Risky business: A study of physics entrepreneurship

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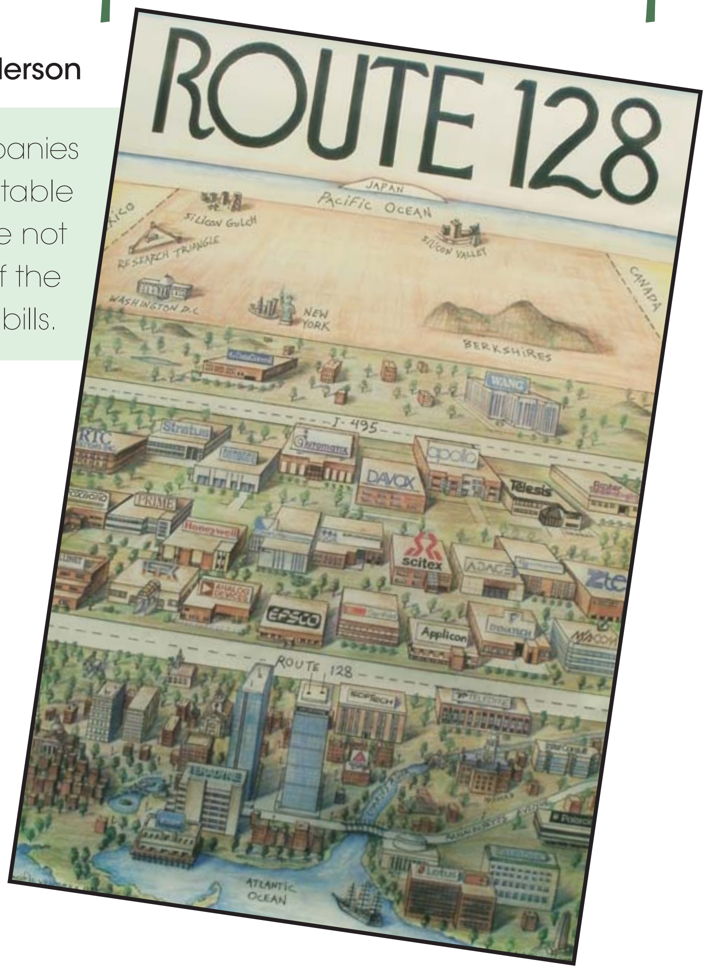
Physicists who work at startup companies create and improve marketable technologies. But their goals are not always aligned with those of the funders who pay the bills.



Route 128, near Boston, passes through a famously dense concentration of startup companies. (Poster by Kirby Scudder, 1987; used by permission.)

Physicists are old hands at entrepreneurship. They played an important role in the first generation of technology-developing companies—startups—that emerged in California's Silicon Valley and along Boston's Route 128 after World War II. Today, perhaps more than ever, physicists are involved in startups either as founders or employees. Max Lagally, a professor at the University of Wisconsin–Madison and cofounder of the nanopositioning company nPoint suggests that in addition to the traditional employment sectors in academic institutions, government labs, and large corporate labs, founding or cofounding a physics-based company can be a fourth career path for young physicists.

Startups give their founders extensive autonomy and offer them the opportunity of creating important new technologies; the founders may even become wealthy. However, many how-to books on entrepreneurship emphasize that startups entail risk at every stage of development,[1] and venture capitalist Daniel Hullah stated at this year's March meeting of the American Physical Society that the history of industry says most startups fail. R. C. "Merc" Mercure Jr, a physics entrepreneur based at the University of Colorado Boulder, has told us that venture capital successes are "black swan events"; they can't be predicted but can be rationalized after the fact.[2]

To understand the nature and dynamics of recent physics entrepreneurship, the Center for History of Physics at the American Institute of Physics (AIP) is conducting a nearly completed four-year study of high-tech startups founded by groups that include one or more PhD physicists (reference 3; see also the article by Michael Jacobs in PHYSICS TODAY, January 1982, page 34). The study, funded by NSF, builds on the history center's successful History of Physicists in Industry research project completed in 2008 (reference 4; see also our article in PHYSICS TODAY, July 2009, page 36). The earlier study found that large corporate R&D laboratories increasingly rely on obtaining new technologies from small startups rather than developing them internally. The large corporation's role is now relatively well understood,

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The 91 startup companies at which the authors conducted interviews are located throughout the US, but they tend to group into regional clusters.

and our new study investigates the structure of physics entrepreneurship.

We have concluded fieldwork, have conducted an extensive literature review, and are working with archivists at a number of repositories to identify and acquire historically valuable records of some of the startups. We surveyed physicists who earned PhDs in the US between 1996 and 2001 and who were working in the US in 2010–11; nearly 1500 of them responded. We've interviewed 129 of the 192 founders and 16 other company officers at 91 startups located in entrepreneurial clusters in 13 states (see the figure above). Of those 91 startups, 6 have gone out of business since we visited, 6 have launched initial public offerings, and 5 have been bought out.

We used qualitative methods in the study because they work best for exploratory, field-focused, and inductive inquiry. They have also generated verbal and richly descriptive data in an area that had not been extensively examined before. Each interview was constructed to allow us to raise some questions that are structured and others that are more open ended.

Our findings describe the value of physics startups to high-tech innovation, startup funding structures, the role of academic technology transfer programs, and regional differences among startup clusters. In addition, we have identified some factors that may be indicators of success or failure; some mistakes to watch out for are summarized in the box on page 44.

From academe to startup to market

Because the large high-tech companies that once supported significant research have switched to development, the role of small startups as creators of innovative physics-based technology has become more important. Lita Nelsen, director of MIT's Technology Licensing Office, describing the general decline of the once-great industrial labs, noted that "we're dependent on the universities to be pushing the frontier of knowledge because the research labs in industry are largely shut down." She added that more than half of the MIT patents for really innovative, early-stage technology are being licensed to startups. According to Nelsen, once a startup has proven an innovative technology, "the large companies will then buy either the product line or the company, and that is a conscious strategy for acquiring new technology now because it reduces their risk." For a proven technology, large companies sometimes pay 100 or even 1000 times what they would have paid had they licensed the same technology from a university at an early stage.

As spelled out in the table on page 42, the companies in the AIP study cover a wide range of fields. Although many startups create technology, most of the interviewees told us that their primary focus is on development rather than research. More than half of the companies are working to develop and perfect new technologies based on research that came from elsewhere. Of those, 41 have brought new technologies out of university research, 6 have transferred their basic technologies from national labs or another government agency, and 2 brought their technologies from previous companies started by the same founder.

Most of the companies transferring intellectual property out of universities or national labs could be classified as "technology push" companies, whereas most of those bringing improvements to existing technologies might be described as "market pull" companies. Market pull companies serve well-defined markets. On the other hand, technology push companies frequently have to find or create their markets. Many have to shift to new markets to find the right niche; some do so successfully, some don't. A third and much smaller group in our sample might best be described as service companies.

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The technology push companies are the riskiest in terms of survival, but they also offer the greatest likelihood of creating breakthrough technologies. Market pull companies, on the other hand, can create important refinements or improvements in existing technologies.

Of the 91 companies in our study, 50 did not have university-related research as a critical component when they began. Most of them were created to provide technological solutions or services to the marketplace. Some had developed technologies based on expertise the founders had developed during graduate school or at another company, but the technology itself was not using intellectual property from the university. Some of the startups provided consulting services or technological resources to other firms or government agencies. Another group had developed solutions to market problems—cheaper components or specialized equipment that did not derive from research. In that last case the intellectual property appeared to lie in the application of established science.

Follow the money

Funding is as critical in physics startups as in other businesses, and those who provide capital exert significant and sometimes decisive control over a company. Furthermore, the sources of funding for physics startups have changed significantly since the late 1990s and early 2000s. As a result, the sources that entrepreneurs select and their choices of when to move from one source to another have been as important in determining the success of their companies as the technologies they are developing. Robert Black, founder of CivaTech Oncology in Research Triangle Park, North Carolina, told us that when you go to a meeting of entrepreneurs, funding is "the first and only topic discussed," and there are lots of opinions as to what works best. Nearly all of our interviewees put great emphasis on financial backing, and based on what they told us, we identified four different models: venture capital, grants from the Small Business Innovation Research (SBIR) or Small Business Technology Transfer (STTR) programs, angel investors, and bootstrapping. Companies typically use varying combinations of the four models at different stages in their development; the precise formula they use depends on both the relative availability of funding sources and the perspectives of founders and funders.

Venture capital (VC) is a form of private equity that invests in the founding and development of businesses. Public VC firms professionally manage funds created from pools of investors' money. Although 25 of the 91 startups in the study relied on at least some VC—the total investment in those companies was about $1.2 billion—both physicists who had used venture funding and those who had not reported significant tensions between the goals of physics entrepreneurs and venture capitalists. Some even claimed that VC stood for vicious or vulture capital. Many of our interviewees added that venture firms have become more conservative over the past decade and are increasingly committed to short-term investments that yield big payoffs. James Vickers, cofounder of tau-Metrix in Santa Clara, California, said that VC firms are "looking for something huge . . . billion-dollar markets." Alex Shimkunas, another Santa Clara physics entrepreneur, said that when he cofounded Nanostructures in 1987, it was easy to get a lot of money from venture firms. These days, he and others agreed, it is quite difficult to get venture funding.

One basic source of tension between physics entrepreneurs and venture capitalists is control over the amount of time allotted to go from proof of concept to a commercial product. Physicists typically want to invest extra time in research to perfect a technology, whereas venture capitalists want to obtain a profitable commercial product as soon as possible. On a closely related theme, physics entrepreneurs often seek to maximize the long-term value of a technology, but venture capitalists focus on maximum short-term return on investment. By accepting venture funding, physicists give up significant control over their company and run the risk that the investors will cut off funding and close the business if deadlines aren't met.

A number of interviewees, however, distinguished between venture capitalists with business backgrounds and those with science degrees. They said scientifically trained investors are more willing to listen and respond to technical arguments for extending the development period and are generally easier for physics entrepreneurs to work with. Interestingly, even though physicists in the two areas with the highest concentrations of venture firms, Silicon Valley and Boston, typically said that their own startups didn't mesh with VC funding, they often described venture capitalists, including those with business backgrounds, as helpful and willing to connect them to alternate funding sources. In contrast, physics entrepreneurs in the Midwest, which has one of the lowest concentrations of venture firms, tended to be more critical in describing venture capitalists.

Hullah presents the view from the other side. He points out that venture capitalists think in terms of an investment portfolio of companies, not individual companies. The "VC model is built on outsize returns from the success of companies. You're taking a huge amount of risk. When companies succeed, they're disproportionally valuable." He adds, "Often in a portfolio of 20 companies you might have half of them that don't recover capital for the venture capital firm. . . . What we're looking to do with initial investments in companies is take out as much risk as possible as quickly as possible. . . . We're looking to make progress quickly, either to fail fast or succeed fast."

Feds, friends, family, and angels

The SBIR and STTR programs provide federal grants to support the development of innovative technologies by small, for-profit businesses. The SBIR program is older, originally enacted in 1982; STTR was enacted 10 years later. Some 55 of the startups we studied drew on some form of government grant or contract. Of those, 52 received at least one SBIR or STTR grant. Together they obtained almost $155 million in SBIR or STTR funding; the median amount received by those companies was $1.15 million. Some firms were awarded multiple grants that enabled them to invest more time in developing their technology.

Today 11 government agencies participate in the SBIR program and 5 participate in STTR. The SBIR program is larger and was more likely to fund the companies in the study. The Department of Energy program, which is typical, states that the goals of DOE SBIR are to provide funding to stimulate innovative technology, encourage small businesses to meet federal R&D needs, support woman- or minority-owned businesses, and increase commercialization of federally funded R&D. Today, the programs have put an increased emphasis on providing "seed capital for early stage R&D with commercial potential."[5]

Applicants to the DOE SBIR and STTR programs stand about a 10% chance of receiving phase-one grants, which are meant to allow participants to achieve a proof of concept. Nearly half of the phase-one recipients obtain phase-two funding, intended to allow the development of products that appear to have commercial potential. Competition for the grants is stiff, but the payoff for successful applicants is that they receive financial support without surrendering control of their company or risking their own resources.

A surprising number of interviewees described the SBIR and STTR programs as essential to the development of their technologies, especially as VC has become harder to obtain. Michael Anderson of Vescent Photonics said that the SBIR and STTR programs are things that the US does very well and that they really help with innovation. However, some individuals said that they avoided SBIR funding because of the application and reporting requirements. Others suggested that SBIR funding detracted from a focus on real products and customers. David Carnahan of NanoLab told us, "If you're just working on government contracts, there's no sense of urgency or working for a very strong purpose." More recently, even VC-funded companies have turned to SBIR and STTR grants as they wait for their markets to grow.

Fields of physicist-entrepreneurs' endeavors

Field	Number of startups in study
Electronics/components	19
Medical devices and equipment	18
Instrument systems	12
Energy	9
Networking and equipment	9
Software	8
Consulting	4
Biotechnology	3
Contract R&D	3
Semiconductors	2
Computer equipment and peripherals	1
Data management and analysis	1
Intellectual property	1
Services	1

Angel investors are wealthy individuals who provide funding for startups, usually in return for ownership equity. Of the 91 companies, 24 had used angel funding at some point in their development. Angels are traditionally single individuals, but we also encountered angel pools, especially in the Midwest where fewer VC firms operate. The investments that angels make are typically smaller than those by venture companies, but angels are usually willing to wait longer to obtain a return on investment and may focus more on issues of company building. Silicon Valley entrepreneur Phillip Paul, cofounder of Eksigent, said that his company originally planned to fund its startup through VC. However, it turned to an angel because angels "will invest at a much earlier stage . . . [if] they like the concept. They'll throw some seed money at it." A recent Harvard Business School paper states that angel-backed startups are less likely to fail than startups using other kinds of funding.[6] However, angel investor Rory Moore points out: "You run out of angel money eventually; friends and families run out of money." Then it's necessary to turn to VC or government funding.

Bootstrapping, the fourth funding model, includes personal investments by startup founders and by their friends and families. Only 10 startups in the study relied entirely on bootstrapping, and they were not typical of other high-tech companies that we visited: Seven were one- or two-person firms providing only consulting or contracted services, and the remaining three improved on existing products instead of creating new technology. However, quite a few founders used their own money or a combination of their money and angel funding to hold them over when other funding wasn't available or to assist them in achieving a proof of concept. Several companies relying primarily on bootstrapping obtained assured revenue by developing customer relations or partnerships with established firms early on. Ningyi Luo, cofounder of Pavilion Integration in Silicon Valley, described a progression of funding that was echoed in different forms by other interviewees. He said that his company began by self-funding; it bought 95% of its lab equipment on eBay. Once its technology was "demonstrated" and protected by patents, he turned to angels and raised \$650 000 to move through technology development to product. Once the angel funding dried up in two or three years, the firm returned to self-funding until it obtained capital from a Chinese VC firm to build a clean room in China for manufacturing.

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Help from the university

The Bayh–Dole Act of 1980 provides that intellectual property created through federally funded research is owned by the sponsoring institution instead of by the federal government. Since most academic science research includes federal funding, the legislation has had a major impact on academic science programs and on the development of technology transfer programs, which license intellectual property to existing companies or to faculty-sponsored startups.[7]

Technology transfer programs are important in determining whether academic research has a chance for commercialization. We accordingly interviewed tech transfer officers at 11 schools and at the Triangle Research Park, being careful to choose institutions whose programs are at different levels of development. Among the schools we visited were Stanford University, MIT, and the University of Wisconsin–Madison; all were active in technology licensing before the passage of the Bayh–Dole Act, and all remain among the strongest in terms of licensing and commercializing intellectual property. In addition, we asked company founders about their utilization of technology transfer programs.

University technology transfer programs can be divided into two types. One sees technology transfer as an immediate revenue stream for the university and focuses on obtaining licensing fees and royalties. The other type concerns itself more with the long-term development of its university's technology spinouts. This second type often takes an equity share in exchange for all or part of its licensing fees and either helps the startups network with potential funders or provides seed funding.

The entrepreneurs had mixed attitudes toward technology transfer offices. They generally praised those that saw startups as potential investments. But in their view, tech transfer offices that see licensing as primarily a revenue stream create a roadblock to technology development in small startups. Several professor-entrepreneurs expressed particular appreciation for their tech transfer programs; for instance, at Harvard University, MIT, and the University of Illinois at Urbana-Champaign, the university covered their patent costs—a major expense—and then licensed the technology to them. MIT's Nelsen said that an "average US patent in the Boston area in technology will cost you somewhere around \$25 000–\$30 000." Global patents easily double the costs. Nearly all faculty cited paying for patenting costs as an important benefit, but not every tech transfer office provides that benefit.

Tech transfer programs differ in the emphasis they put on licensing to startups versus licensing to existing companies. Katharine Ku, director of the Office of Technology Licensing at Stanford, said, "We've taken an agnostic view of startups. . . . We support them, but we don't create them." She added that on average, 10% of their licenses go to startups. Her statement appears to describe most tech transfer programs, although exceptions exist. Faculty entrepreneurs at MIT agreed with Nelsen that the institution puts a strong emphasis on licensing intellectual property to faculty. Nelsen said that about a quarter of her office's intellectual property is licensed by startups coming out of the university, "but from the viewpoint of the . . . really innovative stuff as opposed to little things, more than half." MIT PhD Alexei Erchak, founder of Luminus Devices, confirmed that MIT has "pioneered an environment that encourages companies to spin out of academia."

Location, location, location

Many states, cities, and universities throughout the US are making concerted efforts to foster economic growth by supporting technology entrepreneurship and startups so as to create high-tech clusters. For example, at least 27 states provide funding, ranging from \$1000 to around \$7500, to help startups apply for SBIR or STTR grants. Some of the states also provide matching funds for successful SBIR or STTR applicants located in the state or willing to move there, and others have created venture funds and various mechanisms to promote new startups. However, there is no sure-fire funding model. Only two of the companies in our study had been successfully recruited to a new state, but sometimes financial inducements had influenced the location within a state. Applied Optoelectronics's Stefan Murry told us that his company looked at several areas in the vicinity of Houston, Texas, and picked Sugar Land because it was growing fast and "had an aggressive package of financial incentives" for locating there.

The critical elements for a high-tech cluster to thrive appear to include a combination of the physical resources and human capital represented by academic institutions, other businesses that can supply support and materials, investment sources, and an important amount of serendipity. Perhaps not surprisingly, 52 of the entrepreneurs we interviewed said they started the company at the location they did because that's where they lived.

The clusters show distinct regional variations. For example, Indianapolis, Indiana, is dominated by medical technology startups, and Tucson, Arizona, by optical technology. Other clusters represented many different fields. Both Boston and Silicon Valley have strong entrepreneurial networks, but Boston's is more formal and structured, reflecting the local culture. On the other hand, Stephen Fleming, executive director of the Georgia Tech Enterprise Innovation Institute, said that tech startups in the Atlanta area are impacted by a lack of local VC, and potential angel investors in the region are too risk averse to invest in startups. Funding sources, too, cover a wide gamut by area. Venture capital is strong in traditional entrepreneurial hotspots like Silicon Valley, Boston, and Southern California, but other areas rely on other funding sources. Wisconsin startups, for example, turn to funding from the Wisconsin Alumni Research Foundation and a network of angel investors. Texas entrepreneurs have shown an interesting way of getting VC funds without ceding VC firm control. They obtain funding from multiple venture companies, and thus prevent any one from dominating.

How to create an unsuccessful startup

Our goal in conducting the American Institute of Physics study on physics entrepreneurship is to pull back the curtain on a complex and volatile landscape to better understand trends and processes. We have found no formulas for building or funding the next billion-dollar startup, but we have seen that avoiding the following pitfalls improves an entrepreneur's chances for success:

- Moving to venture capital funding too early, leaving inadequate time to develop the technology.
- Relying too heavily on federally funded Small Business Innovation Research or Small Business Technology Transfer Research grants and thereby moving too slowly to respond to the marketplace.
- Depending on a "make the technology and they will come" approach instead of focusing on the potential market from the beginning.
- Failing to develop business expertise or bring it into the company.
- Insisting on full control of the company rather than ceding or at least sharing control as needed to develop a business strategy.

Paperwork and paper trails

Government regulation is an important concern for all private businesses. We were surprised, however, at the regulations that most vexed startup founders. Few founders mentioned taxation, though several in passing mentioned the complexity of taxation. Many cited the difficulties of providing health care among policies with which they struggled. More frequently, however, government restrictions on immigration and technology exports offended the sensibilities of the founders. Immigration restrictions, they complained, inhibit the growth of their companies. Second only to problems with immigration policy, founders complained about International Traffic in Arms Regulations, which control the export of defense-related material and which, they say, force them to move research abroad. A California entrepreneur reflected the views of many when he told us, "The ITAR rules kill exports."

The high percentage of immigrant entrepreneurs in our study reinforces the importance of immigration reform for the continued success of US innovation. More than a quarter of the founders of the companies we studied had come to the US as immigrants, many as students. And several who were not themselves immigrants were children of immigrants.

A Texas physicist suggested that immigration restrictions were "kicking out 50%" of innovators in the US. Other countries are "hungry" to get those "high-tier" people and offered "very good opportunities." The US, he complained, was "doing the opposite. They are pushing people out." He concluded that although the immediate effect might not be noticed, the US would see a "big effect in 10, 20, or 30 years."

Over time, record keeping at startups will largely determine the extent to which historians and other researchers can understand today's technology culture. However, we found few or no consistent record-keeping policies among the people we interviewed. To the extent that written-records policies had been implemented, they had been imposed by contractual requirements or government regulations. Most interviewees told us that records policies were limited or nonexistent, but that laxity was not seen as a problem because during the initial phases they kept "everything." Lab notebooks, the traditional source for documenting science, were used inconsistently. Some companies made failure to keep a notebook a fireable offense, others left it to the individual. We have begun to link companies with regional or national archives that will work with them to preserve records, but it's too early to tell if those efforts will succeed.

Starting a physics-based company is a complex operation. The payoffs for pulling it off can be significant, but as in other forms of startups, the failure rate is high. Indicators of failure are usually clear, but identifying success is more nuanced. Many founders said that success consists of creating solid businesses that endure over time, make a profit, provide steady employment, and conduct a mix of R&D. Others described success as developing important new intellectual property that could be incorporated into disruptive, game-changing commercial property or processes. On the other hand, venture capitalists and some physicists defined success as obtaining big profits in the short term—turning their money into more money.

Entrepreneurship is popular among scientists, and a large number of physicists—both recent PhDs and mid- to late-career individuals—found startups. However, reducing risk has become a major feature of high-tech entrepreneurship. Since the mid 1990s, venture capitalists have been reducing their investments in seed and early-stage companies and have focused instead on later-stage companies ready to bring products to the market. As a result, in order to establish proof of concept and fund early development, early-stage entrepreneurs have turned to alternative sources of funding, including angel investors and especially the SBIR and STTR programs. The innovators thereby retain control of their technology, at least until products are ready for the market; that move appears to reduce risks. The market, though, remains the final arbiter of success or failure.

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