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What's the Big Idea?

A venture capitalist takes on fusion energy.

I am a venture capitalist and have been for 27 years. Trained in nuclear engineering in the 1970s, I worked in that profession until 1988, when I joined Venrock, the private venture partnership of the Rockefeller family. Since then, I've learned a fair bit about entrepreneurship, risk taking, and how to build great companies. At Venrock, I led the financing of 53 innovative companies from their beginnings, including a 1991 investment in Spyglass, one of the very first Internet companies. Spyglass went public in 1994 and was acquired for $1.9 billion a few years later. Seven of my companies successfully completed initial public offerings, including Check Point Software, on whose board I still serve. Three dozen of the companies were successfully acquired at a profit to everyone involved. And the others—well, they are somewhere still in development, or didn't make it. When I was a managing partner at Venrock, the firm launched over 300 companies. Our earliest greatest hits included Intel and Apple, followed more recently by Check Point, DoubleClick, Gilead Sciences, Imperva, Athena Health, Vontu, Anacor, and CloudFlare.

Venture capital (VC) is itself an innovation—a financial innovation—that can trace its roots back to the great inventors of the nineteenth century. Thomas Edison is famous for his pursuit of a practical and economically viable light bulb. After what some say were 6,000 attempts with various materials, gases, and shapes, in October 1879 he found just the right material and a design that worked. Who supported Edison in this risky endeavor? An early venture capitalist, his father, who set him up in a small laboratory in Menlo Park, New Jersey.

Today's style of institutional venture capital investing began in the 1960s, with roots going back to the 1930s. It grew out of "wealthy family office" operations such as those of the Rockefellers, Whitneys, and Bessemers. George Doriat of Harvard Business School is considered the first venture fund founder. His big deal was the Digital Equipment Corporation (DEC), which is still the granddaddy of all VC investments, with a 50,000-to-one return on cash invested at the time of DEC's initial public stock offering. Venture capital investing was institutionalized in the 1960s, when Congress changed banking laws to allow pension funds and banks to provide capital to new venture firms then being formed. The use of employee stock options to incentivize startups was another important economic innovation for venture investing. But the true magnet for venture capital is a great idea by an ambitious person or team.

Each year in the United States, about 20,000 companies are started, and between 1,000 and 1,200 young startups mature to the point of attracting their first professional venture capital—a number that has held steady for more than a decade. In 2014, venture capitalists invested $51 billion, according to surveys by PricewaterhouseCoopers and the National Venture Capital Association, a level that is likely to be maintained or slightly exceeded for 2015. In 2000, at the height of the dot-com boom, this number spiked to $103 billion.

Venture capital investment accounts for only 0.5% of all private capital investments in the United States. This amount is about 15% of the U.S. government's annual research and development (R&D) investment, and 7% of all private R&D spending—but it packs a big economic wallop. CB Insights and the National Venture Capital Association estimate that 22% of America's 2014 gross domestic product resulted from companies that were originally venture-backed. Forty-six of the Fortune 500 companies, with names like Apple, Intel, HP, Genentech/Roche, and Federal Express, were founded with the sponsorship of venture capital. Correspondingly, about 11% of private employment in the United States is by companies that were venture backed. These are astonishing figures at the macro level. In short, the benefits to society from venture capital, in terms of job creation, quality of life, and growth of the tax base, are huge.

Today I'm involved in what might be the riskiest and most significant venture project of my career. It's an energy development company that, if it succeeds, would change the world in profound ways. The company is Tri Alpha Energy. It is developing a fusion-based technology called Plasma Electric Generator (PEG) that could ultimately deliver commercially competitive base load electric power. Tri Alpha's approach is compact, carbon-free, and sustainable, with an incredibly clean environmental profile. The Tri Alpha fuel is hydrogen and boron. This fuel source is plentiful worldwide. If successful, this technology would address two of the world's great challenges: climate change and the need for limitless, cheap electric power.

Why would a venture capitalist pursue a speculative line of technology? Governments have already poured tens of billions into fusion research for decades, with scientific progress, but little to show for it commercially. Aren't we VCs supposed to be ruthlessly focused on finding ideas that we think can be brought to market with reasonable investments and in reasonable periods of time? Of course. But sometimes an opportunity presents itself that, if it works, can change the future forever and for everyone. Even if it is a long shot, it is worth pursuing. Tri Alpha Energy is a case in point.

Science primer

Historically, fusion-based electricity generation efforts have been hampered by two fundamental challenges: the inability to maintain fuel particles long enough and at temperatures hot enough to allow the nuclei to combine or fuse.

Many strategies to accomplish fusion have been attempted over the decades. The two main approaches are tokamak magnetic confinement and inertial confinement with lasers. The tokamak is a large toroidal-shaped machine developed by the Soviets in the 1950s. It is dependent on an extremely complex magnetic containment system. Tokamaks, which use a deuterium-tritium (DT) fuel cycle, have been the dominant design for fusion reactors.

This is the technology employed for the International Thermonuclear Experimental Reactor (ITER) project in France. ITER is funded by a consortium of governments, including the United States, with a price tag that could be upwards of $50 billion. It will take decades to construct, and its "first plasma" is not expected until at least the late 2020s.

The alternative approach, inertial confinement, is being pursued at the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory. This massive facility produces 500 terawatts of laser power simultaneously directed through 192 beams at a single tiny pellet of frozen DT. The basic idea is to capture heat from very tiny thermonuclear explosions at a high repetition rate. At this point, NIF does not seem like a good candidate for energy generation and is being used for scientific purposes.

Tri Alpha uses yet another approach conceived in the early 1990s by researchers at the University of California (UC), Irvine, led by Norman Rostoker. With the same physics principles used in particle accelerators (which scientists had already proven could confine charged particles), he thought that, using a cylindrically shaped fusion reactor, one could create, confine, and heat a football-shaped plasma rotating on its long axis inside a vacuum chamber. Then, with a well-known technology called the neutral beam injection (a device that converts a powerful accelerating beam of ions into neutral atoms), one could inject a beam of atoms at the outer edge of the plasma, imparting momentum and energy and confining it indefinitely. The configuration is not unlike a child's top spinning on a flat surface. The top is the plasma. Your hands can act like the neutral beam if you use them to impart additional rotational momentum by simultaneously pushing and pulling on both sides of the top, thus keeping it spinning indefinitely.

Rostoker also proposed a hydrogen-boron fuel cycle, or pB^{11}, which fuses a hydrogen nuclei, or a proton, with a boron-11 nuclei. The pB^{11} fuel cycle requires a temperature perhaps 20 to 30 times higher than a DT reaction, but Rostoker thought this was viable because accelerator technology worked at much higher energies than the tokamak. And pB^{11} has the great virtue of being aneutronic: it results in X-rays and three alpha particles with no primary reaction neutrons.

While the DT reaction is therefore easier to achieve scientifically, since the temperature required is relatively low, it has the downside of producing a very high energy (14 MeV) neutron for each fusion reaction, a highly radioactive process. Managing neutrons is a very difficult engineering problem that also results in large amounts of highly radioactive waste. pB^{11} produces no neutrons and is thus much easier to manage during the fusion process, while yielding no high-level waste to manage after the fusion shuts down. Calculations indicate that the potential radiation load for a Tri Alpha Energy reactor would be no more than a modern hospital MRI.

There is a trade-off between operating temperature and radiation, but it's potentially a very smart one resulting in critically better economics. Indeed, from the very beginning, Rostoker had his eyes on a commercially viable approach to fusion-powered electricity. With science that was well understood, and with reduced machine complexity and radioactivity compared to the tokamak, Rostoker's idea had great appeal. The fusion science community, however, was very skeptical. At least one analysis, published in *Science* in 1998, "proved" it was not possible.

Cash first

Venture capital typically provides three key elements to a company. First, it provides money to entrepreneurs. Second, it guides entrepreneurs to remain focused on the prize. Third, by being patient, it allows hard problems to be solved—problems too risky for most companies to tackle alone. Let me explain each of these key points.

Cash is everything to a startup. Money pays for employee salaries, capital equipment, rent, and many other essential things that every modern company requires. Really, though, the money buys time. Time for the people in the project to

Nathalie Blanc and David Christoffel, *Climate Memoirs*, 2015.

During ArtCOP21, Nathalie Blanc and David Christoffel of la Maison des écrivains et de la littérature, participated in *Language as a Battlefield*, a discussion and performance on the power of words to shape reality. Photograph by Garance Marcon.

ARTCOP21

Thierry Boutonnier, *Éteindre l'eau (Turn Off the Water)*, 2011.

French artist Thierry Boutonnier, performing above at Centre d'art Le Lait in 2011, participated in the discussion "Producing without Reproducing: Creating New Models" at ArtCOP21. It focused on the range of ways in which artists are incorporating more sustainable practices into their work. Photograph by Phoebe Meyer.

ARTCOP21

work together to refine and test their ideas, and to progressively reduce the risk of project failure.

Raising all the money you need on day one is very difficult if the science or engineering of the product isn't yet proven. Often the CEO of the startup won't know exactly how much money will be needed at the beginning. So she needs to sort out what can be done with a certain amount of money in a certain period of time—typically 18 months or so to start. If successful, the entrepreneur can go to her investors, show what's been accomplished, and convince them to invest more money, while perhaps even bringing in new investors. Success at this stage generally means that some risk has been reduced. During the venture capital phase of financing, it is generally the case that as risk is reduced, the valuation of a company increases. Therefore, when a company completes a milestone and goes out to raise more capital, that new capital is invested at a higher valuation than the previous round of capital. As valuation rises, the existing owners' stake in the company will be less diluted, which means they get a progressively greater payback for their efforts and investments. This milestone-based financing is core to building a product rooted in difficult science involving many rounds of financing, and therefore to ultimately building a company. During the early steps, when the company has no revenues, an incomplete product, and no real proof that it'll work at all, the money is usually provided by a venture capitalist. There can be several rounds of financing over many years before the company can fund itself by selling products at a profit.

In the case of Tri Alpha, Glenn Seaborg, a former chairman of the Atomic Energy Commission, chancellor of the University of California system, and Nobel Laureate, along with a small group of visionary experts including George Sealy, a Bechtel executive, thought Rostoker's idea had merit. Seaborg and other executives set up a small research project at UC Irvine in 1998 with Sealy as the CEO. With only a few million dollars of backing from individuals, Rostoker and his team demonstrated through a series of studies and computer models that the reactor design had promise and might confine a plasma.

Having achieved this theoretical milestone, but still not at a stage to attract professional venture capital, Tri Alpha raised additional seed money from wealthy family offices of smart investors such as Mike Buchanan in San Francisco and Art Samberg in New York. With this capital, the company built a small prototype confinement machine to demonstrate the most basic elements of Rostoker's approach. In 2005, it worked.

The results of this experiment are what captured my imagination and that of a number of other professional venture investors. Still largely a science project with a long road ahead, the demonstration worked well enough that it led me to make an investment in Tri Alpha on behalf of Venrock. This was a larger capital raise, so I had to reach out to other Silicon Valley venture capitalists, including Dick Kramlich, founder of the venture firm New Enterprise Associates, who now sits on Tri Alpha's board.

Focus

The deal between a venture capitalist and an entrepreneur is really pretty simple. From the VC point of view, I give you cash. In return, you the entrepreneur give me stock in your company at a negotiated price. But (there's always a but), you must spend this money on the project you told me you were going to spend it on, mostly the way you told me you would, and in accordance with good operating principles. In short, you must stay focused on the objective you "sold me."

In addition to cash, venture capitalists provide, through our presence on the board, the tough love necessary for controlling spending, or keeping it directed toward the agreed objective. Rookie entrepreneurs often just can't keep themselves from spending money on things that don't contribute to the company's goal. With millions of dollars in the bank, they can seduce themselves into thinking, "I'll just paint this wall red to spruce up the place," or "I'll buy a real office desk for the CEO." Mostly such expenditures are a waste of precious startup capital. In my experience, the most offensive use of venture capital is presenting to your new investors at the first board meeting a coffee cup or sweater vests with the company logo—not a good sign of treasury stewardship or wise use of time. The board members can afford cups and vests.

But staying focused doesn't just mean avoiding frills; it also means keeping your eyes on the prize. In any new endeavor, a lot of learning goes on. Sometimes that learning can push the company in new directions. R&D folks love to solve problems, and sometimes those problems are not closely related to the product being designed. This is the appeal of the R in R&D. Research is important, of course, but in a raw venture-backed startup, it needs to be ruthlessly carried out in the service of the development of the intended product.

Imagine this: You have created a privately financed energy project inventing a new device, the PEG. You have recruited a world-class scientific and engineering team from all over the globe, with hundreds of total years of experience, to work on this incredible science. You have a national lab-class facility in which to work. Can you imagine the temptation to try just one more idea? It's tempting, for sure, but Tri Alpha has a management team that is singularly focused on bringing PEG to market.

Being privately backed, Tri Alpha also has a board of directors and investor group that is focused on making PEG a reality—the sooner the better. The operational focus and shared decision making between the board and the company management is a model for successful deployment of big dollars over a long time with minimal waste or disagreement. This relationship, experience, and result, in my opinion, make Tri Alpha one of the best cases from the annals of venture investing.

I take away one other significant focus lesson from Tri Alpha. Knowing that this was going to be new science if it worked, in 2005 the company engaged a world-class science panel, which meets twice a year to assess progress. The 10-member panel consists of Nobel laureates, Fermi Prize winners, Maxwell Prize winners, plasma lab directors, and the like. Their experience and perspective about the actual science risks, the public challenges the team might face when they publish results, and the need for theory and experimentation to advance hand-in-hand, were a considerable value in helping the team to maintain focus over the long haul.

Patience

In venture, we always say that it takes longer and costs more. That's certainly been the case for Tri Alpha. The company is still years away from producing "net power out," that is, generating more energy than it takes to create the fusion reaction. Continuing funding when it takes longer is a matter of trust, transparency, good operational capability, and commitment by all parties.

With any long-term venture project such as Tri Alpha, capital is always challenging and often viewed as the biggest risk to early investors. In recent years, the task has become more difficult, as many traditional venture capital sources withdrew from making energy investments with long time horizons, and as other private fusion projects began to compete for the few capital resources available for such investments. Nonetheless, from the perspective of milestone financing, Tri Alpha is incredibly successful—both in attracting capital and in developing a fusion reactor.

As of this writing, Tri Alpha has raised hundreds of millions of dollars in the past 17 years in a total of seven investment rounds, based on a milestone-financing strategy that demanded increasingly successful results. The round in which I participated, in 2005, was used to build a 60,000-square-foot facility on par with the national laboratories; to design and construct a large machine, known as the C-2; and to hire the best talent from more than 25 countries. The C-2 has operated for several years, collecting significant data about containment, control, and management of the plasma in the FRC system. And in August 2015, *Science* reported the containment breakthrough that Tri Alpha had sought, when the C-2 formed a plasma of about 10 million degrees Celsius and held it steady for 5 milliseconds.

Of course, Tri Alpha's path isn't any straighter than Edison's. There were and will be many things that the Tri Alpha team tries that simply don't work, or at least not well enough to pursue further. Sometimes these are just technical elements that take time and money to iron out, but you really don't know unless you try. At the end of the day, Tri Alpha has run over 40,000 experiments over the past several years and has generated a new level of understanding about plasmas and the FRC. Most important, it has shown that Rostoker's theory was spot-on. That's what focus can achieve. With the containment problem solved, it's now time to march up the temperature curve towards pB^{11} fusion and demonstration scale.

Any new science, to be credible, has to be reproducible and understood by the broader scientific community. Tri Alpha has gone to great lengths on these fronts. With its 40,000 experiments, Tri Alpha's scientists can reproduce results on demand, easily and reliably. Just as important, the computer codes used to predict experimental results have vastly improved with time. With nearly 150 published papers on the science, the company is well on its way to building a body of vetted science that everyone with some relevant expertise can understand. And like many science-based companies before it—energy and health care alike—Tri Alpha's science is built on the shoulders of decades of great research by many people around the world, mostly paid for by government R&D investment.

Solving the hard problem

Seaborg's imprimatur, and the technical understanding provided by Rostoker and the team at Tri Alpha, gave the company an ability to raise that initial seed capital. One day, Rostoker's containment idea might be recognized as a seminal contribution to the production of electricity from fusion—an innovation at least as important as Enrico Fermi's controlled fission reaction that led to the development of today's nuclear power industry. Microsoft's Paul Allen, one of Tri Alpha's early investors, says that if the PEG works, the scientists will get a Nobel for physics, but the investors will get one for peace. We should be so lucky. For now, my role is to make sure the company's milestones are reasonable and reachable within the next funding cycle, and to assist in raising those funds.

I'm often asked, how much longer will it take for Tri Alpha to get to market? I don't know exactly. But a good analogy here would be pharmaceutical development, where the risks, scientific difficulty, and proof required are generally comparable. It can take upwards of two decades and $500 million to bring a new drug to market. Tri Alpha is probably on track for that sort of schedule and investment, maybe even longer, and even more money. And like drug startup companies, partnering with industry—in Tri Alpha's case, with the energy generation industry—is required to truly scale up the enterprise. Demonstrating PEG is one thing. Deploying it is another.

Based on my long experience helping to shepherd complex projects to market, based on what has been learned to date, what has been tested, and the clarity of the road map to achieve net power out, the PEG is tracking as well as can be expected. Ultimately, Tri Alpha's technology could drive a multi-hundred-billion-dollar energy market with commercially competitive, emission-free, fusion-powered electricity. That is the prize for Tri Alpha's visionary inventors and scientists, engineers, and investors, but most important, it is the prize for every citizen of the world, made possible by the innovation called venture capital.

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