Stanford eCorner

Convergence Drives New Ideas [Entire Talk]

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Distinguished professor and serial entrepreneur Joseph DeSimone discusses the vibrant chemistry that takes place at the intersection of science and the humanities, academia and industry, and within the walls of his 3D manufacturing startup Carbon. He describes how on-demand parts manufacturing could one day eliminate the need for business inventory and even end up in hospitals.

Transcript

(audience applauding) - Thank you. (audience applauding) Boy, it's really terrific to be here. Thank you for the invitation. And to be back on the Stanford campus, our company is just located one exit north on 280, off in Redwood City, and it's a special opportunity to be here and participate in your activities and kick off the season. Also thought it was really interesting to be here on the fifth anniversary of the passing of Steve Jobs, is today, and the importance that Steve has had as an icon in Silicon Valley. And this is one of my favorite photos of Steve. And it's going to reinforce a little bit of some of the topic I want to talk about here in the beginning, related to ideas, innovation and entrepreneurship. And what is a intersection or feeding ground for those ideas. And as you can imagine from this perspective here, firmly believed that it's a lot of different disciplines coming together that can make a big impact. And Steve is noted for saying it's in Apple's DNA that technology alone is not enough.

It's technology married with the liberal arts, married with the humanities, that yields us the result that makes our hearts sing. And I think that's really the essence of a lot of advances today, that intersection. And if you look around, and you look at there's so many opportunities, actually so many needs for big breakthroughs and big ideas, whether you're thinking about new ways of storing energy, new ways of curing diseases, new ways of protecting information in cyber security or international security, and the opportunities for making an impact, and in particular, being here at a university, and I love quotes, you'll see different quotes coming up. But this quote here from Henry Rosovsky, was being that Harvard, one of my favorites. Research is an expression of faith in the possibility of progress. The drive that leads scholars to study a topic has to include the belief that new things can be discovered, that newer can be better, and that greater depth of understanding is achievable. Research, especially academic research, is a form of optimism about the human condition. And I love the actual poeticness of that statement and that perspective. And it's what really drives me and historically, my students over the years. And what Steve has done so well, when you think about what Apple has done, and you think about the intersection of a great hardware and great software, but really thinking about how it changes society, how we interact with one another, how we think.

And what that really is, is the convergence of disciplines. And I had the privilege of sharing a national academy study on convergence and its impact in driving innovation. And historically the word convergence and its meaning has often implied the convergence of the physical sciences engineering and medicine. In fact, that's the way MIT has classically referred to convergence. But I think what it really means is bringing together disciplines in maybe not so obvious ways and thinking about what emerges from that. But I think more broadly, and what Apple has done, is I think you have to think about extending this to the social sciences, the humanities and perhaps even the performing arts. And thinking about tech and the humanities and the liberal arts is an important aspect. And as part of that, I think a lot of people believe that convergence itself is actually a blueprint for innovation. If one can get convergence right, it can be a real driver for new ideas. And coming back to Apple, when you think about who Apple has gathered around the innovation desk if you will, it's not just the techies, it's not just the hardware and software folks, but looking at some of the recent hires, former CEO of Yves Saint Laurent, former CEO of Burberry, designer from Nike, all these different people coming together in a rather not so obvious way to think about changing the way we live.

And that's a really important pattern. When you think about what does that mean here in universities, universities are interesting. We often deal with an 18th century organizational structure. Right, where there's silos. In fact, I find it ironic that universities are one of the few places where entropy doesn't work. Mixing is not natural here. And here I have to fight through those barriers and encourage a lot of the new people here at Stanford is so many resources here on campus to be able to break through and reach to different connections. And that's really what this is talking about. And you'll see part of this aspect is, and when you think about the kinds of people at Carbon or at Apple, you'll see this metaphor of I shaped people or T shaped people, people that I shape being very monolithic in a particular discipline, and the metaphor of a T shaped person, deep in a subject but be able to go and interact with others. I think nowadays there's a higher calling and it's a pi shaped or comb shape people.

Right, where you actually are deep in multiple subjects. And conversing in multiple subjects. And this really takes it beyond what may be a common language associated with T shaped people. But the ability to be multilingual, and go deep in multiple subjects, which is really important to make a difference today. And part of that, when you gather people around and one of the core cultural values for us at Carbon, is that when you are working with a diverse set of people, that there's going to be a need to be clear about not only what you know, but what you don't know. And there's a vulnerable trust that one has to have if you're going to be clear to your colleagues about what you don't know. And that's a critical characteristic value that we have at Carbon. Let me expand this a little bit further. When I started my academic career, in the early 1990's, I got a chance to be invited to and innovation committee or workshop at a very large chemical firm. I flew outside of the United States to get there, and I walked into this innovation group and it was a pretty sterile looking boardroom like this, but what was really amazing to me was not only was it all white guys around the table, but they all graduated from the same two research groups.

And you know what I mean when I say that, I mean, everybody knew each other, everybody knew what each other knew, and I felt like a martian coming into this environment, and I never felt more like an an outsider then when I did when I walked into that room. And it dawned on me right then and there that this group was at a structural disadvantage. The way they were organized to drive innovation. And you know, a lot of people have talked about this where the recognition at diversity is a fundamental tenet of innovation. I talked a little bit about disciplinary diversity in a beginning, but diversity more broadly defined, and recognizing that diversity plays a really important role, it doesn't always trump ability, but it does so far more often than we expect. And this really great book by Scott Page called The Difference. What I find intriguing in a lot of different sectors of our society and our organizations that once you start talking about diversity, and the role that it has in driving innovation, then very quickly people will come up and start talking about ability, the meritocracy. And there's often a very quick pivot that says that the meritocracy is really the driver and should we be giving up the meritocracy. Clearly, no. Ability matters.

No question about it. But the point is, so does diversity. They're different topics. They're absolutely different topics. Nothing is more impactful than a diverse set of individuals driving towards a common goal to make a difference. And it's this experiential diversity that's really important. You know, recognizing early on, that we learn the most from those that we have the least in common with. Right, and if you think about that, if you're getting part of a design team, and you're fortunate to be a part of a design team you recognize that these different experiences drive the innovation process. I can tell you, more times than naught, that different design teams that I've been associated with, if somebody grew up with not much money, they think about problem solving fundamentally different than somebody that grew up with a lot of money. Not that one is better than the other, they're just different.

And if your goal is to broaden the perspectives around the table, then you have to think about this diversity, this element of diversity to drive innovation. And recognizing that some of the most innovative solutions comes from embracing that diversity of perspective. And so I think, my sort of message here is that I think we need to be intentional about this diversity. Or you're going to lose out. It's really the secret sauce of all the different companies especially those companies that are trying to drive something very profoundly different. And diversity is a recognized fundamental tenet of innovation. Again, I love books, I love quotes. Peter Thiel has a really terrific book, Zero to One. And it's got some really interesting perspectives and the take home for me, was thinking about ideas. And his fundamental tenet that he has is what important truth do few people agree with you on? And then embedded in that, is what he thinks is a zero to one idea.

A profoundly different idea. And that ideas come in two flavors. Seminal zero to one ideas, and then incremental ideas, one to N ideas. And you think about that, and you think about what it is you're working on, and you think about, especially in an academic setting, and thinking about where those breakthrough ideas are. And it's really convincing people about building a different future. And that's really an element of a characteristic. But those of you that think about academia, if you have an idea that very few people agree with you on, and you try to go get funding, right, through traditional mechanisms, peer review. What does that necessarily mean? It's not going to get funded. Which is ironic when you think about NSF and NIH and traditional funding mechanisms. About the need for these breakthrough ideas and having people agree with you.

So one has to be entrepreneurial. And think about getting some of these ideas done, even at a university, because the access to funds, maybe they're professorships, maybe there are other kinds of fellowships that give you the latitude to pursue crazy ideas. But in those ideas are those zero to one breakthrough ideas. And so thinking about the differences between academia and the private sector, I think venture capital is the fuel for some of the craziest ideas. And that's what I love about doing what I'm doing now, bridging academia and entrepreneurship. Another element that you'll think about with ideas anybody know who had this quote? You do not merely want to be considered just the best of the best. You want to be considered the only ones who do what you do. Anybody know? Some of the older folks. Jerry Garcia. Right? And so, again, back to strategy is all about being different, another term that you'll here from the business folks.

Working on different ideas, doing something different. There's a lot of software people now writing a lot of code to push advertisements on people. Right, there's a lot of focus on that. And if you can now do something different than that, or finding a hotel room, or other things, there's a lot of opportunities for driving software to do things that are different. Encourage you to think about those things. That's a bit of a challenge. And then for me too, especially in an academic environment, back to this 18th century quote from Goethe, which is almost like the Nike commercial, Just Do It, the translational aspects of research, coming back to where we started, taking ideas, taking the essence of great research, targeted at addressing societal problems, can be a really powerful mantra. And for us, and over my career, this has meant participating in a number of new companies that did some game changing things that we believe and some are more game changing than others, this was a biodegradable stent that goes away after 18 months. That company was acquired by Guidant, now part of Abbott. We have about a 150,000 people with their degradable stents in them.

This is a nano biotech company called Liquidia. Making particles, engineered particles using the tools of the microelectronics industry to make medicines. So bridging photolithography and medicines for new drug delivery approaches. Again, opportunities for bridging very dramatic ideas. This is a battery company located in Berkeley that has non-flammable electrolytes for lithium ion batteries. Who would be interested in that today? There's a few of us, maybe with laptops on our laps. Let alone on airplanes. And let me tell you about a company that I'm very excited about, and that I'm here representing with a few of my colleagues here and that's Carbon. So, I'm going to talk to you give you a bit of a glimpse into what we think is a breakthrough and additive manufacturing or 3D printing and we use patterned light. And I'm going to refer to light as our chisel.

I love that metaphor of light as a chisel. And this work was described in Science about 18 months ago. Happened to be on the cover of Science. Any embargo on the Science paper was lifted the moment I walked onto the stages of TED. And then our company came out of stealth mode. So I think from an entrepreneurial point of view, I think of that as a entrepreneurial hat trick. Paper in Science, coming out of stealth mode, TED talk. Worked out pretty well for us. That's a good recipe to get launched. So 3D printing, everyone's familiar with 3D printing.

Everyone's familiar with 3D printing. President Obama's talking about 3D printing. And I think it's clear to say that 3D printing has not emerged to be a significant industrial sector yet. In fact, you just look at the dollar, it's only a four or five billion dollar industry. To put that into context, the US polymer industry is a 400 billion dollar industry, okay? And four to five billion includes metals. And the primary reasons why 3D printing has not emerged to be manufacturing, it's a terrific prototyping technology. But the prints take forever. They're not at a speed that's economically viable. The layers give rise to anisotropic properties. And it adds a real problem in designing proper material properties for complex devices.

And the material choices that are available are pretty limited. And so when you think about other great books to read, Geoffrey Moore, Crossing the Chasm. Or Inside the Tornado for those of you in doing entrepreneurship, those are classic books. Geoffrey would say that 3D printing has fallen into the chasm. And the chasm is in this technology adoption curve, where in the beginning of all new technology introductions, the techies drive adoption. Techies love products, in fact they love products that are not complete. They like to cobble together a partial solution and that's part of what they love to do. But to really get to the early majority or the large volume of revenue, you need an economically viable solution. People don't care about technology on the other side of the chasm. They want a solution that's economically viable.

And a technology that falls into the chasm has some significant shortcomings, and a lot of us believe the 3D printing has done that. And I think this is a good representation of it. This is a classic 3D printing technology called SLS. Spreading powder, a laser centering it, pushing it into the table. And then it gets pushed out, and somewhere buried in that cake of powder is a product. This is one of the mainstays of 3D printing today. It's called selective laser centering, SLS. This is being done with a nylon or poly amid powder. Centering it together. This is essentially identical to Hewlett Packard's HP's new technology.

New technology, it's this technology. Maybe done in a bigger format. But it's a centering of powder, right? For an atomic solid, for metals, this works pretty well, because there's essentially no memory of the grain boundary for an atomic solid. But for a molecular solid like a polymer, the mechanical properties of polymers are all derived from what are called chained entanglements. Think of it as spaghetti. And in knots and ties between that entanglements drive the mechanical properties of polymeric materials. And you don't get the entanglements between particles like you do at the center of a particle or from injection molding by this technology. And so there's lots of shortcomings with this technology for molecular materials. So given this perspective that 3D printing is actually 2D printing over and over again, we thought we could come up with a different way. And our approach was focused on could we do this continuously, and I'm a chemist, and I think like chemists do, because I'm chemist and I think about growing crystals.

Chemists like to grow stuff, right? And our approach to doing this, this is actually a video that we did on the stages of TED, we did a live 3D print during a TED talk. This is an accelerated video, a 1 minute video, but it took about 7 minutes to run to print it. And the key to our approach to doing this was a process that would emerge, kind of looks like T1000 out of Terminator 2. Right, growing out of a broth, or out of a puddle. And in order for that to work, we needed a new approach to doing 3D printing. And our approach involved a reservoir shown here with liquid. And at the bottom of the reservoir was a very special window and below the window was a projection system. And in this case operating in the ultraviolet at 385 nano meters, so we're doing UV curing of chemistry. But what's also key about this window, is that it's not only transparent to light, but it's highly permeable to oxygen. Okay, that was a good, that's the punchline.

(audience laughs) It's highly permeable to oxygen. And the key for that is oxygen inhibits the photo-chemistry. Oxygen prevents the photo-chemistry from taking place. So oxygen and light work in polar opposite ways. So it's a chemical approach to growing parts as opposed to a mechanical engineering approach doing 2D printing over and over again. And this is an example of our printer. That was the technology debut about 18 months ago that video, this is actually our first product that we launched this past spring. And this is what we call M1. M for media, it's our first product. You can get a sense of our product line in the nomenclature.

Pretty simple. But this is patter light emerging from underneath, as we pull out more complex objects, and let me just grab this one here, this is actually this part growing out of the broth. This is an air duct for an NASCAR. And you see it coming, pulling out of the liquid, so it's really just coming out of the puddle here. And we're basically using patterned light and doing a choreography with the Z axis and fine tuning a lot of chemistries. I think of this as software controlled chemical reactions to rapidly grow a part. Okay. This particular part has a use temperature of over 225 degrees celsius, right. So this is a really high performance, very high modulus material. It's got a 4.5 gigapascal modulus.

And the essence of our process is shown here. This is something called optical coherence tomography. This is analogous to doing ultrasound imaging but with light instead of sound waves. And this is our window, and this is we're growing a two millimeter diameter part at 200 millimeters an hour instead of a layer by layer approach, these speckles are nano-particles that we added as a contrast agent. So you can see the flow of liquid. And so what's happening is light's coming through right here at the bottom, at this diameter, 2 millimeters to generate this cylinder. But what's happening is oxygen's also coming through. And so the oxygen prevents the light from solidifying the resin right at the window. And it creates a gap, what we call a dead zone, where the photo-chemistry doesn't take place. The dead zone is about thirty five microns thick.

About a third of the diameter of a human hair. And so what happens is we pull the part up, suction forces bring the liquid in underneath and there's a river of resin that flows in underneath the part, maintains the puddle, so as we pull the parts up, it allows us to grow these parts. And so this is our process. And when we start making parts in this manner, if you cleave the part, if I have this bicycle pedal here, if you cleave this part, this is an example of a bicycle pedal that we've printed, and you can see that it's got a lot of different angles to it, while you're printing it. If this were made by a traditional 3D printer, there would be layers oriented relative to the orientation of how you printed the part. And in traditional 3D printed parts, that layering gives rise to anisotropic properties. Properties derived from the orientation of the layers. But when we grow parts in this manner, especially with the kind of chemistry we use, and you cleave the part, there's no remnants of us changing each image slice. It's uniform by all means of analysis. So these parts or isotropic.

They don't have the orientation dependence of mechanical properties. And that becomes really, really important for making final parts. And so as we think about our business and how we want to bring this forward, and you think about the age that we live in today, we live in a subscription age. Right, the age of where you used to by software in a box. Those of us, with discs. Remember discs? Floppy disks? Some of those were 12 inches, way before a lot of you guys were born. Right, then they got smaller and harder. And you don't buy software that way anymore. It's a subscription. Well, we offer our machine in a similar mode, instead of software as a service, this is hardware as a service.

It's a subscription model. You can think of it as a rental. And what this does, it gives a couple things. First of all it's internet connected. We get to push software every five or six weeks to the printer. Our VP of engineering Craig Carlson was the VP of engineering at Tesla. Right, my car just got a software upgrade the other night with new features on it, new parking, new autopilot features. In fact the UI changed, I don't even know where the music is any more right now. I hope we don't do that when we push software. But the ability of pushing software to the device allows us to add new features to the printer.

And one of the most important new features allows us to design new resins and develop the technology to make new resins printable. And control that dead zone in particular. And so the details for example, one of the most important reasons of having an internet connected printer, is there's a whole lot of properties that impact that dead zone. Think about how much light's required to solidify a different resin. You change the chemistry, you change the details of that photo-chemistry. What is the viscosity of the resin? How far does the light penetrate into that liquid? What are the mechanical properties of the part while it's being built? What's the machine configuration? What's the part geometry? And so we've mapped all these fundamentals out, and I'll just show you one example. This is us building an Eiffel Tower. This is the temperature profile that happens while we build something like an Eiffel Tower. Right, you can see the temperature's changing. Right, for chemical reactions, every 10 degree change in temperature, reaction rates double, on average.

Viscosity's changing. This really impacts the details of controlling that dead zone. Here's one of our prototype printers, now operating another factor of 10. This is going at 2000 millimeters an hour. Right, and if you look carefully, you'll see it growing, and then you'll see some smoke coming off the parts. Now, as a chemical engineer, I'm showing off here a little bit. We have to run our 3D printers where we have to start thinking about water cooling them. And heat transfer becomes a limit. On mass transfer and heat transfer become really key limits on us how fast we can go. But this is now two orders of magnitude faster than what we showed on the stages of TED.

And so my point in saying all of that, is that our customers don't have to worry about that. We have a print button. We have a team, yeah it's a simple statement, right? We have the most amazing team of chemists, riologists, kineticists, physicists, figuring out the fundamental cores of how to control the dead zone and make a great part, and that drives an algorithm that drives the printer. So it's a simple print button. And that's what people want nowadays. All they have to do is pick their geometry, pick their resin, and we take care of the rest. And that's how we do this. And you need software to be able to update software over time and having an internet connected device to do that. And so we have over 25 sensors built in to the printer. They stream over a million data points a day, each one back to our servers at Amazon web services.

We're collecting a massive amount of data on how to print well. All the operational data associated with the printer. And this data rich environment is really what you hear about in a digital factory of the future today. Our customers want this kind of operational data. Every time a part is made, call it the born on data, we have a log of data associated with when this part was made. So we have all those operational details. And that can all be fed back into your ERP system. Associated with the manufacturing of these parts. Think about the opportunities for new business models that that transforms. If a part breaks on a car, and you don't have a connection or you don't have traceable parts, you have to recall maybe 600,000 vehicles.

Imagine the opportunity for just recalling the 1200 vehicles associated with that bad lot of resin. If you could have an identifier on the part tied back to all the operational data. Or maybe a medical device in post market surveillance, where you can now have that kind of data associated with your products. Or maybe you have authentic parts, whether you're BMW or Mercedes, and you're thinking about your brand, and your design and maybe your intellectual property, and be able to have that kind of tie back to your particular products. One of the things that's essential for us too, is that those of you that are familiar with 3D printing, it's not uncommon that the first time you try to print something there are defects. And for us, this would be an example of a defect. This de-lamination. This is where maybe the dead zone got away from us. Too much oxygen, not enough light, pulling too fast and it de-laminated. Our customers get to score the quality of the parts.

We get to change the printing algorithms so that class of problem doesn't happen again. And then we get to push new software, and fix the problem. This is a network effect. And if you read another great book by Eric Schmidt on how Google works, or Bill Curly in being part of the 10X club, one of the essential characteristics of a really interesting business model today is having a network effect. That is that more people use this printer, the better it's getting. So the bigger we get, the better we get. And that's a really interesting powerful drive for us going forward in the future. But at the end of the day for us, it's all about having great parts, real parts, and those of you that are familiar with 3D printing you often don't have the materials needed to be a viable part. If you design a bicycle pedal, for maybe a new mountain bike. And you design it on your favorite CAD software, and you print it on a traditional 3D printer, you can actually have the device, you can look at it and say yeah, it looks like what I designed, it's the right intent.

But you often can put it on the bicycle and go for a bike ride, because it will fail. And we have been focused on amazing materials that have final properties. So traditionally, if you look at mechanical properties, this is a stress strain curve, this is a brittle material made by traditional a lot of light based traditional 3D printers. But what you want in the real world are materials that have ductile like properties. Advance materials, so if you think about all the polymeric materials on cars, or the clothing you're wearing, or the wearable electronic devices that you have, there's a range of properties that are necessary to drive the hardware solutions that people are interested in today. So we have to be able to generate those. In our unique approach to doing this, was to use light to set the shape, but we used chemistry to set the properties. And this is all enabled by having software. So for example, we can make a part like this and set the shape, and then we go through a baking process which triggers other chemistries that does chain extension that allows us to go to high molecular weight and have really great material properties. And so we've go a whole family of materials, and we are setting up an app store for resins.

And so you think about why one sets up app stores to begin with, it's to engage our community, engage a developer community, to trigger ideas and innovations from others to work on your platform, but it also does something else for us. It sets up a marketplace for thinking about driving down pricing. If you actually want to go into manufacturing and that's where we're going, you need some truth in pricing. Traditional 2D printing companies you think about your favorite copier, toner is very expensive. You're never going to get to a large volume manufacturing with toner like pricing. So you need to set up a marketplace dynamic and that's what we've been able to do. So we have real materials that allow us to generate real parts. And I'll just walk you through some examples of these. That first one I mentioned that's a cyanate ester, most people don't know what cyanate esters are, which is okay. But you want into companies like Space X, Boeing, NASA, they know what cyanate esters are.

These are advance composite materials. These are materials have used temperatures up over 200 degrees Celsius. Very chemically resistant. Compatible with sterilization. A lot of our surgical tool companies are interested in materials that are sterilizable for applications in medicine. We have these rigid polyurethanes, these are some parts on a mini cooper. We've got parts driving around on these cars for the last almost a year now. Going through a Bavarian winter and now a Bavarian summer. And now going back int a Bavarian winter. I should get back over there for Oktoberfest, actually.

These are some additional parts. And our customers and us are putting these parts through validation studies. Meeting the application needs. Either an iso-standard or UL rating or anything specific to those companies. Examples where we've passed UV testing, door handles that look like injection molded poly carbonate ABS blends as an example. These are some really interesting parts. This was a metal bracket machined out of aluminum for our printer. And once we started having printers, we were using our printers to make parts for themselves. Sort of a singularity moment. Crossing that line.

So this is an example of a part printed out of a rigid polyurethane, that meets all the specifications necessary for this bracket for this motor. And what's really interesting, is you think about additive, this is clearly designed by a human, it looks like something a human would design. But what's really interesting and Jade up here, is a student here at Stanford, did an internship with us, she fed this design into some of the new generative design software and had the software optimize it for stiffness. So keep the mass constant, and what design would give the stiffest part? And the computer spits out some thing that looks more like the Klingon warship than maybe the Starship Enterprise. And very organic looking, but this is where design's going today, in generative design. There's another design where instead of keeping the mass constant and maximize stiffness, keep the stiffness of this, and minimize the mass. And applications of light weighting vehicles. Or minimizing cost by eliminating material. Lowering your carbon footprint. Making a material light, an example.

So those are the kinds of things that when light is your chisel, these kinds of complex structures are easy to access. We have amazing materials for epoxies, you know, electrical connectors. There's over 800 electrical connectors on a Tesla car. This is a 37 billion dollar market. Electrical connectors. And if you walk into these factories, and I was just at Delphi, large company, injection molding company, a room that was five times the size of this room, with 200 ton injection molding machines cranking out electrical connectors. They take plastic pellets, they heat it up to the melting point of the polymer, they use 200 tons of injection force to push a very viscous polymer melt into a very finite cavity, it costs about a half a million dollars, but most importantly, it's a design of a cavity, or design of the part, such you can open up the cavity and pull the part out. It has a symmetry that allows you to open up a cavity. So it was designed for manufacturability, not for use. And I'm really interested in how can we train a 100,000 engineers to design for use, and not focus on manufacturability and use.

It opens up the design space. If you just focus on what it is you want, because with additive manufacturing, complexity is free. You don't have to worry about design rules. And that's the advantage of these kinds of new approaches. Elastomers. We have superpowers in elastomers. And again I am a materials guy, we have superpowers. These elastomers have very high tear strength, very high resiliency, and we can make amazing things from rubber gaskets to hearing aids to athletic footwear. And we have some amazing things coming in a very near future making amazing kinds of footwear products. And it's going to be footwear, that's not just designed for size eight, nine, ten or twelve, but it'll be bespoke.

And it'll be designed for you. And again, that's another fundamental tenant of a digital manufacturing footprint. And so again, just our materials allow us to go through hundreds of thousands of cycle tests, have all the properties to be real materials. And so again with the data centric environment we can see all the different industries, vertical is automotive, consumer products, education, industrial, medical, service bureaus, contract manufacturers, which resins they're using. I get this data every night. At midnight my wife's about to shoot me because I wait for this report every night. Get to see all the data that happens. And we have an amazing set of customers now, again, we launched our product in March, we have lots of different Fortune 500 companies, major industrials, we have service bureaus or contract manufacturers that are supporting many other companies, they're in the business to make parts. Then we have a lot of different academic institutions, and you can imagine, that's really challenging for both University of North Carolina and Duke to be in the same row here. And again, as I mentioned to you, that we're coming out with this printer as a subscription model, it's a rental.

What this really does, is it aligns us with our customer's printing. This is not a transactional sale, it's a partnership. And most importantly, this future proofs our customers. I know the product roadmap, I know when this product's going to be obsolete. Our customers don't have to worry about that. They're not locked in, they're future proofed. And especially for a company like us that's just coming out with a brand new technology, I don't have the heart to have people buy stuff that I know is going to be obsolete. So the subscription model for lots of reasons becomes an important way to move a new product into the marketplace. And then we sell resins, we're setting up that with the app store, and we have some other accessories. But our total reason for being as a company, is to create a new industrial category of 3D manufacturing.

A lot of people are talking about 3D manufacturing, but as you saw in the very beginning, the technology has fallen into the chasm. It's today still about prototyping, and our thesis is that, a lot of companies will do what I would call the long jump. Try to get across the chasm. We have the privilege or opportunity to do a triple jump. All we need to do, we're putting our printer into the existing prototype market. Allowing the prototypers to actually make real parts. We call that functional prototyping. While we're doing that, we've got some signature customers, some signature accounts that we're trying to develop whole solutions for manufacturing. We're going to take the next two or three years and parallel to putting this 3D printer into the prototyping market, we're also developing full manufacturing solutions where we're making hundreds of thousands and millions of parts a year in some new industry verticals. Such as these two worlds would come together.

So we're building out, really a factory of the future. Where there's clusters of our machines. The machines are designed for automated, fluid delivery. Where there's software written to control a fleet of printers. Where we can have encryption data so that people can have the security that they want whether they're an aerospace company, or whether they're in Hollywood and their designs are just as important as the aerospace companies. So all that software, all that infrastructure to build a digital factory, is really, really important. And part of that, and part of our thesis too, is one of the most important places to have unique, mass customized products is in medicine. I talked about it for footwear, but you think about teeth, you think about ears, noses, CPAP masks for sleep apnea, all sorts of places, coronary devices. I told you in the beginning I started a biodegradable stent company. You think about that.

It's not different than buying shoes. If you're on the cath table, and it's an emergency situation, and you've got a blockage, and the interventional cardiologist, she looks up on the TV screen and looks at your blockage, she's makes a decision what size stent that you need in that particular blood vessel. You don't want a standard stent. You want a stent designed for your anatomy. And what's the future's going to be a situation where she can look at that, maybe do some drawings right on the screen, the software calculates what stent you need for your particular blockage, or your particular tributaries off that vessel, hit a print button, it prints a stent, and she can place it into you designed for you, right on the cath table. That's the future. I don't want to push that through the FDA today. But those kinds of things are happening. And in medicine it's going to be a really powerful opportunity. So we believe that this breakthrough approach, real materials, made at game changing speeds, is just the ticket to close the chasm in the technology adoption curve.

And when you think about this, and you think about all the different business schools, Harvard Business School, Stanford, so many people are talking about what is digital going to mean today. And there's so many different business models. On demand inventory. We live in a slow growth economy today. How do you create value if you're a CFO in a slow growth economy? You got to free up capital. It's one of the simplest ways to do it. There's so many companies with billions of dollars of slow moving inventory, inventory that's been sitting around for a decade. And a lot of it's plastic parts. And plastic polymer parts degrade over time. They densify, they get brittle, they hydrolize, they fade, you actually want a fresh part.

Let alone a part that's on your books for all that time period. And so on demand inventory is a new business model, could you have a warehouse in the cloud? Where you just pull it down, make parts as you need them. Or you're on an oil rig somewhere, or maybe you're in a remote village and your water irrigation system's gone down. You need parts. You think about all the different new business models that are going to change. Jeff Immelt, CEO of GE gave a really great graduation speech at NYU this past spring and he talked about the end of globalization. That he believes that all the trade barriers that countries are erecting, are going to require them to have a very different posture going forward. He says his US factories at GE are going to be manufacturing for the US market and exports are going to go down. And that they need to be able to make product in country or in region to be competitive. Local for local production.

And one of the key fundamental tenets of that business model is having a digital factory, a platform that could make anything, a flexible factory. And again, the digital revolution is gonna really enable these entire new business models. And so, but the key is, what's blocking that, is they haven't been economically fabricated, and they're not real parts. So we believe we can be the trigger to open up these entire new business models and we're very excited about that. So, a future fabricated with light, that chisel, think about light as a chisel is really what drives us. And the last thought I'll leave you with, is okay, what's the big deal? Has light, and this sounds risky, has light been used anywhere else to drive manufacturing? Especially here in Silicon Valley to think about the semi conductor industry is driven by patterned light in photolithography. And that's using patterned light in two dimensions. To make all the memory chips, all the wafers, all the integrated circuits that we've come to rely on, it's all made with light. But we're using light in three dimensions. And the opportunities to drive a broader manufacturing footprint and potentially have a bigger impact than even the semi conductor industry is something we're very, very excited about.

So, we've got an amazing company. It's an honor as a faculty member to serve and be part of this team. This is our board of directors. Our boards, as you know, are representative of their investors. And then you got a couple independent board members. Our independent board members include Alan Mulally, who is a former CEO of Ford Motor Company. Another great book, read about Alan Mulally, American icon, how he saved the Ford Motor Company. And he was also president of Boeing Commercial Air Division. Really a big proponent of digital manufacturing. And then Ellen Kullman just joined our board.

She's a recently retired chairman CEO of DuPont, so emphasizing the material science of the App Store for resin focus of our company. So really great advice for us going forward. And then our investors are some of the most iconic investors in Silicon Valley. I love as an entrepreneur coming from the East coast, I love being in Silicon Valley and all you folks here from Stanford are really in a special position. I think being here in Silicon Valley is what it must have felt like being in Florence during the Renaissance. This is the place for doing entrepreneurship. And that's why we here at Carbon are in Silicon Valley. Our investors include Sequoia Capital. Think about Cisco and Apple and PayPal and Yahoo and WhatsApp. SilverLake, the largest private equity technology firm.

They broke all their rules to lead a Series B investment in a start up company. Because they new the impact that digital manufacturing was going to have. And then Google Ventures, when I walked on the stages of TED, Larry Page and Sergei Brim were in the audience, we had a booth, we had our parts, shortly thereafter Google Ventures lead our series C. And then most recently we did a series C extension, led by our customers, people that are really focused on manufacturing and BMW, GE, Nikon and JSR. We're very excited to have them on the team. And with that, I'm really thrilled to be here and thank you for your attention. I'd be happy to answer any questions. (audience applauding) Question, yes? - [Audience Member] (mumbling) address larger parts? And the second question is, the networking algorithms you mentioned, is that supervised (mumbles)? - Yeah, so the question was, what is our product roadmap and in particular he asked about larger parts, and yeah, absolutely. You can see the product roadmap be absolutely focused on, actually that window technology, the key to having a window that was extensible to larger areas was something that we actually had to technologically tick off on series B funding, and so our window now is scalable to large areas, and our product roadmap reflects that. And your second question? - [Audience Member] Are you going to supervise or unsupervised algorithms with your networking? Or what exactly do you mean by that? - You know, I don't even know what that means, actually.

Oh so the machine learning aspects. I'm a chemist so I appreciate that. Being comfortable with what you don't know. I'm sharing, vulnerable trust here. We're a little bit more like a Mechanical Turk right now. But as our censors get in, so it's more humans intervening on this. But the opportunity for doing analysis is there. Great question. Yes. - [Man] Do you see plastics and polymers replacing metals as you're going forward? - Did you see the movie The Graduate? (audience laughs) You're a little young.

There's a classic line in The Graduate where they said plastics, plastics, plastics, right? That was in the 70's I think. There was a Star Trek movie later on, one where they're trying to rescue the whale and they needed a big pool of water and Scotty, you don't even know Star Trek. (audience laughs) Scotty needed, he was looking for some transparent aluminum and they had polycarbonate and he says "You're still using polymers?" That joke should resonate. (audience laughs) It's not. So will polymers take over metal? So in your car, that car is loaded with advanced polymeric materials and composites. And polymers are more expensive than metal and glass, and so you ask why are polymers making such an infiltration into automotive? Well the reason is, it can simplify manufacturing steps. Because you can make more complex things, they can be lighter weight, they can be safer, so there's a lot of reasons and a whole host of applications why yes, polymers is a massive industry. It's a 400 billion dollar industry in the United States. You think about all the wearables, I'm pointing to a metal watch, but you think about all the wearables people have, and all you devices, your laptops, there's so many places where advanced materials, especially in aerospace, automotive, consumer electronics, those are all polymeric materials. So yes, it's a huge market but it's been held back by not having real materials made economically.

Wow, I felt like I really dated myself there. Yes. - [Student] So some people have expressed concern about the durability of the using CLIP. So have you been able, some of these people are Wohlers Associates, I believe. - Yeah, Terry Wohler. - [Host] Can you please repeat the question? - The question was Terry Wohler had Wohler's report, and I think it was we had an article by Forbes or Fortune and you always, what's really great is you always have, when you put yourself out there, a lot of people will comment on what you're doing. And Terry is grounded in the current industry and he was asking about UV stability in particular. And if you're knowledgeable in materials, polymeric materials, what you'll quickly acknowledge is that some of the most UV unstable materials, one of the most UV unstable materials, is natural rubber, which makes up all the car tires that are baking in the sun. And a lot of those materials are stabilized by things like carbon black and other things that allow a material to have great material properties to be UV stable. And so using a similar approach, we have very stable systems.

But that has not been the history. If you use light to set the shape, and to set the properties, you're gonna be hard pressed to have a UV stable system, but using our approach with light to set the shape and chemistry to set the properties, our customers have already proven that we have stable systems. That was a long winded answer. - [Student] (out of mic's range) be able to like rigorously test the-- - Yeah, you need to, to get into a lot of these applications and so we, not only us, but our customers. You know what's really interesting too from an entrepreneurship point of view, you can give a customer a set of data, and they're like that's great, we're going to do it ourselves. And they replicate what it is you're doing. So even that UV data that I showed you on the screen, was not our data, it was our customer's data. Yes. - [Female Student] How are you going about changing the mindset of engineers in the industry from DFM to design for use? - Yeah, so it's coming to places like this. - [Host] Could you repeat the question? - The question was, how do we train a new generation of engineers to think about design freedoms or additive manufacturing versus traditional manufacturing.

And I think the key place is to start with where a lot of new engineers are emerging, put these new tools out, that's why we're really focused on getting some printers into the university setting. When we look at some of our big customers, what's interesting is they have prototyping shops, where they're already, it's like preaching to the choir, they already know, but the engineers at these companies don't buy in, in fact, hate 3D printing. I can't tell you, I've had so many CTO's and CEO's of some of the biggest companies in China and in the United States come and visit Carbon and some of them come reluctantly. We had a common investor in one story, and the common investor said you got to go see Carbon and go see these parts. And he said "I hate 3D printing. "It's never going to amount to anything. "In fact, I'll change my name "if it ever amounted to anything." And you may know who I'm talking about now, he's notorious for saying that. But we had those folks hold on to these parts and say that we've changed their world view. So, it's a combination of how do we penetrate an existing marketplace and major industrials but also starting with universities as a little bit of our tactic. - [Host] Last question.

- Yeah. - [Male Student] Hi. How do you think if 3D printing is going to become the huge thing that everybody thinks it's going to become how do you think Carbon is going to handle the change into people having a 3D printer in their home? - So what's interesting is the consumer marketplace, the maker space, the maker community emerged very quickly. And with, and I think there's a lot of people that are probably frustrated by the quality of what they're making. But there are some great examples where it is working. But I think the content is quite limited there. And there's other people competing in that marketplace. And it's one of the most innovative marketplaces for ideas and it's one we want to foster and that's why we put printers in service bureaus. We actually had a bunch of skateboard experts down in the San Diego, LA area make skateboard wheels and new trucks and the whole goal was to beat the crap out of our parts and show that, and they were skateboarding for like an hour. And nothing, and the video terminated.

So they were really happy campers. So we're feeding that community but we're trying to do something that no one's doing. And that's doing 3D manufacturing. And that is really the opportunity to cross the chasm for economic buyers. But with some of our partners, there is a consumer facing. When we start coming out with products that you all will be using, you'll see Carbon and how we brand Carbon with some of these new products. It's something that we'll be exploring here in the very near future that we're excited about. - I'm sure you'll agree this was incredibly fascinating. Please join me in thanking our guest. (audience applauding)