CRITICAL NATIONAL NEED IDEA

Critical National Need Idea Title:

The Need Research and Development in Manufacturing and Metrology

Submitting Organization:

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Contributing Organizations:

None

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SUMMARY

***"Man is a tool-making animal."* – Benjamin Franklin**

Making things is important. A vibrant manufacturing community is a fundamental component of economic well-being in a society. The wealth of the United States, and of the world for that matter, is created through mining, through agriculture, and through manufacturing. Among those three fundamental wealth-creation mechanisms, manufacturing is the one that is least dominated by proximity to natural resources, and it is the one that is the most obedient to intellectual prowess. Making things is an integral part of what it is to be human. Continuing innovation in manufacturing is largely responsible for raising huge numbers of people out of poverty throughout the world. Manufacturing is a fundamental component of national security as well. The ability to manufacture goods domestically and cost-effectively is important in a world where political uncertainty and competing national interests remain concerns.

There is a prevailing sentiment in the popular press and among the general public that manufacturing jobs are naturally and inevitably flowing from high-wage countries to low-wage countries. This sentiment is wrong, and even worse, it dissuades many creative entrepreneurs, scientists, researchers, and students from applying their energies, their talents, and their creativity in the competition of brains that is beneficial to everyone.

"The prosperity the United States enjoys today is due in no small part to investments the nation has made in research and development at universities, corporations, and national laboratories over the last 50 years. Recently, however, corporate, government, and national scientific and technical leaders have expressed concern that pressures on the science and technology enterprise could seriously erode this past success and jeopardize future US prosperity. Reflecting this trend is the movement overseas not only of manufacturing jobs but also of jobs in administration, finance, engineering, and research."[1]

Wages, the most frequently and prominently cited rationale for job migration, are only a portion of the total cost of manufactured goods. Process productivity, transportation costs, transportation delays, waste, and rework, are easy examples of additional costs and benefits that must be considered, and are costs which can be directly addressed through research and innovation. Product functionality, product efficiency, and the ability to rapidly change in response to a changing market are important manufacturing considerations as well. A race to the bottom of the wage scale is a race to declining standard of living. A race to higher productivity, greater efficiency, and greater innovation raises the standard of living for everyone on the planet.

We should not say that the United States cannot remain competitive in manufacturing in the face of low-wage competition. Rather, we should ask how, in the face of low-wage competition, the United States can remain competitive in manufacturing. One way is to increase our productivity. The low-wage argument works if one assumes that our manufacturing operations are already as productive as they can be. Clearly that is not the case, and most researchers in manufacturing and metrology fields know that this is not the case. They can easily point to examples where significant productivity improvements have been made. Researchers, however,

need incentives and funding to pursue new ideas in manufacturing. How can scrap rates be reduced? How can raw materials be utilized more efficiently?

Another way to compete is to manufacture products that others cannot. The ability to manufacture with greater precision across all size scales enables the development of new products, and it enables improved efficiency and lower costs in existing products. Manufacturing and metrology have traditionally been separated spatially and temporally in manufacturing environments, and they are pursued as separate research fields. Clearly greater precision in manufactured parts will require tighter integration of manufacturing and metrology. Measurements have to be made, and the information has to be made available in time to affect the process already underway.

A variety of nanotechnology applications are on the horizon and tools for manufacturing, metrology, and assembly will be critical to the integration of nanotechnology with micro and meso-scale technologies. As a result, the US has realized that focusing efforts in manufacturing (from macro to nano-scale) is critical for sustaining a competitive advantage in the global economy [2]. Building the capability to advance the fabrication of microscale and nano-scale features directly impacts technology progress and will inevitably demand grand challenges in multi-scale assembly processes.

Precision in manufacturing is explicitly a green activity. The efficiency of an engine or a power generation turbine is directly connected to the precision of manufacture. The service life of machinery is directly related to the precision of manufacture, and increased service life save the energy expended in the manufacture of a replacement. In the 1990s, manufacturing output in the United States expanded by 41%, but industrial consumption of electricity grew by only 11%. The introduction and use of energy-efficient products have enabled the US economy to grow by 126% since 1973 while energy use has increased by only 30%

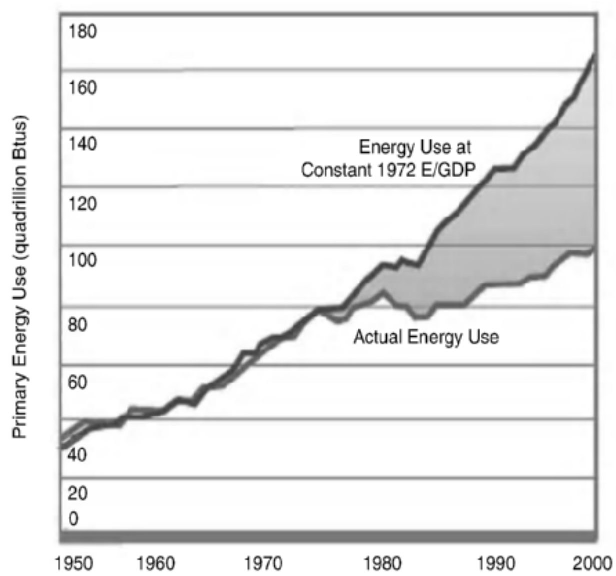

Figure 1 US primary energy use, 1950-2000. The efficiency of energy use has improved substantially over the last 3 decades. SOURCE: National Energy Policy Development Group. National Energy Policy. Washington, DC: US Government Printing Office, May 2001.

In all of manufacturing there is a need to revitalize and support our historical strength in innovation. Innovation creates and sustains the productivity advantage, leads to new products, creates new jobs and industries, reduces waste, and improves the standard of living. Even though human beings have been manufacturing from the dawn of recorded time, new manufacturing processes, and new ways to use existing processes are research areas that are full of promise. There are many researchers, entrepreneurs, and students ready and willing to work in manufacturing and metrology research, yet the funding sources for such research and development are sparse. Organizations such as the National Science Foundation do not see “development” as part of their mission. Corporate research departments are often easy targets for cost-cutting in difficult economic times. Manufacturing education tends to focus on “lean” use of existing technologies rather than on innovation.

Examples of High-Risk High-Reward Science and Technology

On machine measurement – In the aerospace industry, as an example, monolithic machined components are rapidly replacing sheet metal assemblies. This is largely due to the high costs associated with assembly operations, and the development of the ability to machine thin structures using high speed machining [5]. As the cost savings have become apparent, monolithic machined components have grown larger and larger, see Figure 2. Using existing systems, the tolerance requirements for the largest parts are difficult or impossible to achieve. The tolerance requirements for the large-scale monolithic components are based on assembly requirements (the parts must fit together). The difference in coefficient of thermal expansion between the machine and the workpiece combined with the poor thermal environment easily create errors larger than the tolerance. The shops are generally not temperature controlled (and temperature control is expensive), the spindle and drive motors get hot, the hot chips fall on the workpiece, the coolant temperature changes, and so on. Indeed, for parts of all sizes, one of the leading causes of difficulty in the machining of precision parts is the control of the thermal environment [6]. Temperature effects are “the largest single challenge to attaining maximum accuracy” [7].

Figure 2 Machining a large aerospace cargo floor

Real-time error correction of machines - Coordinate Measuring Machines are routinely measured for the errors and corrected in software. For the most part machine tools are not. Machine tools look like CMM’s but they are different. CMM’s exist in controlled thermal environments. Machine tools are generally in poorly-controlled thermal environments. CMM’s do not have on-boards heat sources. Machine tools have powerful heat sources in the spindle, the drives, and in the manufacturing operation. An example of a high-risk high-reward technology would be real-time measurement and correction of machine tool errors. This might be enabled by a hybrid combination of laser tracking and frequency comb lasers. It seems feasible to make existing machines in existing environments more accurate by an order of magnitude through new real-time measurements.

Measurement-facilitated assembly – There are many operations where it is difficult or impossible to see the components to be assembled. Within conventional scale manufacture, metrology tools and relocation fixtures have been refined over more than a hundred years and can function at levels comparable to conventional machine tool precision. As dimensional scales reduce, so too do tolerances on components, leading to precision requirements beyond conventional fixturing and metrology systems. While nanometer scale relocation methods have been developed for microelectronic manufacture, with the possible exception of the AFM, metrology tools capable of operating with micro to nano scale parts within small volumes simply do not exist. Even metrology AFM systems can only really be considered 1 or 2-D tools with limited geometric capability in terms of dimensional measurement of component geometries.

Maps to Administrative Guidance:

The nature of the challenge face by US manufacturing and metrology research and development has been well documented in a number of sources including [1], [2], and [3]. The National Research Council has identified “Grand Challenges for Manufacturing” [3]:

1. achieve concurrency in all operations

2. integrate human and technical resources to enhance workforce performance and satisfaction

3. instantaneously transform information gathered from a vast array of sources into useful knowledge for making effective decisions

4. reduce production waste and product environmental impact to "near zero"

5. reconfigure manufacturing enterprises rapidly in response to changing needs and opportunities

6. develop innovative manufacturing processes and products with a focus on decreasing dimensional scale

All of these identified grand challenges are directly addressed by research to more tightly integrate manufacturing and metrology operations.

Justification for Government Action:

It is quite clear that neglecting manufacturing and metrology research and development has a direct and negative impact on the US economy. The loss of jobs, and more importantly the loss of manufacturing as a wealth generation mechanism has put the leading role of the US as an economic power, the continuously-rising US standard of living, and US national security at risk.

In the current economic climate, there US corporations simply do not have the resources to fund the required research work. The NIST TIP program is perhaps ideally situated to address this problem. By providing leverage, but requiring matching funding, the program is designed to encourage direct participation of corporate America and academics in the research and development programs.

Improved funding in manufacturing and metrology research will directly increase the number of students with the skills and knowledge required to reinvigorate America’s industrial base.

“If you want good manufacturing jobs, one thing you could do is graduate more engineers. We had more sports exercise majors graduate than electrical engineering grads last year.” **- Jeffrey R. Immelt, Chairman and CEO, General Electric** [4]

A competition in the area of manufacturing and metrology would likely draw proposals from universities including the University of North Carolina at Charlotte, Northwestern University, Clemson University, the University of Michigan, and the University of Florida. Industrial partners would likely include many major US manufacturers including Boeing, Alcoa, Caterpillar, General

Electric, and more. Many of these potential partners have expressed concerns that the US government is not funding research and development work in a way that the governments of their competitors in Germany, Japan, and China do.

TIP funding in manufacturing and metrology will leverage the corporate funding that is available, and lead to better interaction between universities and industry. Even more important, funding in this topic will draw the entrepreneurs, researchers and students necessary to revitalize a critical segment of the economy.

The United States has a long history of innovation, creativity, and development in manufacturing and metrology. There is a large core of entrepreneurs, researchers and students eager to devote their energies in these rich research fields, and it is clear that there are many opportunities for innovation. Successful invigoration of this segment of the economy is leveraged many times through wealth generation and job creation. By the same token, failure to act is also leveraged through economic contraction and job loss. While the investment needed to invigorate the manufacturing base is substantial, if the manufacturing base were lost, the effort required to re-create it would be daunting indeed.

It is the expansion of the scientific underpinnings of manufacturing, and sustained innovation that hold the promise of delivering a renewed and internationally competitive manufacturing base in the United States.

From atoms to aerospace, from sensors to systems, from science to standardization, from principle to practice, from origination to optimization, precision manufacturing is enabled through precision measurement. Manufacturing and metrology are inextricably linked, yet they have been pursued as separate research activities. TIP funding in the topic of Manufacturing and Metrology would lead to the integration of precision manufacturing research and development with precision measurement research and development, across the spectrum of length scales, across frequency scales, and across manufacturing disciplines.

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