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Why America Needs A National Network for Manufacturing Innovation

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A National Network for Manufacturing Innovation (NNMI) could play a pivotal role in spurring U.S. industrial competitiveness and revitalizing American manufacturing.

The United States lacks an integrated, well-funded national network of large-scale, industry-led manufacturing innovation centers. Leading manufacturing nations around the world, from Germany to Taiwan, have such centers, which accelerate technology deployment, operate demonstration facilities and test beds, support education and training, and perform applied research on new manufacturing processes, among other activities. The proposed National Network for Manufacturing Innovation (NNMI) would fill this void. This report explains why action on this proposal is vital to U.S. manufacturing competitiveness and worthy of investment even in a time of tight budget constraints. It then articulates key principles that should guide the development of the NNMI.

EXECUTIVE SUMMARY

America needs a National Network for Manufacturing Innovation. This paper sets forth the argument for this proposition in two parts. The first part makes the case for an innovation-centered national manufacturing policy. It lays out key challenges facing the U.S. manufacturing sector, advances reasons why the nation should care about manufacturing, and sets forth the rationale for an active federal role in fostering manufacturing innovation. Crucially, this role should be catalytic, not directive; federal actions should spur other key players, especially the private sector, into action and foster stronger collaboration among them.

The second half of the paper articulates five key principles that should govern the design of the NNMI. These principles are:

- A focus within each of the NNMI's constituent Institutes on significant, industry-defined innovation challenges, particularly in process innovation;
- Support for the full innovation process, including technology roadmapping, applied research, operation of demonstration facilities and testbeds that benefit small and medium-sized manufacturing enterprises (SMEs), education and training at all levels, and development of standards and credentials;
- Collaboration among academia, business, government, and other partners, led by manufacturers;
- A bottom-up competitive process, managed by the federal government, to identify innovation focus areas and select collaborative teams;
- Private-public co-investment, with manufacturers providing about 50 percent of each Institute's resources and federal and state agencies carrying most of the balance.

INTRODUCTION

Over the past three years, the U.S. economy created about 500,000 net new manufacturing jobs. Considering that the last time manufacturing employment expanded for even a single year was in the 1990s, that ought to be cause for celebration. But while this is good news, American manufacturing is hardly out of the woods. The decline in this sector in the intervening decade—the closure of 17 manufacturing establishments per day; the loss of 5.8 million manufacturing jobs; and an 11 percent decline in manufacturing output (when properly measured)—was so severe that the recent recovery barely begins to undo the damage.[1]

In fact, the United States needs to take a new approach to manufacturing, one that comes to grips with the rapidly evolving economic landscape of the 21st century. American factories and American workers face stiff international competition across the full spectrum of manufacturing industries, from old to new, low-tech to high-tech. To overcome its challenges, American institutions will have to collaborate in ways that they generally have not in the past: across levels of government, within industries, up and down supply chains, and spanning the boundaries that separate production, research, and training.

This kind of collaboration is well-established across the rest of the world. As Wayne Johnson, formerly of HP and now CalTech, puts it, "We in the United States find ourselves in competition not only with individuals, companies, and private institutions, but also with governments and mixed government-private collaborations."[2] Such collaborations are not unknown in the United States, although they are not the norm. For instance, the U.S. semiconductor industry, faced with a severe threat some 30 years ago, worked with government, academia, suppliers, and others to create a collaborative system that continues to provide value to the industry and other stakeholders. (See Box 1)

Box 1: Collaboration Key to the Survival and Long-term Success of the U.S. Semiconductor Industry

The semiconductor industry is fiercely competitive, yet it has supported for decades a number of collaborative activities that have allowed the industry to sustain a remarkable trend of improvements in manufacturing processes and introduction of new products. Smaller, faster, cheaper, and more powerful and functional integrated circuits enable new products, businesses, and entire new industries. Three collaborations in particular have been important to this success and to the continuing health of the U.S. semiconductor innovation ecosystem and U.S.-based production activities. According to the U.S. National Science Foundation, the United States exported more than $47 billion in semiconductor goods in 2010 and ran a trade surplus of over $17 billion in the sector.[3]

The Semiconductor Research Corporation (SRC), established in 1982, is a consortium of semiconductor companies that supports university research with the objective of discovering new potential technologies and growing the pipeline of talent. SRC sustains a robust research enterprise and has in place processes that provide guidance and feedback to researchers, mentor students, and extract and deliver results and value to members.

SEMATECH is the industry consortium that seeks to address common manufacturing problems. Closer to production than SRC, SEMATECH expedites transition of new technologies, materials, and processes into manufacturing. Established with help from the federal government in 1987, industry has fully funded SEMATECH since government funding was terminated in 1996.

The International Technology Roadmap for Semiconductors (ITRS) identifies technology needs for the next 15 years. The ITRS collaboration has allowed the various components of the semiconductor industry to keep up with the cadence of technology advances to smaller and smaller dimensions.

A central goal of the semiconductor industry's collaborative system is innovation. This goal must now become central to all U.S. manufacturing industries. The first part of this paper explains why this is so. The second part of the paper focuses on one important mechanism for creating the kind of collaboration that can achieve this goal: a National Network for Manufacturing Innovation. [4] NNMI would include:

- A significant number (15 or more) large-scale Institutes for Manufacturing Innovation (IMIs) that focus on innovation challenges of interest to a diverse group of firms, often across multiple industries;
- Strong industry leadership of and financial participation in the IMIs;
- Federal and state support, either on a temporary or permanent basis;
- Collaboration with universities, community colleges, and other institutions in research, education, and training;
- Commitment to engage with small, medium-sized, and large manufacturers;
- Mechanisms to ensure that NNMI's work is rapidly absorbed by and benefits production facilities in the United States.

NNMI, if properly designed, can transform the shop floors of manufacturers of all sizes, and particularly SMEs, by helping them seize the extraordinary innovation opportunities that the present moment offers. It would be comprised of innovation and technology hubs, not merely basic research facilities with technology transfer arms. Each IMI must be able to undertake the full range of activities that are appropriate to the innovation challenge that it is tackling. The federal government must play a catalytic role in bringing NNMI into existence. In the long run, NNMI promises to help create a new culture of collaboration within the private sector and between the private sector and its partners in education and government. NNMI alone will not cure what ails the U.S. manufacturing sector—a more comprehensive national strategy is needed—but it is a vital step toward such a cure.[5]

PART I: AMERICA NEEDS AN INNOVATION-FOCUSED NATIONAL MANUFACTURING POLICY

The case for NNMI rests on several premises. Policymakers must accept that U.S. manufacturing is in bad shape and that something should be done about it. If that premise is adopted, the obvious question is: who should do what? We argue that only the federal government can breathe life into national manufacturing policy. But it should do so in a way that empowers and motivates a diverse array of non-federal actors—particularly industry, academia, and the states—to collaborate toward shared objectives. Innovation should be prominent among these objectives, because it has unique potential to strengthen the competitive advantage of U.S. production facilities. NNMI should be the central instrument for pursuing this objective. This section lays out the following five premises:

1. U.S. manufacturing is in bad shape;
2. Manufacturing should remain a vital component of the U.S. economy;
3. The federal government must take an active role in driving solutions to America's manufacturing challenges;
4. National manufacturing policy should emphasize innovation;
5. Collaboration among all key stakeholders is central to a successful, innovation-oriented policy.

Premise #1: U.S. Manufacturing Is In Bad Shape[6]

Something bad happened to the U.S. manufacturing sector about a decade ago. After more than a century as a global productivity and output leader and a prodigious creator of new industries, America's manufacturing competitiveness suddenly eroded. The sector's problems have been masked somewhat by measurement errors and were overshadowed by the economic and political crises of the 2000s. But they are real and serious. U.S. manufacturing remains a powerful economic engine, and it has even recovered a bit of lost ground in the past couple of years. These gains, however, will not be sustained unless the structural challenges facing the sector are tackled.

Jobs

U.S. manufacturing employment peaked in 1979, and it declined at a modest rate of a half a percent per year in the 1980s and 1990s. In the 2000s, though, it fell off a cliff, dropping more than four percent per year during that decade. In all, a third of U.S. manufacturing jobs—just under six million—evaporated. In fact, a larger share of manufacturing jobs

disappeared during this "lost decade" than during the Great Depression of 1929-1933. Employment shrank in every major manufacturing industry, and manufacturing employment shrank in every state but one. While roughly a half-million manufacturing jobs have been regained in the current recovery, that figure is less than a tenth of those that were lost in the prior decade.

Investment

On an average day in the 2000s, 17 fewer factories were running than the day before. Not surprisingly, total real manufacturing fixed investment shrank during that decade; the establishments that survived did not grow quickly enough to outweigh those that closed their doors. Like the decline in employment, the decline in investment was pervasive, covering virtually every sector of manufacturing.

While the nascent manufacturing recovery does signal manufacturing's ability to again be a core driver of U.S. economic growth, this vision won't be realized without an effective national manufacturing strategy with NNMI at its core.

Productivity

Manufacturing productivity—the value of output produced by each unit of input—did not decline in the 2000s. Indeed, many have argued that rapid productivity growth accounts for the drop in employment in this period—fewer labor inputs were needed to produce the same amount of output. But as the Information Technology and Innovation Foundation (ITIF) has shown in great detail, there is no necessary correlation between these two indicators. Rapid productivity growth should lead to lower prices, which in turn may expand demand and maintain or expand employment. This virtuous cycle characterized much of U.S. economic history. For a number of technical reasons, manufacturing productivity growth has been mismeasured and has not been as rapid as official statistics show. The motor vehicle industry, for instance, actually experienced a productivity decline of about 6 percent between 2000 and 2010. Although manufacturing remains a bulwark of innovation, the productivity data suggest that the sector is not realizing gains on the shop floor to the degree commonly believed. In fact, when the statistical biases are corrected, ITIF estimates that manufacturing productivity grew by less than half the rate between 2000 and 2010 than was reported in official government statistics.

International Comparisons

The U.S. share of global manufacturing output declined sharply in the 2000s after rising in the 1990s. The Chinese share rose rapidly through both decades. China's rise is due in part to the tremendous expansion of Chinese domestic demand and in part to the tremendous expansion of Chinese exports. Standard economic theory would predict that labor-intensive, low-skill production in a global market should migrate to places with low labor costs, like China. That trend is reflected in the data; U.S. decline was more rapid in low-tech manufacturing during the 2000s than in medium- and high-tech manufacturing. But the latter sectors still lost ground. U.S. trade in advanced technology products, for example, went from a slight surplus in 2000 to a $99 billion deficit in 2011. Not all high-income countries had this experience. Germany and Korea, for example, held their ground overall and strengthened their international profile in medium- and high-technology manufacturing.

Temporary Positives

Manufacturing has helped to lead the fitful recovery of the past three years. Pent-up demand for durable goods such as cars accounts for some of this growth. Falling labor costs at home, combined with rising labor costs abroad, especially in China, have contributed to some "onshoring." The natural gas boom is driving the production of goods used in gas wells and pipelines, and cheap gas is attracting energy-intensive facilities such as petrochemical plants. Of these three factors, only the gas boom is both desirable and durable over the medium-term. Cyclical factors will play themselves out if the recovery continues, while declining compensation is a symptom of deeper problems in the U.S. economy. While the nascent manufacturing recovery does signal the sector's ability to again be a core driver of U.S. economic growth, this vision won't be realized without an effective national manufacturing strategy with the NNMI at its core.[7]

Premise #2: Manufacturing Should Remain a Vital Component of the U.S. Economy

The bad news about manufacturing bothers most Americans. A poll by the non-profit Alliance for American Manufacturing, for example, found that "By a sizeable margin, voters rate manufacturing as the industry 'most important to the overall strength of the American economy.'"[8] But not everyone agrees. Lawrence Summers, President Obama's Chief Economic Advisor from 2009 to 2010, for instance, has contended that "America's role is to feed a global economy that's increasingly based on knowledge and services rather than on making stuff."[9] A future in which high value-added, knowledge-based services replaces manufacturing has some attractive features, but it is simply not attainable. While such services are vital to the economy and deserve national attention along with manufacturing, they cannot replace manufacturing. We briefly explore several of the key reasons here.

Trade

The United States must make and export more manufactured goods if it is to fix its trade deficit. America benefits enormously from international trade. We buy basic commodities like petroleum, unique high-value products like wine, and everything in between on the world market. In fact, Americans like foreign-made products so much that the United States has run trade deficits of more than a half-trillion dollars per year over the past decade.[10] Each year's deficit adds to the nation's cumulative foreign debt, which will at some unknown point trigger a crisis if it continues to grow unchecked. Manufacturing is such a dominant component of U.S. trade (accounting for 65 percent of U.S. exports) that service exports simply cannot grow fast enough to offset the deficit in manufacturing trade. U.S. service exports grew by about 8 percent per year over the last decade, a pace that was dependent in large part on unsustainable, bubble-driven financial services exports. Yet, as Howard Wial of the University of Illinois has shown, this rate would have to accelerate by about 70 percent, to 13.5 percent per year over the coming decade, for the United States to balance its trade by relying on services alone.

Multiplier Effect

Manufacturing creates a lot of additional activity in other parts of the economy. As economists say, it has a big multiplier effect, both in terms of economic output and

employment. Every dollar of manufacturing output supports $1.34 in output from other sectors—the largest multiplier of any sector.[11] The average new manufacturing job leads to the creation of from two to five additional jobs in other sectors; for high-tech manufacturing, the employment multiplier may be even greater.[12] That is substantially higher than the average multiplier effect for jobs created in the service sector. As Gene Sperling, Director of the National Economic Council (NEC), explains the impact of manufacturing on driving economic and employment growth, "If an auto plant opens up, a Walmart can be expected to follow. But the converse does not necessarily hold—that a Walmart opening does not definitely bring an auto plant with it."[13]

Manufacturing jobs pay more and generate higher employment multipliers than comparable jobs in other sectors.

Good Jobs

Manufacturing jobs pay better than comparable jobs in other sectors. A May 2012 U.S. Department of Commerce report found that the total hourly compensation (which includes employer-provided benefits) for workers in manufacturing jobs was 17 percent higher than for workers in other kinds of jobs.[14] Likewise, a 2011 Brookings report found that the average weekly earnings in manufacturing are 19.3 percent higher than the national private sector average, even though manufacturing employs a greater than average share of workers without a college degree.[15] Growing good-paying, medium-skill jobs in manufacturing is an essential element of any national strategy that seeks to address economic inequality in the United States.

National Security

Manufacturing is vital to U.S. national security. The U.S. military still relies on planes, tanks, and ships, even as it has increasingly added sophisticated information and communications technologies to its arsenal. Unfortunately, the growing dependence of U.S. defense systems on foreign suppliers for critical products and technologies has contributed to the erosion of the nation's defense industrial capacity.[16] Indeed, the manufacturing base upon which the defense sector rests is in trouble. A recent study by Michael Webber of the University of Texas found that thirteen out of sixteen manufacturing industries that "have a direct bearing on innovation and production of novel mechanical products and systems" have shown "significant signs of erosion" since 2001.[17]

Innovation

Manufacturing firms create a disproportionate share of new products, and the sector punches above its weight with regard to productivity growth. Data from the National Science Foundation show that 22 percent of manufacturers reported product or process innovations in the previous three years compared to only 8 percent of non-manufacturers.[18] Manufacturing firms pay for and perform approximately 70 percent of U.S. industrial research and development, even though manufacturing accounts for only about 12 percent of the economy.[19] Even after adjusting for the measurement errors discussed previously, manufacturing productivity rose more than 50 percent faster than productivity in the rest of the private economy between 2000 and 2010.[20] These linkages between manufacturing and innovation mean that the success of knowledge-based services like R&D often depends on the success of domestic production activities. As President George W. Bush's Council of

Advisors on Science and Technology put it, "The proximity of research, development, and manufacturing is very important to leading-edge manufacturers."[21]

Premise #3: The Federal Government Must Take an Active Role in Driving Solutions to America's Manufacturing Challenges

Manufacturing is not the federal government's job. Nobody believes that federally owned factories should or will play the kind of catalytic role in the future U.S. economy that they did in the nineteenth century when interchangeable parts were invented at U.S. government armories.[22] But that does not mean that the federal government should sit on the sidelines and hope that the private sector, the technical community, or the states will solve the problems of the U.S. manufacturing sector. While all of these actors should be deeply involved in manufacturing policy—it must be a *national* policy, not merely a *federal* policy—each faces significant limits on what it can do, and there are some things that only the federal government can do. As Ricardo Hausmann of Harvard and César A. Hidalgo of the Massachusetts Institute of Technology (MIT) put it, "A laissez-faire disregard of the government-provided requirements for competitive manufacturing, justified under the often repeated prohibition against "picking winners", is bound to guarantee that a country will end up losing the march towards prosperity by making public-private cooperation impossible in constructing the productive ecosystem."[23]

Nations are increasingly competing with each other to drive high-value job creation and harness the advantages of a globally leading manufacturing innovation ecosystem.

Market Failures

Markets fail to adequately incentivize manufacturing innovation, particularly process innovation. It is widely acknowledged among economists that successful innovations yield benefits for competitors, suppliers, and consumers as well as the innovating firm. These "spillovers" are a disincentive for investment. Many studies show that this disincentive leads private investment in both R&D and capital equipment to fall short of the level that would be optimal for the economy.[24] This market failure particularly affects the approximately 250,000 SME manufacturers which comprise the backbone of U.S. manufacturing and which are shouldering an even heavier load as the supply chains of large firms become more complex.[25]

This market failure particularly plagues the development of new manufacturing processes. New and improved processes are harder to protect using intellectual property rights than innovative products. In addition, at least one study finds that firms invest more in product R&D when they invest more in process R&D.[26] So reducing process R&D also reduces product R&D. As a result, manufacturers under-invest in solving process challenges, particularly those that would help not only multiple firms in an industry, but also multiple industries.

Other market failures limit the scale-up of innovative manufacturing processes, the installation of new capital equipment, and the full integration of manufacturing systems across supply chains. Investments in these kinds of innovation require large up-front capital and training outlays. They often take many years to pay off. MIT's William Bonvillian refers to this problem as the "mountain of death," alluding to the better-known "valley of

death" that disrupts the translation of research ideas into marketable products.[27] Even though manufacturing firms play a large role in U.S. innovation, that role would be even larger were it not for these market failures.

Policies Abroad

Decisions about where to locate new plants and whether to revitalize existing ones are influenced by the policies of foreign governments as well as by market forces. Governments increasingly seek to influence investment decisions by offering tax breaks, infrastructure support, and other kinds of incentives to international firms. In addition, they may support locally owned firms with capital subsidies or protected markets. More nefariously, some governments repress labor, condone intellectual property theft, and manipulate their currency values in order to expand their manufacturing footprint.[28]

The reality is that nations are increasingly competing with each other to drive high-value job creation and harness the advantages of a globally leading manufacturing innovation ecosystem.[29] As Greg Tassey, Senior Economist at the National Institute of Standards and Technology (NIST), argues, "Competition among governments has become a critical factor in determining global market share among nations."[30]

State Limitations

Many state governments have implemented policies to attract manufacturing investment, but these policies face intrinsic limitations. States (along with regional organizations and localities) have a long history of supporting local industry. They are typically more knowledgeable than federal agencies about the unique attributes of their economies, and state leaders face direct pressure from voters to take action. However, all too often, these efforts are merely symbolic, since office-holders must show results before the next election, or they result in costly subsidies as states compete in a "race to the bottom" to woo plants with financial incentives.[31]

Academic Neglect

The scientific and engineering research community has received little support in recent decades to focus on the technical challenges posed by manufacturing. Responsibility within the federal government for funding academic manufacturing research is scattered among many agencies, and it has rarely been a priority for any of them. Research faculty are rewarded more by their institutions for originality and breakthroughs than for engineering advances and practical problem-solving.[32] That bias is also reflected in U.S. engineering programs, where a focus on "engineering as a science" has increasingly moved university engineering education away from a focus on real problem solving toward more abstract engineering science.[33] As the *Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing* concluded, "[T]he discipline of manufacturing…does not fit well into normal boundaries of degree programs, departments or even schools, and as a result often finds itself marginalized."[34]

Market Forces

Manufacturers respond in the end to the bottom line. Although some companies perceive the communities in which they operate to be important stakeholders, managers cannot afford to be too sentimental. Competition will ultimately drive firms that favor

unprofitable locations out of business. The location that maximizes profits, all factors taken together (including subsidies and other impacts of government policies), will be the one that gets the work. Americans should not expect the patriotic sentiments of managers of U.S.-headquartered companies to overcome the tidal pull of the bottom line. The U.S. business environment must be attractive if manufacturers are to invest here, and it's the role of the federal government to ensure that the United States offers the best environment in the world for manufacturers to build and operate skill-intensive, high-value-added production facilities here.

Premise #4: National Manufacturing Policy Should Emphasize Innovation

The federal government must do more effectively what only it can do, and must also foster collaboration among other key players, so that they can overcome the barriers described above. In a series of papers over the past couple of years, ITIF has laid out a comprehensive national strategy for manufacturing that addresses challenges related to technology, talent, tax, trade, regulation, and finance.[35] NNMI focuses on only two of these, technology and talent. This focus should not be taken to imply that the other policy areas are unimportant. If federal policies fail to improve the broader business environment for manufacturing, then the impact of a successful innovation policy will be blunted. However, if manufacturing policy fails to emphasize innovation, tax, trade, and other policies will have too little to act on, risking a "race to the bottom" that would be bad for everyone.

The United States needs to be producing things other countries cannot (or producing the same things more efficiently) and the only way to achieve that is through high levels of innovation in product and process technology.

High-skill, High-wage Jobs

Innovation creates manufacturing jobs that engage workers' brains as well as their brawn, which in turn enhances their compensation. Process innovations improve labor productivity, so that each hour of work creates more value. Innovative products command higher profit margins than products that have been on the market for a while. Both kinds of innovation expand the pie that is shared by employers and workers. Contrary to popular belief, opportunities for manufacturing innovation are not restricted to electronics or other high-tech sectors. Emerging technologies have the potential to infuse innovation into a wide range of older manufacturing industries, like metals, paper, and textiles.

No Race to the Bottom

The United States does not want to be competing for commodity production processes that depend heavily on unskilled labor. This kind of work should continue to migrate to low-wage locations, offering opportunities for economic development abroad and mutually beneficial international trade. A policy that seeks to protect non-innovative U.S. manufacturing from foreign competition would be costly to consumers and send dangerous signals to the rest of the world. A policy that drives down wages in order to compete on cost would be even worse. The United States needs to be producing things other countries cannot or producing the same things more efficiently. The only way to achieve these goals is through high levels of innovation.

American Strengths

Americans are good at innovation. The United States spends more on R&D than any other country. U.S.-based companies, such as Apple or Google, have been responsible for the signature innovations of the 21st century. America's entrepreneurial culture is the envy of

the rest of the world. The U.S. workforce is flexible and well-educated. The nation is home to many of the world's finest research universities, and its 1,600 community colleges provide a responsive mechanism for training and skill development. An innovation-centric policy would build on these national strengths.

Regional Manufacturing Clusters

The national economy is comprised of diverse regional economies that have great potential to capitalize on innovations in specific manufacturing industries. Geographically concentrated clusters of manufacturers have attracted skilled workers, sophisticated customers, and specialized institutions over a long period of time, creating what Gary Pisano and Willie Shih of the Harvard Business School have labeled an "industrial commons" that serves each region.[36] Although Silicon Valley's electronics and Detroit's cars are world-famous, little-known clusters like medical devices in Minnesota, farm equipment in Boise, Idaho, and aerospace products in Southern California dot the American economic landscape.

Manufacturing innovation demands institutional innovation that leads to systematic, mutually-beneficial collaboration among all key stakeholders.

Stickiness

Innovation offers the most sustainable pathway to competitive advantage. The skills and know-how embodied in workers, the routines and processes that are built into innovative production and supply chains, the relationships that link R&D to the shop floor—all of these are hard to imitate. Virtually any product can be reverse-engineered in today's economy, but innovation means that the imitators' target is always moving.

New Manufacturing Paradigms

Manufacturing is on the cusp of a technological revolution. It is rapidly becoming smarter, greener, cheaper, and better. A recent study by the IDA Science and Technology Policy Institute (STPI) for the U.S. Office of the Director of National Intelligence identifies several trends that will lead manufacturers to "rely less on labor-intensive mechanical processes and more on sophisticated information-technology-intensive processes."[37] In addition to additive manufacturing, the technology focus area of a pilot institute of the NNMI, game-changing technologies cited by STPI and other analysts include bio-manufacturing, nano-manufacturing, advanced materials, robotics, modeling and simulation, and real-time optimized production ("smart manufacturing"). The integration of diverse components into novel production systems that can respond rapidly and precisely to customer demands is perhaps the biggest opportunity of all. It's no surprise that manufacturing executives rank innovation among their very highest priorities today.[38]

Premise #5: Collaboration among All Key Stakeholders Is Central to a Successful Innovation-Oriented Policy

U.S. economic policy has traditionally tended to assume a bright line between public and private responsibilities. Within the conventional framework, goods are viewed either as public goods or private goods, and responsibility for providing them is assigned to the corresponding sector.[39] Basic research, for example, is a public good and therefore should be government-funded; product development, by contrast, is a private good and should be

funded by firms. Manufacturing innovation does not fit into these conceptual boxes very well. It demands institutional innovation that leads to systematic, mutually-beneficial collaboration among all key stakeholders.

Shared Benefits, Shared Investments

Key manufacturing innovation resources often provide benefits that cannot be fully captured either by individual firms or by the general public. Instead, their benefits are shared within an industrial or regional community that has both public and private components. The skills of production workers are an example. Many U.S. manufacturing firms used to maintain internal promotion ladders that were supported by major investments in training. They could do so secure in the knowledge that workers would stay with them for many years. The firm would reap the benefits of these investments and could share these benefits with workers in the form of high compensation. This kind of privately-funded training is far less common now.[40] Indeed, U.S. companies invest about half as much in training as a share of GDP as they did a decade ago.[41] At the same time, production facilities and workers are both more mobile than they used to be. Workers are therefore expected to bear the brunt of training costs nowadays. But there are still many benefits of this training that spill over to the broader industry and region; the presence of a rich pool of highly-trained workers is a key element of the industrial commons that attracts investment. The United States has not reinvented its training system to fit the twenty-first century global economy. One result is that manufacturers frequently state that skill shortages are a major constraint on expansion and make it hard to introduce process innovations.[42] What's needed is a collaborative innovation system that shares the costs fairly among all the beneficiaries.

Invent Here, Produce There Syndrome

The United States excels at generating radical new technologies and spawning companies that bring them to market. But the nation's ability to sustain innovation after these breakthroughs and to foster incremental improvements in manufacturing processes and systems of production has eroded.[43] The story in this area is similar to the one in the skills area. U.S. manufacturers that once willingly took the risks of introducing and debugging new processes are less willing to do so now. The expected returns to individual manufacturers from taking such risks have declined as competition has intensified. Many have outsourced production in response. Yet upgrading domestic production facilities through process innovation has spillovers that benefit other firms in the industry and associated regional clusters. And once production migrates, it's very hard to re-establish. Computer hardware, composite materials, and automobile components are just a few of the complex products that have been subject to the "invent here, produce there" syndrome.[44] Collaboration among the beneficiaries of manufacturing innovation would help to stem the tide.

Speed and Complexity

The extraordinary opportunities for innovation in manufacturing depend on knowledge from a wide range of fields. Ideas from fundamental math and science disciplines must be integrated with applied engineering fields and hands-on know-how. These bodies of knowledge are held and developed by different manufacturing stakeholders. Yet, they must

be brought together quickly and effectively if domestic production facilities are to benefit from these innovation opportunities. Many countries around the world are systematically pursuing many of the same ideas.

Convergence of Industry and Thought Leaders

President Obama's proposal to establish a NNMI reflects a convergence on the broad concept of collaboration to accelerate innovation in recent years. The federal National Science and Technology Council, made up of leaders of technical agencies, and the President's Council of Advisors on Science and Technology, a non-governmental body comprised of business and academic leaders, have both advanced similar concepts.[45] The Brookings Institution has proposed that individual states work with industry to create advanced manufacturing innovation centers.[46] The Council on Competitiveness, which brings together leaders from business, academia, and labor, has argued for "partnerships to create a national network of advanced manufacturing clusters and smart factory ecosystems."[47] Beyond the Beltway, the Edison Welding Institute (EWI) and the Manufacturing Institute (the research arm of the National Association of Manufacturers), after an extensive process of consultation, called for collaborative research centers that would bridge what EWI calls the "missing middle" in the manufacturing innovation process.[48]

PART II: WHAT NNMI SHOULD DO AND HOW IT SHOULD BE SET UP AND PAID FOR

Manufacturing is a large and diverse sector, producing about $2 trillion worth of goods each year. Cars, computers, paper, chemicals, industrial machinery, breakfast cereal—all these things and many, many others are classified as manufactured goods. The innovation challenges that face the sector are as diverse as it is. Some manufacturing industries are comprised mainly of small establishments that lack the financial resources to invest much in new technologies. Others face foreign competitors that are insulated from innovation risks by government subsidies and protection. Still others have done too little to generate new ideas and deepen their skill base over the years.

The design of the NNMI should reflect this diversity. Manufacturing innovation is not susceptible to a one-size-fits-all solution. Above all else, the Network and its constituent Institutes for Manufacturing Innovation must be responsive to bottom-up demands and opportunities. At the same time, of course, the creation of new Institutes will require choices among these demands and opportunities to ensure that public investments are devoted to national goals that have a reasonable chance of being achieved. This part of the paper lays out the principles that should guide these choices.

Principle #1: Each IMI Should Focus on a Significant, Industry-defined Innovation Challenge, Particularly in Process Innovation

This principle has three key terms in it. "Industry-defined" is the most important one. Manufacturers will be the users of whatever the IMIs create. They know their markets and production systems and have a sense of what kinds of innovations are likely to give domestic production facilities a competitive advantage. This sense can be enriched through dialogue with other IMI partners, such as government agencies and universities, but

ultimately it will be up to companies to capitalize on the IMIs' work. Manufacturers should therefore lead the development of IMI proposals, defining the scope and focus of the Institutes, and make significant investments in their operations, as discussed in more detail below. Many technical focus areas have been proposed by industry (as well as academia, government research agencies, and private research organizations) for the creation of potential Institutes for Manufacturing Innovation, as Box 2 shows.

"Focus" will differentiate the IMIs from typical academic or government research institutions. Rather than seeking to contribute to a global pool of scientific knowledge, the IMIs will build an interconnected web of skills, knowledge, and capabilities that support a large but nonetheless limited number of facilities and operations in the United States. Many IMIs are likely to focus on a particular type of manufacturing process, although some might focus on specific materials, supply chain integration methodologies, or enabling technologies. In addition, an IMI's area of focus should have applications in large, medium, and small establishments and where reasonable across more than one manufacturing industry.

Manufacturers should lead the development of IMI proposals, defining the scope and focus of the Institutes, and make significant investments in their operations.

Box 2: Focus Areas Proposed by Respondents to the Advanced Manufacturing National Program Office's "Request for Information" for NNMI[49]

- Advanced materials—lightweight materials
- Alternative energy development
- Amorphous metals manufacturing
- Autonomous robotics, autonomous systems manufacturing
- Batteries—energy storage
- Big data
- Bio-inspired electronics that reduce power requirements in servers, perform intelligent processing in robots, and do automatic testing of complex systems
- Biomanufacturing (including biomimicry), biotechnology, biomaterials and products, biomedical materials and device fabrication, tissue engineering, synthetic biology and customized or personal medicine, healthcare
- Castings—sand, die, investment, and permanent mold
- Carbon fiber components
- Carbon nanotubes
- Chemical coatings
- Complex systems that are intelligent, self-adaptive, self-tested, and self-repairable
- Composites materials manufacturing and coatings
- Control technologies
- Cyber infrastructure
- Design tools
- Diamond-based devices
- Digital manufacturing
- Energy—the reduction of energy use in energy-intensive processes and development of clean energy (photovoltaics, biofuels, offshore wind), increasing overall energy efficiency and sustainability
- Flexible electronics
- Flexible film and coating technology used for thermal, electronic, chromic, and optical applications

- Fluid power, pneumatics
- Forming and joining technologies
- Fuel cells
- High-precision machining
- Industrial processing
- Industrial robotics; flexible 'smart' automation technologies
- Large-scale manufacturing
- Laser manufacturing
- Metal injection molding
- Metrology
- Microelectromechanical systems
- Modeling and simulation
- Nanobiomaterials manufacturing
- Nanoscale, nanotechnology, nanostructures, microtechnology
- Netshape metal forming—forging, extrusion, rolling, drawing, hydroforming, sheet forming, precision forming
- Optics
- Organic electronics
- Pharmaceutical manufacturing, both small molecule and biologically derived products
- Photonics foundry for the production of photonics ICs
- Powder and fiber metal fabrication
- Precision machining
- Process industry modernization
- Product data standards for interoperability
- Semiconductor materials and manufacturing equipment
- Sensors, sensing, and instrumentation technology, sensor integrated manufacturing
- Software for complex manufacturing systems
- Supply chain automation technologies
- Sustainable manufacturing
- Thermal processing

The full set of responses to the Advanced Manufacturing National Programs Office's Request for Information on NNMI may be found at: http://manufacturing.gov/rfi_responses.html.

"Significant" means big enough to make a difference to an industry, region, or group of associated industries and establishments. An annual budget (from all sources, including industry) in the range of $30-$50 million per Institute would allow the average IMI to maintain an experienced technical staff, support specialized suppliers, interact with a wide range of firms, and operate a user facility. An IMI on this scale would be an order of magnitude larger than most large U.S. university research centers (such as the National Science Foundation-funded Engineering Research Centers) and roughly the same size as the average Fraunhofer Institute. (The Fraunhofer Institutes, which support the manufacturing sector in Germany, are described in Box 3)

Principle #2: IMI Activities Should Support the Full Innovation Process

Many people associate innovation with basic research and the transfer of technology invented as a result of basic research from the lab to industry, whether to a start-up or to an established firm. These activities are important, but they are only part of a much larger and more complicated process of innovation. Innovation means doing something new and different *in practice*. Having new knowledge available is just one potential starting point for changing real-world operations. Innovation also encompasses skills, methods, and equipment that must be integrated with novel production processes and new products. Moreover, the innovation process may encompass the implementation of new and different business models, methods of supply chain integration, managerial techniques, workforce skills, and more. Indeed, "significant" innovation that is timely enough to provide a competitive advantage in manufacturing will generally require activities across many of these categories.

Box 3: Germany's System of Fraunhofer Institutes

Germany's 60 Fraunhofer Institutes conduct cutting-edge, industrially relevant research that seeks to translate emerging technologies into commercializable products across a wide variety of sectors and technology platforms, including advanced machining, optics, robotics, microelectromechanical systems, nanotechnology, and wireless technologies.[50] The Fraunhofers' annual research budget of €1.8 billion ($2.33 billion) and staff of 20,000 scientists and engineers is funded seventy percent by industry and thirty percent by the federal and state governments. Government support is viewed as essential because it "enables the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now."[51]

The Fraunhofers take a particular focus on applied manufacturing research, including private-public partnerships in advanced materials, factory operation and automation, manufacturing and engineering automation, and machine tools and forming technology. For instance, the Fraunhofer Production group, which supports adaptive, digital, and high-performance production, has an operating budget of $195 million per year.[52]

The core objectives of the Fraunhofer Institutes are to "promote innovation, strengthen the technological base, improve the acceptance of new technologies, and help train the urgently needed future generation of scientists and engineers."[53] Notable Fraunhofer successes include the development of the MP3 compression algorithm and triple-junction solar cells.[54] In 2011, the Fraunhofers produced 673 invention disclosures and 494 patent applications, bringing their total active rights and patent applications to over 6,130. The Fraunhofer Society holds equity investments in 86 companies, including eight spin-offs in 2011.[55] Five to ten percent of each Fraunhofer's budget derives from IP licensing.

The IMIs must be innovation and technology hubs, not basic research facilities with technology transfer arms. Each must be able to undertake the full range of activities that are appropriate to the innovation challenge that it is tackling. These activities will vary across Institutes, but might include:

- Technology strategies and follow-on roadmapping in which IMI member firms align their needs and visions for progress and identify milestones for fulfilling these visions;

- Generic applied research in the IMI focal area in which many or all IMI members participate and gain access to the results;
- Contract research that allows IMI personnel to stay abreast of cutting-edge developments while providing unique services to individual members;

- Operation of user facilities, such as rapid prototyping or "testbed" facilities, libraries or databases, and validation and testing equipment, which can dramatically reduce the risk of innovation for SMEs and support workforce training;

- Development and dissemination of credentials, certifications, and other skills standards for technical workers as well as training technologies and curricula;

- Practical education of production engineers as well as researchers through collaborative work with academic institutions on IMI research and in user facilities; and

- Development of technical standards, measurement tools, instrumentation, software, and new management methods.

Principle #3: IMIs Should Be Independent Organizations That Are Led By Manufacturers

The IMIs should be independent membership organizations (although they may be "hosted" for administrative purposes by an academic or non-profit member) that unites all of the key players who have an interest in the innovation-based path to domestic competitiveness in manufacturing. Each IMI should be governed by a board of directors that represents all membership categories. Industry, as the predominant user of its outputs, should have a plurality of votes on the board. The board will determine the agenda, activities, and resource allocation of the IMI.

IMI membership should include manufacturers of all sizes. It is essential that medium and small manufacturers play a significant role in every IMI. Other membership categories should include research and training institutions, federal agencies and state governments, and other organizations, such as labor unions and industry associations. Each kind of member brings a unique capability and perspective to the effort, yet each will have to adapt its standard operating procedures if the collaboration is to work.

- *Big companies* will bring deep technical expertise, global perspective, and responsibility for managing complex supply chains to the IMIs. Every IMI should have at least two (and preferably at least ten) large manufacturers as members so they balance one another. These members will need to commit to making initial use of IMI outputs at their domestic production facilities. Foreign-domiciled

manufactures should be welcome to participate in NNMIs as long as they meet the conditions stipulated in Box 4.

- *Medium and small companies,* who own and operate the vast majority of manufacturing establishments, will bring flexible capabilities and a storehouse of hands-on experience to the IMIs. Every IMI should have a substantial network of SMEs with which it interacts. SME members will generally need to expand their portfolio of relationships and take a longer-term view of their operations in order to gain from participation in an IMI. IMI fee scales should take into account their limited financial resources.

- *Research institutions,* such as universities, federal labs, and non-profit research organizations, will bring fundamental scientific and engineering knowledge and talent to the IMIs. Every IMI should have at least one institution that anchors it in the research community and shares students and researchers with it. These members will most likely have to adapt to IMI membership by rewarding research, education, and training related to applied problems (including on industrial sites) more than they presently do.

- NNMI's mission of creating and sharing knowledge, skills, and capabilities will be most closely aligned with its research institution partners, and these partners would make appropriate "host" members for IMIs from an administrative perspective (e.g., human resources or facilities management). However, these missions diverge sufficiently that fully integrating IMIs into the host institution would risk compromising the IMI's mission.

- *Training institutions,* such as community colleges and technical high schools, will bring the capacity to deliver hands-on learning to front-line workers. Every IMI should be engaged in identifying and working with training institutions to close potential skill gaps.

- *Federal agencies*, will bring convening power and a focus on manufacturing-dependent national missions to the IMIs. Although the main objective of every IMI should be U.S. industrial competitiveness, many IMIs will also advance one or more federal missions (such as national defense, energy security, or workforce training). Federal agencies that participate in IMIs will have to accept that they will not control the IMIs the way that they do dedicated facilities, such as national labs. Unless NNMIs are truly industry led, they will not succeed.

- *State governments*, along with regional organizations and local governments in many cases, will bring geographically focused commitments to the IMI. Most IMIs should include subnational public sector partners that connect them to the unique manufacturing identities and capabilities of particular places. These partners will have to reconcile themselves to the IMI serving the nation as well as the region. They should not seek to restrict access by IMI members from outside the region to an Institute's outputs and activities. But because knowledge tends to diffuse most quickly to people and institutions that are geographically close to its origin, the

states and regions hosting IMIs will nonetheless gain benefits that will make IMI membership worthwhile.

- *Other organizations, such as labor unions and industry associations,* should they choose to participate, could bring additional unique capabilities that vary depending on each IMI's specific focus area.

Box 4: Multinational and Foreign Domiciled Manufacturers

NNMI is intended to support the competitiveness of domestic production facilities, regardless of the headquarters location of their owners. The intended beneficiaries are American workers, communities, and by extension the entire economy. While manufacturing innovations will undoubtedly diffuse internationally over time, multinational corporations that participate in the program should be required to deploy IMI-generated innovations in their domestic facilities first. In addition, manufacturers that are domiciled in countries that are either (1) on the Special 301 Priority Watch List of the U.S. Trade Representative or (2) forbid U.S.-domiciled manufacturers from participating in publicly funded manufacturing innovation programs should not be permitted to participate in NNMI.

The federal government's job will be to ensure that the NNMI gets built and performs well, not to control it.

Principle #4: The Federal Government Should Establish an NNMI Program to Manage a Bottom-Up Competitive Process for Establishing IMIs and Improving Their Performance over Time

The federal government's job will be to ensure that the NNMI gets built and performs well, not to control it. Federal agencies, like the Department of Defense, that buy and use manufactured goods, can play supporting roles as IMI members and may fund IMI projects with their own manufacturing R&D budgets. But it is manufacturers who will be the immediate beneficiaries of the IMIs and who must therefore play leadership roles in conceiving and operating them.

Although the focus areas for IMIs should be defined by industry in a bottom-up fashion, the federal government will play a vital role by orchestrating a competition among IMI proposals and co-investing in the winners. (Funding is discussed in more detail below.) The competition itself and the promise of federal co-investment will encourage new dialogue across traditional dividing lines within and across industry and between manufacturers, research institutions, and other partners. Clear guidelines for proposals, building on the principles described above, will spark organizational innovation as teams coalesce. If there are more Manufacturing Institute proposals than funds are available to support them and the proposals are equal on other merits, the criteria should be designed to select those technology areas that have the widest possible beneficial impact on U.S. manufacturing establishments in terms of boosting their productivity and supporting their ability to produce higher value-added products.

The competition for the national additive manufacturing innovation institute, which is intended to serve as a pilot for NNMI and which concluded in August, demonstrates the power of this process. (See Box 5)

A new NNMI program should manage the competitive process. Mission agencies that may become partners in particular IMIs will have difficulty being perceived as unbiased arbiters of the competition. Basic research agencies that rely primarily on peer review are not well-positioned to reach manufacturers or to evaluate large-scale industry-oriented proposals. The National Institutes of Standards and Technology, within the Department of Commerce, has the mission of supporting the nation's industrial competitiveness and is poised to be the lead federal agency for NNMI.[56] (NIST runs programs that are highly complementary to NNMI, such as the Manufacturing Extension Partnerships and a variety of manufacturing R&D programs) NIST should play this role, but NNMI will be such a large program relative to NIST's size that NIST should be required to draw upon the expertise and capabilities of mission and basic research agencies to organize and manage the program.

Box 5: National Additive Manufacturing Innovation Institute Pilot

Additive manufacturing, also known as 3-D printing, is a family of cutting-edge processes that allow products to be made layer by layer, rather than by cutting or bending materials. Additive processes are already used to make objects that are used in relatively stress-free environments, like architectural models and jewelry, but they are not yet capable of making rugged and durable components, like engine parts. Experts agree that the potential of this technology is enormous; the sale of additive manufacturing products and services is projected to surpass $6.5 billion by 2019.[57] To achieve its potential, materials must be developed, process controls improved, standards for machinery and software established, technicians and engineers trained—in short, a complex innovation process of great value to a wide range of manufacturers must be catalyzed and coordinated. These qualities make it an appropriate technology focus area for an IMI.

In May 2012, the federal government announced that it would establish a National Additive Manufacturing Innovation Institute (NAMII) using the existing budgets and authorities of several federal agencies. The announcement triggered excitement in the manufacturing community and stimulated 12 proposals from university-industry teams around the country, which each put enough money on the table to match or exceed the $30 million initial federal investment in NAMII. The winning team includes 40 companies, 9 research universities, 5 community colleges, and 11 non-profit organizations in Ohio, Pennsylvania, and West Virginia. This team assembled more than $40 million in matching industry and state funding. In September 2012, NAMII opened its doors in Youngstown, Ohio, and it recently issued its first request for proposals.[58] In addition, some of the teams that did not win the award are continuing to collaborate in this field.

In addition to running the competition to establish new IMIs, the NNMI program will have the responsibility of making the IMIs into a network that is more than the sum of its parts and that continually gets better at what it does. The program ought to share best practices across the IMIs and facilitate standardization where appropriate. It should serve as a hub of hubs, convening technical conferences and working groups. Not least, it must evaluate the IMIs to ensure that they warrant public co-investment. While continued industry investment will be a make or break factor in sustaining the IMIs—and in

determining whether they are providing real value to manufacturers—the IMIs must also be contributing effectively to workforce development, connecting with SMEs, and, more broadly, having an impact on domestic production facilities.

Principle #5: Manufacturers Should Generally Provide 50 Percent of the Resources for Each IMI, with Federal and State (or Other Regional) Co-Investment Comprising Most of the Balance

Innovation is a risky process. Some innovations fail. Others are quickly imitated. And most provide benefits to customers and society in excess of what the innovator receives. For these reasons, it makes sense for investments in innovation to be shared, especially in manufacturing, where international competition is particularly fierce.

The exact number of IMIs will depend on industry demand and state and federal budgets. However, a network of 25 IMIs, with an average annual budget of $40 million, totaling $1 billion per year, is a nice target.

Yet, as befits its leadership role in the IMIs, the private sector should be their dominant funder. Having a financial stake in the IMIs will provide a strong incentive for manufacturers to pay attention to them. Industry funders will want to shape IMI agendas and activities so that domestic production establishments can easily use what the IMIs produce. Part of the industry investment in the IMIs should support them as institutions, and part may be devoted to specific projects of value to many industry members. In-kind resources, particularly personnel, should be an important component of industry's contribution. Hands-on involvement in IMI activities by member company employees will speed innovation, because innovation often depends on knowledge that cannot be written down, but instead is learned through doing and interacting. (Research institution personnel should also be on-site contributors at IMIs)

The new federal NNMI program will be a minority investor and focus on capital and institutional needs that are typically the hardest to fund in partnership entities. The program should provide the initial infusion of funds that gets IMIs off the ground and sparks co-investment and team-building by the partners. The federal share of IMI funding should decline as an IMI matures and demonstrates clear value to industrial funders. Moreover, as their capabilities grow, IMIs should be able to compete for grants and contracts from other federal agencies on an equal basis with other performers. However, it may be necessary for the NNMI program to provide a modest share of IMI funding on an ongoing basis, as long as industry continues to co-invest, so that the IMI has the freedom to take a longer-term perspective and to generate and pursue new, higher risk opportunities than industry itself might be willing to fund, especially given the increasing short-term investment orientation of many companies. IMI proposals should include a long-term business plan that describes a projected funding path.

State governments or other regional actors, such as local governments or foundations, should also co-invest in the IMIs. Although IMIs serve the nation, many will have a central physical facility that will likely provide significant benefits to manufacturers located near it. Many such IMIs will build on an existing regional asset base, deepening and expanding an industrial cluster or group of inter-linked clusters. These geographically focused benefits provide the rationale for state or regional funding. One form that such funding could take would be to support SME membership in IMIs. State or regional funding for IMIs could

also be packaged with their support of Manufacturing Extension Partnership (MEP) centers. MEP centers will complement IMI activities and accelerate the diffusion of their innovations to SMEs. (See Box 6)

Although industry, federal, and state or regional sources will provide the lion's share of an IMI's resources, some IMIs might also generate revenue from other sources. Contract research for individual companies is one such source, although in order to keep their mission focused on the industrial ecosystem broadly, such revenue should be limited to 10 percent or less of an IMI's budget. IMIs might also earn revenues by licensing intellectual property that they generate and hold. Whether any particular IMI will have the potential to do so will depend in part on prior agreement among the members. The importance and nature of intellectual property varies widely across manufacturing industries, and intellectual property policy at each IMI will very likely reflect these particularities.

Support for the NNMI program office, as opposed to the IMIs that make up the network, should be provided primarily by the federal government. This office will be responsible for selecting and evaluating IMIs and should not be dependent upon them or upon their members.

Box 6: The Manufacturing Extension Partnership

The Manufacturing Extension Partnership is a collaborative federal-state program that focuses on boosting the productivity, competitiveness, and innovation potential of small and medium-sized manufacturers. MEP's field staff features over 1,300 technical experts, located in every state and serving as trusted business advisors focused on solving manufacturers' challenges and identifying opportunities for growth. MEP serves an essential role in sustaining and growing America's manufacturing base by placing technologies and innovations developed through research at federal laboratories, educational institutions, and corporations directly into the hands of U.S. manufacturers. NNMI will amplify the payoff from the public investment in MEP. MEP will be in a unique position to connect research and technological discoveries made at NNMIs focused on various technologies/industries with the SMEs they work in direct contact with in districts across the country.

MEP has a proven impact in terms of boosting employment and economic growth, with every $1 of federal investment in MEP generating about $30 in total new sales annually for manufacturers that work with it.[59] It should be noted that other countries invest much more as a share of their GDP in programs comparable to MEP. Japan invests roughly thirty times more as a share of GDP than the United States, and Canada ten times more.[60]

The exact number of IMIs will depend on industry demand and state and federal budgets. A network of 25 IMIs, with an average annual budget of $40 million, totaling $1 billion per year, strikes us as a good target. At least $500 million for an NNMI on this scale would come from industry sources. If the federal government covered 35 percent of the Institutes' cost, the federal share would be $350 million per year, plus the budget of the program office, which might be 1 percent of the total, or $10 million, annually. (This figure would represent a 48 percent increase in NIST's $750 million annual budget for fiscal year 2012.

As noted above, other federal agencies with an interest in manufacturing innovation would participate in technical and administrative aspects of the NNMI program. Program funds should be transferred to them to support their participation.) State governments and regional organizations would be expected to contribute the remaining $150 million. The funding from each source need not be distributed evenly over time; for instance, a large up-front federal and state capital investment would allow IMIs to get up and running and focus industry funding on ongoing projects and activities.

As noted, as a general guide, manufacturers should provide at least 50 percent of the resources for each IMI. However, there should be a range of cost sharing options reflecting technology risk and maturity. In some cases, the higher risk and earlier development stage of certain technologies may merit different levels of contribution from key actors.

CONCLUSION

America needs a National Network for Manufacturing Innovation. NNMI will strengthen the innovation capabilities of U.S. production facilities, which are essential for success in a highly competitive global manufacturing economy. NNMI will build on national strengths in research and education, bringing these strengths to bear on a sector that has not been as closely connected to them as it needs to be in a world that demands ever-rising skill and technology levels. NNMI will foster collaboration that will help to solve problems and seize opportunities of value to a wide range of manufacturers of all sizes. As Lockheed Martin puts it, NNMI "is the right initiative at the right time."[61]

NNMI is a vital investment in the future of the U.S. economy, even in this time of tight federal budgets. Deficit reduction is an important priority over the medium- and long-term, but policymakers should protect federal spending today that enables future generations of Americans to have the opportunities as good as those that their parents and grandparents have had. We should not eat our seed-corn, yet that is precisely what across-the-board federal spending cuts threaten to do. The innovation opportunities that we have highlighted—which promise to make manufacturing smarter, greener, cheaper and better in other ways—have been noticed around the world. In Europe, Canada, and Japan, as well as in many developing countries, governments are working hard to help their manufacturers seize the moment. The United States cannot afford to remain passive. If it does, the dismal history of the 2000s may well repeat itself.

NNMI alone will not fix all that ails U.S. manufacturing. There is no single silver bullet that will revitalize American manufacturing; many policy improvements are needed to both macroeconomic and innovation policy approaches. But creating NNMI would be a very important step. It would fill a major gap in the current U.S. innovation system for manufacturing. At least as important, it would send a powerful message to the world: the United States is no longer taking manufacturing for granted.

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