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The Insider

JOSH WOLFE, EDITOR

As we go into the holiday season, we bring you a very special gift. On top of revealing one of the hottest new emerging technology areas, we sit for a rare and exclusive interview with a very special friend and guest. He is a lifelong learner, technology tinkerer, visual visionary and a six-time Academy Award nominee responsible for the two highest-grossing films of all time (nearly $2B for *Titanic* and $3B for *Avatar*): James Cameron. Inspired in part by his father (an electrical engineer) and originally studying physics in college, he became a miniature-

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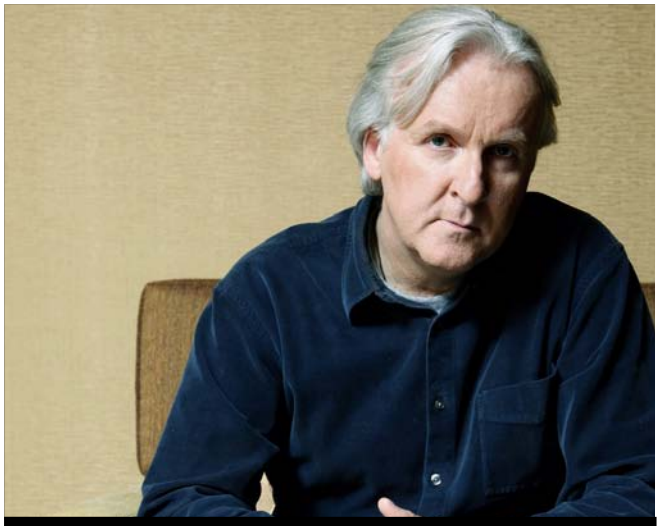
James Cameron: Blockbuster Businessman



JAMES CAMERON

James Cameron is an award-winning director, producer, screenwriter, environmentalist and entrepreneur. Over the last 20 years, he has written and directed some of the largest blockbuster movies of all time, including *The Terminator*, *Aliens*, *The Abyss*, *Titanic* and most recently, *Avatar*. His films have pushed the limits of special effects, and his fascination with technical developments led him to co-create the 3-D Fusion Camera System. He has also contributed to new techniques in underwater filming and remote vehicle technology. Cameron's first job was as a truck driver and he wrote only in his spare time. After seeing *Star Wars*, he quit that job and wrote his first science fiction script for a ten-minute short called *Xenogenesis*. Soon after, he began working with special effects, and by 1984 he had written and directed the movie that would change his life—*The Terminator*. Cameron was the founder and CEO of Digital Domain, a visual effects production and technology company, and is a co-founder and co-chairman of Cameron | Pace Group, an industry leader in 3D technologies and pro-

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BRAD FELD

Brad Feld: Turning Computers Into More Useful Tools

Brad Feld has been an early stage investor and entrepreneur for more than twenty years. Prior to co-founding Foundry Group, he co-founded Mobius Venture Capital and, prior to that, founded Intensity Ventures, a company that helped launch and operate software companies. He is also a co-founder

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TERRY WOHLERS

Terry Wohlers: Manufacturing The Future Of 3D Printing

Terry Wohlers is principal consultant and president of Wohlers Associates, an independent consulting firm he founded 25 years ago. Through this company, Wohlers has provided consulting assistance to more than 170 organizations in 23 countries. He has authored nearly 400

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James Cameron: Blockbuster Businessman

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duction services. He has received three Academy Awards, two honorary doctorates and sits on the NASA Advisory Council.

How did you get started in the movie business?

I was working as a truck driver, and on Saturdays I would drive 70 miles to the USC campus, and spend the entire day in the library looking at books, periodicals and dissertations so that I could learn about visual effects. It was all pretty technical stuff, everything from optical printing, to film sensitometry, to optics. I'd collate photocopies into binders and ended up creating my own technical library of state-of-the-art cinema visual effects. In effect, I gave myself a post-grad education. When I finally got a job doing visual effects, I was the most knowledgeable guy in the whole facility, but my knowledge was entirely theoretical. I had to learn many harsh realities of actual production. Theory and practice were colliding, and it was a very interesting time.

What sort of equipment were you using when you first started shooting?

When I started working professionally, we used what I call "meat grinder cameras," where the film ran through moving sprockets. I started cutting on an upright Moviola editing machine, and then I graduated to a flatbed. I learned how to load all the different kinds of cameras, and I could load an Arri IIC magazine in the dark in record time! That's a lost art. I don't know how many people in the world today still know how to load that kind of camera.

What were the challenges in using that early equipment for the type of films you wanted to make?

The equipment was very standardized—you got some film, or if it was a low budget film, you shot on short ends. We were pushing the envelope in the area of motion control, which was an expensive and exotic process at the time. We achieved some high-end effects with low-cost workarounds, as we couldn't afford all the right equipment. Almost everything I used to work with is obsolete today, yet one of the strangest things about filmmaking is that in some ways, nothing has changed for me, because it's still storytelling. You've got to understand what the audience wants to see, you still have to create great characters and stories, you still have to imagine it, and go through the steps of design and execution. But none of the techniques, none of the cameras and none of the processes that we used when I started out in the early '80s are used today. Not one thing.

When was the first time you saw a digital effect that you thought was truly magical or amazing?

I remember the exact moment. It was in 1988, when we started *The Abyss*. I had written a sequence that I didn't know how to execute, where water raises itself off the ground and makes faces. I could visualize it perfectly with surrealist clarity, but no one knew how to do it. We considered claymation and other advanced methods using high-speed photography of water projected onto white clay. That probably would have worked—although it would have looked different.

I was skeptical of computer animation, but looked at some test shots. It was all very crude at that point, but we decided to do two more tests with two different companies. (One of them was Industrial Light and Magic, with CEO Dennis Muren, who I think has more Oscars than Meryl Streep. Dennis was visionary enough to see that this is where things were heading.) Interestingly enough, neither test was particularly good, but effective enough to know that the whole thing was possible. We had 16 shots, and a year to complete it, and we barely got it done. When people saw the sequence, they couldn't process how something so utterly impossible could be so photorealistic. It was a huge moment, both for us and for the effects industry at large.

What made you decide to start your own visual effects company?

I was friends with Stan Winston and he was working on *Jurassic Park*. I saw some of the test shots and I realized that this digital curve was going vertical. We both believed that the future was in computer generation, not in the effects we had been previously doing, including prosthetics and animatronics. Stan already had a few animation workstations going, and I said "why have four workstations when you can have 400? Let's go get some money and do a company." I never thought I had a particularly good head for business, until founding Digital Domain.

How did the business get started?

We started in 1992 by raising $15 million from **IBM** [IBM], and they came in for 50% of the company. I think they wanted some synergy with the film industry so they could understand it better, especially as Hollywood began embracing technology. The team included Stan and myself, and Scott Ross as a third partner. Scott had been running Industrial Light & Magic, so he had big organizational skills. I remember

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model maker. His work has inspired engineers, technologists and entrepreneurs the world over from *Aliens, Terminator, Terminator 2: Judgment Day, The Abyss and True Lies.*

Earlier this year, I joined Jim and the cast from *Avatar* for the opening of the high-tech immersive *Avatar* exhibit at Paul Allen's Experience Music Project in Seattle. Jim shares some of his secrets for filmmaking, breakthrough digital effects and the way technology (specifically technology he has patented) is revolutionizing the way we experience immersive movies and bringing the ideas and imagination of science fiction to life.

And speaking earlier of miniature-models, there is an avalanche of activity in three-dimensional printing, personal fabrication and human-computer interaction. We bring you two exclusive viewpoints on the field from an investor—VC Brad Feld, behind a new investment in the space and also an early investor in the technology behind *Guitar Hero*—and industry guru Terry Wohlers, who many look to for the past, present and future of 3D printing and the new revolution in personalized manufacturing.

As always, here's to thinking big about thinking small and to the emerging inventors and investors who seek to profit from the unexpected and the unseen…

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one funny conversation about who would run the optical department. I told him there wouldn't be an optical department—it would all be digital. That decision influenced the makeup of the initial core technical group, because we had to create a way to manage hundreds of artists to work in the same color space across an entire company. Those tools didn't exist at that point. He didn't think it could be done—but we did it.

Is it true that *Avatar* was conceived within Digital Domain?

I started Digital Domain with the goal of being the first all-digital effects facility. We started with a focus on CGI, computer animation and digital composite. The first shots that came to us were digital 2D composite, so we didn't spend enough of our time and energy on 3D character creation. Stan and I wanted to create great characters, like **Disney** [DIS] did. We just wanted to do it a new way, with computer animation instead of animatronics and cell animation. After three years, I felt that Digital Domain was going too far into digital composite. So I wrote *Avatar* to drive us to create organic CG characters, CG environments and naturalistic photo-realistic lighting. I put in all the things that we wanted to put into a film, rolled it up in a ball of wax and called it *Avatar*. It's not like I had some blinding bolt of inspiration to do a movie about blue people on another planet; it was extremely Machiavellian. I just wanted to push Digital Domain to the next threshold.

Now, jumping ahead many years to when you actually did start work on *Avatar*, what effect was the most challenging?

In *Avatar*, our goal was to create a photorealistic humanoid character with full emotional affect, so viewers wouldn't question the physical reality of the character. We knew that was the Holy Grail. It took a lot of work, but I knew we had achieved it when people looked at the early shots and asked, "how did you do that makeup?" That's when I knew we had achieved our goal—viewers were not questioning the fundamental reality of what they were seeing, they assumed it was makeup, not a digital effect.

How did you achieve such amazing photorealism?

It was an end-to-end chain of processes, where we had to improve the capture process and the animation pipeline. We worked with Weta Digital to create the virtual equivalent of all the facial muscles, and the neuromuscular symphony that goes on below the skin. For a long time, we believed that if we could just scan the actor better, we'd get enough data to have a believable character. That wasn't the answer; we had to get below the surface, at the muscular level. We have as many muscles in our face as we do from the neck down. These are the most unusual muscles in the body because a lot of them are only anchored on one end. The face is an incredibly complex, fluid system. Eventually, we learned that there is no generic human. Every actor is different, and we figure it out character, by character. It's not only the way their facial muscles are physically constructed, it's also how they fire.

How does the technology for that capture system work?

We've got a motion capture environment, with a grid of cameras and marker dots on the person, which records the physical body portion of the performance. For *Avatar*, we created a head rig: a conformal carbon fiber helmet with a little standard depth camera that only photographs the face. It moves with the actor, and provides all the inputs for what we call the surface mesh. That drives this very complex system of virtual neuro-musculature. Image-based facial performance capture had never been used in a feature film before. We coupled the process for gross body motion with the facial performance to get two data streams for each character. One is their image-based facial recording; the other one is a cloud of moving points that represent their body motion. The two are put together later in the pipeline, when we get that scene ready for a virtual camera session. The scene has been captured and the actors are long gone by the time we look at the raw data, which we call the volume. I'll then go into the volume with a virtual camera, and do all my coverage—it might be a helicopter shot, it might be a running shot, like a steady cam shot or a hand-held shot. We play back the actor's performances, almost like a video game character. Our virtual art department creates the jungle, or the mountains, or the human base around them.

"I wanted to create great characters, like Disney did. I just wanted to do it a new way, with computer animation instead of animatronics and cell animation."

How does the technology impact the actor—does it change his or her performance?

We can change the physicality but we can't change the actor. The emotional, vocal and physical components of the performances are all theirs. The beauty of the virtual production workspace is that we're not dealing with additional takes because of focus or camera coverage or lighting. In a typical movie scene, I'd have to do a master shot from one spot, and then we'd do our entire scene over and over again for different shots. It's not because the actor didn't do it well the first time—we'd do it because I had to move in for a close-up, or light it better than the wide shot. Virtual production takes all that away. We only repeat scenes for performance.

The actors love it, because suddenly they're free of this highly artificial process of movie acting. They just act the character and the moment in a very pure way. We can completely change the staging of the scene, and everything we've done before doesn't matter. Once we get one take that we like from beginning to end, I do all my coverage from that take. In fact, one of the most powerful moments in *Avatar* is when Zoe's character believes she's been betrayed by Sam's character. She yells at him and pushes him away and has this breakdown. There's camera coverage all over the place, with probably 20 or 30 different angles in the scene. But in reality, that was all just one take.

Do you find most actors excited about working in this new environment, or are there hesitations?

I recently spoke on virtual performance at the Screen Actors' Guild. Their mouths were hanging open because they had no idea what any of this meant. They worry that we're replacing actors, but truly we're

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empowering actors in a way they've never been empowered before. Movie acting has become highly artificial, because actors have to hit the same emotional peaks over and over to film different shots. Actors learn to hold back, and some shots are compromised because they haven't reached the good spot yet. We uncouple the acting from the photography, the lighting, and the camera placement. When I'm with the actors, all I work on is their relationships to each other and the dramatic epiphany that has to take place in that moment.

How do the economics balance out when you replace the physical with the virtual? Is it cheaper or more expensive to film this way?

It's a wash. Well, it's cheaper than physically building an imaginary world, but it's apples to oranges—you can't compare it. What is the cost of actually creating a banshee in the real world? There's no pricing on that, because it's not possible. It's a longer process—normally we finish the day with footage, but in this process, we just have a bunch of data at the end of the day.

More recently you've started another company, Cameron-Pace. How did that come to be?

Cameron-Pace was never really a startup. Vince Pace had his business, Pace. We had met years earlier while working on *The Abyss*, and we had done dive expeditions together, and had similar backgrounds. I approached him in 2000 about creating a 3D camera system. I offered a simple deal: I'd put up the money, we'd own it 50/50, and we'd split any profits 50/50. Over the next few years it snowballed into a business, where we bought big chunks of **Sony** [SNE] technology, lenses from Fujinon, and things like that. Vince was supplying all the sweat equity and the effort began to dominate most of his Pace business. Finally we realized we'd created a 3D business and we were partners in it, so we began to strategize. What can this company be? What kind of capital will we need?

What does the future hold for this business?

We do not want to settle for anything less than having our hand in everything to do with 3D production. Film, cinematic film, theatrical films, documentaries, broadcasts, live sports—everything. To service those industries on a global scale, we needed to grow to three or four times the size, with more inventory, more people, and a training center. The company is at 45 people right now, and we expect to multiply that over the next 12 to 18 months, adding everything from camera techs who set up the rigs and work on individual productions, to engineers that work in remote trucks, making sure that the images are recorded correctly, to design engineers and machinists in the prototyping shop.

What's your secret for business success?

Ultimately you have to do this stuff because it's fun. I don't need CPG as a business to make money; they're interesting pursuits and I know it's going to make my filmmaking better, as a side effect. But that's not even the primary driver. For me, it's about what can we build that's new, what kind of tools can we put in the hands of other filmmakers, and what happens then? What will it be like when every TV is 3D, and we were at least partly the architects of that? To me, that's exciting. ET

Brad Feld

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of TechStars. Brad currently serves on the board of directors of BigDoor Media, Cheezburger Networks, Fitbit, Gnip, MakerBot Industries, Oblong, Orbotix, Standing Cloud and Zynga for Foundry Group. Previously, Brad served as chief technology officer of AmeriData Technologies. AmeriData acquired Feld Technologies, a firm he founded in 1987 that specialized in custom software applications. Brad had grown Feld Technologies into one of Boston's leading software consulting firms prior to the acquisition. He also directed the diversification into software consulting at AmeriData, a $1.5 billion publicly-traded company that was acquired by GE Capital in 1995. In addition to his investing efforts, Brad has been active with several non-profit organizations and currently is chairman of the National Center for Women & Information Technology. Brad is a nationally recognized speaker on the topics of venture capital investing and entrepreneurship and writes widely read blogs at www.feld.com and www.askthevc.com. Notable companies that Brad has invested in and/or sat on the boards of include Abuzz (acquired by NYT), Anyday.com (acquired by PALM), Critical Path (CPTH), Cyanea (acquired by IBM), Dante Group (acquired by WEBM), DataPower (acquired by IBM), FeedBurner (acquired by GOOG), Feld Group (acquired by EDS), Gist (acquired by RIMM), Harmonix (acquired by VIA), NetGenesis (IPO), ServiceMagic (acquired by IACI), and ServiceMetrics (acquired by EXDS). Brad holds Bachelor of Science and Master of Science degrees in Management Science from the Massachusetts Institute of Technology. Brad is also an avid art collector and long-distance runner. He has completed eighteen marathons as part of his mission to run a marathon in each of the 50 states.

Can you give us a quick overview of Foundry Group and what you do?

We are an early-stage software and Internet investor. We are focused on a set of horizontal themes—there are four partners and we all work on everything together. We invest around the U.S.—usually $5 million to $15 million over the life of a company. We've got 40 investments made out of two funds—a $225 million fund we raised in 2007 and a $225 million fund we raised in 2010.

What first got you interested in 3D printing?

One of our themes is "human computer interaction." We strongly believe that the relationship between computers and humans in 20 years will be radically different than the relationship today. 3D printing fits in this theme—in the same way that the Apple II changed the relationship between man and machine (to make it "personal") and the HP LaserJet made it possible for everyone to have a high resolution printer on their desktop, we think in a decade everyone will have a 3D printer on their desktop.

What was the feeling you got the first time you actually printed an object?

Awesome. It's the ultimate in making something when you design a simple 3D object using a lightweight CAD program and 15 minutes later hold the object you've designed in your hand.

What's your favorite object you've printed?

Yoda. He's my hero. I also enjoy my chess set.

Brad Feld: Turning Computers Into More Useful Tools

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"One of our themes is 'human computer interaction.' We strongly believe that the relationship between computers and humans in 20 years will be radically different than the relationship today."

How do you fit 3D printing into the broader maker movement, and what excited you enough to make an investment in this space?

3D printing is a core component of the maker movement. Being able to print whatever you need to make whatever you need—well—it just fits together.

What impressed you about the MakerBot team?

Amazing founders who are obsessed with 3D printing. The Thing-o-matic is a remarkable product—we bought one before we invested and my partner Jason Mendelson, myself, and Ross Carlson (our IT guy) put it together over about 20 hours. There was a lot of "wow—this is amazing" during the assembly process—even more when we started printing stuff. Given what the MakerBot team has achieved with a very modest investment, we realized these guys, and the company, are special.

Where do you see the company in 5 years? In 20 years?

I think the MakerBot products will be the standard for desktop 3D printing within 5 years and as ubiquitous as HP laser printers became within 20 years.

Foundry Group has a number of investment themes—and this fits into "computer human interaction"—what other trends do you see happening within this theme?

A radical shift in UI/UX (i.e. Oblong), rapid evolution of 3D visualization and data capture (Organic Motion and Occipital), reinventing of basic robotic concepts due to the power of the smartphone (Orbotix), and exciting companies that start with the letter O. Also, the reinvention of play (Sifteo, Orbotix), and human instrumentation (Fitbit).

When new technology areas start gaining traction, how do you think about distinguishing real future merits from current consumer fads?

We pay no attention to consumer fads. We are focused on the entrepreneur and their long term obsession about building something amazing.

Let's shift attention to Fitbit—what does Fitbit do and how did this company first come to your attention?

Fitbit is by far the most interesting human instrumentation device I've encountered. I believe that in a decade humans will be fully instrumented—there will be no need to count calories, measure blood sugar levels to decide how much insulin to take, or measure your blood pressure on a regular basis. This will be done "automatically" and the data will be part of a human/machine feedback loop to help deliver the right amount of insulin, deliver low blood pressure medication, or tell you what you can eat and when you should be eating it. A year before we invested (about two years ago), I became obsessed with the notion of human instrumentation and bought every product I could get my hands on (I now have several boxes of crap that I don't use anymore.) Fitbit continually rose to the top of the list for the products I was using.

What was the skeptical feedback you got when thinking about investing in the business?

Something we hear regularly—"consumer electronics are hard." Our response to this is "whatever." We're glad it's hard—that means less people will try to create them and less VCs will fund them.

Some might argue the increasing prevalence of technology in our lives is not a good or natural trend. How do you react to this? Does any part of your vision of the future scare you?

Resistance is futile—the machines have already taken over. They are just waiting patiently for us as we enter all of human knowledge into them and connect them to everything. I'm an optimist—I think the machines will be our friends and we can have a nice symbiotic co-existence.

You've said that "the way humans interact with computers 20 years from now will make the way we interact with them today look silly"—can you paint us a picture of some of your visions of the future?

I'll give two examples. First, the idea that people will walk down the street typing on a piece of glass with their thumbs is absurd. The next time a plane that you are on lands, look around. 25%-50% of the people will power up their smartphones and spend the next few minutes scanning their e-mail. What a silly way to communicate. Next, observe carefully your next video conference. It's awesome that we can see the pimples on people's faces because of HD video over IP, but it's crazy that we can't actually interact with the data we are describing or showing to each other. Oh—and wires—there are way too many wires in my life.

Hardware companies face very different challenges than software companies. What lessons do you have for companies pursuing non-software innovations?

All of the hardware-related companies that we invest in have magic software at the core. We love hardware products that are wrapped around software that evolves regularly. Use the hardware to make the user experience magical, but make sure the software is doing all the real work.

Several of your investments seemed to have spawned from personal passions—love at first sight with the Makerbot, remote control robotic toys, exercising with Fitbit, etc. —how important is passion in the venture capital business?

For us, it's everything. We only invest in companies with products and people that we are excited about.

What other non-consensus technology themes are you watching that would surprise people?

We believe there is a huge opportunity in machine to machine communication (our Glue and Adhesive themes). We also believe that there will be a continuous opportunity investing in new (and old) protocols (our Protocol theme). ET

Terry Wohlers: Manufacturing The Future Of 3D Printing

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books, articles and technical papers and has given 90 keynote presentations on five continents. In 2007, more than 1,000 industry professionals from around the world selected Wohlers as the #1 most influential person in rapid product development and additive manufacturing. In 2004, Wohlers received an Honorary Doctoral Degree of Mechanical Engineering from Central University of Technology (Bloemfontein, South Africa).

How did you get interested in 3D printing?

Back in the late 1980s, I read a short article on stereolithography—the very first 3D printing technology. I thought to myself "Wow, if this works as described, it could be the best thing since computer-aided design and manufacturing." I contacted the company that the article was about, and it sent me some materials and a videotape. I thought it was fascinating. By 1990, there were several companies that had introduced other types of 3D printing machines and materials.

What led you to begin consulting in this technology space?

In 1988 at an exposition in Philadelphia, I had the privilege of organizing and offering a conference session on the subject of 3D printing. Attending the session was an individual from the world's largest manufacturer of in-the-ear hearing aids. Afterwards, he approached me about using the technology to manufacture their products. At the time, they manufactured hearing aids manually: they made an impression of the patient's ear canal using a silicon material, and then used it to create a single-use mold to produce a custom hearing aid shell in plastic. I worked for that company for four years as a technology consultant tracking and reporting on the newest developments in 3D scanning and 3D printing technology. It didn't take much to be an expert back then, because the field was so new that no one knew much about it. Soon I was accepting new consulting assignments on additive manufacturing and 3D printing technology, and writing and speaking on the subject as well. 3D printing subsequently changed the whole world of hearing aid manufacturing and became the standard method of custom shell production at most major companies in the business.

What makes 3D printing so special?

Conventional manufacturing relies on milling, drilling, molding, casting, or forming, and those processes have limitations. With 3D printing or additive manufacturing, anything you can create on the computer, from a human skull to wild artwork, can be digitally sliced and then printed. This is significant because typically, the more complex a part, the greater the cost, but in 3D printing you get complexity for free. It is capable of producing highly-intricate parts and assemblies that would otherwise be cost prohibitive to manufacture conventionally. I've seen lighting designs, sculptures and fashion products that could not be made any other way.

What are some of the major breakthroughs you've seen in this space?

One is the 3D printing of metals. These include titanium alloys, cobalt-chrome, even gold for use in dental crowns and jewelry. Another important success has been the ability to manufacture end-use parts and products. For example, many parts on the new Boeing 787 aircraft are produced with this technology, and it's also widely used on military aircraft by **Boeing** [BA]. These developments and innovations will have a much bigger impact than using 3D printing simply as a tool for modeling and prototyping. The next frontier, and the biggest economic opportunity, is using it to manufacture actual products.

When did this shift from prototyping to manufacturing begin?

The first companies to adopt this were the hearing aid manufacturers. Aerospace came next—getting parts on aircraft and into space. Parts built with this technology have been on the international space station and on the entire fleet of the space shuttle for many years. That really opened my eyes, because aerospace is a very demanding and highly regulated industry. One of the biggest success stories in this industry is the use of 3D printing to create highly-sophisticated environment control ducting for a fighter jet made by Boeing. More than 20,000 of them have been manufactured and installed without a single failure. Producing parts this way can eliminate part numbers, inventory, labor and even entire assembly lines. Also, it reduces weight, fuel, maintenance, and certification paperwork, resulting in significant cost savings.

What is the cost of a commercial-quality 3D printing system today?

It depends on the type of machine, class of material, and the maximum part size. For a machine that can produce industry-standard parts, the cost starts in the $15,000 to $20,000 range at the low end, and at the high end, more than $1 million. But 10 years ago, you couldn't buy any system for $15,000. The price-performance ratio has improved dramatically. You're also seeing a community of makers and DIY enthusiasts embrace this technology, and you can now find inexpensive 3D printing machines available as a kit for as low as $500.

What's a common misconception people have about 3D printing?

One misconception is that these devices will end up in everyone's home, as a tool that could replace any part that breaks on an automobile or a kitchen appliance. That misconception can be found among people close to the technology as well as the general public and the media. The average person simply wouldn't own a machine that accepts the material types needed to properly make parts such as a front bezel for a car stereo or a refrigerator handle. It is possible to make these types of parts on a 3D printer, but they wouldn't consist of the right strength properties, color, texture or surface finish. Most people, by their very nature, probably wouldn't want to mess with it. They'd rather order that part online or go to a nearby shop.

Are there other biological applications for additive manufacturing, beyond hearing aids, where this process really benefits the form and function of the end product?

Orthopedic implant manufacturing is really growing impressively. The Europeans have had CE approval for more than four years for a titanium acetabular hip cup, which is implanted into the pelvis as part of a hip replacement. More than 30,000 of these have already been manufactured. I wouldn't call it mainstream just yet, but it's growing in popularity, and earlier this year, the FDA certified a similar product and process, so I suspect we'll see the same growth in the U.S. The product is standard but I expect we'll see more development in custom implant products. A custom hip cup is more expensive but potentially much better because standard implants require choosing the closest size, and removing healthy bone in order to make it fit. With the custom product you reduce that problem.

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"Conventional manufacturing relies on milling, drilling, molding, casting, or forming, and those processes have limitations. With 3D printing anything you can create on the computer, from a human skull to wild artwork, can be printed."

Another biological application is the production of medical models for surgeons to help plan complex surgeries. Typically, these are craniofacial models produced from CT or MRI scans that contain information on what's underneath the surface of the skin tissue—including blood vessels and any fractures, defects or tumors. These models have been used to plan surgeries and have reduced hours of operating room time and reduced patient trauma. A company in Colorado, called Medical Modeling, has made tens of thousands of models for surgeons to help them plan surgeries. All of the conjoined twins that have been separated in recent history have benefitted from these models. Many are produced in a translucent material with blood vessels visible in red, so before separating the twins, they know exactly where to cut the blood vessels and other hard and soft tissue.

Out of all these amazing applications, what is the one idea that just blows your mind?

I've gotten to the point where nothing really surprises me because almost anything is possible now. Yet, I believe the most exciting development is the printing of cells to produce living tissue. This is happening already, globally, although a lot of work is ahead to print complete organs with blood vessels. Material is printed to produce a biodegradable scaffold structure, which is the shape of the replacement, whether it's bone or soft tissue. The shape of what needs to be reproduced is captured through CT or MRI scanning. This data is used to drive an additive manufacturing machine that builds the scaffolding, which provides the shape and structure into which living cells are printed. After implantation, the cells grow and eventually replace the scaffolding as it degrades and is absorbed by the body.

I believe that in the future we'll be able to order up body parts, such as kidneys. The supply of transplant organs does not meet the current demand, so a lot of money and energy is going into printing living organs. Researchers have printed hard and soft tissue, including bones and bladders and experimental implants. I saw an interesting example in China, nine years ago, where a piece of bone was removed from a dog. They scanned the missing piece, built a new one, and implanted it. The before-and-after x-rays looked perfectly healthy.

Every year you publish a comprehensive industry report called the Wohlers Report. How do you go about pulling this together?

This year's Wohlers Report is the 16th annual edition. It was developed with help from 58 co-authors, 70 service providers, 32 system manufacturers, and many others worldwide. In the report, we use quantitative and qualitative survey data to gauge the growth and health of the industry, including the numbers of systems being installed worldwide. An entire part of the report is dedicated to building end-use products. Another section is dedicated to research and development, what is being funding by the U.S. government, and what's going on at universities and research institutes around the world. In the final part, we close with what we believe will occur in the future.

Were there any surprising findings from this year, compared to the past several years, in terms of growth or applications?

The biggest surprise has been the rapid growth at the very low-end, in what I call personal 3D printers. Interestingly, this market segment started with an academic, open-source project called RepRap in the U.K. Growth in that area went from almost nothing in 2007 to an estimated 5,978 units last year. This caught a lot of people by surprise, including me. Will it continue to grow at that level? Most of these buyers are engineers, DIY enthusiasts and schools. Will the average individual buy one? Probably not, but that market can expand once the machines are simplified and improved. The big opportunity is in the education market. Think of all the ways schools could benefit from multi-disciplinary labs. They could involve not only engineering and manufacturing, but also biological sciences (molecular modeling), medicine (orthopedic implants and tissue engineering), fashion design (clothing, footwear, and jewelry), sports science (protective gear), law enforcement and forensics (recreation of crime scenes), archaeology (bones and artifacts), interior design (space and facilities planning), and architecture (scaled models).

What companies are recognizing that opportunity and are moving into that arena?

HP [HPQ] has partnered with **Stratasys** [SSYS], but so far they haven't made a big commitment. It's hard to say who will get into it. **Canon** [CAJ]? Epson? **Amazon** [AMZN]? Will **Apple** [AAPL] come out with a product called the iPrint? This is still a relatively small industry, but if you consider total future sales, our conservative forecasts predict that the next **Google** [GOOG] or Facebook could emerge from this business.

If you had to list the greatest challenges in the industry, whether technical or market-related, what comes to mind?

The industry has developed few official standards. If you look at any developed industry, whether it's jet fuel or electronics, they have standards that companies follow to ensure quality. Currently, the automotive, aerospace, and medical companies have to shoulder the burden of testing. An effort to develop standards began two years ago by ASTM International, and most recently they formed a partnership with ISO. I've had the pleasure of participating in this important effort, and the activity here will accelerate the growth and development of this industry.

Another challenge is the development of a broader range of materials, specifically plastics and metals. Presently, 3D printers are compatible with a small fraction of materials used in conventional processes such as injection molding. We need to push harder and further, because the limited number of materials available is an obstacle to growth.

A third challenge is the development of more reliable and repeatable machines. Five identical systems placed at five different sites with five different technicians would yield five different results in part quality. This is fine for making models and prototypes, but real manufacturing processes require consistency, reliability, and repeatability. We've made progress in this area, but there's a lot of work yet to be done. ET

The Emerging Tech Portfolio

Company[symbol]	Coverage Initiated	Current Price	52-week range	Mkt Cap ($mil)	Buy/Sell/Hold
INTELLECTUAL PROPERTY INCUMBENTS Leading researchers in the physical sciences, with big potential for spin-offs and revolutionary breakthroughs					
GE [GE]	8/07	$14.70	$14.02-$21.65	$155,190.00	Buy
Hewlett-Packard [HPQ]	3/02	25.39	21.50-49.39	50,450.00	Buy
IBM [IBM]	3/02	177.06	141.28-190.53	208,690.00	Buy
LIFE SCIENCES Companies that are working at the cutting edge of medical technology					
Life Technologies [LIFE]	11/05	36.08	35.30-57.25	6,430.00	Buy
Nanosphere [NSPH]	11/07	1.56	0.89-5.95	67.77	Buy
ELECTRONICS Companies that have corralled the key intellectual property that will be the foundation for next generation electronics					
Nanosys [private]	3/02	n/a	n/a	n/a	n/a
NVE Corporation [NVEC]	7/03	53.50	50.42-69.46	255.52	Hold
ENERGY Companies that are developing high-efficiency, low-cost alternative energy technologies					
First Solar [FSLR]	8/07	40.32	40.05-175.45	3,480.00	Buy
A123 Systems [AONE]	9/09	2.05	2.01-10.99	258.46	Buy
ENABLING TECHNOLOGIES Tools and instrumentation that enable critical science and technology discoveries					
Veeco [VECO]	3/02	22.04	22.04-57.67	853.32	Buy
FEI Company [FEIC]	1/03	36.32	23.01-42.25	1,360.00	Buy
Accelrys [ACCL]	3/02	6.38	5.68-8.95	353.90	Buy
INVESTMENT VEHICLES Funds that have investments in promising emerging technology companies					
Harris & Harris Group [TINY]	5/02	3.46	3.17-6.30	107.26	Buy
PowerShares Lux Nanotech Portfolio [PXN]	8/07	5.79	5.41-10.62	21.92	Buy
PowerShares WilderHill Clean Energy [PBW]	8/07	5.03	4.90-11.42	246.30	Buy

Word on the Street

Stock prices as of November 25, 2011

GE: GE lost 9.4% on the month as recession fears intensified. Vice Chairman John Rice said that sales in emerging markets should grow in the low double digits in the next 12-18 months. GE sees sales of Energy Infrastructure products in China growing at least 25% annually. Analysts forecast GE's revenue will stay flat around $150B between FY 2011 and 2012, although EPS is expected to increase from $1.37 to $1.57.

HPQ: HP edged more than 1% higher after new CEO Meg Whitman calmed investors' frayed nerves by promising to restore credibility, put a stop to big acquisitions and focus on core operational improvements. HP reported Q4 non-GAAP net revenue of $32.3B and earnings of $1.17 per share, which beat analysts' forecasts of $32.05B in revenue and EPS of $1.13. Whitman called 2012 a "rebuilding year." Wall Street now expects HP's revenue to fall to $125.3B in 2012 from $127.24B this year, as HP has unusually high European exposure.

IBM: Big Blue lost nearly 2% despite Warren Buffett revealing a $12B stake, his first big investment in technology. Buffett announced Berkshire Hathaway had secretly amassed a 5.5% position in IBM, saying he'd been watching IBM's transformation from a hardware manufacturer to an IT services firm. According to Buffett: "I don't know of any large company that really has been as specific on what it intends to do and how it intends to do it as IBM."

LIFE: Life lost nearly 11% on the month. It introduced GeneArt Algae Engineering Kits, the first commercially available genetic modification and expression systems for photosynthetic microalgae. LIFE has become a hedge fund favorite: Glenview Capital has invested $665M making the stock its largest position, while John Paulson has nearly $400M invested.

NSPH: Nanosphere gained more than 18% after reporting Q3 revenues of $0.6M (all product sales), compared to total revenues of $0.4 million in the prior year period. Its net loss was $9.5M, versus $10.9M in Q3 2010. CEO William Moffitt declared, "We are entering a chapter in Nanosphere's history that will be marked by significant market penetration and placements for our Verigene System."

NVEC: NVE slipped 2.6% on no news.

FSLR: First Solar fell 6.8% on the month to a new 52-week low. A senior FSLR executive said competitors are "desperate" to sell inventory after adding too much capacity that has led to a supply glut and plummeting prices. First Solar is completing a factory in Vietnam to accelerate its own cost reduction. Barclays Capital initiated coverage of the stock with an Equal Weight rating.

AONE: A123 Systems shares were decimated by nearly 41% after it sliced its full-year revenue outlook by 20% following cuts in Fisker Automotive Q4 battery orders. A123 now expects 2011 revenue of $165-$180M, down from $210-$225M. A123 had invested $20.5M in Fisker in January 2010, receiving convertible preferred stock in Fisker in return. A123 has warned investors that if Fisker falls short of its strategic plan, A123 may not recover this investment. A123 also posted a Q3 loss of $63.7M ($0.51 per share), compared with a loss of $43.7M ($0.42 per share) for the prior year period. Q3 revenue more than doubled to $64.3M (from $26.2M in Q3 2010), topping analyst estimates of $63.8M, as battery shipments reached a record high. But higher costs left gross margin at -30.4%.

VECO: Veeco lost 14.1% on the month, falling to a new 52-week low. Goldman Sachs launched coverage of the LED industry, giving Veeco a Neutral rating. Goldman sees the adoption of LEDs in general lighting as a multi-decade opportunity, representing $11B in potential revenues by 2015. Goldman set a $28 target for VECO, cautioning that "moderating demand for MOCVD tools is not fully reflected in current consensus estimates." ThinkEquity raised its rating on Veeco to Buy (from Hold), upping its price target from $29 to $30. "Recent policy announcements in China, along with improving utilization at LED chip manufacturers likely provides the bridge to a resumption of orders in Q1 2012. We expect volatility in the shares until clear signs of order recovery becomes evident, but we see limited downside at these levels, as we believe cash provides support, as well as expect more positive news than bad over the coming months." The policy announcement refers to China's plan to ban incandescent bulbs above 100 watts by October 2012, which should spur significant growth for the LED industry. Deutsche Bank believes this is positive news for MOCVD manufacturers like Veeco.

FEIC: FEI Company hit a new 52-week high after posting record earnings for the fourth consecutive quarter. During Q3, FEI posted $26.2M in net income ($0.63 per share), as sales rose 34% to $205.3M. Analysts had expected a $0.55 in EPS on $203.9M in revenues. FEI had reported earnings of $11.9M ($0.30 per share) on revenue of $153M in Q3 2010. Cash and investments fell to $435.7M after FEI repurchased $50M worth of shares during the quarter. FEI's quarterly orders in the life sciences and research and industry categories reached double-digit growth, but was offset by weakness in the electronics market. McAdams Wright Ragen downgraded FEIC to Hold (from Buy)

ACCL: Accelrys gained 6.1% despite reporting Q3 results (all figures in non-GAAP due to merger with Symyx) with lower revenues and net income. ACCL's net income of $5.4M ($0.10 per share) on revenues $38M compared unfavorably with Q3 2010's net income of $5.7M ($0.10 per share) on $41.7M in revenues. ACCL generated $9.3M in positive free cash flow during the quarter. For FY 2011, Accelrys expects revenue of $152-155M with $0.32-34 in EPS. Accelrys benefitted from the November IPO of Intermolecular [IMI], in which it had a nearly 11% stake. The company sold its shares at the IPO for $39.7M in net proceeds and was issued a $27.3M secured promissory note by Intermolecular in exchange for licensing rights. Northland Securities downgraded the stock from Outperform to Market Perform.

TINY: Harris & Harris lost 4.2% on the month. The investment firm reported its Net Asset Value at the end of Q3 was $135.8M ($4.38 per share). TINY shares today trade at a steep 21% discount to its NAV. We continue to rate the stock a Buy.

PXN: The PowerShares Lux Nanotech portfolio lost 6.3% on the month.

PBW: The PowerShares WilderHill Clean Energy portfolio lost 11.3% on the month.

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