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DAVID A. GARVIN
ALDO SESIA

N12 Technologies: Building an Organization and Building a Business

The potential, they believed, was enormous—and the challenge equally large. But if CEO Brad Berkson (HBS MBA '91) and COO Trip Flavin (HBS MBA '94) got it right, N12 Technologies, their Cambridge, Massachusetts startup, could well upend the entire carbon fiber composites industry. N12's value proposition was that its vertically-aligned carbon nanotubes (VACNTs), branded as NanoStitch, dramatically strengthened the interlaminar region of carbon fiber composites, leading to large improvements in cost, shear resistance, and fatigue life.

Carbon fiber composites were formed by taking sheets of resins bound by fiber or fragment reinforcements and layering them together. Intermediaries, known as "prepreggers," combined the resin and carbon reinforcements to form uncured pre-impregnated sheets, which they then sold to end users (original equipment manufacturers (OEMs) or suppliers) to form component parts for products as diverse as bicycles, hockey sticks, racing cars, wind turbines, and airplanes. When these parts came under stress, cracks and breaks could occur, weakening or de-laminating the composite to the point of structural failure. (See **Exhibit 1** for more on composites.) NanoStitch, which was based on the latest advances in nanotechnology—the ability to manipulate atoms and molecules at microscopic scale in order to produce new materials and properties (see **Exhibit 2**)—was a possible solution to the problem; it was a drop-in material laid in between sheets (layers) during composite lay-up. This translated into value in one of two ways: making a part more durable and resistant to stress and fatigue, or making a part with fewer resin sheets (and therefore lower cost and weight) while maintaining current levels of strength and fatigue. These advantages, however, would only be realized if N12 could produce the material at scale.

Berkson and Flavin and the N12 team had already surmounted many of the early scaling-up challenges of the new company as it grew from four to 27 employees. But in early 2016, N12 was entering a new and pivotal stage. Berkson had promised investors that the company would increase capacity by a hundredfold and significantly reduce unit cost in two years, 2018, resulting in revenues approaching \$60 million and an EBITDA of over 20%. This was a bold commitment given that in fiscal year 2015 the company's revenues were less than \$1 million with a net loss of \$4.5 million.

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The Company

Founding and Launch

NanoStitch had its roots in a research laboratory at the Massachusetts Institute of Technology (MIT). The laboratory (necstlab, pronounced "next lab") identified and patented a process for using aligned, vertical arrays of carbon nanotubes (CNTs) to reinforce composites. The tubes themselves, with diameters measuring in billionths of a meter (about one ten-thousandth the thickness of a human hair), were not new; the advance was in their orientation and alignment. When viewed under a powerful microscope, the resulting materials resembled a dense forest of perfectly positioned trees, all tightly packed and pointing in the same direction (see **Exhibit 3**). The precision of alignment helped to solve a persistent problem—the nearly random orientation of previously produced CNTs—that had in the past limited their ability to improve the performance of composites. The lab's tests suggested that VACNTs could increase the shear strength of carbon fiber and other composite materials by 10-40%.

The lab team built and operated a small reactor (essentially a sophisticated oven) to make VACNTs one batch at a time. This work caught the attention of Jeffrey Sabados, a Navy Seal and serial entrepreneur, who co-founded N12 Technologies (N12 stood for "nano to the 12th power") in 2010. MIT's family of patents—covering the architecture, articles, and methods of using vertically-aligned carbon nanotubes in composites and one for a continuous process to grow VACNTs—were licensed to N12. The following year Sabados raised funding from investors. With that capital, N12 set out to grow VACNTs in a commercial setting.

Proving the Science

Sabados hired Ryan Williams and David Degtiarov in June and September 2012, respectively. Dina Deresh, a chemistry major at the time, served as an intern during the summer of 2012 and joined the company full time in January 2013. She was viewed as a member of the original startup team. Williams was a classically-trained materials scientist with a PhD and extensive experience in nanostructures, while Degtiarov was a self-taught engineer who had worked previously at another nanotechnology startup. It was their job to prove the science outside the confines of a research laboratory.

"It was super-exciting," Degtiarov recalled. "We were building the basic infrastructure, outfitting the lab, and were doing it all ourselves, like running to Home Depot to buy our first screwdriver. You feel like you are completely out on a limb, building the branch you are sitting on." Deresh said, "Every day there were new discoveries. It was fast-paced with lots of back and forth among the three of us." Williams added:

> There were two years of running the company out of a coffee shop looking for money. Then we had to find space and replicate the MIT lab. There were four of us in one room—Jeff, David, Dina, and myself. We had a couple of hundred thousand dollars and, as the technical team, had to ask 'what do we buy?' 'How do we outfit a basic lab?' It was very hands-on—buy equipment, put it together, try it out. We were developing the initial process—making little samples, business card size, one by one, here at midnight.

For guidance, they were using MIT's patented "recipe" to build and operate the reactor. But according to Degtiarov, there were many missteps, as well as starts and stops. After considerable tinkering, including deviating somewhat from MIT's instructions, Degtiarov and Williams were able to grow VACNTs in their own reactor using the same silicon substrate as originally specified. N12's process was considerably faster: it could produce a small sample in four minutes versus the more than 1 hour it took in the MIT lab. Still, capacity was extremely limited. At best, the N12 reactor could produce less than 500 square meters of VACNTs in a year. Once they had built a working reactor, they built a second one.

Williams and Degtiarov began producing small amounts of VACNTs for several paying customers who wanted to test NanoStitch to confirm its properties. Williams recalled: "Having orders, as stressful as it was, also created focus. As we ramped up production, we collected more and more data on what worked and what did not. Happy accidents helped to inform development."

Throughout this period, money was tight. Sabados had rented one room in a building where the original startup team shared space with the two reactors. "We had a column on the whiteboard that listed what each of us could spend for the week/month—for example, David had $500, Ryan had $300, and I had $50," Deresh said.

Building the Organization

Senior Leadership

Complementary Talents In January 2013 Sabados left for other opportunities. Berkson, who was an early investor and on the board, took over as CEO and Flavin became COO. Together Berkson and Flavin brought a diverse set of skills to the company. They had similar backgrounds—both were engineers, Harvard Business School graduates, and ex-McKinsey consultants—yet were quite different in personality and temperament. As Berkson put it, "We went into the same oven, but came out differently. Trip sweats the details; he is humble and conservative to a fault. I am more of a risk-taker, impatient, always thinking we should move faster." Flavin added, "It is a story of differences that are complementary. It works because we know how to navigate a partnership."

In part, these differences reflected their prior work experiences. Berkson had a background with startups, having founded IP-Mill, Inc., which sought to commercialize business process technology utilizing unique identifiers (UID/RFID), as well as serving on several boards. He had also previously worked in the U.S. Defense Department under Donald Rumsfeld, and, prior to joining N12, was a senior advisor in the areas of aerospace and defense at Virginia-based Joshua Capital. Flavin, on the other hand, had over 25 years of experience leading large-scale operational turnarounds, organizational change efforts, and broad-based innovation at several top tier consumer products companies, including Coca-Cola, Gillette, and Procter and Gamble. From 2005-2009, Flavin headed global operations for Gillette's razors and blades business, where he was responsible for managing a $1.6 billion budget and 6,400 employees.

Flavin gladly took the COO role at N12, where he could apply his passion for operations, product development, and new product and process rollouts and not be burdened with the demands of raising financing and other CEO duties he found less interesting. Berkson noted, "The things I do, Trip hates doing. It was implicit between the two of us that we would have different responsibilities. I would raise the next round of capital and would focus on business development and finance as well as a bit of human resources, while Trip would focus on operations. Yet because of our common backgrounds and perspectives, we never second-guess each other." The secret to successful teamwork at the top, he observed, "is to find someone you completely trust—and who is nothing like you."

A Dose of Discipline Flavin, who initially started as a part-time consultant in early 2013, had an immediate impact on the development process. "In a way, Trip coming in was just as important as the money we got from investors," Williams said. "He broke down things we were trying to do. He excels at deconstructing problems." Flavin elaborated:

> Early on, we had a problem with repeatable production performance. So we took some high level performance data over time and looked at it in a top-down manner. We used this approach to identify what the causes might be. It was simple hypothesis-driven analysis, following the data. It was less about doing new experiments to identify the sources of the problem and more about using historical data to figure things out. What we did was to isolate the problem so that David and Ryan could each take the necessary steps in their areas to fix it.

Flavin also focused attention on pacing and sequencing. He explained:

> These guys were doing amazing things, but there was no written plan or timeline in place. Most of it was in their heads. What we needed was to develop a rhythm or a cadence. It is hard to know what the right cadence is because it is a judgment call. But you start out with an annual business plan, which was lacking, then you track the plan quarterly and build monthly work plans. We started to have daily and weekly meetings to outline what we needed to accomplish. It is Toyota-based thinking: when you are off track you pick up the pace to get back on track. We have gotten better at this but it is difficult to create a culture of doing whatever it takes to get back on track. And doing so in a development environment like ours with all of the uncertainty makes it doubly hard.

The team began to meet regularly. On Mondays, they discussed the goals for the week, then the goals for each day to achieve the week's targets. Each subsequent morning, they would meet to discuss progress against goals, problems and issues, and possible solutions. "It must have felt to Trip like he was herding cats," Degtiarov noted. Williams jokingly added, "The first time we had to fill out a Gantt chart [used in project management to show tasks or events displayed against time] it felt like the yoke of management was upon us."

At the same time, Flavin strove to shield Williams and Degtiarov from changing business priorities so they could focus on the task at hand. He explained, "If you don't isolate creative engineers from a creative CEO, you end up with a creative mess. What I tried to do was bring consistency to the organization, a continuity of thought. I did not want our priorities to change without reason or cause. We needed stability."

Production, Operations, and Technology Development

For the first year, N12's production, operations, and technology development team *was* Williams and Degtiarov (with Deresh's assistance). Of the pair, Williams said:

> David is highly technically-minded and hands on. He's also largely self-taught: he's an autodidact. He'll teach himself computational fluid dynamics over the weekend. He doesn't have the "I shouldn't try this," or 'no, don't do this," filter. I am more focused on the scientific side, on the process and analysis, and ask "what do we know? What don't we know?" Our division of labor has been pretty natural. I've attended to the science, thinking about what is going on inside the reactor, while David has focused on the engineering and constructing the reactor. What made us effective is that we were very open and comfortable with helping each other. We never had any notions of "turf" and always felt like we could contribute, criticize, and build upon each other's work.

"What amazed me," added Deresh, "was that Ryan, a PhD, and David, a talented engineer, took my suggestions and ideas and always considered them while we were developing the technology. We all had an equal voice even though I was just an undergraduate finishing my course work in chemistry. And it continued when Paul and Chris joined the company."

Horizontal Expansion In July and September 2013, the company hired two new employees: Paul Jarosz, a PhD chemist and materials scientist, and Chris Gouldstone, an applications engineer with two degrees from MIT. Jarosz had previously worked at a competing nanotech company; one of his reasons for coming to N12, he explained, was to have the challenge and freedom to innovate: "My immediate goal at N12 was to find a material on which to grow our VACNTs that was flexible and inexpensive enough to use in a continuous process."

Gouldstone, on the other hand, was brought in as a composites expert (at first on a part-time basis and then full time in February 2014). His assignment was to build a composite lab that N12 could use to create composites (i.e., layers of pre-impregnated sheets) with and without NanoStitch, test them both, and then ship them to customers to do their own testing.

A business development expert also came on board during this period. These additions, which grew the organization from four (Willams, Degtiarov, Deresh and Sabados) to seven people, felt "natural" according to Williams. "It was a horizontal expansion that mapped well onto the process and work flows we needed to establish. It did not bring additional hierarchy." Jarosz observed, "I was accountable to my peers." Still, there were subtle changes. "I no longer knew everything that was going on in the organization," said Degtiarov.

Vertical Expansion Additional growth came quickly. By fall 2014, the production, operations, and technology development organization had more than doubled in size, as had the entire company, which went from seven to 16 employees (see **Exhibit 4** for an organization chart over time). "We were maxed out," Williams said. "We couldn't do any more with the resources we had." The growth spurt brought with it the company's first hierarchy. Not only did Williams, Degtiarov, and Gouldstone each gain two direct reports, but there was, for the first time, a formal separation of responsibilities between Williams and Degtiarov. Williams' team would run production and would strive for consistent, reliable output, while Degtiarov's team, called the Manufacturing Technology Group, would be responsible for building the second-, third-, and fourth-generation reactors. Gouldstone would head the Applications Group, focused on testing and quality control. Williams observed:

> When we added hierarchy, David, Chris, and I went from "doing the work" to "managing the work." I used to be the guy in the room running the reactor. But now that is the job of the people reporting to me; my job is to support them. The three of us had to learn how to navigate team dynamics and set team priorities. It was really the first time in our careers we had to manage others and think about company culture. It was challenging, especially deciding when to step back and let the teams figure something out on their own, even if they floundered a bit, rather than just going in and doing it ourselves.

For a hands-on engineer like Degtiarov, the new organization structure meant learning to delegate. It also meant that integration became more of a challenge. Degtiarov and Williams went from doing everything together to having distinct and at times competing responsibilities and resources under their leadership. Knowledge was less easily accessed. "When we made this organizational change, I began to lose my understanding of the complete process," Degtiarov said. "At seven people I could still understand it all, but with 16 people distributed across different departments I no longer have all the details." Williams added, "Now I spend a large part of my time communicating—making sure that I understand what the four or five people on my team are doing, integrating that into my head, and communicating that to other teams in the organization. Sometimes, it feels as if I am not doing work, just synthesizing what others are doing."

Gouldstone took a slightly different tack because quality control testing was a more established discipline. "I started out by documenting the processes," he explained, "so that the new people reporting to me could follow a consistent, standardized approach. Included were processes for documentation itself. In addition, we created a visual system to track jobs in queue."

Drawing on the approach they had learned from Flavin, each team leader established weekly team meetings on Monday. "We go over what we learned the prior week, what our priorities are for the current week, and what are the bottlenecks that are preventing the team from being efficient," Williams explained. "We also ask, 'what are some things that we've never tried before?" To improve coordination, Gouldstone had a member of Williams' team attend the Applications Group's Monday meeting and share the production flow for the week. "My primary concern is the quality of what we are producing right now—the risk of shipping something before it is ready and the reputational risk that would carry," Gouldstone explained. "On the other hand, I am equally concerned about using the wrong quality metrics and unduly delaying shipment of good material."

The change in the organization structure created a loss of intimacy between the original team members. To minimize the loss, Gouldstone, Williams, Jarosz, Degtiarov and Deresh began to meet for breakfast on a bi-weekly basis. "These 'not-so-secret' meetings are to try and stay connected as we once had been," Gouldstone explained. "We use the time to have open and candid discussions about the workplace." "What we had in the early days was very special," added Deresh, who now reported to Williams.

In 2015, the company added 11 more people. The additional resources led in some cases to further task specialization. For example, Deresh no longer was a production operator; she had responsibilities decoupled from the operator role.

Business Development and Sales

Meanwhile business development was staffing up in parallel. In November 2013, N12 formally created business development as its own separate function with the hire of Ian Sanderson. Sanderson had a diverse background: he had worked for the U.K. counterterrorism unit (where he got to know Berkson through Defense Department connections), been a professional race car driver and later raced power boats, and ran a sports marketing agency. He had also been involved in the design of military boats using advanced composites. He recalled his initial reactions to N12: "I was intrigued by the technology, but nervous about the numbers and volumes that were being projected." At the time, the company was mostly talking about VACNTs in aerospace, but Sanderson quickly surmised that because of the very long adoption/qualification process in that industry, N12 needed a go-to-market strategy that included industries with shorter adoption/qualification processes. He explained:

> There was a need early on to craft a compelling story, to get the product positioning just right. We needed the marketplace to know that N12 was not a R&D shop for carbon nanotubes. Our aim was to develop an industrial scale product.

Just as the production, technology and testing teams grew, so too did the business development team. Robert Nagel, a college friend of Berskon's, came on board as Director, North American Automotive and Consumer in 2014. Nagel's career was largely in sales and construction. But he had also raced cars for the Porsche and Acura factory teams and proved adept at generating sponsorships for those teams. David Patterson also joined in 2014 on a part time basis and was assigned responsibility for the aerospace and defense markets. He had served in the U.S. Air Force for 26 years and later worked for Boeing and the U.S. Defense Department.

Building the Business

Going to Market

Overcoming Skepticism CNTs had been around for more than two decades. Although they had generated much interest, the performance advantages were, as Berkson put it, "long on hope and short on facts." Many composite users had invested in CNTs only to find that the promised gains in strength or fatigue-resistance failed to materialize. In some cases, performance actually declined. N12 argued that the problem had been the random orientation of the CNTs into the composite layers and that the company's ability to grow vertically-aligned CNTs would produce very different results. Still, the atmosphere at potential clients was typically skeptical and unwelcoming.

N12 therefore focused its initial conversations with likely customers on data from its own tests as well as those conducted by the MIT laboratory, with the goal of providing hard evidence of the advantages of NanoStitch. The initial appeal targeted scientists and technical experts. The company provided a 15-page general presentation to interested customers and followed up with a 45-page presentation that went into more specifics concerning the technology for more serious customers who signed nondisclosure agreements (NDAs).

N12 decided to focus on four key markets in order of their expected time to market (i.e. the time it would take for NanoStitch to be tested, qualified, and incorporated in products): consumer (sporting goods/leisure), automotive, wind energy, and aerospace/defense. Consumer had the shortest adoption/qualification period of approximately one to two years. It was the segment in which N12 hoped to establish its brand identity.

Aerospace/defense was at the other end of the spectrum: it had an adoption/qualification process that typically lasted 10 to 20 years. Because safety was such a key concern, testing was more extensive and lengthy before parts and components could be approved for use in an airframe or engine. This meant that the earliest N12 could sell into the aerospace/defense market for the next generation jetliners, for example, was a decade or more in the future. But once a composite part was fully qualified and accepted, it generally provided 20-30 years of cash flow (the typical jetliner production run).

The automotive and wind energy markets fell between these two extremes.

"Pay-As-You-Go" versus "Build It and They Will Come" Initially, N12 had planned to finance its growth by working with five or six end users as partners in joint development agreements (JDAs). The idea was that each of these partners would contribute $1 million, which would fund further development. Partners would receive product for testing, NanoStitch tailored for their applications, and exclusivity for a narrow time period or segment of the market. But before partners were willing to sign JDAs, they insisted on receiving "proof of concept" – hard evidence that NanoStitch did what was promised. Berkson noted, "Potential partners were not comfortable anteing up the money unless they had thoroughly tested the material." N12 also discovered that their offer of exclusivity and tailoring the product had limited appeal. The company had conversations with six possible partners to no avail.

The company was caught in a dilemma: it could not grow enough VACNTs to meet the demand for test materials, but at the same time could not increase its capacity without additional funding. The result, according to Berkson, was that "we went from a pay-as-you-go model to a build-it-and-they-will-come model. There was no debate on this as a board. We had no other choice." With this strategy, N12 would build capacity ahead of demand, anticipating future sales. Later, Berkson closed on two capital raises of $7 million and $20 million from individual investors, which were critical to fund the company as it pivoted away from the JDA approach. (See **Exhibit 5** for N12's funding history.)

Push and Pull Strategies N12's business development team decided to use two complementary approaches to creating demand: a "pull strategy" and a "push strategy." The approaches differed in the degree to which they targeted end users (pull) versus intermediaries (push).

For the consumer segment, N12 was primarily relying on a pull strategy, appealing directly to end users with the goal of convincing them of NanoStitch's advantages. The team believed that these end users, which included high-end manufacturers of bicycles and sporting goods equipment, would then require their prepreggers to apply NanoStitch in the composite sheets they provided. The objective, as Sanderson put it, was to "agitate the market." By late 2015, the strategy in consumer had expanded to include a push element as well. Berkson explained, "We found that there was enough demand from customers for a fairly common resin system used in bicycles, golf clubs, hockey sticks and helmets. So we reached out to one of the largest prepreggers producing that resin system, a Japanese conglomerate with enough penetration in the consumer market that we signed an NDA with them. They are now validating NanoStitch for use in their resin system, and we have begun discussions about jointly targeting customers."

For the aerospace/defense segment, N12 also started with a pull strategy. But end users, including companies such as Boeing and GE Aviation, told N12 that it needed to be talking directly to their prepreggers. N12 therefore added a push element for this segment as well, trying to generate interest at the major suppliers of composite sheets to aerospace and defense firms. This approach, the business development team argued, made sense because these intermediaries had an in-depth understanding of the industry's product pipeline, because aerospace firms typically did not shift from prepregger to prepregger once materials were fully qualified, and because many prepreggers were searching for additional sources of differentiation. "Prepreggers are at a limit to what they can do on their own," Nagel said. "The resins they are using have little room for increased properties, yet there is growing demand from their customers for stronger, lighter, longer-lived composite materials." At least one major prepregger, who supplied about 50 aerospace end users, had expressed interest in NanoStitch and was now in the process of finalizing a testing and IP agreement with N12.

In the auto segment, the company planned to use a pull strategy, but with a clear progression from high-end to mass-market use. Nagel was starting with race cars—targeting, for example, the Corvette Race Team as well as Indy-style car teams. From there, the plan was to move into expensive luxury and sport cars such as Ferraris and McClarens, then into higher volume but still expensive vehicles such as the Acura NSX, and finally into mass market automobiles and SUVs such as Fords, Hondas, and the like. For high-end vehicles with composite parts suppliers relied on prepregs. For mass-market vehicles, the industry did not use prepregs but relied on resin transfer molding, which would require N12 to prove that NanoStitch could be used with that production process. Nevertheless, Berkson predicted that NanoStitch would be in mass-market autos in five to ten years.

Finally, in the wind energy segment, N12 was focusing on use of NanoStitch in turbine blades, which were getting larger. Wind energy companies were looking for new lightweight materials. N12 was talking to blade designers such as Siemens and several suppliers were already testing NanoStitch.

Path to Growth N12 planned to ramp up its sales volumes slowly and steadily over time by shifting from segment to segment, moving from test materials to specialized consumer and automotive parts to high volume, mass-market components and products (see **Exhibit 6**). In 2016-2017, N12's revenues would continue to come from selling test material to both end users and prepreggers. In 2018-2020, the company projected that it would still sell test material for companies to evaluate the properties of NanoStitch and test material to build prototype parts but would also be selling into the high-end consumer segment on a small scale. It was likely that NanoStitch would be limited initially to use in high-end products because those consumers were more likely to pay a premium for enhanced performance.

N12 was currently in discussions with a manufacturer of high-end specialty bicycles and an ice hockey equipment company that supplied the National Hockey League (NHL). The bicycle company wanted exclusivity, but N12 would only grant it if the company agreed to use NanoStitch in all of its bicycles and commit to purchase a certain volume at a preset price over a five-year period. The bicycle company rejected the proposal. Berkson noted, "What we are trying to do is forward-sell our capacity." He added:

> There are really four phases of development in the consumer segment, which is our entry market: testing, prototyping, limited production, and then full production. The testing volume per customer is 5-10 square meters of NanoStitch. The prototype volume is 50-100 square meters. We think we will need less than 1,000 square meters to meet the prototype needs for the consumer segment in 2016. But in three or five years, if we truly succeed in the consumer market, we'll need full production in the millions of square meters. That scaling is quite daunting.

Scaling the Technology

Gen I Reactor Back in 2013, the task of ramping up production capacity to meet the ambitious volume goals had fallen largely to Degtiarov, Williams, and Jarosz: the former two to build the continuous reactor and the latter to identify a continuous substrate on which to grow the VACNTs. Having proved that they could grow VACNTs in a batch reactor, the three had to prove that they could grow them at scale. "We knew that this was our do-or-die moment," Williams said. "If we could not grow VACNTs using a continuous process, there would be no company." Building such a first-generation continuous reactor (known internally as "Gen I") would require significant changes in technology and systems. It was analogous to shifting from producing something on a stationary cookie sheet to producing it on a moving conveyor belt.

The continuous process would need to feed a roll of substrate into the reactor without having to open and close a door. While the batch reactor exposed the process to the elements (when the reactor door was opened) the continuous process would eliminate this type of exposure and the associated problems that could arise that often negatively affected the consistency of material output. Because of this crucial difference, Williams observed, "We had to go back and re-look at every step in the batch process. We would ask ourselves, 'what happens if we turn this knob?' We would then try it and see." It was largely a matter of trial-and-error. As Degtiarov put it, "It's like surfing, when you're trying to catch a wave. You need to be in the right place at the right time. There are 30 parameters such as temperature and humidity that can influence the growth process for VACNTs. Nothing is stable. An imperceptible piece of dust can cause havoc. You need to be an artist." Much of the artistry came from interpreting the output of the reactor in real time without direct access to its core or internal data.

A continuous reactor, however, was no good if the company could not use a continuous substrate. By the summer of 2013, Jarosz had already proved that the company could grow VACNTs using a much cheaper substrate than the vastly more expensive silicon then in use. That was step one; now Jarosz had to figure out how to find and train a supplier that could provide a continuous substrate (which in practice meant finding a supplier who could coat a continuous substrate with a necessary chemical which Jarosz and Deresh had been doing manually). "We needed to think about material cost, suppliers of the substrate material we would use, the availability of the material, and the material's compatibility with the production process," Jarosz said. "At the time, we were financially constrained, so I had to experiment and test on the cheap."

Jarosz spent most of 2014 working with outside suppliers to develop the ability to coat the continuous substrate for N12. Hundreds of possible suppliers were initially interested, but most ultimately said "no thanks." One supplier finally agreed to work with N12 largely because "the former CEO told them that N12 was going to bring them business in the millions of dollars." (The alternative was an investment in machinery of over $500 million to bring the process in-house, which was about $499 million more than N12 could afford.) By November 2013, N12 had its supplier in place. "Proving that we could use a cheaper continuous substrate, and finding a supplier who would coat it, was as important to scaling as the continuous reactor itself," Flavin said.

Meanwhile, Williams and Degtiarov were working hard on building a continuous reactor. By spring 2014, the pair had succeeded. Their first-generation continuous reactor could produce roughly 10x the amount of square meters of VACNTs on an annual basis that the batch reactors could produce. Despite reliability issues and limited capacity, Gen I was viewed as an unequivocal success because it proved the concept of continuous production.

Gen II Reactor In the summer of 2014, Williams and Degtiarov began the design of the second-generation reactor (nicknamed "Long Cat"), while continuing to manage the production from Gen I. "It was like changing tires on a moving car," Williams explained. "Even though we are able to build on the technology we have already developed and transfer the knowledge we have gained through experience, there are additional technical and execution risks with each subsequent generation. It is not simply flipping a switch." The goal of Long Cat was to produce VACNTs at 10x the capacity of its predecessor while also improving reliability. With the design in place, the build-out of Long Cat commenced in early 2015; in May the reactor came online. But it had problems and could initially produce only 30% of its design capacity. In the fall and winter of 2015, Degtiarov's team worked intensely to solve the problems. "If we have 20 performance targets for NanoStitch, we are only hitting about one-third of them," Berkson said. "We clearly have more work to do."

On the overall process of rolling out new technology, Williams said:

> There are three distinct phases: build the machine, debug the machine, and then qualify the machine for manufacturing. We have tended to underestimate the time needed for the build phase, which is largely engineering. The debug phase is a combination of process and engineering. You've built the machine; now you have to understand how to drive it properly. What might have worked on the prior generation does not always work on the next. Qualification is about standardization, reliability, and yield. Put simply, the stuff we grow on Monday has to be the same quality and specs as what we grow on Friday.

Gen III and IV Reactors N12 had a long way to go to meet its production capacity targets for 2018/2019. Berkson wanted excess capacity to projected sales for those years as a hedge against production problems and to be ahead of the curve for the large step-up in production levels projected for 2021. To meet production targets, the company needed to develop two additional generations of reactors. Gen III (nicknamed "Fat Cat" because it would produce wider sheets of VACNTs) had a planned annual capacity 10x that of Long Cat's. Gen IV (nicknamed "Hyper Cat") would be another huge step forward; it had a planned annual capacity 10x that of Fat Cat's (see Exhibit 7 for capacity figures). "The end goal is to automate," Degtiarov said, "to have the reactor collect and analyze its own data and self-regulate the production process. We want Hyper Cat to have minimal human involvement."

In the meantime, however, there were capacity shortfalls. In early 2016, the business development team had generated more demand for test material than N12 could provide. There was, in fact, a three-month backlog. Over 100 companies—a combination of end users and prepreggers—wanted test material, typically about one to three square meters each. Twenty customers were already actively testing NanoStitch, and N12 hoped to increase that figure to 50 within six months provided Degtiarov's team could work out the issues with Long Cat.

"One of the biggest challenges we have," explained Flavin, "is matching our technical capabilities to demand. If we build our capabilities too soon, we run the risk of burning money. If we build too slowly, we will lose credibility in the marketplace. Either could be death for a startup."

Economics and the Business Model

Ultimately, the adoption of NanoStitch would come down to cost versus performance. To support the price premium of adding NanoStitch to composites, end users would need to see substantial benefits on one of several dimensions such as reduced weight, added strength, or durability. The firm's pricing plan was two-fold. It would charge different prices depending on the customer segment. For example, because of the extensive quality control and testing required for aerospace composites, N12 would need to charge those customers about one-third more than it needed to charge the high-end consumer segment. As production scaled up, the prices to all segments would reduce over time.

The company projected it would be profitable by 2018 selling NanoStitch primarily to the high-end consumer segment. If the company were to do no more than that, Berkson observed, "It would be a nice little business." But investors had bought into the idea that Berkson and Flavin could scale the business. The company was forecasting significant sales growth jumps in 2018, 2021, and 2027. If the N12 team did succeed, the company's market valuation would approach $10 billion. (See **Exhibit 8** for the company's projected annual earnings before interest, taxes, depreciation and amortization, EBITDA.)

Becoming a "Buttoned-Up" Organization

Scaling was not just about production. It also required scaling the organization's capabilities beyond manufacturing, establishing and documenting processes and policies ranging from strategic planning to budgeting to customer engagement to accounts receivables. Flavin cited performance reviews as a representative example: "I used to do them all, but now with twenty-plus employees that's impossible." He recently sent out a template for all the managers to use and explained the process at a leadership team meeting in advance of the first formal review process scheduled for early 2016.

Berkson and Flavin had already taken a number of measures to instill greater discipline in the organization. They had instituted an annual priority-setting meeting each fall with N12's leadership team to establish both company and departmental goals for the following fiscal year, as well as other regular meetings to create focus and cadence—what they called a "leadership drumbeat." (See **Exhibit 9**.) They had also established a bonus plan for the leadership team and set up weekly group lunches.

But much work remained. "I worry that we haven't documented enough of our processes or the reasoning behind the decisions we have made" Jarosz said. "When there were only five of us, we relied successfully on communal knowledge, which gets more difficult to maintain as the organization grows. I've been advocating for more documentation, but thus far the absence of documentation has not kept us from getting material to our customers."

Williams reflected on the changes in culture and practices:

> We now have many more processes from an engineering, production, and quality control perspective. What was once inherently known by team leaders, as if in short-hand, now needs to be explicitly communicated. That is a major change in the culture. It means we have had to learn about information exchange. For example, at times someone from my team may be talking to someone in David's or Chris' team yet the three of us, as team leaders, remain unaware. We have to make sure everyone is on the same page. We don't need extensive reports, but we do need tools—things as simple as shared spreadsheets, databases, or weekly reports. We probably underestimated the need for standardization and the investment it would take to get these tools and systems in place.

"It is a huge shift in how we interact with each other from the early days," Deresh added. "It used to be an open discussion with everyone. But as we grew, that was no longer sustainable. Now that we are broken up into what we call 'buckets,' it is a struggle to keep everyone in the company on the same page. Most of the communication is now within your own team."

Changes required tradeoffs to be made. "I understand that each department and team cannot have their own policies, but I wish I had more opportunity to influence company-wide approaches," Williams said. "When you scale an organization, you have to apply some structure across the entity. It is a fine line to walk because we are still a small organization; only a short time ago we had total freedom. Now I have to advocate for my team members' autonomy yet still fit within a manageable company-structure." Degtiarov expressed similar views. "I am guarding my team's autonomy jealously," he explained, but added that his perspective had changed with time. "I came to N12 as a hardcore engineer. But I had to evolve professionally. I had to learn how to build a team, how to adapt. Everyone that was once involved with the company who would not or could not show flexibility, either in opinion or approach, is no longer here."

Berkson summed up the challenge facing N12:

> The day of reckoning is when you go from startup to a buttoned-up organization. It is a 'high degree of difficulty' transition, like going from a seedling to a full-grown tree. You start off as a completely immature operation, taking an idea from a university and scaling it up, and end up putting in the quality and process management capabilities to satisfy some of the most challenging applications and clients in the world. We still have a lot to do. But when the GEs of the world come knocking on our door, we need to be ready. I believe that day will come sooner rather than later.