Can Applied Research Build Manufacturing Muscle?

By investing in applied research, the National Network for Manufacturing Innovation hopes to give American producers sustainable competitive advantages.

By **Alan S. Brown**

America Makes awarded Optomec, Inc., a contract last January to incorporate thermal imaging in Optomec's proprietary laser and electron beam metal 3D printing systems. Adding the sensor would provide greater processing control and give customers more confidence in part properties.

America Makes is a public-private-academic partnership, one of four that make up the National Network for Manufacturing Innovation. Located in Youngstown, OH, its more than 100 members conduct research in additive manufacturing.

Boeing 787 production line. Boeing is a member of Digital Design and Manufacturing.

Richard Grylls, Optomec's LENS general manager, sounds almost embarrassed about his enthusiasm for America Makes.

"I have a very high, healthy skepticism about what organizations like this are able to do, and whether they would have any real benefit," he said. His company, after all, had research contracts with the Air Force and other government agencies before it joined the partnership. "Even without America Makes, we might have ended up with money to conduct this research," Grylls added.

Funding Tests

He then went on to describe the project: "America Makes funded us to test the sensor. We're doing the very simple things that go into getting a product ready for production, characterizing materials and production parameters and evaluating the performance of the parts to make sure they don't break up in 50 hours because they overheat. You usually don't get government funded research to do this kind of project. It's something that bridges the gap between basic research and production. This type of research is immensely valuable." Grylls paused for a moment, then added, "Without America Makes, I'm not sure the Air Force would have funded this project. No, possibly not."

Michael Garvey also has good things to say about America Makes. He is president of M-7 Technologies, which develops multisensor measurement equipment for precision machining. He was pulled into the partnership by a Youngstown State University researcher who was using M-7's technology to characterize metal 3D printed parts.

"I saw 3D manufacturing coming, but didn't realize it would come across the horizon so quickly, let alone land in our backyard," said Garvey, whose firm is also located in Youngstown.

He ponied up $50,000 for a full membership in America Makes and said it was money well spent. "Part of the value was the relationships I was able to create," Garvey explained. "Even though I own a small family business, I now know the president of Siemens USA and the heads of other large companies," he said.

Through America Makes projects, Garvey was able to show his technology to 3D OEMs and end-users and learn more about their needs. Equally important, he has been able to share his new-found knowledge with his existing customers, shops that do subtractive machining and might benefit from additive manufacturing.

Lynn Ferguson's small company, Dante Solutions, also came to America Makes through a university, Case Western Reserve. Ferguson develops software to predict how molding can produce residual stress and distortion in fin-

A hybrid robotic exoskeleton, below, printed by 3D Systems, means Amanda Boxtel can leave her wheelchair behind while sightseeing in Budapest, Hungary, left. She was left paralyzed from the waist down after a skiing accident. Photos: 3D Systems.

ished parts. Case Western is testing the software to see how it analyzes the stresses created by the hot lasers used to melt or sinter metal powders in 3D manufacturing. As this technology moves up the food chain to more critical parts, such as hot jet turbine fuel nozzles and blades, Dante's software is likely to become more important. "We're hoping that by interacting with the companies in America Makes, we can promote our company and services," Ferguson said.

New Type of Research

Somewhere, **Michael F. Molnar,** *Wisconsin Alpha '86*, is smiling.

After spending 30 years in manufacturing, most recently as director of environmental policy and sustainable development at Cummins, Molnar joined the National Institute of Standards and Technology (NIST) as chief manufacturing officer in 2011. There, he became a key player in putting together the National Network for Manufacturing Innovation (NNMI).

NNMI's goal is to develop factory-ready manufacturing processes and products. The interactions among America Makes' small and large companies and universities are exactly what Molnar hoped to achieve. He thinks America Makes and its sister NNMI hold the key to reinvigorating American manufacturing.

Saving U.S. manufacturing has not always been a slam-dunk case. For much of the early 2000's, many economists, especially in Washington, believed that a $1 billion warehouse complex is just as valuable to the economy as a $1 billion computer chip factory. "Engineers know instinctively that this is not true," Molnar said.

This is because manufacturing is so intimately linked with innovation, he explained. Although it accounts for only 12 percent of the U.S. economy, manufacturers do 70 percent of all private sector R&D, employ 60 percent of all R&D personnel, and earn 70 percent of U.S. patents awarded to U.S. entities.

Increasingly, economists have come around to this point of view. The U.S. National Research Council's ongoing study, *Making Value in America*, and MIT's report, *Production in the Innovation Economy*, argue that manufacturing, design, and innovation are linked intimately with one another. When scientists and engineers struggle to commercialize new processes, lower costs, and boost productivity, they innovate in ways that build sustainable competitive advantages. When manufacturing moves offshore, these opportunities for future innovation—not only manufacturing success, but the design and engineering of products that take advantage of an intimate knowledge of production capabilities—move with it.

Manufacturing also creates good jobs. According to U.S. Commerce Department data, new factory workers earned 38 percent more than new hires in other industries and earned 17 percent more wages and benefits than their counterparts in other sectors.

Yet manufacturing jobs are not limited to factory workers. Today's factories outsource many functions they once did themselves. Some, like cleaning heat exchangers and managing logistics, are blue collar. Others, such as verifying equipment and designing products, are professional. In Michigan, for example, the fastest growing automotive jobs are in software. The vast majority of these jobs are not classified as "manufacturing," though they would not exist without factories.

This is why University of California, Berkeley, economist Enrico Moretti argues that the average factory job supports 1.6 non-manufacturing jobs. Moretti also estimates that advanced manufacturing, which relies heavily on specialized skills and services, creates nearly five jobs for every manufacturing position.

Policymakers wanted to preserve the U.S. manufacturing base and its potential for future innovation, but did not want to try to pick winners and losers from among existing industries. Instead, they decided to start by backing new, enabling technologies that might benefit a wide range of industries.

Michael Molnar—key player in putting together the National Network for Manufacturing Innovation.

These "platform" technologies included additive manufacturing, power electronics, digital design, and lightweight metals. While these technologies are already commercial, their uses are limited to niche fields. By making them more widely available, NNMI hopes to spark innovation and give U.S. manufacturers sustainable advantages in industries as diverse as aerospace, automotive, biomedical devices, and industrial products.

This called for a new type of research program. Policymakers envisioned a series of research centers, each focused on a single technology, which brought all the players together in a centralized location where they could learn from one another. Their deliverables would be factory-ready processes, products, best practices, information, and training.

A Big Change

This was a big change for federal programs, which typically focus on basic research and leave development to industry. To show NNMI was truly different, Molnar launched it in an unusual way: he built America Makes as a prototype to see how it would work. His team started stitching together 3D research programs from 10 different agencies to form one single program in February 2012. America Makes opened its doors in July.

Other things set America Makes apart. Instead of setting the research agenda, the government asked competing teams of manufacturers and universities to submit competitive proposals outlining their approach. This produced some surprises. According to M-7's Garvey, America Makes started out as a dark horse candidate but won out on the strength of its proposal.

Competing teams not only had to match federal funds, but they had to show how their institutes would become self-supporting after five to seven years. Typically, large corporations and universities dominate federal research programs. America Makes goes beyond the usual suspects, and includes many small and medium-sized enterprises, smaller schools, and the community colleges that will educate the next generation factory workforce.

By February 2014, NNMI had added three more research centers on fields as diverse as power electronics, lightweight metals, and digital design and manufacturing.

Yet the one thing they all had in common—the thing that really sets them apart from other federally funded research programs—was their emphasis on applied research.

The Gap

The United States is the world's R&D powerhouse. Through federal entities like the National Science Foundation, National Institute of Health, and its own national laboratories, the federal government funds a large share of the world's basic research. Coupled with early development, this work has launched industries as diverse as semiconductors, satellite communications, PC's, LED monitors, the internet, medical devices, and biotechnology.

Yet the manufacturing base for many of these industries has shifted overseas. Molnar argues that the government needs to support more applied research if it wants to keep emerging industries in the United States.

In part, this is due to the changing nature of commercialization. While large corporations still spend heavily on development, venture capital-funded startups play an increasingly important role in transforming basic research into new products and processes. Unfortunately, Elisabeth Reynolds explained, many of these firms move manufacturing offshore before their innovations reach market.

Reynolds, executive director of MIT's Industrial Performance Center, recently investigated the fate of 150 manufacturing startups that licensed MIT technology between 1997 and 2008.

She found that the United States excels at creating innovation ecosystems—places like Silicon Valley, Boston's Route 128 Corridor, North Carolina's Research Triangle Park—where startups can find specialized skills, equipment, and employees needed to overcome technical challenges.

But when it came time to scale up, many firms were pulled offshore, often by the very venture capitalists who funded them in the first place.

As one advanced materials CEO told Reynolds, "venture capitalists cannot make money on something that costs $100 million and takes at least 10 years to build. The technological risk is high and there is a high burn rate. They are much more comfortable with a software deal that will cost them $20 million. They have to pull away just [when the company] is trying to finalize the product and get it ready for

commercial production." To satisfy his venture backers, he agreed to financing from an emerging nation's government investment fund. In exchange for $40 million, he promised to locate some R&D and manufacturing there.

Other firms were recruited. Singapore lured a biotechnology firm with a $30 million investment and promises to develop specialized manufacturing capabilities, provide low-cost space, and educate the company's workforce.

The firm became the foundation of Singapore's now thriving biotech innovation hub.

A semiconductor startup agreed to be acquired by its Japanese research partner, which was willing to spend years to commercialize its technology.

The Japanese company also had relationships with potential customers.

Other MIT 150 startups, especially in the semiconductor industry, located in Asia to be near potential customers.

Headlamp casings are among the auto parts now being developed for the industry with the aid of 3D printing. Photos: 3D Systems.

Gap in Funding

Each company faced a gap in funding when they were ready to scale up to production. Each did what was best for itself and its investors.

However, the movement overseas of innovative technology—often financed with federal research dollars—represents a loss for the United States in several ways, Reynolds argued. First, it deprives the nation of the knowledge, skills, and capabilities that come with scaleup, and this will impact future innovation. Second, as the center of gravity for many industries shifts overseas, those nations are better able to compete for the top talent and technologies.

This has already happened in consumer electronics and the semiconductor industry. Finally, the shift of production overseas limits the economic benefits—jobs, investment, exports, tax revenue —that arise from manufacturing.

Yet some developed countries have kept factories at home. Germany, for example, remains a thriving manufacturer. In fact, manufacturing accounts for nearly 21 percent of the economy, compared with 13 percent for the United States and 12 percent for the United Kingdom.

Moreover, Germany's manufacturing sector is growing. Exports, mostly manufactured goods, rose to $1.5 trillion in 2013, from just over $1.3 trillion in 2010. It continues to increase exports to China and Asia. At the heart of Germany's success are its small and medium sized enterprises (SME's).

This may come as a surprise, since U.S. SME's were flattened by Chinese competition over the past 15 years.

Niche Markets

Most German SMEs stick to niche markets, where they dominate. A 2007 study by Bernd Venohr, a management consultant, found that more than 1,130 German middle market companies ranked either first or second in their global markets, or first in their European markets.

These firms rarely compete on price. Instead, they command premium prices through superior quality and product performance, Charles Wessner noted. Wessner, the founder and director of the National Academy of Sciences' Technology, Innovation, and Entrepreneurship Program, is an expert on innovation policy.

One key to German SME manufacturing success is the Fraunhofer-Gesellschaft (Fraunhofer Society), Wessner

explained. This $2.5 billion enterprise operates more than 60 research institutes with 22,000 employees and 250 business focus areas and core competencies.

The average institute employs between 300 and 400 people, and does affordable, short-term applied research. It gives SME's access to researchers and equipment they could not otherwise afford, so they can constantly upgrade their processes and products and keep ahead of the competition. Fraunhofer's success is an important reason why German firms can charge premium prices in the face of unrelenting global competition.

Fraunhofer also provides a pipeline of talent through Germany's "dual system" of vocational education, which combines academic studies with factory apprenticeships. Not only do Fraunhofer centers train factory workers, but they hire many science and engineering graduate students.

Unlike the United States, where universities celebrate basic research, German schools value applied research. As a result, jobs at Fraunhofer are highly competitive. Ph.D.'s typically work at a center for four to six years before going off to private companies, taking their knowledge and skills with them.

Dental patients are also benefiting from developments in 3D printing. Photo: 3D Systems.

Wessner is quick to point out that Fraunhofer is not a panacea. Certainly, it helps existing businesses keep ahead of the competition. Yet Fraunhofer's emphasis on existing businesses often precludes the type of groundbreaking innovations that launch new startups and create new industries.

Molnar is quick to agree. The National Network for Manufacturing Innovation is not trying to be another Fraunhofer. Instead, it seeks to build on its strength in research. By commercializing new technologies, Molnar hopes the United States can not only create new industries, but leverage those industries to improve the performance of other manufacturers throughout the economy.

Additive manufacturing is an example. Today, it enables medical firms to customize dental and orthodontic implants for individual patients.

Tomorrow, it could customize consumer products, build high-value but low-volume aerospace parts, or make possible designs that would be impossible to make any other way. Manufacturers that understood how to use this technology could create competitive advantages in the marketplace.

The same is true of power electronics, the focus of another NNMI. These semiconductor chips, which convert and control power, could enable U.S. manufacturers to boost the energy efficiency of everything from motors and fans to appliances and computers.

Similarly, interoperable digital tools, the focus of a third NNMI, would allow companies to design, test, and manufacture parts across the supply chains of multiple industries. It would give manufacturers enormous flexibility to take advantage of specialized manufacturing processes.

America Makes, which is only two years old, is taking its first baby steps in this direction. This year's applied research projects involve slightly more than 100 enterprises, from large and small companies to university and government labs.

"People want to be part of America Makes to see what its deliverables will become. They could be sets of best practices, or materials databases, or training. Our goal is not just to take a technology from point A to point B, but prove it on the factory floor," said Scott Deutsch, America Makes' director of communications and special programs.

Incorporate New Ideas

Most members like the mix of participants. For small companies, like Dante, M-7, and Optomec, America Makes provides the exposure they need to get their technologies into production. Meanwhile, Deutsch said, large companies benefit from working with more agile SME's, which have the flexibility to incorporate new ideas into products faster than larger companies.

Jim Williams, vice president of aerospace at 3D Systems, which pioneered 3D printing, believes America Makes can help his company solve problems it could not attack profitably.

Williams knows this from his experience running Paramount Systems, a company that specialized in aerospace parts. 3D Systems acquired it in 2012.

Aerospace companies loved 3D manufacturing because it enabled them to make short runs of complex products economically, Williams explained. Aerospace companies, however, were used to buying materials based on their

specifications. They knew that if they processed a specified material in a certain way, it would yield parts with certain properties.

"That doesn't exist in the additive manufacturing community," Williams said. "When I talked about this with additive material suppliers, I couldn't get anywhere with anyone. Aerospace is not a large market. There was no volume and no return on investment for doing the R&D work needed to create a materials database. These companies could not see how to monetize their investment or who the customers would be. Without the volume, OEMs turned their attention to other, faster growing markets."

At America Makes, he found many companies interested in developing those types of materials databases. They will help 3D manufacturing increase its presence in aerospace, and also expand in other demanding fields, like medical devices and precision equipment.

Building a database is a far cry from re-establishing American manufacturing prowess. Yet that database, and the best practices and technical training programs developed at America Makes are important steps on the path to making 3D manufacturing easier to implement up and down the supply chain.

Bipartisan Support

America Makes and its sister NNMI's still face many hurdles. The research centers are still working through intellectual property questions. They have yet to prove they can attract top graduates to applied research, or launch the type of technical training programs industry needs. And while NNMI has attracted some bipartisan support, applied R&D is hardly a priority in this cost-cutting age.

The United States does not have to play by the rules, Molnar argued. He admits that if the U.S. tried to compete with overseas producers by making incrementally better televisions, it would be hard to make a dent in the market.

But what about the next generation of displays? What if we find a way to print giant flexible television screens that can stretch across an entire wall?

"If we're innovative, if it's a disruptive technology, we could change the rules and get it back. No country is better positioned to change the rules than the United States," he said.

And if American basic research finds a way to manufacture those flexible displays, Molnar believes the National Network for Manufacturing Innovation will be there to ensure American factories manufacture them.

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