7. Erosion of the U.S. Defense Industrial Support Base

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“The optimist fell from a 10-story window; as he passed each bar, he shouted to his friends inside, ‘I’m alright so far.’”

The United States defense industrial base suffered a massive erosion of capability between 2001 and 2008. By analyzing 16 individual manufacturing sectors that underpin the U.S. defense industrial base, it is possible to determine the true health of the entire defense industry food chain, from small companies up to the major systems integrators.

For 13 of the 16 industries, significant erosion has taken place without any signs of recovery, despite a fairly robust period of economic growth between 2002 and 2007. Only two of the 16 underlying defense manufacturing industries showed growth while one held steady over that period.

The erosion of the defense industrial base identified in this analysis is cause for concern to the overall health of the national innovation system that supports the military enterprise.

Erosion of industrial sectors has occurred many times in history. But the current economic cycle is different. The three main corrective mechanisms — economic growth, research and development investments and improvement of the skill base — either are not working or are not being applied.

Economic growth following the 2001 recession did not pull a majority of these national manufacturing sectors out of their tailspin. There is little investment in basic research and development or in advanced production processes. And there are fewer students enrolled in the science and engineering fields that support these industries. The country is losing a highly skilled workforce that cannot easily be retrained.

Many other secondary corrective mechanisms and potential policy levers exist to turn the situation around, but they are either at risk of
being cut or they are being pursued unsatisfactorily. These include the protection of intellectual property, increasing access to capital and establishing flexible currency rates to make American companies more competitive.

Furthermore, the industries showing erosion are still important and relevant to the health of the defense sector — as well as the economy as a whole — as compared to obsolete industries producing goods that are no longer in demand, such as typewriters or buggywhips.

Consequently, the erosion of the defense industrial manufacturing support base is worth the attention of policymakers, who need to determine the root causes of erosion, and the efficacy of different policy levers to reverse the trends.

Over the last few years, the popular press has noted with particular alarm the loss of total manufacturing jobs starting in 2001. The stated cause for such attention has been the concern that cumulative job loss might be a drag on the overall economy, hurting quality of life and the strategic economic and geopolitical position of the United States. The financial collapse of September and October 2008 has borne out such concerns.

Since 1940, total manufacturing employment has varied from a low of 12 million employees shortly after World War II, to a high of nearly 20 million employees at the start of the 1980s, then back down to almost 12 million employees in early 2009.²

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**Figure 1: Total Manufacturing Employment from 1940 To 2009**²³

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Overlaid on the manufacturing employment chart on page 246 are gray vertical bands that denote periods of economic recession in the United States. The chart reveals that the erosion in the manufacturing base defined by the loss of employment has occurred many times historically, but that the recent downturn starting in 2001 is different from all prior periods. Historically, erosion and the subsequent expansion of the manufacturing base were in sync with the rest of the economy’s movements. That is no longer the case.

The erosion of the industrial sector and manufacturing employment that began in 2001 displayed different characteristics in that the loss of jobs was swifter than in previous downturns (though not as severe as the job loss during the early 1980s) and continued well past the end of the recession. More than one million jobs were lost during the eight-month recession ending in November 2001, after which job loss continued for more than another two years, with the loss of an additional two million jobs. Job loss slowed in early 2004, ultimately declining to 13 million manufacturing jobs in late 2008 before a more rapid decline into 2009.

That the erosion would continue in a sustained fashion after the recession ended has been unprecedented since World War II, with other periods of job erosion ending either the same month as when the recession ended (typical), or within two months (unusual).

From an analytical perspective, this extensive erosion invites the question as to whether manufacturing employment is a naturally-occurring and useful adjustment to inefficiencies in the economy, or whether it presents a challenge to the health of the national innovation system. That is, it would be useful to determine whether the manufacturing base eroded in an undesirable way that is detrimental to the country’s ability to innovate.

Because of the importance of the manufacturing support base to innovation, and because most discussions about the manufacturing support base use only one top-level indicator such as jobs without digging into individual industries, the attempt here is to provide a more detailed analysis.

The Manufacturing Support Base Is Essential For U.S. Innovation

The manufacturing support base is a key part of the nation’s economy. It provides for robust defense capabilities and nourishes the innovation life cycle. In popular culture and the media, commentators and
articles that discuss the national manufacturing base are often essentially referring to the aggregate attributes of the sector without paying much attention to the pieces that comprise the whole. Moreover, many confuse the manufacturing base as essentially synonymous with large corporations or prime contractors such as Boeing, Lockheed Martin and Ford. Media reports about profit growth or the number of jobs that have been created or eliminated at these big companies are not indicative of the entire system.

The manufacturing base includes several components that comprise the “innovation food chain.” The large integrators are at the top of the chain and include major defense prime contractors and manufacturers whose names are easily recognized. Their products, such as military vehicles, ships and planes, incorporate the innovations and capabilities of the lower-tier suppliers and support industries.

By many modern standards, the major defense systems integrators are no longer considered key innovators. The top tier of defense contractors “have increasingly focused on the complex system-integration function [and] are relying more on supplier expertise to design new sub-system solutions,” according to a report by the RAND Corp. The major integrators have shifted their core competencies away from innovation and towards integration, scheduling and management of a vast network of suppliers. They are pushing the burden of innovation lower into the supply chain.

It is no secret that these large companies rely increasingly on smaller companies for their innovation. Instead of making innovation their key responsibility, major integrators now achieve innovation either by purchasing smaller companies that are innovative, or by incorporating those companies into their supply chain.

In turn, the smaller innovative companies are focused on developing new subsystems or specific capabilities. But even many of these companies are integrators, pulling together advanced materials, semiconductors, printed circuit boards and motors to make components or small systems that can be further integrated into larger systems.

This new industrial configuration in which the major defense companies no longer carry primary responsibility for innovation, forces the burden for new ideas and breakthroughs on the middle-tier in the innovation food chain to companies like Cisco, Sony and Goodrich. Furthermore, some companies lie somewhere between the innovators and integrators. For example, jet engines made by GE Power Systems include many complicated and innovative components, but the engines themselves are inserted into larger integrated systems.
The most innovative smaller companies are more directly dependent on the manufacturing support base for their success. They are less likely to have their own in-house machine shop, mold- or printed circuit board-making ability that can be utilized for prototyping. They rely on basic manufacturers to help them with their product and process iterations that are the essential aspects of the innovation process. Their ability to apply innovation depends directly on the existence of a healthy support base that can quickly manufacture advanced mechanical and electronic systems.

This notion of having a robust and innovative manufacturing base is echoed by Michael Porter’s concept of the “competitiveness diamond,” which includes a prominent role for “related and supporting industries” in competitive sectors of the economy. Studies at Harvard and RAND that use Porter’s clusters model find that a business environment that encourages strategic rivalry and competition is the single-most critical driver of innovation and competitiveness.

The Harvard study of hundreds of industry clusters worldwide finds that dependence on a healthy local support base allows innovative companies to thrive. In traditional economic terms, this concept is captured in the notion of “transaction costs.” If a healthy support base is nearby, then costs are lower. But if the support base has moved offshore, then transaction costs for innovation increase as companies are forced to overcome time zones, language and cultural barriers in order to work with companies that are located far away.

If the manufacturing support base no longer adequately serves the innovative companies, then their ability to be competitive is hindered and innovation does not move up the chain to the top-tier integrators. Consequently, the health of the entire innovation food chain, and thus the entire national innovation system and the defense industrial base, relies on the health of the foundation of the entire system: the manufacturing support base. The manufacturing support base will be analyzed within this context in this chapter.

Prior studies of the defense industrial base have looked at the value of small segments of the support base, such as machine tools. This study incorporates other basic industries into its scope. Furthermore, prior analytical studies and policy debates have emphasized a top-down approach to new acquisition strategies needed to keep the major defense prime contractors healthy and prosperous. The current system is designed to ensure innovation and productivity among the top integrators. It embodies a tacit belief that if the major integrators are healthy, then the entire innovation system will also be healthy.
This top-down perspective needs to be reconsidered. A perspective from the bottom up is needed.

That is, the health of the big defense prime contractors depends on the innovation capability of the underlying manufacturing support base. If the lowest tier of the manufacturing support base is healthy, then the innovators will be operating effectively, and consequently the top-tier integrators will also succeed.

For semantic purposes, the U.S. defense industrial base is considered to be the end-to-end capability within the United States to design and produce advanced military weapons systems. The manufacturing support base from materials to finished product is comprised of making, bending or shaping materials; producing components; applying treatments; or providing manufacturing-related services such as rapid prototyping.

The materials sector is not included in this analysis, but materials
provide the foundation of the manufacturing and defense industrial base. Consequently, a separate study of the materials industries is warranted.

If the overlooked manufacturing support base that props up the entire national innovation system continues to deteriorate in the United States, but grows and thrives overseas, then large numbers of America’s most innovative companies might be inclined to move overseas to be closer to production and the necessary support base.

Significant deterioration of companies that design and make discrete components is triggering a fundamental hollowing out of the national innovation system.

**Sixteen Industries Comprise the Manufacturing Support Base**

The sectors included in this study are those within the manufacturing support base that have a direct bearing on innovation and production of novel mechanical products and systems. The output from these sectors is used directly in the design process of other industries. Their capabilities are considered critical to the ability to apply innovative mechanical designs. Sectors that support the production of chemicals, pharmaceuticals or software are not considered for this study because their connection to mechanical systems is not explicit, though clearly they are an important area for continued innovation of U.S. industry.

The scope of this study also includes the electromechanical, thermomechanical and optomechanical sectors. Each has relevance to the innovation of mechanical systems. If the particular process, function, service or output of the industry is an enabler of innovation, it is included. For example, the machine tool industries are included because the ability to manufacture more complicated forms with better machine tools enables many more design possibilities. The machine tool sector therefore plays an essential function in innovation.

This study does not include automotive, agricultural or aerospace equipment industries because these are integrated systems and therefore do not qualify as components of the underlying manufacturing support base.

The following criteria were used to determine what industries make up the manufacturing support base:

- Their technological advances impact the capabilities of upstream producers or integrators;
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• Their output is embedded, integrated or involved in the manufacture of larger systems; and
• Their output must be integrated into more than one type of system. Electronics fit into a range of consumer, military and other integrated products, but jet engines do not qualify because they are dedicated to one type of system.

Using these criteria, the range of manufacturing industries was narrowed from 764 to the 16 considered for this study. Those sixteen industries are shown in Table 1 along with their NAICS codes, and are described in greater detail below.9,10

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<thead>
<tr>
<th>NAICS Code</th>
<th>Industry Description</th>
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<tbody>
<tr>
<td>3315.......</td>
<td>Foundries</td>
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<tr>
<td>33211......</td>
<td>Forging and Stamping</td>
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<td>33271......</td>
<td>Machine Shops</td>
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<td>332811.....</td>
<td>Metal Heat Treating</td>
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<tr>
<td>332997.....</td>
<td>Industrial Pattern Manufacturing</td>
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<td>333295.....</td>
<td>Semiconductor Machinery Manufacturing</td>
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<td>333314.....</td>
<td>Optical Instrument and Lens Manufacturing</td>
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<td>333511.....</td>
<td>Industrial Mold Manufacturing</td>
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<td>333512.....</td>
<td>Machine Tool (Metal Cutting Types) Manufacturing</td>
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<td>333513.....</td>
<td>Machine Tool (Metal Forming Types)</td>
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<tr>
<td>333514.....</td>
<td>Special Die and Tool, Die Set, Jig and Fixture Mfg.</td>
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<tr>
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<td>Bare Printed Circuit Board Manufacturing</td>
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<tr>
<td>334413.....</td>
<td>Semiconductor and Related Device Manufacturing</td>
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<tr>
<td>334418.....</td>
<td>Printed Circuit Assembly (Electronic Assembly)</td>
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<tr>
<td>33451.......</td>
<td>Navigational, Measuring Electromedical and Control Instruments Manufacturing</td>
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<tr>
<td>33591.......</td>
<td>Battery Manufacturing</td>
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The 16 industries and groupings are not intended to be the comprehensive list of all industries that are connected to the manufacturing support base for the innovation supply chain.

Some other industries that might be considered include Computer and Peripheral Equipment Manufacturing (3341), Communications Equipment Manufacturing (3342), Electronic Capacitor Manufacturing (334414), and Fiber Optic Cable Manufacturing (335921). A broader
analysis could develop a ranking system for the industries and industry groups that hold the most influence in enabling the innovative capacity of broader industry segments.

**Methodology for Studying the Manufacturing Support Base**

Typical studies and discussion of the manufacturing sector have been limited to aggregate employment statistics by noting job growth or loss with each economic cycle. Though jobs are a useful statistic and provide insight into the overall state of the sector, studying the employment figures alone is not enough to analytically determine whether an unacceptable level of erosion has occurred. For example, in the U.S. agriculture sector, employment has dropped steadily for many decades. However, agricultural output remains high and the United States retains the ability to feed itself and export excess production. Similarly, the number of telephone operators in the United States has dropped dramatically over the last three decades, despite significant growth in the number of phone numbers and daily phone calls. Increased productivity on farms and by the telephone companies more than made up for job losses, thereby yielding growing economic activity for these two industries in the face of declining employment.

Given these two examples and many others like them, it is safe to conclude that studying employment figures alone is not enough to make sound conclusions as to whether a particular sector or industry is deteriorating. Consequently, this report uses three primary indicators to determine whether an industry is eroding: employment, economic activity (contributions to GDP by shipments), and the number of establishments.

If decreases are evident in output, the number of establishments and employment, then the industry is considered to be eroding. If all three indicators are increasing, then the industry is considered to be growing.

For some industries, the picture is mixed, leading to a less conclusive determination of its health. A stoplight chart reflecting all three indicators for each of the 16 industries is compiled at the end of the industry-specific analysis to help compare the various industries and to make a qualitative determination about their erosion status.
Industry-Specific Analysis

Statistics are plotted for each of the 16 industries that comprise the manufacturing support base in order to make a qualitative determination for each as to whether they have eroded, held steady or expanded during the last economic recovery from 2001 to the end of 2007. The three indicators are stacked in the charts, with employment information in the top panel, economic activity in the middle panel and number of establishments in the bottom panel.

The time periods of the last two recessions are also shown as gray bars on the graphs for reference purposes. The data sources are noted in the legends for each plot: ‘BLS’ refers to data coming from either the Bureau of Labor Statistics’ Current Employment Statistics Survey or the Quarterly Census of Employment and Wages; ‘ASM’ refers to the Annual Survey of Manufacturers by the U.S. Census Bureau; ‘Census’ refers to the 2002 Economic Census; and ‘NBER’ refers to the National Bureau of Economic Research. (For an explanation of data sources, see endnote 11.)

Generally, the monthly Current Employment Statistics Survey was used for employment figures whenever possible, and the Quarterly Census of Employment and Wages was used for establishment estimates. Wherever the Current Employment Statistics Survey data were not available, combined employment information from the Quarterly Census of Employment and Wages, and the Annual Survey of Manufacturers were used instead.

For the charts, employment figures include total employees (not seasonally-adjusted) and are plotted in the thousands. The economic activity is labeled “Corrected GDP by Shipments” and presented in millions of 2005 dollars, except for the two industries for which materials costs were not subtracted: metal heat treating and industrial pattern manufacturing. For these two industries, “GDP by Shipments” are plotted in millions of 2005 dollars, but without correcting for materials expenditures. The data on establishments are plotted without any adjustments or corrections.

For some panels that include data from two different sources, the data do not necessarily overlap. These gaps or differences in data are primarily the result of the agencies using slightly differing standards for employment and definitions of what qualifies as an establishment. Because the charts are being used to spot trends rather than quantitative results, these incongruities are not of special concern.
**FOUNDRIES** (NAICS Code 3315)

Foundries show significant erosion in all three indicators from the levels just before the last recession. Employment dropped from more than 205,000 in March 2001 to less than 150,000 in August 2008, remaining below even the employment levels at the end of the 1991 recession. GDP dropped from just below $20 billion in 2000 to just above $16 billion in 2005, and recovering to almost $18 billion in 2006. The number of establishments appears to be on a steady slide from around 2,800 in 2001 to less than 2,300 in early 2008. Overall, this industry group has experienced significant erosion.

This industry group comprises companies primarily engaged in pouring molten metal into molds or dies to form castings. Ferrous and nonferrous foundries are considered a part of the support base because casting is an initial step for most manufacturing processes. The ability to make castings out of novel materials and to produce more complicated shapes and larger sizes has a direct impact on the entire product innovation process.
FORGING AND STAMPING (NAICS Code 33211)

The forging and stamping industry shows erosion in all three indicators since the end of the 2001 recession. Employment dropped from more than 130,000 in March 2001 to just over 110,000 in August 2008. GDP dropped from just over $16 billion in 2000 to just over $13 billion in 2006. The number of establishments is on a slow slide from just over 2,700 in 2001 to just over 2,600 in 2008. The increasing GDP despite lower levels of employment and decreasing number of establishments is a good sign and is likely attributable to the widespread productivity gains that took place in the manufacturing sector over that time period.

This industry comprises companies that are primarily engaged in manufacturing forgings from purchased metals, manufacturing metal custom-roll forming products, manufacturing metal stamped and spun products (except automotive, cans and coins), and manufacturing powder metallurgy products.

Six national industries comprise this NAICS group: iron and steel forging, nonferrous forging, custom-roll forming, crown and closure manufacturing, metal stamping and powder metallurgy part manufacturing. Forging and stamping is a part of the manufacturing support
base because its various processes (hammering mill shapes, surface finishing, using rotary motion of rolls with various contours to bend or shape products, stamping, spinning, compacting in a shaped die and sintering) make it possible to manufacture products with different shapes and qualities.

**MACHINE SHOPS** (NAICS Code 33271)

The machine shops industry shows a typical erosion and expansion as expected with economic cycles. After losing more than 40,000 jobs during the recession of 2001, employment has since grown to exceed pre-recession employment of approximately 260,000 employees by an additional 20,000 employees. GDP dropped from just over $23 billion in 2000 to $19 billion in 2003, then showed a recovery to $22 billion in 2006. The slight decrease in the number of establishments appears to have stabilized at nearly 21,600, indicating a total loss of a few hundred establishments. The slight recovery in GDP and the industry’s addition of tens of thousands of jobs suggest that overall this industry has held steady and is poised to expand.
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The machine shops sector includes companies engaged in machining metal parts on a job or order basis. Generally, machine shop jobs are low-volume, using machine tools such as lathes (including computer numerically controlled), automatic screw machines, and machines for boring, grinding and milling.

Machine shops are a component of the support base because of their ability to provide a service to innovators producing low-volume prototypes and other complicated testbeds. This activity is an important part of the iterative innovation process. The value of machine shops is particularly important for innovative smaller companies that do not have the resources to support those capabilities in-house.

**Metal Heat Treating** (NAICS Code 332811)

The metal heat treating industry shows a mixture of neutral to bad news. After losing a few thousand jobs during and after the 2001 recession, employment has since grown back nearly to prior levels. GDP dropped from approximately $4.5 billion in 2000 to approximately $3.5 billion in 2003, and showed reasonable recovery in 2004. The decrease
in the number of establishments is continuing. The industry’s addition of jobs suggests that it has held steady, but is at the mercy of the late 2008 economic downturn.

The industry comprises establishments primarily engaged in heat-treating of metal using annealing, tempering and brazing. It is a component of the support base because new capabilities, characteristics and outcomes from the treatment and qualities of metals enable new designs of mechanical systems. For example, novel processes that produce materials that have improved characteristics of strength, corrosion-resistance or particular electromagnetic characteristics all have an impact on the innovation and design process

**INDUSTRIAL PATTERN MANUFACTURING** (NAICS Code 332997)

The industrial pattern manufacturing industry shows erosion in all three indicators from the levels just before the last recession. Employment dropped from more than 7,500 in March 2001 to less than 5,000 in March 2008. GDP dropped from just over $750 million in 2000 to just under $650 million in 2004, after showing a slight increase over the
year before. The number of establishments appears to be on a steady slide from around 650 in 2001 to 480 in early 2008. Note that the cost of materials was not subtracted out of the shipments values (because of a lack of data), which makes the GDP information even worse than presented here. This industry has endured significant erosion and does not show signs of recovery.

The industry comprises companies primarily engaged in manufacturing industrial patterns. It is a component of the support base because advances in the production of patterns yields the possibility of a greater range of shapes, casts, molds and tools for the production of complicated parts. The industry is necessary to greater innovation in the manufacture of different designs.

**SEMICONDUCTOR MACHINERY MANUFACTURING**
(NAICS Code 333295)

The semiconductor machinery manufacturing industry shows a mixture of indicators. According to the BLS data, employment dropped
from more than 24,000 in March 2001 to a little over 18,500 in March 2008, while the ASM data show a more severe 50 percent drop in employment, from around 50,000 in 2000 and 2001 to about 25,000 in 2005. The number of establishments has oscillated between 215 and 240. The GDP declined substantially from just over $12 billion in 2000 to between $6 billion to $8 billion in 2003-2005, but it is important to note that market activity for semiconductor machinery in 2000 was abnormally high. Thus, the GDP of this industry remains in 2008 at or above levels from just before the market increase in 2000. That the value of shipments remains high despite drastic decreases in employment is likely attributable to increased productivity.

Overall, this industry appears to be enduring growth and contraction on a cycle that is different from the macroeconomy. Therefore, this industry is holding steady and did not endure significant erosion prior to the market collapse of 2008.

Semiconductor machinery manufacturing includes companies engaged in making wafer processing equipment, semiconductor assembly and packaging equipment and other semiconductor-making machinery. The industry is a critical component of the support base because semiconductor machinery manufacturing creates a host of components that allow a wide range of possible designs. Among all the different industries in the support base, this one is among the most critical. Innovations in semiconductor machinery equipment, such as the integration of novel optics, lasers and control systems, enable greater advances in compactness, transistor density, thermal properties and other characteristics of semiconductor chips.

Because of the ubiquitous nature of embedded electronics and advanced electronic semiconductor components in modern mechanical systems, these improvements have a cascading effect, thereby contributing to a greater level of innovation that expands capabilities, reduces cost and weight, and minimizes the number of components.

**Optical Instrument and Lens Manufacturing**
(NAICS Code 333314)

The optical instrument and lens manufacturing industry shows slight to severe erosion in all three indicators. According to the BLS data, employment dropped from approximately 28,500 in March 2001 to 23,200 in March 2008, while the ASM data show a drop in employment from around 21,000 in 2001 to about 16,000 in 2005. The industry’s
GDP decreased from just over $2.6 billion in 2000 to just over $2 billion in 2005. The number of establishments has dropped slightly, from nearly 580 to 560. Overall, this industry has experienced significant erosion and, immediately prior to the economic downturn in late 2008, there were no obvious signs of recovery.

The industry comprises establishments engaged in the manufacture of optical instruments and lenses, such as binoculars, microscopes (except electron and proton), telescopes, prisms and lenses (except ophthalmic). It also includes companies that coat, polish and mount lenses (except ophthalmic).

With the increasing integration of optical components in advanced equipment, especially in the telecommunications field, advances in optics and optical instruments allows production of a new generation of products. For example, new designs for miniature lens arrays have led to wavelength multiplexing, which is of great value for optically-based telecommunications equipment. Advances in optical instruments have positive spillover benefits in the design in sensing and control applications in machinery and numerous other industrial applications.
INDUSTRIAL MOLD MANUFACTURING (NAICS Code 333511)

The industrial mold manufacturing industry shows significant erosion in all three indicators from the levels just before the last recession in 2001. Employment dropped from nearly 55,000 in 2001 to less than 38,000 in August 2008, remaining well below even the employment levels at the end of the 1991 recession. GDP dropped from approximately $4.6 billion in 2000 to approximately $3.6 billion in 2006. The number of establishments appears to be on a steady slide from over 3,000 in 2001 to less than 2,300 in early 2008. Overall, this industry has experienced significant erosion during a period of overall economic growth, and shows no signs of recovery.

Firms in this industry engage in manufacturing industrial molds for casting metals or forming other materials, such as plastics, glass or rubber.

It is a component of the defense industrial support base because advances in the production of mold patterns yields the possibility of a greater range of shapes, casts, molds and tools for the production of complicated parts. A healthy mold industry promotes innovation up the sup-
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Supply chain by allowing companies to develop sophisticated product designs. Because all manufactured items have a shape, industrial molds are considered — along with machine tools and semiconductor machinery — to be one of the most critical industries in the manufacturing support base. In general, mold makers are similar to machine shops, except they produce fewer components at much stricter tolerances, better finish quality and with much higher value per unit. In general, the equipment for mold makers is much more expensive than for machine shops and employees are much more highly skilled.

**MACHINE TOOL — METAL CUTTING MANUFACTURING**
(NAICS Code 333512)

The machine tool (metal cutting) manufacturing industry shows erosion in all three indicators. Combined employment dropped from nearly 60,000 in 2001 to almost 45,000 in August 2008, remaining well below even the employment levels at the end of the 1991 recession. Employment figures started moving up from a low of just fewer than 40,000 at the beginning of 2004. GDP dropped from approximately $2.5 billion...
in 2000 to $1.8 billion in 2005, although it has shown slight recovery over the period of 2003 to 2006, due to the impact of tax credits for purchasing machine tools that were in effect during that period. The number of establishments has decreased by about 20 percent, from more than 1,500 in 2001 to less than 1,300 in early 2008. Overall, this industry has endured significant erosion, though it shows some signs of slight recovery in GDP and employment that might continue depending on the severity of the 2008 - 2009 downturn.

These companies primarily manufacture metal cutting machine tools, except for hand tools. It is a component of the defense industrial support base because advances in metal cutting machinery (such as lathes, mills and CNC machines) have a profound impact on the ability to create more sophisticated components out of a wider range of materials. Consequently, it enhances greater innovation up the supply chain because it allows for the manufacture of different designs. Because machine tools provide a fundamental capability in the innovation process (for the creation of prototypes and finished products), they are considered, along with industrial molds and semiconductor machinery, as one of the most critical industries in the support base.

**MACHINE TOOL — METAL FORMING — MANUFACTURING**

(NAICS Code 333513)

The machine tool (metal forming) manufacturing industry shows erosion in all three indicators. Combined employment dropped from nearly 60,000 in 2001 to almost 45,000 in August 2008, remaining well below even the employment levels at the end of the 1991 recession. Notably, the employment figures have increased from just fewer than 40,000 at the beginning of 2004. GDP dropped more than 45 percent, from approximately $1.4 billion in 2000 to $0.8 billion in 2005, rising slightly for 2006. The number of establishments has decreased from about 700 in 2001 to less than 600 in early 2008. This industry has endured significant erosion, with the growth in combined employment likely the result of growth in the metal cutting component of the industry.

These companies are engaged in manufacturing metal forming machine tools (except hand tools), such as punching, sheering, bending, forming, pressing, forging and die-casting machines. It is an essential component of the support base because advances in metal forming machinery (such as metal presses) have a big impact on the ability to create more sophisticated components over a wider range of sizes and from
more diverse materials. Because machine tools provide a fundamental capability in the innovation process for the creation of prototypes and finished products, they are considered to be one of the most critical industries in the manufacturing support base.

**Special Die and Tool, Die Set, Jig and Fixture Manufacturing** (NAICS Code 333514)

The special die and tool, die set, jig and fixture manufacturing industry shows signs of erosion in all three indicators. Employment dropped about 30 percent from nearly 100,000 in 2001 to about 68,000 in August 2008, remaining well below even the employment levels at the end of the 1991 recession. GDP dropped more than 20 percent, from approximately $6.7 billion in 2000 to $5.1 billion in 2006, and has remained at that depressed level for the four years from 2002 to 2006. The number of establishments has decreased steadily from more than 5,500 in 2001 to about 4,200. Overall, this industry has endured significant erosion and does not show any signs of recovering.
This U.S. industry comprises tool and die shops primarily engaged in manufacturing special tools and fixtures, such as cutting dies and jigs. It is similar to industrial mold manufacturing and is a component of the support base because advances in the production of tools, dies and jigs yields the possibility of a greater range of shapes, casts, molds and tools for the production of complicated parts. Consequently, innovation is enabled because of the greater range of possibility in the manufacture of different designs.

**Bare Printed Circuit Board Manufacturing**  
(NAICS Code 334412)

The bare printed circuit board manufacturing industry shows signs of severe erosion in all three indicators. Employment dropped more than two-thirds from a peak of nearly 150,000 employees in 2001 to less than 50,000 employees in August 2008, remaining well below the employment levels at the end of the 1991 recession. GDP dropped more than 50 percent, from approximately $7.3 billion in 2000 to $3.3 billion...
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in 2006. The number of establishments has decreased steadily, dropping more than 40 percent from about 1,900 in 2001 to about 950 in early 2008. Overall, this industry has endured significant erosion and does not show any signs of recovering.

Establishments in this industry are primarily engaged in manufacturing rigid and flexible printed circuit boards without mounted electronic components. These companies print, perforate, plate, screen, etch or photoprint interconnecting pathways for electric current on laminates.

The industry is a critical component of the defense industry manufacturing support base because of the ubiquitous nature of electro-mechanical systems that include embedded circuit boards. With innovations in the shapes, densities, compactness, electromagnetic attributes or other characteristics of circuit boards, new designs for systems that include the boards are possible. Boards that are more efficient and have lower noise and electrical losses enable the adoption of ultra-sensitive electronics and low-power equipment. They are in high demand. Because electronics play such an important role in most integrated weapon systems, improvement in this support industry has a cascading
impact, enabling a tremendous level of new innovation to expand capabilities, reduce cost, reduce weight and minimize the number of components. Without a robust printed circuit board industry, the entire U.S. defense supply chain is at risk.

**SEMICONDUCTOR AND RELATED DEVICE MANUFACTURING**
(NAICS Code 334413)

The semiconductor and related device manufacturing industry shows a mixed picture. Employment dropped more than one-third from 310,000 in 2001 to 200,000 in August 2008, remaining below the employment levels at the end of the 1991 recession. GDP dropped more than 35 percent over the course of a single year, from approximately $76 billion in 2000 to $49 billion in 2001, but has shown some growth since then, eventually reaching nearly $60 billion in 2005. The number of establishments has cycled up from just over 1,600 in 2001 to just over 1,700 in 2006, before dropping back down below 1,600. With erosion in employment, signs of growth in GDP and expansion in establishments, the industry appears to be holding steady.
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This industry comprises companies engaged in manufacturing semiconductors and related solid-state devices. Examples of products include integrated circuits, memory chips, microprocessors, diodes, transistors, solar cells and other optoelectronic devices.

This industry is a critical component of the support base because of the widespread use of semiconductors and other electronic components in a range of optoelectronic and electromechanical systems. Innovations in the manufacture of semiconductors and electronic devices in terms of compactness, dedicated circuits, transistor density, thermal properties, power consumption and other characteristics have a cascading effect on the systems that incorporate them because of the new features that can be included.

**Printed Circuit Assembly — Electronic Assembly — Manufacturing** (NAICS Code 334418)

The printed circuit assembly industry shows a confusing mixture of indicators. Employment dropped more than 20 percent from 67,000 in 2001 to less than 50,000 in 2003, before slightly recovering to just above the employment levels at the end of the 1991 recession near 54,000 in August 2008. GDP dropped approximately 50 percent from $16 billion in 2000 to approximately $7 billion in 2006.

Despite significant losses in GDP and employment, the number of establishments has increased steadily from just fewer than 900 in 2001 to approximately 1,170 in early 2008. The reason for the growth in the number of establishments is not clear. Severe losses in employment and the precipitous drop in GDP have contributed to the industry having undergone substantial erosion.

This industry includes companies that are primarily engaged in loading components onto printed circuit boards. It produces printed circuit assemblies, electronic assemblies and modules. The industry’s products are printed circuit boards that have some or all of the semiconductor and electronic components inserted or mounted. They are used in a wide variety of electronic systems and devices.

This industry is a critical component of the defense industrial support base because of the many electromechanical systems that include embedded circuit boards. The industry fosters innovation in the shapes, densities, compactness, electromagnetic attributes and other characteristics of loaded circuit boards. New processes for manufacturing the boards enable tighter design standards, more compact layouts and new
designs for a wide range of complex products. New technology for automated loading of surface-mount components onto circuit boards (as compared with through-hole mounting) allow for inclusion of much smaller electronic components. This enables lower-power consumption, lower thermal loads and more compact overall design. Improvements in the production of loaded circuit boards and electronic assemblies have substantial upstream ripple effects on the ability to innovate the design of embedded electronics.

**Navigational, Measurement, Electromedical and Control Instruments Manufacturing** (NAICS Code 3345)

The navigational, measurement, electromedical and control instruments manufacturing industry group shows neutral to positive indicators. Employment continued a downward, decade-long trend by decreasing from 479,000 in 2001 to 444,000 in August 2008, although more than 20,000 employees were added since the beginning of 2004. GDP for the sector dropped from $68 billion in 2000 to approximately
Defense Industrial Base

$62 billion in 2002, but has since recovered to exceed pre-recession levels of $75 billion in 2006. The number of establishments has held steady at nearly 7,500. With slight losses in employment, a stable number of establishments and growth in GDP, this industry group overall appears to be expanding and enjoying productivity gains.

These manufacturers produce navigational, measuring, electromedical and control instruments. Their products include aeronautical instruments, appliance regulators and controls, laboratory analytical instruments, navigation and guidance systems and physical properties testing equipment.

These industries are considered a part of the defense industrial support base because improvements in their products change the range of possibility for integrated systems that include them. For example, the new generation of global positioning-based guidance equipment has changed the way vehicles and planes are designed and operated. Improved sensors and control devices have enabled the creation of computer-controlled machine tools that can achieve tighter tolerances, with subsequent impacts on the design of products.
**Battery Manufacturing** (NAICS Code 33591)

The battery manufacturing industry has experienced severe erosion in all three indicators. Employment dropped more than 25 percent from a peak of nearly 39,000 in 2001 to 29,000 employees in August 2008, remaining well below the employment levels at the end of the 1991 recession. GDP dropped by nearly one-third, from approximately $4.5 billion in 2000 to just over $3 billion in 2006. The number of establishments has decreased less severely, declining from about 280 in 2001 to about 230 in early 2008. Overall, this industry has eroded significantly and does not show signs of recovery despite massive increases in the number of batteries being consumed worldwide.

The industry is comprised of storage battery and “primary” battery manufacturing, with the former related to rechargeable batteries such as lead acid and nickel cadmium, the latter related to wet or dry primary batteries such as disposables (9V, AAA, AA, C, D, etc.), and watch batteries. These industries are considered to be part of the defense industrial support base because improvements in power density, capacity, cycle life-
times and weight enable the development of an entirely new range of embedded and portable electronics and power systems. The creation of a new generation of rechargeable and high-power density batteries has revolutionized portable electronics and allows for a range of electronic systems to be built with more powerful and faster processors.

**Summary: Which Sectors Are Eroding, Holding Steady or Recovering**

For 13 of the 16 industries that comprise the defense industrial manufacturing support base, significant erosion took place in two or more indicators without any signs of recovery. It should be noted that this erosion occurred during a period of solid U.S. economic growth and during a period of robust global expansion of all of the industries analyzed.

An assessment for each of the industries and the three indicators is illustrated below. Black circles denote significant erosion; hatched circles

<table>
<thead>
<tr>
<th>NAICS</th>
<th>Industry Description</th>
<th>Employment</th>
<th>Economic Activity</th>
<th>Establishments</th>
<th>Overall Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>3315</td>
<td>Foundries</td>
<td>●</td>
<td>❋</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>33211</td>
<td>Forging and Stamping</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>33271</td>
<td>Machine Shops</td>
<td>❋</td>
<td>❋</td>
<td>❋</td>
<td>Healthy</td>
</tr>
<tr>
<td>332811</td>
<td>Metal Heat Treating</td>
<td>❋</td>
<td>●</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>332997</td>
<td>Industrial Pattern Mfring</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>333295</td>
<td>Semiconductor Machinery</td>
<td>❋</td>
<td>❋</td>
<td>❋</td>
<td>Holding Steady</td>
</tr>
<tr>
<td>333314</td>
<td>Optical Instrument and Lens</td>
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<td>●</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>333511</td>
<td>Industrial Mold Manufacturing</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>333512</td>
<td>Machine Tools (Metal Cutting)</td>
<td>●</td>
<td>❋</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>333513</td>
<td>Machine Tools (Metal Forming)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>333514</td>
<td>Special Die &amp; Tool, Die Set, Jig</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>334412</td>
<td>Bare Printed Circuit Boards</td>
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<td>●</td>
<td>●</td>
<td>Eroded</td>
</tr>
<tr>
<td>334413</td>
<td>Semiconductor and Related Devices</td>
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<td>●</td>
<td>❋</td>
<td>Eroded</td>
</tr>
<tr>
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<td>●</td>
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<td>Eroded</td>
</tr>
<tr>
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<td>❋</td>
<td>❋</td>
<td>Healthy</td>
</tr>
<tr>
<td>33591</td>
<td>Battery Manufacturing</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Eroded</td>
</tr>
</tbody>
</table>

**Figure 3:** A stoplight chart summarizing the three indicators for each industry or industry group in the manufacturing support base. Black circles denote that the indicator eroded; hatched circles denote that the indicator held steady or showed significant signs of recovery; and white circles denote that the indicator expanded.
denote indicators that either held steady or showed signs of expansion after initial erosion; and white circles denote expansion.

By looking qualitatively at all three indicators, an overall determination of the industry’s status coming out of the recent seven-year recession and recovery period can be made. This is noted in the far right column as one of the three following choices: eroded, holding steady or expanded.

Two industries — machine shops and electronic instruments — both showed signs of health due to expansion in employment or economic activity. One industry — semiconductor machinery — appears to be holding steady. The remaining thirteen industries all showed significant erosion. It should also be noted that many of these indicators were taken up to the time of September 2008, after which demand for products in virtually every consumer and industrial category fell off a cliff.

**Sector Relevance**

Unlike the fate of many industries that have famously eroded or disappeared due to the complete loss of demand for their products, the 13 industries that have eroded remain important. Their products are still widely used. These industries are far from being obsolete. The worldwide market for the output from these industries continues to grow significantly in size.

Some of the industries have been identified as critical to the national innovation system. For example, the National Academies of Science conducted a study of the printed circuit board industry because of its strategic importance to the development and maintenance of advanced weapons and intelligence systems.¹²

The RAND Corp. conducted a similar study of the erosion of the semiconductor manufacturing technology industry.¹³ Furthermore, ongoing concerns about the health and importance of the machine tool industry have generated many other studies that raised concerns.

The U.S. Department of Energy has also noted the importance of batteries for enabling innovation in the energy sector. There are dozens of other industries that are key players in the manufacturing and defense industrial support base that are worthy of more detailed analysis similar to the third-party reports on printed circuit boards, machine tools and the semiconductor industry.
Discussion of Driving Factors of Erosion
And Potential Policy Options

As part of this research, several dozen meetings and interviews were conducted with a range of business owners, executives and engineers in the manufacturing support base industries and prime integrators. Also included were individuals from academia and think-tanks who study the economy and the manufacturing base; members of executive branch government agencies, including the National Institute of Standards and Technology, the Departments of Defense and Commerce; trade associations; and staff members for legislative committees and elected officials.

What is clear from these conversations is the widespread concern over the erosion in the aggregate manufacturing sector. Consistent themes emerged about recovery mechanisms and obstacles to implementing them.

The primary corrective mechanisms identified include economic growth, sustained investments in research and development and investments in a skilled workforce. Many other secondary corrective measures were also identified, such as targeted government industrial technology development programs, pressure on international currency valuations, reducing barriers to accessing capital, adjusting tax policies and improving protection of intellectual property.

There is a sense among the those interviewed that the three primary corrective mechanisms either are not working as before, or that they are not being applied by the government. The economic system has fundamentally changed. Furthermore, the sentiment was that the secondary mechanisms, while useful in conjunction with the primary corrective mechanisms or in slowing or preventing erosion, are not suitably robust enough to encourage recovery on their own.

Traditional Corrective Mechanisms

Economic growth was observed to be the most fundamental and effective corrective mechanism to stem industrial erosion. Economic cycles are considered a healthy process for weeding out inefficient enterprises. However, during the most recent 2001 to 2008 cycle, economic growth did not work as it has in all previous economic recoveries. That is, even as the economy expanded, these industries continued to erode.

Widespread concern was also expressed about stagnant national investments in research and development, and the large-scale shift from
applied to basic research. Research and development is no longer being deployed to sustain the health of the manufacturing support base of the national innovation system.

All interviewees complained about the skill base of available workers. Small manufacturing companies are concerned that fewer young people are learning skilled trades. Students who do well in math and science are more inclined to attend college than they are in pursuing jobs in manufacturing that depend on their acumen for understanding automation and computers. Modern and productive manufacturers feel that they are not appealing to college-bound students. They are also not satisfied with the much broader base of unskilled workers.

One moldmaker said he had to lay off more than a dozen people during the most recent recession ultimately leaving him with just his sophisticated machinery and one employee. When his business started to recover and he sought to hire a second employee, he could not find anyone with suitable skills. His former employees had already moved on to other positions and were not interested in returning to an industry that exposed them to future layoffs. Thus, in order to expand, he had to train a new employee from scratch, a proposition that takes years in the

![Figure 4: The number of international students enrolled in science and engineering (S&E) fields in the U.S. for the 1998 - 1999 to 2006 - 2007 school years.](image)
mold manufacturing industry because the work is highly skilled and more complex than basic machining.

By contrast, machine shop employment has recovered significantly, partly because the skill required for standard machining can be learned through short courses taught at community colleges. Consequently, there were fewer complaints from this industry and the data show that it has made a significant recovery.

The higher-technology industries in the support base, such as electronic instruments, semiconductors and machine tools, are more sensitive to shortages of college-educated workers in the engineering fields. A recent National Academy of Sciences study noted the relative decrease in the number of American students in those disciplines in contrast with growing enrollment in those disciplines in other countries such as China.14

Not only is domestic student enrollment in science and engineering fields considered too low, the number of foreign students enrolling in these fields in American universities has dropped for the first time since statistics were originally tabulated in 1971, according to the Open Doors reports by the Institute for International Education (see Figure 4 on previous page).15

**Remaining Issues to Study**

This initial analysis should be expanded with follow-on studies. It is imperative that United States policymakers understand the true health of the industries that enable innovation throughout the entire society. The concept of the support base should be expanded to include more industries that are worthy of analysis. Industries that are slightly higher up the innovation food chain such as the manufacture of consumer electronics, machinery and engines should be considered a part of the support base for separate analyses.

Of particular value would be a dedicated study on the health of the different materials industries. Advanced materials are a critical enabler for the manufacturing base and, consequently, the entire innovation system.

In addition to studying employment, economic activity and establishments for each industry in the manufacturing support base, more categories that reflect the health of each industry should be considered. Some of these indicators should include total R&D spending, patents
filed and the number of products developed. Each industry should be compared to global capabilities, market size and growth.

There also is the need for a rigorous study of policy options and corrective mechanisms aimed at improving the health of the U.S. manufacturing support base that were identified through the course of this research.

Furthermore, there needs to be a much better understanding of the growing demand for skilled workers and the implications for the U.S. manufacturing support base. Different policy mechanisms involved in addressing education, immigration and job retraining must be analyzed.

Another area needing rigorous study is the manufacturing support base’s access to capital. There are growing concerns about a shortage of lending institutions with expertise in manufacturing and their willingness to make loans. Determining whether these barriers are the result of a simple risk/benefit scenario, or whether more subtle biases in the system exist would be useful from a policymaking perspective. Furthermore, analyzing the potential effects of government-backed, low-interest loans would be a valuable contribution to this field of study.

Oppressive tax burdens were also frequently cited during interviews as damaging to the U.S. manufacturing support industries. Consequently, analyzing tax policy options that exist and their potential effects (both good and bad) would be useful. In particular, it would be important to determine whether the combination of property taxes and slow depreciation on capital equipment that are built into the tax system introduce an investment bias away from manufacturing industries and toward services or other industries that are not as equipment-intensive.

5. Personal communication, senior executive at prime contractor for the Department of Defense.
   • Data from the “Quarterly Census of Employment and Wages” by the Bureau of Labor Statistics, is available via an online tool at http://data.bls.gov/PDQ/outside.jsp?survey=en.
   • “The Economic Census of 2002” is available online with interactive tables, reports and search tools at http://www.census.gov/econ/census02/.
   • According to the ASM from 2005 (page 6), “the contribution of nonemployers, relatively small for this sector, may be examined at www.census.gov/nonemployerimpact.”
   • The CPI conversion factors that were used for 1997-2005 are as follows with the year noted in parentheses: 0.882 (1997), 0.835 (1998), 0.853 (1999), 0.882 (2000), 0.907 (2001), 0.921 (2002), 0.942 (2003), 0.967 (2004), and 1.000 (2005). Conversion to 2005 dollars was achieved by dividing current-dollar information in the year it was reported by that year’s conversion factor, e.g. $1,000 in 1997 is equivalent to (1,000/0.882) = $1,134 in 2005.
15. “Open Doors: Report on International Education Exchange” publications are available from the International Institute for Education at http://www.opendoors.iienetwork.org/. Data for Figure 5.1 are from the 2004 and 2006 reports.