I-Corps has proven effective: Through 2020 the program has spawned more than 1000 startups, which have attracted \$760 million in investments.⁷ Federal agencies, including NASA, the Department of Defense, and the Department of Energy, now also host I-Corps cohorts. Although it's not the only model for developing a business, it introduces questions and steps that are important for any potential entrepreneur.

Teamwork

I-Corps applicants begin by assembling a team of three people: an entrepreneurial lead, who will spearhead the business's development and is often a late-stage graduate student or post-doc; a technical lead, who is typically the inventor and often the research's principal investigator (PI); and an industry mentor who can provide independent advice and feedback. The mentor should have a background in the relevant technical area, and it helps if they have entrepreneurial experience or have previously been an I-Corps mentor.

The makeup of the team highlights a few important roles in a startup. The entrepreneurial lead should be passionate about

securing funding for the company and helping it grow. They'll therefore need to be able to communicate clearly and concisely with nonscientists. The entrepreneur must be able to tell a story that not only conveys the function and importance of the new technology but also creates excitement and presents a clear path to success.

Graduate students and postdocs who contributed to the invention can be natural fits for an entrepreneurial role. They have a deep understanding of the underlying technology, and they may already be interested in moving away from academia: A 2017 survey found that about half the people with physics PhDs work in the private sector (see the article by Anne Marie Porter and Susan White, *PHYSICS TODAY*, October 2019, page 32). Joining a startup can be a particularly exciting entry point into an industrial career because it involves building something new and playing a myriad of roles. It is riskier, however, than taking a position at an established company. Fewer than half of deep-tech startups become profitable,⁸ and only a small fraction of those develop into "unicorns"—wildly successful startups worth at least \$1 billion.

The technical lead's scientific expertise and vision drive the continued R&D at the heart of the startup. They may be less directly involved than the entrepreneurial lead in building and marketing the company, though, and the company's first employees are likely to be scientists who will also facilitate technical development. The technical lead can therefore be a sensible role for a PI.

Some professors may want to dive headfirst into a startup and embrace its new challenges; those so inclined are well positioned to eventually take on a full-time role as chief technology officer. But in the long run, many will choose to remain in their faculty positions.⁹ So how does one find the time to start a company? Many universities allow professors to use up to 20% of their time, or one day per week, on consulting or other related professional activities. A sabbatical can be dedicated to getting a company up and running, as can a temporary leave of absence. In the long term, however, a professor will devote the majority of their working time to the university, which means serving the company only in a part-time consulting or advisory capacity.

The industry mentor is essential in part because graduate students, postdocs, and university professors are unlikely to have training or experience in business. Like the scientific community, the business world has its own jargon, procedures, and

norms that can make communication and collaboration with outsiders challenging. Alumni offices, incubators, and advisory boards at universities can be good places to look for potential mentors. Local and regional professional societies and previous I-Corps participants can also provide guidance.

Working in industry requires a different mindset compared with academia, where research often happens on longer timelines and can be redirected by intellectual whimsies. Scientists at a startup must be goal oriented and focused on probing the details of the technology being developed, understanding why things go wrong, and directly addressing issues that arise. The work can't get sidetracked, and problems have to be solved in a robust way on the timeline laid out by the business plan.

Circumstances vary, of course, so the roles—and who should fill them—aren't set in stone. More important is recognizing the different kinds of contributions that will be essential to a startup's early success: clear communication and storytelling to generate excitement and investment, technical expertise to quickly advance the product's TRL, and guidance from the private sector to help facilitate the business's nontechnical progress. Although certain people may be able to contribute in multiple areas, building a strong team is important; starting a business is a lot of work, and it doesn't have to rest on a single person's shoulders.

The real world

When a team is selected to participate in the I-Corps program, the members are tasked with evaluating the market opportunity for their new product. Most startups fail not because the technology doesn't work but because a market for their product doesn't exist.⁷ So the team approaches potential customers, partners, and stakeholders to understand the product's potential value. Through those discussions, they try to answer various questions: Who would be interested in the product and why? How might they want to use it? Does it represent a significant enough advance to be worth incorporating into an existing product?

I-Corps teams are required to have at least 100 such meetings over the course of seven weeks. That number may sound daunting, but the information gathered from those meetings is crucial for understanding whether a startup can be successful and, if so, how it should proceed. (In fact, many teams take more than 100 meetings.) Importantly, potential investors will want to see that kind of market research when they're deciding

DEEP-TECH STARTUP SUCCESS STORIES

► **Ink** was founded by MIT researchers in 1997. The company's low-power displays generate images by manipulating microparticles using electric fields. The now widely used technology is perhaps best known for its application in e-readers such as the Kindle and Nook.

► **Alien Technology** was founded by researchers at the University of California, Berkeley, in 1994. The company's fluidic self-assembly process enables high-

speed manufacturing of RF identification (RFID) chips. Alien is a leading manufacturer of RFID-based devices and has relationships with Walmart, Hewlett Packard, and the US Department of Defense, among others.

► **Peregrine Semiconductor**, now pSemi, was founded in 1990 by researchers at the US Naval Ocean Systems Center in San Diego, California. The company's high-performance RF CMOS integrated

circuits, which implement silicon-on-sapphire and silicon-on-insulator technology, are used in a wide range of devices, including some Samsung Galaxy phones and Apple products.

► **Eden Park Illumination** was founded in 2007 by researchers at the University of Illinois at Urbana-Champaign. The company's UV lamps produce 222 nm radiation that reduces pathogens but is still safe for human exposure. The coronavirus pandemic has spurred their installation in retail and dining spaces.

whether to fund an endeavor. But making professional connections is important not just for identifying funding sources and potential customers. The new contacts will also have valuable expertise, and having so many meetings gives team members an opportunity to practice their pitch and hone their ideas.

Through all that effort, teams may learn that pursuing commercialization is unlikely to yield success, and that's okay. Not every idea is going to be successful, and it's better to find out early. The teams that do receive promising feedback will have gained a deeper understanding of both their product's value and their potential customers and investors.

Before a startup can move on to securing funding, the company needs to be incorporated. For a startup, that process achieves two primary goals: It details how equity is divided among the partners and enables the company to license any necessary intellectual property from the university.¹⁰ Although it's possible to pursue a do-it-yourself approach using online tools, the process can be complicated. Hiring a lawyer to facilitate it is generally prudent to make sure everything is done correctly. A common legal structure for startups is a C corporation, which separates the owners from the company both legally and financially, and for tax reasons, they're frequently incorporated in Delaware.

Show me the money!

New startups can benefit from federal funding specifically targeted at the development and commercialization of basic research. The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs issue grants expressly for that purpose. The primary difference between them is that to get an STTR grant, a company must partner with a research institution that will receive at least 30% of the funds. That model is well suited to startups using technology that came from academia because the company has a natural partner—the university lab that spearheaded the research. The partnership can provide continuity and facilitate a smooth transition of the research from the university to the company.

SBIR and STTR grants are awarded by 11 federal agencies, including DOD, DOE, and NSF. The grants come in three phases. Phase 1 awards support six months of exploratory research (1–3 on the TRL scale) and can provide up to \$250 000, although they typically don't exceed \$150 000. If the results are promising, the researchers may apply for a phase 2 award, which would be used to expand on the initial results and start moving from the research into the development stage (TRL 4–6). Phase 2 awards last for up to two years and can provide up to \$1 million.

The awards given in phase 3 are different in that they don't come with additional funding. Rather, they “derive from, extend, or complete” work done under a prior SBIR grant and must use funding from an external source. Although an award without funding may seem unusual, its value comes from the 20 years of SBIR/STTR data-rights protection that it bestows.¹¹ The government has access to the data produced under the award, but the data can't be disclosed to outside agencies. The protection therefore safeguards the company's value and provides a right to sole-source contracts.

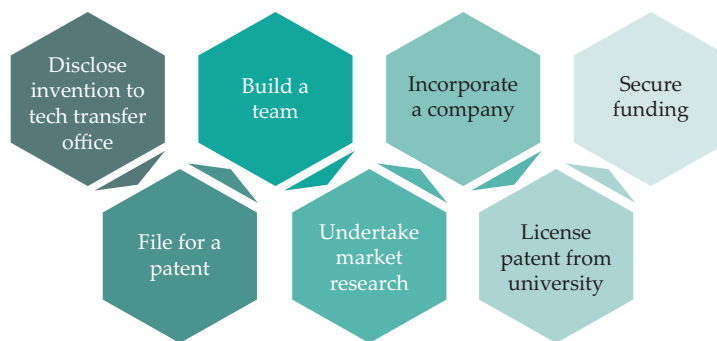


FIGURE 3. BUILDING A COMPANY from a basic discovery involves many logistical steps before the R&D can start. Although not comprehensive, this sequence captures some important benchmarks.

SBIR and STTR grants are important examples of what's called nondilutive funding, in which owners don't have to give up equity in their company in exchange for financial support. But they're not the only examples—some government agencies have other small-business grants, and financial support can also come from, say, foundations or startup competitions.

The structure of a phase 3 award, however, hints at an important point about startup funding: Deep-tech companies often need private financial support to get up and running. Grants can be a good starting point, but eventually the company will almost certainly have to secure outside money. The sources of those investments broadly fall into two categories: angel investors and private-equity firms.

Angel investors are high-net-worth individuals who provide startup funding in exchange for equity in the company, meaning the funding is dilutive. Because the money is coming from an individual, they may be looking for a project that will not only provide them a return on their investment but also feel exciting or influential. Securing investment from an angel can hinge on the entrepreneur's ability to develop a personal relationship with that individual. Angels are more likely to invest at an earlier stage than a firm might, and they're usually more hands-on regarding the company's development.

Private-equity firms pool capital, such as pension funds, from high-net-worth individuals and from institutions. They then invest that money in private companies to generate returns for their contributors. Startup funding typically comes from venture capital (VC), a type of private equity that focuses on higher-risk investments in less mature industries. Still, the firm may want to see a technology at a higher TRL than an angel investor would (perhaps a 6 or 7 rather than 3–5).

VC funding is also dilutive, and the firm may require a majority stake in the company in exchange for its investment, thereby leaving the founders with less control over their company's future. The firm may also set ambitious goals for the company's development to speed up the return on its investment. That heavy hand, however, comes with an upside: Whereas angel investments are typically around a few hundred thousand dollars, VC investment is often more than a million dollars.

Navigating the landscape

Although personal relationships may be less important for attracting VC investment, translating the science into language

BASIC RESEARCH	1	Basic principle observed
	2	Technology concept formulated
	3	Proof of concept established
DEVELOPMENT AND INNOVATION	4	Small-scale prototype in the lab
	5	Large-scale prototype in the intended environment
	6	Prototype system verified at near-intended performance
DEPLOYMENT	7	Pilot demonstration at precommercial scale
	8	Technical and manufacturing processes in place
	9	Product commercially available

FIGURE 4. AN INNOVATION'S MATURITY can be characterized by its technology readiness level (TRL). Research at low TRLs (1–3) is typically performed at universities and funded by grants from foundations and the federal government. Work on technologies at high TRLs (7–9) is often funded by corporations. Startups can help bridge the gap between those development levels.

that investors can understand is still crucial. The entrepreneur will have to convince the firm that the idea is groundbreaking and in demand enough to eventually make the investors a profit—their primary focus—while also assuring the VC fund managers that the startup has the technical capabilities to develop the product. Scientists often focus too much on an invention's uniqueness rather than its market potential, and that can weaken their argument. Assembling a strong team that combines business and technical expertise is critical for convincing investors that the company is poised for success and can achieve its goals.

Researchers coming from academia can struggle to manage investors' expectations. Many academic seminars or conference talks end with broad statements about a technology's potential, but investors can hear them as assertions about what the company plans to accomplish. Setting and communicating realistic goals is critical for ensuring that everyone is on the same page. And building some wiggle room into any proposed timeline can help with meeting deadlines. In academia, progress often happens on a more flexible schedule; at a startup, missing deadlines costs investors money.

Technologies born from research in the physical sciences can be a harder sell for investors than, say, service- or algorithm-based ones because they require more time and money. Whereas a tech startup founded on applying artificial intelligence may be able to create its product within a year, the R&D behind a manufactured product often takes five to seven years and sometimes more. It may also involve multiple rounds of in-

vestment totaling tens or even hundreds of millions of dollars. Cutting-edge deep technologies can also be difficult to explain, which makes it challenging to convince investors of the potential value—and important that the entrepreneur is an adept communicator and salesperson for their idea.

On the bright side, physical-sciences technologies can be easier to bring to market than medical and pharmaceutical products, which typically require years of clinical testing and wading through red tape. But regulations may still govern a deep-tech startup's eventual product—for example, a new rechargeable battery would have to be proven safe for consumers and the environment. If regulatory hurdles exist, someone with the appropriate expertise should be part of the team.

One characteristic that many startups have in common is their end goal. Success usually means being bought by a larger company. At the outset, entrepreneurs might imagine their company growing, becoming self-sufficient, and flourishing. Although that trajectory is possible, it's not the only picture of success. Selling is the fastest and easiest way for investors to get their return on investment and move on to the next opportunity. Another option is an initial public offering, which enables them to realize their gains by selling stocks to public investors. But that process is arduous and expensive, so a sale is most investors' preferred route.

Deep-tech startups based on university research are high-risk, high-reward endeavors. But when they succeed, they enable cutting-edge, undeveloped technologies to realize their potential in commercially viable products (see the box on page 46). And the researchers behind the company reap more than just financial benefits. They also get the satisfaction of influencing people's lives with their work.

Thanks to David Grier and Andy Kent for sharing their experiences and continuing to teach me outside the classroom, and to Dan Pisano, Steve Blank, and Steve Weinstein for sharing their insights.

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